F2833x Digital Motor Control

Introduction

In this module, we will look into an application that is not usually considered to be the domain of Digital Signal Processors: real-time control of electrical motors. In the old days, the control of speed and torque of electrical motors was performed using purely analog technology. Since the appearance of microprocessors, more and more control units have been designed digitally, using the advantages of digital systems. This improves the degree of efficiency and allows the implementation of more advanced control schemes, thanks to increased real-time computing power. It is a natural progression to use the internal hardware computing units of a DSP to transfer the calculation from a standard microprocessor to a DSP. This way, we can implement more advanced algorithms in a given time period.

However, to use a digital controller for motor control, the system needs a little more than computing power. The output signals of the digital controller to the power electronic are usually generated as pulse width modulated signals (PWM). It would be most cost-effective if the controller could be equipped with an internal PWM-unit. To control the operation of the motor we need to do some measurements for currents and voltages – analogue to digital converters (ADC) will be helpful as well. A typical unit to perform a position/speed measurement is an optical encoder; quite often, we build in a Quadrature Encoder (QEP). Recalling all parts of the F2833x we discussed in this Teaching - CD, you can imagine that the F2833 is an ideal device for Digital Motor Control (DMC).

The chapter will not go into the fine details of electrical motors and drives. Instead, it will give you a sense of what needs to be done to use the F2833x to control the motor of a vacuum cleaner or the motor of an electrical vehicle. To fully understand these principles, it requires many more classes at university. If you are on a course of electrical engineering that focuses on drives and power engineering, you might be familiar with most of the technical terms. If not, see this chapter as a challenge for you to open up another application field for a Digital Signal Controller.

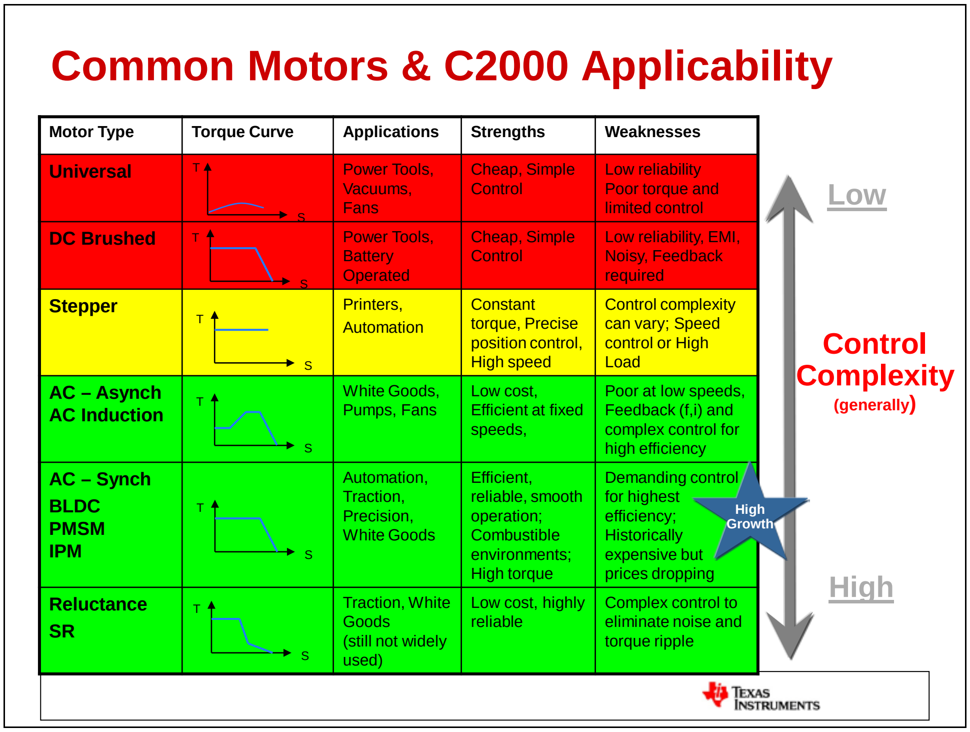
Chapter 18 is based on a Texas Instruments Presentation “TIs C2000 Real-Time MCU for Digital Motor Control“(August 2009). Depending on the laboratory equipment at your university, you might be offered the chance to attend a laboratory session to build a working solution for such a motor control.

Module Topics

Basics of Electrical Motors

Motor Categories

In order to classify the different electrical motors families, we can distinguish motors driven by direct current (DC) and motors driven by an alternating current (AC). DC motors are the most popular ones: both stators and rotors carry an excitation created by coils or windings in which DC current circulates. In order to ensure the motor rotation by commutating the windings, brushes are permanently in contact with the rotor.



Common Motors & C2000 Applicability

Motor Type	Torque Curve	Applications	Strengths	Weaknesses
Universal	T / s	Power Tools, Vacuums, Fans	Cheap, Simple Control	Low reliability Poor torque and limited control
DC Brushed	T / s	Power Tools, Battery Operated	Cheap, Simple Control	Low reliability, EMI, Noisy, Feedback required
Stepper	T / s	Printers, Automation	Constant torque, Precise position control, High speed	Control complexity can vary; Speed control or High Load
AC – Asynch AC Induction	T / s	White Goods, Pumps, Fans	Low cost, Efficient at fixed speeds,	Poor at low speeds, Feedback (f,i) and complex control for high efficiency
AC – Synch BLDC PMSM IPM	T / s	Automation, Traction, Precision, White Goods	Efficient, reliable, smooth operation; Combustible environments; High torque	Demanding control for highest efficiency; Historically expensive but prices dropping
Reluctance SR	T / s	Traction, White Goods (still not widely used)	Low cost, highly reliable	Complex control to eliminate noise and torque ripple

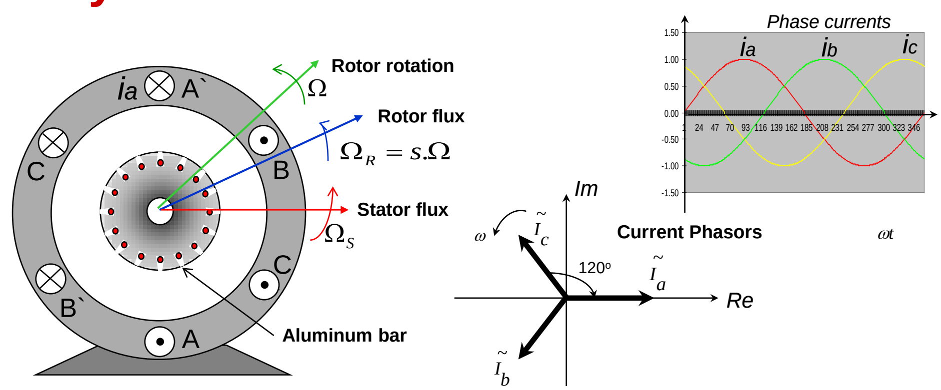
Under the classification of AC motors, we have synchronous motors and asynchronous motors; both motor types are induction machines.

Asynchronous machines require a sinusoidal voltage distribution on the stator phases in order to induce current on the rotor, which is not fed by any currents nor carries any magnetic excitation.

Synchronous motors are usually called “Brushless DC Motors” (BLDC) but can also be called “Permanent Magnet Synchronous Motors” (PMSM) depending on their construction and the way they are being controlled. In this type of motor, we have one sinusoidal or trapezoidal excitation on the stator and one constant flux source on the rotor (usually a magnet).

Asynchronuous Motor

Asynchronous Motor: ACI



Theory of Operation:

- Rotor placed in a moving magnetic field (flux) will have current induced – which produces another magnetic field
- The interaction of these two magnetic fields produces the rotational torque

- Stator flux is variably controlled by feeding current
- Rotor flux is induced by the stator flux
- Rotor and Stator rotate at different speeds = Asynchronous
- Angle between rotor and stator flux can be regulated to determine torque
- Rotor position is never known

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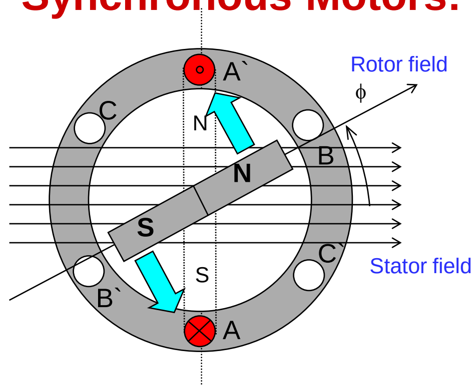
Synchronous Motors: BLDC and PMSM

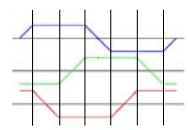
Synchronous Motors: BLDC & PMSM



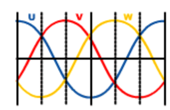
Rotor speed (rad/s): $\Omega = \frac{\omega}{p}$ gives $\frac{120.f}{p}$ (r.pm)

f : AC supply frequency (Hz)

p : motor poles



BLDC Back EMF



PMSM Back EMF

Theory of Operation:

- Fixed rotor flux (magnetic field) and a produced stator flux
- The interaction between the two fields produces a torque which will cause the motor to rotate

- **Stator flux is variably controlled by feeding current**
- **Rotor flux is constant by permanent magnets or current fed coils**
- **Rotor rotation is at same frequency as supplied excitation = Synchronous**
- **Angle between rotor and stator flux can be regulated to determine torque**
- **Rotor position can be measured or estimated**

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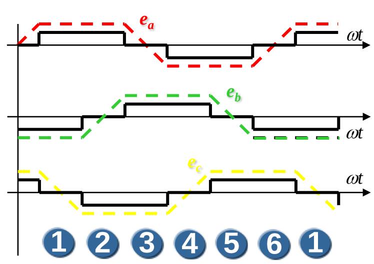
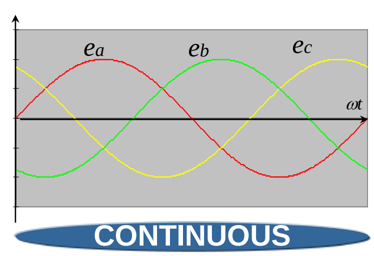
Which Synchronous? BLDC vs. PMSM

Continuous States = More Complex

Back EMF of BLDC Motor



Back EMF of PMSM



- **BLDC Motors**
  - **Easier to control** (6 Trapezoidal states)
  - **Torque ripple at commutations**
  - **Better for lower speed**
  - **Noisy**
  - **Doesn't work with distributed winding**
  - **Not as efficient, lower Torque**
  - **Lower cost**

- **PMSM Motors**
  - **More complex control** (continuous 3Ph Sine Wave)
  - **No torque ripple at commutation**
  - **Higher max achievable speed**
  - **Low noise**
  - **Work with low-cost distributed winding**
  - **Higher efficiency, higher Torque**
  - **Higher cost**

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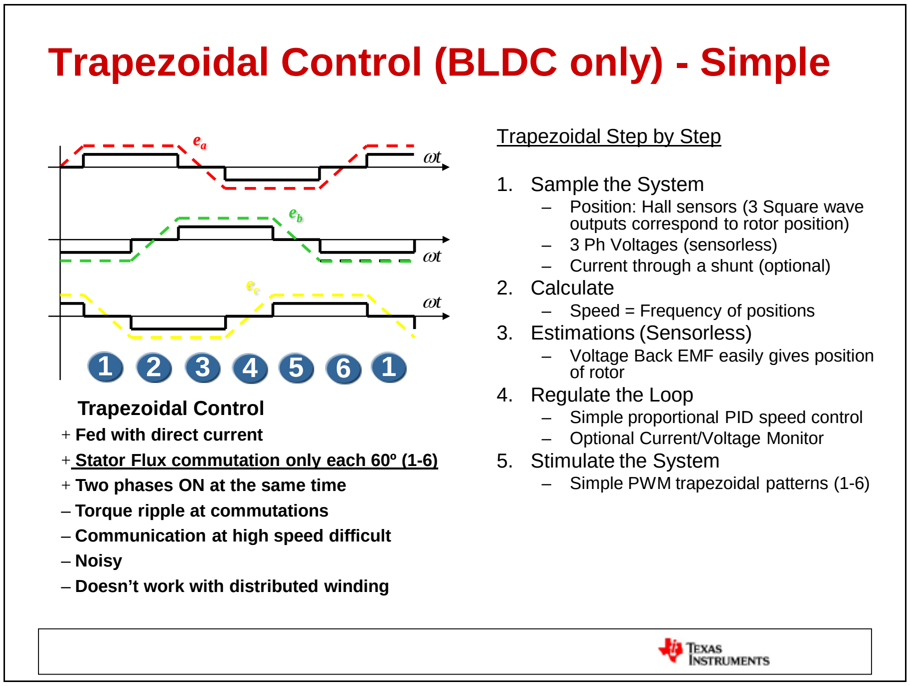
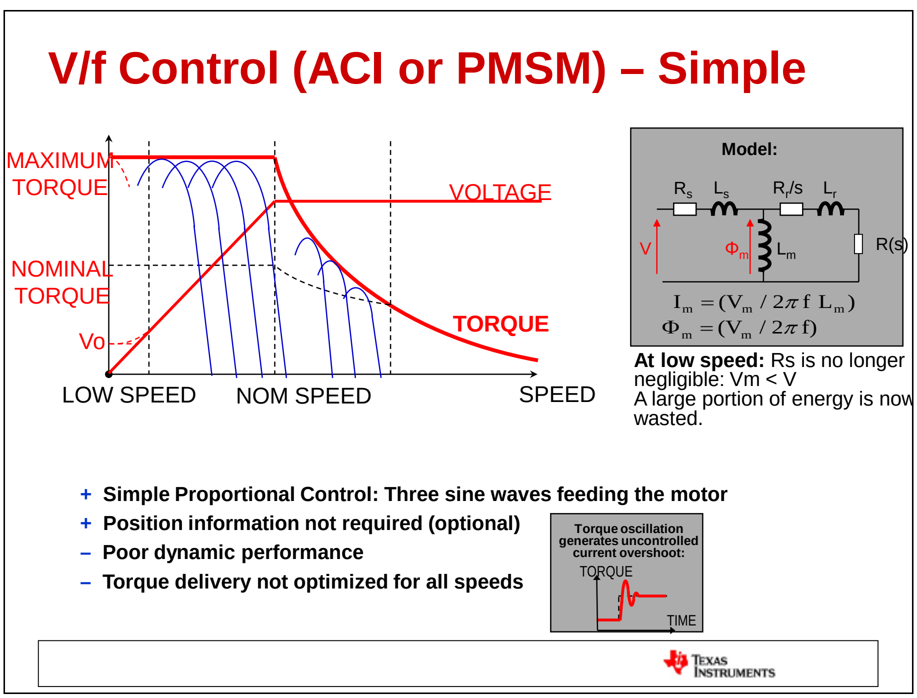
Motor Control Principles

Trapezoidal Control



Scalar Control ("V/f")



The V/Hz regulation scheme is the simplest one that can be applied to an **asynchronous motor**. The goal is to work in an area where the rotor flux is constant (Volts proportional to speed).

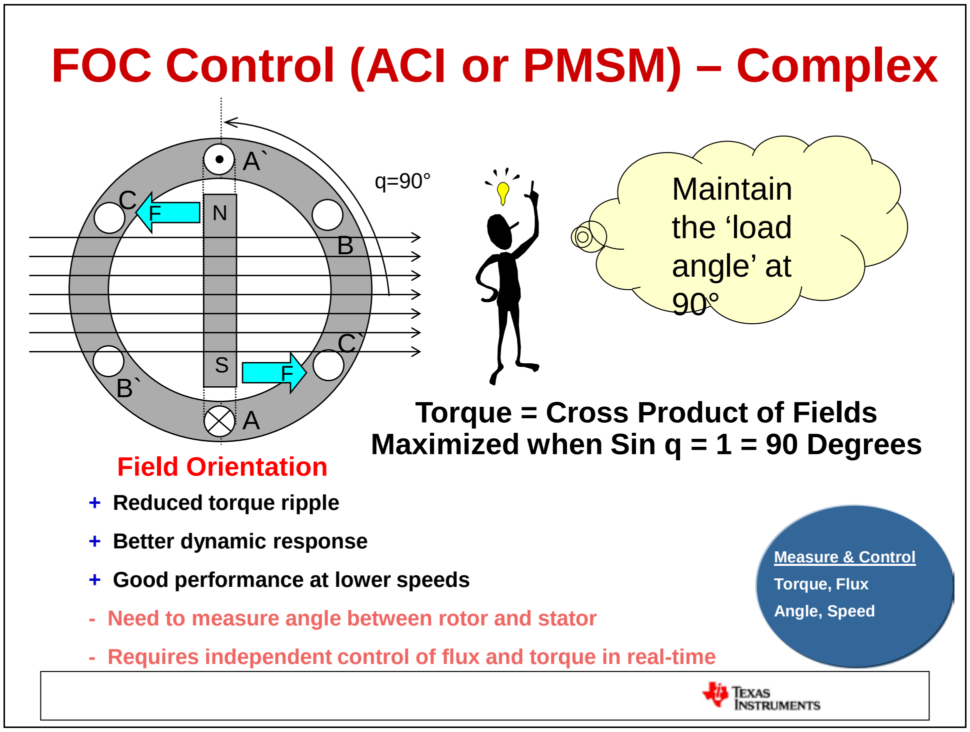
In practical solutions, the speed sensor is optional as the control is tuned to follow a predefined “speed-profile versus load table”, assuming the load characteristics are known in advance.

Obviously, this type of control bases itself on the steady electrical characteristics of the machine and assumes that we are able to work with a constant flux in the complete speed range the application targets. This is why this type of control does not deliver a good dynamic performance and a good transient response time; the V/Hz profile is fixed and does not take into account conditions other than those seen in a steady state. The second point is the problem at startup of AC induction motors, which cannot deliver high torques at zero speed; in this case, the system cannot maintain a fixed position. In practice for low speed, we need to increase the delivered voltage to the stator compared to the theoretical V/Hz law.

Field Oriented Control (FOC)

Instead of using a pure sine wave shaped modulation of the PWM stage, in recent years the space vector theory has demonstrated some improvements for both the output crest voltage and the harmonic copper loss. The maximum output voltage based on the space vector theory is 1.155 times larger than the conventional sinusoidal modulation. This makes it possible to feed the motor with a higher voltage than the simpler sub-oscillation modulation method. This modulator enables higher torque at high speeds, and a higher efficiency. Torque distortion is also reduced.

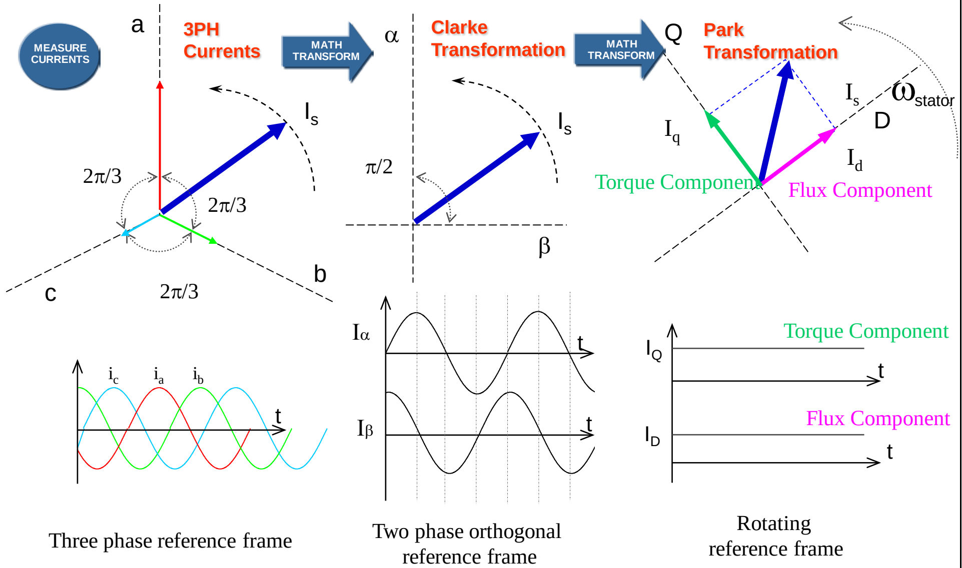
The space vector PWM technique implemented into the existing TI DMC library reduces the number of transistor commutations. It therefore improves EMI behavior.



A typical characteristic of FOC - PWM command strategy is that the envelope of the generated signal is carrying the first and the third harmonics. We can interpret this as a consequence of the special PWM sequence applied to the power inverters. Literature also mentions the third harmonic injection to boost out the performance we get out of the DC bus capacitor. This third-harmonic exists in the phase to neutral voltage but disappears in the phase-to-phase voltage.

FOC Coordinate Transform (Clarke / Park)

FOC: Torque & Flux Deduced from Currents

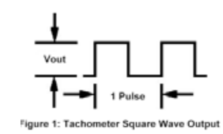


FOC Measurement of Motor Position and Speed

FOC: Angle & Speed are Measured or Estimated

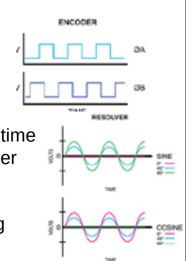
ACI

- Measured
  - Tachometer: Square wave output proportional to speed
- Estimations
  - Angle estimated from Integral of Sinusoidal Back EMF Voltage with closed loop voltage compensation
  - Speed estimated from Estimated Flux, measured current, and motor model



PMSM

- Measured
  - Encoder: 2 Square waves give position, speed calculated by change over time
  - Resolver: SIN + COS waves give position, speed calculated by change over time
- Estimations
  - Angle estimated from Integral of Sinusoidal Back EMF Voltage with Sliding Mode Observer technique
  - Speed calculated from change in angle over time



Advantages of Vector Control

Why FOC? Performance Comparison

Performance Comparison Control Algorithms	Volts per Hertz Control	FOC: Vector Drive	FOC: Servo Drive
Velocity Loop bandwidth in Hz	1Hz	50 Hz	100 Hz
Minimum speed with full load (RPM)	90	0	0
Maximum speed with 25% load (RPM)	1.5 X Base Speed	2.5 X Base Speed	2.0 X Base Speed
Minimum acceleration time (seconds)	3	0.1	0.01
Minimum deceleration time (seconds)	3	0.1 w/DB	0.01
Maximum starting torque (%)	150%	200%	200%
Speed regulation at full load (%)	± 3% (base)	± 0.01% (set)	± 0.01% (set)

The numbers above are for comparison only. Specific system dynamics will affect exact data.

FOC

- System responds faster to changes in set point or load change
- Minimum speed at full load is now essentially zero
- Starting torque is increased
- Very little torque ripple
- Reduces Cost
  - Optimally size motor for the task at hand
  - Current controlled, so the inverter can be optimized

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FOC Step By Step

FOC: Step By Step

Measure & Control
Torque, Flux
Angle, Speed

1. Sample the System
   - Current
   - Voltage (Sensorless)
   - Speed (ACI Sensored)
   - Speed & Position/Angle (PMSM Sensored)
2. Transform sampled data and calculate useful quantities
   - Measure Currents → Use Clarke/Parke Transform → Torque & Flux
   - ACI Sensored
     - Measure Speed + Torque & Flux Components → Angle
   - ACI Sensorless
     - Measure Voltage + Stator Current (Clarke) → Angle Estimation
     - Angle Estimation + Stator Current (Clarke) → Speed Estimation
   - PMSM Sensored
     - Measured Speed and Measured Angle
   - PMSM Sensorless
     - Measured Voltage + Stator Current (Clarke) → Angle Estimation
     - Angle Estimation → Speed Estimation
3. Regulate the Loop
   - PID techniques are most common; Controls to a reference value
   - Regulate speed, position/angle, current, flux and maximize torque
4. Stimulate the System
   - Inverse transforms of Park and Clarke
   - PWM Pattern generation to drive the voltage/current source

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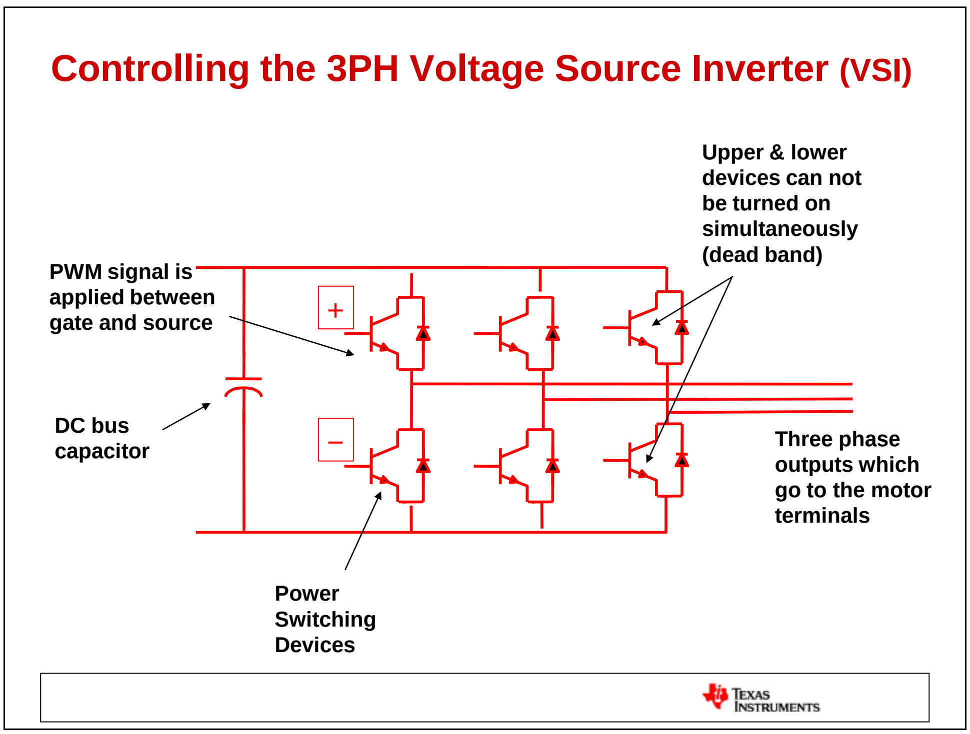
3-Phase Power Switches

As we saw in the previous basic diagrams, we need to apply three 120° phase shifted excitation signals to the power circuitry of the motor. As you have seen in Chapter 7 (“PWM”), a PWM signal can be used to modulate sinusoidal signals. With three independent switching pattern streams and six power switches, we can deliver the necessary phase voltages to generate the required torque imposed by the load. The goal is to build the correct conduction sequences in the IGBTs to deliver sinusoidal currents to the motor to transform it to a mechanical rotation.

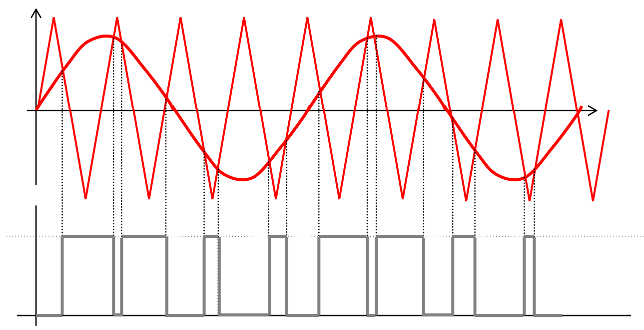
This is traditionally achieved by comparing a three-phase sinusoidal waveform with a triangular carrier. In the digital world, on the DSP processor, we compute a sinusoidal command and apply it to the PWM units that generate the appropriate PWM outputs usually connected to gate drivers of the IGBTs from the inverter.

Basically we are “chopping” a DC voltage, carried by the DC bus capacitor, in order to build the appropriate voltage shapes for the stator phases, with the goal of having a good efficiency during this energy conversion process. This is a power electronics concern: we need to minimize the noise introduced by these conducting sequences and source of harmonics.



Sine PWM VSI Control

Traditional (Old) Sine PWM VSI Control

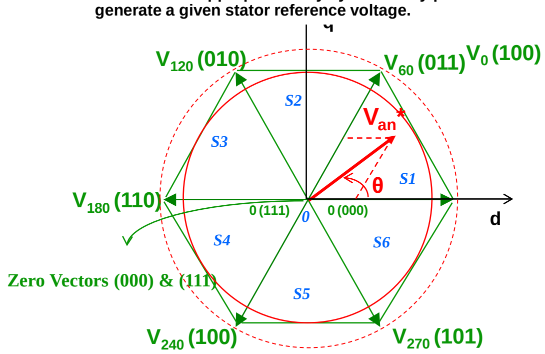


- **Inputs**
  - **Triangular Switching Frequency (5-25 kHz typically)**
  - **Sine wave = Carrier Trying to match (V or I Reference, 0-1000 Hz typically)**
  - **Image not to scale; Typically 100s of triangle periods in each Sine wave**
- **Output**
  - **When they cross, you switch the PWM**

Space Vector PWM VSI Control

Space Vector PWM VSI Control

Theory: A special switching sequence of the upper three power devices of a VSI results in 3 pseudo-sinusoidal currents in the stator phases. Calculate the appropriate duty cycle – every period - needed to generate a given stator reference voltage.



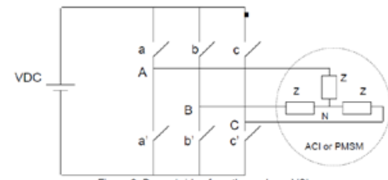


Figure 2: Power bridge for a three-phase VSI

c	b	a	$V_{s\alpha}$	$V_{s\beta}$	Vector
0	0	0	0	0	O_0
0	0	1	$\frac{2}{3}V_{DC}$	0	U_0
0	1	0	$-\frac{V_{DC}}{3}$	$\frac{V_{DC}}{\sqrt{3}}$	U_{120}
0	1	1	$\frac{V_{DC}}{3}$	$\frac{V_{DC}}{\sqrt{3}}$	U_{60}
1	0	0	$-\frac{V_{DC}}{3}$	$-\frac{V_{DC}}{\sqrt{3}}$	U_{240}
1	0	1	$\frac{V_{DC}}{3}$	$-\frac{V_{DC}}{\sqrt{3}}$	U_{300}
1	1	0	$-\frac{2}{3}V_{DC}$	0	U_{180}
1	1	1	0	0	O_{111}

Table 2: Switching patterns, corresponding space vectors and their (α,β) components

For review of the calculations, please see detailed theory in SVGEN documentation from DMC Library (SPRC080 or SPRC125).

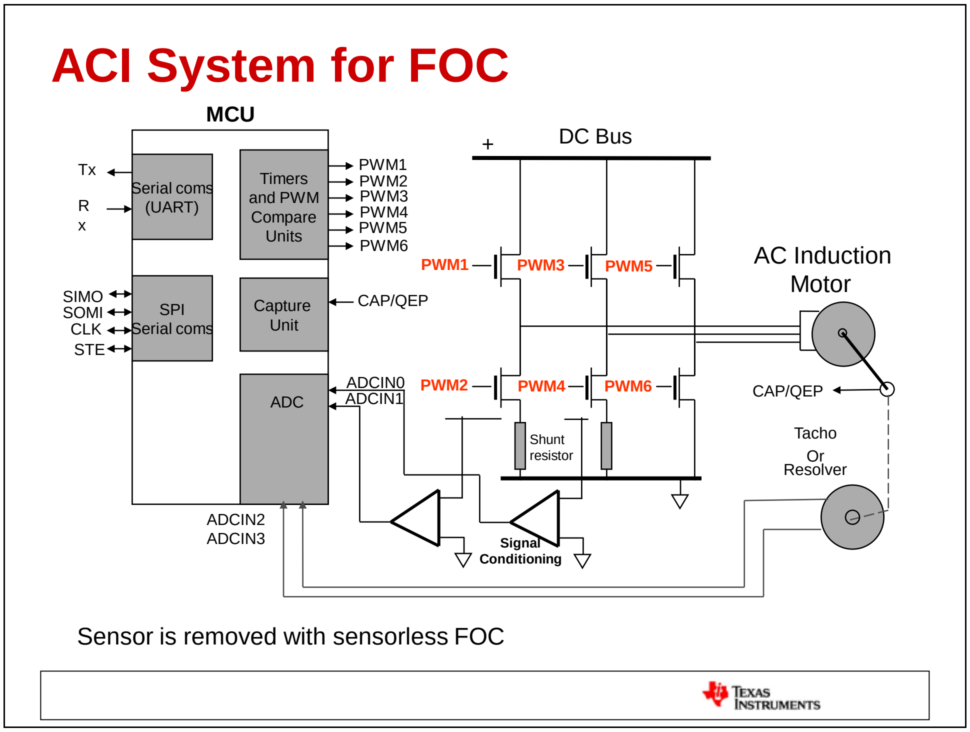
SVPWM Benefits vs Traditional Sine PWM

- **15% boost in torque**
- **30% less switching losses (higher efficiency)**
- **30% reduced EMI due to fewer transistor commutations**
- **Reduced harmonic copper losses**
- **Capacitor reduction**
  - The use of smaller DC link capacitor will introduce DC bus ripple
  - Controllers with processing overhead can digitally compensate for the ripple on the DC bus, allowing for a greater ripple limit
  - This smaller capacitor size can reduce system cost

FOC Control Schematics

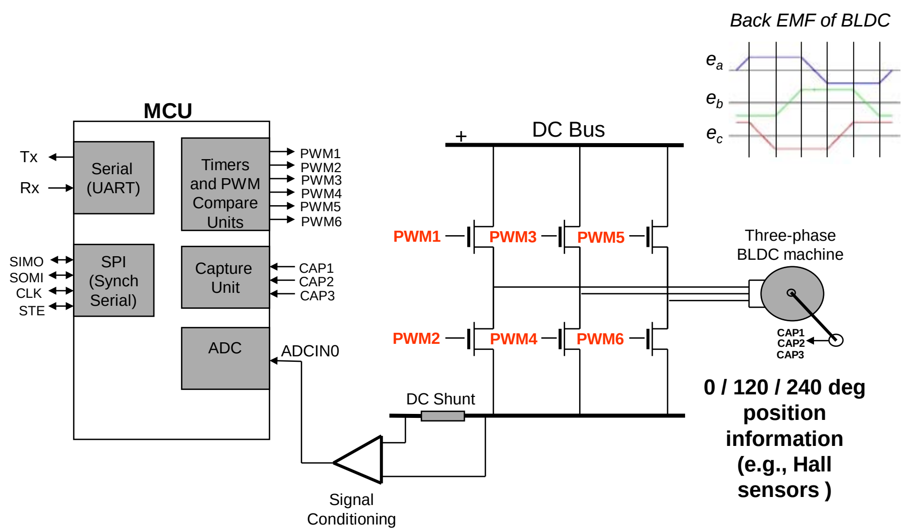
Field Oriented ACI control

The overall system for implementation of the 3-phase ACI control unit is shown in the next slide. The ACI motor is driven by the conventional voltage-source inverter. The F2833x is generating six pulse width modulation (PWM) signals by means of space vector PWM technique for six power- switching devices in the inverter. In a “sensored” measurement mode, a tachometer or resolver is used to feedback speed and position. By contrast, in a “sensorless” measurement mode, two input currents of the PMSM (i_a and i_b) are measured from the inverter and they are sent to the F2833x via two analog-to-digital converters (ADCs).

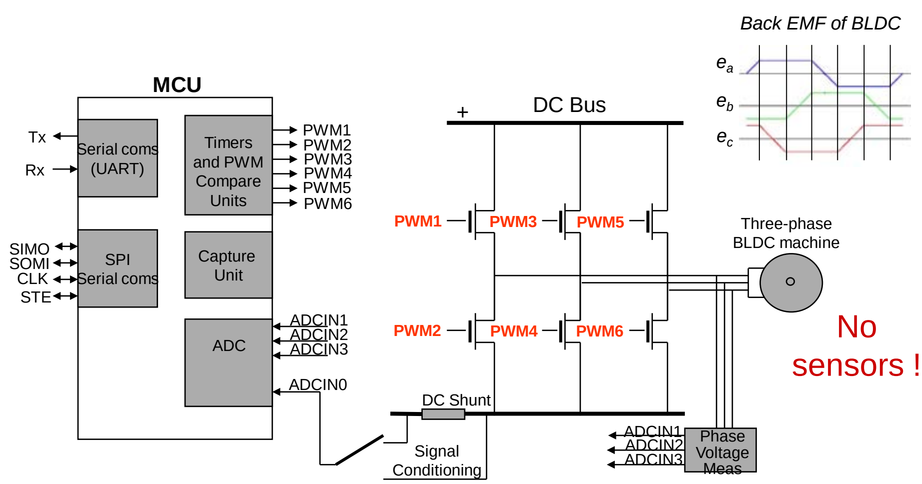


Field Oriented Brushless DC control

BLDC System – Sensored, Trapezoidal

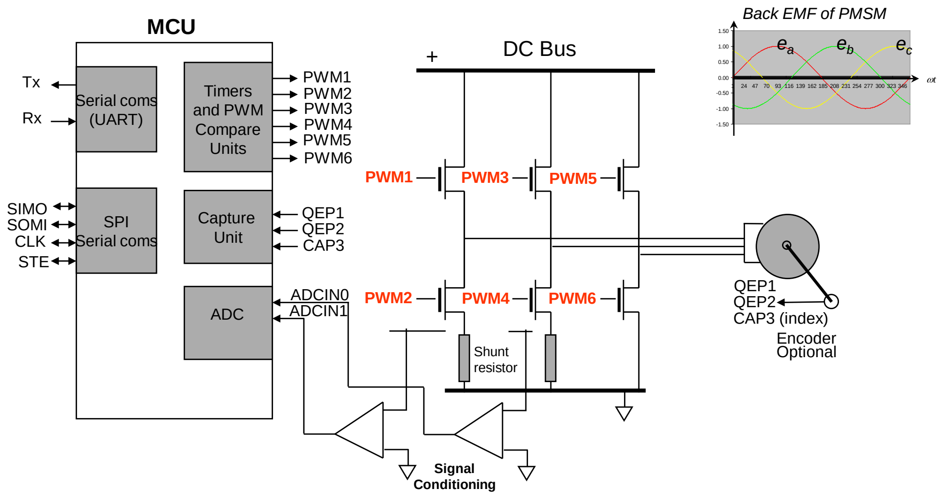


BLDC System – Sensorless, Trapezoidal



Field Oriented PMSM control

PMSM System – FOC/Vector



Sensor is removed with sensorless FOC

F2833x Features for Motor Control

Software

Software for Real-Time Controllers

Header Files
- Init routines and functions
- Named bit fields
- Peripheral Examples

CCS v4 Sample Projects and Workspaces
- Eclipse-based code editor and debugger
- Tool kit demonstration workspaces show how to set up watch windows and graphs for real-time analysis
- General Purpose GUI ready for customization

Demonstration GUIs
- Peripheral Explorer
- Renewable Energy Kit
- Digital Power Kits

Foundation Libraries
- Math primitives
- Signal Processing
- Floating-point
- Control Law Accelerator
- Flash API
- **IQMath**

Application Libraries
- **Digital Motor Control**
- Digital Power

System Examples
- **Robust Modular Frameworks**
- Multiple Digital Power Conversion Types
- **Multiple Motor Types**
- Power Line Communication

3rd Party Resources
- **Diagram-based code generation**
- Software libraries

CCS Debug Tools
- **Real-time Debug**
- Graphical Analysis
- DSP/BIOS RTOS and scheduler
- Plug-ins and add-ons

3rd Party Tools
- **Modeling and Simulation**
- Debug tools
- Emulators

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C2000 Software for DMC Concept

Methodology
- Highest precision & most numerically accurate
- Modular libraries (C source) for easiest re-use and customization
- Removal of fixed point scaling and saturation burden
- Easiest to tune for your custom motor
- Documentation: DMC theory, software, BOM, schematics

Customers can self serve and achieve high productivity!

Achieved by
- IQMath
- Application Frameworks: DMC Library & Incremental Build
- Partner Tools for simulation, GUI programming, and auto code gen

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IQ – Math Functions

IQMath

- Library and Compiler Intrinsic
  - Move your decimal point to where you need it
  - Write in floating point, compiler does all the work
- Start-up, tuning, and debug effort are reduced
  - Change numerical range on the fly, global or local
  - Tune for best resolution and dynamic range
  - Remove quantization effects
  - Scaling and saturation are a thing of the past
  - Better integration with simulation and code gen tools
  - Single source set to move between fixed and floating point processors
  - Easy re-use and re-tuning for new systems

IQmath: Choose your decimal

Range or Resolution?

Based On The Required Dynamic Range Or Resolution

31 0

S I I I I I I I I I I I I I I I I . Q Q Q Q Q Q Q Q Q Q Q Q Q Q Q (Q15)

GLOBAL_Q	Max Val	Min Val	Resolution
28	7.999 999 996	-8.000 000 000	0.000 000 004
24	127.999 999 94	-128.000 000 00	0.000 000 06
20	2047.999 999	-2048.000 000	0.000 001

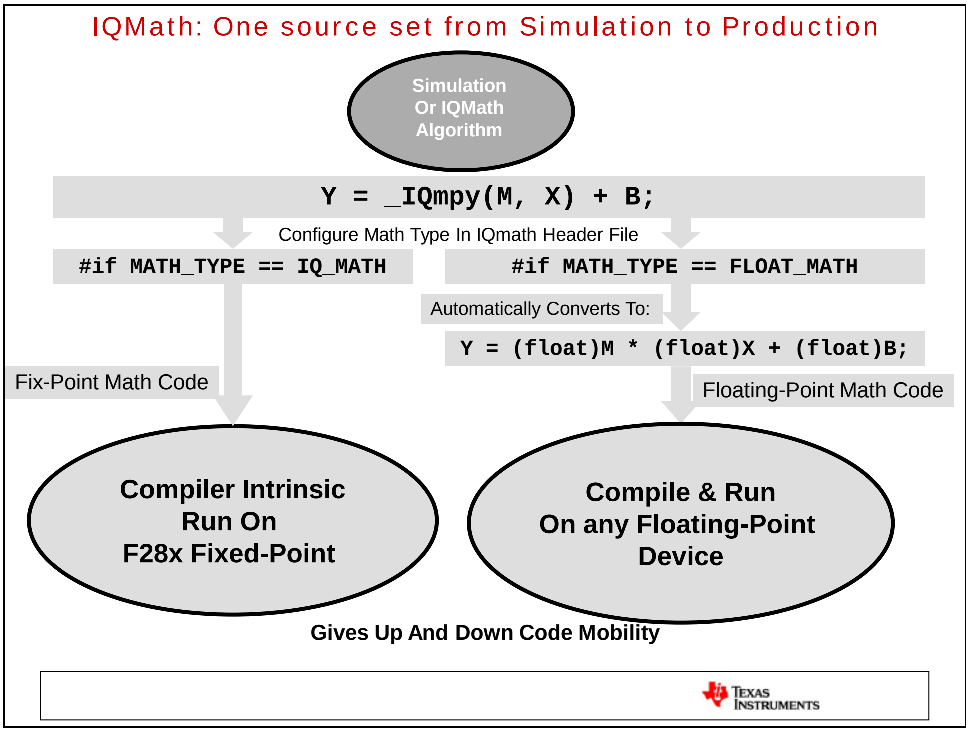
The user selects a "Global Q" value for the entire application:

```
#define  GLOBAL_Q  24    // set in "IQmathLib.h" file
_iq  Y, M, X, B;
Y = _IQmpy(M,X) + B;     // all values are in I8Q24
```

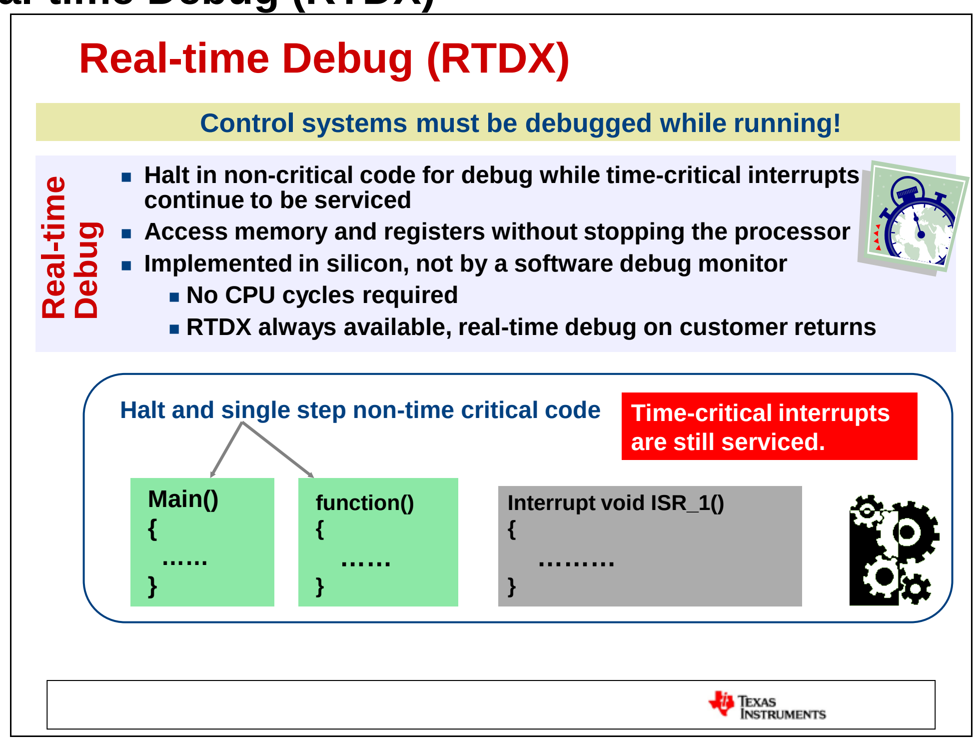
The user can also explicitly specify the IQ value to use:

```
_iq20  Y, M, X, B;
Y = _IQ20mpy(M,X) + B;   // all values are in I12Q20
```

Probably one of the most important advantages of programming in IQMaths is the ability to switch from a fixed-point environment to the floating-point processor world. When the programmer uses a conditional compilation technique, based on “#if – else – end if” directives, the same C code can be used for fixed-point and floating-point translation.



Real-time Debug (RTDX)



Texas Instruments Digital Motor Control Library

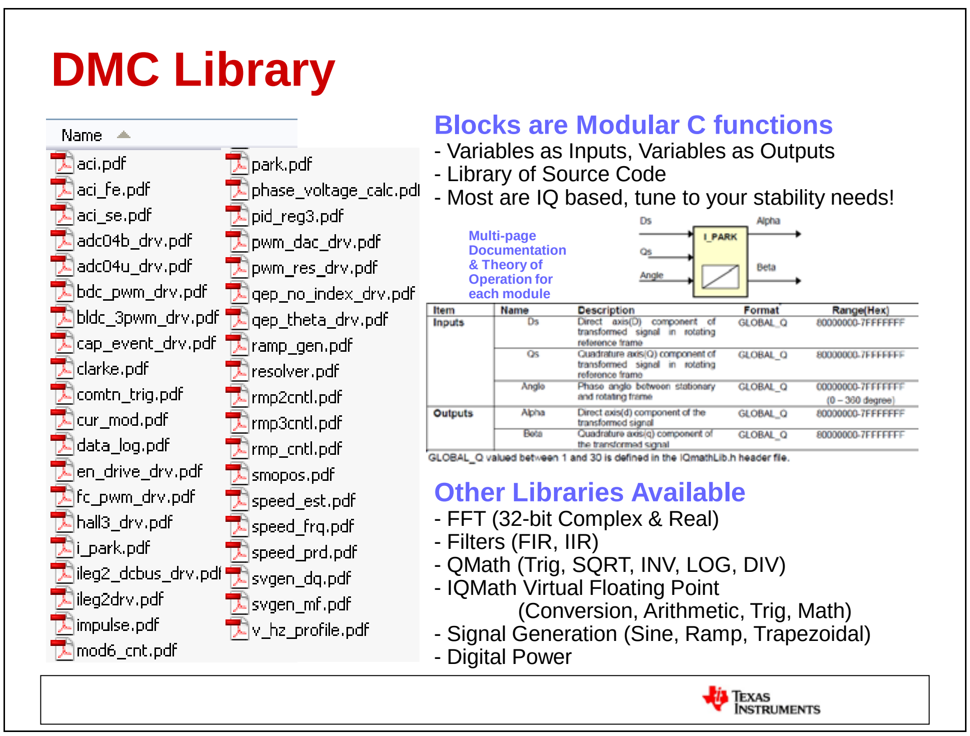
Software Modules

Texas Instruments Digital Motor Control (DMC) Library is available free of charge and can be downloaded from the Texas Instruments website. It consists of a number of useful functions for motor control applications. Among those functions, there are pure motor control modules (Park and Clark transforms, Space Vector PWM etc) as well as traditional control modules (PID controller, ramp generator etc) and peripherals drivers (for PWM, ADC and others).

Based on this DMC library, Texas Instruments has developed a number of application notes for different types of electrical motors. All applications examples are specially designed for the C2000 platform and come with a working example of the corresponding software, background information and documentation.

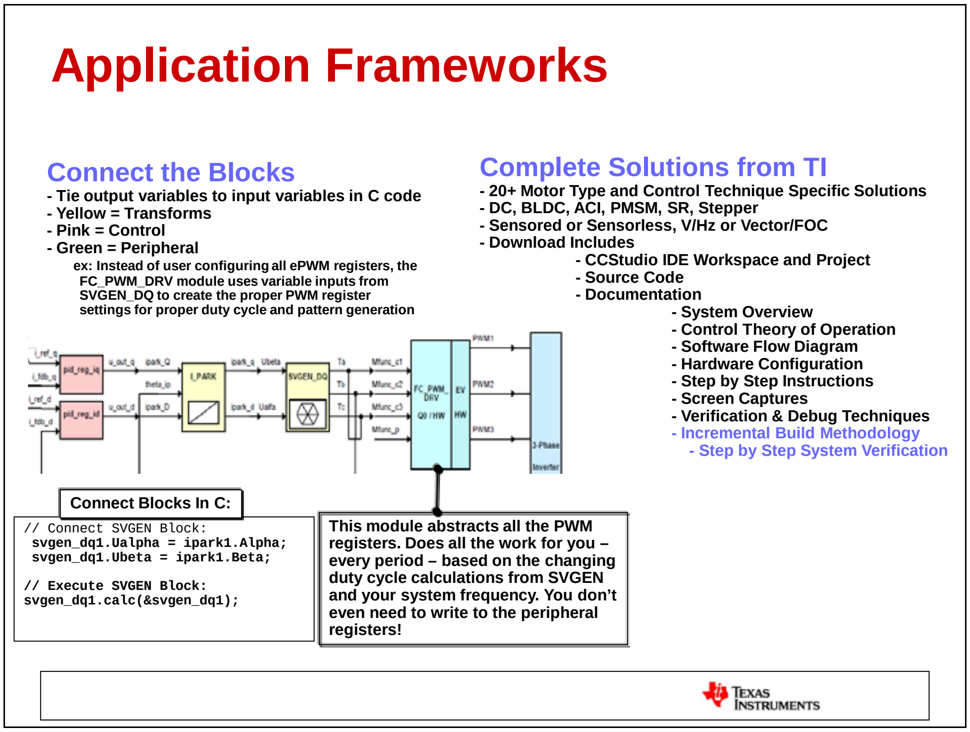
One branch of this library is dedicated to the F2833x and takes advantage of the 32-bit IQ-Math data format.

The following slide shows the software modules available for the C2000 family:



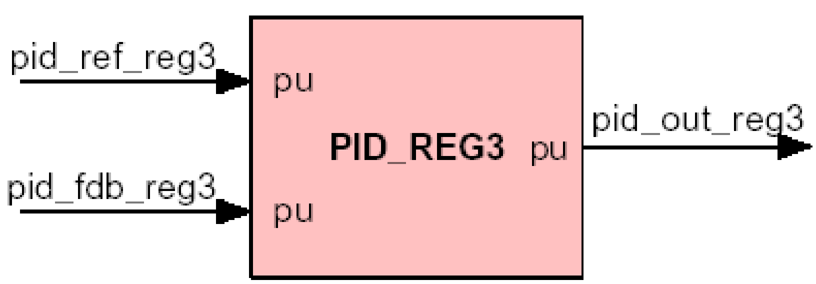
The Application Framework

All Digital Motor Control Library solutions are based on are based on a framework system, shown in the following slide. Although the modules are written in optimized IQMath code, all of them can be accessed using a C language interface.



What the user has to do is simply to select the correct blocks, to define the variables for input and output lines of the corresponding blocks and to connect these "lines" by passing variables. All modules are supplied with a dedicated documentation file.

For example, the file "pid_reg3.pdf" explains the interface and the background of the PID-controller:



All functions are coded for 32-bit variables in IQ-Math-format. The functions are used as instances of a predefined object class, based on a structure definition in a header file.

Texas Instruments DMC Solutions

Texas Instruments offers a set of more than 20 complete solutions for different types of motors, switching and control techniques, all based on this application framework.

Application Frameworks, Hardware, and Application Notes

MOTOR TYPE	CONTROL	FEEDBACK	C2000 SOLUTION
STEPPER	Microstepping	Sensorless	SPRAAU7
DC	Speed & Position	Sensored	SPRC177, SPRC214
ACI	V/F	Sensored	SPRC130, SPRC194
	FOC	Sensored	SPRC077, SPRC207
	FOC	Sensorless	SPRC078, SPRC195, SPRC922
BLDC	Trapezoidal	Sensored	SPRC175, SPRC213
	Trapezoidal	Sensorless	SPRC176, SPRC196
PMSM	V/F	Sensored	SPRC129, SPRC210
	FOC - Resolver	Sensored	SPRC178, SPRC211
	FOC	Sensored	SPRC179, SPRC212
	FOC	Sensorless	SPRC128, SPRC197, SPRC922, TMDS1MTRPFCKIT, TMDS2MTRPFCKIT
SWITCHED RELUCTANCE	Two Quadrant	Sensorless	SPRA600
OTHER			DMC Library: SPRC080, SPRC215 Designing High Performance DMC: SPRT528

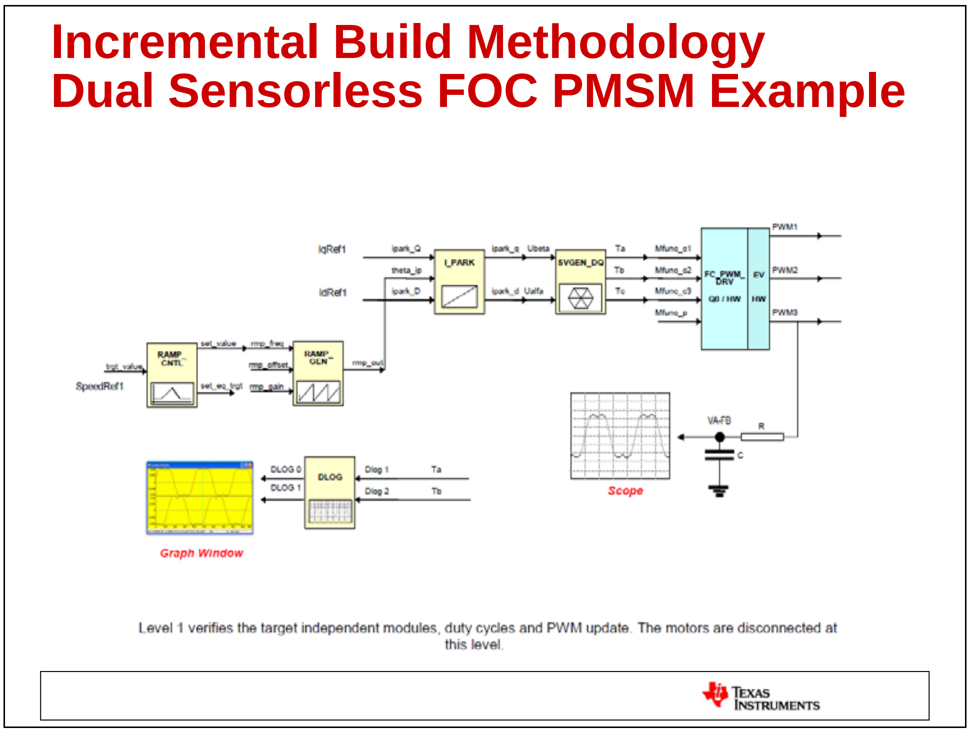
These solutions follow a simple principle for testing the software, accessing the power drives and closing the control loop: an incremental build methodology. The basic idea is to define a macro and to use a conditional compilation (called: “Build Level”) to include more and more modules into the final machine code. Such a technique is very helpful when the user tests a motor drive system for the very first time.

The following slides explain this sequential method with the example of a PMSM Field Oriented Control System.

Example: PMSM Framework

Build Level 1

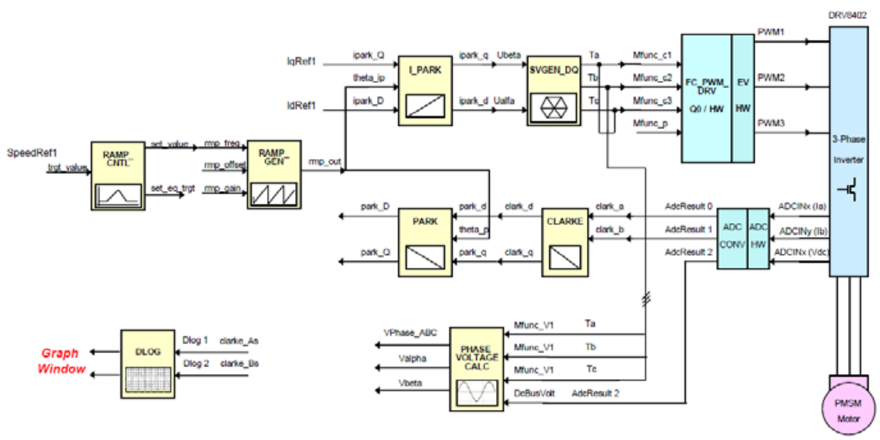
Build Level 1 is used to verify the target independent modules, such as PWM frequency, duty cycles and updates of the PWM unit. The motors are disconnected at this level. Two software modules “RAMP_GEN” and “RAMP_CNTL” are used to stimulate the PWM system via the inverse PARK module and the Space Vector Generator module.



An oscilloscope is used to monitor the shape of the PWM signals and the pulses series generated by the SVGEN module.

Build Level 2

Incremental Build Methodology
Dual Sensorless FOC PMSM Example



Level 2 verifies the analog-to-digital conversion, offset compensation, clarke / park transformations, phase voltage calculations

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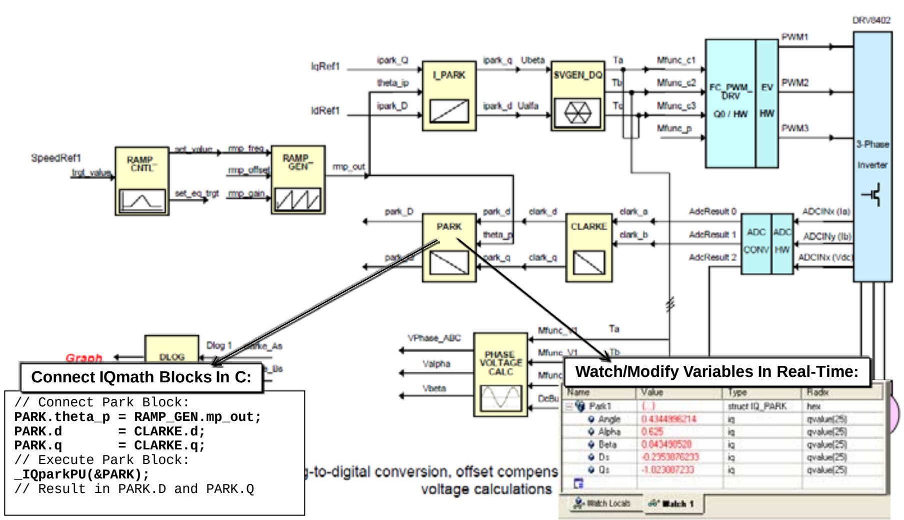
Incremental Build Methodology
Dual Sensorless FOC PMSM Example



Level 2 verifies the analog-to-digital conversion, offset compensation, clarke / park transformations, phase voltage calculations

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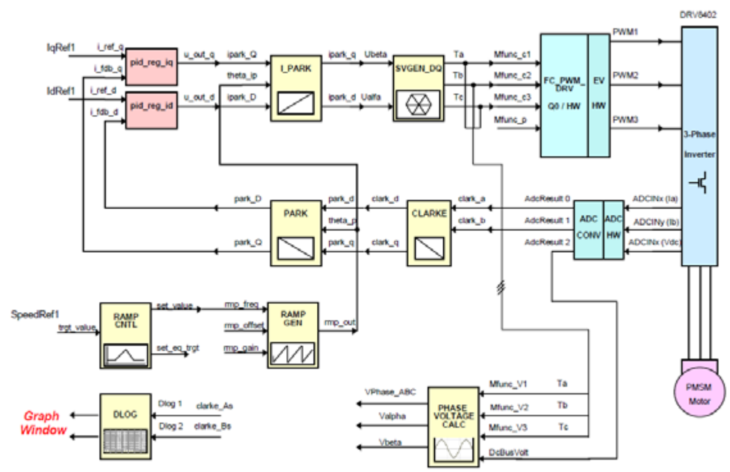
Build Level 3

Incremental Build Methodology
Dual Sensorless FOC PMSM Example



Level 3 verifies the dq-axis current regulation performed by pid_id and pid_iq modules

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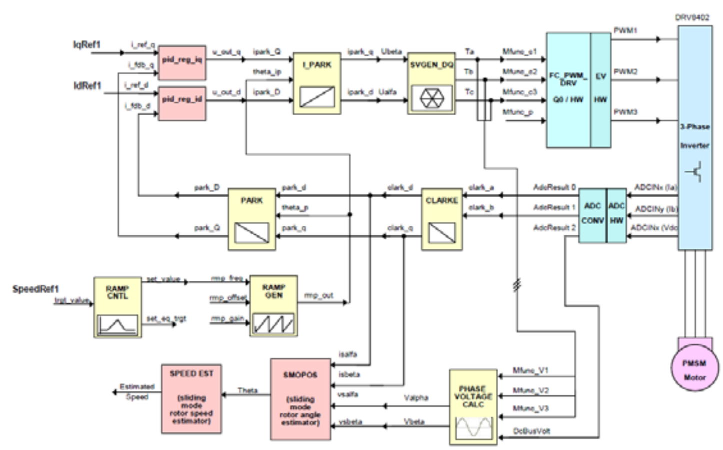
Build Level 4

Incremental Build Methodology
Dual Sensorless FOC PMSM Example



Level 4 verifies the estimated rotor position and speed estimation performed by SMOPOS and SPEED_EST modules, respectively.

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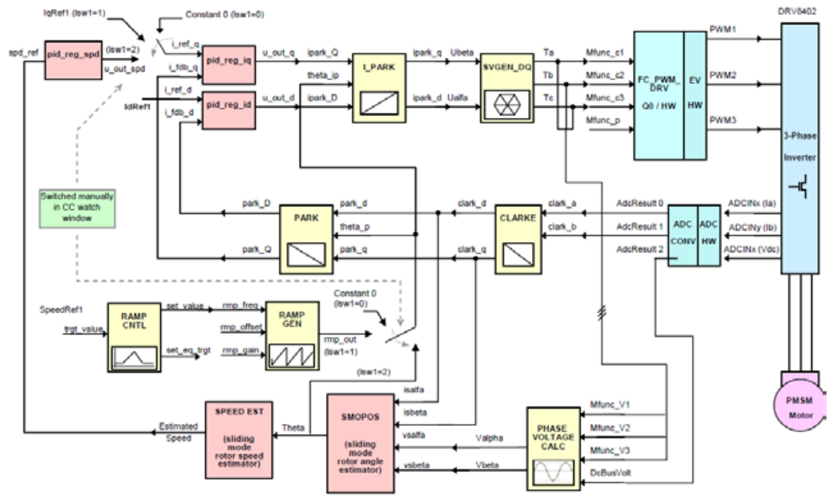
Build Level 5

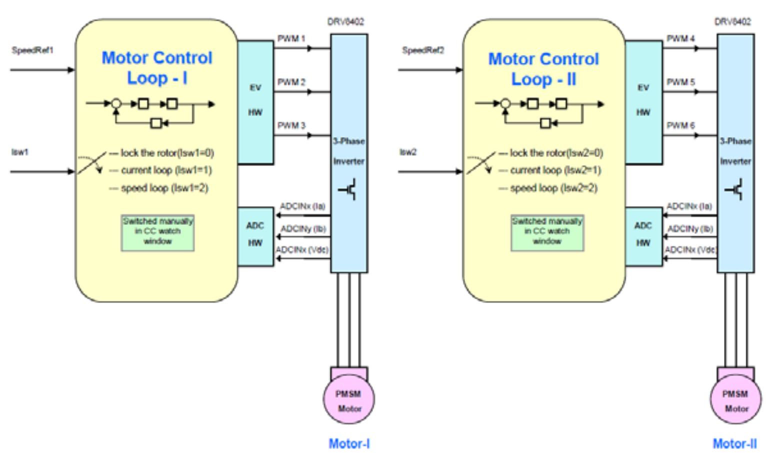
Incremental Build Methodology
Dual Sensorless FOC PMSM Example



Level 5 verifies the speed regulator performed by pid_spd module. The system speed loop is closed by using the measured speed as a feedback.

Build Level 6

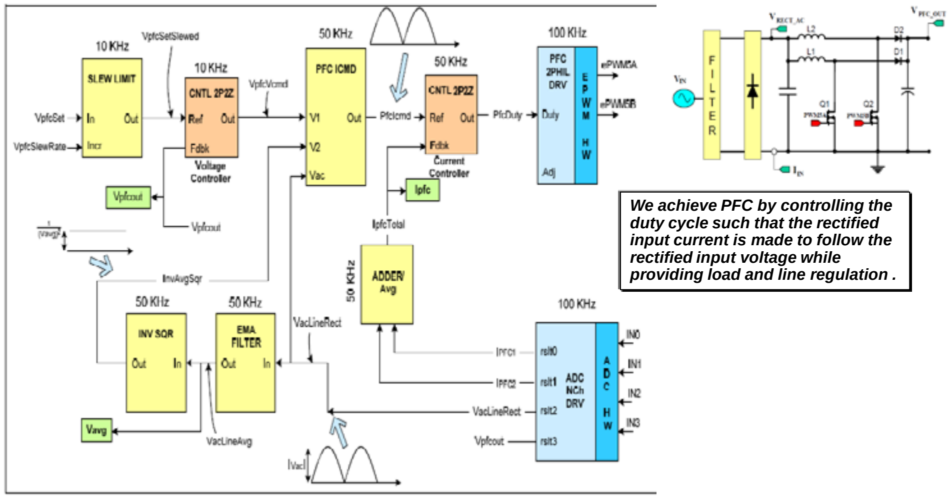
Incremental Build Methodology
Dual Sensorless FOC PMSM Example



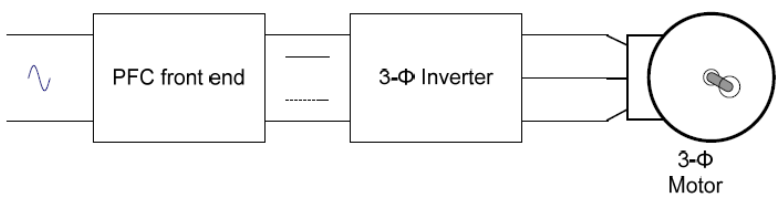
Level 6 verifies the sensorless FOC of two motors simultaneously using Sliding Mode Observer

Power Factor Correction (PFC)

MIPS leftover…integrate digital PFC!



Why add Power Factor Correction?



Why: In an AC-Rectifier, the 3-phase inverter stage and the motor act as a non-linear load and will draw harmonic currents from the line. These harmonics result in losses and such currents can distort the line voltage.

Some countries and regulatory bodies limit the distortion to the line a product can inject (see IEC 61000-3-2).

How: Generate an intermediate DC Bus from an AC source while drawing a sine wave input current that is exactly in phase with the line voltage

A PFC stage has become an integral part of most power supply designs…usually done with a standalone PFC chip…why not have the MCU control this digitally!

C2000 Motor Control Hardware

To start an exploration for motor control, based on C2000 controllers, Texas Instruments offers a set of low cost tools:

controlSTICK: Low Cost Evaluation

$39 Kit includes

- **Simple USB memory stick form factor evaluation tool**
  - Piccolo F28027
  - Onboard USB JTAG emulation
  - Header pins provides access to most Piccolo pins
- **11 example projects explain most Piccolo peripherals**
- **Jumpers and patch cords to easily connect pins together**
- **USB extension cable**
- **Code Composer Studio V3.3 with 32KB code size limit**
- **Complete hardware documentation**
  - Gerbers, schematics, etc

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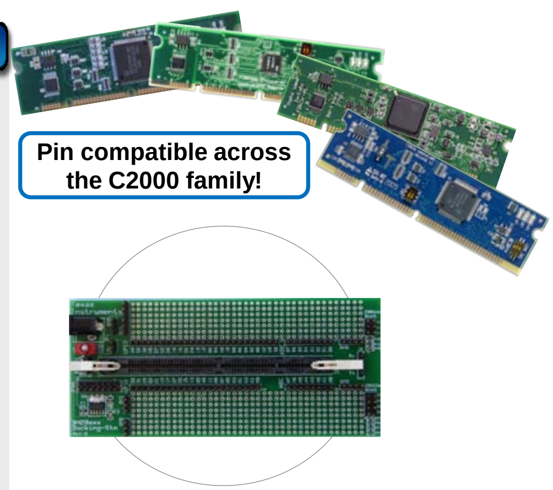
controlCARD: Modular, Robust, Standard

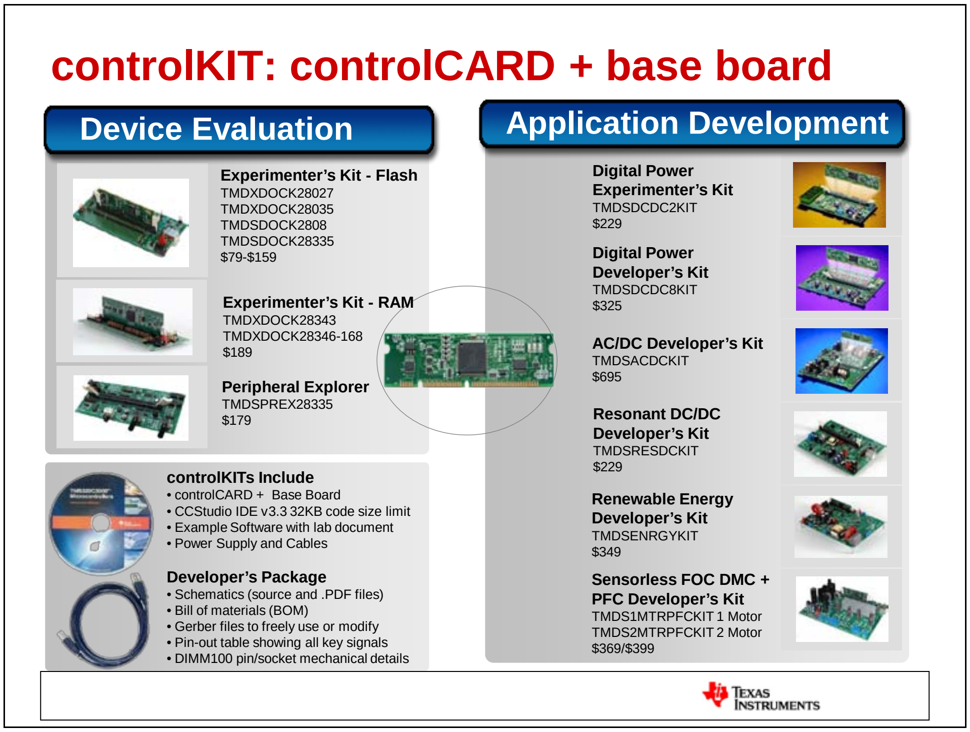
controlCARD

- **Low cost, small form factor**
- **Standard DIMM interface**
  - Includes analog I/O, digital I/O, and JTAG signals available at DIMM interface
- **Robust design**
  - Noise filter at ADC input pins
  - Ground plane
  - Isolated UART communication
  - Supply pin decoupling
- **All life support circuitry**
  - Clock, Power Supply, LDO, etc
- **Multiple versions available**
  - Piccolo F28027
  - Piccolo F28035
  - Delfino F28335
  - Delfino C28436
  - F2808
  - F28044
  - $49-69

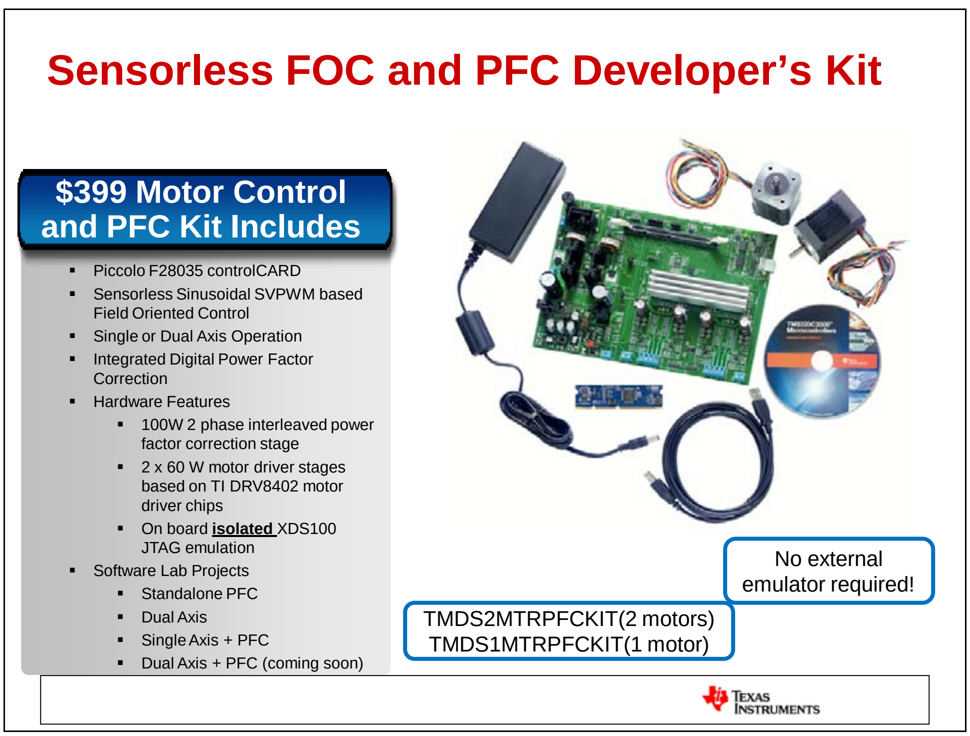


Texas Instruments

A set of base boards allows the user to go deeper into different application areas, such as Digital Power Supply or Digital Motor Control.

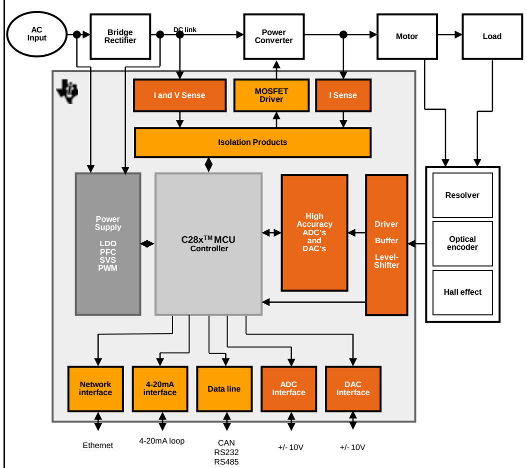


For Digital Motor Control the following package includes all you need to experiment with PMSM motors.



Summary

Benefits of C2000 for Motor Control



- **High energy efficiency via advanced Control**
  - Variable speed Real-time control
  - Better dynamic and transient control
- **Overall System performance optimization**
  - High Level of Integration
  - Provides Control and Supervision
- **Quicker Return on Investment**
  - Portfolio of compatible devices from lowest cost to highest performance
  - Long term SW and tools compatibility
  - System Cost Optimization
- **Low System Cost**
  - Integrated OSC, Watchdogs
  - Analog Comparators
  - Fault Detection
  - Limited life support
  - No external GPIO filters needed

TEXAS INSTRUMENTS

Motor Control Development Kit

The Digital Motor Control Kit "TMDS2MTRPFCKIT" is an ideal target to experiment with control loops for electrical motors.

This kit comes with a set of documentation, including all the software that is needed to build software projects as described in this Chapter. You can also download this software from the Texas Instruments website (www.ti.com):

- Search for literature number "sprc922.zip" to obtain the board specific software
- Search for literature number "sprc675.zip" to get the software baseline for this kit
- Search for literature number "SPRUGQ1" to get the Quick Start Guide for the board.