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# STSPIN Motor Control

Design Considerations for  
Brushless Direct Current  
Motor Control

Assessing Low-Power Brushless,  
Brushed, and Stepper Motors —  
and Their Drivers



**MOUSER**  
ELECTRONICS

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# Forward

By Tom Hopkins, STMicroelectronics

I was in elementary school when I built my first motor, more than 50 years ago. We all built one back then, winding surplus telephone wire around nails to make the magnets for the rotor and stator (field) of a very crude series-wound motor, or we'd use horseshoe magnets for the stator to build a crude direct current (DC) motor. Then we'd hook it up to a D cell battery or two—and it turned. Later, I had an electric train set and I could change the direction and speed using the “throttle”. I didn't know then that motors would play such a large role in my engineering career.

The first practical electric motors, meaning they could do useful work, were demonstrated in the late 1830's. A hundred years later, thanks to the electrification of the world, electric motors were common in many applications including fans, drives for power machinery, power tools, and appliances. These motors were mostly brushed DC, universal (brushed), or induction motors (single- or three-phase) and typically had only two speeds—On or Off. Universal motors could have several speed settings by switching between different field windings. Varying the applied voltage to DC and universal motors would also vary their speed, so a simple controller

using a variable transformer could be used for speed control, as with my model train.

The first electronic speed controls for high volume applications were basically simple Triac-based phase controls for universal motors used in applications like power drills. The introduction of rechargeable NiCad batteries made possible the first cordless power tools in the early 60's and brought with it pulse-width modulation (PWM) control for DC motors. In the mid 70's, I worked on a PWM control for a 12V trolling motor. We had to bring a horse tank into the lab so we could run the motor under load and keep it cool.

Stepper motors, with their inherent position accuracy, were used in applications like printers and machine controls. These were often driven with a very simple bridge driver and series current-limiting resistor that improved the speed performance of the motor but dissipated 10 times (or more) the power than was delivered by the motor. PWM current mode drives for stepper motors were first introduced in the late 70's.

Since the 1980's the sophistication and performance of motor control has accelerated dramatically. The reduction in the cost of the electronics

and materials, such as rare earth magnets, coupled with the push for higher performance and efficiency has driven a wave of development. Higher efficiency motors, like brushless direct current (BLDC) motors, have become commonplace, replacing brushed DC motors in power tools and induction motors in home appliances. Solutions using field-oriented control (FOC) for BLDC drives and microstepping for stepper motors have become ubiquitous. The common element in these is that the electronics have become much more sophisticated to drive these improvements in efficiency and performance.

It's an exciting time to be involved in motor control. The advances are coming rapidly and the systems, like the camera gimbal used in drone photography, are demanding ever higher performance. The articles here represent the latest achievements in motor driving.

Tom Hopkins received his BSEE degree from Kansas State University in 1976 and an MBA from Arizona State University in 1983. After graduation from KSU, Tom started his career at Motorola Semiconductor where he worked as an IC design engineer and applications engineer. In 1981 Tom joined SGS (now STMicroelectronics) and has worked on automotive, industrial and computer peripheral applications specializing in power electronics. He has managed applications engineering groups focused on power conversion and motor control for more than 25 years. Tom has 25 patents in the areas of electronic circuits and power electronics. He has published more than 50 papers in internationally recognized conferences and magazines on a range of topics from a solar photovoltaic power system to motor control and drive.



# Who is STMicroelectronics?

STMicroelectronics (ST) is a global semiconductor company offering one of the industry's broadest product portfolios. ST serves customers across the spectrum of electronics applications with innovative semiconductor solutions for the Internet of Things (IoT) and Smart Driving. By getting more from technology to get more from life, ST stands for life.augmented.

## Product Portfolio

ST's products are found everywhere today, and together with our customers, we are enabling smarter driving and smarter homes, factories, and cities, along with the next generation of mobile and IoT devices.

Because ST has such a wide portfolio, ST is able to offer system solutions, development kits, and software to help customers get to market as fast as possible.

## The Internet of Things: Solutions for Smarter Personal Devices, Homes, Cities, and Factories

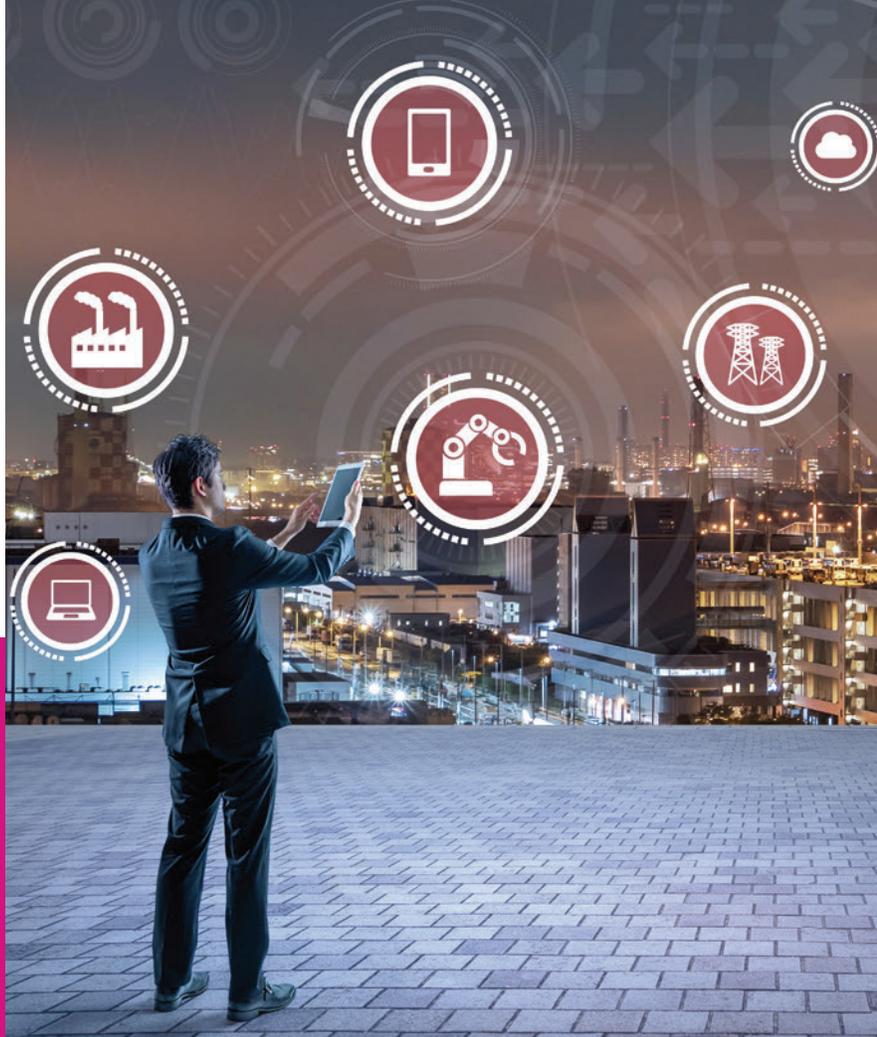
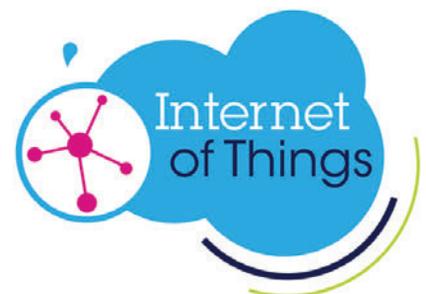
Due to the fragmented nature of IoT, the markets we serve span our entire customer base—from our largest customers to the tens of thousands of smaller and equally important customers we serve through our distribution partners and mass-market initiatives.

Our daily lives as individuals benefit from the “Smart Things” we carry and use extensively. ST is a leading supplier of many of the key technologies going into the next generations of personal consumer devices: Sensors and Actuators, Microcontrollers for low and ultra-low power processing, Secure solutions, Power and Analog components, and RF & Connectivity products. ST makes developing prototypes fast and affordable with a range of development ecosystems, including its STM32 Open Development Environment.

ST addresses the rise of the smart home and smart city systems through their core: energy

consumption and management systems, or the future smart grids and their applications. Its solutions address the critical functions: combo chips inside the smart meters that help consumers and utilities track and balance electricity, water, and gas consumption and billing; more intelligent street lighting that senses its environment and dims or switches off to adjust to lighting conditions and municipal needs; and sensors that measure traffic flow and can re-route around obstructions.

ST also provides technologies that enable manufacturing and other industrial sectors to achieve better efficiency, flexibility, and safety through automation and robotics—what we call Smart Industry. The current shift, often labelled the “fourth industrial revolution” is making industrial systems smarter with the combined application of a broad range of products, including Microcontrollers, Sensors and Actuators, Motor Control, Signal Conditioning, Industrial Communication Solutions, Secure solutions, Power Supplies, Protection Devices, Wireless Modules, and Display and LED Controllers.





## Smart Driving: Safer, Greener, More Connected

It is estimated that 80% of all innovations in the automotive industry today are directly or indirectly enabled by electronics, which means a constant increase in the semiconductor content per car year after year. ST's Smart Driving products and solutions are making driving safer, greener, and more connected through the fusion of several of our technologies.

Driving is safer thanks to our Advanced Driver Assistance Systems (ADAS) products—vision, radar, imaging and sensors, as well as our Adaptive Lighting Systems (ALS) and User Display Technologies. Driving is greener with our energy-management processors (EMU, ECU), high-efficiency smart power electronics at the heart of all automotive subsystems, Silicon Carbide devices for electric cars, and more. And vehicles are more connected using

our car-to-car and car-to-infrastructure (V2X) connectivity solutions, infotainment system and telematics processors, Global Navigation Satellite System (GNSS) positioning technologies, tuners, amplifiers, and sensors.



*ST's Smart Driving products and solutions are making driving safer, greener, and more connected through the fusion of several of our technologies.*

# Motor Control Software Development Kit



By Greg Gumkowski, STMicroelectronics

The new SDK v5.0 will help to provide developers with a more complete motor control ecosystem to implement the high performance and high efficiency solutions required for standalone and Internet of Things (IoT) motor control applications of the future.

STMicroelectronics (ST) has a long history of providing 3-phase brushless motor control solutions, including the first release of the Motor Control Software Development Kit (SDK) back in 2002. The SDK has evolved over time and in 2008, support was added for the STM32 microcontroller family, and sensorless field-oriented control (FOC) was included. More recently, several advanced features have been added to the SDK, including a motor profiler for automatic detection of a motor's electrical and mechanical parameters. The FOC algorithms running on permanent magnet synchronous motors (PMSM) are widely used in high-performance motor drives for Air Conditioning, Home Appliances, Drones, Building & Industrial Automation, and Medical and E-bike applications.

ST is introducing the new SDK v5.0, a version which will offer an improved development approach using the Motor Control Workbench graphical user interface (GUI) together with a workflow supporting the STM32CubeMX GUI configurator. This new version will also provide a simplified firmware

architecture that will be based on the STM32Cube hardware abstraction layer (HAL)/low layer (LL) libraries.

## The STM32 PMSM FOC SDK v5.0 will include, among others, the following advanced features:

- Maximum torque per ampere (MTPA) control, which optimizes the motor torque for each load and increases efficiency
- Feed-forward control to improve current control at high speeds
- Start “on-the-fly”, which provides smooth drive insertion for applications where the rotor is already turning (e.g. outdoor fans in air conditioners and smoke extractors)
- Digital power factor correction (PFC), with single-stage boost topology using the same microcontroller that runs the motor control FOC algorithm (coming in v5.1)
- Single and dual motor control FOC applications with a single microcontroller
- Plug-n-Spin operation, utilizing the “motor profiler” algorithm for automatic detection of a motor's electrical parameters (stator resistance (Rs), inductance (Ls), and motor-voltage constant (Ke)), as well as mechanical friction and inertia.

# Design Considerations for Brushless Direct Current Motor Control

By Cheng Peng, STMicroelectronics

With the rapid evolution of Industry 4.0 and the Internet of Things (IoT), coupled with the push for higher efficiency in motor control, brushless direct current (BLDC) motors are being used increasingly in diverse application segments. Examples include:

1. Industry and automation, for blowers, cooling fans, and industrial robotics
2. Emerging high-tech, for drones, gimbal control, and collaborative warehouse robots
3. Home applications, for power tools and vacuum cleaners

When a motor is selected for an application or system, designers focus principally on response time to speed/torque commands, noise level while spinning, and power efficiency.

While all BLDC motor control topologies share a common “backbone”—motor control scheme/algorithm (digital part, “commutation logic”) + pulse-width modulation (PWM) + power stage (analog/power, “inverter”)—some applications come with specific requirements and system considerations.

## Overview of BLDC Motors

Brushless DC motors offer multiple technical advantages. Among them:

- High efficiency
- Smooth and silent spin
- Low torque ripple
- Fast response time

Moreover, the cost of BLDC motors and associated controller circuitry have fallen significantly over the past decade. Thus both technical advantages and lower cost have accelerated BLDC motor adoption in numerous application domains worldwide.

From an application perspective, BLDC motors are mainly



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used to accomplish one of two types of motion patterns: spinning or positioning. The motion pattern required, and the specifications of the motor selected (e.g. rated voltage, current, and revolutions per minute (RPM)), are key factors in defining the appropriate electrical motor control design to employ.

From an electrical design and thermal optimization standpoint, an integrated topology (six metal-oxide semiconductor field-effect transistors (MOSFETs) built into the motor driver integrated circuit (IC)) is preferred when the required motor phase current is low (e.g. less than 2-3A), while a discrete topology (six discrete MOSFETs mounted on the printed circuit board (PCB)) does a better job with higher currents (e.g. above 10A). This is because heat dissipation is easier to manage with discrete packages, and they typically have lower on-resistance and therefore lower dissipation.

## Spinning

In a spinning motion pattern, the speed-loop and current/torque-loop can typically be included in the motor control algorithm. Regarding the resulting motor phase current waveform, trapezoidal and sinusoidal control schemes are the two main options. For some applications, sensorless control schemes that depend on electrical feedback from the motor, like back electromotive force (BEMF) and current sensing, are

preferred. Positioning applications, on the other hand, are more suited to the use of Hall sensor outputs, which provide the rotor's electrical position at a 60-degree resolution, or position encoders/sensors, which provide rotor positioning data at a much higher resolution (e.g. less than 1 degree).

## Fan Application

In low-power applications, a cooling fan for a computer laptop, desktop, or server provides a good example. Since the load torque of the fan changes little while spinning and low noise levels are required, an all-in-one, integrated motor control IC is usually the best option. Generally, no external microcontroller is used in this type of motor control system due to cost considerations. There is typically 4-wire communication (voltage supply (Vs), ground (GND), PWM-in, and tech-output) between the host and fan-control system. PWM-in and tech-output can be replaced by an inter-integrated circuit (I2C) clock and data in some applications. The host commands and monitors the fan RPM as the baseline.

Increasingly in emerging designs, fan fault conditions in areas such as motor phase current are monitored. In addition to spinning the motor, a full-featured protection system is also required to protect the fan and complete the design. Indeed, protection against overcurrent, undervoltage lockout, overtemperature, and short-circuits are all widely supported in today's motor driver ICs.

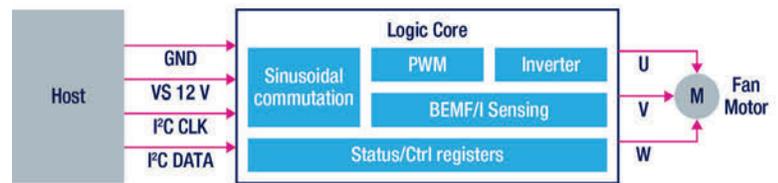


Figure 1. Block diagram of a conceptual motor control for a fan application. (Source: STMicroelectronics)

Using a server fan as an example, the supply voltage of this type of fan is typically 12VDC, although 24V is sometimes used. Since the fan load (blades + air resistance) does not vary significantly at a given speed/RPM, a sensorless control scheme can achieve the target level of performance. However, sinusoidal control schemes are increasingly chosen by fan manufacturers because they offer better power efficiency and lower noise levels. In a typical fan, a sensorless sinusoidal motor control scheme is far simpler than a full-featured field-orientation control (FOC) design. The motor phase current of the fan is usually less than 3A. Therefore, an integrated fan motor control IC has become an industrial trend. A conceptual server fan motor control block diagram is shown in (Figure 1). Since sensorless control algorithms can present some design challenges at low speeds due to BEMF waveform distortion, the host will usually not allow them to maintain very low speeds (e.g. less than 10% of full motor speed).

## Drone Propeller Application

Although radio-controlled (RC), fixed-wing model airplanes have been available in hobby stores for decades, they have never gained the popularity already enjoyed by their modern successor: the drone (commercially-available, non-military). Most commercial drones are powered by a 2-6 cell Li-ion battery. This means that the propeller motor's rated supply voltage ranges from about 6 to 18V. Although there has been recent talk about parcel delivery using drones, the most common drone payload today is a camera used for aerial photography. For a typical 6-cell drone carrying a camera, the propeller's motor current is usually below 20A. A drone is expected to fly with the load swiftly in outdoor conditions. Its 3D movement is enabled by 4 to 6 propellers spinning precisely, and in parallel. Typically, a drone propeller motor has 6 to 7 pole pairs, although it can have more. Since the propeller must be capable of reaching 10,000 RPM, it can be challenging to reliably employ a Hall sensor in the motor due to the effects of vibration. Therefore, the propeller motor is frequently controlled using a sensorless, full-featured FOC scheme, with sinusoidal control and both speed and current/torque loop enabled. 1 to 3 shunt resistors are required on the

propeller electrical speed controller (ESC) board to sense and provide a motor phase current value to the control algorithm every PWM cycle.

The integrity of the motor phase current sensing feedback signal is essential to the performance of the motor. To avoid excessive heat dissipation, a very-low resistance shunt resistor (e.g. 10mΩ) can be used. An op-amp is usually employed to amplify the current sensing voltage enough (0-3.3V typ.) for the analog-to-digital converter (ADC) to pick up. It is critical then to properly balance the shunt resistor value and the amplification factor so as to fit within the ADC operating range. When the motor is loaded lightly and spinning slowly, the current-sensing voltage must still be sufficient for the ADC to sample; when the motor is fully loaded and spinning at full speed, the ADC input is not saturated.

An op-amp amplifies both the signal and the noise together. In other words, a high amplification factor increases the noise level undesirably. Certain low-pass filters may be used to remove noise from the IQ and ID in the control scheme. As motor phase current is alternating current (AC), not DC, and motor control is enabled by the PWM, a higher PWM duty-

cycle results in higher applied voltage per motor phase, and thus higher current. Motor phase current sampling is usually synchronous with the PWM signal to reduce the effect of noise. During every PWM cycle, the motor phase current rises during the on-time, and decays (not ceasing immediately) during off-time. So the ADC sample timing is important. Typically, U, V, W PWM are central-aligned and ADC-sampling occurs around the center point of the PWM. Short ADC latency is always desirable. In FOC control, high-side and low-side PWM per phase is typically set as complementary. PWM frequency is usually above 20kHz (40kHz is fine also). Designers will not select a PWM frequency lower than 4MHz, as this is within the audible domain.

It is usually more thermally efficient and cost effective to use external MOSFETs on the ESC board, as shown in (Figure 2).

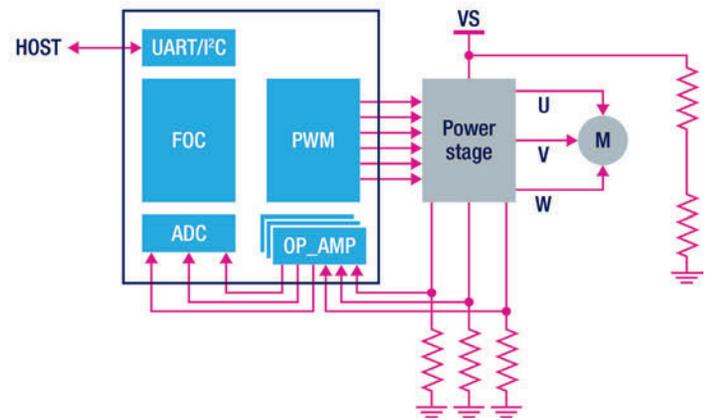


Figure 2. Block diagram of a conceptual motor control for a drone application. (Source: STMicroelectronics)

## Power Tool Application

Brushed DC motors have been used in power tools, such as drills, for decades. However, BLDC motors have started receiving greater attention due to better power efficiency coupled with a reduction in the cost of the motors and associated control circuitry. Many high-end power drilling tools on the market today already use BLDC motors. The typical current rating of a power tool is much higher than that of a drone propeller, and power drills must be capable of adjusting to the various types of material it may encounter during operation. For example, when drilling a hole in a typical household wall, the drill bit first meets the relatively soft drywall, then the much harder wooden stud. This

means that the load torque can vary considerably during operation. A Hall sensor is thus needed to provide the rotor's position in real-time. Considering the high current rating, a discrete topology using external MOSFETs is required. Since motor current is very high, a small shunt resistor (about 1-5mΩ) is recommended for current sensing, although the noise level can be quite high when such a small resistor is used. This is one of the key challenges in BLDC-based power tool design. While it's true that a dedicated current sensing IC can provide flawless motor phase current feedback, this is usually not a cost-effective solution for power tools. A typical power tool BLDC motor control block diagram is shown in (Figure 3).

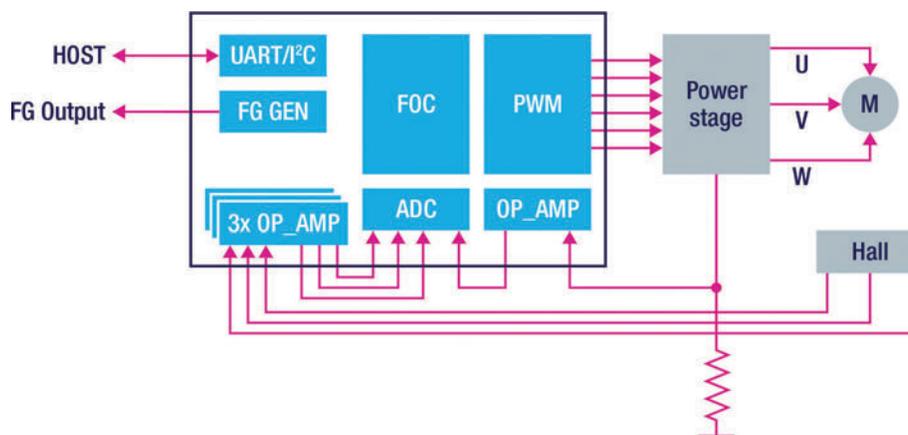


Figure 3. Power tool motor control system block diagram. (Source: STMicroelectronics)

## Positioning

A gimbal application like the one shown in (Figure 4) performs pan & tilt operations in most application scenarios.

Some engineers may consider stepper motors for positioning motion patterns. Indeed, stepper motors are designed for positioning and have some intrinsic advantages. For example, a stepper motor typically has 200 steps per revolution (360 degrees) and can hold its rotor at any step by design, and stepper motor control is simple and open-loop. However there are also disadvantages inherent to this type of motor which make them less suitable for positioning in BLDC gimbal motor applications, particularly when used for a drone carrying a camera.

1. Stepper motors are typically slow and thus cannot move a camera with enough speed to compensate for drone movement.
- 2 A stepper motor's open-loop control cannot achieve the level of power efficacy that a BLDC motor can reach.
3. Stepper motors are generally more expensive than BLDC motors.

In gimbal axis motion control, a motor is commanded to move from position A (e.g. 25 degrees) to position B (e.g. 67 degrees) in a forward or backward direction. When at position A, the motor is stationary. It then accelerates at a specified ratio, reaches the full specified speed, and continues traveling. As it approaches position B (destination), it decelerates at a specified ratio before finally stopping at position B. The motor current must be circulated in a particular manner while the motor stops at position B. Below, in (Figure 5), is the trapezoidal speed profile that the motor will follow.

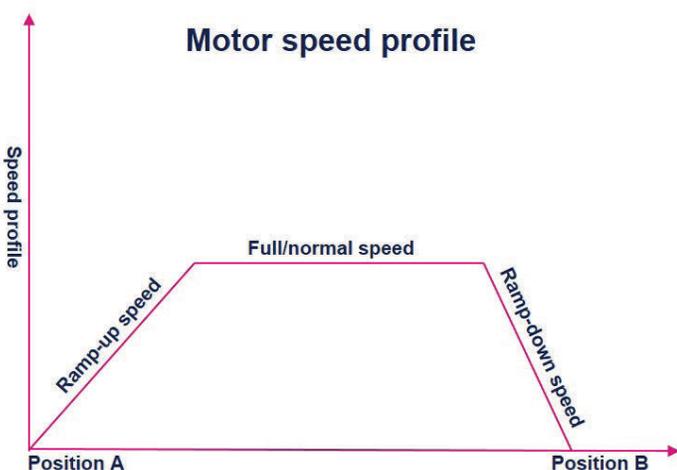


Figure 5. Trapezoidal speed profile in gimbal axis motion control. (Source: STMicroelectronics)



Figure 4. Example of a drone-mounted gimbal application for camera pan & tilt. (Source: STMicroelectronics)

Regarding Gimbal axis position control, it can be beneficial to abstract/encapsulate its motion pattern into a set of atomic motion commands, which are needed in host-gimbal communication. Below is a basic example to illustrate this concept.

- positioning commands: GoTo\_ABS, GoTo\_DIR, GoHome
- motion commands Spin
- Stop command: Stop, hardstop

### Parameter definition:

- ABS\_POS Absolute position encoder degree
- INC\_POS Incremental position encoder degree

### Positioning command:

- **GoHome:** Brings the motor into HOME position (absolute encoder counter is zero) from existing position (minimum path)
- **GoTo\_ABS(ABS\_POS):** Bring the motor into ABS\_POS position (minimum path)
- **GoTo\_DIR(DIR, ABS\_POS):** Bring the motor into ABS\_POS position at specified direction (forward or reverse)
- **GoTo(INC\_POS):** Bring the motor into INC\_POS position (could be multiple rounds (e.g.  $n \cdot 360$  degree + m degrees))

### Motion command:

- Spin(DIR,eHz): spin the motor in a given direction at target electrical speed (Hz or inc\_pos/s)

## Stop command:

- **Stop()**: stop motor with a deceleration phase
- **HardStop()**: stop motor immediately

Regarding the rotor position feedback, the 60-degree resolution provided by the 3 pairs of Hall sensors used in many BLDC motors is frequently not enough. Since many gimbal BLDC motors have 6-pole pairs above, each mechanical revolution is equivalent to six rounds of electrical resolution. A 12-bit position encoder/sensor (absolute encoder and/or incremental encoder) is desirable. A simplified control scheme is illustrated in (Figure 6).

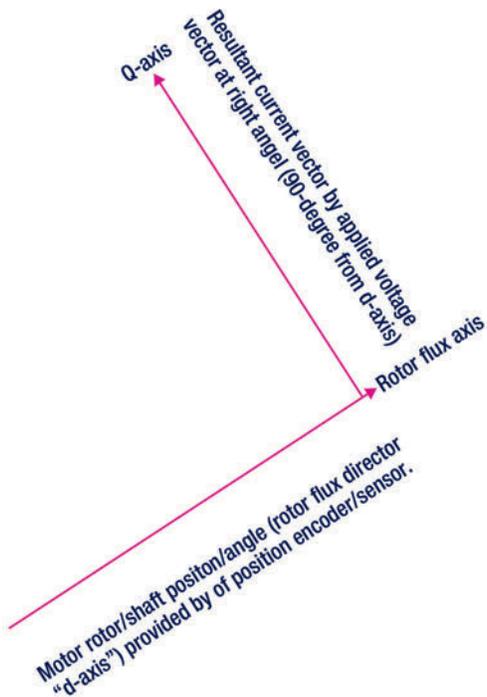


Figure 6. Gimbal axis BLDC motor position control.  
(Source: STMicroelectronics)

A block diagram illustrating an axis control system design is shown in (Figure 7).

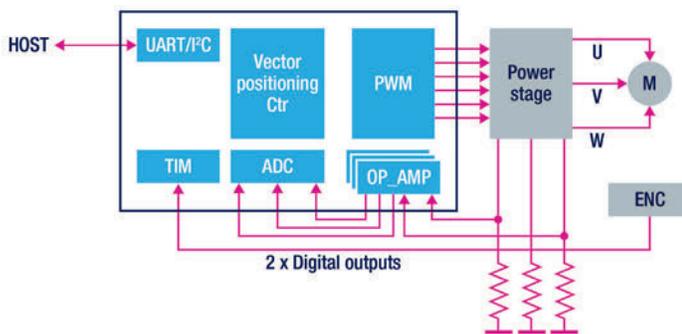


Figure 7. Gimbal axis motor control system block diagram  
(Source: STMicroelectronics)



## Conclusion

Over the last few years, BLDC motors have received increasing attention in industrial and consumer application domains due to their fast response to speed and torque commands, quiet spinning, smooth rotation with low torque ripple, and superior power efficiency. Adding to these advantages, recent advancements in integrated motor control ICs have allowed designers to significantly reduce the size, weight, and cost of the power electronic controller circuits used in BLDC applications.

# Case Study

By Cheng Peng, STMicroelectronics

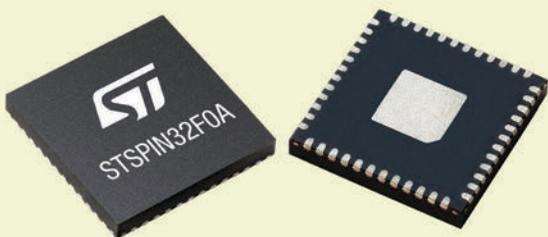
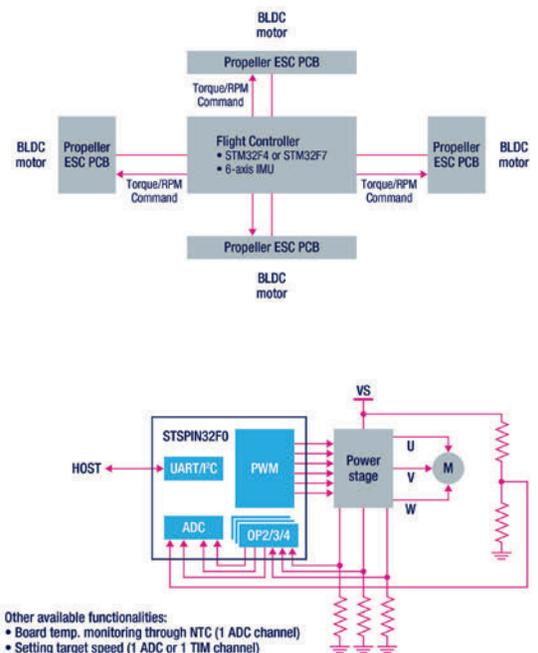
## Solution for Drone Propeller Electrical Speed Controller

In last few years the use of drones in the consumer, commercial, and industrial markets has increased exponentially, with rapid advances in technology making them faster, more agile, and easier to control. With the number of manufacturers growing in proportion to this market demand, drone engineers are tasked with designing ever-higher performing drones as rapidly as possible.

The weight and size of the circuitry play critical roles in drone performance. The drone's propeller ESC, for example, must be both light and compact. A typical high-performance drone propeller ESC requires 4 to 6 BLDC motors, a power stage, gate driver, and microcontroller. Therefore the

first hurdle designers must overcome is how to implement these blocks using a minimum of components, which would otherwise mean a larger, heavier, and more expensive PCB.

The STSPIN32F0 is the innovative solution to these design challenges. A 3-phase gate driver, 12-bit ADC, and 12V linear regulator are fully integrated in the STSPIN32F0, significantly reducing component count and enabling manufacturers to design much lighter and more compact ESC circuits. And to speed up the development process, the STSPIN32F0 has a built-in Arm® Cortex® M0 microcontroller with motor control algorithm library, FOC, and full set of GUI tools provided by ST.



### STSPIN32F0A Advanced BLDC controller with embedded STM32 MCU

#### Three-phase gate driver for high performance

- 600mA current capability to drive a wide range of power MOSFETs
- Real-time programmable over-current
- Integrated bootstrap diodes
- Integrated 32-bit STM32F0 MCU with Arm® Cortex®-M0 core
- Operational amplifiers and comparators
- On the field FW boot loading capability (STSPIN32F0A)
- On-chip generated supplies for MCU, driver and external circuitry

[mouser.com/stm-stspin32fo-controllers/](https://www.mouser.com/stm-stspin32fo-controllers/)

# Case Study

By Cheng Peng, STMicroelectronics

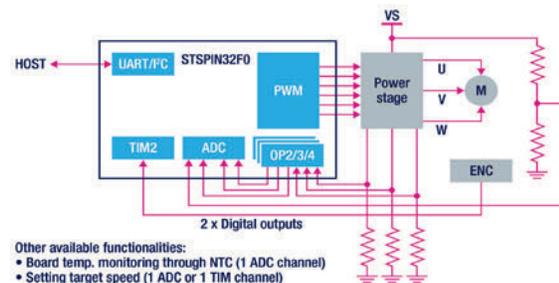
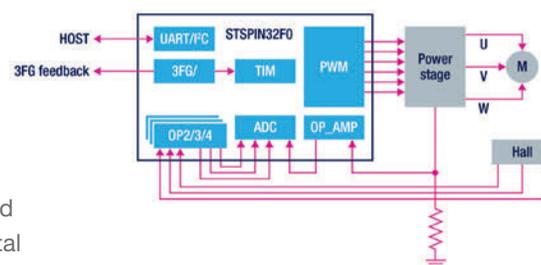
## Solution for Power Tools

The demanding requirements and competitiveness of today's power tool market mean manufacturers must design products faster and at lower cost. This puts design engineers under pressure to speed up development efforts while looking for ways to reduce system cost—all without compromising performance and innovation.

The main blocks of a typical high-performance power drill include a BLDC motor, gearbox, power stage, gate driver, and microcontroller. Traditional designs use discrete components in these blocks, which increases the cost and complexity of the final product. So a primary challenge designers face in power tool design is limiting the component count. Other challenges engineers must contend with is the complexity of designing the motor feedback interface to the drive system, and the development time required to develop the motor control software

algorithms for their applications.

These obstacles are overcome with ST's STSPIN32F0 advanced BLDC controller with embedded microcontroller unit (MCU). The 3-phase gate driver, 12-bit ADC, and 12V linear regulator are all integrated in the STSPIN32F0 to reduce the need for external components, lowering total system cost. The device also features an innovative on-chip peripheral to generate PWM and easily interface various motor feedback systems—including Hall sensor and current sensing—to the motor drive, further simplifying the design process. And to shorten the development cycle, the STSPIN32F0 features a built-in STM32 Arm Cortex M0 microcontroller which includes free, advanced motor control driving algorithms. FOC along with a 6-step motor control software library and GUI tools significantly reduce tuning time and effort.



Other available functionalities:  
• Board temp. monitoring through NTC (1 ADC channel)  
• Setting target speed (1 ADC or 1 TIM channel)



[mouser.com/stmicroelectronics-stspin-drivers/](https://www.mouser.com/stmicroelectronics-stspin-drivers/)

## STSPIN220, 230, 240, 250 Motor Drivers

Low-voltage monolithic motor drivers for battery-operated systems

- Tailored for portable: ideal for battery-operated motors
- Extremely low operating voltage 1.8 – 10V, ideal for battery-operated motors
- Ultra-miniaturized 3 x 3mm QFN package
- Powering small, but also medium-size motors
- Extended battery life
- Reliable: Full set of protection function with UVLO, over-current and thermal protection



By Bill Schweber for Mouser Electronics

## Assessing Low-Power Brushless, Brushed, and Stepper Motors—and Their Drivers

Understand the characteristics of these motors and their drivers to make the most appropriate choice.

Low-power direct current (DC) motors are seeing an increased range of applications as a result of many factors. First, the motors have become more efficient and powerful due to new magnetic materials. Second, they are now easier to control via smarter power-control integrated circuits (ICs) with integral field-effect transistors (FETs). Third, even though most Internet of Things (IoT) applications are sensor-only situations and have no motion requirements, the growing diversity of IoT applications, in general, has spurred a need for these small-scale motors.

What is a low-power DC motor? There is no formal definition or standard, but the universal industry understanding is this: A motor with an average “root mean square” (RMS) drive current of up to 1A and a peak current of 2A

is considered a low-power device. That may seem like a lot of current when compared to the milliamp-range current consumption of the associated electronics; however, many of these motors are used in applications with low duty cycles, so their aggregate energy needs are low to modest, even if their peak-power requirements are much greater than their electronics.

The applications for low-power motors are diverse and range in use from fun to convenient to critical. They include wireless, smart-HVAC room vents; industrial process adjustments and process fine-tuning; scientific instrumentation with positioning stages; toys and amusement products; robotic actuators; and medical equipment such as positioning of probes, control of fluid flow, and cycling of lab tests.



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## Consider the Three Basic Motor Topologies

The three commonly-used motor configurations for low-power DC motors are brushed, brushless DC (BLDC), and stepper. Each uses interaction between the currents in coils (or windings), permanent magnets (in most designs), and the resultant magnetic field attraction/repulsion to instigate motion. They have some similarities but differ in how they control necessary switching of current flow through the rotor and stator windings.

They also differ in what they can do, how well they do it, and the flexibility they have in their controllability. In brief:

- The brushed motor is the oldest DC motor design. As the rotor turns, contact brushes (which are actually made as solid contacts, usually of graphite) touch corresponding areas on the rotor (Figure 1). As the rotor turns, the change in brush contact points causes reversal of the current flow direction and, thus, the magnetic field. Then, the magnetic field interaction between the rotor and stator reverses, and the rotor is urged to keep moving.

This mechanical commutation is conceptually simple. However, the down side is that the brushes wear and need replacement, implementing smart control is harder because the switching action is hard on and hard off, and the brushes generate electromagnetic interference (EMI), also known as radio-frequency interference (RFI).

In its simplest form, the brushed motor requires no electronics for control; it simply free runs as a function of current and mechanical load. In other cases, the motor power rail is turned on and off via a simple transistor circuit to activate the motor, so there is some basic control. The use of a driver IC can improve performance and allow

some amount of control over speed and torque.

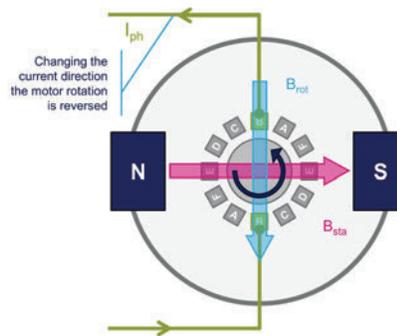


Figure 1. In the brushed DC motors, the changing direction of the current (commutation) reverses the direction of the motor. It can be done entirely by mechanical means, using “brushes” that make contact with the rotor body. (Source: STMicroelectronics)

- The BLDC motor replaces mechanical commutation with an electrically switched commutation of the coils, with the current switching via transistors—most likely Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) at these power levels, preceded by gate drivers (some designs use Insulated Gate Bipolar Transistors (IGBTs)). A separate controller turns the coil-control switches on and off at the precise instant necessary to keep the motor turning at the desired speed (Figure 2). (Note: BLDC motors are sometimes called electronically commuted (EC) motors, which is an accurate description.)

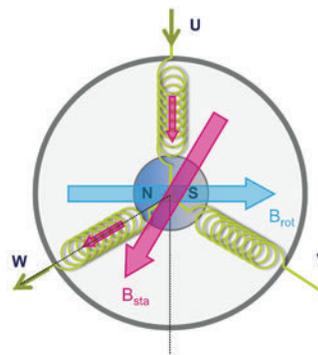


Figure 2. In the brushless DC motor, the rotor's magnetic field is always present and generated by a permanent magnet. When current is directed from one motor phase to another, the magnetic fields are combined, thus, generating the changing stator field. (Source: STMicroelectronics)

Due to electronic control, the on/off current flow does not have to be hard-switched on and off. Instead, the switching can be shaped at the gate driver with controlled rise and fall times to reduce EMI/RFI. However, the tradeoff is that the softer switching also results in power loss and reduced efficiency, which the designer must balance. Some newer gate drivers use a variety of sophisticated and subtle tricks to make this tradeoff less harsh.

- The stepper motor takes the concept of the BLDC motor further, by using a large number of coils (or poles) positioned around the motor periphery (Figure 3). By sequencing the turning on and off of these poles, the rotor is induced to step and rotate precisely, and it can be directed to do so in both forward and reverse directions.

The number of poles can be as few as 16 or as high as 128 (or more, in some cases) with rotational precision on the order of a degree (depending on the number of poles). Stepper motors are available in unipolar two-phase and bipolar two-phase, three-phase, and five-phase configurations. The bipolar two-phase is the most common one.

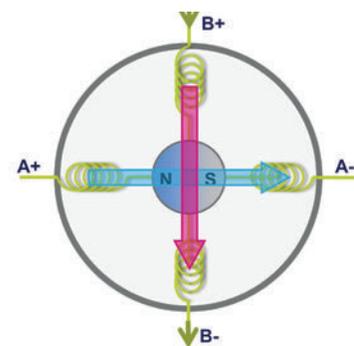


Figure 3. In the stepper motor, the rotor's magnetic field is generated by a permanent magnet, while the stator magnetic field is generated by forcing a current in one phase. As a result, the rotor will align with the stator's magnetic field so the targeted step position is reached. (Source: STMicroelectronics)

The stepper motor is well suited for rapid stop/start motions, positioning, and back/forth motions but not for

longer-term continuous rotation. It is used in applications such as printers and positioning stages (just two of its many uses). Furthermore, even though positioning precision is a function of the number of poles, using an advanced technique where adjacent poles are partially turned on—called microstepping—allows the stepper to have much finer and well-controlled steps than the number of physical poles indicated.

## Motor-Control Chain Requires Strategy and Power Muscle

A complete motor-control system consists of several functional blocks (Figure 4), including:

**The controller** – The controller decides what the motor must do to meet the application’s needs at a given instant and defines what power is necessary for which poles and when. This controller can be a fixed-function dedicated IC, or it can be a part of a larger, firmware-based system.

If the motor has a feedback loop—as many do, using a sensor at the rotor shaft—then the controller also assesses the motor’s position and velocity versus the intended values, and it determines the appropriate changes essential for power control.

- **The output** – The controller’s output goes to gate drivers that translate the low-voltage and current on/off commands into higher currents (and often higher voltages) required by the MOSFETs (or IGBTs). This path may be galvanically isolated in many cases.
- **The MOSFETs (or IGBTs)** – The MOSFETs (or IGBTs) are the actual power switches that control the current flow to the motor coils.
- **The motor coils** – The current running through the motor coil windings generates an electromagnetic field, which interacts with stationary magnets in the motor causing it to start to rotate.

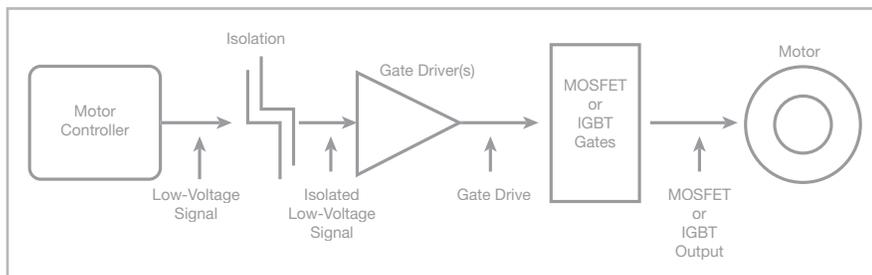
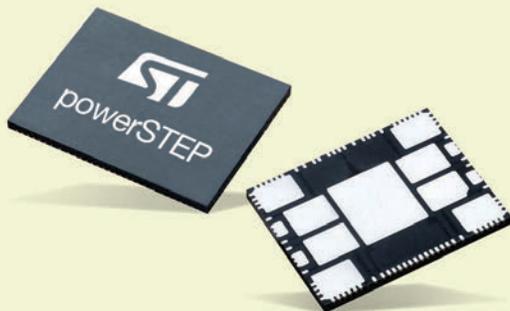


Figure 4. The signal path for motor control begins at a low-voltage controller (which may be a programmable microcontroller unit (MCU) or a dedicated control IC). This low-voltage, then, passes through the gate drivers (with optional isolation, depending on the application) to control the MOSFETs or IGBTs—which are the on/off switches that direct current to the motor coils or poles. (Source: Mouser Electronics)



[mouser.com/stm-powerstep01/](https://www.mouser.com/stm-powerstep01/)

## PowerSTEP01

System-in-package integrating microstepping controller and 10A power MOSFETs for superior smoothness and accurate positioning

- Dual full bridge with  $R_{DS(on)} = 16m\Omega$
- 10A<sub>r.m.s.</sub> maximum output current
- Smoothness with up to 1/128 microsteps/step
- Operating voltage: 7.5 - 85V
- Easily programmable with SPI
- Programmable speed profile and positioning
- Adjustable output slew rate
- Sensorless stall detection
- Full set of protection functions

## Integrated Circuits (ICs) Address Motor Similarities and Differences

One of the advantages of low-power motors, beyond their modest current and voltage needs, is that MOSFET gate drivers can be integrated with controllers and optimized for the specific needs of different low-power DC motors. A look at a trio of related offerings from STMicroelectronics (ST) clearly illustrates this idea.

This trio of ST products share many basic characteristics that simplify their use across multiple products with different motor types. They also provide ease modeling and require a minimal learning curve. Some of the features shared by these low-power, motor-drive ST products include:

- High integration using microcontroller unit (MCU) interface, control logic, a driver, and a MOSFET power bridge (only a few non-critical, passive components—and no active, external components—are necessary)
- A low operating voltage of 1.8V to 10V—which is well suited for low-voltage motors, especially those that are operated from small battery packs
- A high output current of up to 1.3A (RMS) and 2A (peak) for each output bridge
- A standby power consumption down to 80nA
- Enhanced reliability due to under-voltage lockout (UVLO), as well as over-current and thermal protection
- A small 3 × 3mm quad flat no-lead (QFN) package

An explanation of these three motor-drive ICs shows their similarities and differences. The STSPIN220, which is designed for stepper motors, integrates both control logic and a high-efficiency, low drain-source on resistance  $R_{DS(ON)}$  power stage (Figure 5). The controller implements a pulse-width

modulation (PWM) current control with a programmable off time. It also allows a position resolution of 256 microsteps per full step, for extreme smoothness of motion.

The similar siblings of the STSPIN220 include: the STSPIN230, a monolithic driver for the widely used three-phase BLDC motors; the STSPIN240 monolithic driver for two independent brushed DC motors; and the STSPIN250, which is for a single brushed DC motor. (Note: The STSPIN250 is for a single motor, compared to the two-motor STSPIN240. It can deliver a higher current of 2.6A (RMS) and 4A (peak).) All these ICs share front-end designs and operational commands to the extent possible; functionally, their differences lay in the motor-side interfaces.

### Making the Choice

Confusing as it may seem, deciding which motor type to use is both an easy and difficult decision. Of course, whenever there are basic guidelines, there will be applications that are exceptions to these guidelines. Each motor type offers a different speed versus torque, angle versus torque, and stall behavior, which must be considered with respect to the application priorities and constraints.

In general, situations that are a good fit for the stepper motor are not suitable for either the brushed or brushless motor. The reason is that the former is better suited for constant start/stop/positioning priorities, while the latter two are better for continuous rotation. When choosing between a brushed or brushless motor, consider the following attributes:

- Brushed motors have a more limited life than BLDC motors, with brushed motor life dependent on bearings and brush wear, while BLDC lifespan is a function of bearing wear only. Also, conductive dust from brush surface scraping can contaminate other surfaces.

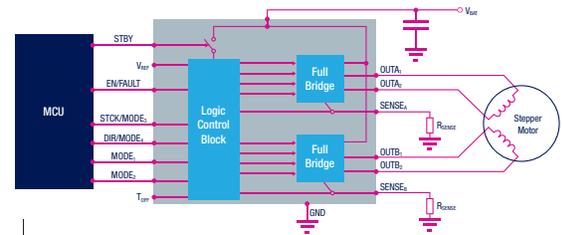


Figure 5. The STSPIN220 integrates both control logic and a high-efficiency, low on-resistance power stage for stepper motors. It includes a programmable off time for efficiency and supports resolutions up to 256 microsteps per full step. (Source: STMicroelectronics)

- High-quality brushed motors can reach 10,000rpm, while BLDC motor designs can reach five to even ten times that speed.
- Brushed motors can operate directly from the power source and, thus, need just two wires, while BLDC motors need electronic commutation and at least three wires, plus any sensor wires.
- Efficiencies are roughly the same, but the sources of inefficiency differ. For brushed motors, most inefficiency comes from losses in the windings and brush-related friction, while BLDC motors experience the same—regarding winding losses—plus the additional eddy-current losses, which increase with speed.
- Control circuitry is potentially more complex for steppers and simpler for brushed motors, but new ICs such as those from ST are largely eliminating these differences.
- A low-end brushed motor, like those used for an inexpensive toy, can be the cheapest solution by far in terms of motors, wiring, and control electronics (if any), but obviously, it can provide only, very limited performance.

### References

Countless motor-related references cover academic theory, implementations, applications, mechanical issues, electrical issues, thermal concerns, drive functions, and basic to advanced controls.

One good reference is ST's [An Introduction to Electric Motors](#). For more insight into stepper motors and microstepping (which is not as intuitive as brushed and brushless motors) look at ST's Application Note AN4923, [STSPIN220: Step-Mode Selection and On-the-Fly Switching to Full-Step](#).





# Case Study

By Enrico Poli, STMicroelectronics

## Solution for Safe Gas Metering Applications

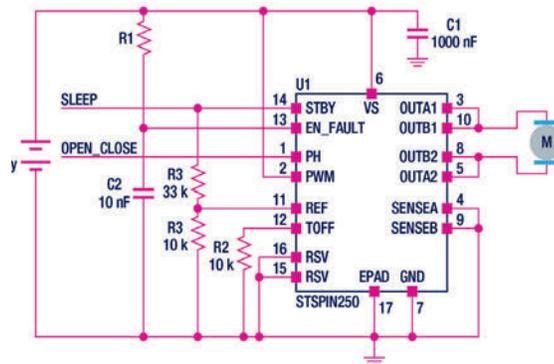
Natural gas is one of the most widely-used fossil fuels in the world, and as a result gas meters have become ubiquitous in residential, commercial, and industrial settings to measure gas consumption. The integrated circuits used in today's gas meters are supplied by batteries, and to keep gas suppliers' cost down they are expected to last for many years without maintenance. Thus, low power consumption is a key consideration for manufacturers in gas meter design.

In addition, modern gas meters must be equipped with automatic shut-off valves to interrupt the gas supply during events such as earthquakes, to reduce the risk of fire and explosion resulting from gas leaks. These valves are motorized

and run off the same battery supply as the meter's other circuitry, so engineers face the added challenge of integrating a motor driving circuit that has minimal impact on the meter's overall battery life.

STMicroelectronics' STSPIN250 low voltage brushed direct current (DC) motor driver answers this challenge convincingly with a device specifically

designed for battery-powered scenarios. With very low operating voltage and standby consumption of less than 80nA, it can also be forced into a zero-consumption state for even greater power saving. Thus the STSPIN250 can drive the valve motor reliably and with negligible impact on battery duration, rendering it uniquely suited for use in automatic gas shut-off valve designs.



### STSPIN820

Smooth & silent stepper motor driver

World's smallest, 256  $\mu$ steps capable, and 45V rated motor driver

- Extreme position accuracy and motion smoothness: with up to 1/256 microsteps per full step
- Integration of the PWM control and the power stage made by 500m $\Omega$  R<sub>DS(ON)</sub> MOSFETs
- Compact 4 x 4mm QFN makes it the smallest integrated microstepping driver with these ratings

guarantees one of the best performance-cost trade-offs

- Compact 4 x 4mm QFN makes it the smallest integrated microstepping driver with these ratings

[mouser.com/stmicroelectronics-stspin-drivers/](https://www.mouser.com/stmicroelectronics-stspin-drivers/)



By Bill Schweber for Mouser Electronics

## Programmable Versus Fixed-Function Controllers: Alternatives for Complex Robotic Motion

Control of today’s sophisticated robot arms, regardless of their size or power, often requires simultaneous management along multiple axes for their motion control. Modern electronics—the motors, power-switching devices (Metal-Oxide Semiconductor Field-Effect Transistors [MOSFETs] or Insulated-Gate Bipolar Transistors [IGBTs]), device drivers, control systems (now digital, formerly all analog), and feedback sensors—now make achieving precise motion control easier than it was just a few years ago (Figure 1). At the same time, however, the demands on system performance have increased dramatically, so the overall project is as difficult as ever.

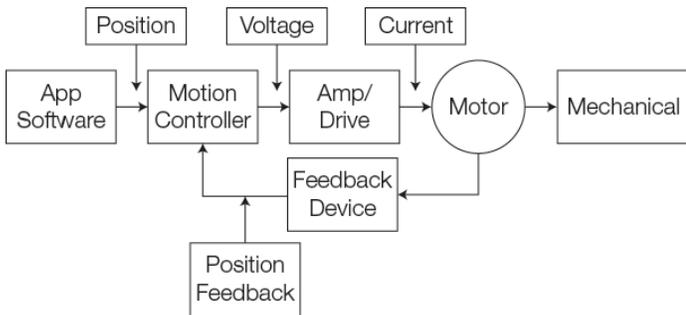


Figure 1: A basic motion-control system for robotics includes algorithm-execution functions, motor drivers, power devices, and a feedback path; mechanical linkages, motor, and sensor (in most cases); and voltage and current measurement and control at key points. (Source: National Instruments)

Nonetheless, there’s one unavoidable fact: Robotics is largely a mechanical function, so the realities of such systems must be part of the control loop. These include gear backlash, mechanical tolerances, vibration, motor performance, rotating mass inertia, momentum, flexing of mechanical structures, variable loads, and more. For these reasons, it is important to decide what type of motor is the best fit—usually the choice is between brushless DC motors and stepper motors in low/moderate power situations.

Another necessary decision is related to sensor-based feedback. Most robotic applications use some type of feedback sensor to accurately gauge the end-effector’s position, and thus velocity and acceleration (recall that velocity is the time integral of position, and acceleration is the time integral of velocity). This feedback transducer can be a Hall-effect sensor, a synchro/resolver, or an optical encoder. While it is easiest to put the encoder on the motor, placing it there may not provide required data about the end-effector’s actual situation, with sufficient accuracy for the application, due to mechanical issues noted above. Therefore, the sensor may need to be mounted closer to the load endpoint.

Some motion-control applications operate without a sensor, which reduces cost and mechanical complexity. Rather than using a sensor for feedback, Sensorless Field-Oriented Control (FOC, also called vector control) uses precise, synchronized readings of the current and voltage at each phase of the motor windings; FOCs then perform complicated frame-of-reference transformations and matrix calculations in real time to determine the motor’s position. Eliminating the

sensor reduces hardware cost, but it necessitates significant computational capability and more complex programming. Many robotic designs still prefer to use sensors because FOC does not provide the same level of confidence, credibility, and robustness that using direct-sensor readout offers.

## Understanding Basic Robotic Configurations

While the general public may associate the term “robot” with a mobile, life-like servant or assistant, most robotic systems in the industrial domain are stationary and use a variety of mechanical arms and configurations to perform tasks. Among the most common arrangements are:

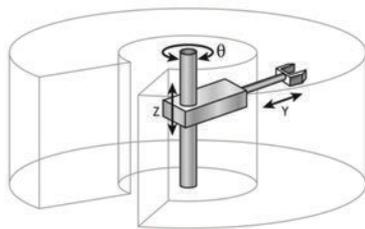
- The **Cartesian robot**, which has three linear axes of motion, one each in the x, y, and z-planes (Figure 2). This setup is used in pick and place machines, application of sealant, and basic assembly.

Figure 2: The Cartesian robot is the easiest to comprehend and control because it has the simplest equations and works in the x, y, and z planes. (Source: RobotPark)



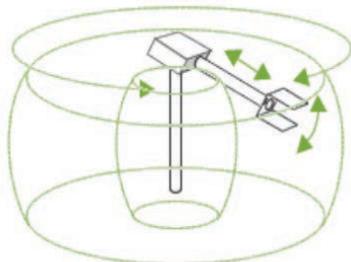
- In a **cylindrical robot**, all motion is confined to a cylinder-shaped zone. It combines linear motion in the y plane, linear motion in the z plane, and rotational motion around the z-axis (Figure 3). This robotic arrangement is used for assembly, tool handling, and spot welding.

Figure 3: The cylindrical robot has motion along two linear axes and around one rotational axis. (Source: RobotPark)



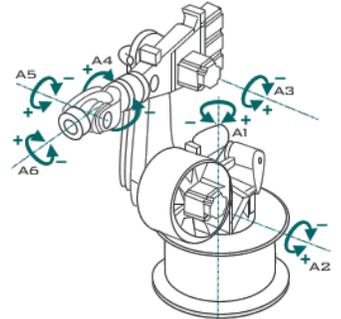
- The **spherical or polar robot** combines two rotary joints and one linear joint, and the arm is connected to the base with a twisting joint (Figure 4). Motion is defined by a polar coordinates system and confined to a spherical zone. They are found in welding, casting, and tool-handling applications.

Figure 4: The spherical or polar robot combines motion around two rotary axes and along one linear axis, and it requires numerous calculation intensive transformations between coordinate frames of reference. (Source: RobotPark)



The approaches cited here offer three degrees of freedom, using a combination of linear and rotary motion; however, some applications need only one or two degrees. More advanced robotic arms or articulated robots combine additional linear and rotary motion, for almost human-like dexterity and flexibility (Figure 5). Some leading edge arms provide six, eight, or even more degrees of freedom.

Figure 5: The articulated robot arm combines multiple rotation and linear motion modes for many degrees of freedom, but it also requires careful coordination among the actuators and arms. (Source: RobotPark)



Other designs use special combinations of linear and rotary motion for application-specific situations, such as the parallelogram implementation; an implementation used for precise and rapid motion over short distances, for example, pick and place of tiny components. As the number of degrees of freedom increases, achieving rapid, smooth, accurate, and synchronized control along each of these degrees grows exponentially more challenging.

## Considering Trajectory Profiles

The motion-control objective in robotics seems simple enough: have the end-effector optimally reach its target position as quickly and accurately as possible with the supported load. Of course, there are tradeoffs involved, as in all engineering decisions, depending on the priorities associated with the optimum result in the given application.

For example, is it acceptable to accelerate and decelerate more quickly to more rapidly reach a higher velocity if the result is overshoot and if there is even possible oscillation at the end point? Is it worth trading accuracy for speed, and to what extent? How are the choices of acceleration, velocity, and position related to the desired transition from position A to position B? What are the priorities and parameters that define “optimum” in a particular application?

Specialists in motion control for robotics and other motion applications have developed standard trajectory profiles that provide various ways to implement the desired tradeoff solution for a given application. All choices involve significant real-time calculation based on the present situation and feedback signal, but some impose a more substantial, high-resolution computation burden. These profiles include:

- The simple trapezoid, where the motor accelerates at a fixed rate from zero to a target velocity, stays at that velocity, and then ramps down at a fixed rate to zero velocity at the desired

position (Figure 6). Higher rates might speed up the entire positioning cycle, but they might also induce sudden changes in acceleration motion, called the jerk, which, in turn, adds to inaccuracy and overshoot.

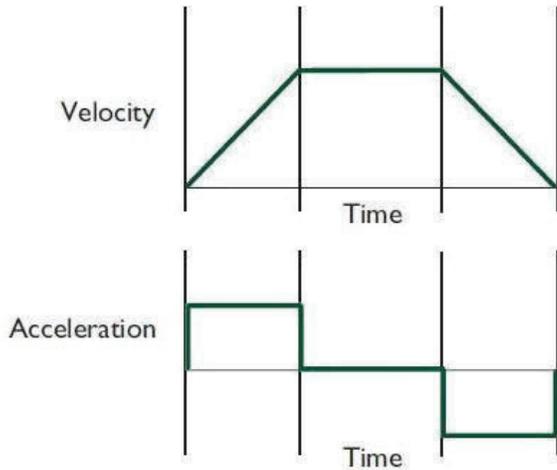


Figure 6: The simplest motion-trajectory profile is the trapezoid, which has constant acceleration to the target velocity, constant path velocity, and constant deceleration between start and endpoints. (Source: Performance Motion Devices)

- **The S-curve**, a frequently-used enhancement to the trapezoid, where the acceleration rate ramps up from zero, then decreases as the target velocity is achieved (Figure 7). Then, as the target position is reached, the deceleration rate is ramped up and then reduced as the endpoint is near. The S-curve actually has seven distinct phases, in contrast to the three phases of the trapezoid.

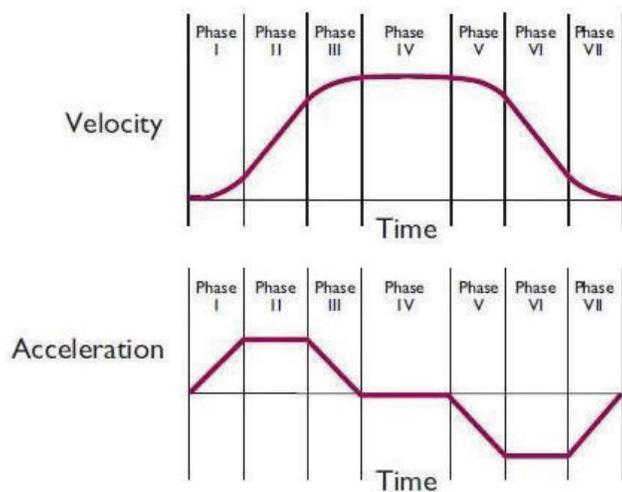


Figure 7: The S-curve path is more complicated than the basic trapezoid, but it eases the jerk (change in acceleration) at each transition point of the path. (Source: Performance Motion Devices)

- **In contoured motion**, the user establishes a set of desired positions, and the motion controller directs a smooth, jerk-free transition profile through all of these points (Figure 8). This allows the ultimate in flexibility and control, which is necessary for advanced motion situations. The required calculations of control directions to achieve smooth curve-fitting are complex and must be accomplished without loss of resolution due to rounding or truncation errors, despite the many calculations.

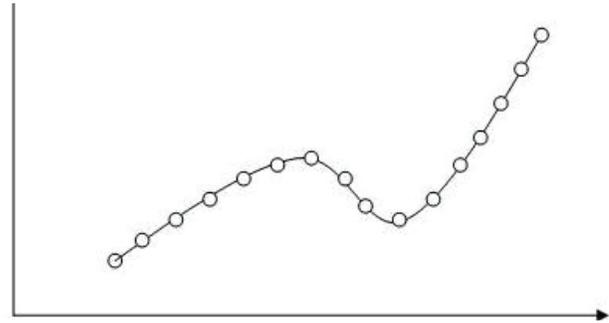


Figure 8: The contoured-motion path allows the user to define a series of position marker points between starting and ending points, and the controller must guide the end-effector through these in a smooth curve. (Source: National Instruments)

There are other profiles in use, some of which are associated with specific application groups or industries. Regardless of the desired profile, it's one thing to want it and another to make it happen. The well-known, highly effective Proportional-Integral-Derivative (PID) closed-loop control algorithm is the most common approach used to drive the motor and end-effector to do what is wanted with high enough accuracy and precision (Reference 1).

Effective control of a single axis is a manageable project, but robotic control becomes far more difficult when this control extends to two, three, or more motors and degrees of freedom, which must be closely coordinated and synchronized with the performance along one dependent on the status of the others.

### Determining Standard Versus Custom Motion Control Applications

For standard motion control applications, a dedicated, fixed-function, embedded controller Integrated Circuit (IC) offers ease of use and rapid time-to-market. In contrast, if a non-standard, customized profile is needed or if the correlation between the various axes is complicated and must accommodate unusual or unique events, then the design team may consider a fully user-programmable processor. This solution is implemented with a processor with Digital Signal Processor (DSP) capabilities for the computation-intensive aspects or with a Field-Programmable Gate Array (FPGA). When considering programmable devices,

Reference: IEEE GlobalSpec Electronics360, "Proportional Closed-Loop Control: The Foundation of Automated Systems"

the vendor, third-party tools, and available software modules are factors in making a specific selection, in addition to the hardware functions of the IC itself.

Note that these controllers are generally not the same as motor drivers, which are the MOSFET/IGBT drivers/devices that control motor power, for two reasons. First, these power devices must be sized to the motor, independent of the controller. Second, the high-density complementary metal-oxide-semiconductor-based process technologies used for these digital controllers are very different than the processes for power devices. For smaller motors, however, it is possible to integrate the controller with the driver and power device. Despite the fundamental differences, the term “controller” often refers to the power-device functional blocks, which can lead to confusion in keyword searches.

Some examples of motion control ICs show the spectrum that these devices span. STMicroelectronics Low-Voltage STSPIN stepper motor drivers integrate in a small QFN 3x3 package both the control logic and a high-efficiency power stage (Figure 9). The integrated controller implements PWM current control with fixed OFF time and a microstepping resolution up to 1/256th of a step. These devices offer a complete set of protection features including overcurrent, over temperature and short-circuit protection and are optimized for battery power applications.

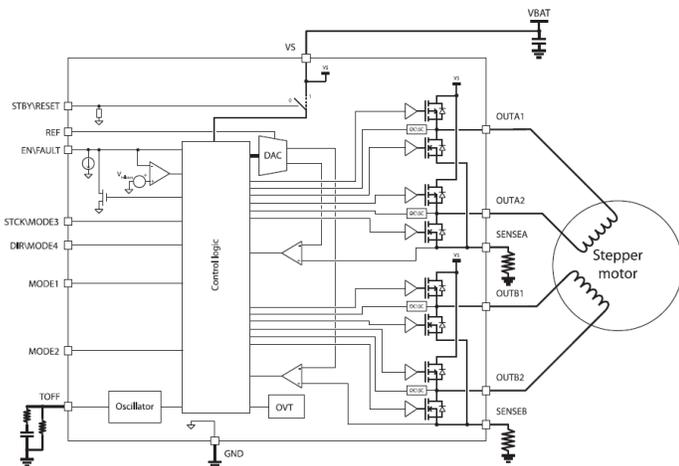


Figure 9: The STSPIN220 is a stepper motor driver integrating a microstepping sequencer (up to 1/256th of a step), two PWM current controllers and a power stage composed of two fully-protected full-bridges. (Source: STMicroelectronics)

One of the issues with stepper motors, even when used in microstepping mode, is that their output motion can vibrate as they start or stop their step motion. While not a problem in many situations, it can be a concern in the handling of delicate objects like glassware, or if it induces system resonances. Therefore, the

STSPIN motor drivers allows the user to tailor the rise/fall (slow decay + fast decay) of the current drive and establish rise and fall transitions for this current to minimize vibration (Figure 10).

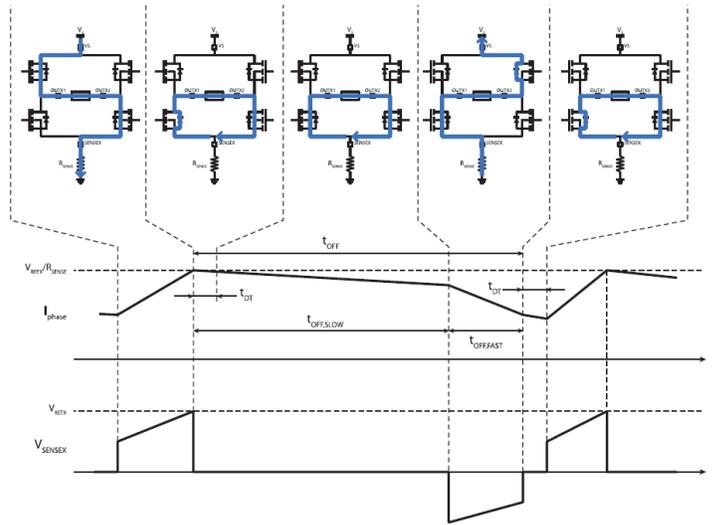


Figure 10: In application, the STMicroelectronics STSPIN220 implements two independent PWM current controllers, one for each full bridge. The decay sequence starts turning on both the low sides of the full bridge. When 5/8ths of the programmed OFF time (tOFF,SLOW) has expired, the decay sequence performs a quasisynchronous fast decay leading to optimal micro-stepping current regulation. (Source: STMicroelectronics)

At the top end of the motion-control pyramid are advanced units such as those in the STSPIN32F0, (Figure 11), which combines a 32-bit ARM® Cortex®-M0 core STM32F0 microcontroller and a three-phase, half-bridge gate driver in a tiny 7x7mm QFN package. The STSPIN32F0 delivers the flexibility and power of a microcontroller-based drive with the convenience, simplicity and space-efficiency of a single IC.

Key features and benefits this motor control solution from STMicroelectronics offers include on-chip operational amplifiers and comparator to support a wide variety of motors and algorithms bring flexibility and scalability to the applications. Also included are on-chip generated power supplies for the MCU and external circuitry.

The STSPIN32F0 also benefits from an extensive development ecosystem including the STEVAL-SPIN3201 board, software tools, firmware libraries and middleware on top of the popular motion-control algorithms such as Field-Oriented Control (FOC) and 6-step control to streamline firmware development. Additional capabilities of the STPINE32F0 also include types and number of input/output, and housekeeping functions like timers, comparator, and thermal protection.

Target applications of the STSPIN32F0 include 3-phase motors, power tools, fans, and small white goods as well as some high-end applications like robotics, 3D printers and drones.

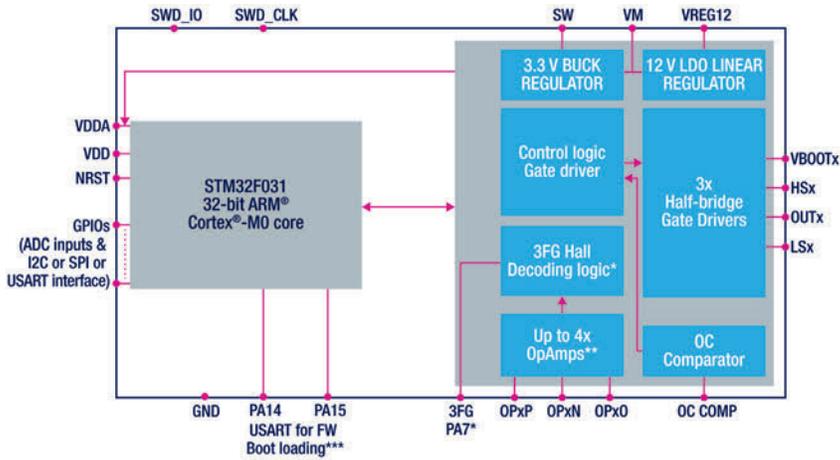


Figure 11: The The STSPIN32F0 from STMicroelectronics bringing the high computational power of STM32 32-bit microcontroller together in the same IC with a 3-phase gate driver for N-channel power MOSFETs. This enables designers to realize very precise field-oriented control of the electric motor, 6-step sensorless or other advanced driving algorithms, including the speed control loop. (Source: STMicroelectronics)



## Conclusion

Motion control options for robotics range from basic, dedicated-function ICs to highly integrated, extremely flexible MCUs with a large array of auxiliary processing and support functions. Although embedded devices may seem limiting, some of them allow selection of a variety of motion profiles and setting of critical parameters, and they are quite adequate, have low cost, and are easy to use. For advanced designs with unique or extremely sophisticated requirements, or designs needing additional levels of connectivity along with control, MCUs offer effective solutions with evaluation and development kits supported by verified code packages, debug and code-development tools, and validation suites.



By Mouser Staff

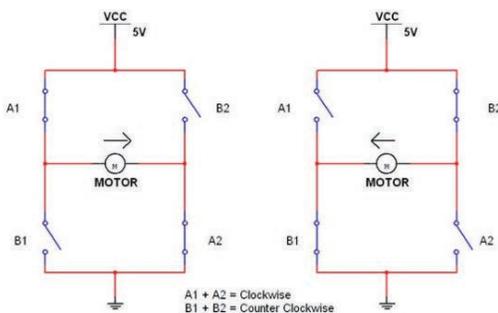
## Basics of MOSFETs and IGBTs for Motor Control

These two power-control switches can be used for the application; each brings tradeoffs to the design based on basic performance specifications, maximum ratings, thermal issues, and cost.

Today's motors are increasingly driven via electronic controls, which offer better control of speed, position, and torque, as well as much greater efficiency, rather than via direct connection to their source of power (whether AC or DC). To do this, the motor-control circuit must switch the current flow to the motor's coils on and off quickly, with minimal switching-time or conduction-period losses in the switch itself.

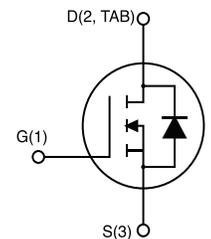
That's where MOSFETs and IGBTs are used. Both of these semiconductor devices serve the needs of motor drive and power control; each is better suited in some application situations. These electrically controllable switches are similar in function and attributes, and have some overlap in internal design, and yet they are quite different in many ways. In most applications, these switches are used in an H-bridge configuration (Figure 1), where they control the current flow path to two or more motor coils. This allows full control of the motor speed and direction.

Figure 1: In the basic H-bridge, a quartet of switches controls current flow and thus motor direction as cross-pairs of switches on or off. Note that the upper switches are floating and not connected to ground. (Source: 48projectsblog)



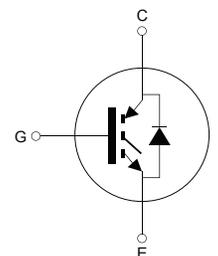
The MOSFET is a field-effect transistor that, depending on size and design, can switch a few hundred milliamps to tens of amps, and single-digit voltages to thousands of volts. Although there are many ways to draw it on a schematic, the most common symbol is shown in (Figure 2). Note that there are just three connections: source, drain, and gate; the gate controls the current flow from source to drain. Smaller MOSFETs can be fabricated directly on a standard MOS IC die, and so can be part of an integrated, single-chip solution (but only at fairly low power levels, due to die size and dissipation issues).

Figure 2: One of the common schematic representations of the MOSFET, with drain (D), gate (G), and source (S) terminals. (STripFET F7 Power MOSFET from ST Microelectronics)



The IGBT is a bipolar transistor, also a three terminal device, but with an emitter and collector as connections for the current path being controlled. Like the MOSFET, it has a gate to control that path, (Figure 3). As a bipolar device, it's very difficult to build an IGBT on a standard MOS IC process; thus, IGBTs are discrete devices. The IGBT combines the simple gate drive of a FET with the high-current/high-voltage handling capability of the bipolar transistor.

Figure 3: One of the common schematic representations of the IGBT, with collector (C), gate (G), and emitter (E) terminals. (H Series 600V IGBT from ST Microelectronics)



Note that many IGBT circuits also need a reverse-blocking (anti-parallel) diode which cannot be fabricated with the IGBT, so the IGBT+diode combination is often co-packaged and offered as a single module. Single-ended topologies such as boost-PFC power supplies do not need this diode, and use an IGBT alone.

The drive current needed at the gate to turn on either device varies, but is typically about 10% of the rated current of the device. Driving this current (sourcing) into the gate's capacitance fast enough for required turn-on speed, and pulling it out (sinking) for the turn-off cycle are two of the largest challenges in developing a complete motor-drive circuit, (Figure 4). In addition, for safety, electrical compatibility with low-voltage digital signals, or to “float” the upper device's driver, the path must often include galvanic isolation between the digital output of the controller's processor and the driver circuit.

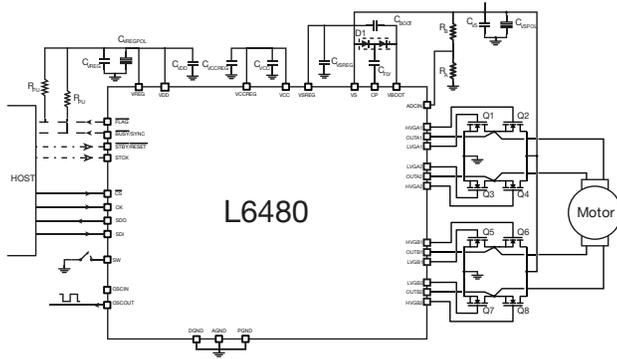


Figure 4: The ST Microelectronics L6480 dual full bridge gate drive circuit controls four pairs of MOSFETs in a dual H-bridge from a 5Mbit/s SPI bus. (Source: STMicroelectronics)

## Key parameters

As with most electronic components, there are a few primary parameters and performance specifications that determine the initial match between the device and the application. These are followed by a large number of secondary parameters and then by tertiary ones that, when taken as a group, point to a suitable choice. Of course, there is no single “best” choice, as any selection forces decisions with respect to the weighting of the many unavoidable tradeoffs of component selection (including cost, of course). For both devices, the top-level parameters are the current-handling and peak-voltage ratings, as these determine if a specific part can support the motor's load requirements.

For MOSFETs, the next critical parameters are on-resistance ( $R_{DS(on)}$ ) and gate capacitance. Lower on-resistance means reduced resistive loss and voltage drop when conducting, and thus reduced dissipation load and increased efficiency. Advances

in MOSFET design have reduced on-resistance to tens of milliohms—small, for sure, but still a potential problem when handling tens or hundreds of amps.

Gate capacitance determines the current and slew rate needed to turn the gate fully on and off with the desired transition time (which relates to switching speed). The amount of current to be injected or pulled out is based on the basic equation  $I = C \, dV/dt$ ; there's no way around that.

For IGBTs, the next critical specification is the on-state voltage drop  $V_{drop}$  of about 2 V, which is the sum of the diode drop across the internal PN junction and its internal driving MOSFET; it never goes below a single-diode threshold value.

If these parameters were static, selection would be easier. But the reality is that both MOSFET  $R_{DS(on)}$  and IGBT  $V_{drop}$  are affected by temperature and current level, and power devices such as these do have significant self-heating. For MOSFETs, the voltage drop is resistive and proportional to current, and  $R_{DS(on)}$  increases with temperature. For IGBTs, the drop is diode-like, increasing with the log of the current, and is relatively constant with temperature.

In general, when comparing MOSFETs and IGBTs, the former offers higher switching speeds (MHz); higher peak current; and a wider SOA (safe operating area). But their conduction is strongly dependent on temperature and voltage rating; as the voltage rating goes up, the reverse recovery performance of their integral diode deteriorates, increasing switching losses. IGBTs are available with higher current ratings, and are rugged, but have slower switching speed; their lack of an internal reverse-recovery diode means you must find an IGBT co-packaged with a diode matched to your application.

For motor-drive applications, starting guidelines are that MOSFETs are a better choice at lower voltages and currents, and at higher switching frequencies; IGBTs are a better choice at higher voltage/current and lower frequencies. Caution: All guidelines have many exceptions, depending on the application's specifics. Since most motors need only lower-frequency operation (a function of the number of poles and the maximum rpm), IGBTs are a viable option for this application.

## Thermal and packaging considerations

No discussion of MOSFETs and IGBTs for motor drive is complete without discussion of dissipation and packaging. Since motors involve power control, the switching component must be able to dissipate the inevitable heat that results from internal losses. The industry has standardized on a relatively few package sizes and types for these devices (D2PAK, D-Pak, TO-220, TO-227, and TO-262 for small/moderate power levels), which simplifies heat-sink and cooling options.

Thermal modeling of the package and its dissipation performance at the power levels is critical. Vendors provide detailed thermal models, and the basic modeling is fairly straightforward. Vendors also provide application notes that walk designers through the basics with examples. The initial modeling usually only requires a spreadsheet, but a more advanced thermal-analysis applications program may be needed to investigate heat-sinking and related options. Both MOSFETs and IGBTs can be paralleled to carry higher current or physically spread the thermal sources—often a need in motor drive—but each needs a different configuration of additional passive components to balance and equalize current flow.

There's more to modeling than the component's thermal situation. Even if you can get rid of enough of the heat from the MOSFET or IGBT to keep it below its SOA rating, that heat has to go somewhere. In some cases, there is an easy dissipation path to "outside," but in many cases, the heat the device gives off becomes a problem for the rest of the PC board or box. Therefore, the thermal analysis must look at system-wide impact of dissipation, especially as many motor applications are in enclosed or challenging environments where ambient temperatures are high and cooling airflow is low.

## Making the choice

There is no single "best" choice of individual model or even between a MOSFET or IGBT in most cases. The reality is that the decision is made on many performance parameters and their relative priority, as well as availability and cost.

Fortunately, ST Microelectronics manufactures a variety of both MOSFETs and IGBTs, so they can provide a balanced assessment of the decision of which type of switch to use. In addition to in-depth data sheets, ST also offers solid application notes on general design issue, supplemented with detailed designs (and their analysis) for specific applications plus a library of proven reference designs (layout, BOM) that you can use as a starting point.

*For motor-drive applications, starting guidelines are that MOSFETs are a better choice at lower voltages and currents, and at higher switching frequencies; IGBTs are a better choice at higher voltage/current and lower frequencies.*

# Video

## STMicroelectronics Low-Voltage STSPIN Motor Drivers

STMicroelectronics' STSPIN32F0 is a system-in-package that reduces the number of components and design complexity for driving three-phase BLDC motors. It includes an advanced BLDC controller that integrates 3 half-bridge gate drivers for power MOSFETs or IGBTs, with bootstrap diodes and an interlock that prevents cross-conduction. It also includes a fully featured STM32 MCU with an ARM® Cortex®-M0 core to perform FOC, 6-step sensorless, speed control loops, and other advanced driving algorithms. The STSPIN32F0 can operate from an 8 to 45 V supply and includes a 12 V linear regulator for the gate drivers and a 3.3 V switching regulator to supply the MCU and external components if needed. Its versatility makes it ideal for consumer and industrial motor drive applications.



# Video



## STSPIN820, silent, high-precision all-in-one advanced motor driver

ST, a pioneer in the field of motor and motion control, offers a wide range of motor drivers covering the requirements of brushed DC motors, stepper motors and brushless DC motors over an extensive range of voltage and current ratings. Our line-up of STSPIN motor drivers embeds all the functions needed to drive motors efficiently and with the highest accuracy, and include an advanced motion profile generator to relieve the host microcontroller, while ensuring robustness and reliability thanks to a comprehensive set of protection and diagnostic features.

The STSPIN820 Stepper Motor Driver integrates control logic and a low  $R_{DS(ON)}$  power stage and is housed in a very small QFN 4x4mm package. The integrated controller implements a PWM current control with fixed OFF time and a microstepping resolution up to 1/256th of the step. The device can be forced into a low consumption state and offers protection features like overcurrent, overtemperature and short-circuit protection.

Able to work in a wide voltage range from 7 to 45V with a current level up to 1.5A, meeting the operating conditions of most industrial applications, the STSPIN820 achieves a resolution of up to 256 microsteps, guaranteeing very precise positioning as well as smooth and silent motion.

In a miniaturized 4 x 4mm QFN package, the STSPIN820 monolithic stepper motor driver integrates the expertise and excellence of ST's motor drivers for integration and performance.

### IDEAL FOR

#### Bipolar stepper motors in applications from 7 to 45V such as:

- CCTV, security and dome cameras
- 3D printers
- Textile and sewing machines
- ATM and cash handling machines
- Medical equipment
- Industrial 2D printers
- Office and home automation
- Points of sale (POS)
- Robotics

### KEY FEATURES & BENEFITS

- Extreme position accuracy and motion smoothness: with up to 1/256 microsteps per full step
- Integration of the PWM control and the power stage made by 500mΩ  $R_{DS(ON)}$  MOSFETs guarantees one of the best performance-cost trade-offs
- Easy step-clock and direction interface
- 7 to 45V operating voltage for wide range of applications
- Maximum reliability: UVLO, over-current and thermal protections
- Compact 4 x 4mm QFN makes it the smallest integrated microstepping driver with these ratings

# Products for Smart Industry Selector Guide

## Stepper motor drivers and controllers

Part number	Package	General description	R <sub>DS(on)</sub> (Ω)	Supply voltage (V)		Output Current-Max	Operating temperature		
				Min.	Max.		Min. (°C)	Max. (°C)	
PoweStep01	VFQFPN 11x14x1	System-in-package integrating microstepping controller and 10A power MOSFETs	0.016	7.5	85	10	-40	150	
STSPIN220	VFQFPN 16 3x3x1.0	Low Voltage Motor driver with up to 256 microsteps and embedded PWM current control	0.2	1.8	10	1.3			
L6474	HTSSOP28; PowerSO 36	Motor driver up to 16 microsteps with SPI and advanced current control	0.3	8	45	3			
L6472	HTSSOP28; PowerSO 36	Full features motor driver up to 128 microsteps with SPI, motion engine and advanced current control							
L6470									
L6208	PDIP24, PowerSO 36, SO24	Stepper motor driver with embedded current control							52
L6208Q	VFQFPN 48 7x7x1.0								
STSPIN820	TFQFPN 4x4x1.05 - 24L	Compact advanced 256 microsteps motor driver with step-clock and direction interface	0.5	7	45	1.5			
L6258	PowerSO36	PWM controlled high current DMOS universal motor driver	0.6	12	34	1.2			0/-40*
L6228	PDIP24, PowerSO 36, SO24	Stepper motor driver with embedded current control	0.7	8	52	1.4			-40
L6228Q	VFQFPN 32 5x5x1.0								
L6219	SO24, PDIP 24	Stepper motor driver	-	10	46	0.75			-20
L6482	HTSSOP38	Stepper controller with SPI, motion engine, gate drivers and advanced current control featuring 128 microsteps	-	7.5	85	-	-40	150	
L6480			-			-			
L297	PDIP 20; SO-20	Stepper motor controller	-	4.75	7	-			

Note \* Extended to -40 in EA version

## Brushed DC motor drivers and controllers

Part number	Package	General description	R <sub>DS(on)</sub> (Ω)	Supply voltage (V)		Output Current-Max (A) RMS max	Output Current-Max	Operating temperature	
				Min.	Max.			Min. (°C)	Max. (°C)
PWD13F60	VFQFPN 10x13x1.0	High voltage full bridge with integrated smart driver	0.3	6.5	600	8	32	-40	150
STSPIN240	VFQFPN 16 3x3x1.0	Low voltage dual brushed DC motor driver	0.2	1.8	10	1.3	2		
STSPIN250		Low voltage brushed DC motor driver	0.1	1.8	10	2.6	4		
L6205	PDIP20; PowerSO-20; SO20	Versatile DMOS dual full bridge motor drivers with embedded PWM current control	0.3	8	52	2.8	7.1		
L6206	PDIP24; PowerSO 36; SO24								
L6206Q	VFQFPN 48 7x7x1.0								
L6207	PDIP24; PowerSO 36; SO24								
L6207Q	VFQFPN 48 7x7x1.0								
STSPIN840*	TFQFPN 4x4x1.05 - 24L	Compact dual brushed DC motor driver with embedded PWM current	0.5	7	45	1.5	2.5		
L6225	PDIP; PowerSO-20; SO20	Versatile DMOS dual full bridge motor drivers with embedded PWM current control	0.7	8	52	1.4	3.55		
L6226	PDIP24; PowerSO 36; SO24								
L6226Q	VFQFPN 32 5x5x1.0								
L6227	PDIP24; PowerSO 36; SO24								
L6227Q	VFQFPN 32 5x5x1.0								
L6201	PowerSO-20; SO-20	DMOS full bridge motor driver	0.3	12	48	1	5		
L6202	PDIP 18						10		
L6203	MW 11L								
L2293Q	VFQFPN 32 5x5x1.0	Push-pull four channels motor driver with diodes	-	4.5	36	0.6	1.2		
L293D	PDIP 16; SO-20						2		
L293B	PDIP 16					-			
L293E	PDIP 20								
L298	MW 15L; PowerSO-20	Dual full bridge motor driver				2	-		

Note \* Coming soon

# Products for Smart Industry Selector Guide

## Brushless DC motor drivers and controllers

Part number	Package	General description	R <sub>DS(on)</sub> (Ω)	Supply voltage (V)		Output Current-Max	Output Current-Max	Operating temperature	
				Min.	Max.			Min. (°C)	Max. (°C)
STSPIN32F0	VFQFPN 48 7x7x1.0	Advanced BLDC controller with embedded STM32 MCU, DC-DC and optimized for FOC	-	8	45	-	600	-40	150
STSPIN32FOA		Advanced BLDC controller with embedded STM32 MCU, DC-DC, extended V Range and optimized for 6-step control		6.7					
STSPIN230	VFQFPN 16 3x3x1.0	Low voltage 3-phase integrated motor driver	0.2	1.8	10	1.3	2		
STSPIN233*		Low voltage 3-phase integrated motor driver optimized for 3 shunts configuration							
L6234	PDIP20; PowerSO-20	Triple half bridge integrated motor driver	0.3	7	52	2.8	5		
L6235	PDIP24; PowerSO-36; SO24	3-phase 6-step integrated motor drivers with embedded Hall sensors decoding logic	0.3	8	52	2.8	7.1		
L6235Q	VFQFPN 48 7x7x1.0					2.5			
STSPIN830*	TFQFPN 4x4x1.05-24L	Compact 3-phase integrated motor driver optimized for 3 shunts configuration	0.5	7	45	1.5	2.5		
L6229	PDIP24; PowerSO-36; SO24	3-phase 6-step integrated motor drivers with embedded Hall sensors decoding logic	0.7	8	52	1.4	3.55		
L6229Q	VFQFPN 32 5x5x1.0								
L6230	PowerSO 36; VFQFPN 32 5x5x1.0	Triple half bridge integrated motor driver optimized for 3 shunts configuration							

Note \* Coming soon

## Ecosystem for stepper motor drivers and controllers

Part number	Tooltype	Core product	Evaluation software	Firmware	Companion board
X-NUCLEO-IHM14A1	Expansion board for STM32 NUCLEO board	STSPIN820	-	X-CUBE-SPN14	NUCLEO-F030R8, NUCLEO-F334R8, NUCLEO-F401RE, NUCLEO-L053R8
X-NUCLEO-IHM06A1	Expansion board for STM32 NUCLEO board	STSPIN220	STSW-SPIN002	X-CUBE-SPN6	STM32 NUCLEO board F4, F0 or L0 series
EVLPOWERSTEP01	Evaluation board	POWERSTEP01	STSW-SPIN002	X-CUBE-SPN3	STEVAL-PCC009V2 interface board
X-NUCLEO-IHM03A1	Expansion board for STM32 NUCLEO board	POWERSTEP01	STSW-SPIN002	X-CUBE-SPN3	STM32 NUCLEO board F4, F0 or L0 series
EVAL6482H-DISC	Discovery kit	L6482	STSW-SPIN002	STSW-SPIN005, STSW-SPINDISC01	-
EVAL6482H	Evaluation board	L6482	STSW-SPIN002	STSW-SPIN005	STEVAL-PCC009V2 interface board
EVAL6480H-DISC	Discovery kit	L6480	STSW-SPIN002	STSW-SPIN005, STSW-SPINDISC01	-
EVAL6480H	Evaluation board	L6480	STSW-SPIN002	STSW-SPIN005	STEVAL-PCC009V2 interface board
STEVAL-3DP001V1	Reference design	L6474	STSW-3DP001	-	-
EVAL6474H	Evaluation board	L6474	STSW-SPIN002	X-CUBE-SPN1	STEVAL-PCC009V2 interface board
EVAL6474PD	Evaluation board	L6474	STSW-SPIN002	X-CUBE-SPN1	STEVAL-PCC009V2 interface board
X-NUCLEO-IHM01A1	Expansion board for STM32 NUCLEO board	L6474	STSW-SPIN002	X-CUBE-SPN1	STM32 NUCLEO board F4, F0 or L0 series
EVAL6472H-DISC	Discovery kit	L6472	STSW-SPIN002	STSW-SPIN004, STSW-SPINDISC01	-
EVAL6472H	Evaluation board	L6472	STSW-SPIN002	STSW-SPIN004	STEVAL-PCC009V2 interface board
EVAL6472PD	Evaluation board	L6472	STSW-SPIN002	STSW-SPIN004	STEVAL-PCC009V2 interface board
EVAL6470H-DISC	Discovery kit	L6470	STSW-SPIN002	STSW-SPIN004, STSW-SPINDISC01	-
EVAL6470H	Evaluation board	L6470	STSW-SPIN002	STSW-SPIN004	STEVAL-PCC009V2 interface board
EVAL6470PD	Evaluation board	L6470	STSW-SPIN002	STSW-SPIN004	STEVAL-PCC009V2 interface board
X-NUCLEO-IHM02A1	Expansion board for STM32 NUCLEO board	L6470	-	X-CUBE-SPN2	STM32 NUCLEO board F4, F0 or L0 series
STEVAL-IKM001V1	Evaluation kit EVAL6470H and STEVAL-PCC009V2	L6470	STSW-IKM001V1S	STSW-IKM001V1	-
X-NUCLEO-IHM05A1	Expansion board for STM32 NUCLEO board	L6208	STSW-SPIN002	STSW-SPIN005	STM32 NUCLEO board F4, F0 or L0 series
EVAL6208Q	Evaluation board	L6208Q	STSW-SPIN003	-	STEVAL-PCC009V2 interface board
EVAL6208N	Evaluation board	L6208	-	-	-
EVAL6228QR	Evaluation board	L6228Q	-	-	-

# Products for Smart Industry Selector Guide

## Ecosystem for brushed DC motor drivers and controllers

Part number	Tooltype	Core product	Evaluation software	Firmware	Companion board
X-NUCLEO-IHM12A1	Expansion board for STM32 NUCLEO board	STSPIN240	STSW-SPIN002	X-CUBE-SPN12	STM32 NUCLEO board F4, F0 or L0 series
X-NUCLEO-IHM13A1	Expansion board for STM32 NUCLEO board	STSPIN250	STSW-SPIN002	X-CUBE-SPN13	STM32 NUCLEO board F4, F0 or L0 series
X-NUCLEO-IHM15A1*	Expansion board for STM32 NUCLEO board	STSPIN840	-	X-CUBE-SPN14	L0, F0, F3, F4
EVALPWD13F60	Evaluation board	PWD13F60	-	-	-
EVAL6227QR	Evaluation board	L6227Q	-	-	-
EVAL6227PD	Evaluation board	L6227	-	-	-
EVAL6225PD	Evaluation board	L6225	-	-	-
EVAL6207Q	Evaluation board	L6207Q	STSW-SPIN003	-	STEVAL-PCC009V2 interface board
X-NUCLEO-IHM04A1	Expansion board for STM32 NUCLEO board	L6206	STSW-SPIN002	X-CUBE-SPN4	STM32 NUCLEO board F4, F0 or L0 series
EVAL6206Q	Evaluation board	L6206Q	STSW-SPIN003	-	STEVAL-PCC009V2 interface board
EVAL6206N	Evaluation board	L6206	-	-	-
EVAL6205N	Evaluation board	L6205	-	-	-
EVAL2293Q	Evaluation Board	L2293Q	-	-	-

Note \* Coming soon

## Ecosystem for brushless DC motor drivers and controllers

Part number	Tooltype	Core product	Evaluation software	Firmware	Companion board
STEVAL-SPIN3201	Evaluation board	STSPIN32F0	-	STSW-SPIN3201	-
X-NUCLEO-IHM11M1	Expansion board for STM32 NUCLEO board	STSPIN230	-	X-CUBE-SPN11	STM32 NUCLEO board F4, F0 or L0 series
STEVAL-SPIN3202	Evaluation Board	STSPIN32F0A	STSW-SPIN3202	-	NUCLEO-F030R8, NUCLEO-F103RB, NUCLEO-F302R8
X-NUCLEO-IHM16M1*	Expansion board for STM32 NUCLEO board	STSPIN830	-	X-CUBE-SPIN16	-
X-NUCLEO-IHM17M1*	Expansion board for STM32 NUCLEO board	STSPIN233	-	X-CUBE-SPIN17	NUCLEO-F030R8, NUCLEO-F103RB, NUCLEO-F302R8
P-NUCLEO-IHM001	NUCLEO Pack with NUCLEO-F302R8 and X-NUCLEO-IHM07M1	L6230	-	X-CUBE-SPN7, STSW-STM32100	-
X-NUCLEO-IHM07M1	Expansion board for STM32 NUCLEO board	L6230	-	X-CUBE-SPN7, STSW-STM32100	STM32 NUCLEO board F4, F0 or L0 series
STEVAL-IHM042V1	Evaluation board	L6230	-	STSW-STM32100	-
STEVAL-IHM043V1	Evaluation board	L6234	-	STSW-STM32100	-
EVAL6230QR	Evaluation board	L6230	-	-	-
EVAL6235Q	Evaluation board	L6235Q	STSW-SPIN003	-	STEVAL-PCC009V2
EVAL6229PD	Evaluation board	L6229	-	-	-

Note \* Coming soon

# Mouser stocks the widest selection of the newest products from STMicroelectronics



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