TECHNICAL DATA
AP6245, Rev -

Brushless DC Motor Controllers: Improved control & efficiency for motor control systems

Introduction

The continuing evolution of power components coupled with advancement of DSP's a allows increased performance and efficiency for Modern Brushless DC (BLDC) motor controllers. Sensitron has a 40+ year history of designing compact power solutions that have been used in many high reliability systems that require precision control and efficiency. As both mechanical and electrical technology has evolved, this has led to much improved performance for both simple and complex motor systems. This proven technology offers significant advantages and improves time to market.

The demand for electric motors has been steadily increasing annually Compound Annual Growth Rate (CAGR) of 18% projected to rise through 2032 to a TAM (Total Available Market) of $108 billion in the US alone. With similar growth rates in EU. China and Asia have been higher as these countries continue to modernize and improve infrastructure.

The market has several sectors from high power to smaller "micro" power motors. The mid-range horsepower motors outpace that of smaller fractional horsepower types. This demand is driven by environmental systems as electric vehicles continue to drive and fund advancements. The beneficiaries are industrial, avionic, military and space as they continue to demand higher power and improved efficiency with size and weight reductions. The European markets have a directive to improve motor efficiency. Ownership and cost of developing and maintaining designs are key factors in military and avionic markets as they require long-life product support. To achieve these goals, Sensitron has kept pace producing and developing reliable and efficient motor power systems control techniques must be considered. The brushless DC motor and controller are the most sensible choice based upon its reliability, efficiency and size.

The BLDC motor provides a proven advantage due to efficiency and size in demanding motor applications. These motors are brushless, requiring less maintenance, and less system down time while improving cost of ownership. These motors utilize electronic controllers that can be simple to complex dependent on system requirements. Brushless Direct Current (BLDC) motors typically have efficiency of over 80%, with the most advanced motor controllers in the 95% range. These motor controllers use Pulse Width Modulation (PWM) to drive a motor from DC power. The system will also typically require power conditioning to ensure the proper voltage parameters are met. This can range from rectification of an AC signal to Electromagnetic Interference (EMI) filtering that is required in most applications. Sensitron is a leading provider of AC rectification in high reliability military, avionic and space markets.

Motor Applications

Defining and understanding the motor application is essential to selecting the optimum controller choice. A comprehensive table can be found at the end of this document. As an overview for the purpose of the discussion common motor control techniques and applications can be broken down as shown in Table 1.

Table 1. Motor Control Techniques and Applications

System Types	Application	Control Type	Sensitron Product Group	Output Power
Environmental systems: Fans, Pumps, and Compressors	Rotate at constant or multiple RPMs	**Speed**	SMC, SMCS, SMCV2	15A to 68A, 100V to 1200V
Constant Force: Wing Slats & Flaps, Doors, Fins	Maintain force while changing direction	**Torque**	SMCT, SMCV2	10A to 150A, 100V to 1200V
Pointing Systems: Turrets, Radar, Robotics, Satellite Communications,	Move to precise location	**Position**	SMCV2	Up to 100A, 100V to 1200V

Each of these systems utilizes specific motor control techniques with tuning of control loops – torque, speed and/or position. Precision and efficiency are determined by the method which is used in controlling the motor voltage that is required to achieve torque (current) control, velocity (speed) control or position control. Sensitron provides several types of controllers. Each has its benefits.

a) Analog Controller b) Digital controller c) Line Replaceable Unit (LRU)

Avionic Applications

Ensuring safety of civilian aircraft electronic systems requires rigorous design approach and certification especially for programmable devices. To ensure passenger safety in electronic designs, the US Federal Aviation Administration (FAA) implemented specifications to conform with flight safety in 2005. This is a well-defined rigorous evaluation and documentation process that has several levels of certification that are dependent on the criticality of the role of the device in the aircraft. The cost for development is significant. Analog controllers are ideal for use in avionic applications due to the size and the certification costs, since there are no programmable devices. For example, **DO178** defines development and test for software.

Space Applications

There has been significant change in the space industry largely because of the proliferation of the Low Earth Orbit LEO commercial communication constellations. These are typically lower cost and shorter mission life where quantity has made the failure rate due to the rigors of the space environment. Analog motor controllers are commonly used in space applications to minimize the cost of radiation tolerant components such as DSP, ASICs or FPGAs. Higher orbit and deep space missions typically require radiation tolerant devices. Radiation testing and characterization may still be required. Total Dose Testing tests the life of electronics in an equivalent environment due to the radiation having a cumulative effect. Single Event Testing checks the reaction to events such as solar flares. The Commercial satellite market, generally low earth Orbit (LEO), is very cost competitive. This market has tended to utilize non-radiation tested products. The higher orbit Medium Earth Orbit (MEO) and Geosynchronous Earth Orbit (GEO) typically require TID and SEE data and parts having a radiation hardness assurance plan. Deeper space missions also will need this data.

Analog Motor Controllers

The benefit of the analog approach is that these motor controllers come in a compact form. Analog motor controllers do not utilize microprocessors. The control loops are defined using resistors and capacitors. Knowledge of control loops and tuning to ensure performance and stability is required. This is supported in data sheets. Engineers have also developed spread sheets that will ensure calculations for selection of the component ensure loop stability and meet system performance.

Digital Motor Controllers

Performance advantages: Flexibility & Efficiency

The continued performance improvements of digital signal processors have made it possible for improved efficiency and performance. The digital motor controller internal control loops are commonly configured with software or a Graphical User Interface (GUI). This has electrical and system engineering benefits that enable designers to create flexible products and improve time-to-market. Modifying performance or changing motors with similar power range typically does require a physical PC board modification.

Digital Signal Processing (DSP)

The versatility of digital motor controller designs utilizes powerful DSP devices that are now available. These processors enable a single design to be used in a wide range of systems from sensorless to complex multi-axis position control systems. The processing power of the DSP, along with associated GUI, takes the complicated math out of the user's designs, using parameters directly from the system. These parameters are from electrical characteristics of the motor: type, impedance, voltage, current, etc. to the full system requirement such as rpm, holding torque, position, etc. They are used to meet the expected motor system performance goals where the torque, speed and position loops are calculated for the designer based these parameters as provided to the processor via GUI.

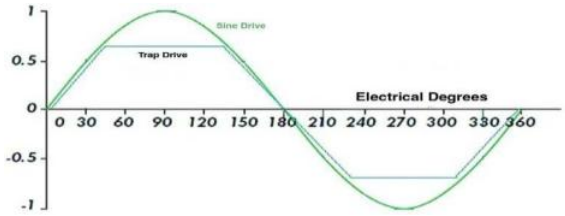

Figure 1. Commutation Signals

The control logic in the DSP provides the complex mathematical calculations and algorithms required to gain the efficiency of the field-oriented control (FOC) via a sinusoidal motor commutation technique that is used in Sensitron's DSP based controllers. This technique delivers power to the motor by means of an efficient sinusoidal (sine) waveform (see Figure 1). The sinusoidal signal is used to commutate/spin the motor and provides maximum voltage/speed and reduces noise by over 30% relative to a trapezoidal (trap) drive. The trapezoidal wave shape produces harmonics that can affect EMI. The torque ripple on a sinusoidal motor can be as low as 1%, whereas ripple for the trapezoidal motor can be up to 13-14%.

The processing power of digital motor controllers enables flexible motor control designs. The applications range from a sensorless motor system, such as a fan or pump, to a complex multi-axis design, such as those that are used in turrets and robotics.

Speed Controllers

A speed controller is typically used in a system where speed is the most important performance criteria – such as a fan or pump. The voltage applied to the motor is proportional to speed. The speed controller uses internal sensing and algorithms that are required for speed regulation, sets the control loop parameters. The Sensitron

SMCS series motor controller is an example of an analog design for sensorless speed control. Whereas the SMCV controller is a digital controller that can be configured for sensorless speed control.

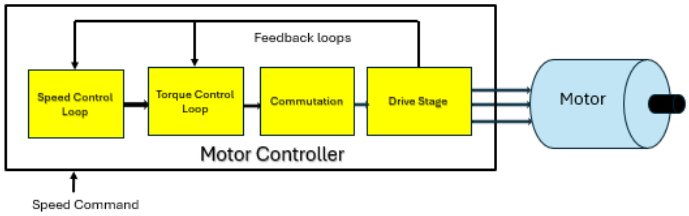

Figure 2. Sensorless Motor Control System

Torque Controllers

Torque is proportional to current applied to the motor. Torque controllers are used in applications that require holding torque and changes in direction, since these controllers maintain smooth transitions in torque through zero speed. The bandwidth for the current/torque loop is greater than that of the speed loop. Controlling current/torque to the motor allows for precision control of torque while compensating for back-EMF and motor winding resistance

changes with temperature. The Sensitron SMCT analog motor controller and the Sensitron SMCV digital controller can both be configured as torque controllers.

Position Controllers

A position controller utilizes an interface with position sensors such as a resolver or encoder that is placed on the motor or at the load. The position loop is the outer control loop in this system. The speed and torque loops must be tuned as well. All three control loops must be tuned based on the motor and system parameters. Motor control applications will utilize a torque or speed controller with the customer's algorithms that can be programmed into a digital controller by the end user as with the Sensitron SMCV2 motor controller

Programmable Motor Control Devices

Graphical User Interface (GUI)

There are many parameters that can affect system performance. The digital motor controller has a Graphical User Interface which the user can enter to optimize the motor performance. A GUI is the perfect tool to minimize the time impact of additional tuning. Another benefit of tunable controllers is that a motor can be swapped out, and a replacement made operational in a short time, with a simple change of parameters. Also, multiple motors can be used with the same controller. This will reduce the cost of ownership, which is a key consideration for motor control systems.

Figure 3 . Sensitron Graphical User Interface (GUI)

Interfacing

DSP-based solutions also allow for interfacing with host processor-controlled systems that communicate on serial networks such as CAN, RS-485, RS-422. They can also be configured to operate in the same manner as an analog motor controller: using input voltage to command the speed and/or torque. On-board or system processors can coordinate 2 axis movement as required in satellite base stations, radars, turrets or robotic systems. Sensitron has multiple motor controllers that incorporate all control algorithms and sensor interfaces, as well as provide advanced protection, such as over temperature, overcurrent, etc. This is true for both analog/trapezoidal drives such as the Sensitron SMCT, SMCS and SMC along with the SMCV digital/sine drives. These devices have protection built in the hardware. The DSP based solution also can have soft limits set that interface with the motor control system, with parameters set by the GUI. The control and power stages for these motor controllers are available in compact form, such as a hybrid or module, which can be integrated into larger systems. Sensitron provides a “systematic re-use” topology that allows portions of any control system to be adapted to meet custom motor requirements.

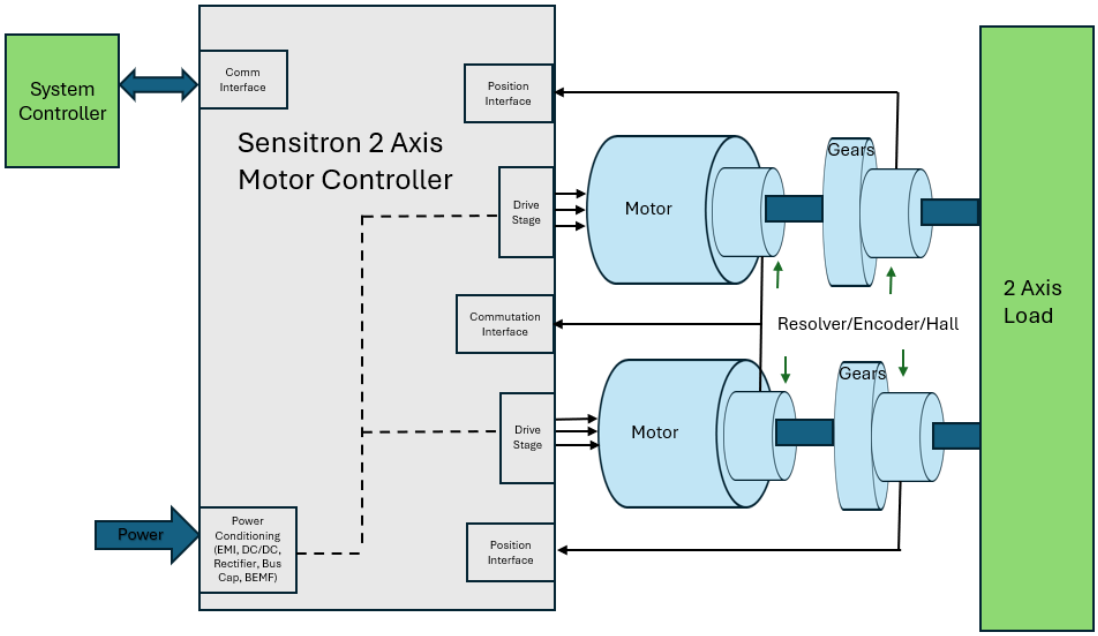

Figure 4. Dual Axis Motor Control

The controllers and supporting electronics typically are mounted on or near the motor. The motor system will also include a DC bus capacitor to reduce ripple, and possibly EMI filters to reduce noise on the system bus. Consideration must also be given to dissipate motor energy Back Electromotive Force (BEMF) that is generated while the motor is rotating. A large amount of mechanical energy could be converted back into electrical energy, and this must be considered in the overall system design, with implementation of a braking resistor or other methods to store or dissipate this energy, such as capacitor networks or batteries. For higher voltage systems, the bus capacitor should be of good quality and have low equivalent series resistance (ESR) to reduce bus ripple. This capacitor should be located close to the controller to reduce resistance.

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Power Stage

The power for the motor controller is supplied though a power bridge stage. That converts the signals to a wave form that will provide the voltage to commutate the motor windings to provide motion to the application. This portion of the motor takes advantage of different technology as well. This can be done using various power drives/devices such as bi-polar transistors, MOSFETs, SiC and GaN devices. This also includes the circuitry to drive these power components. It is the power portion of the system shown below. Sensitron has an extensive catalog of the power bridges used in applications where the motor control algorithms are already designed by the end users. The proliferation of very powerful DSP devices in many electronic systems – can implement a motor control function. Sensitron can provide the driver stage in any form as well.

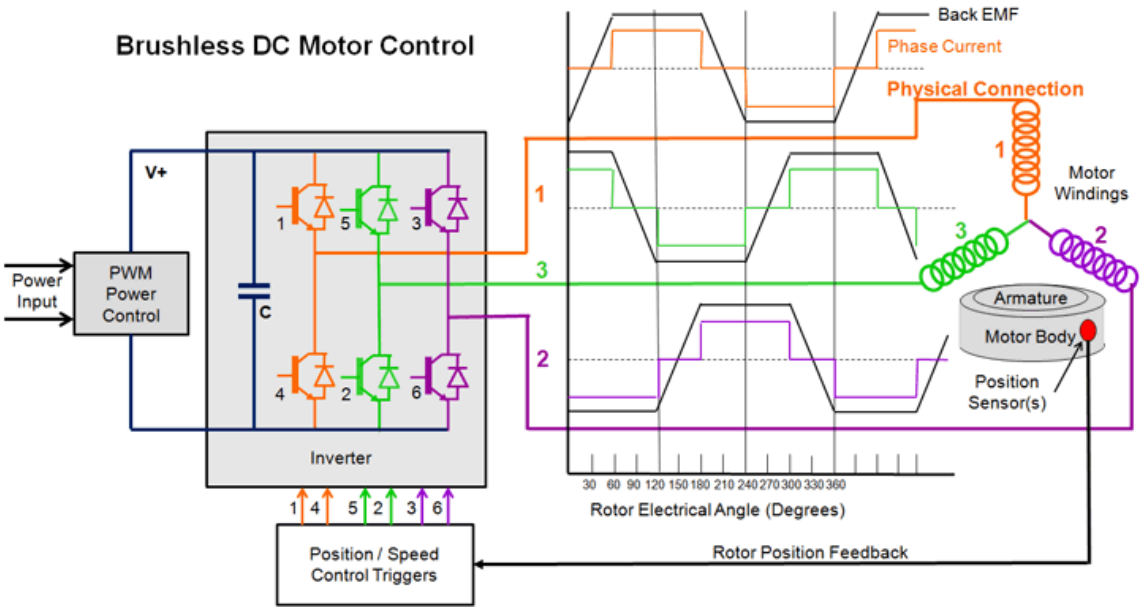
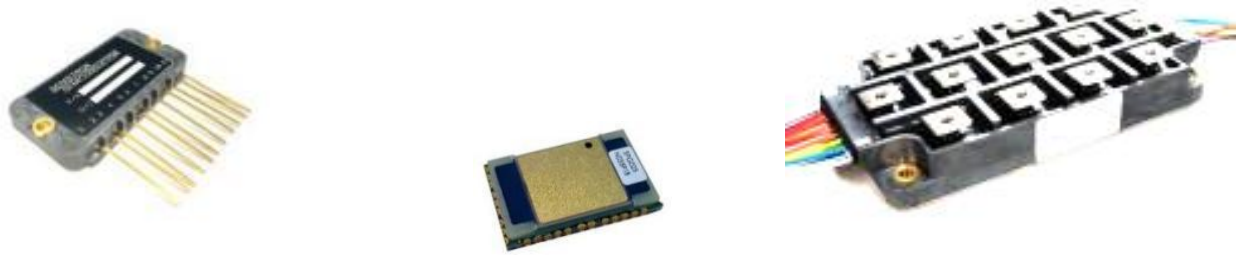


Figure 5. BLDC Motor control Block diagram

Sensitron offers a complete family of powerstages from Si based MOSFET, GaN, IGBT and SiC devices in multiple power package types and voltages as shown below.



a) Light weight b) Surface mount GaN c) High power SiC

Figure 6. Sensitron Bridge technology

Electro Magnetic Interference (EMI)

Most electronic systems must meet Electromagnetic Interference (EMI) standards for system compatibility. This ensures that the electronics will not interfere with or be susceptible to interference with other systems. Standards govern the device's radiated radio frequency (RF) emissions as well as susceptibility. There are commercial and military standards such as MIL-STD-461 that are typically used for US military and avionics systems, and less rigorous FCC standards in the US. Europe issued an EMC Directive (89/336/EC) in the 1980s and other countries have similar standards. A quality motor and controller system must be designed to meet these standards and have an EMI filter integrated into the system. This filter can be found either at the motor, or located in a box level motor control solution, at or near the motor. In a larger system, an overall solution is used. The object is to reduce the cost of qualifying the system as well as meeting control system size and weight constraints. To achieve these goals, several applications utilize the systematic use of Sensitron's motor controllers for control functionality, along with an integrated customer interface, and EMI filter.

Back Electromotive Force (BEMF)

When a motor decelerates the mechanical energy of the motor can convert back into a DC voltage. This must be accounted for in the design of a system. A controlled deceleration is best, however rapid deceleration can put large voltages back into the system causing significant damage if not controlled or regulated. Good design techniques include considering this voltage and dissipating it in resistor banks or storing it in capacitor banks.

Defining System Requirements

Motor control systems have many variables to consider for optimum performance. Motor controllers must be tuned to match the system requirements. These include motor parameters, system performance, impedance, voltage, current sensors, etc. This will help define the type of motor controller required as well as help tuning the controller to meet the system requirements. An example is shown in figure 7. Please contact Sensitron for an Excel version.

Growing Demand

Modern motor control products will continue to meet the growing demand for automation and motor control, as complex systems can now be supported with compact solutions. Sensitron has a long history of providing base level motor controller functions, along with essential building blocks to meet system needs, while our system and box level designs provide all the processing power required for precise and efficient motor control.

For additional information on motor control, power bridges, solid state power controllers and other power products including surge protection and diodes., please see the Sensitron website: www.sensitron.com

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Part number: TBD		Motor Control Information Sheet				
Customer	**Location**		**Contact Info**			
			Name:	E:Mail:	Phone:	
MC Application Considerations	Possible Answers					Comments
Application Info						
Brushless DC Motor	YES	NO				
Type of Platform	Ground Vehicle	UAV Platform	Aircraft	Stationary		
What is moving (load)	Pump	Acuator	Turret	Fan	Compressor	
Duty Cycle	Always On	Other				
Base plate Temperature range						
Maximum Altitude	Sea level	30K ft	50K ft	Other		
Operating Temperature	-40°C to 71°C	-40°C-85°C	-55°C-85°C	-55°C-125°C		
Motor Information						
Brushless DC Motor	YES	NO				
Motor Used	Mfg & Part number:					
Number of Poles						
Motor Inductance						
Control & System						
Type of Feedback	Sensorless	Speed	Torque	Position	Other	
Type of Sensor	none	Hall	Resolver	Encoder		
Resolver	Ref Voltage & Freq:		L-L output voltage:			
Control Input	Analog (Vscale)	Digital (type)				
Means of Control/Data Bus	CAN	RS-232	Discrete			
DC Bus Voltage	28V	100V	300V	600V		
Continuous Motor Current	25A	50A	100A	150A		
Peak Current						
Maximum Motor RPM						
Minimum Motor RPM						
Start Up Characteristics	me to full speed/load					
Accuracy Required	RPM	Torque	Position			
Desired PWM frequency	10 kHz	20 kHz	30 kHz	Higher		
Type of Certifications Require	N/A	DO-178	DO-254			
Size						
Other needs						
Current Motor Controller Supplier						
Program Information						
Name						
Schedule	Prototype	LRIP	Production			
Quantity	Prototype	EAU				
Target Price						

Figure 7. Sensitron Motor Control Parameters

About Sensitron
Sensitron has over 50 years of heritage as a leading manufacturer of high reliability power electronic component solutions for the Defense, Aerospace, Space, and Medical markets. Our products provide rugged, lightweight, and cost effective solutions for switching power supplies, AC-DC rectification, primary & secondary power distribution, motion control, transient voltage spike protection, and custom applications. Sensitron is certified to MIL-PRF-38534, Class K, for Hybrid Microelectronics, MIL-PRF-19500 for JANTX, JANTXV and JANS discrete diodes, and registered to AS9100.