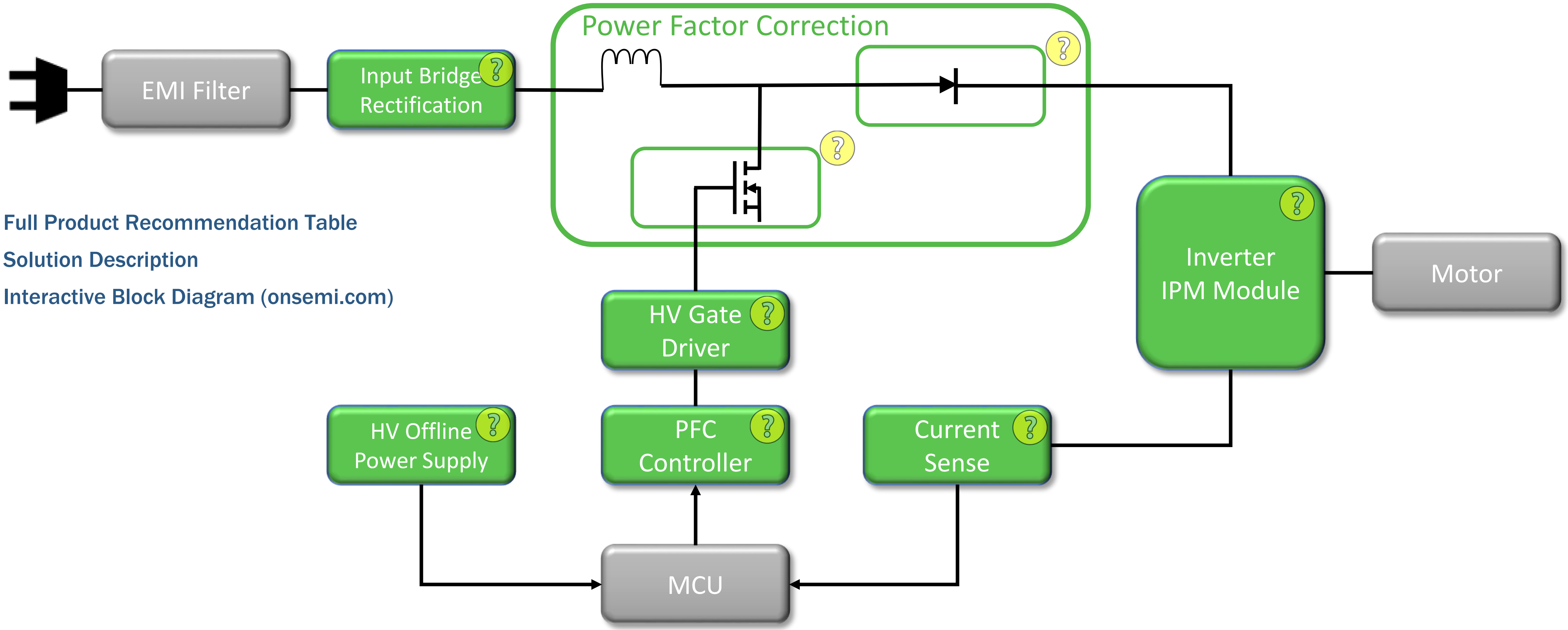
IPM Inverter Motor Control



Full Product Recommendation Table

Solution Description

Interactive Block Diagram (onsemi.com)

ON Semiconductor®

Block Diagram Name: IPM Inverter Motor Control

Suggested Block	Option	WPN	Why Select?	WPN Description
Input Bridge Rectification	1	DFB2560	120 VAC Input, <= 2.5 hp	Diode Bridge, 600 V, 25 A
Input Bridge Rectification	2	DFB2060	230 VAC Input, <= 2.5 hp	Diode Bridge, 600 V, 20 A
Input Bridge Rectification	3	DFB2060	230 VAC Input, <= 4 hp	Diode Bridge, 600 V, 20 A
Input Bridge Rectification	4	DFB2560	230 VAC Input, <= 7.5 hp	Diode Bridge, 600 V, 25 A
Input Bridge Rectification	5	No Solution	460 VAC Input, <= 2.5 hp	
Input Bridge Rectification	6	No Solution	460 VAC Input, <= 4 hp	
Input Bridge Rectification	7	No Solution	460 VAC Input, <= 7.5 hp	
Power Factor Correction, Controller	1	NCP1654	Low-Power Active PFC	Power Factor Controller, Single Channel CCM
Power Factor Correction, Controller	2	FAN7672	Mid-Power Active PFC	Power Factor Controller, Interleaved Two-Channel CCM
Power Factor Correction, Controller	3	FAN9673	High-Power Active PFC	Power Factor Controller, Interleaved Three-Channel CCM
Power Factor Correction, Boost Diode	1	FFSP0665A	120/230 VAC Input: <= 2.5 hp (Assumed 1CH CCM)	SiC Diode, 650 V, 6 A
Power Factor Correction, Boost Diode	2	FFSP1065A	230 VAC Input: <= 4 hp (Assumed 1CH CCM)	SiC Diode, 650 V, 10 A
Power Factor Correction, Boost Diode	3	FFSP2065A	230 VAC Input: <= 7.5 hp (Assumed 1CH CCM)	SiC Diode, 650 V, 20 A
Power Factor Correction, Boost Diode	4	FFSP05120A	460 VAC Input: <= 4 hp (Assumed 1CH CCM)	SiC Diode, 1200 V, 5 A
Power Factor Correction, Boost Diode	5	FFSP10120A	460 VAC Input: <= 7.5 hp (Assumed 1CH CCM)	SiC Diode, 1200 V, 10 A
Power Factor Correction, Boost MOSFET	1	FCB070N65S3	120/230 VAC Input: <= 2.5 hp (Assumed 1CH CCM)	MOSFET, N Channel, 650 V, SUPERFET III Easy Drive, 70 mohm
Power Factor Correction, Boost MOSFET	2	FCH099N65S3	230 VAC Input: <= 4 hp (Assumed 1CH CCM)	MOSFET, N Channel, 650 V, SUPERFET III Easy Drive, 99 mohm
Power Factor Correction, Boost MOSFET	3	FCP165N65S3	230 VAC Input: <= 7.5 hp (Assumed 3CH CCM)	MOSFET, N Channel, 650 V, SUPERFET II Easy Drive, 165 mohm
Power Factor Correction, Boost IGBT	4	NGTB40N120FL3	460 VAC Input: <= 4 hp (Assumed 1CH CCM)	IGBT, Ultra Field Stop Trench, 1200 V, 40 A
Power Factor Correction, Boost IGBT	5	NGTB25N120FL3	460 VAC Input: <= 7.5 hp (Assumed 3CH CCM)	IGBT, Ultra Field Stop Trench, 1200 V, 25 A
Inverter, Intelligent Power Module	1	FNB43060T2	120/230 VAC Input: <= 2.5 hp	Intelligent Power Module, SPM45H, 600 V, 30 A
Inverter, Intelligent Power Module	2	FNB35060T	230 VAC Input: <= 4 hp	Intelligent Power Module, SPM3V, 600 V, 50 A
Inverter, Intelligent Power Module	3	FNA27560	230 VAC Input: <= 7.5 hp	Intelligent Power Module, SPM2V 34, 600 V, 75 A
Inverter, Intelligent Power Module	4	FSBB10CH120D	460 VAC Input: <= 2.5 hp	Intelligent Power Module, SPM3V, 1200 V, 15 A
Inverter, Intelligent Power Module	5	FSBB20CH120D	460 VAC Input: <= 4 hp	Intelligent Power Module, SPM3V, 1200 V, 20 A
Inverter, Intelligent Power Module	6	FNA25012A	460 VAC Input: <= 7.5 hp	Intelligent Power Module, SPM2V 34, 1200 V, 50 A
Current Sense	1	FAN4174	Typical Performance Control, Single Placement	Op Amp, RRIO, 3.7 Mhz, Single
Current Sense	2	FAN4274	Typical Performance Control, Dual Placement	Op Amp, RRIO, 3.7 Mhz, Dual
Current Sense	3	NCS2005	High Performance Control, Single Placement	Op Amp, RRIO, 8 Mhz, Single
HV Offline Power Supply	1	NCP1060	8 W Max Supply Capability	Integrated SMPS Controller, 700 V, 100 kHz, 8 W
HV Offline Power Supply	2	NCP1063	12 W Max Supply Capability	Integrated SMPS Controller, 700 V, 100 kHz, 12 W
HV Gate Driver	1	FAN3100C	Single Channel Driver, Medium Current	Gate Driver, Low-Side, Single, CMOS Input, 3 A
HV Gate Driver	2	FAN3121C	Single Channel Driver, High Current	Gate Driver, Low-Side, Single, CMOS Input, 10 A
HV Gate Driver	3	FAN3226C	Dual Channel Driver, Medium Current	Gate Driver, Low-Side, Dual, CMOS Input, 3 A
HV Gate Driver	4	FAN3225C	Dual Channel Driver, High Current	Gate Driver, Low-Side, Dual, CMOS Input, 5 A

Return to Block Diagram

Welcome to the April installment of the Block Diagram of the Month series. Each month we provide a specific application solution with recommended ON Semiconductor content from across the various product taxonomies available. This month our focus is Line-Voltage Industrial Motor Control. Please note that this is a huge application space with many more potential configurations.

Line-Voltage Industrial Motor Control

Motors are responsible for consuming more than 50% of the produced power in industrialized nations. At least 80% of these motors are AC induction motors (ACIMs) and devour energy at an average efficiency of only 44%. Ever-increasing electricity costs are slowly driving legislation and guidelines which dictate efficiency improvements for motors used in residential and industrial applications. These improvements in efficiency come primarily from two paths: 1) Using intelligent electronic controls to more effectively drive induction motors, and 2) Transitioning from ACIMs to permanent magnet-based brushless DC (BLDC) motors.

Both paths require power semiconductor-based inverters. At its core, a 3-phase motor inverter sourced from the AC line is comprised of the following circuit blocks:

- EMI Filter
- Input Bridge Rectification
- Power Factor Correction (PFC)
- Inverter Output Bridge
- Current Sensing
- High-Voltage Offline Power Supply
- Motor Controller (ASSP, MCU, or DSP)

Excluding the EMI filter, which is mostly capacitors and inductors, the remaining blocks are comprised of a significant amount of silicon hardware. Depending on the block, there is a broad set of requirements from 3.3V to >=1200V components. A low-power, baseline industrial control with active PFC may have 15+ semi sockets; whereas, a fully-featured industrial control could include more than 100 semi sockets.

The term Industrial Motor Control encompasses a wide array of end applications, environments, and ultimately specifications. This block diagram represents the largest segment of mid-power motor controls which are powered from the AC line, with attached motors ranging from zero to 7.5 horsepower (hp). At these power levels, AC input voltages of 120 to 460 VAC are common, depending on the installation location. Some locations will have single-phase power, while others will offer 3-phase connections. To meet these diverse application conditions, a motor control designer must have access to an equally diverse selection of power semiconductors and associated support.

At ON Semiconductor, we have an extensive portfolio with hundreds-to-thousands of viable solutions across the various blocks, depending on the target specifications. This includes our motor-specific power silicon product lines, which are known through-out the industry for their performance, reliability, flexibility, and cost-effective design. In addition to our extensive offerings, we have world class technical support through our FAEs, Motor Control Specialists, and Labs.

Return to Block Diagram

Input Bridge Rectification

Depending on the input power configuration, it has one of two functions:

- For non-PFC designs or 3-phase input configurations:
  - Its function is to rectify the AC input voltage into a HV capacitor and output a steady DC bus voltage.
- For PFC design configurations:
  - Its function is to full-wave rectify the AC input voltage into a unipolar output for the PFC stage input.

Single-phase implementations are done with a 4-diode bridge or four discrete diodes. For non-PFC designs, the option of using only 2 diodes and half-wave rectifying is possible at the expense of larger bus caps. For non-PFC, 120 VAC input, it is also possible to use a voltage-doubler configuration to effectively double the bus voltage for the drive.

Three-phase input power at these levels seldom requires active PFC. Implementation is typically a 6-diode bridge (expensive), two 4-diode bridges (using half of the second one), three 4-diode bridges (one bridge per phase, paralleled), or six discrete diodes.

600V diode technologies can be used up to about 265 VAC input or 425 VDC bus. 1200V diodes are desired above 265 VAC through 460/480/575 VAC. When considering power and design margins, many designers require >1200V diodes for 575 VAC inputs; whereas, others require 1500 V diodes for anything above 265VAC due to harsh power conditions in industrial environments. Other industrial voltage levels exist beyond this discussion. Consult your ON Semiconductor FAE for additional guidance.

Power Factor Correction

Active PFC is mostly implemented in single-phase input power configurations. The PFC block serves three purposes:

- Forces AC line input current to be sinusoidal in shape (matching AC line input voltage waveform).
- Forces AC line input current to be synchronized with the AC line input voltage.
- Provides a steady DC bus voltage to the remainder of the motor control.

Achieving these goals improves the Power Factor (PF) and input harmonics of the motor control; and it dramatically increases the efficiency of how power is delivered by the power company. Many commercial and industrial customers are fined for operating poor-PF equipment. Additionally, new standards and legislation are continuously being written, requiring minimum PF for motorized equipment. Often the most effective way to meet these new requirements is to design active PFC circuitry into the motor control.

When pondering PFC circuitry, there are many architectures to consider: boost, multi-channel boost, buck/boost, buck, various types of bridgeless, and so on. Within a given architecture, there are operating modes to consider: discontinuous, boundary, and continuous. Multi-channel PFC topologies must also consider channel phasing (interleaved or not), count, sharing, shedding, etc. Boost single, two, and three-channel PFC topologies are very common for industrial motor control applications. It is important to not confuse the number of AC line input phases with the number of PFC channels as they are not related.

A clear advantage of boost PFC is that the motor output bridge will always see the same DC bus voltage, regardless of input voltage. For example, it is viable to design a product that does not require output derating when operated across the universal input range of 85 to 265 VAC. Multi-channel boost PFC is a great option for decreasing the size of the individual PFC components (inductors, MOSFETs, and diodes) by using multiple parallel and interleaved channels which

Return to Block Diagram

share the current flow. It often allows through-hole designs to be transitioned to surface mount technologies and can improve a mechanical designer's ability to fit bulky inductors and sink-attached components into a smaller volume.

A boost PFC schematic will include: boost switch (IGBT or HV MOSFET, 1 per channel), boost diode (1 per channel), gate driver (to drive the switch, 1 per channel), and a PFC controller. IGBT switches are common at bus voltages above 600V or PFC switching frequencies below 40 kHz. At higher frequencies and lower bus voltages, super-junction MOSFETs are preferred. The arrival of Silicon Carbide (SiC) diode technology is a winner for PFC as it significantly improves output diodes losses at higher switching frequencies. High-performance gate drivers and feature-packed PFC controllers handle the safety-critical design aspects, allowing the motor-controller to focus on spinning the motor efficiently.

ON Semiconductor offers one of the largest portfolios of IGBTs, super-junction MOSFETs, SiC diodes, high-performance gate drivers, and PFC controllers that cover applications from <10 to >20,000 watts.

<u>Inverter Output Bridge</u>

The output bridge is where the actual motor driving takes place. The output bridge, controlled by the Motor Controller, is responsible for many things:

- Translating the controller's logic-level signals to high-voltage, high-current outputs to the motor.
- Monitoring the motor's phase currents to ensure that a safety-critical phase-to-phase short has not occurred, and quickly/independently disabling the motor output until the Controller IC addresses the problem.
- Monitoring the output bridge's bias supply voltages to ensure the power semis are not operating in their linear region, where they could be easily damaged. Under-voltage lockout should be automatic.
- Monitoring and reporting the output bridge's temperature to the Motor Controller, allowing over-temperature conditions to be intelligently mitigated by disabling the drive or reducing the motor output power momentarily.
- Reporting faults and irregularities back to the Motor Controller for further action.

A 3-phase inverter output bridge consists of many power silicon devices:

- 6x IGBTs or HV MOSFETs
- 6x HV Freewheeling Diodes
- 3x Low-Side Gate Drivers
- 3x High-Side Gate Drivers
- 3x Bootstrap Diodes for High-Side Driver Power Supply
- 1x Temp Sensing NTC or Diode
- 4x Under-Voltage Lockout Comparators
- 1x Short-Circuit Detection Comparator

Intelligent Power Modules (IPMs) are highly-integrated semiconductor modules equivalent to the above power semis plus many passive discretes. By any account, a typical IPM replaces between 45 and 100 discrete components. They are designed to be fault tolerant, PCB friendly, heat sink compatible, and easy to interface with a controller IC. Additionally, they have built-in isolation of >=2kV from their thermal interface to the heat sink. These high-density modules make

Return to Block Diagram

them an ideal low-EMI solution that meets the rigors of safety agency compliance. IPMs are the go-to solution for industrial motor controls below 10 hp. Power Integrated Modules (PIMs), take the stage from 10 hp to >100 hp.

It is important to not confuse the 3-phase motor output with the number of phases of AC line input power. These are unrelated. Most industrial motors being driven by inverter motor controls are manufactured with their windings in a three-phase arrangement. Our IPMs are specifically designed to drive 3-phase motors of various types: AC induction motors (ACIMs), brushless DC motors (BLDCs), brushless AC motors (BLACs), and permanent magnet synchronous motors (PMSMs) to name the most popular.

Or course, it is certainly possible to design discrete power semis into industrial motor drives. Although less common, there are certainly application conditions that appreciate such solutions: unusual voltage requirements, drives <100 VDC, high switching frequencies, specialized multilevel inverters, and other motor topologies.

In addition to power semi solutions for 3-phase motors (ACIM, BLDC, BLAC, PMSM, etc.), we also have complete solutions for permanent magnet DC (PMDC) motors and stepper motors.

Current Sensing

Current and voltage sensing are at the heart of every industrial motor control. This sensing typically monitors bus voltage and motor phase currents and reports them to the Motor Controller IC. It is imperative that these precision circuits accurately and reliably report the true instantaneous conditions of the signals being monitored in order to have a safe and efficient control design. The solution is well-performing operational amplifiers (Op Amps). Motor controls typically require mid-range performance from an Op Amp. Desirable features are low offset, rail-to-rail I/O, wide temperature range (-40 to +125’C), and a bandwidth of 3.5 to 8 MHz. A basic control will require 3 to 4 Op Amps.

High-Voltage Offline Power Supply

The offline power supply is responsible for providing low-voltage power rails to various portions of the design. In motor controls, this supply is typically driven from the voltage present on the bulk capacitors, and can range from 0 to >800 VDC, depending on the AC line voltage, PFC implementation, and other factors. Common low-voltage supply rails for a basic motor control are:

- 15VDC for PFC controller/gate driver and IPM/gate drivers for IGBTs/HV MOSFETs.
- 3.3VDC/5.0VDC for the Motor Controller and analog signal processing circuitry. i.e. op amps and comparators.

Like PFC architectures, offline power supplies can take many forms including flyback, LLC, and HV buck. Industrial motor controls are typically implemented with flyback supplies in applications where multiple output voltages are required to be isolated from the DC bus or one another. HV buck topologies are more common in basic industrial motor controls where the control has limited (or no) interaction with other electronic devices. This allows the non-isolated HV buck supply to be designed with minimal cost and mechanical space in comparison to a flyback supply. Each topology has it sweet spots and must be carefully considered when looking over the overall system architecture.

We have more than one hundred switch-mode power supply (SMPS) solutions. Knowing which one to select for a given application requires a solid understanding of the output voltage rails desired, their power levels, fault tolerance capability required, EMI footprint goals, isolation requirements, environmental conditions, etc.

Return to Block Diagram

Motor Controller (ASSP, MCU, or DSP)

The Motor Controller is responsible for managing the motor's commutation/rotation. It does this by generating 6 channels of PWM signals to the output bridge. These PWM signals are calculated and generated by the controller to optimally spin the motor. There are many types of motor control algorithms and modulation schemes available. Selecting an optimal controller IC for an application requires many factors to be carefully considered:

- Motor Type (ACIM, BLDC, Stepper, …) and Size (hp or kW)
- Bus Voltage Levels
- Safety Compliance Required
- Loop Operation: Open or Closed
- Rotor Sensing Method: Single Sensor, Multi-Sensor, Sensorless, ...
- Control Loop Bandwidth
- Load Type and Dynamics: Fan, Pump, Conveyor, Servo, ...
- Related Features: On-Chip PFC Control, Communication Interfaces, ...

We offer ASSPs for stepper, BLDC, and sensorless BLDC applications.

Next Steps

ON Semiconductor has one of the broadest portfolios of power semiconductors for residential, commercial, and industrial motor control applications. We offer solutions for ACIM, BLDC, BLAC, PMSM, PMDC, and stepper motors. Samples, evaluation boards, design guides, whitepapers, calculators, and development tools are available. Engage our FAEs and Motor Specialists to get a head start on selecting the optimal parts for your next motor design.

Return to Block Diagram