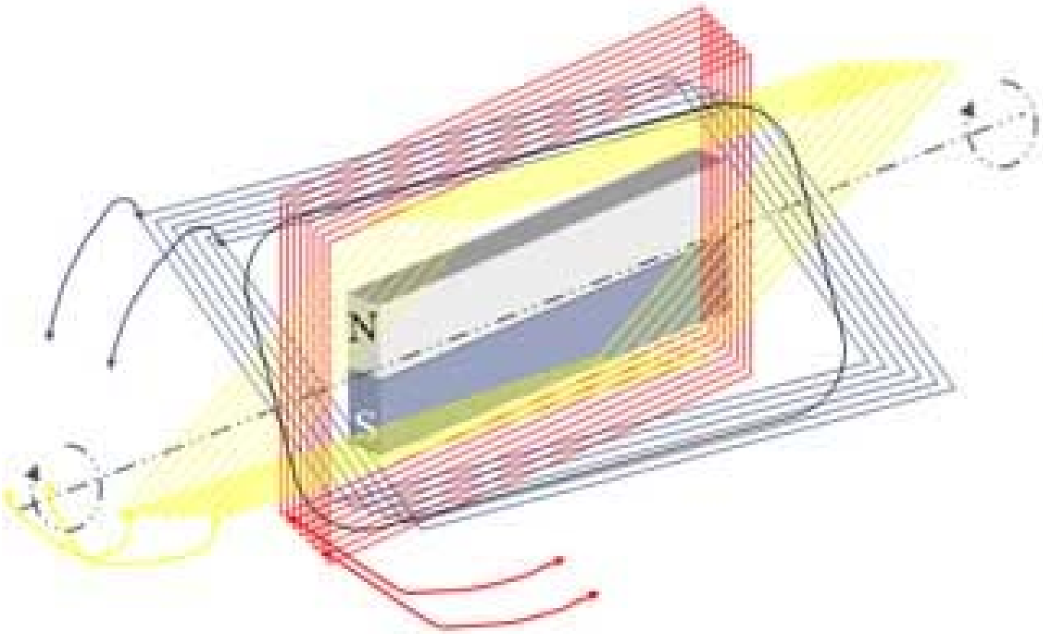
TI Digital Motor Control Solutions

SPRB167A

Agenda Timeline

• **Motor Control Fundamentals**	**25 min**
– AC Induction and Permanent Magnet Motors	
– Scalar and Vector Control	
• **Applications:** **Smarter controllers, high performance, lower cost**	**15 min**
• **Controller Selection**	**10 min**
• **Motor Control Collateral Overview**	**25 min**
– Development Tools Overview: Faster HW+SW Development	
– Modular Software Libraries: Development Accelerators	
– Incremental Build Technology: Easy Deployment	
• **Completing the signal chain: TI Analog and Communications**	**25 min**
• **Get Started Today with TI!**	**5 min**
• **Question and Answers**	**10 min**

Three Phase Machine Fundamentals

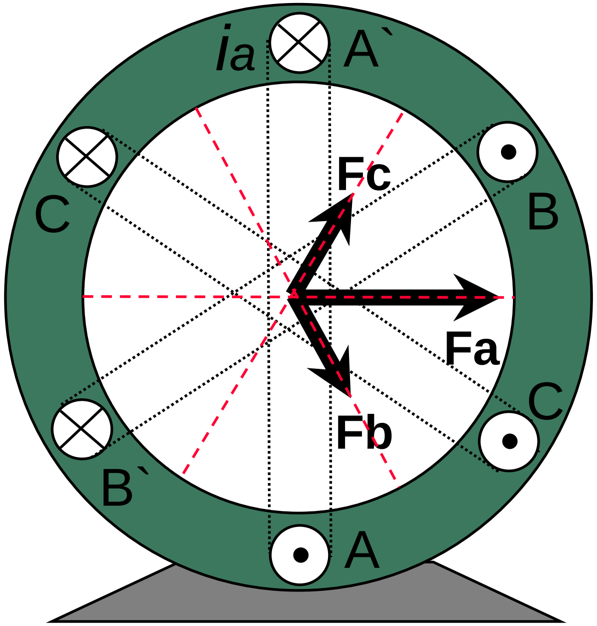


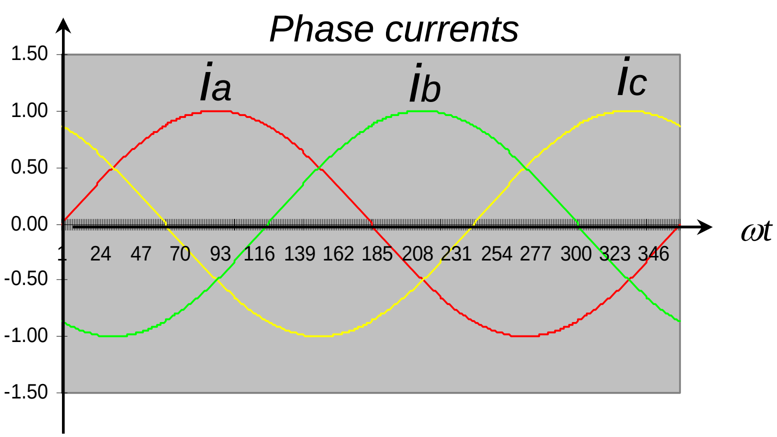
Conceptual

Practical

- Three phase machines have three windings, separated in phase by 120°- a third of a rotation.

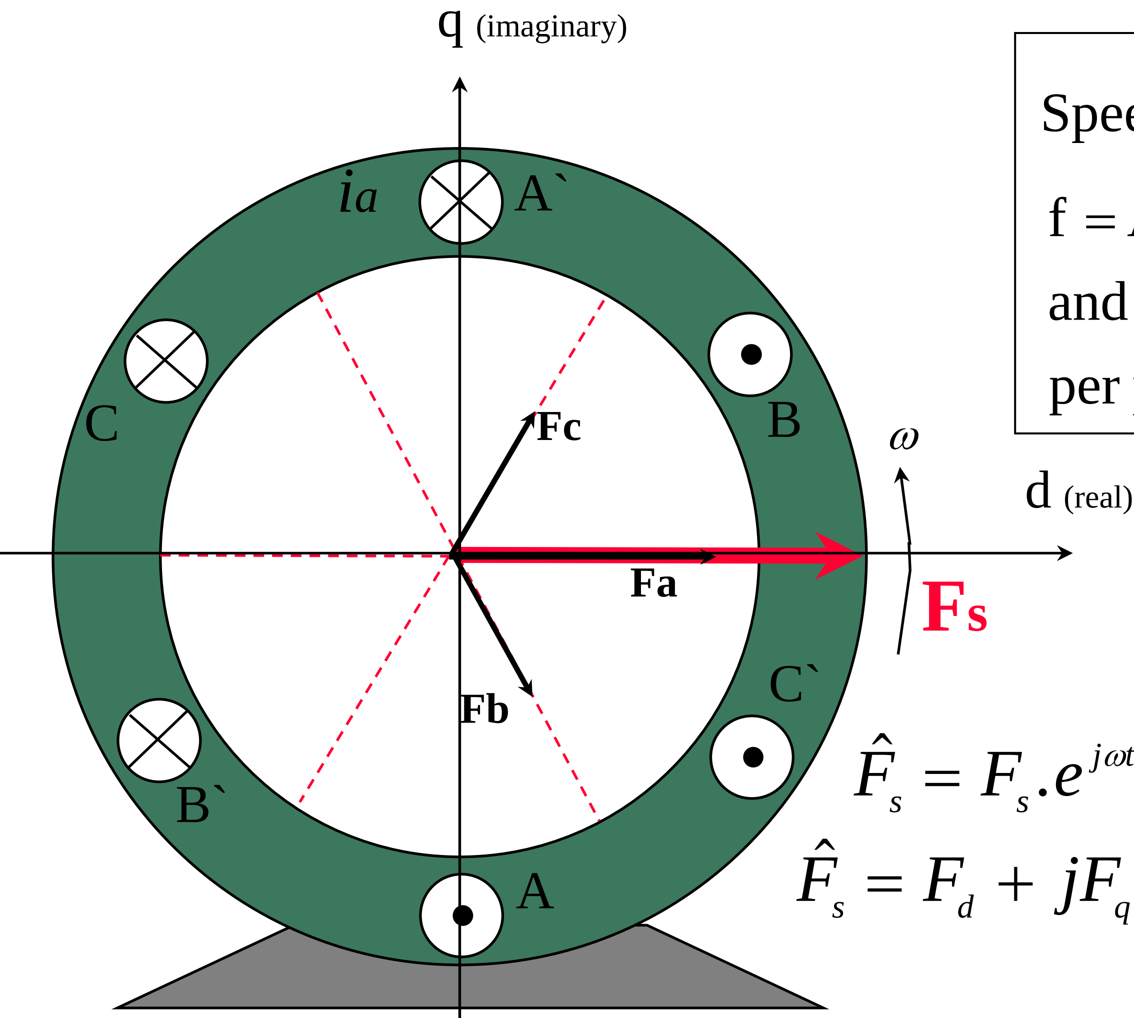
Three Phase Machine Fundamentals





- The three phase winding produces three magnetic fields, which are spaced 120° apart physically.
- When excited with three sine waves that are a 120° apart in phase, there are three pulsating magnetic fields.
- The resultant of the three magnetic fields is a ***rotating magnetic field.***

Three Phase Machine Fundamentals



$$\hat{F}_s = F_s . e^{j\omega t}$$

$$\hat{F}_s = F_d + jF_q$$

$$\hat{F}_s = F_a \sin(\omega t).e^{i0^o} + F_b \sin(\omega t + 120^o).e^{i120^o} + F_c \sin(\omega t + 240^o).e^{i240^o}$$

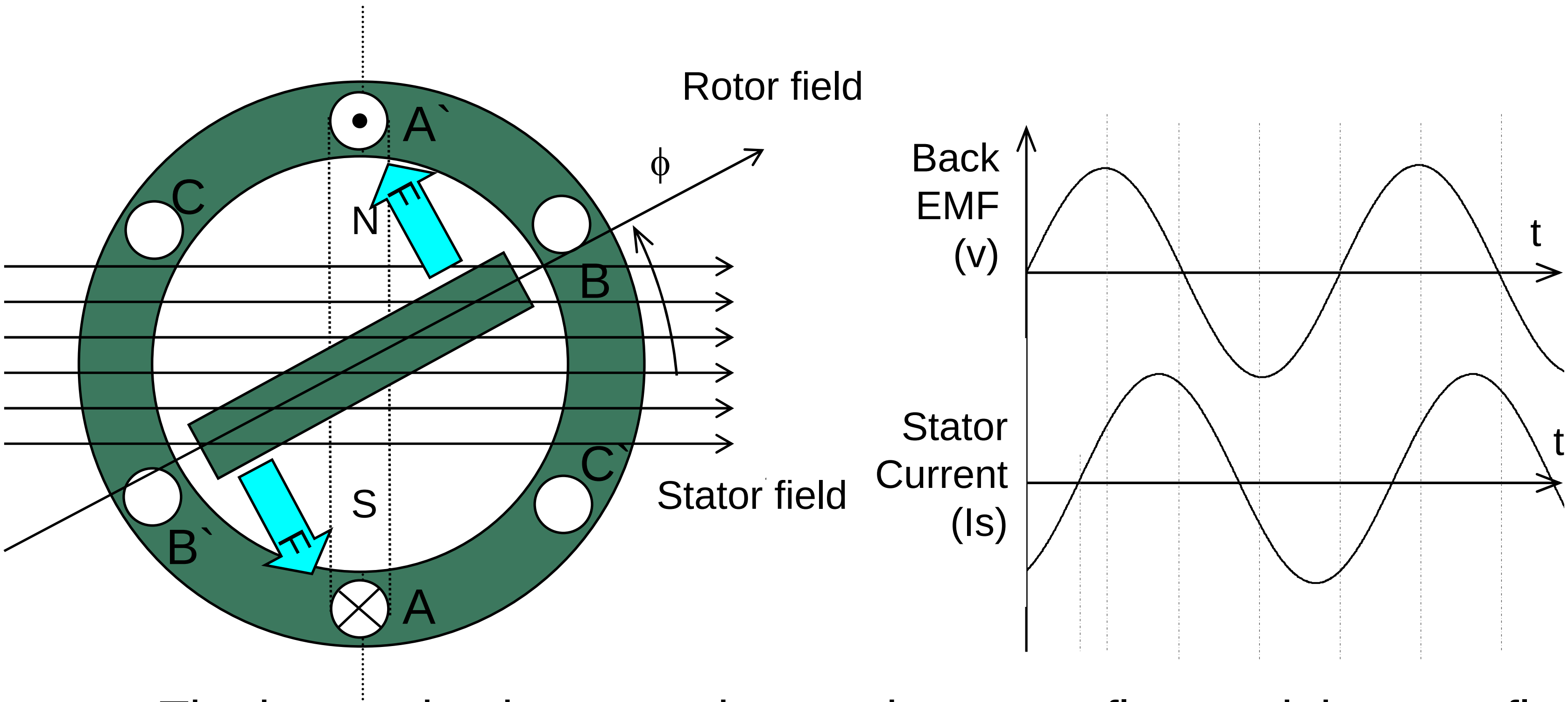
$$\text{Speed (in r.p.m.)} = \frac{120\,\text{f}}{\text{P}}$$

f = AC supply frequency,

and P = # of poles for the motor, per phase

For instance, a 3 phase machine, with: 60Hz Three Phase Supply; and 4 poles per phase will have a synchronous speed of 1800 r.p.m.

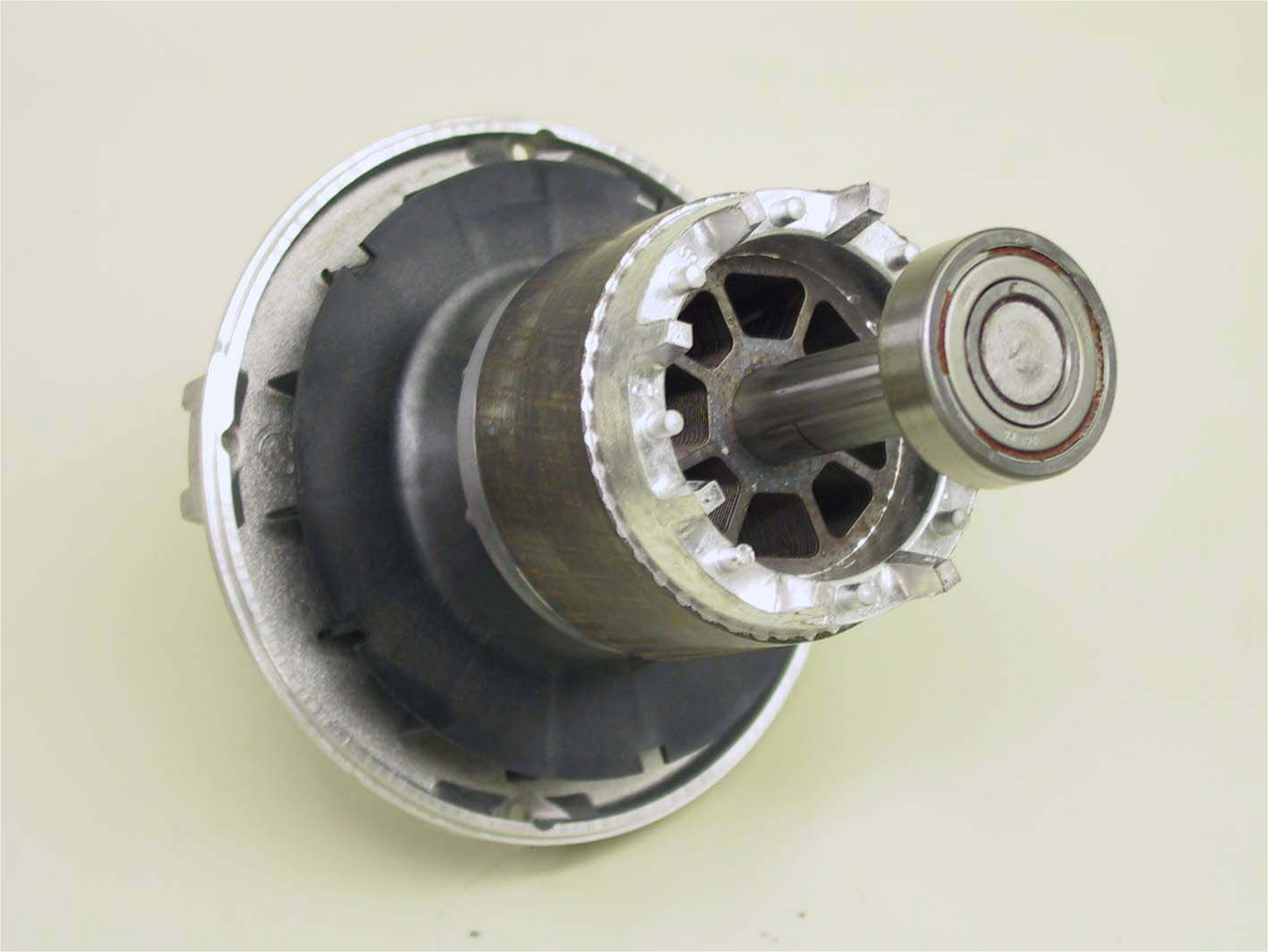
Permanent Magnet Motor Operation



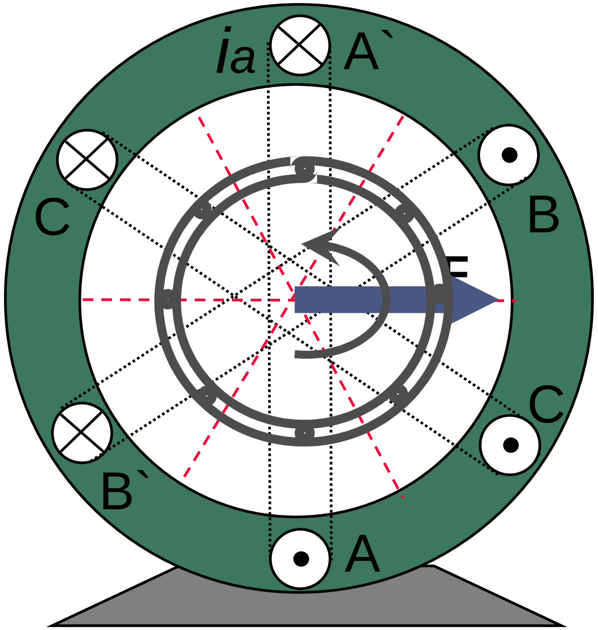
- The interaction between the rotating stator flux, and the rotor flux produces a torque which will cause the motor to rotate.
- The rotation of the rotor in this case will be at the same exact frequency as the applied excitation to the rotor.

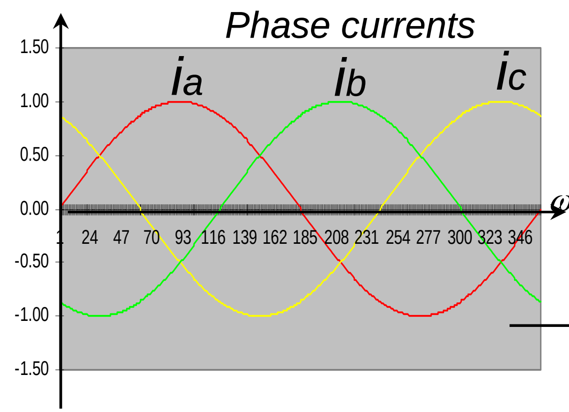
- This is an example of Synchronous operation.

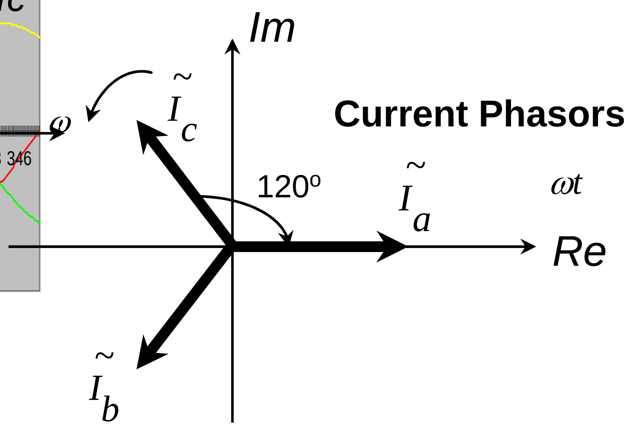
Internal View: Induction Motor Rotor



ACI Operation Fundamentals







- The induction machine has a rotor that is a closed circuit – in the case of the squirrel-cage induction motor it is two rings joined by bars along the rotor axis.
- The rotor when placed in a moving magnetic field will have induced currents, which produce an induced magnetic field.

The interaction of these two magnetic fields produces the rotational torque.

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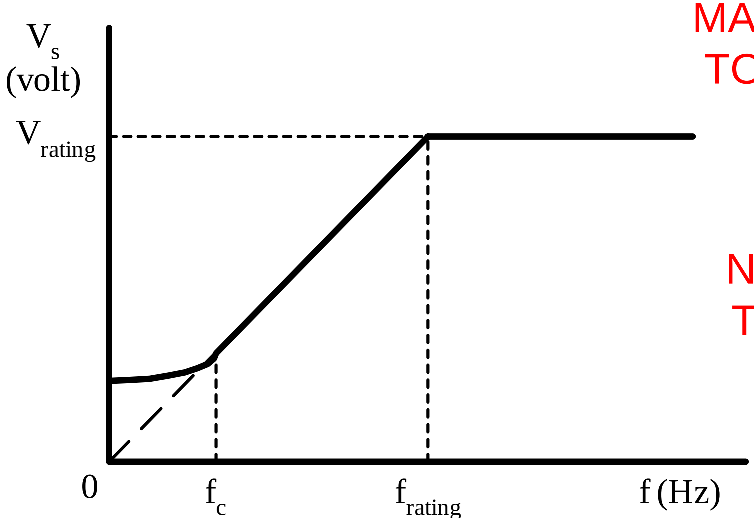
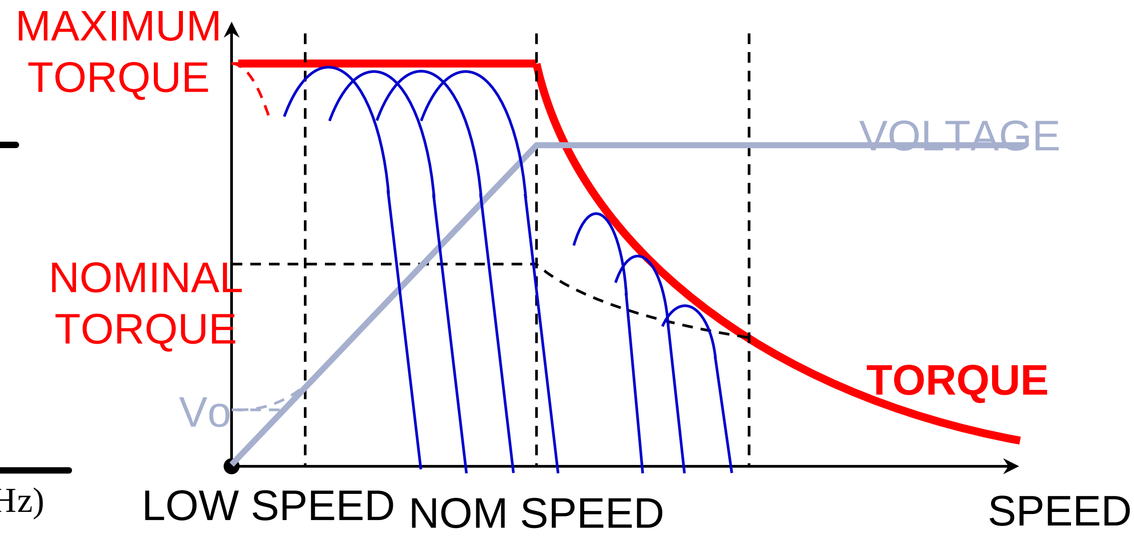
Scalar V/F control of 3-ph Induction Motor



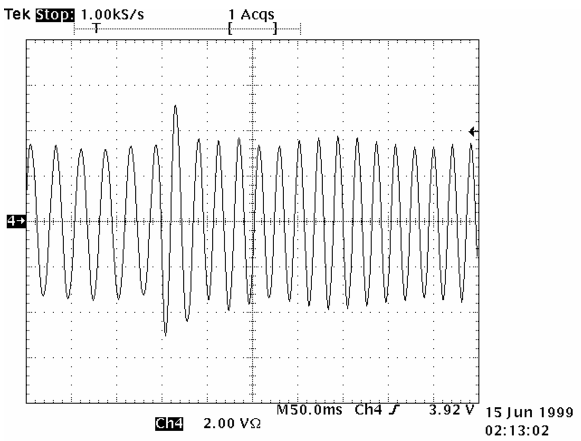


+ Simple to implement: All you need is three sine waves feeding the ACI
+ No position information needed.

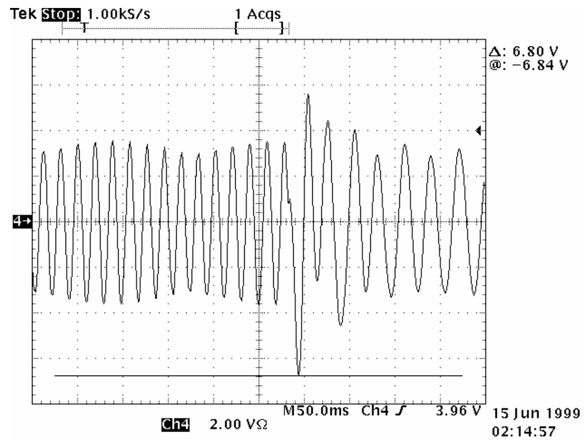
– Doesn't deliver good dynamic performance.

Limitations of the Scalar Technique

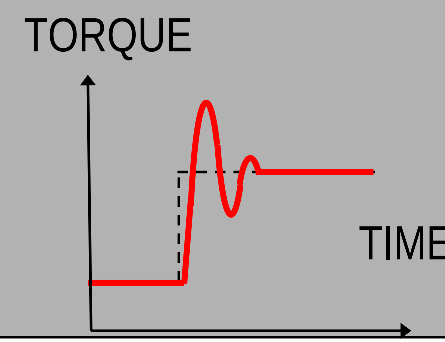
ACCELERATION



DECELERATION



Torque oscillation generates uncontrolled current overshoot:



High peak current:

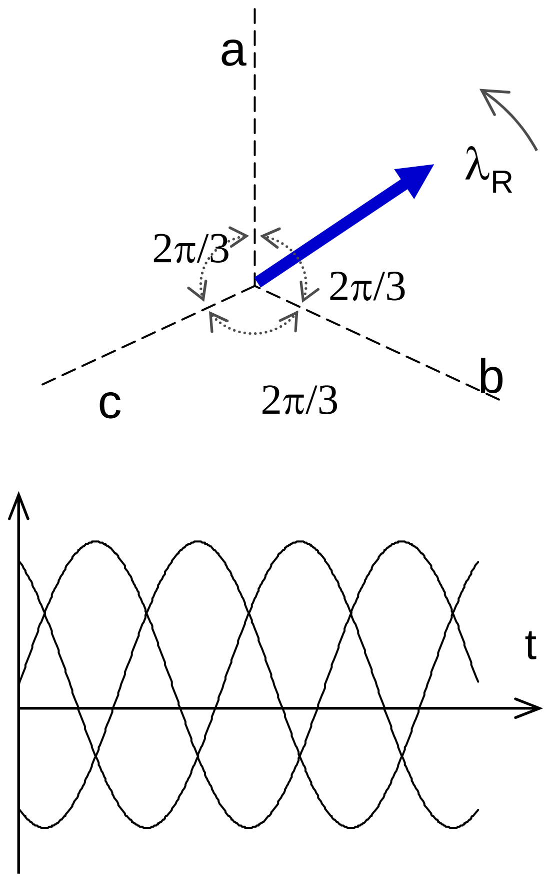
In V/f the rotor flux and current are not controlled: Current reaches values based on circuit parameters.

Poor response time:

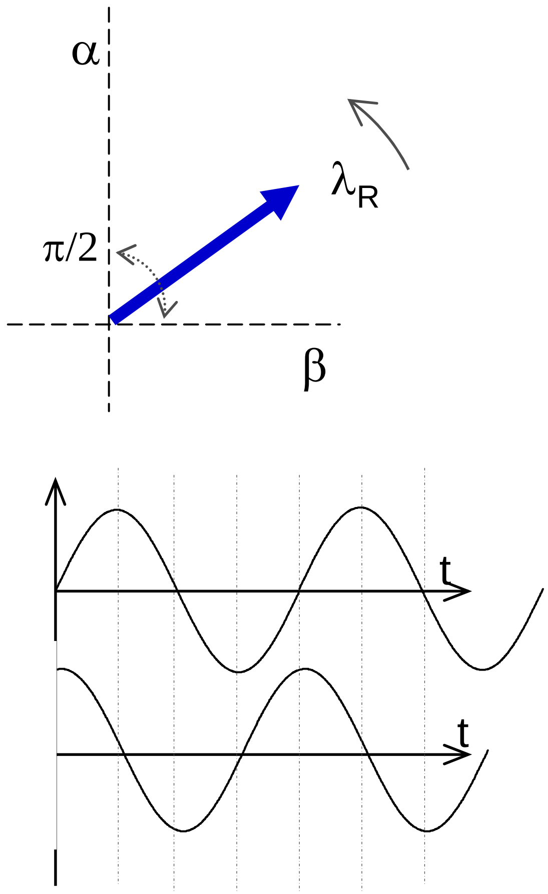
A solution to minimize these current overshoots is to decrease the performances of the speed regulator.

Slow speed regulator $\Rightarrow$ poor mechanical behavior.

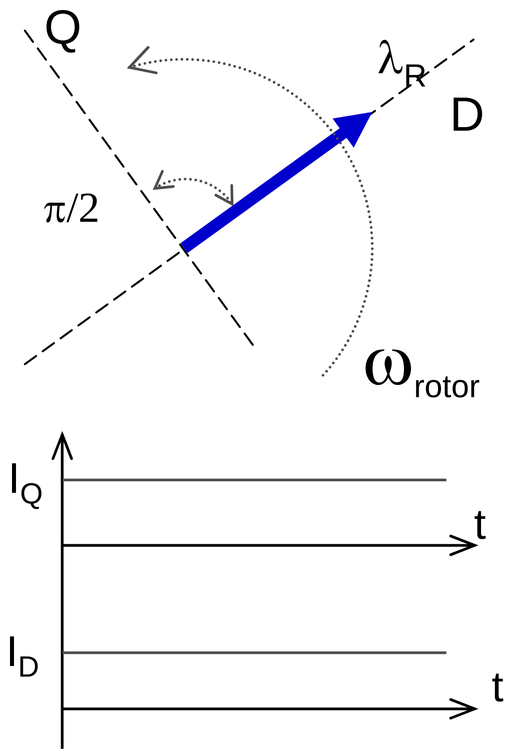
Stationary and Rotating Reference Frames



Three phase reference frame

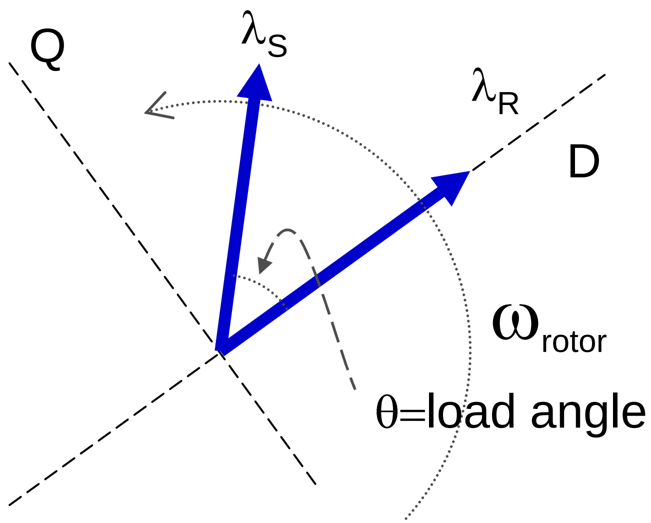


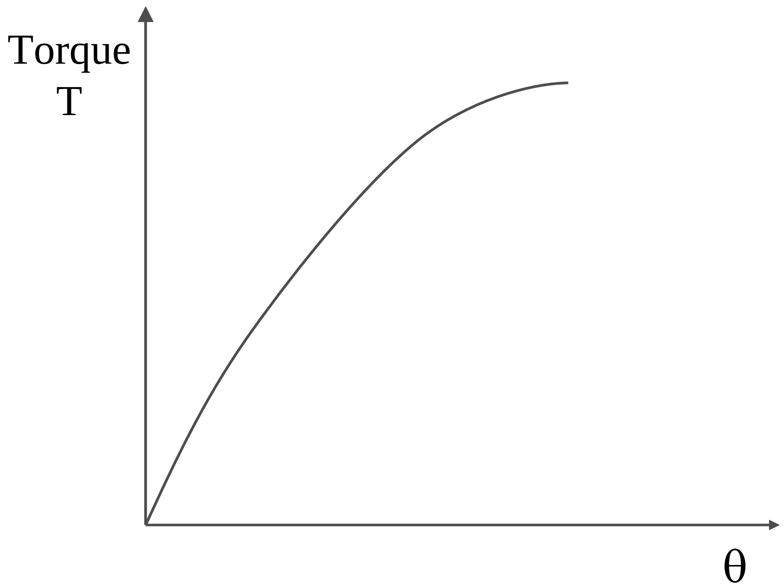
Two phase orthogonal
reference frame



Rotating Orthogonal
Reference Frame

Motor Flux Interaction





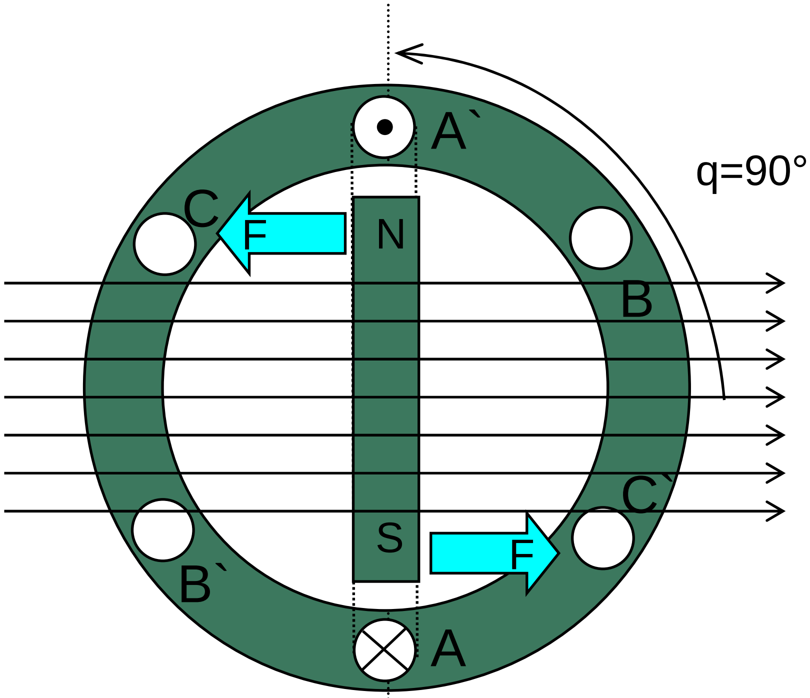
Torque $T = \lambda s \cdot \lambda r \sin(\theta)$

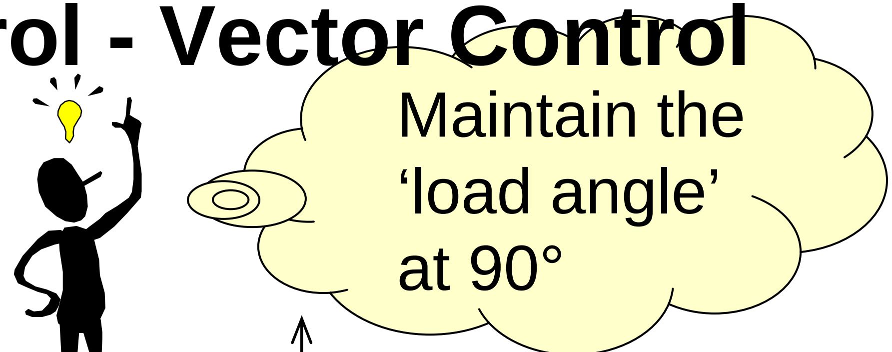
λs and λr constant

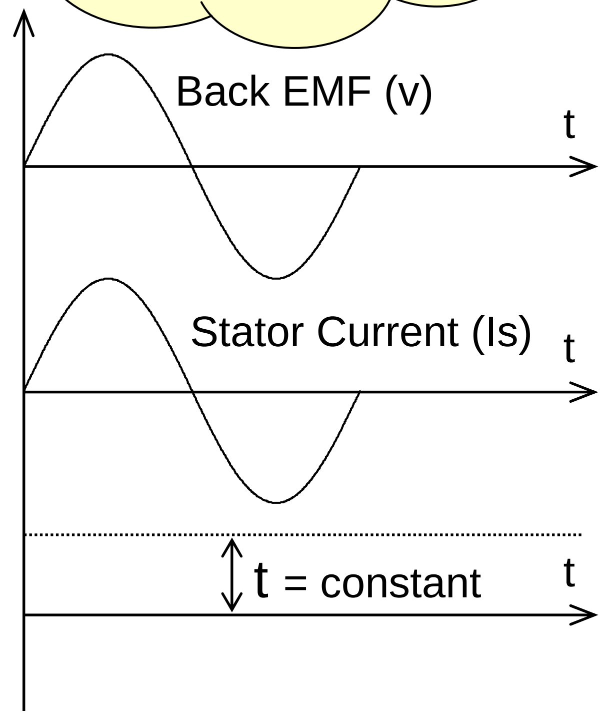
Vector Control of 3-Ph Induction Motor

- FOC is a control strategy for 3-ph AC motors, where torque and flux are independently controlled.
- The approach is imitating the DC motors' operation.
- Direct FOC: rotor flux angle is directly computed from flux estimation or measurement.
- Indirect FOC: rotor flux angle is indirectly computed from available speed and slip computation.

Field Oriented Control - Vector Control





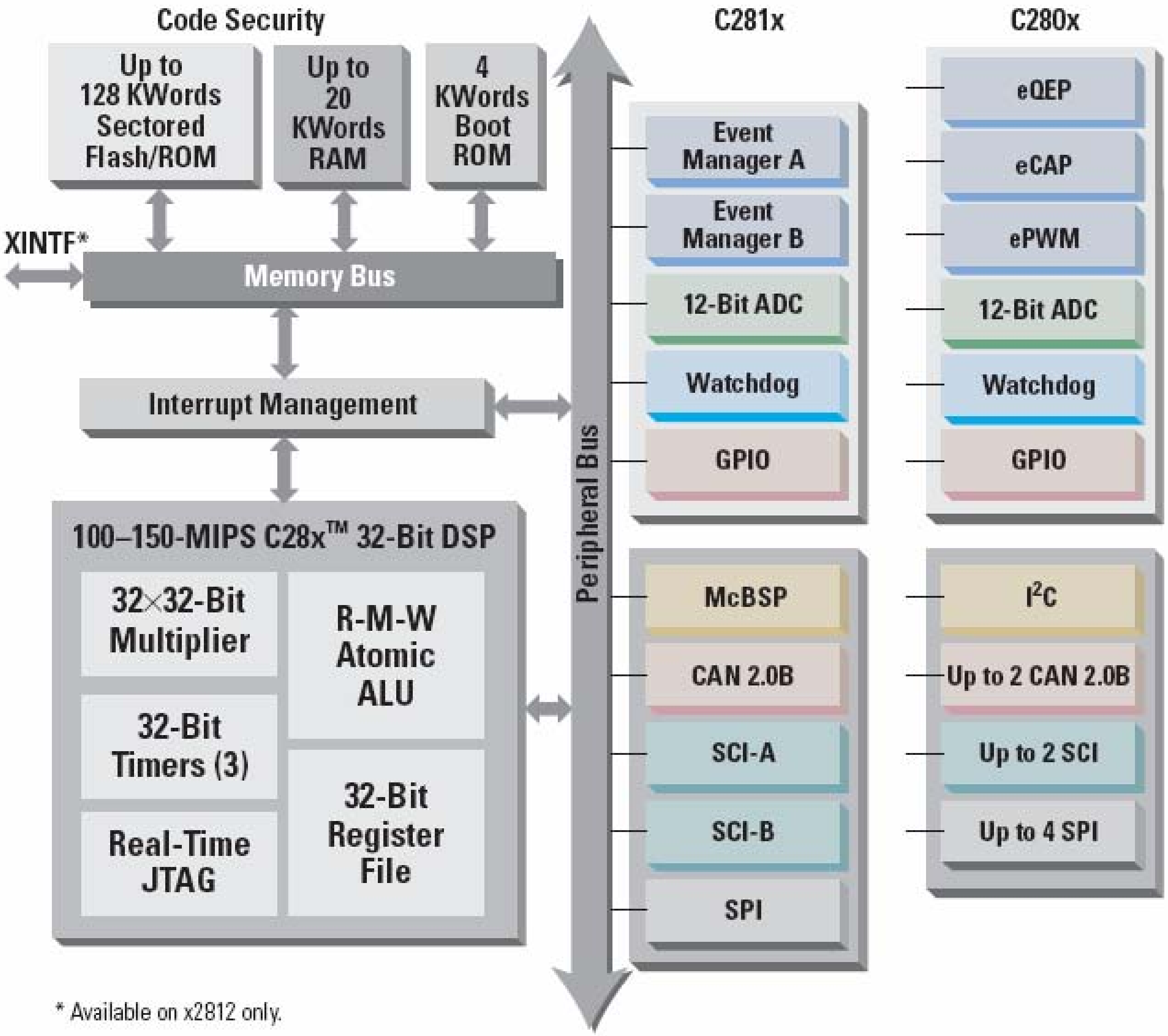


+ No torque ripple

+ Better dynamic response

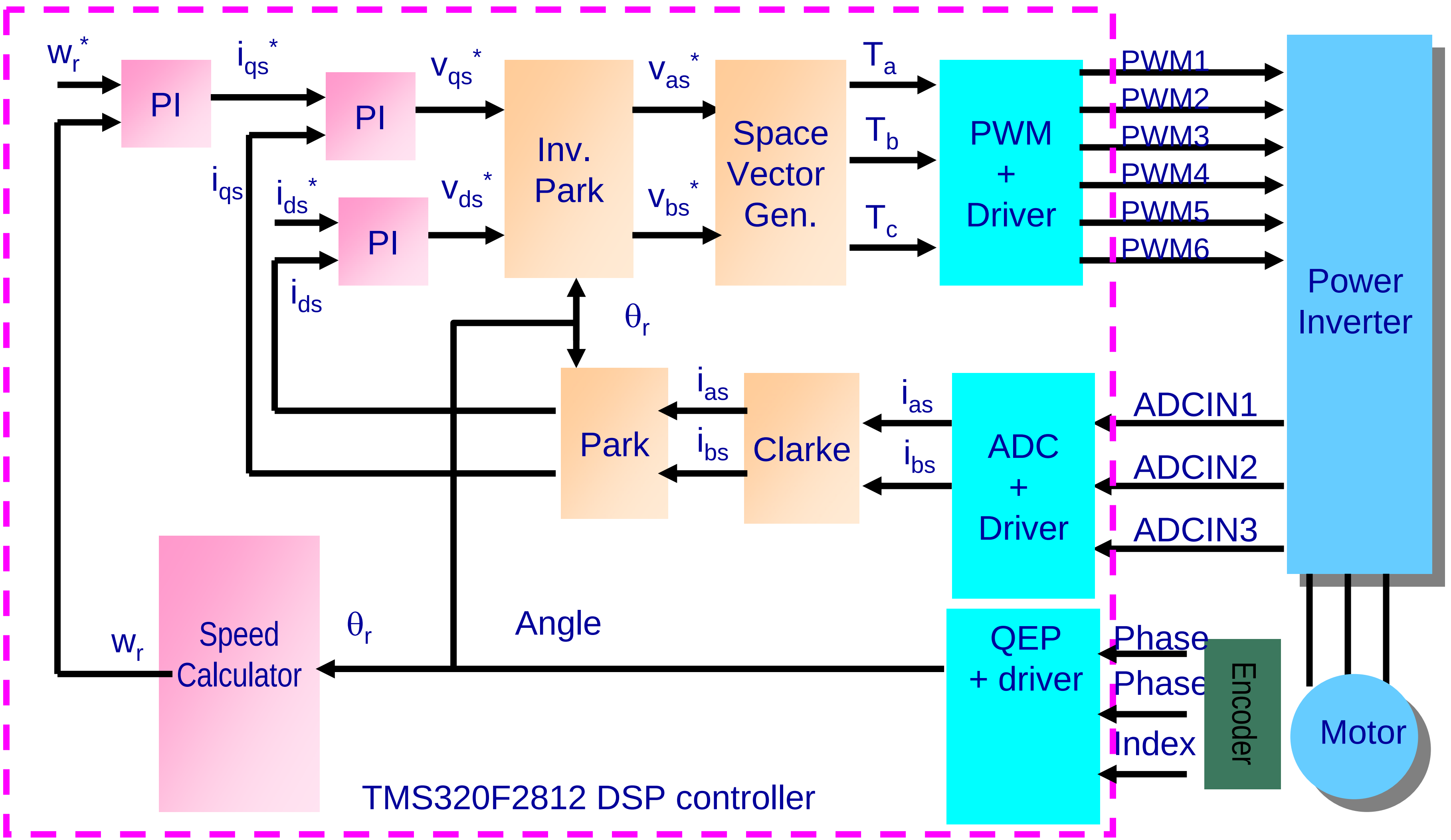
– Need good knowledge of the rotor position

C28x Controllers

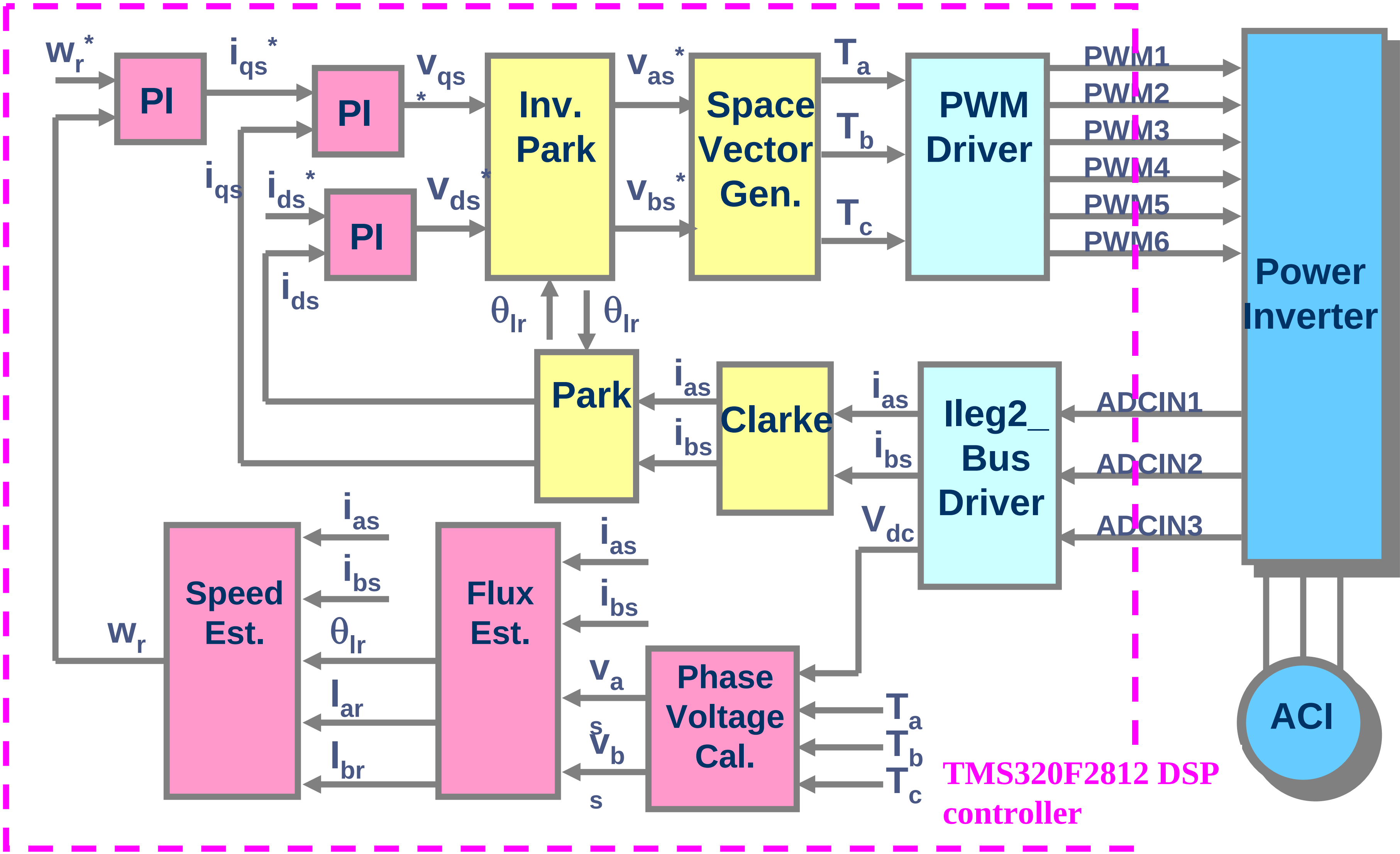


* Available on x2812 only.

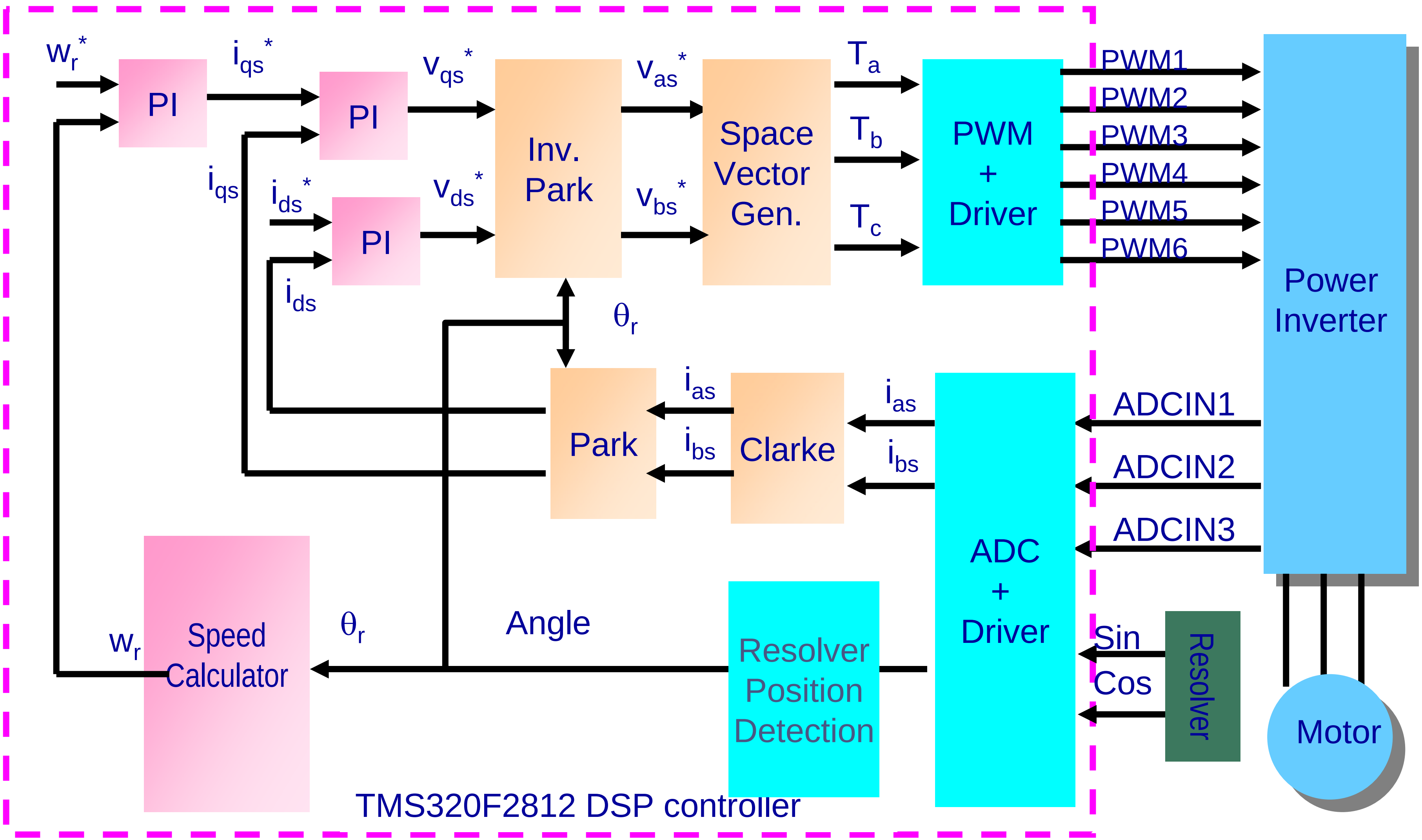
PMSM FOC with TMS320F2812 DSP



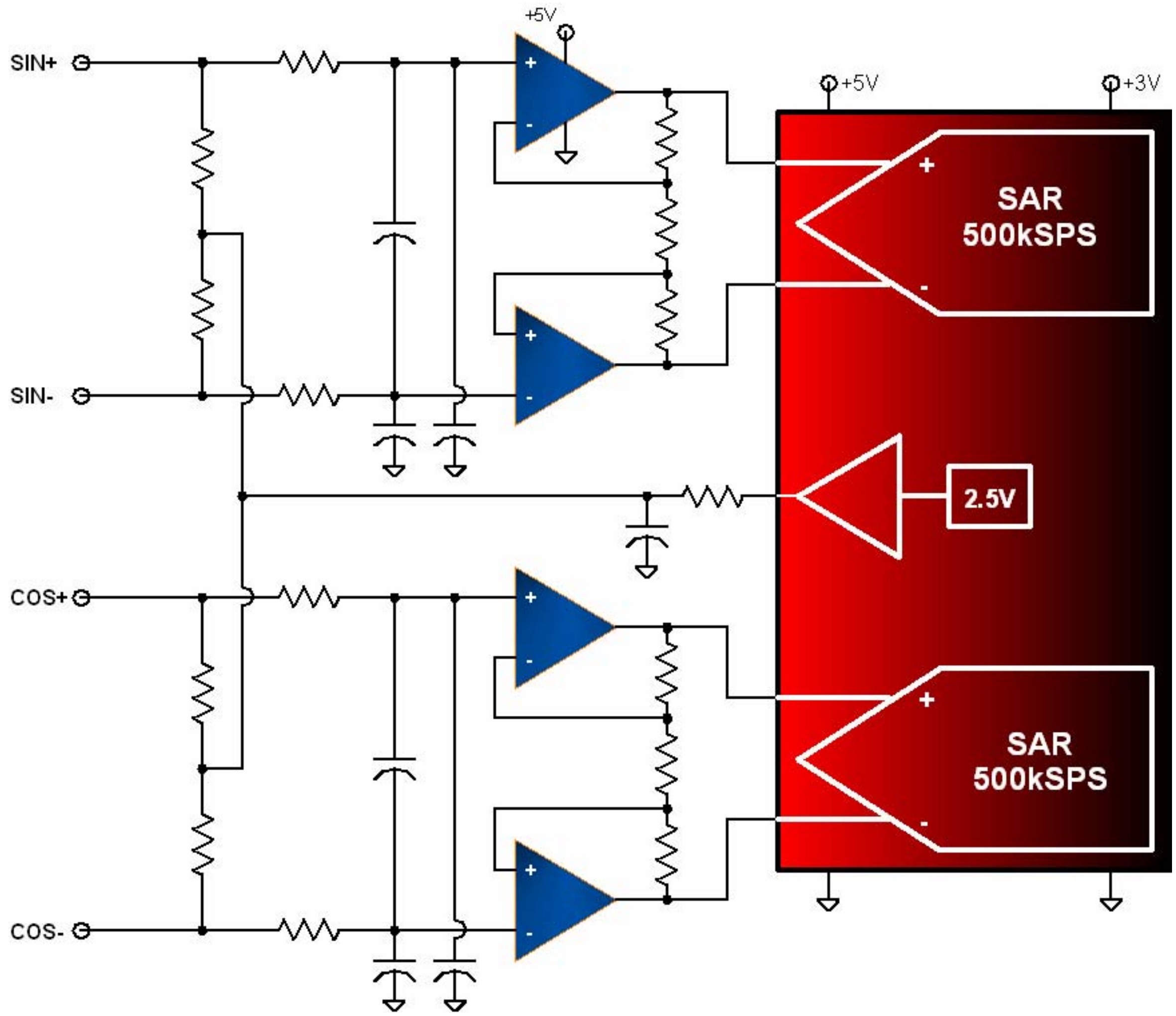
ACI FOC System with TMS320F2812 DSP



FOC TMS320F2812 DSP + Resolver



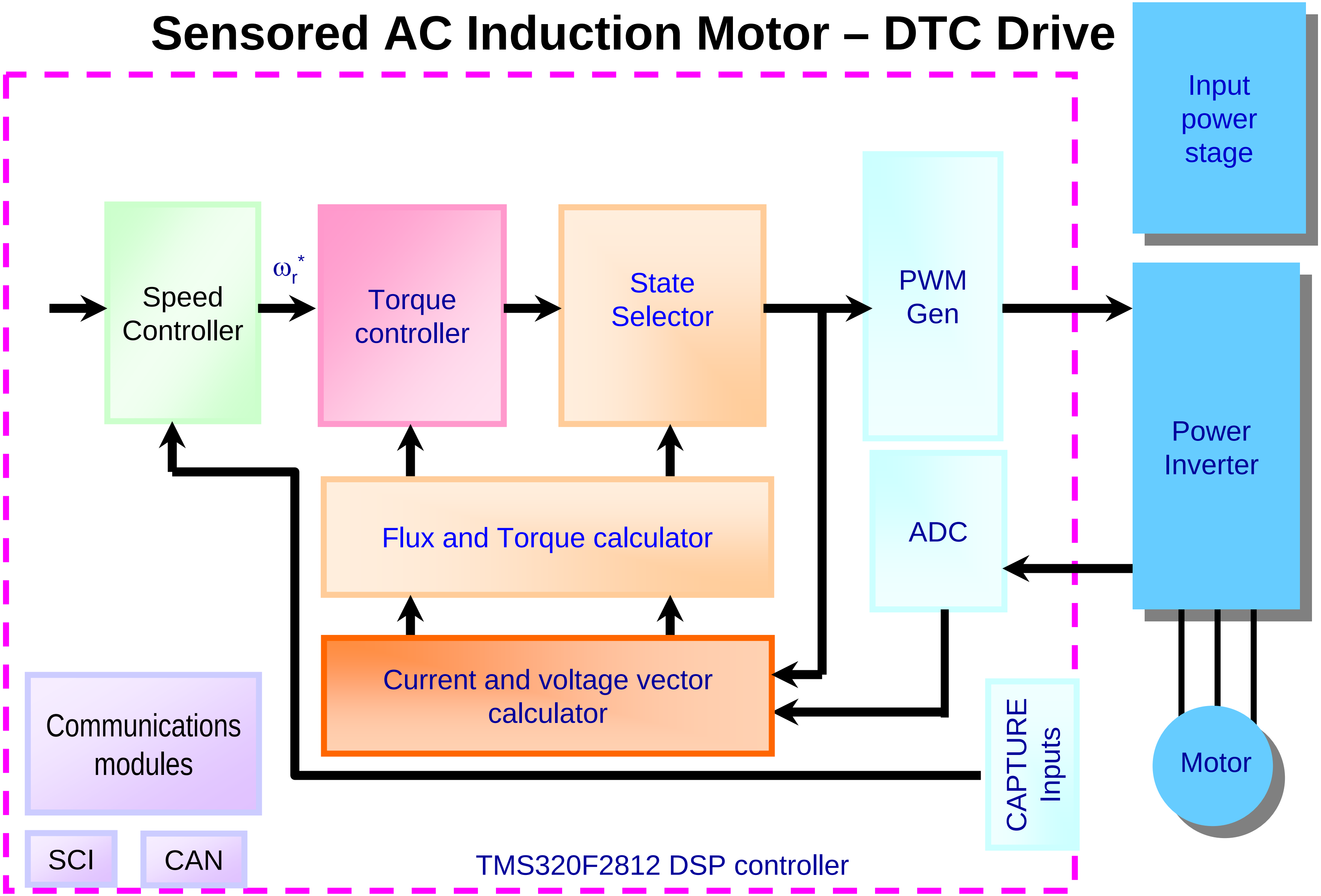
Cost Effective High Accuracy Position Measurement by Resolver



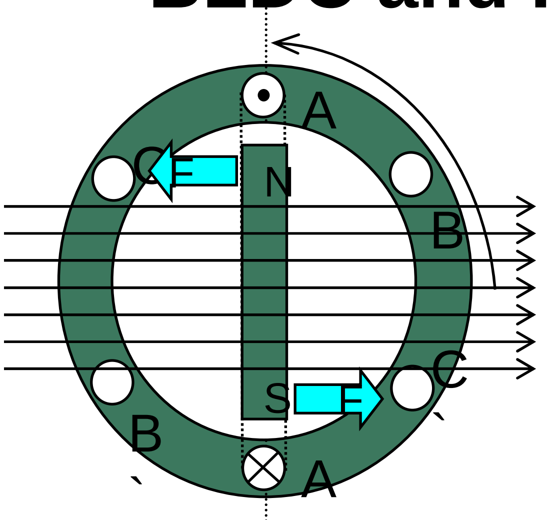
12Bit
OPA4340
ADS7861

16Bit
OPA4350
ADS8361

Sensored AC Induction Motor – DTC Drive

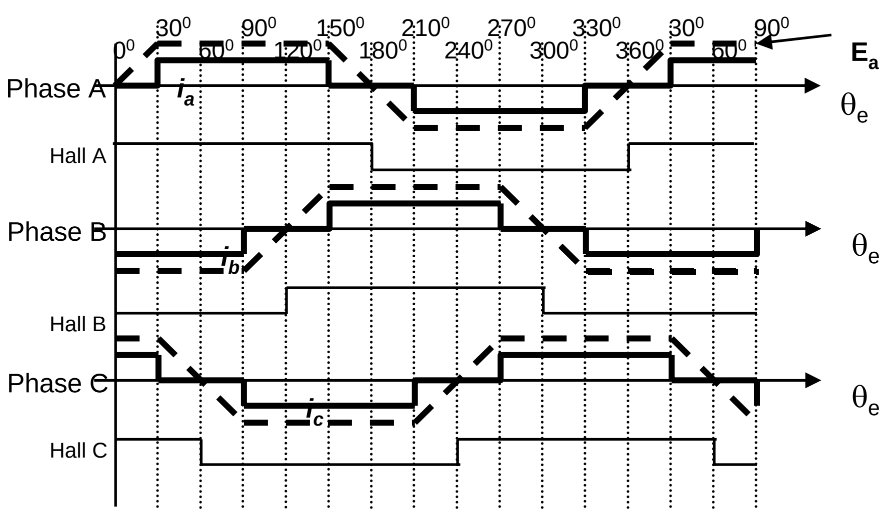


BLDC and PMSM Motor Types

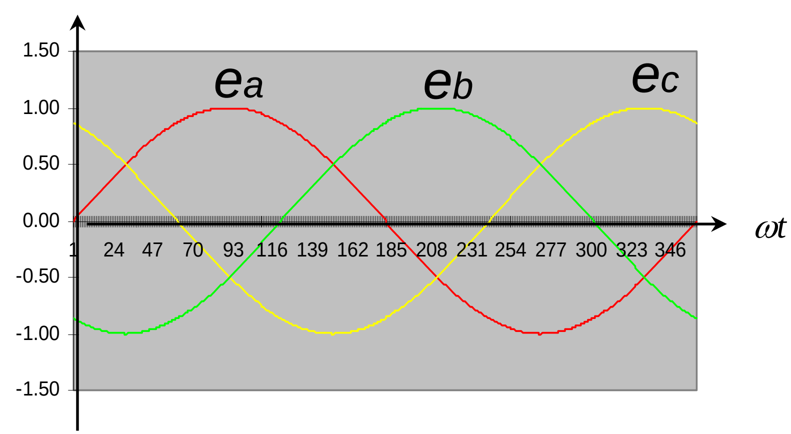


- Both (typically) have permanent-magnet rotor and a wound stator
- BLDC (Brushless DC) motor is a permanent-magnet brushless motor with trapezoidal back EMF
- PMSM (Permanent-magnet synchronous motor) is a permanent-magnet brushless motor with sinusoidal back EMF

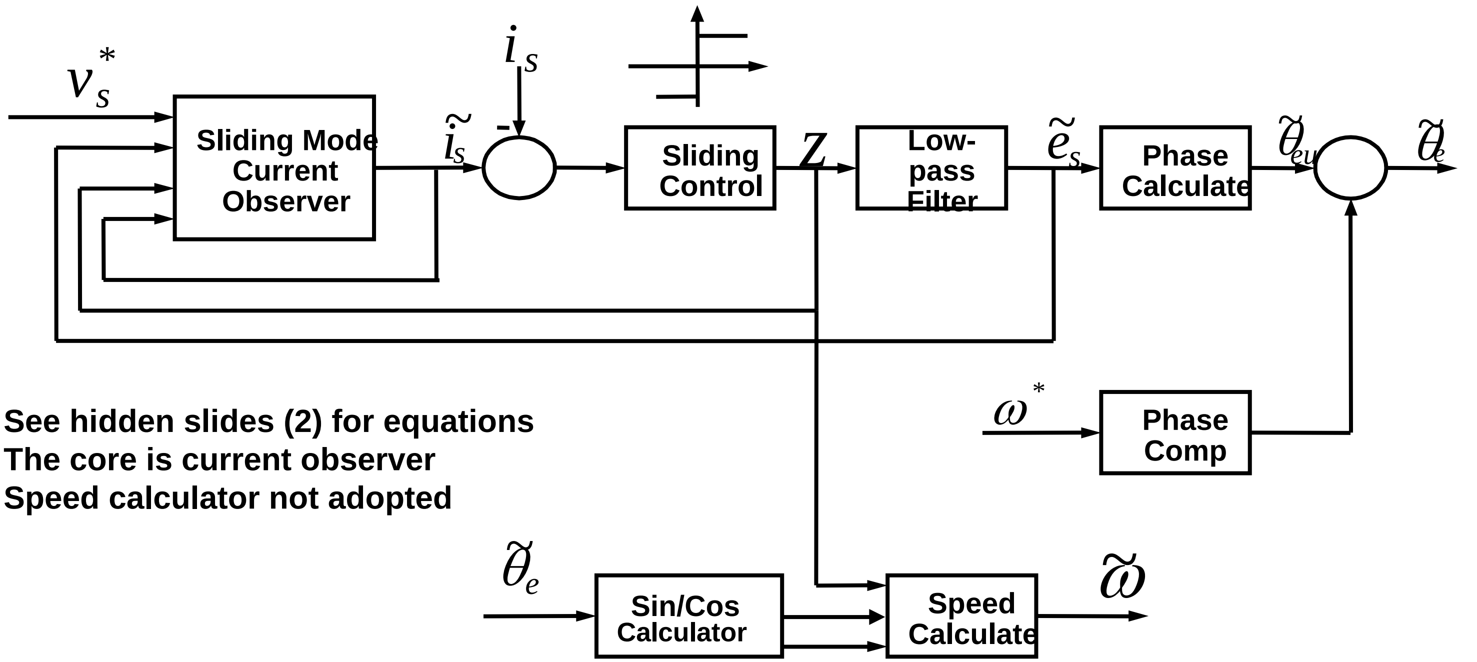
Back EMF of BLDC Motor



Back EMF of PMSM



Sliding Mode Observer



- See hidden slides (2) for equations
- The core is current observer
- Speed calculator not adopted

- Based on well established robust control technique: Non-linear Sliding Mode Control
- Bang-bang control type -> “High Gain”
- A priori feel of bounds of uncertainties and disturbances -> To tune sliding control gain
- Different techniques can be adopted to remove ripple effect

Sliding Mode Observer

- Based on well established robust control technique: Non-linear Sliding Mode Control
- Bang-bang control type -> “High Gain”
  - Tolerate parameter variations
  - Reject disturbances
  - Converges quickly, no numerical divergence
- A priori feel of bounds of uncertainties and disturbances -> To tune sliding control gain
- Different techniques can be adopted to remove ripple effect

SMO Equations

$$\frac{d}{dt}\tilde{i}_s = A\tilde{i}_s + B(v_s - \tilde{e}_s + z)$$

$$A = -\frac{R}{L} I_s \qquad B = \frac{1}{L}$$

$$L = \frac{3}{2} L_m$$

Current observer

$$z = ksign(\tilde{i}_s - i_s)$$

Sliding control

$$\frac{d}{dt}\tilde{e}_s = -\omega_0 \tilde{e}_s + \omega_0 z$$

Low-pass filter

SMO Equations (continued)

$$\tilde{\theta} = \arctan(-\tilde{e}_{s\alpha}, \tilde{e}_{s\beta})$$

From estimated back EMF to rotor angle

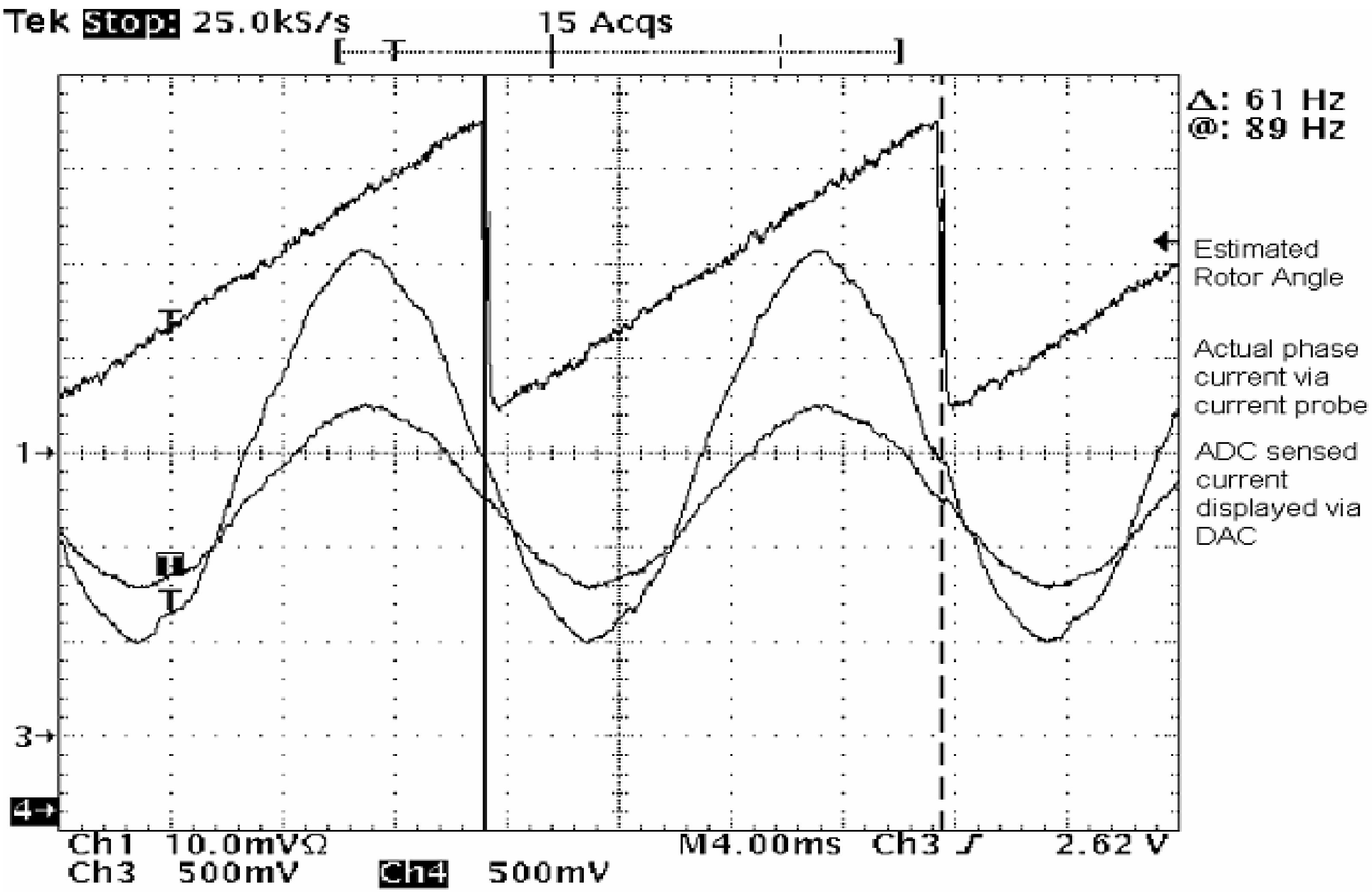
$$e_s = \frac{3}{2} k_e \omega \begin{pmatrix} -\sin\theta \\ \cos\theta \end{pmatrix}$$

$$\tau = 3/2 \; K_E \; i_q$$

Torque equation:

- Correct measurement of current
- Correct estimation of rotor angle

Experimental Result



Limitations of Sensorless Control / SMO

- Back EMF at low speeds is small, so the operation at low speeds is less than satisfactory. Also the algorithm becomes more sensitive to noise effects.
- At startup the back EMF is non-existent, and the startup must be achieved by other means:
  - Ramp up of frequency – Reverse rotation may occur, in some cases this can be an issue.
  - Detection of rotor position by signal injection
  - Hall effect sensors

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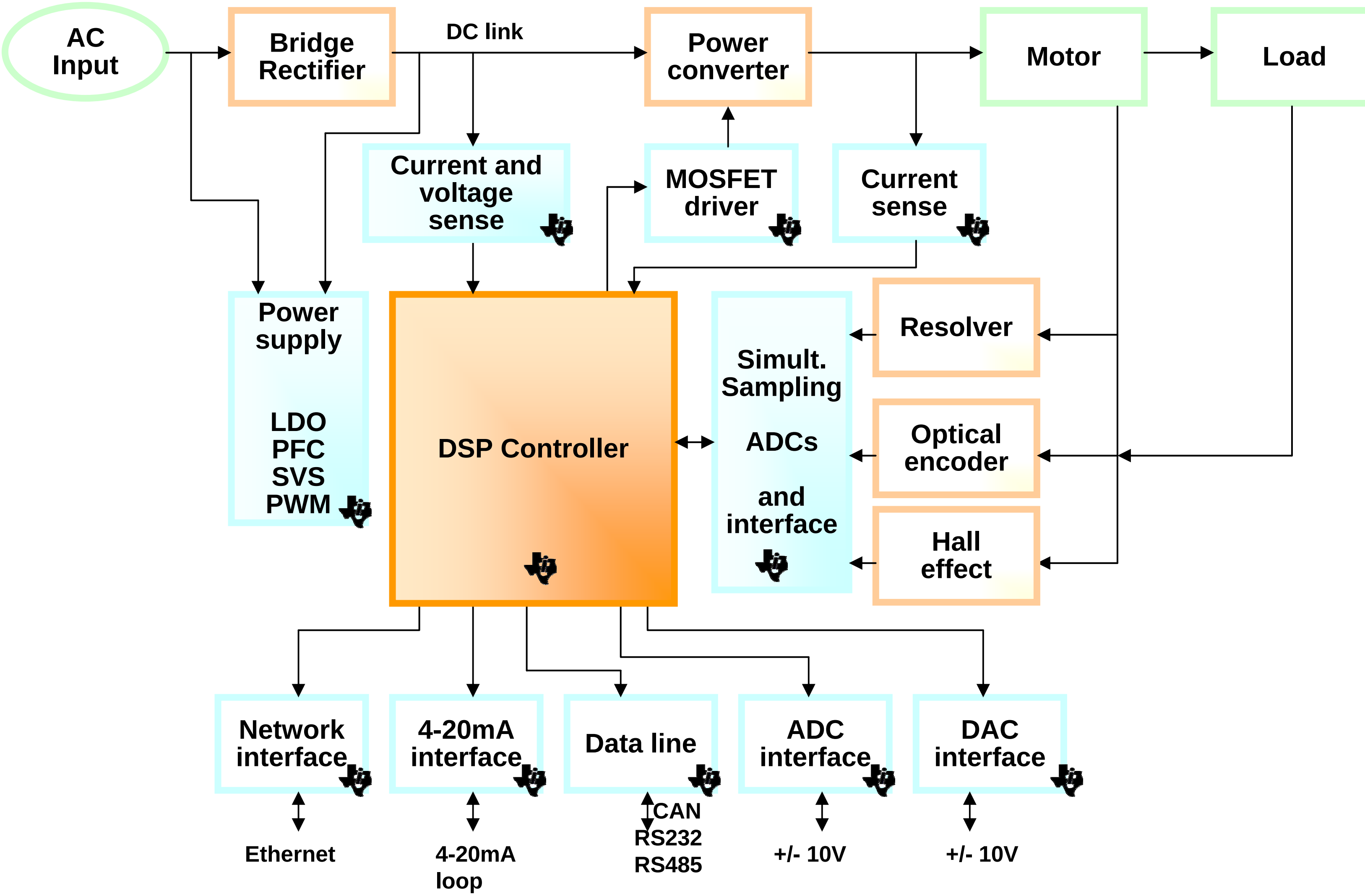
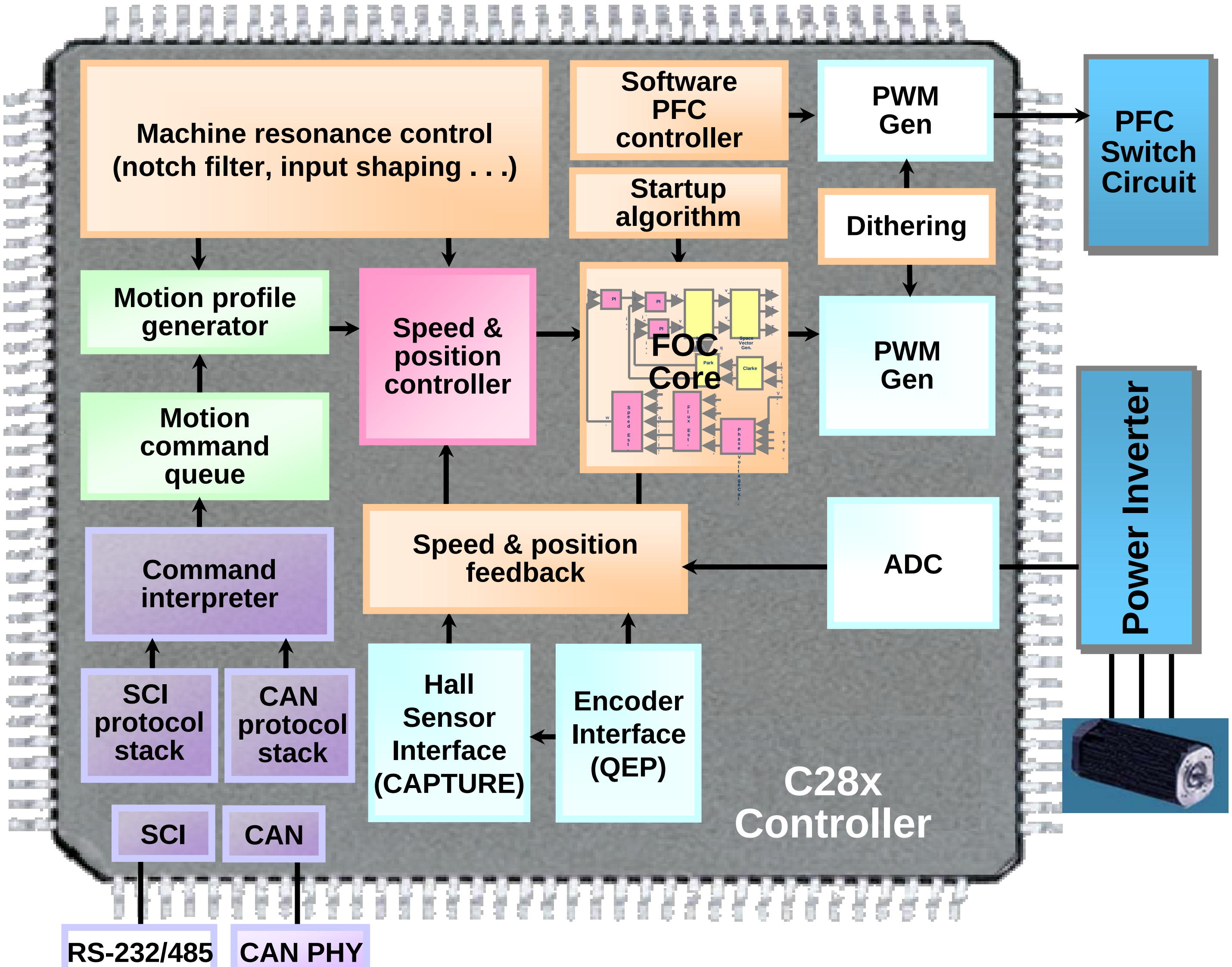
Motor Control System Components From TI

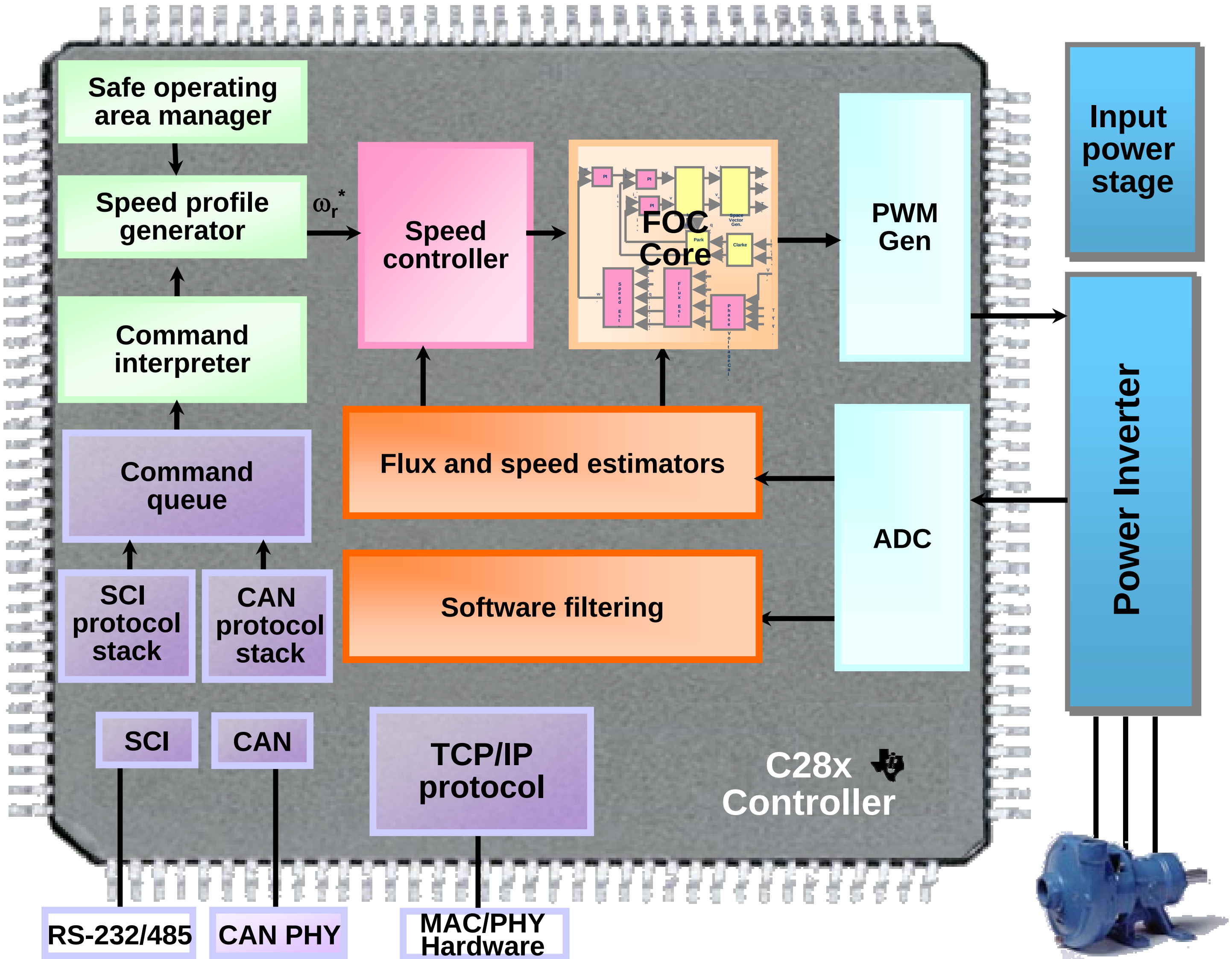


Servo Block Diagram



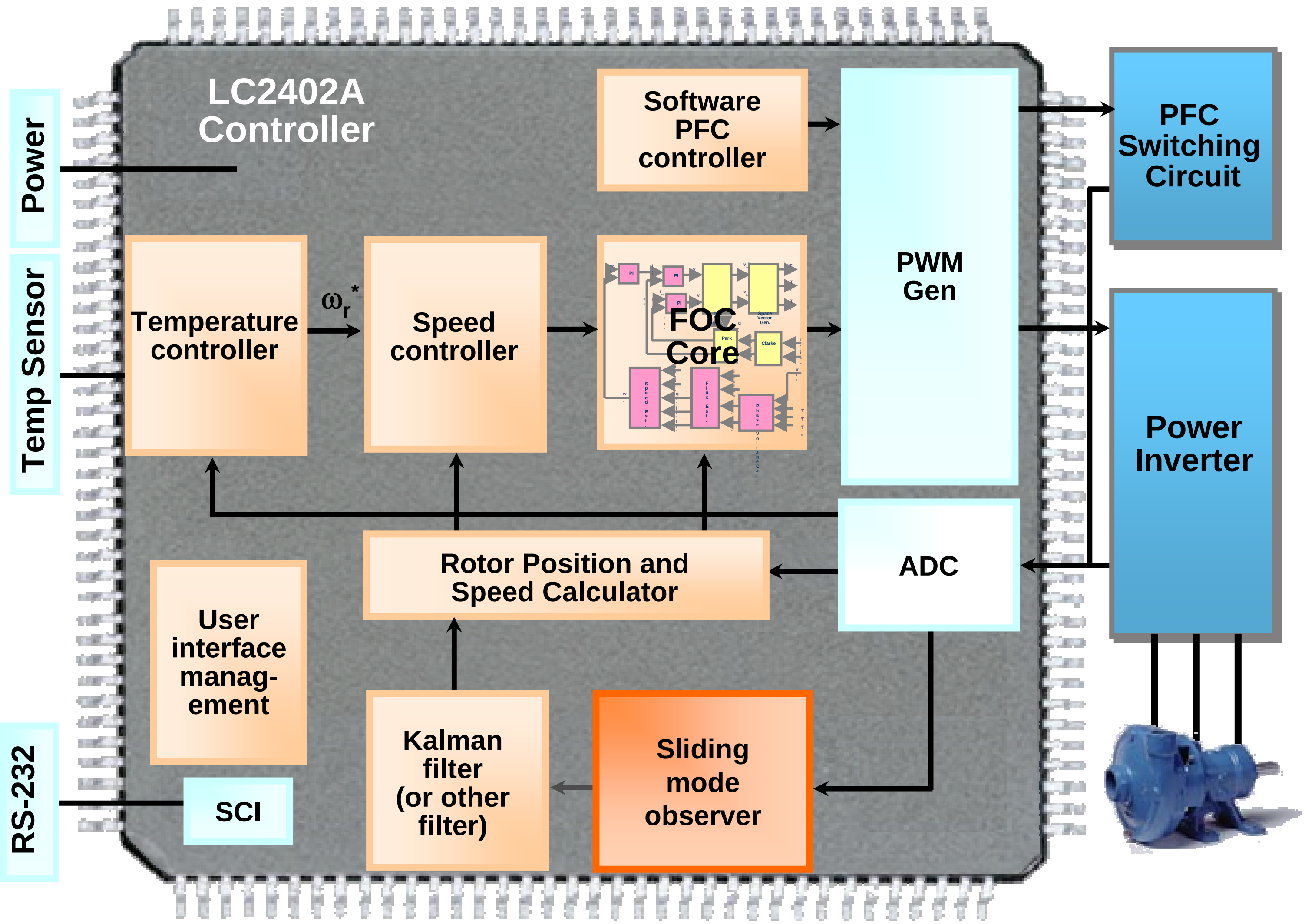
- Discrete PFC controller eliminated
- Replaced trapezoidal or sine commutation with FOC: Enhanced performance
- Machine resonance control: Performance enhancement. (e.g., Cost saving on damper)
- Moved motion profile processing into same processor: Eliminates second microprocessor
- Added Spread spectrum PWM Generation: Reduces size of EMI filter

Industrial: AC Induction Motor Drive



- MIPS enable high performance
  - FOC gives full torque from zero to full speed
  - Enables four quadrant operation
- Software integrates a variety of "auxiliary" functions
- Flexible software enables one controller for many drives.

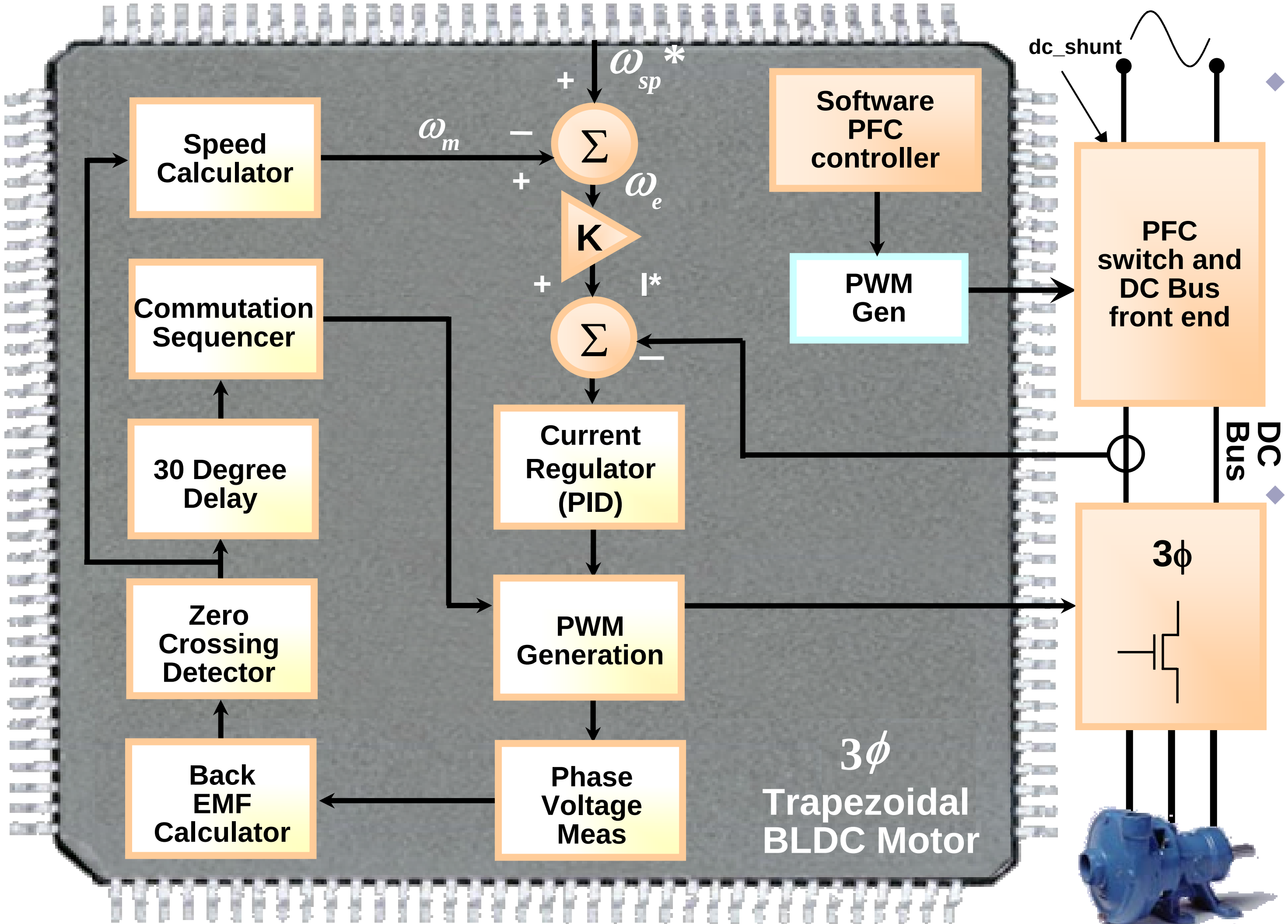
Appliance: Refrigeration Compressor Control



- Discrete PFC controller eliminated
- Higher efficiency driven by sensorless FOC + possible use of PMSM motor.
- Eliminated separate (electronic/electro mechanical) thermostat
- Added Spread spectrum PWM Generation: Reduced size of EMI filtering

Parasiliti F., Petrella R., Tursini M.: "Rotor speed and position detection for PM synchronous motors based on sliding mode observer and Kalman filter", Proc. of the European Conference on Power Electronics and Applications (EPE), Lausanne, 1999.

Application: Refrigeration Compressor Control

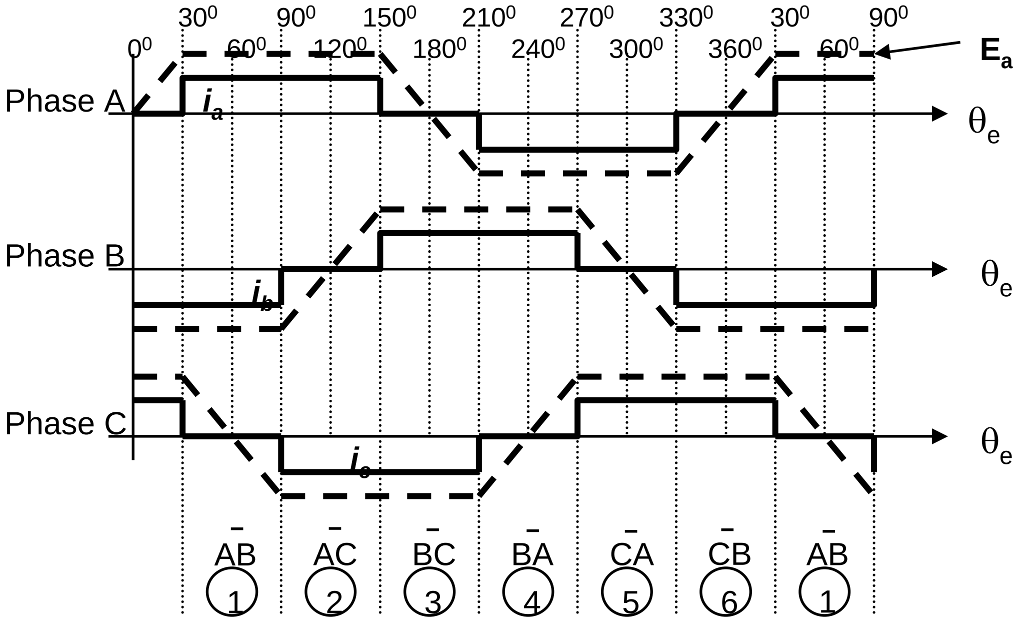


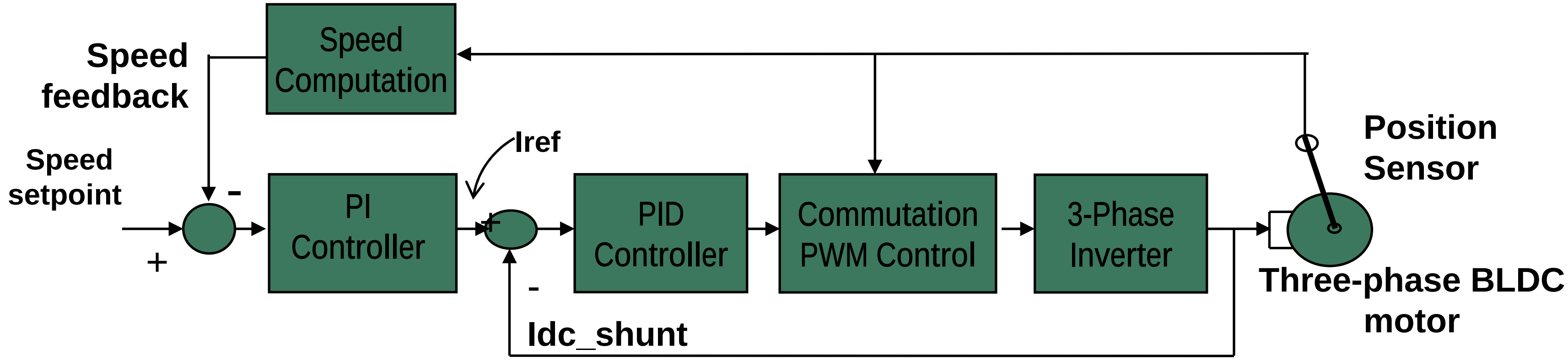
- Trapezoidal sensorless control for constant speed applications enables low cost implementations.
- Keep compatibility with existing trapezoidal motors

- See TI Application reports (SPRA498 and BPRA072) for more details

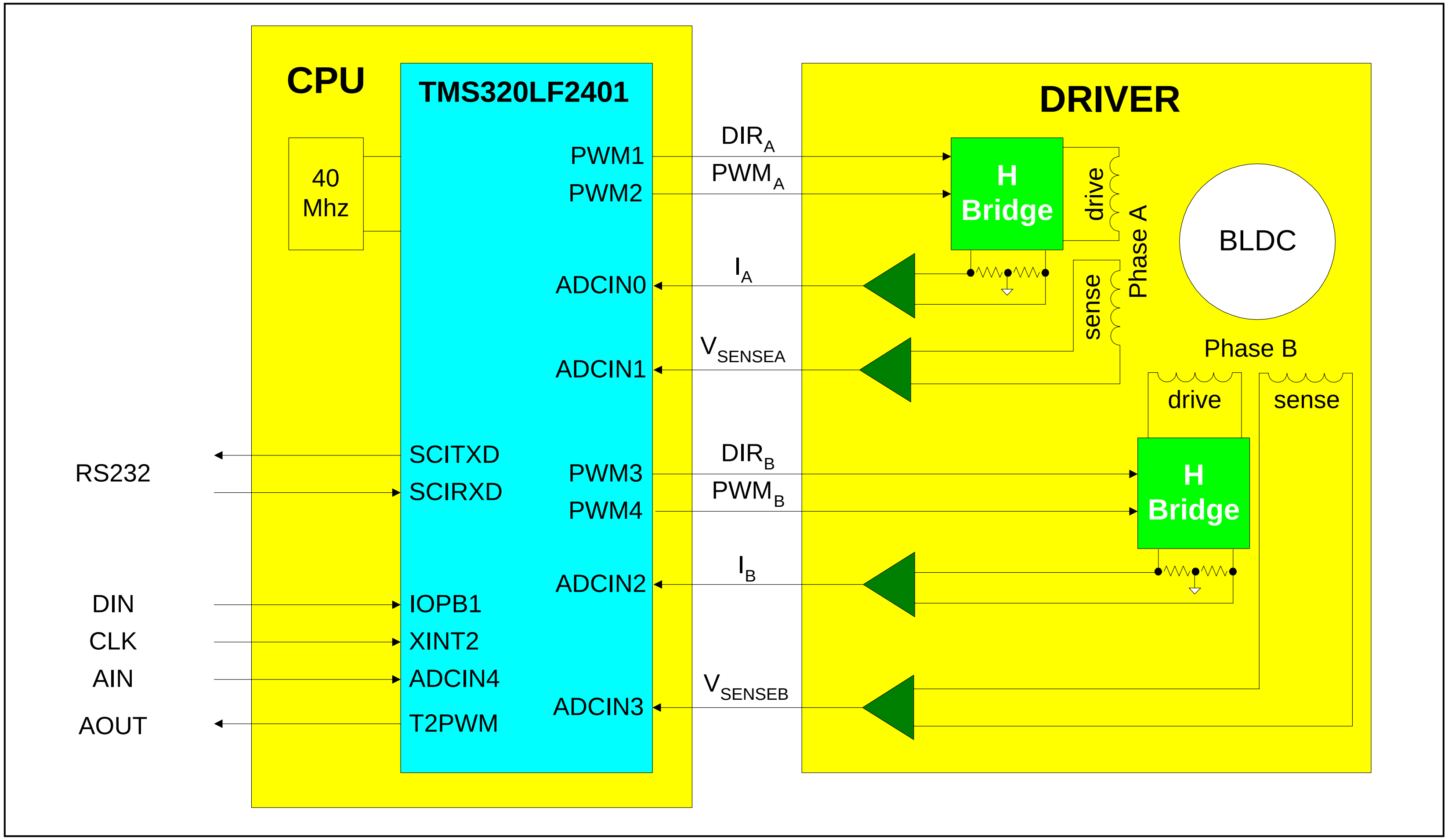
Sensored Trapezoidal BLDC Motor Control

- Phase current must be turned on and off in order and at the right time in order to follow back EMF – commutation
- Capture interrupts can be used to trigger commutation when Hall sensors are used
- Capture function can also be used to help calculate motor speed



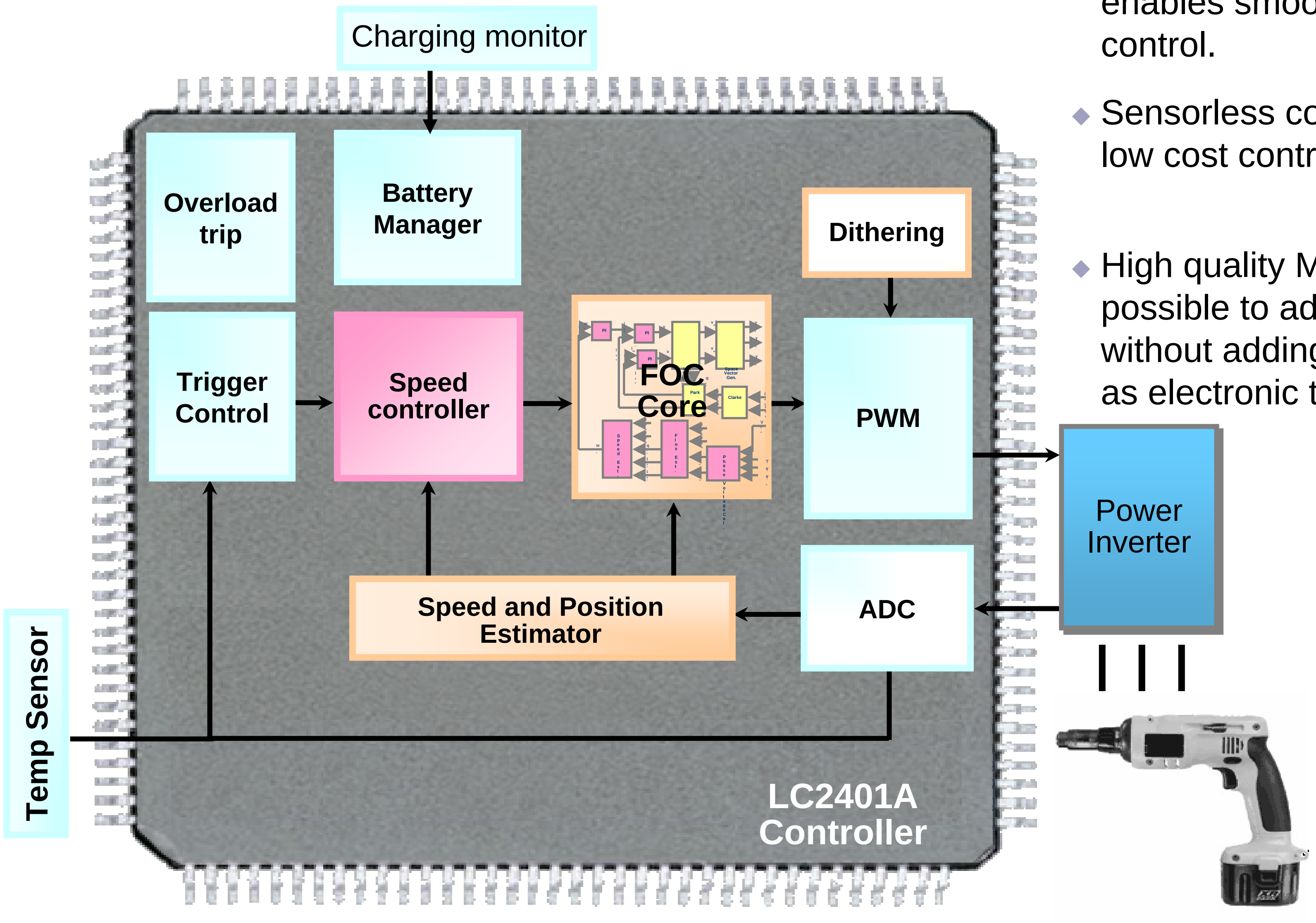


Sensorless Stepper Motor Control



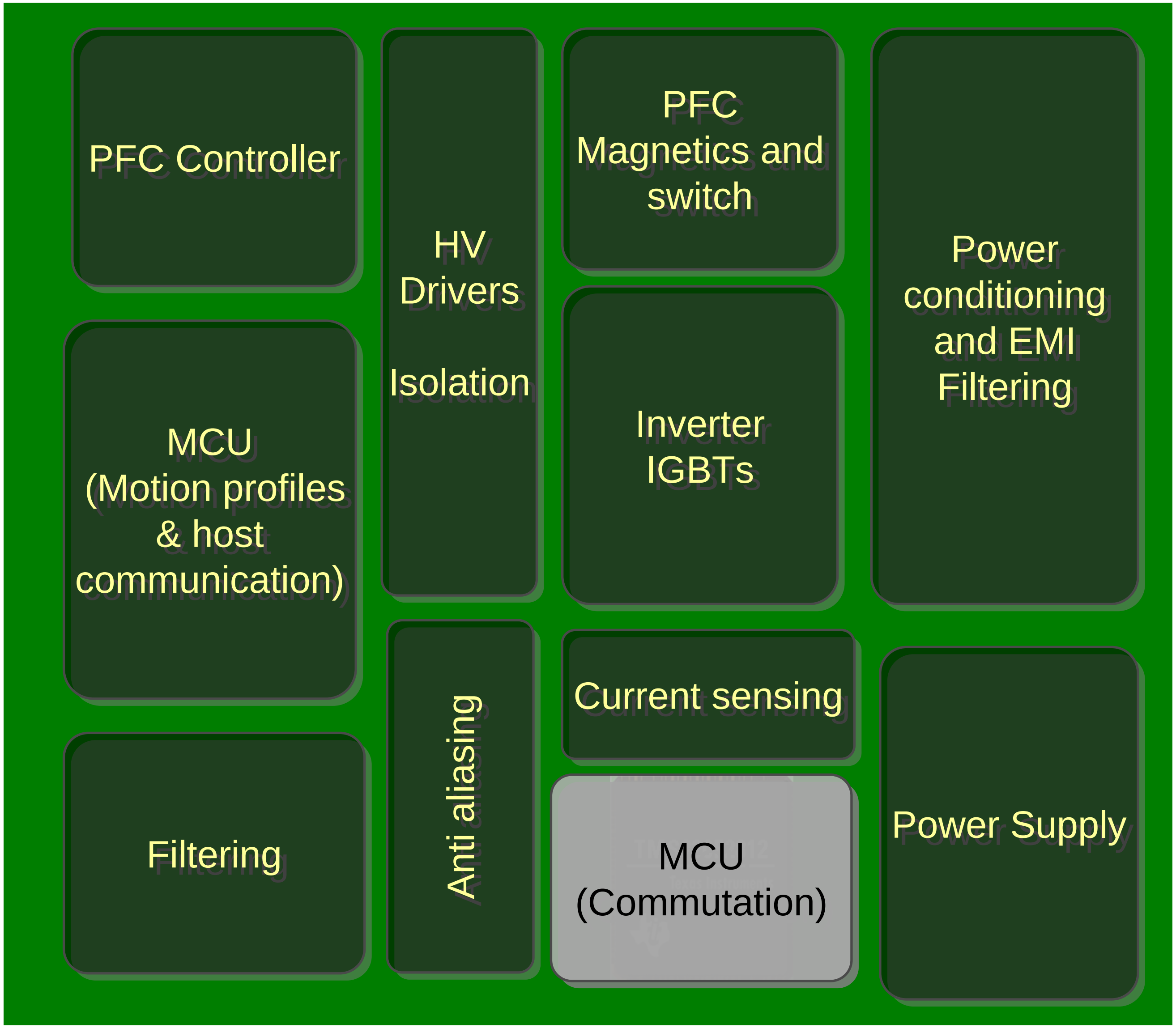
D3 Engineering (Rochester, NY)

Appliance: Power Tool Control

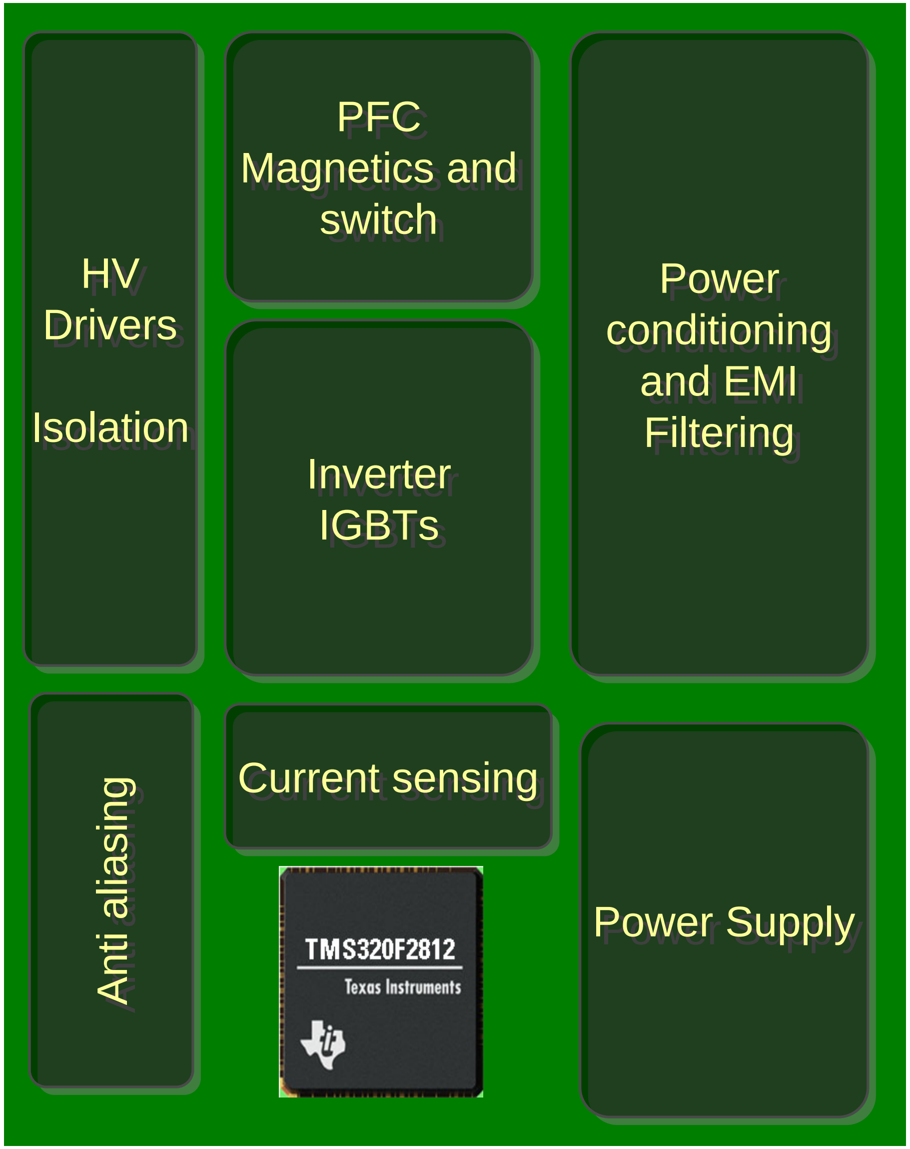


- Field oriented control enables smooth torque control.
- Sensorless control drives low cost control
- High quality MIPS make it possible to add features without adding cost – such as electronic torque control

Servo Drive / Servo Amplifier Hardware Partitioning



Servo Drive / Servo Amplifier Hardware Partitioning



Benefits from TI C2000™ Digital Signal Controller

Improved system performance

- **Less torque ripple**
- **Higher control bandwidth**
- **Lower EMI profile**

Lower system cost

- **Lower component count**
- **Smaller system size**
- **Improved system reliability**
- **Easier to manufacture**

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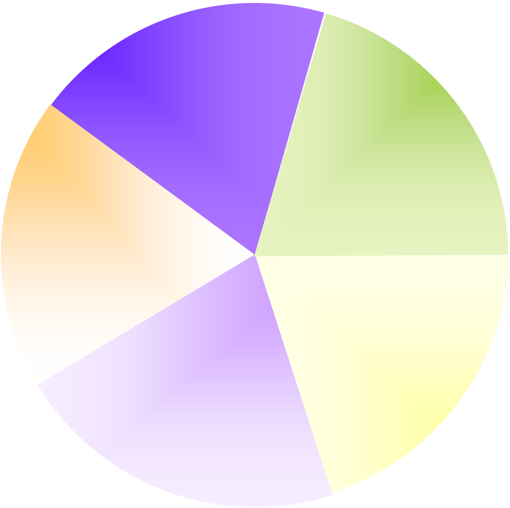
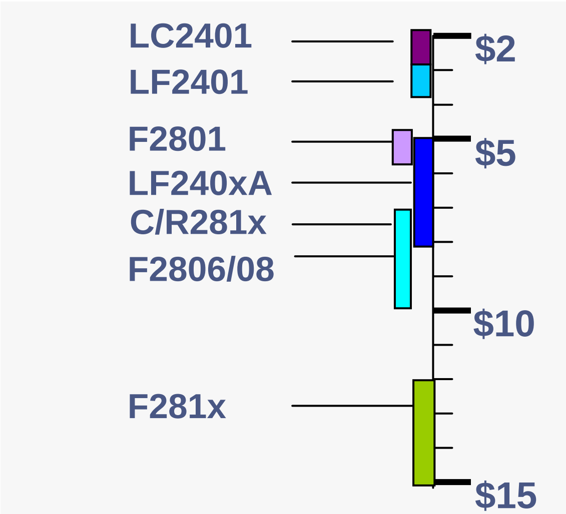
Selecting a Controller

A controller to be used for motor control must provide:

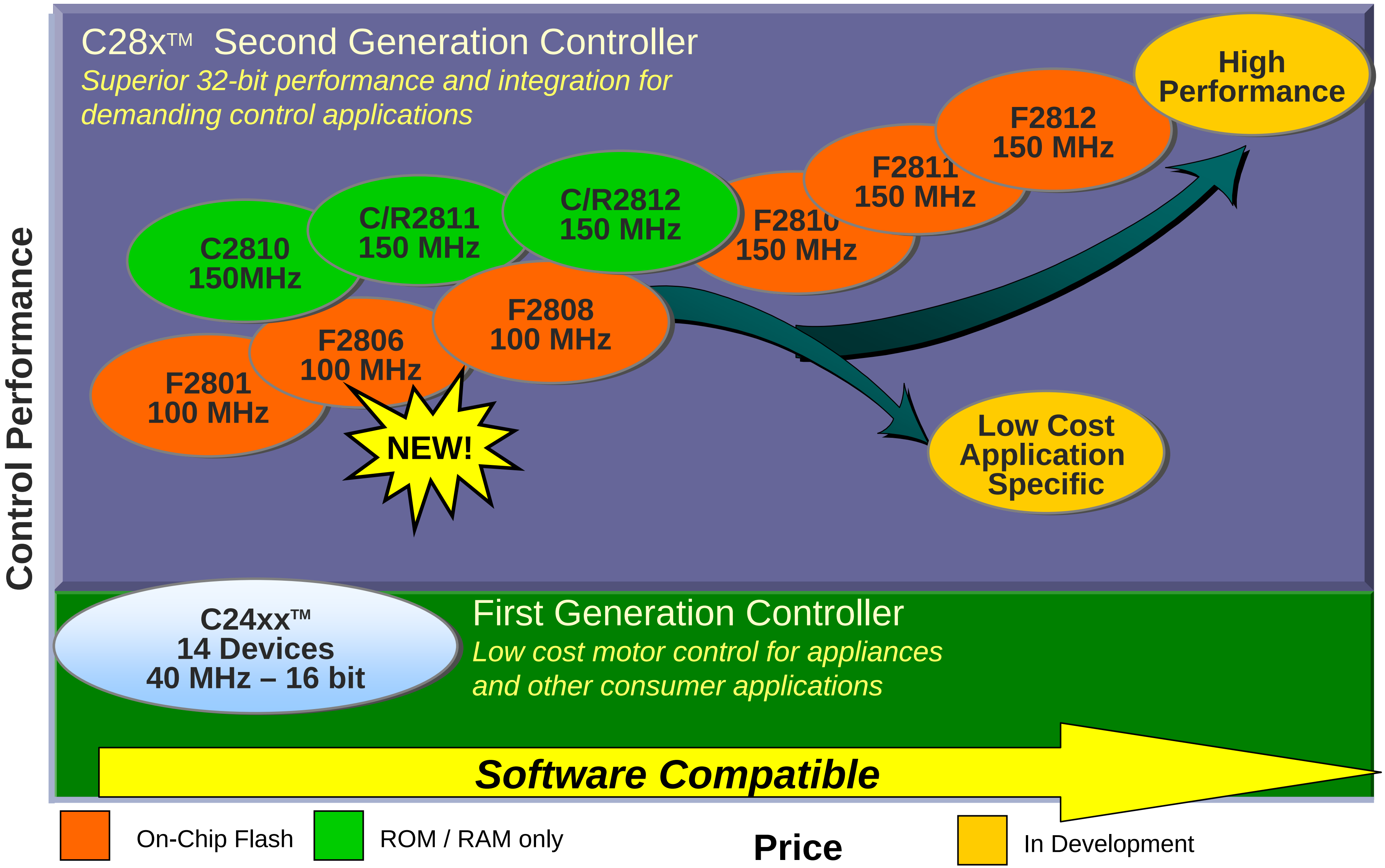
- **Performance:** Computational ability
  - 100+ sustained MMACS @ 32 bits
- **Ease of use:** Tools and Collateral
- **Peripheral Integration:** Flash, ADC, PWM, Sensor interfacing, communications all on one chip
- **Third party development support**
- **Price:** Broad range from sub $2.00 - $15.00



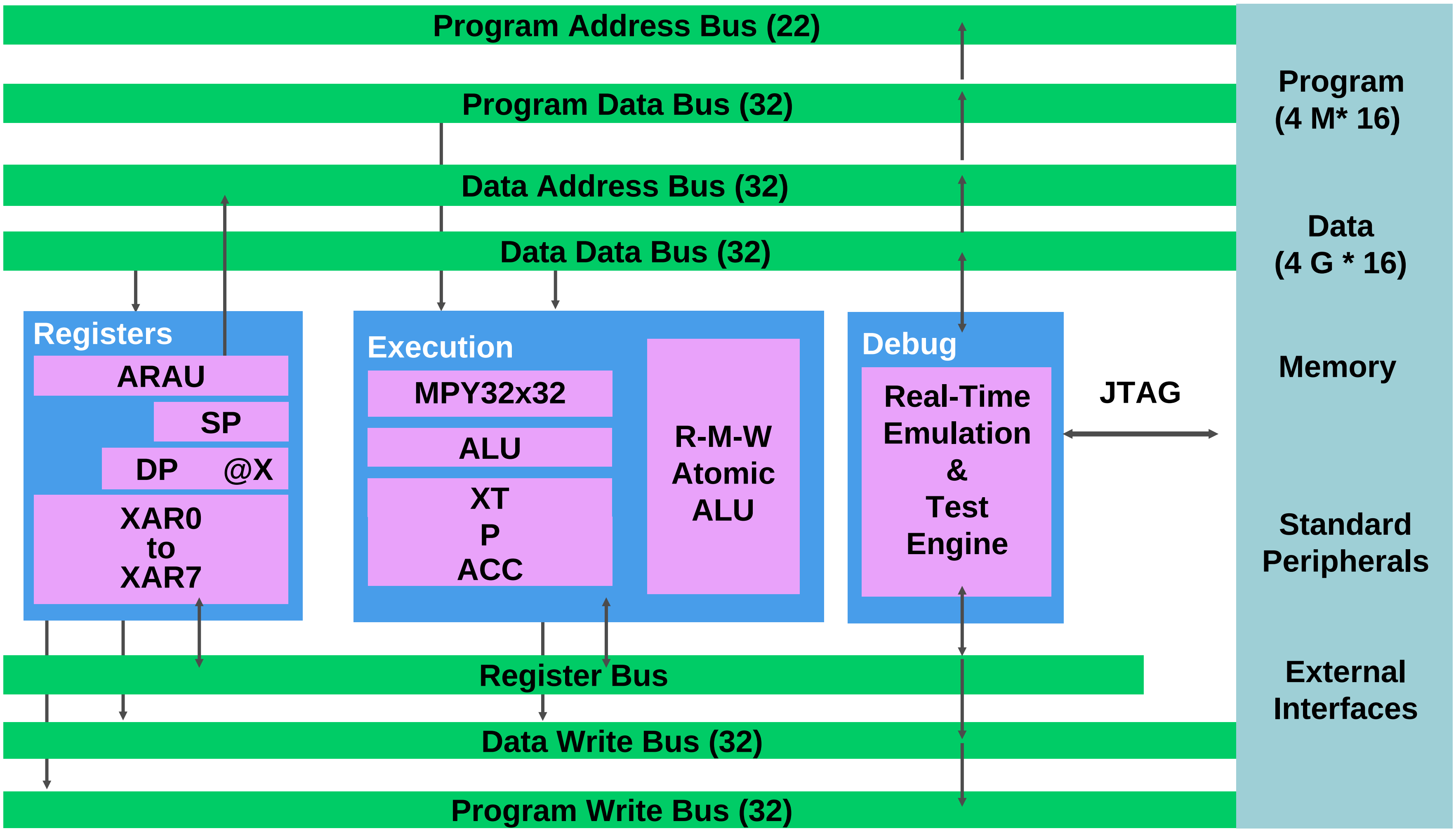


40-150MIPS and $2-$15

C2000 Product Portfolio



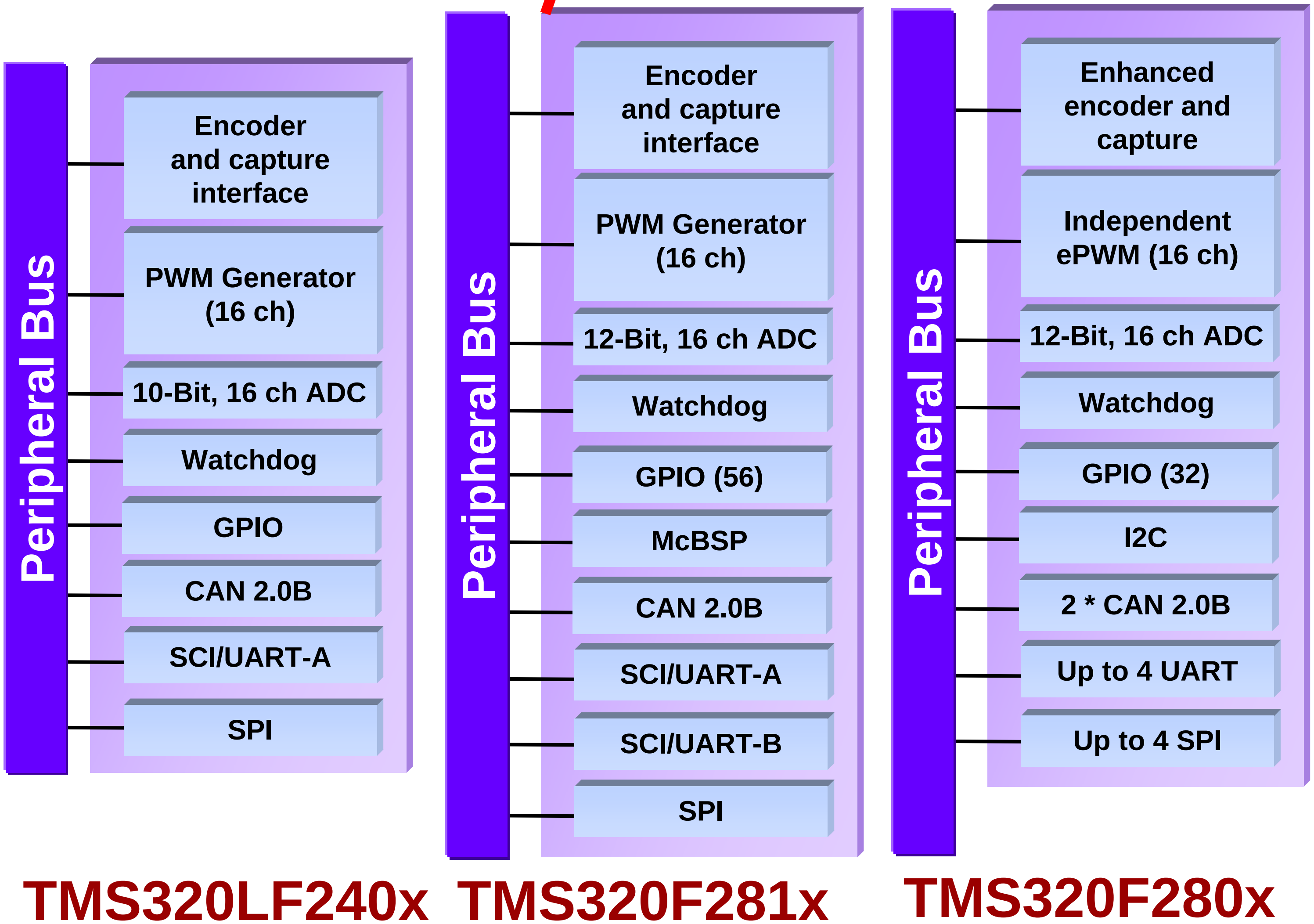
Internal Busing determines quality of MIPS



Multibus architecture makes better use of the processor cycles: Instruction, fetch, decode and execute can happen on the same clock cycle with multiple buses

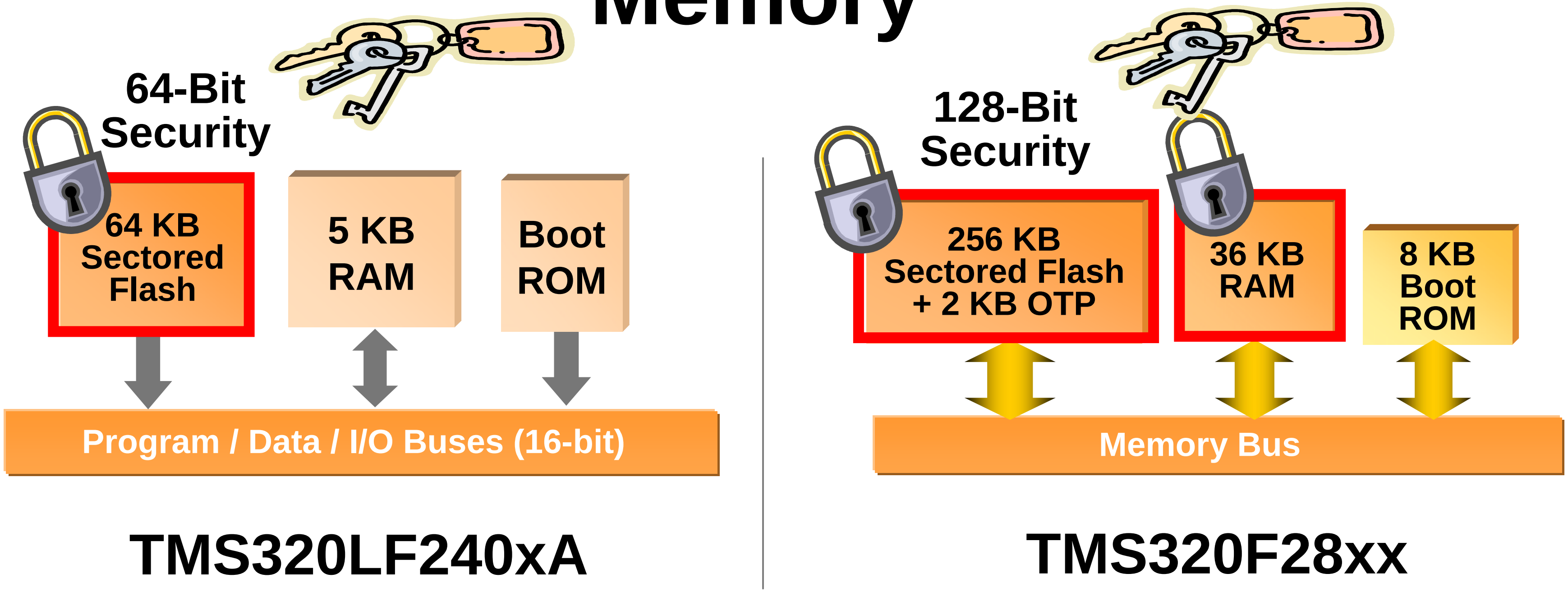
SMART peripherals

~~On chip peripherals drive integration~~



- Encoder and timer capture interfaces
- PWM Generation
- Synch/Async serial ports
- Watchdog timer
- On-chip ADCs with dual sample and holds

Memory



Flash from 16 KB – 256 KB	ROM from 12 KB – 256 KB	RAM from 1 KB – 40 KB

- 128-bit user defined password is stored in Flash
- 128-bits = 2^{128} = 3.4×10^{38} possible passwords
- To try 1 password every 2 cycles at 150MHz, it would take at least 1.4×10^{23} years to try all possible combinations!

Agenda Timeline

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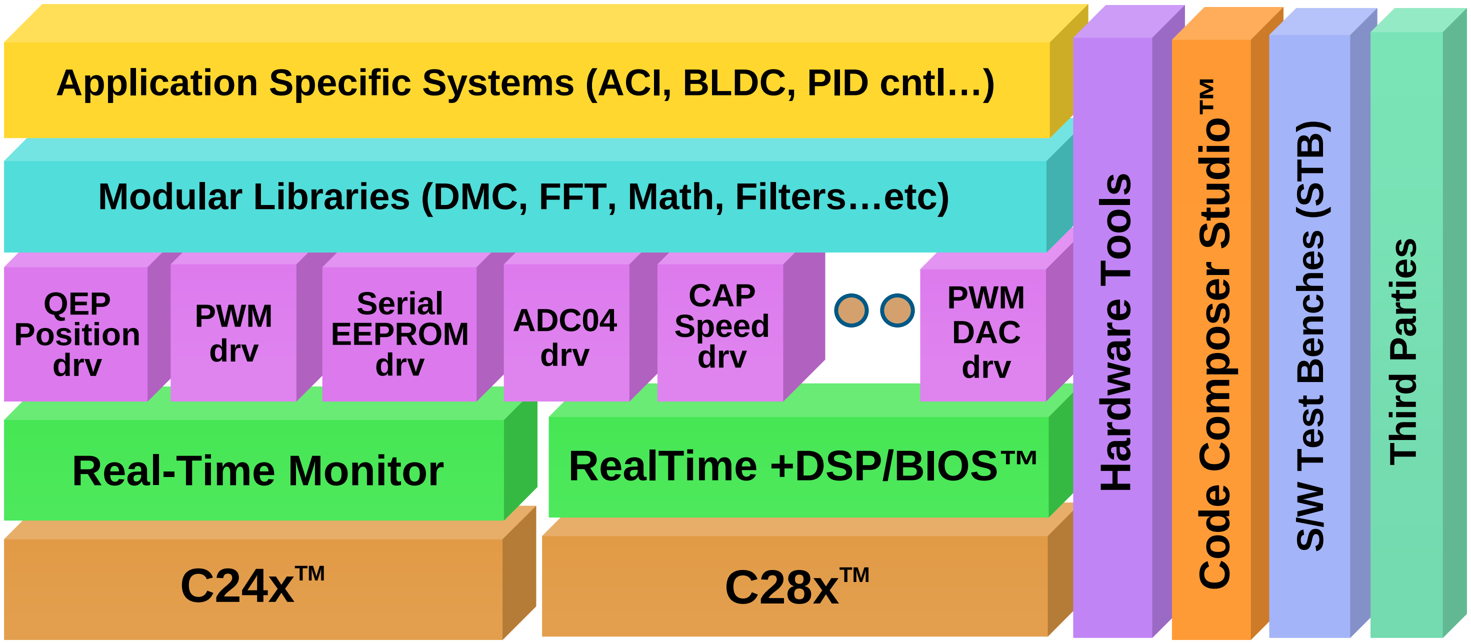
Modular Software Development for Control Systems

All Modules Available in C/C++ Environment

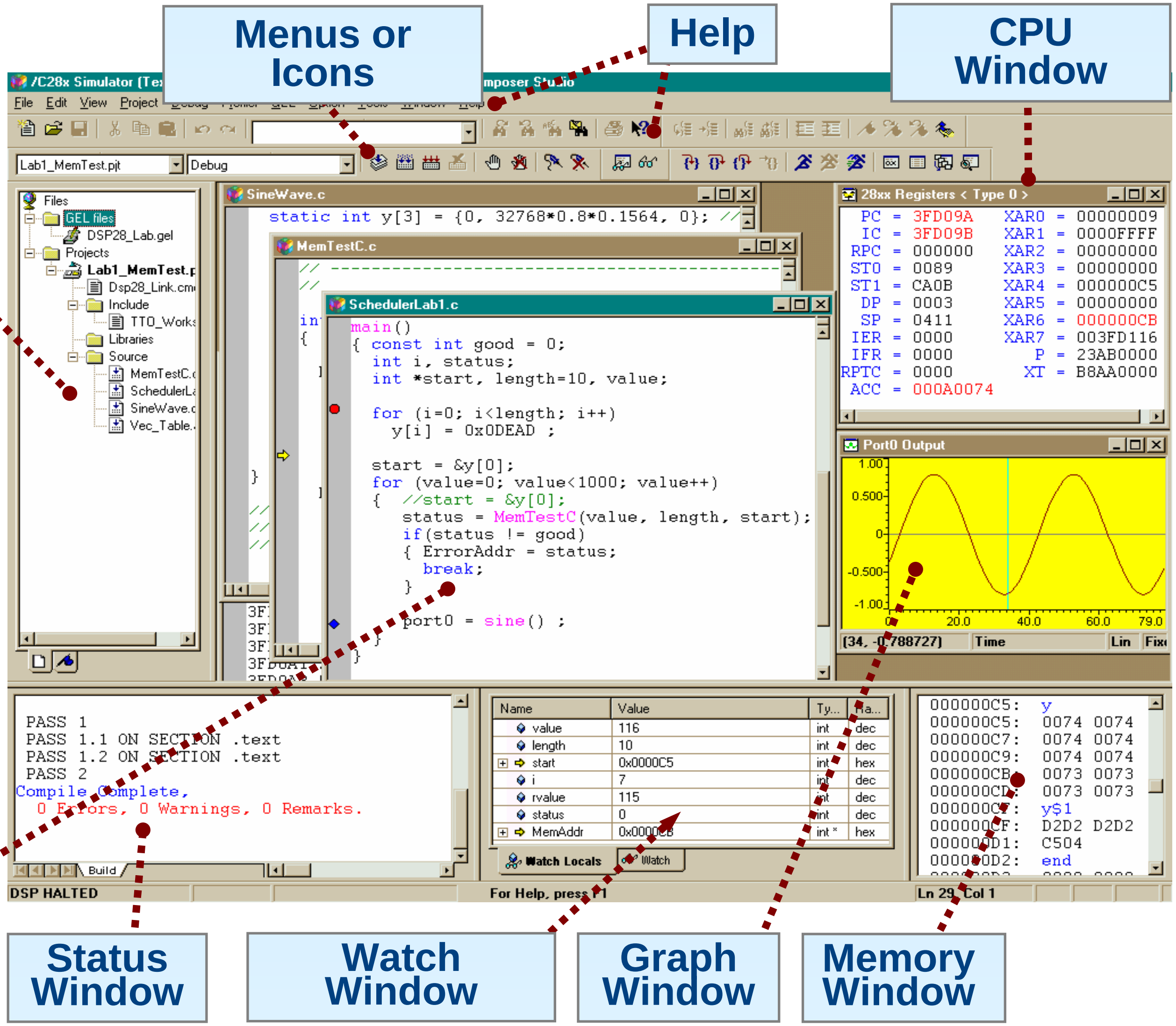


- Reduces time to market
- Provides reuseable software

Gets you there. Quickly.

Code Composer Studio Components:
Fully Integrated, Easy to Use Development Tools

Project Manager
- Source & object files
- File dependencies
- Compiler, assembler & linker build options



Productive Editor:
- Structure expansion

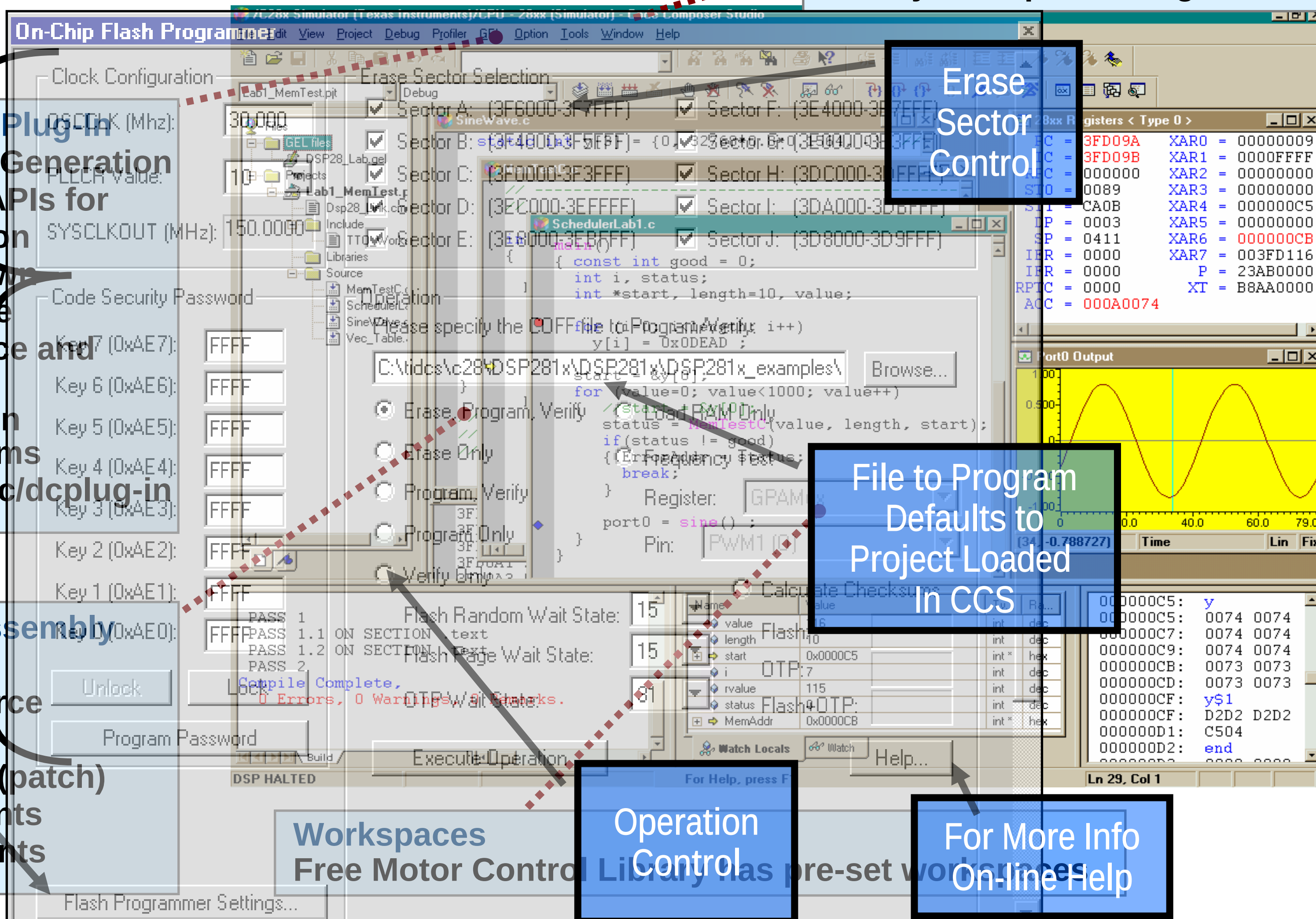
Code Composer Studio Components:
Fully Integrated, Easy to Use Development Tools

Flash Memory Plug-In
- Easy Set-Up and Programming

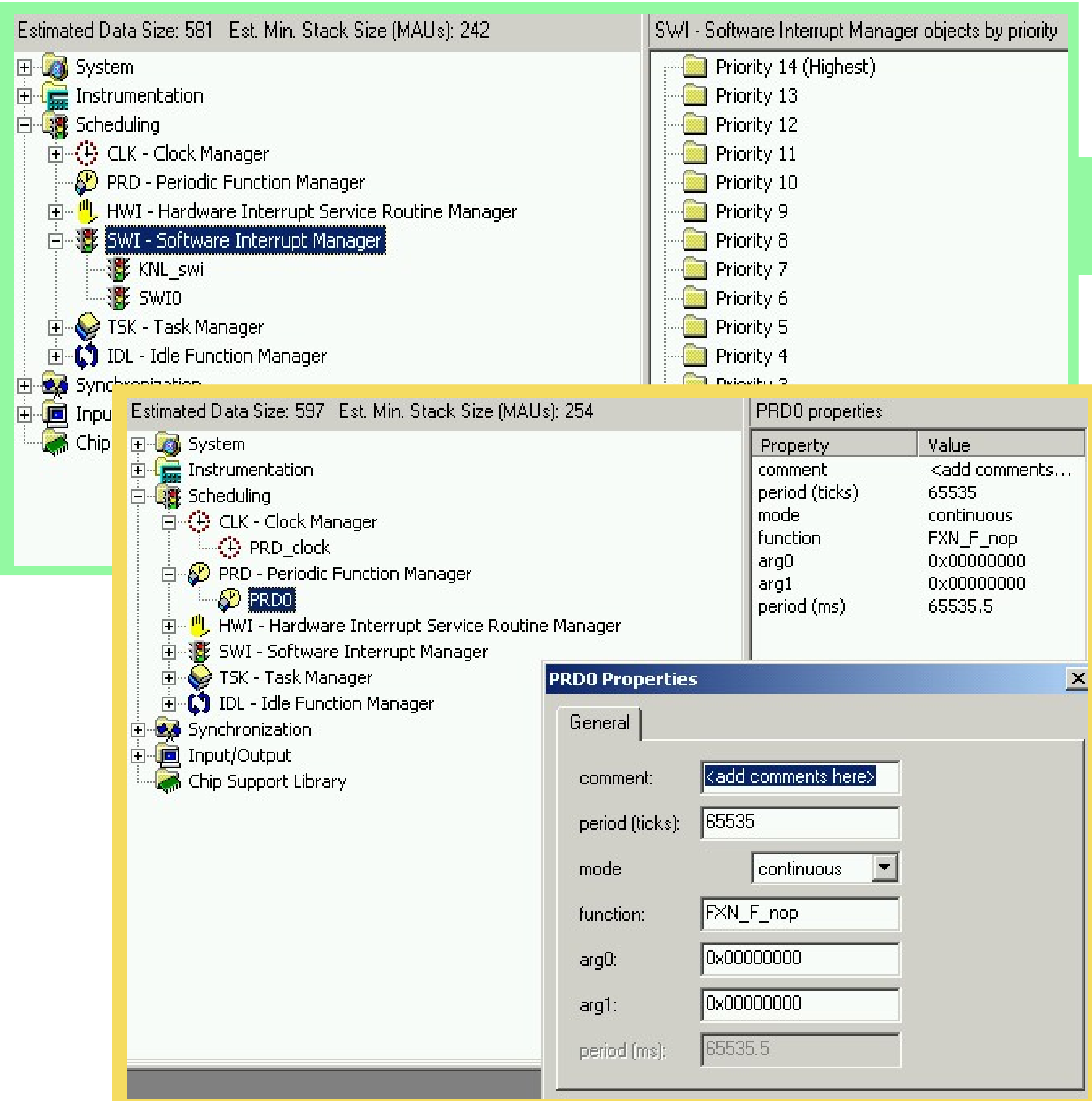
Data Converter Plug-In
- Point & Click Generation
- Auto Create APIs for
  - Initialization
  - Power Down
  - Read/Write
- Initialize device and peripheral
- 117 devices on 5 DSP platforms
- ti.com/sc/dcplug-in

Full C/C++ & Assembly Debugging
- C & ASM source
- Mixed mode
- Disassembly (patch)
- Set break points
- Set probe points

Workspaces
Free Motor Control Library has pre-set workspaces



DSP/BIOS™: Handling Multiple Event Sources



DSP/BIOS makes it easier

- **Interrupt Driven Events: DSP/BIOS provides HWI and SWI management to simplify interrupts and multitasking**
- **DSP/BIOS provides CLK manager to simplify implementation of periodic tasks**

Real-time Debug

Control systems must be debugged while running!

Real-time Debug

- Allows you to halt in non-critical code for debug while time-critical interrupts continue to be serviced
- Access memory and registers without stopping the processor
- Implemented in silicon, not by a debug monitor: Easy to use, no application resources required!

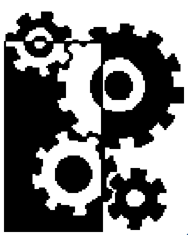
Halt and single step non-time critical code

Time-critical interrupts are still serviced.

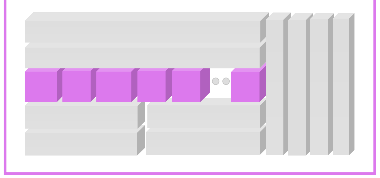
```
Main()
{
  ……
}
```

```
function()
{
  ……
}
```

```
Interrupt void ISR_1()
{
  ………
}
```



C28x C/C++ Header Files & Peripheral Examples



Bit-fields simplify peripheral programming C/C++:

- **CCS Auto-complete speeds programming**
- **Compiler optimizations speed target code**
- **Examples/Documentation accelerate deployment**

Name	Val...	Type	Radix
⊟ CpuTimer0Regs	{...}	struct CPUTIMER_REGS	hex
⊞ TIM	{...}	union TIM_GROUP	hex
⊞ PRD	{...}	union PRD_GROUP	hex
⊟ TCR	{...}	union TCR_REG	hex
all	1	unsigned int	unsigned
⊟ bit	{...}	struct TCR_BITS	hex
rsvd1	0001	(unsigned int:0:4)	bin
TSS	0	(unsigned int:4:1)	bin
TRB	0	(unsigned int:5:1)	bin
rsvd2	0000	(unsigned int:6:4)	bin
SOFT	0	(unsigned int:10:1)	bin
FREE	0	(unsigned int:11:1)	bin
rsvd3	00	(unsigned int:12:2)	bin
TIE	0	(unsigned int:14:1)	bin
TIF	0	(unsigned int:15:1)	bin

http://www.ti.com

Keywords: SPRC097, SPRC191

On-Chip Analysis Features Enables Flexible Debugging

Two hardware analysis units can be configured to provide any one of the following advanced debug features:

Analysis Configuration	Debug Activity
2 Hardware Breakpoints	Halt on a specified instruction in Flash
2 Address Watchpoints	A memory location is getting corrupted. Halt the processor when any value is written to this location
1 Address Watchpoint with Data	Halt program execution after a specific value is written to a variable
1 Pair Chained Breakpoints	Halt on a specified instruction only after a specific interrupt service routine has executed

Hardware Development Tools

Evaluation Modules

- C24x™ or C28x™ Development board
- C-Compiler/Asm/Lnk
- Full Version Code Composer Studio IDE
- Emulator (XDS510PP+ or USB)
- Power Supply
- **Price: $1,995-2,295**

DSP Starter Kits

- LF2407, LF2401, F2812, F2808 evaluation board
- Compiler/Assem/Linker
- Code Composer Studio (tied to board)
- Power Supply
- **Price: $345 - $595**

Power Modules

- DMC550 or DMC1500 from Spectrum Digital Interfaces to EVM, DSK or standalone operation
- Protection features provide convenient s/w development platform
- DMC1500: 350V 7.5 Amp (Supports 3ph and 1ph; BLDC, ACI, SR) **Price $1749**
- DMC500: 24V 2.5 Amp (Supports Brushless DC) **Price $499**

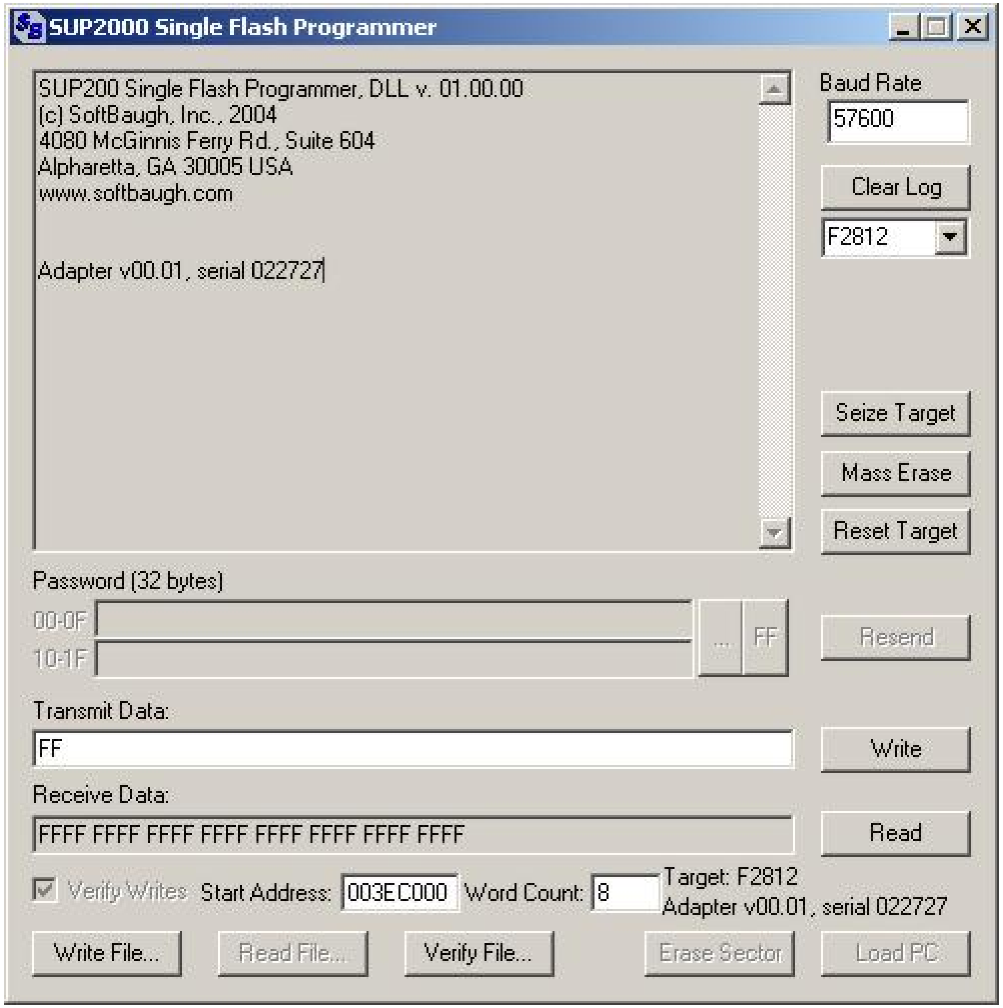
http://www.ti.com/c2000hwtools

Flash Programming Hardware

Softbaugh

- Uses SCI bootloader
- 10 pin header
- USB to host
- 2KW/sec program
- 20 sec max erase
- Single Unit Programmer
  - $199
- 8 Site Gang Programmer
  - $899

www.softbaugh.com

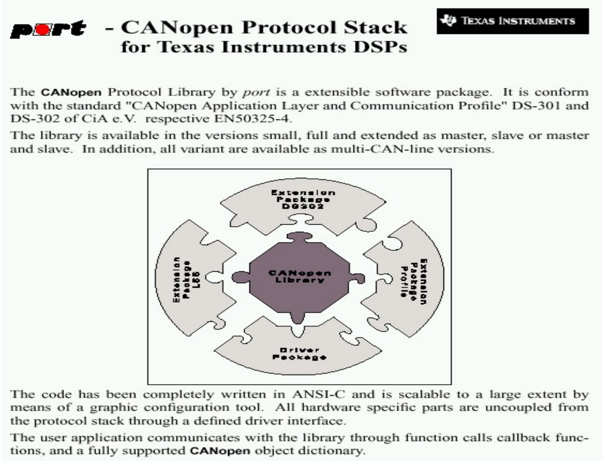


CAN 2.0B

- **PORT GmbH** [Germany] has developed an extensive CANopen protocol stack for the 240xA and 28x devices. Port closely works with **Vector Informatik.**

- The contact for Port is :

PORT GmbH
Heinz-Jürgen Oertel
phone +49 345 77755-0
Halle/Saale – Germany
oe@port.de
Web : http://www.port.de



port - CANopen Protocol Stack for Texas Instruments DSPs

TEXAS INSTRUMENTS

The **CANopen** Protocol Library by *port* is a extensible software package. It is conform with the standard "CANopen Application Layer and Communication Profile" DS-301 and DS-302 of CiA e.V. respective EN50325-4.

The library is available in the versions small, full and extended as master, slave or master and slave. In addition, all variant are available as multi-CAN-line versions.

The code has been completely written in ANSI-C and is scalable to a large extent by means of a graphic configuration tool. All hardware specific parts are uncoupled from the protocol stack through a defined driver interface.

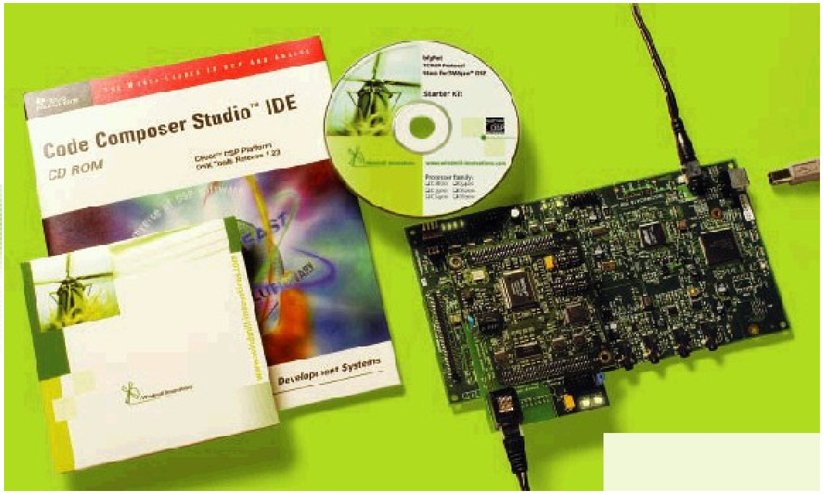
The user application communicates with the library through function calls callback functions, and a fully supported **CANopen** object dictionary.

Ethernet

- **Windmill Innovations** in Holland has developed an extensive TCP-IP protocol stack for the 28x devices.

The contact for Windmill is :

Windmill Innovations
Rutger van Dalen
phone +31 33 2465314
Nijkerk – Holland
rvdalen@windmill-systems.com
Web : http://www.windmill-innovations.com



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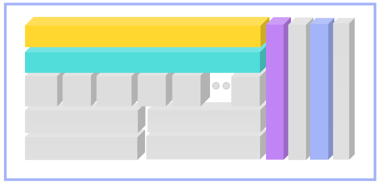
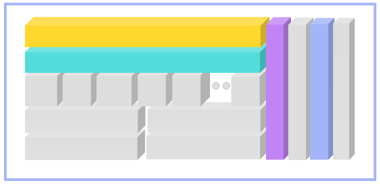
The Foundation:
Software Libraries



- **Motor Control Specific SW Modules**
- **Peripheral & Communication Drivers**
- **Trigonometric and Log Routines**
- **Signal Processing Functions**
- **Signal Generator Functions**
- **Power Conversion Related Functions**

http://www.ti.com/c2000appsw

The Foundation: Software Libraries



Motor Control Specific SW Modules

Forward and Inverse Clarke/Park Transforms, BLDC Specific PWM Drivers, Leg Current Measurement Drivers, BLDC Commutation triggers, ACI Speed and Rotor Position Estimators, PID Controllers, Extended Precision PID Controllers.

Peripheral & Communication Drivers

SCI (UART) Packet Driver, Virtual SPI Drivers, Virtual I2C Drivers, Serial EEPROM Drivers, GPIO Driver.

Fixed Point Trigonometric and Log Routines

Fixed Point Sine, Cosine, Tangent routines, Square Root, Logarithm Functions. Reciprocal calculation.

IQ Math 32-Bit Virtual Floating Point Library

Multiply, Divide, Multiply with Rounding, Multiply with Rounding and Saturation, Square Root, Sine and Cosine, routines.

Signal Processing Functions

FIR (Generic order), FIR (10th order), FIR(20th order), FIR using circular buffers. 128, 256, and 512 point complex and real FFTs.

Signal Generator Functions

Sinewave generators, Ramp Generators, Trapezoidal Profile generators

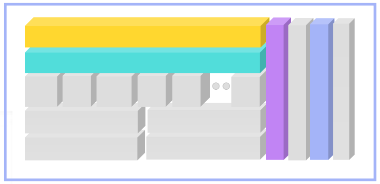
Power Conversion Related Functions

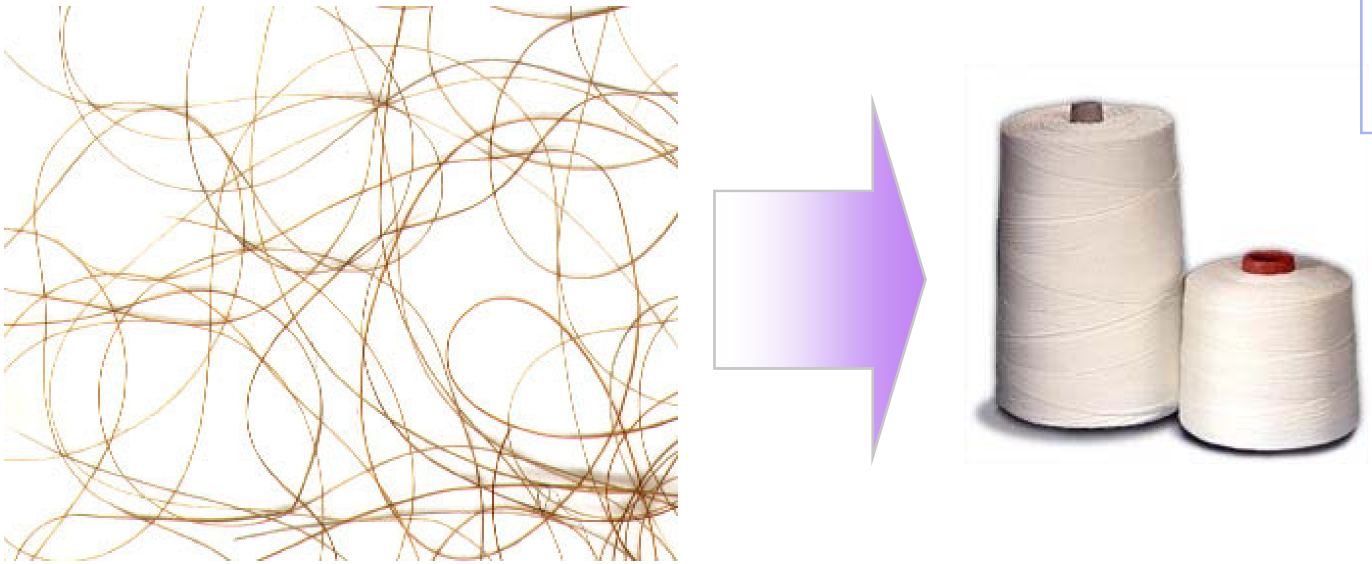
RMS computation, real power and apparent power computation, THD computation, PFC controllers.

Application Frameworks: Starterware

more coming soon

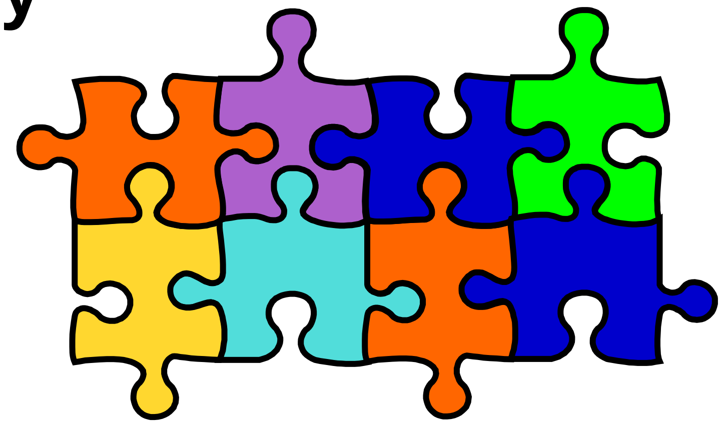
System	Motor Type	Sensored	Sensorless	Description	C24x™ DSP	C28x™ DSP
ACI1-1	1 ph AC Induction	•		Tacho I/P VHz / SinePWM/ Closed Loop (CL) Speed PID	•	
ACI3-1	3 ph AC Induction	•		Tacho I/P VHz / SinePWM / CL Speed PID	•	•
ACI3-2	3 ph AC Induction		•	MRAS (speed estimator) VHz / SinePWM / CL Speed PID	•	•
ACI3-3	3 ph AC Induction	•		Tacho I/P FOC / SinePWM / CL Current PID for D, Q / CL Speed PID	•	•
ACI3-4	3 ph AC Induction		•	Direct Flux Estimator + Speed Estimator FOC / SinePWM / CL Current PID for D, Q / CL Speed PID	•	•
PMSM3-1	3 ph Permanent Magnet Synch	•		QEP FOC / SinePWM / CL Current PID for D, Q / CL Speed PID	•	•
PMSM3-2	3 ph Permanent Magnet Synch		•	SMO (Sliding Mode Observer) Position Estimator FOC / SinePWM / CL Current PID for D, Q / CL Speed PID	•	•
PMSM3-3	3 ph Permanent Magnet Synch	•		Resolver / FOC / CL Current PID for D, Q / CL Speed PID		•
PMSM3-4	3 ph Permanent Magnet Synch	•		QEP / FOC / Position Control		•
BLDC3-1	3 ph Trapezoidal Brushless DC	•		3 Hall Effect I/P Trapezoidal / CL Loop Current PID / CL Speed PID	•	•
BLDC3-2	3 ph Trapezoidal Brushless DC		•	BEMF / Zero Crossing Detection Trapezoidal / CL Loop Current PID / CL Speed PID	•	•
DCMOTOR	Brushed DC	•		Speed & Position / QEP without Index		•



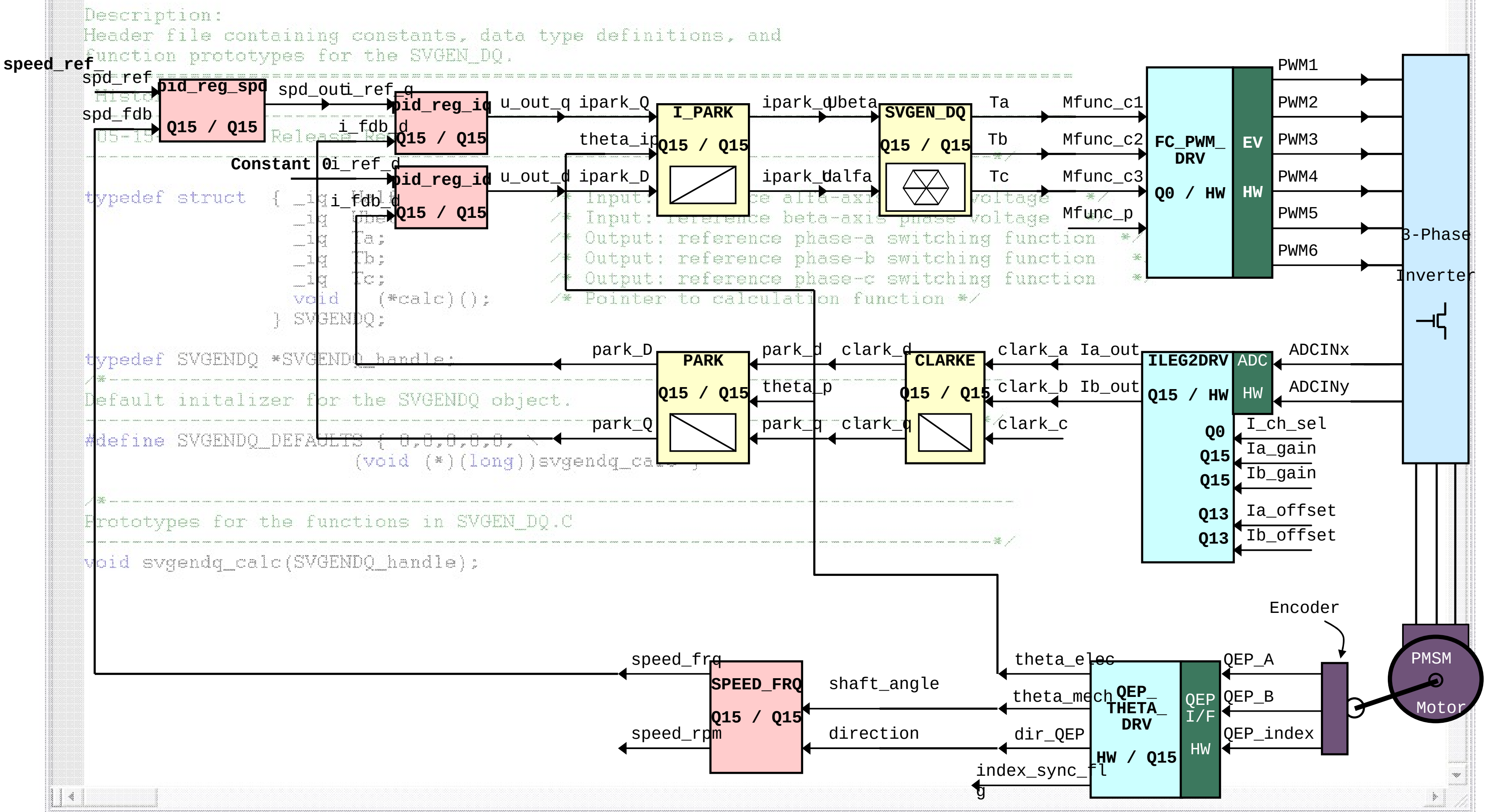


Modular Block oriented library

- Blocks make systems easy to represent and understand
- Simplify debug
- Enable incremental deployment

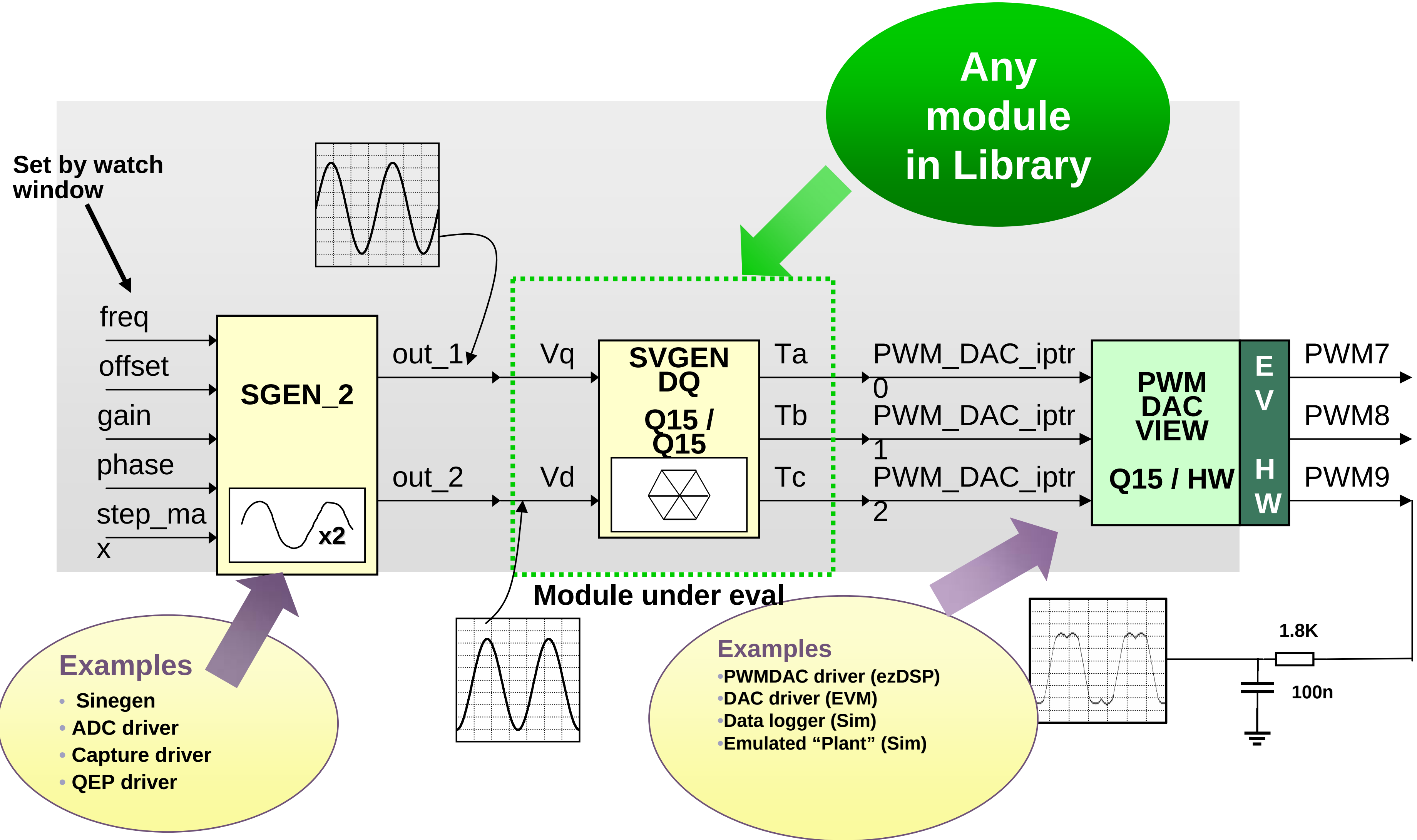


Modular S/W Implementation of Sensored FOC for PMSM

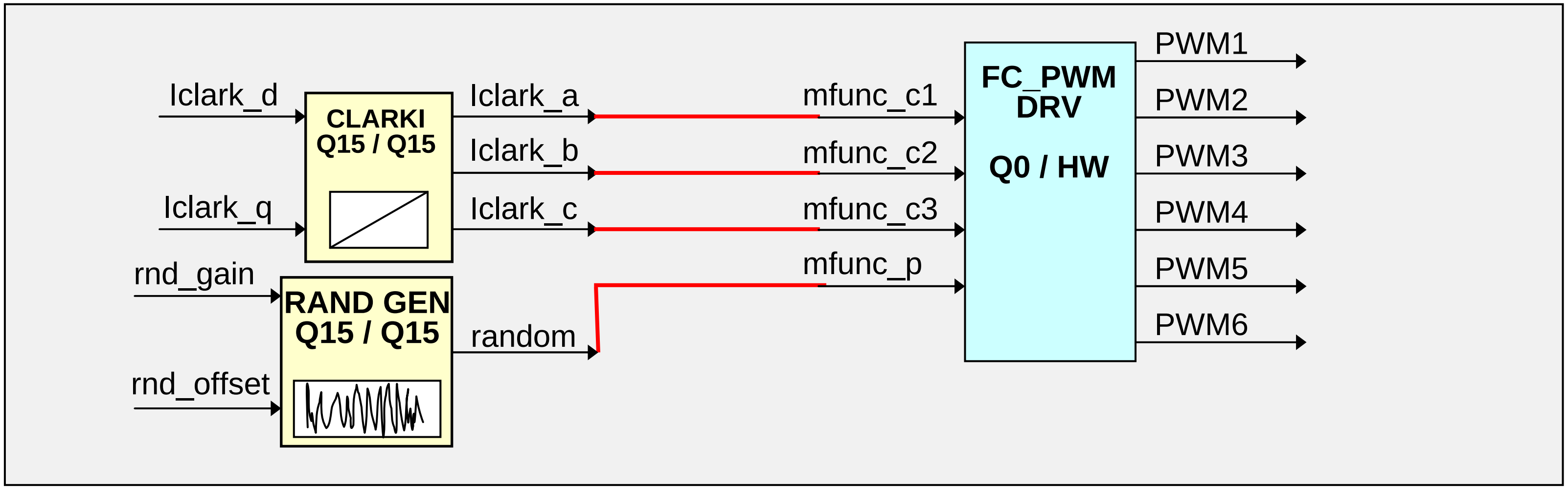


Software Test Bench: STB

Ease of use: All modules offered as an STB packaged as a CCS project



Interconnecting Modules

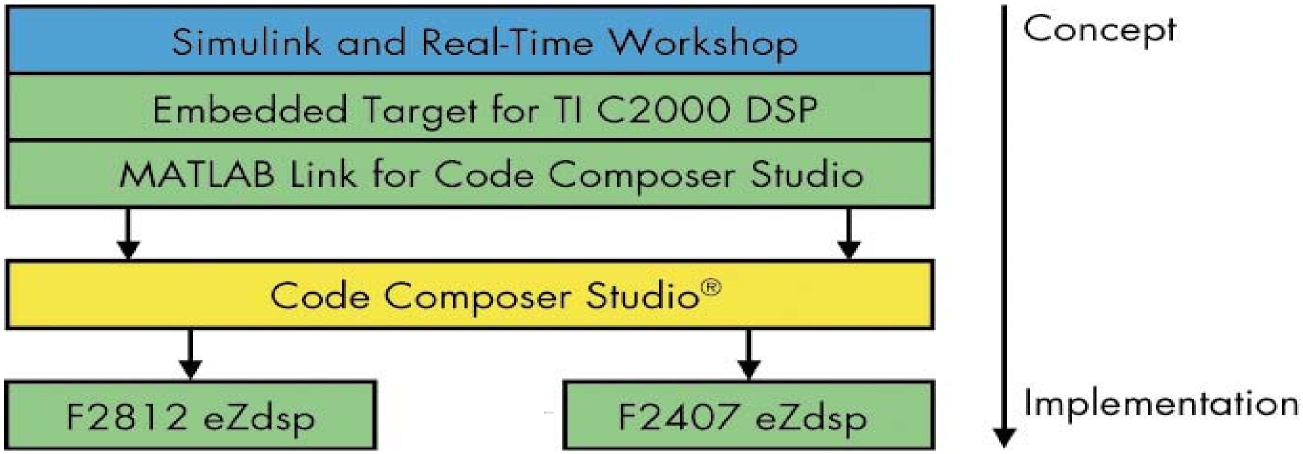


At the "C" level:

```
clarkInv(&dqBuffer, &fcPwm.InputBuffer)
fcPwmInputBuffer.ditherIn = randomGen1.calc(&randomGen1)
fcPwm.calc(&fcPwm);
```

At the "GDE" level: Just "join the blocks"

Embedded Target Integrates Simulink® and MATLAB® with eXpressDSP™ Tools and C2000™ Controllers

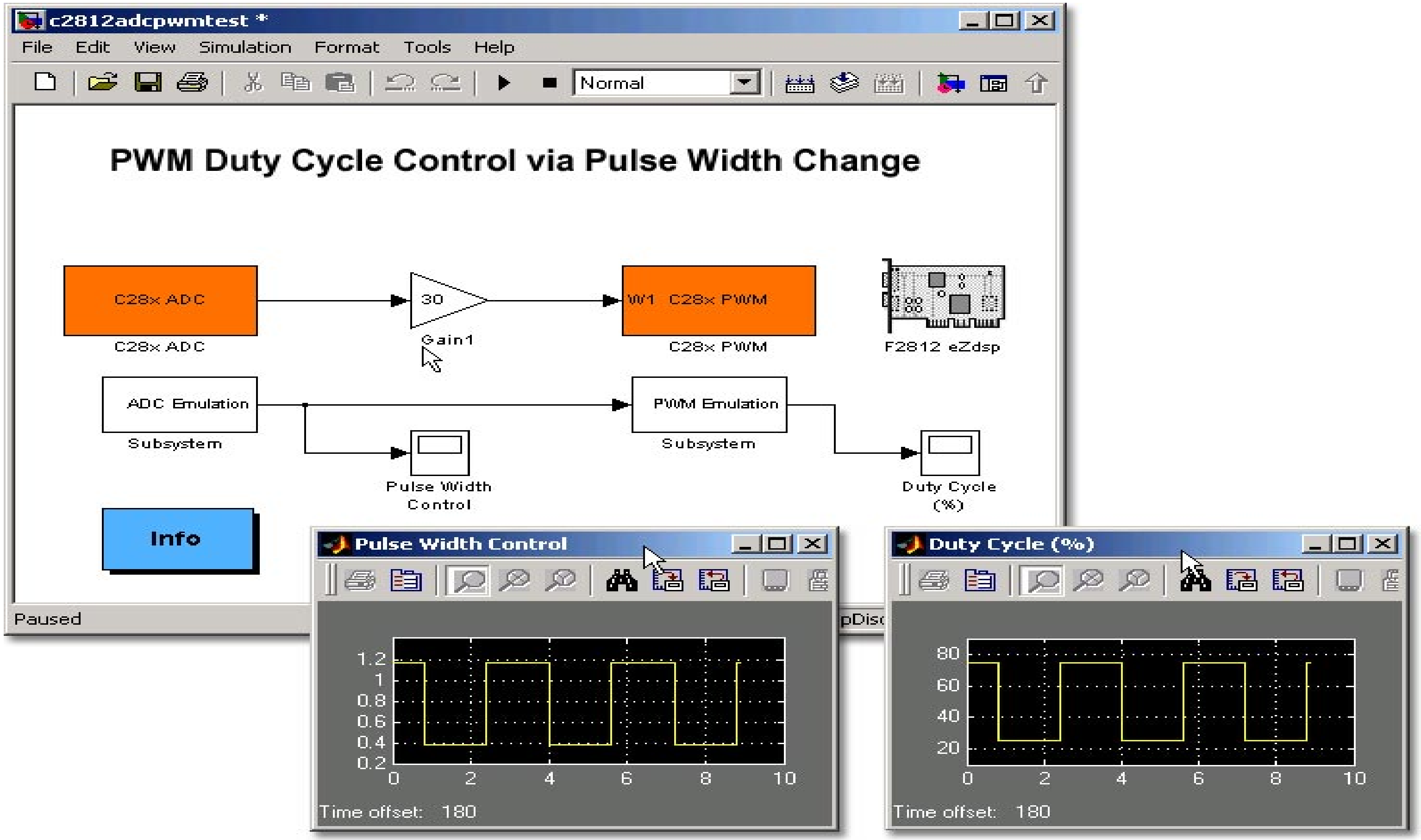


Key Features

- Design and Simulation
- Automatic code generation
  - Embedded Target for C2000
  - Documentation, re-usable C code
  - Support for on-chip peripherals
- Verification of embedded implementation
  - MATLAB Link for Code Composer Studio
  - Auto debug, testbench
  - Real-time visualization

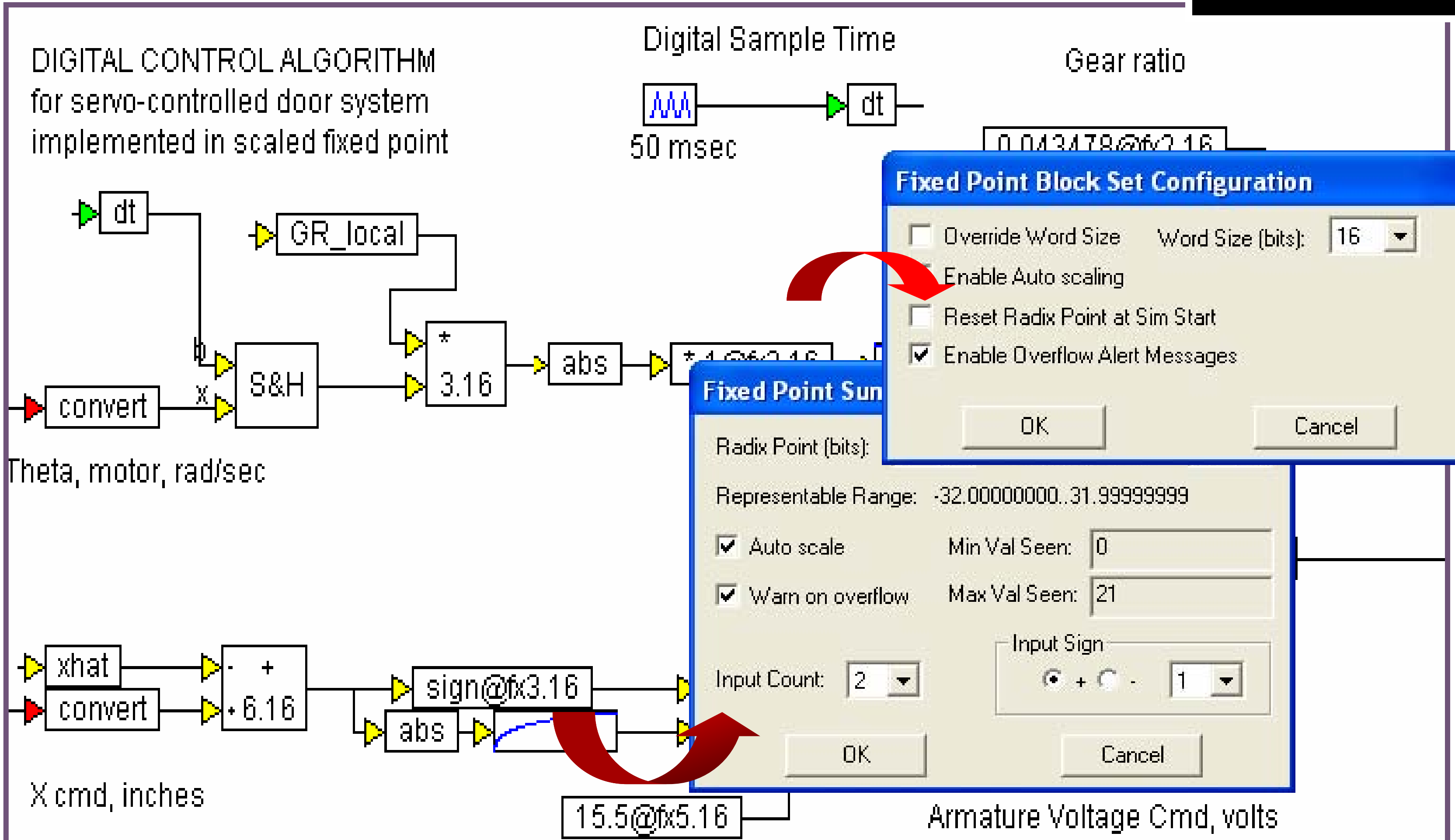
http://www.ti.com/c2000embeddedtarget

Embedded Target Integrates Simulink® and MATLAB® with eXpressDSP™ Tools and C2000™ Controllers



http://www.ti.com/c2000embeddedtarget

Example of GDE Motor Control



http://www.vissim.com/

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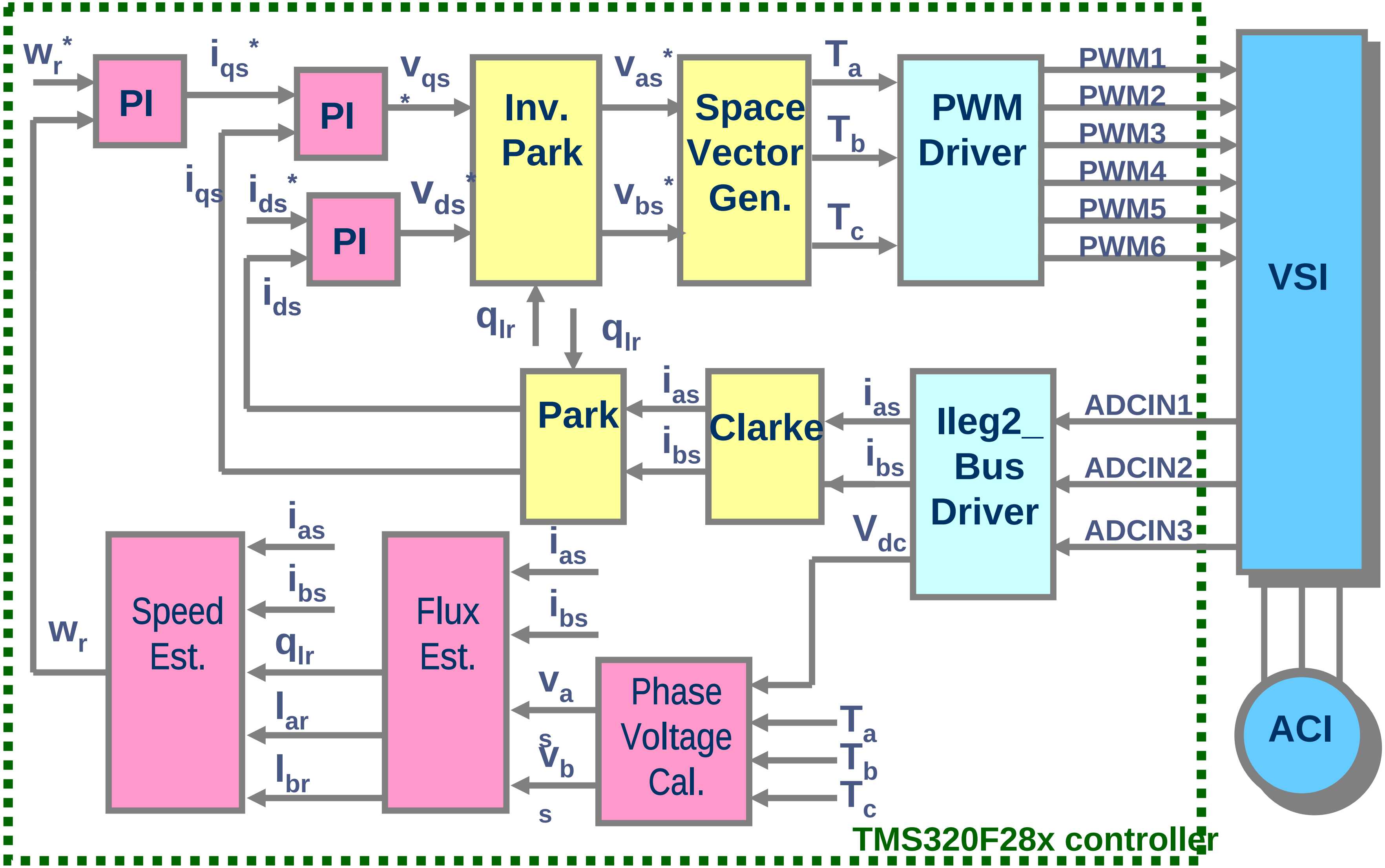
Incremental System Build

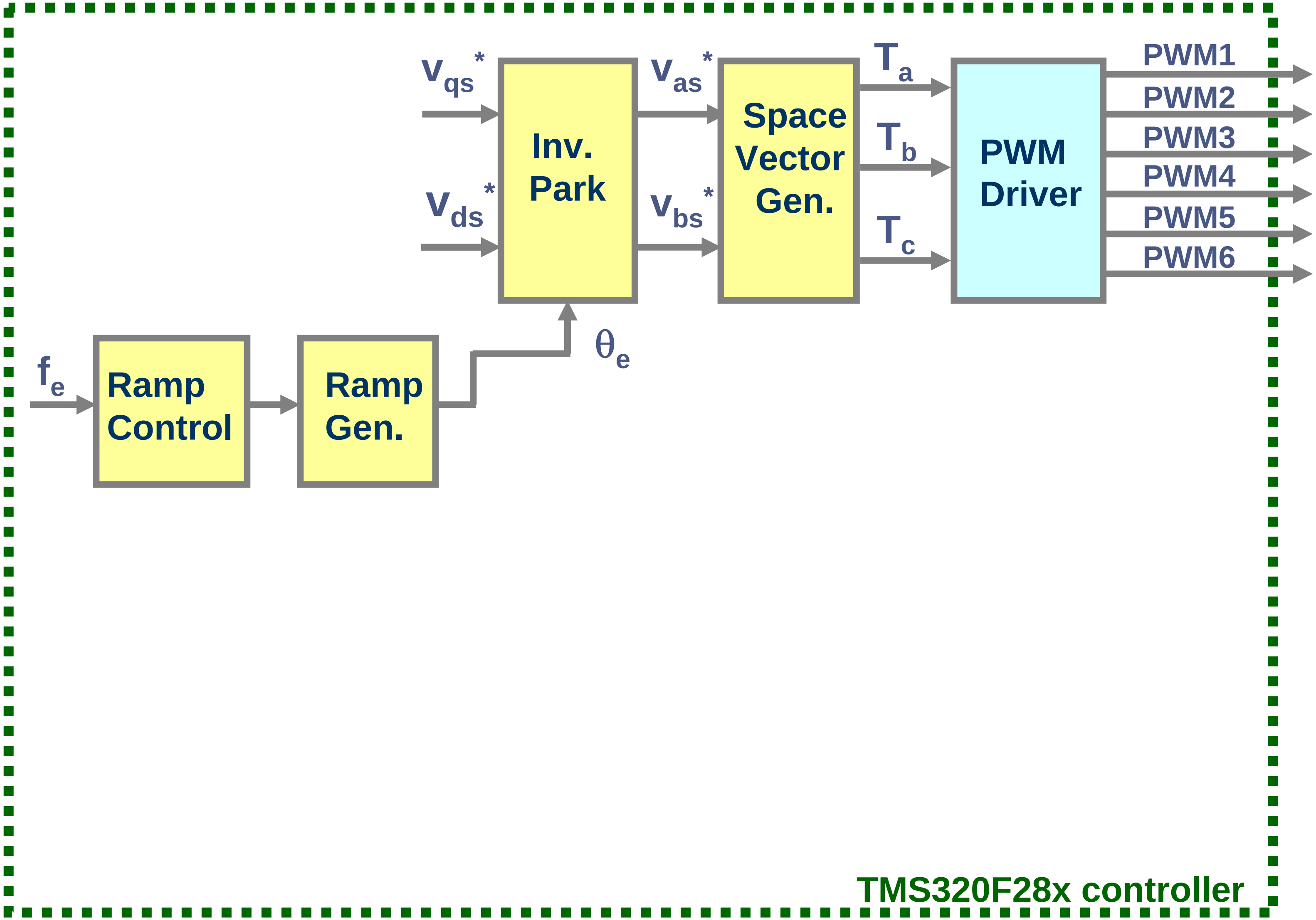
- Incremental system development/debug is built in
- Incremental system development/debug relies on modular software blocks
- Incremental system development/debug is flexible/systematic
- Incremental system development/debug applies to multiple processors, drives and motors

ACI Sensorless Field Oriented Control



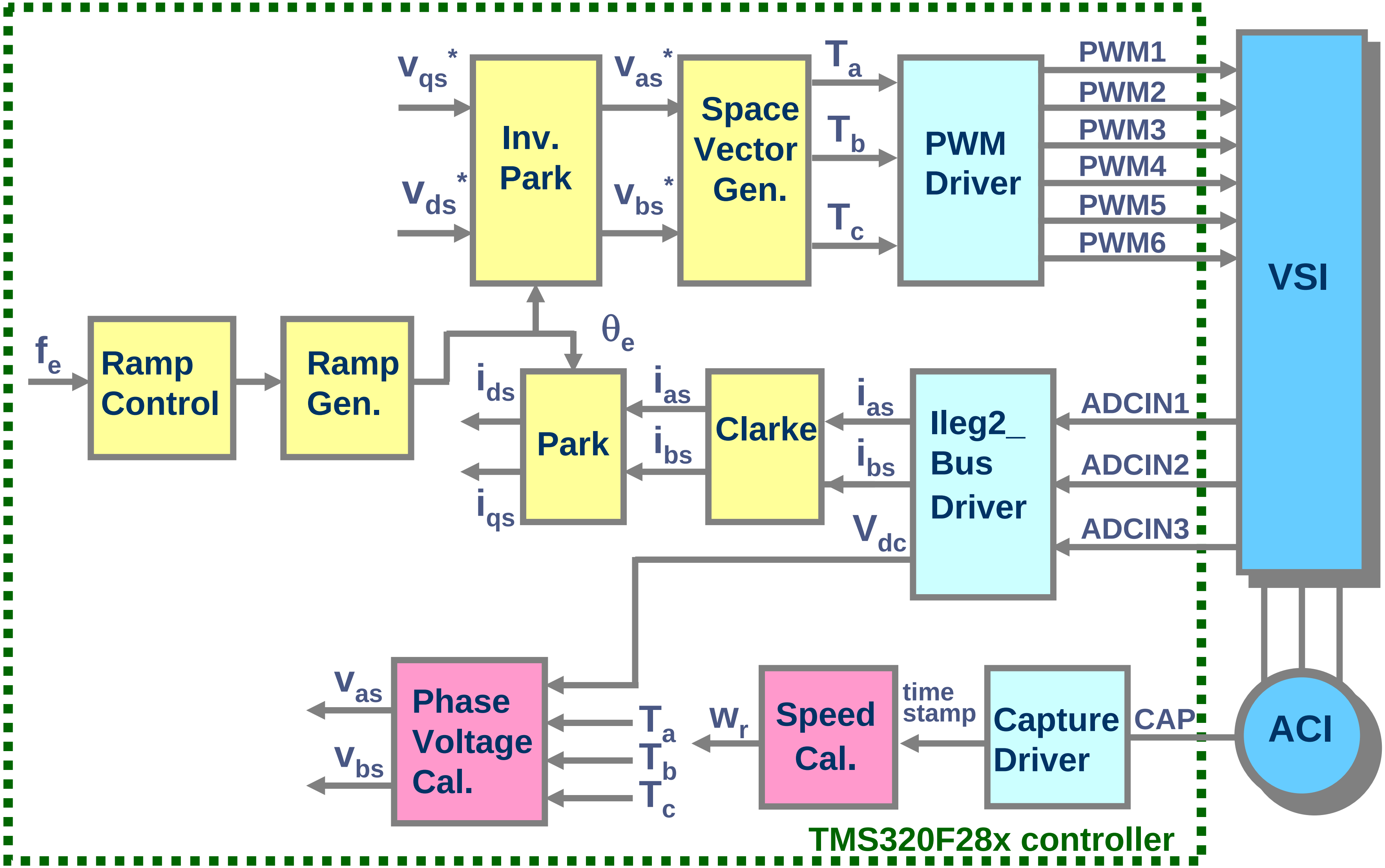
Build Level 1

SVGEN/ PWM Tests					



Build Level 2

	Measure-ment Tests				



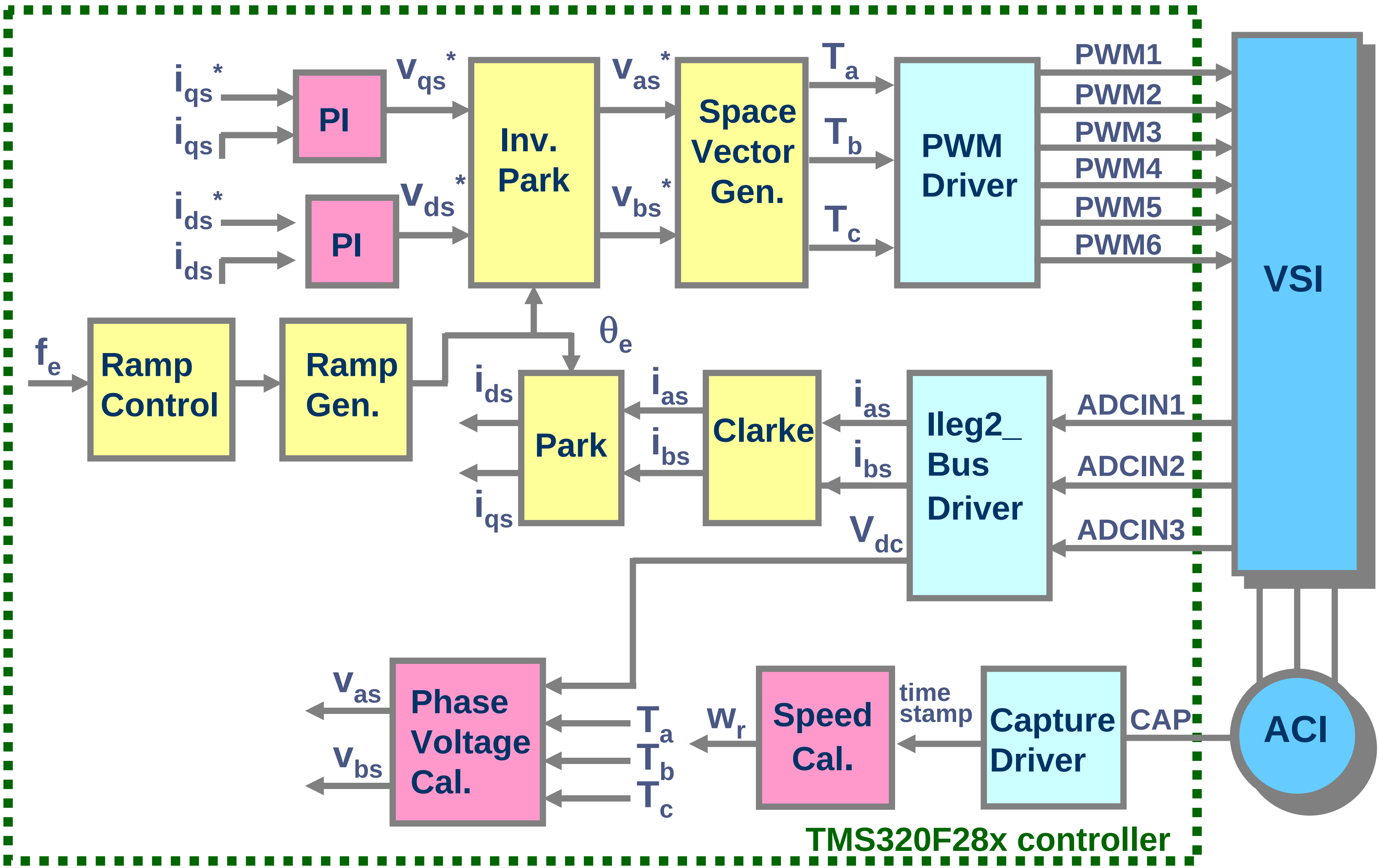
Incremental Builds Header File

build.h

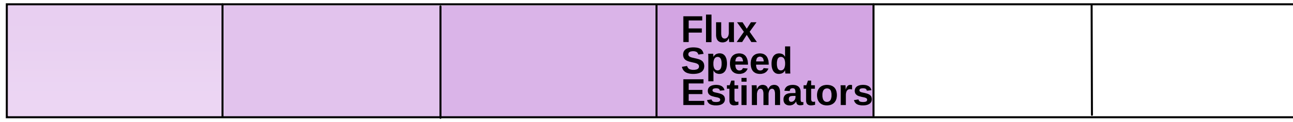
```
/*------------------------------------------------------------------------------
Following is the list of the Build Level choices.
------------------------------------------------------------------------------*/
#define LEVEL1  1   /* SVGEN_DQ and FC_PWM_DRV tests */
#define LEVEL2  2   /* Currents/DC-bus voltage/speed measurement tests */
#define LEVEL3  3   /* Two current PI regulator tests */
#define LEVEL4  4   /* Flux and speed estimator tests */
#define LEVEL5  5   /* Speed PI regulator test (Sensored closed-loop DFOC system) */
#define LEVEL6  6   /* Sensorless closed-loop DFOC system  */
#define ALWAYS_RUN
/*------------------------------------------------------------------------------
This line sets the BUILDLEVEL to one of the available choices.
------------------------------------------------------------------------------*/
#define   BUILDLEVEL    LEVEL3
```

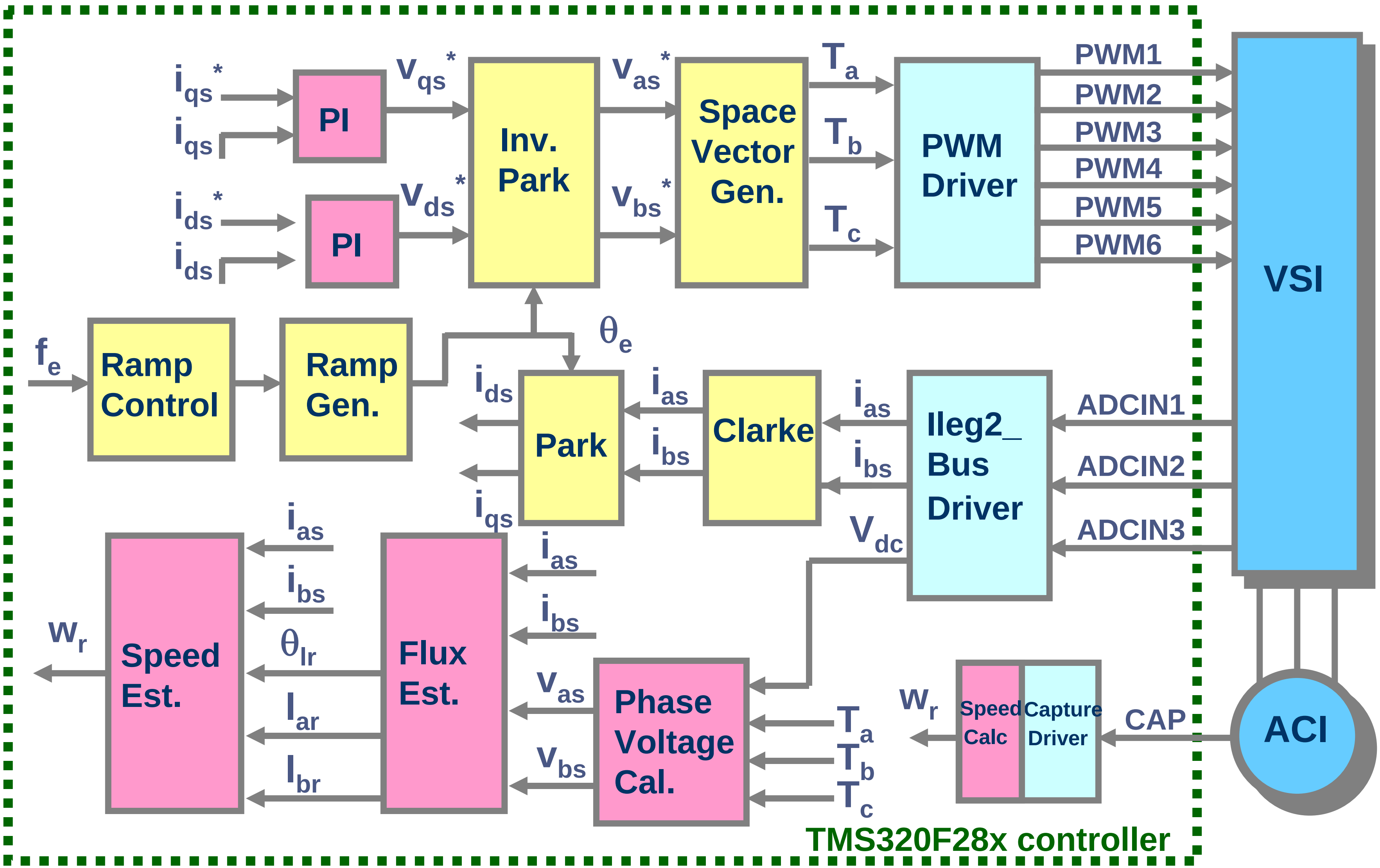
Build Level 3

		PI Regulator Tests			



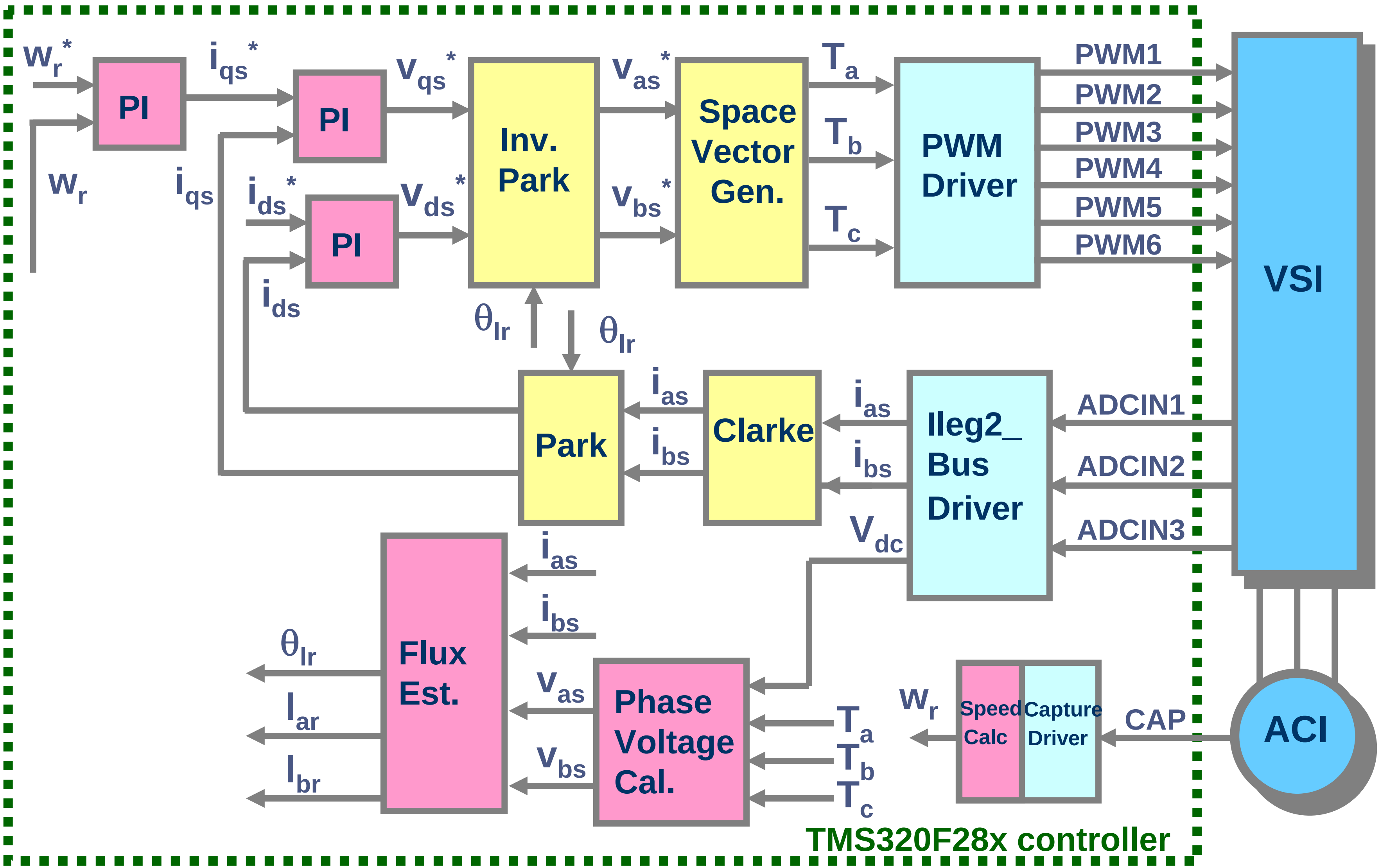
Build Level 4





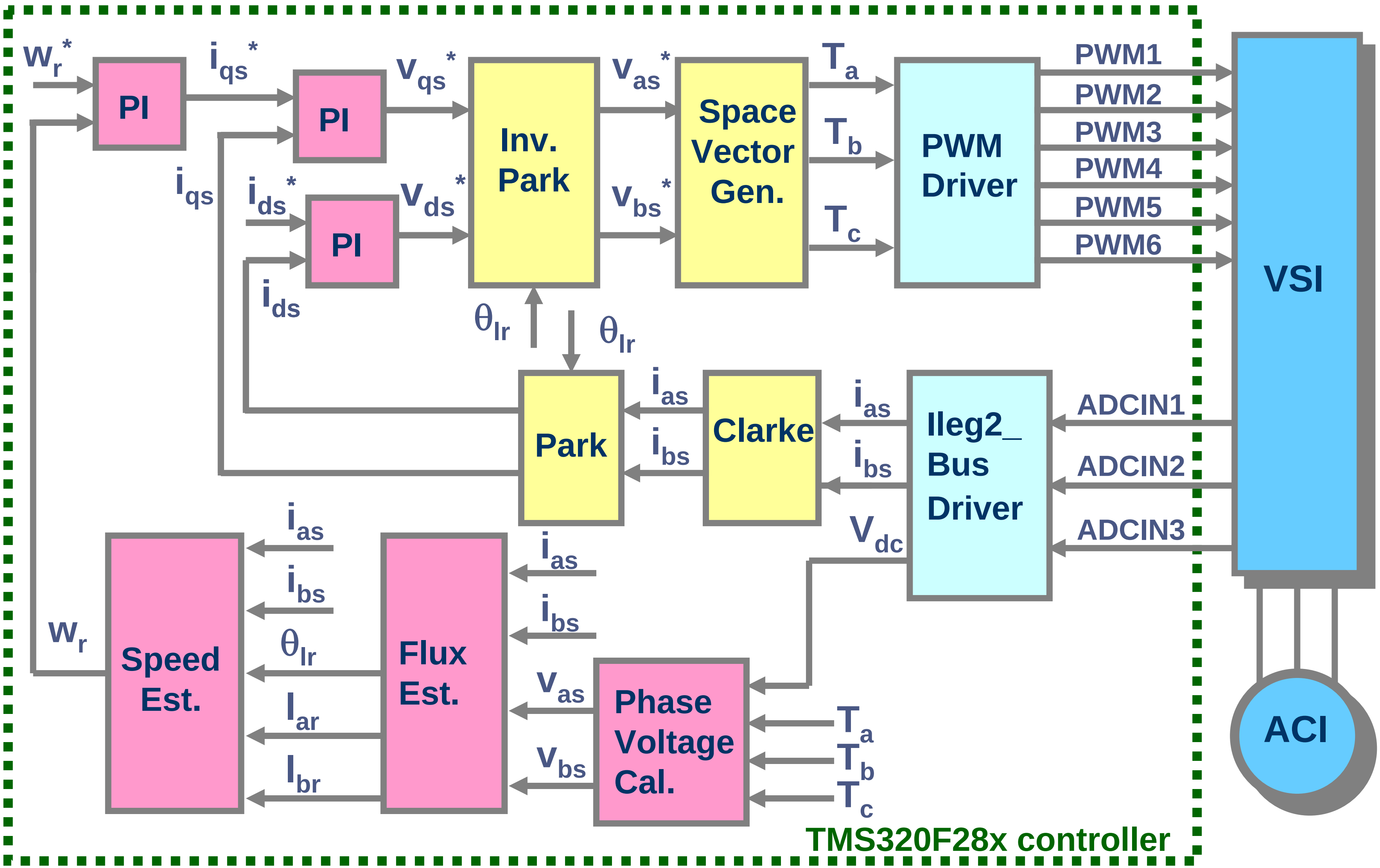
Build Level 5

				Speed Regulator Tests	



Build Level 6

Sensorless FOC System



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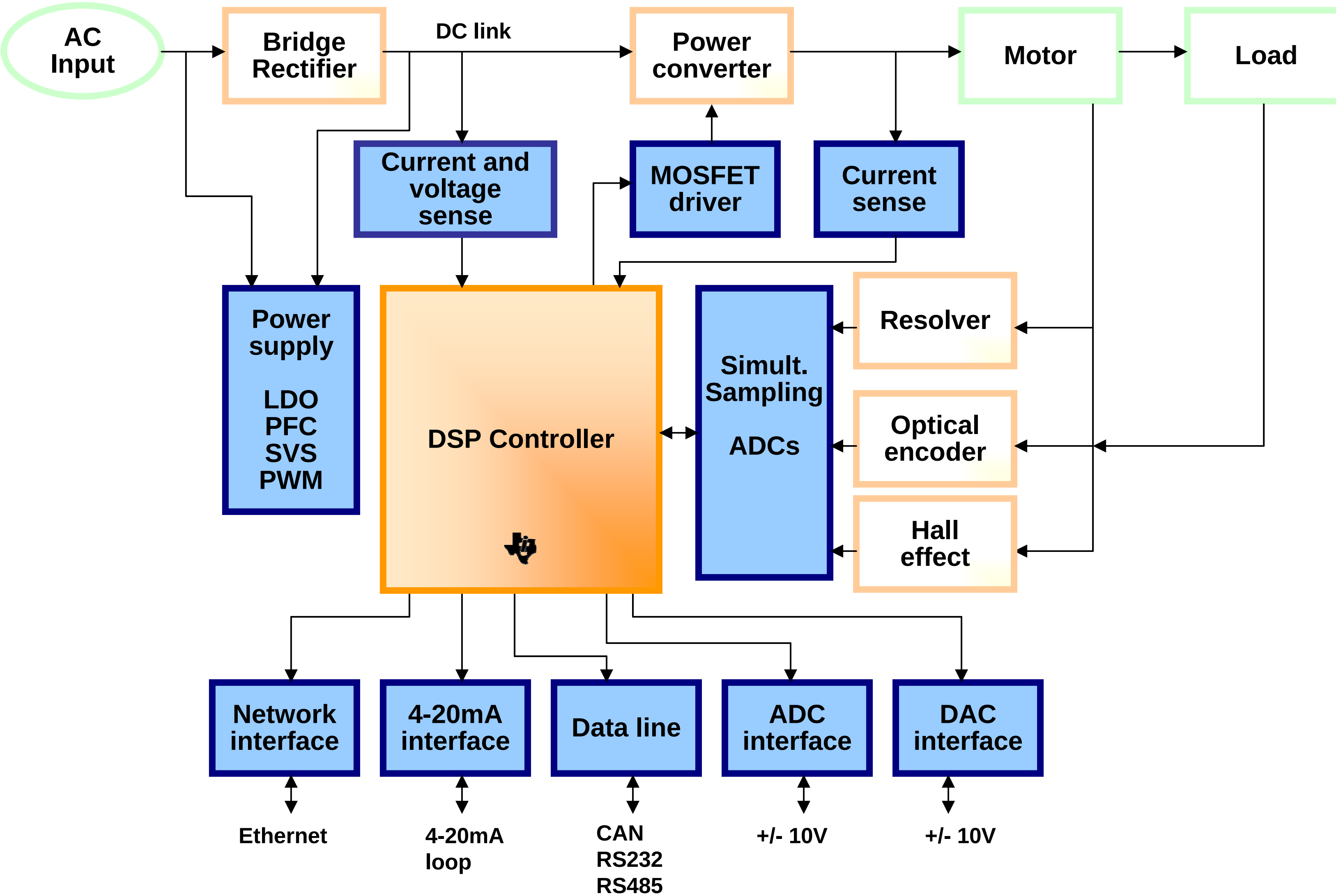
Motor Control System Components From TI



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High Performance Analog
For
Industrial Motor Control

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- **Industry recognized applications and systems expertise**

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  - Reference Designs
  - Evaluation Modules
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  - Design Tools & Software
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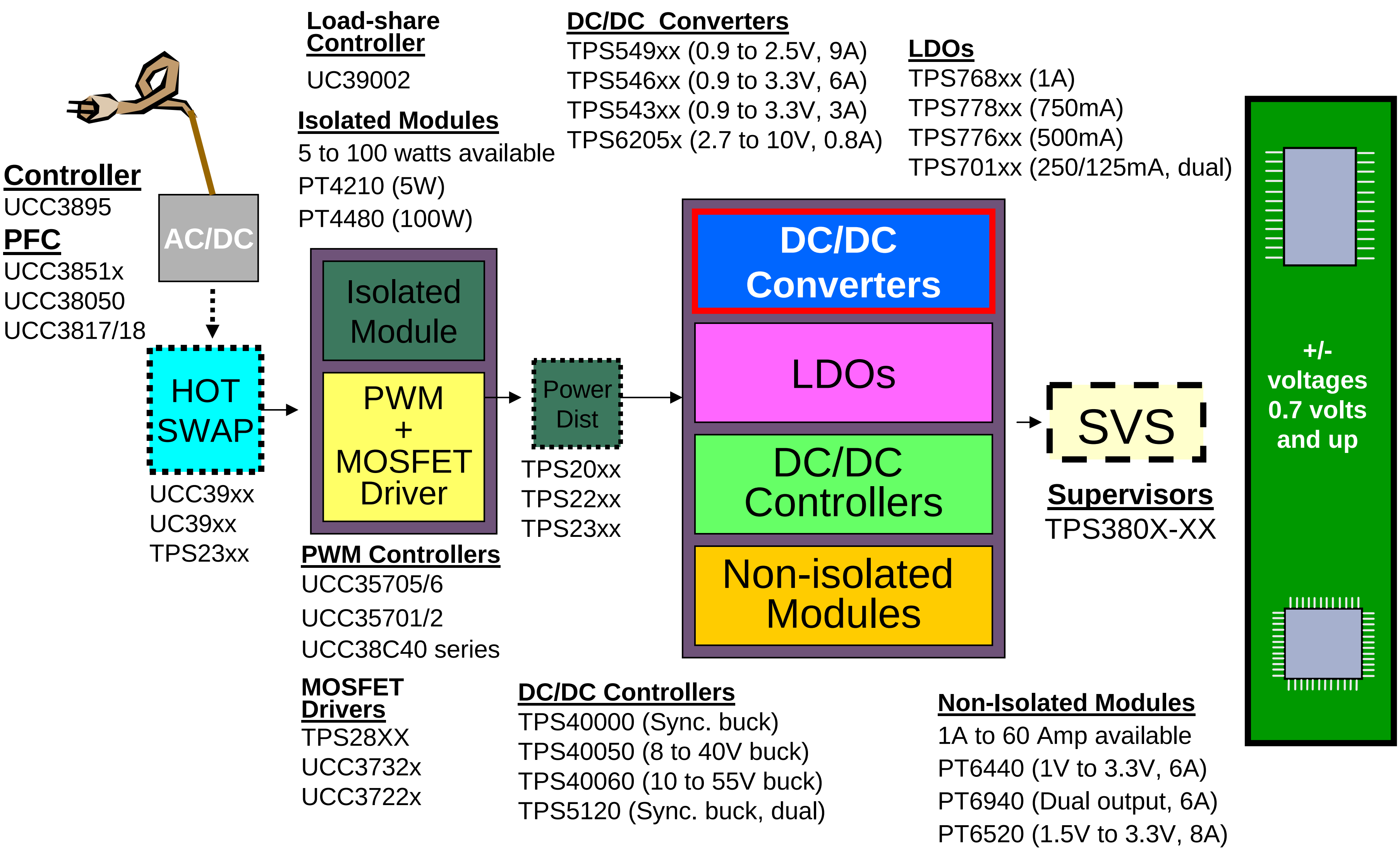
  - power.ti.com

Complete System Power Solutions



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Complete, Tested Power Supply Designs

- Schematics
- BOM
- Implementation Notes

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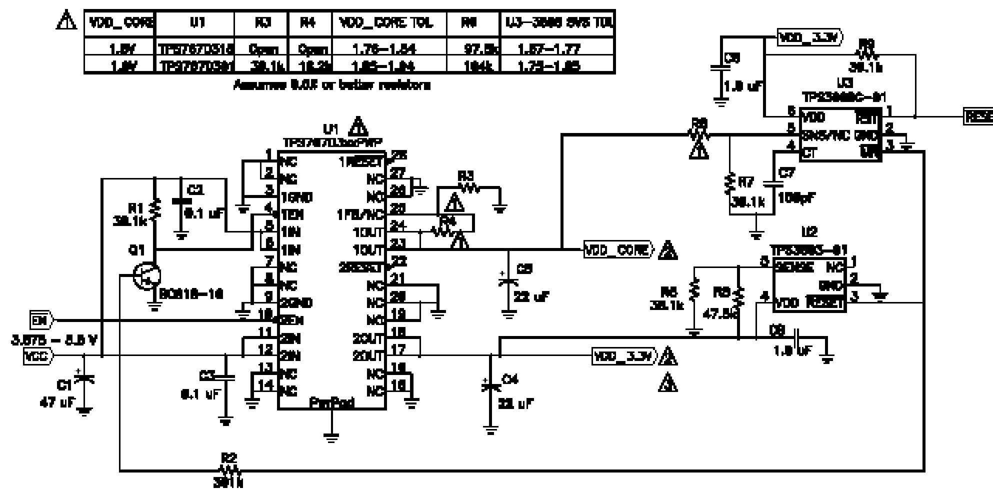


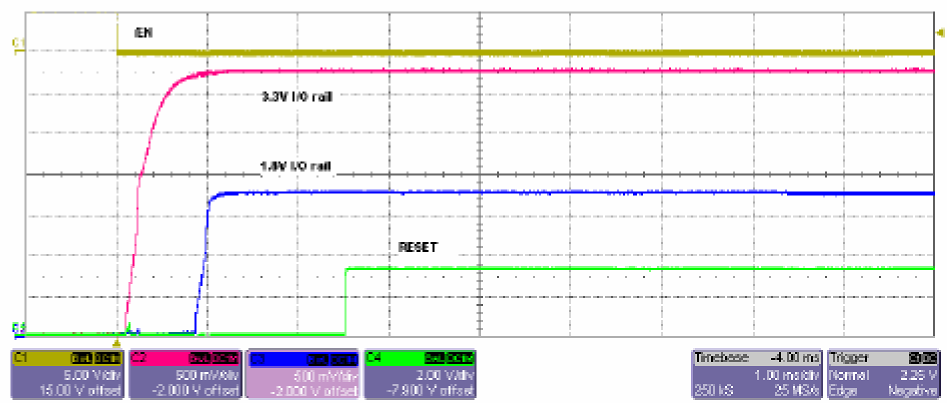
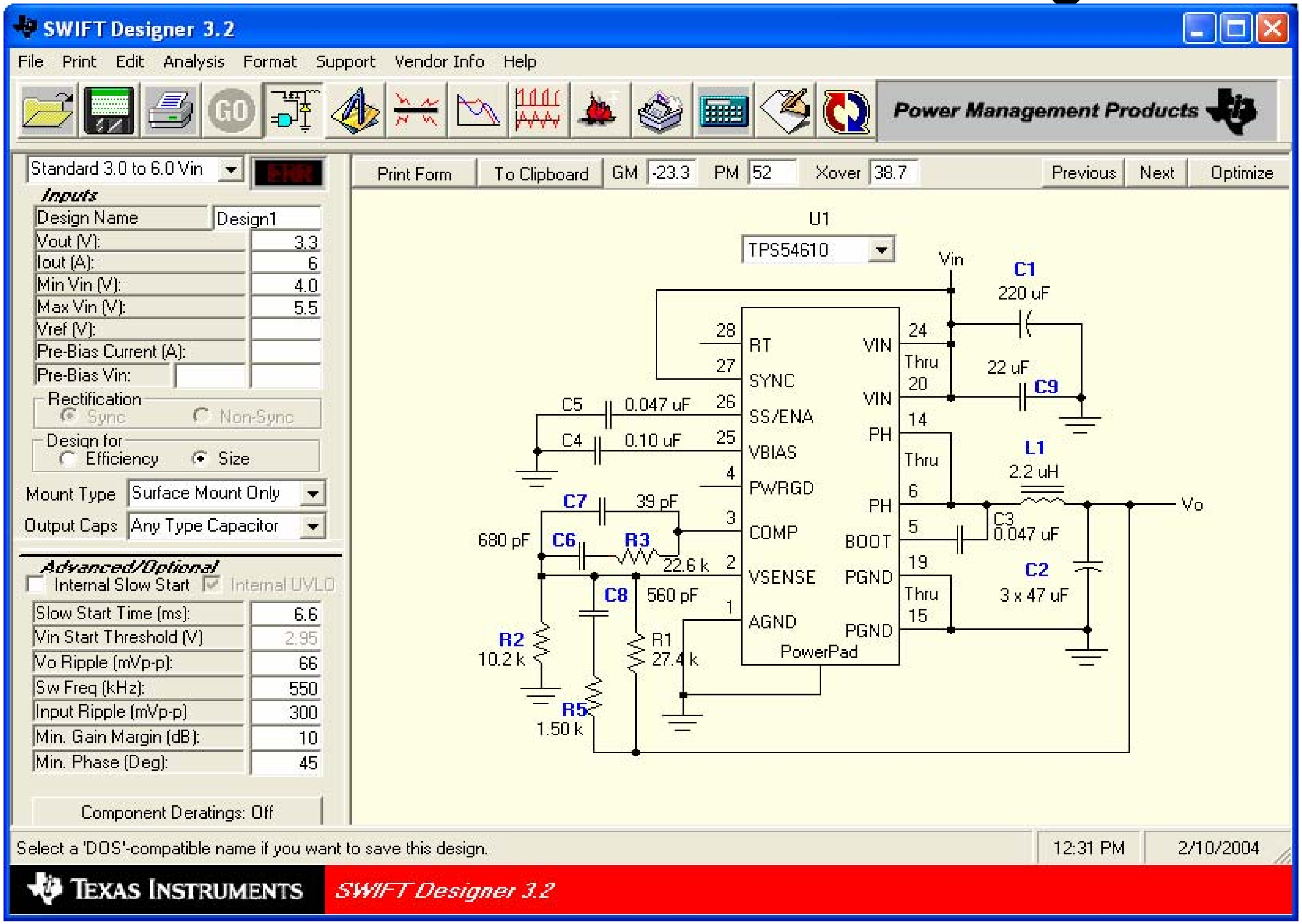


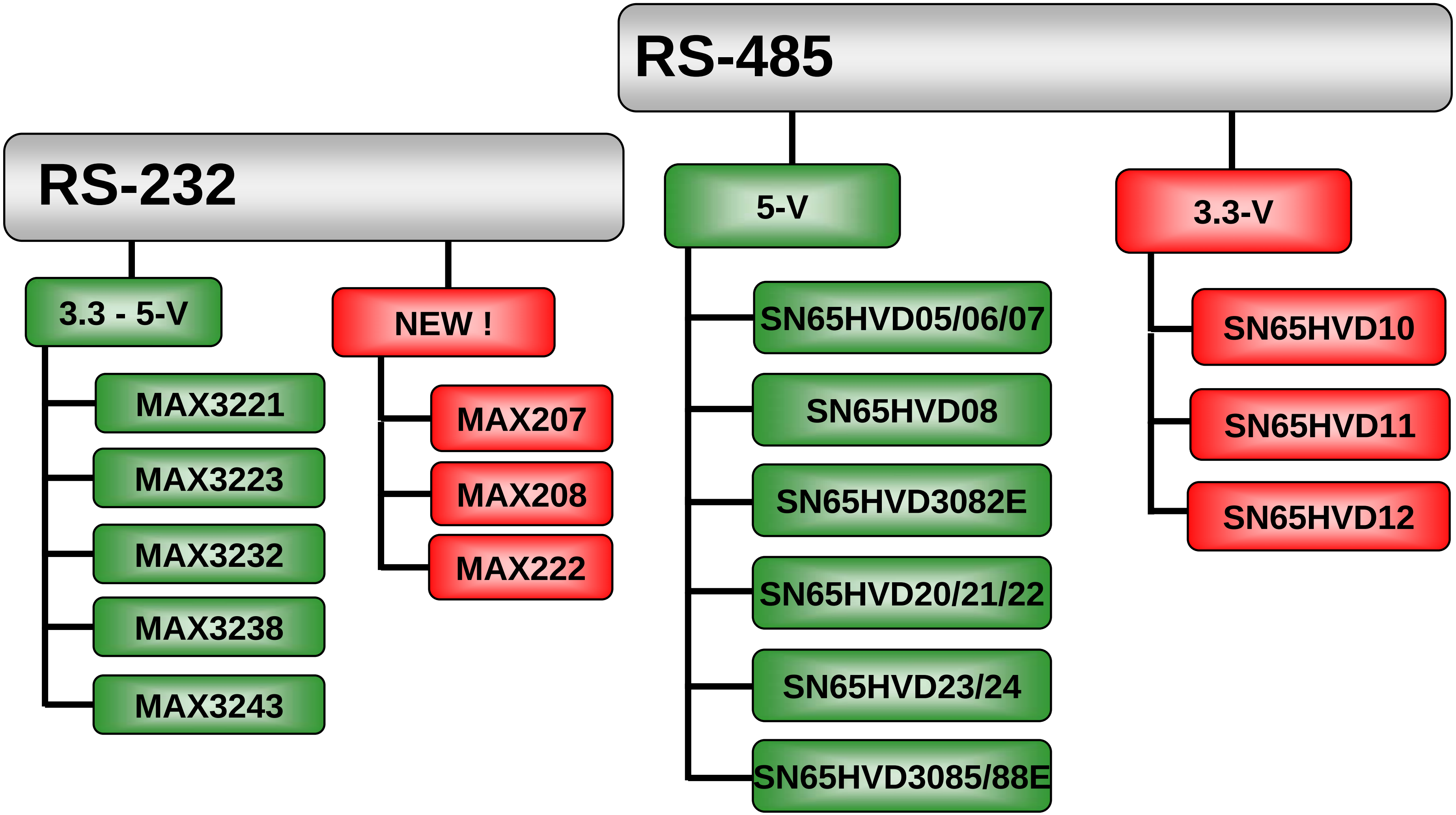
Figure 2 - Power up from enable when V_{IN} = 5.0 V

For Easily Customized Power Designs: SWIFT/TPS40k/TPS60k Design Tools

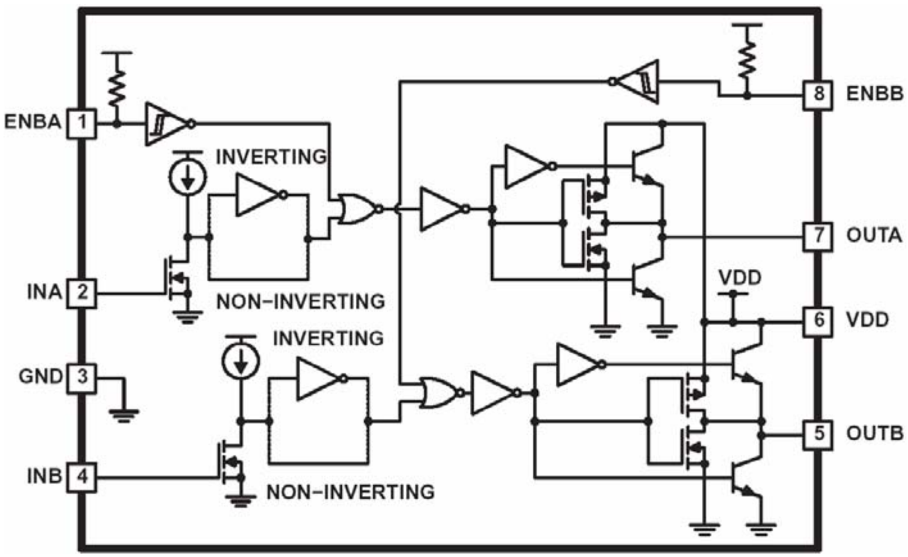


Visit power.ti.com to Download Power Design Software

TI Interface Products for MC System



FET Drivers in MC System



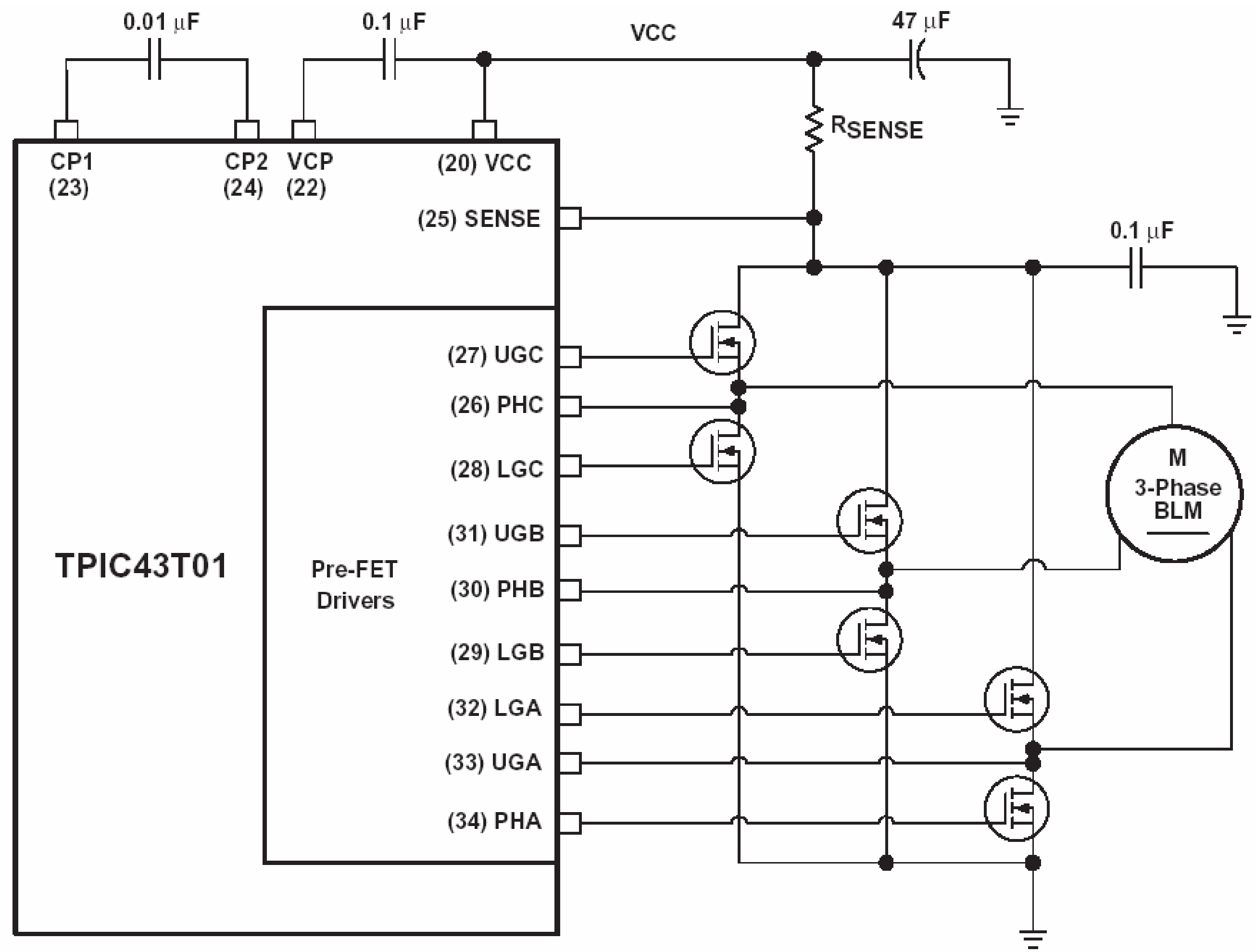
- Deliver 4A through Miller Plateau
- Available in MSOP PowerPAD™
- 20/15nS Rise/Fall Times
- 4-15V Supply Range

UCC27423: Dual 4A, High Speed, Inverting Low Side Driver

UCC27424: Dual 4A, High Speed, Non-Inverting Low Side Driver

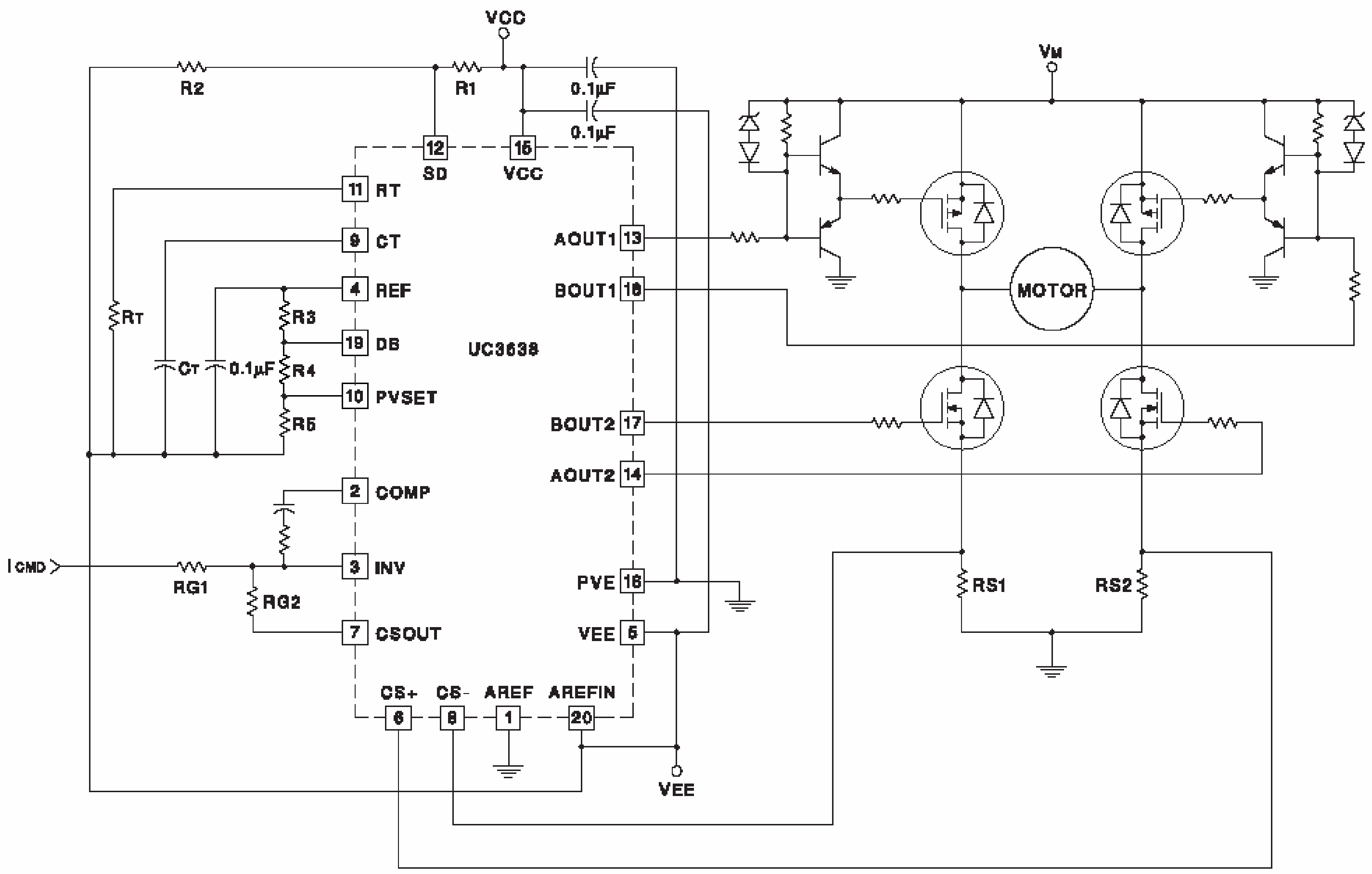
UCC27425: Dual 4A, High Speed, Low Side Driver with one Inverting and one Non-Inverting Output

Intelligent Drivers in MC System



Low cost stand alone controllers for low power applications

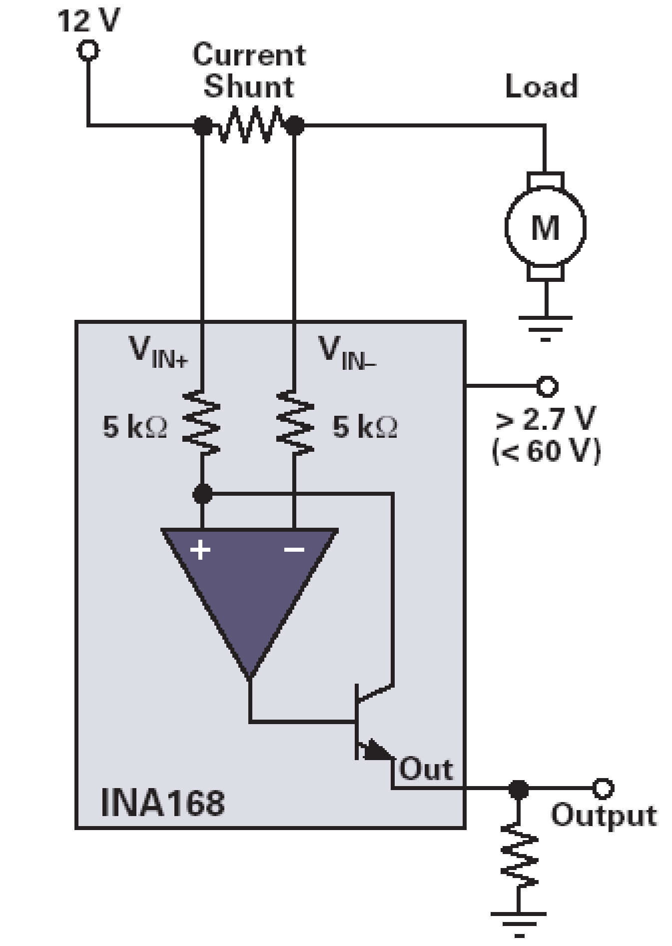
Motor Controllers



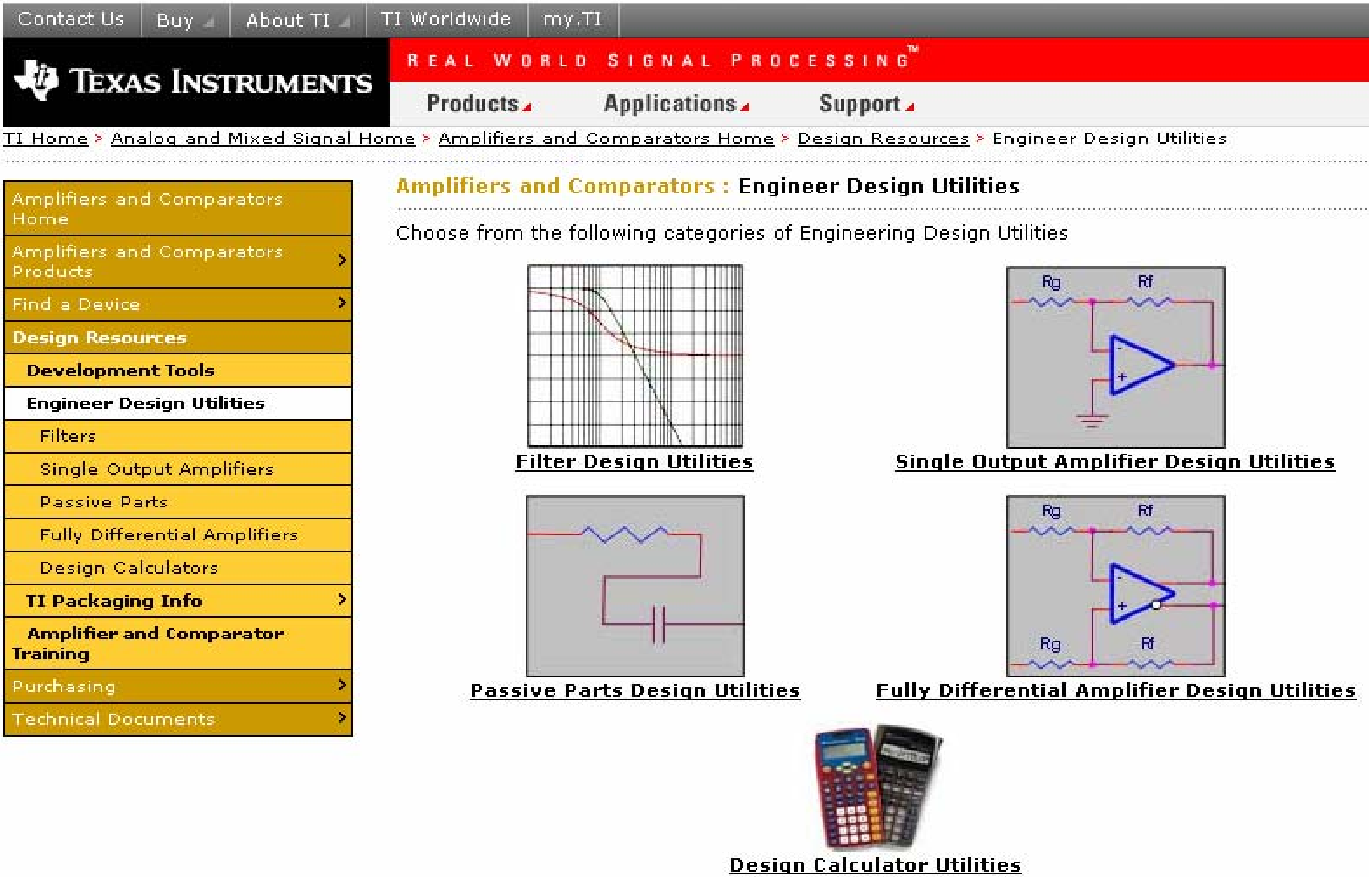
BLM Controllers: UC2625, UC3625, UCC2626, UCC3636
Stepper Controllers: UC3717, UC3770
DC Motor Controllers: UC2638, UC3637, UC3638

Amplifiers in MC System

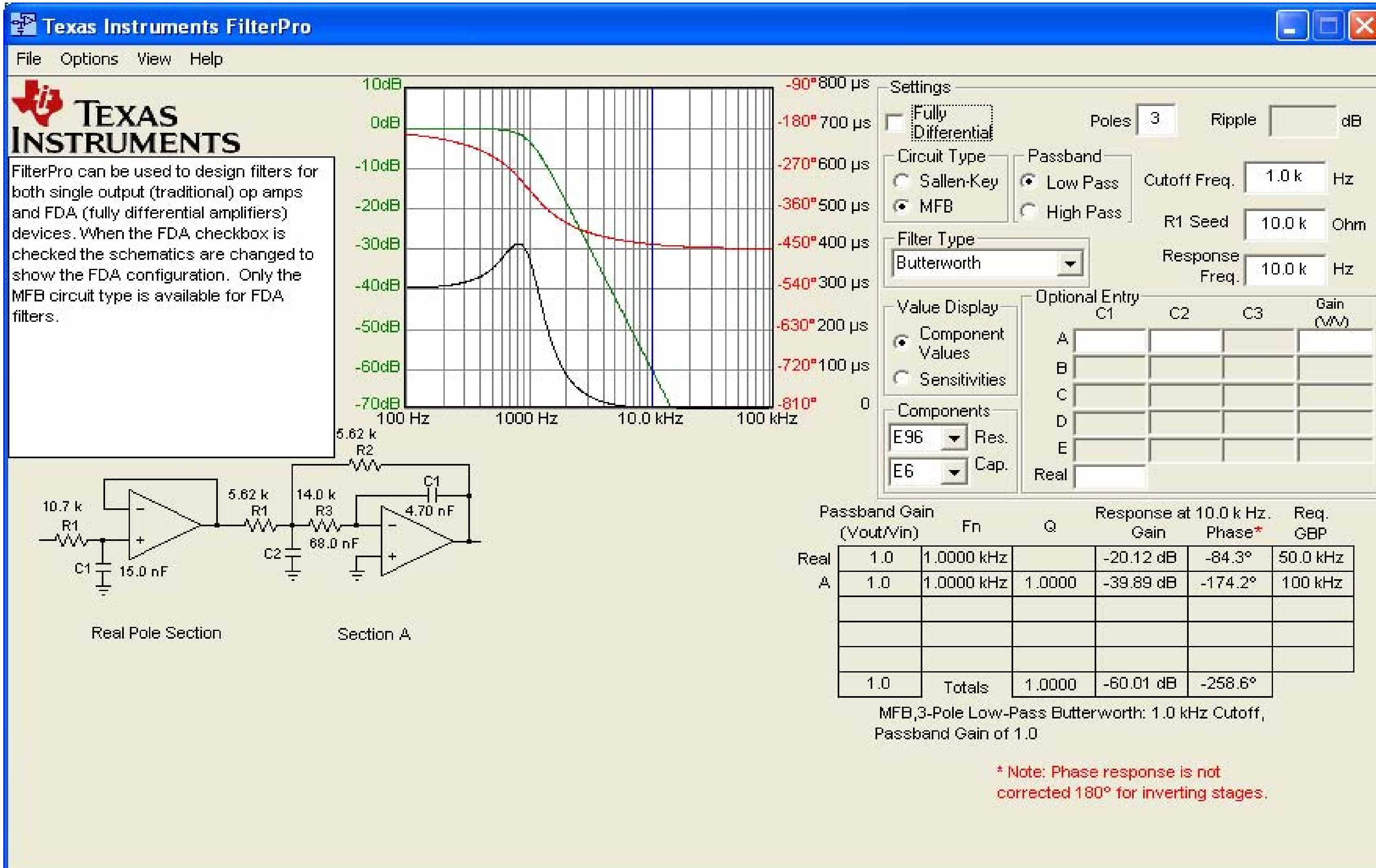
- Difference Amplifiers
  - INA168, Automotive Current Shunt
- CMOS Amplifiers
  - Rail to Rail (5-100mV)
- Isolation Amplifiers
  - To 3500VRMS
- Instrumentation Amplifiers
- Difference Amplifiers
- High Speed Amplifiers
- 4-20mA Transmitters
- Voltage References
- Temperature Sensors
  - I2C, 12bit Resolution



Amplifiers: Design Utilities



FilterPro Design Tool



ADC and DAC in MC System

General purpose Analog-to-Digital and Digital-to-Analog Converters

ADCs

- Single Channel
- Multi Channel
- ±10V Input

DACs

- Single Channel
- Multi Channel
- ±10V Output

For general monitor/control functions

Simultaneous Sampling Analog-to-Digital Converters

Serial Interface

2x2 Channel ADS7861 – 500KSPS
2x2 Channel ADS8361 – 500KSPS

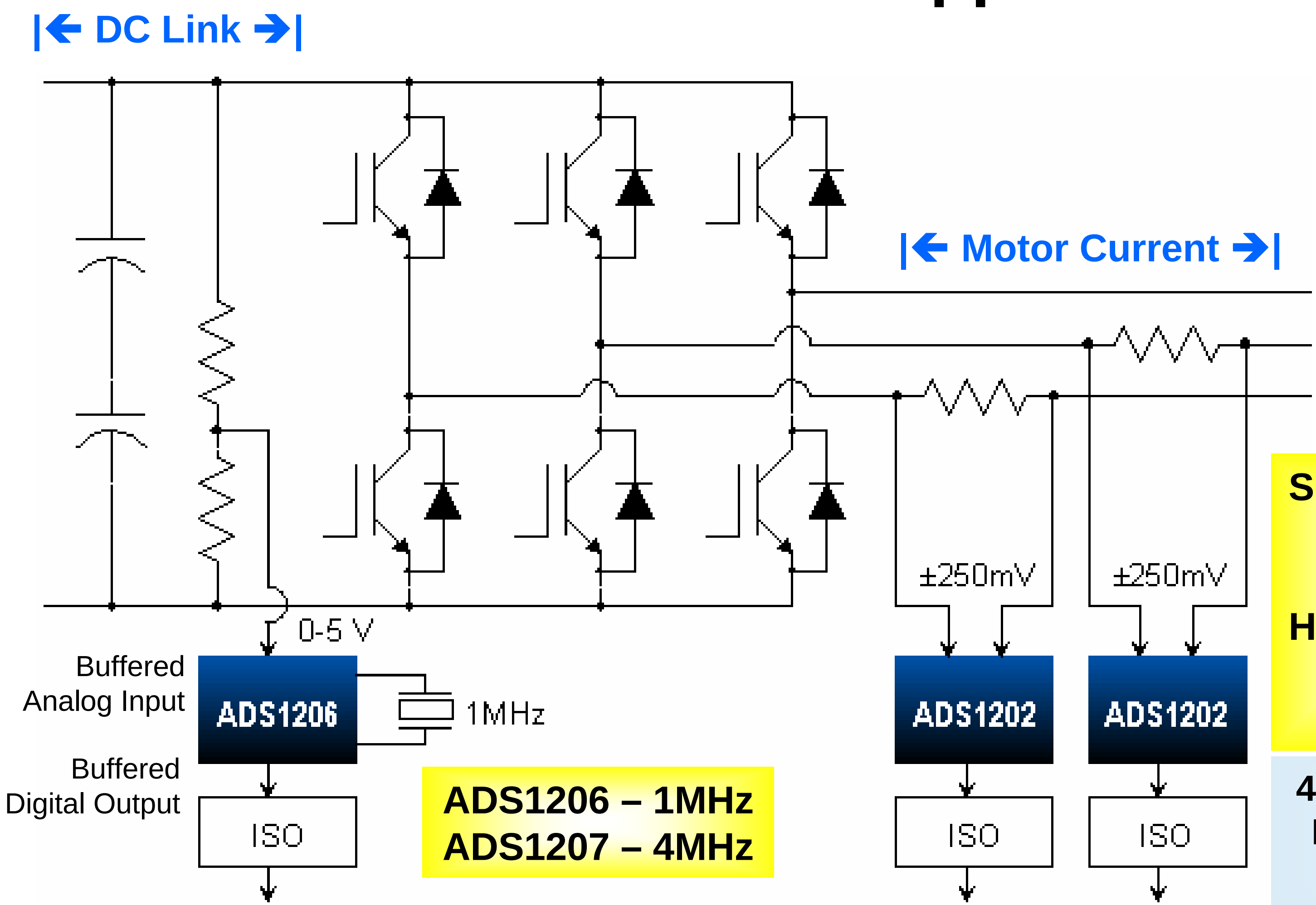
Parallel Interface

2x2 Channel ADS7862 – 500KSPS
6 Channel ADS7864 – 500KSPS
6 Channel ADS8364 – 250KSPS

NEW!

ADS7869: 12-Channel Analog Motor Control Front End with Three 1MSPS, 12-Bit ADCs

DC-Link Voltage and Phase Currents Measurement for Servo Application



ADS1206 – 1MHz
ADS1207 – 4MHz

Shunt R:
ADS1202
ADS1203
Hall Effect:
ADS1204
ADS1205

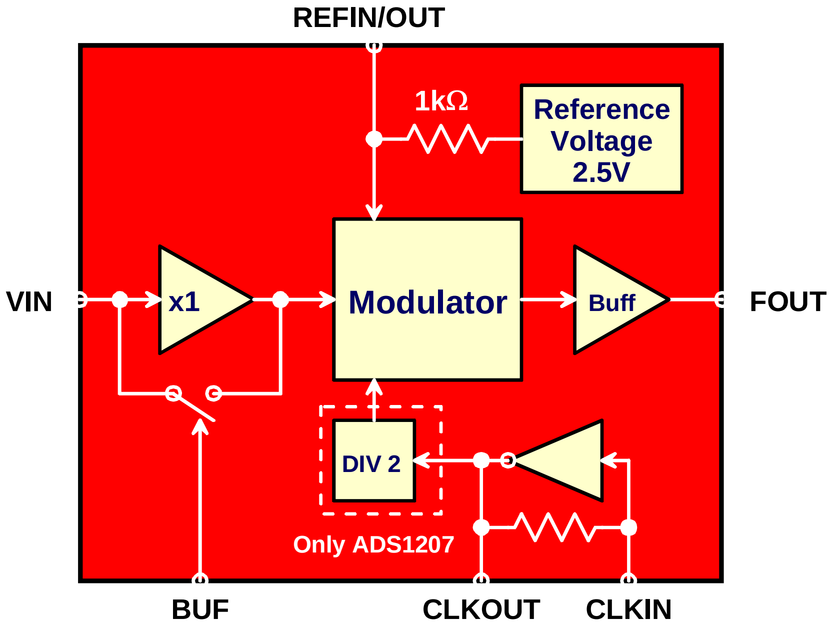
4kHz Current Loop 16-bit Accuracy

ADS1206 & ADS1207

1MHz & 4MHz Voltage-to-Frequency Converter

Features:

- Synchronous Operation
- Frequency Set By External Clock
- Maximum Input Frequency:
  - 1MHz for ADS1206
  - 4MHz for ADS1207
- Selectable High Impedance Input
- 2% Internal, 2.5 V Reference Voltage
- High Current Output Driver
- Alternate Source For AD7740
- 8-lead VSSOP Package



Key Differentiators:

- Higher performances than AD7740
- Input frequency 4MHz
- Output buffer
- Low price - ASD1206 1Ku $0.98
  - ASD1207 1Ku $0.98

Applications:

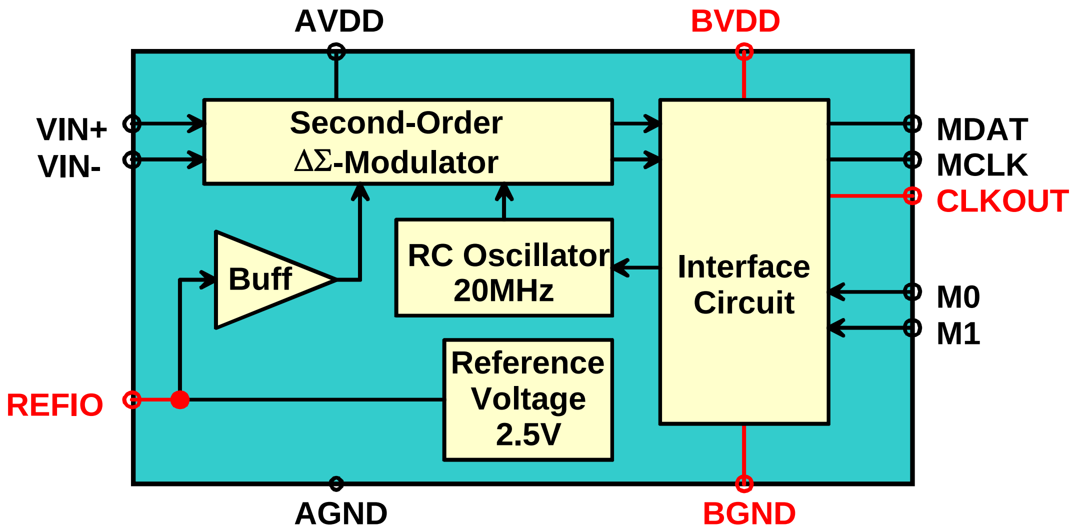
- Galvanic Isolation Measurements
- High Voltage Measurements
- Low Cost A-to-D Conversion
- Motor Control
- Industrial Process Control

ADS1203

1-bit 10MSPS, 2nd Order ΔΣ Modulator

Features:

- 16-Bit Resolution
- ±250mV Input Range
- 3LSB INL Max
- 1% Internal Voltage Reference
- 83dB SNR Min
- -95dB THD Typ
- Flexible Serial Interface
- 8-lead TSSOP Package
- QFN 3x3 – Coming Soon



(Pins Highlighted in RED are Available Only in QFN Package)

Key Differentiators:

- Higher performances than AD7400
- Implemented Manchester Coding
- On Board Oscillator
- Output buffer
- Low price 1Ku $2.70

Applications:

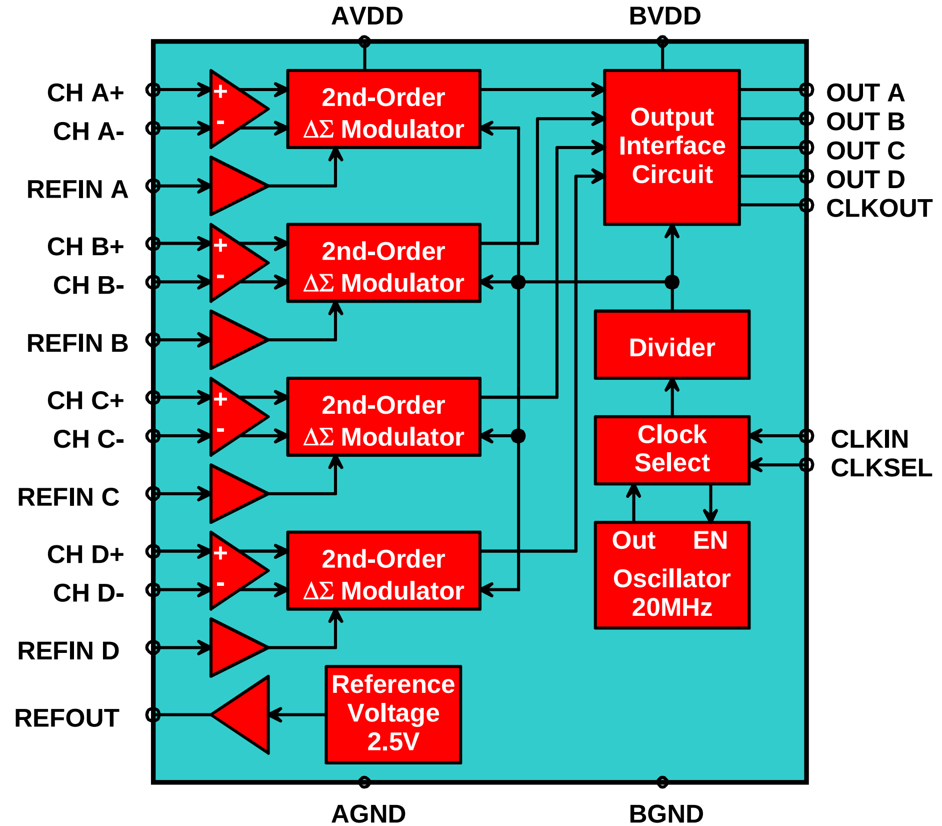
- Current Measurement
- Motor Control
- Closed-Loop Servo Control
- Power Converters
- 3-Phase Power Monitor

ADS1204

1-bit 10MSPS, 2nd Order ΔΣ Modulator

Features:

- 16-Bit Accuracy
- Input Range ±2.5V @ 2.5V
- Gain Error: 0.5%
- Dynamic Range 100dB
- 86dB SNR Min
- Four Independent Modulators
- Four Input Reference Buffers
- On Board 20MHz Oscillator
- QFN-32 (5x5) Package



Key Differentiators:

- First in Industry
- Low price 1Ku $6.75

Applications:

- Current Measurement
- Motor Control
- Power Converters

ADS1202 Design Resources

ADS1202 Data Sheet:

http://www-s.ti.com/sc/ds/ads1202.pdf

Application Notes:

- Choosing an Optocoupler for the ADS1202 Operating in Mode 1
  http://www-s.ti.com/sc/psheets/sbaa088/sbaa088.pdf
- Combining ADS1202 with FPGA Digital Filter for Current Measurement
  in Motor Control Application
  http://www-s.ti.com/sc/psheets/sbaa094/sbaa094.pdf
- Interfacing the ADS1202 Modulator With a Pulse Transformer in Galvanically Isolated Applications
  http://www-s.ti.com/sc/psheets/sbaa096/sbaa096.pdf
- Clock Divider Circuit for the ADS1202 in Mode 3 Operation
  http://www-s.ti.com/sc/psheets/sbaa105/sbaa105.pdf

ADS1202 Reference Design Users Guide

http://www-s.ti.com/sc/psheets/slaa186/slaa186.pdf

ADS1202 Evaluation board:

http://focus.ti.com/docs/prod/folders/print/ads1202.html#developmenttools

- Evaluation board users guide
  http://www-s.ti.com/sc/psheets/slau111/slau111.pdf
- Evaluation board interface for C5000 and C6000 DSP
  http://focus.ti.com/docs/toolsw/folders/print/5-6kinterface.html

Related parts, ADS1204:

http://www-s.ti.com/sc/ds/ads1204.pdf

Texas Instruments

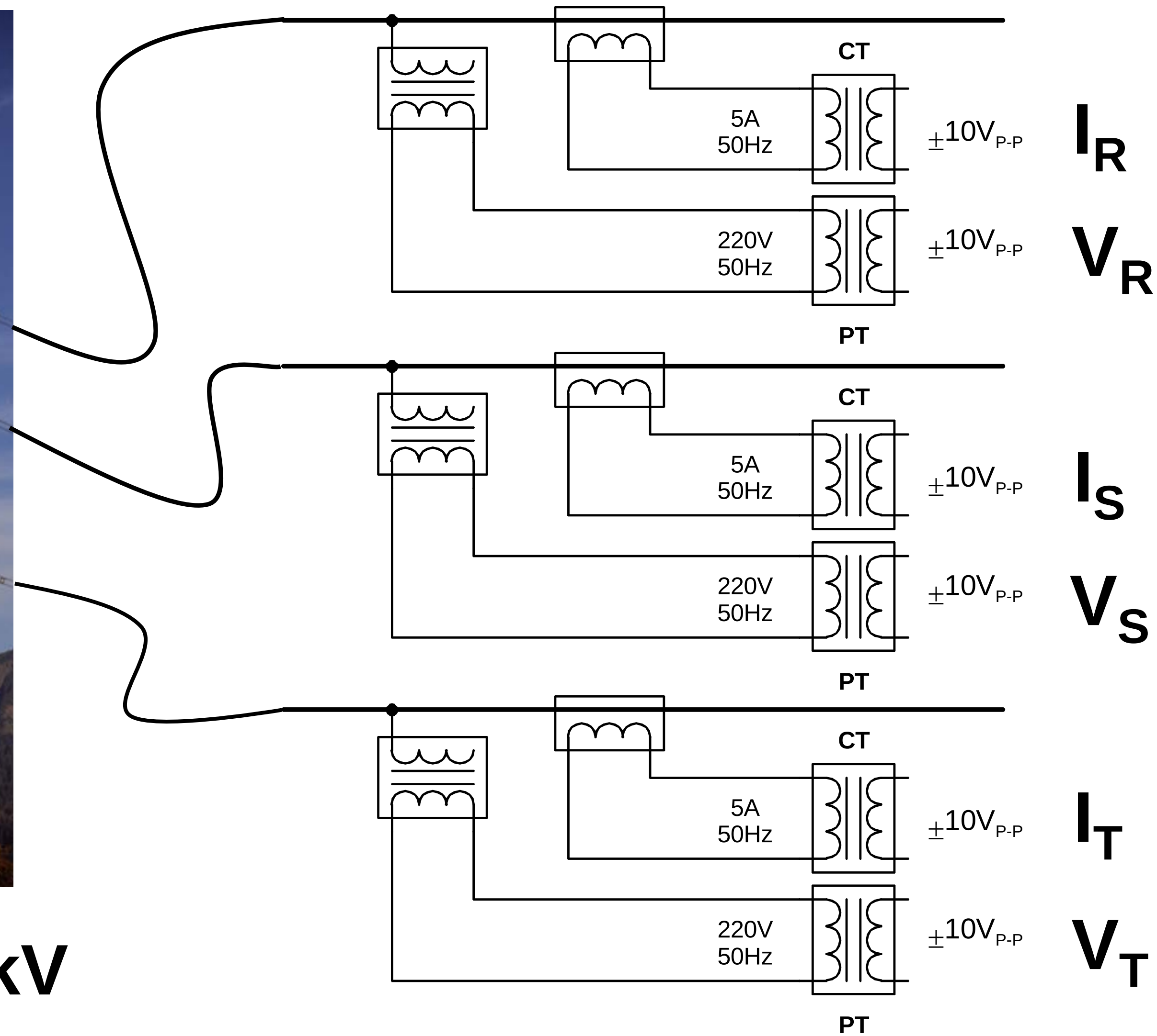
Why Simultaneous Sampling?

Example:

High Performance Analog
For
Power Distribution System

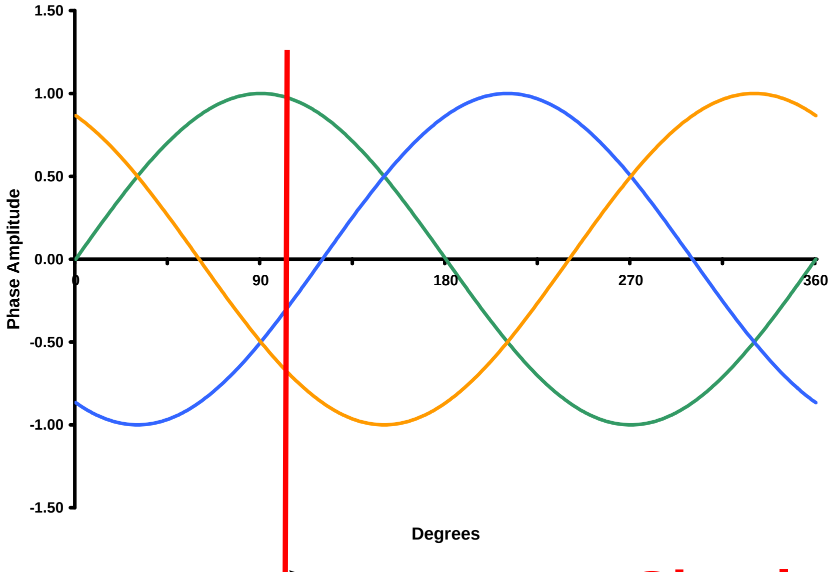
ADC application in Power Distribution System

Three Phase Power Measurement



220kV/110kV/10kV

Three Phase Currents and Voltages



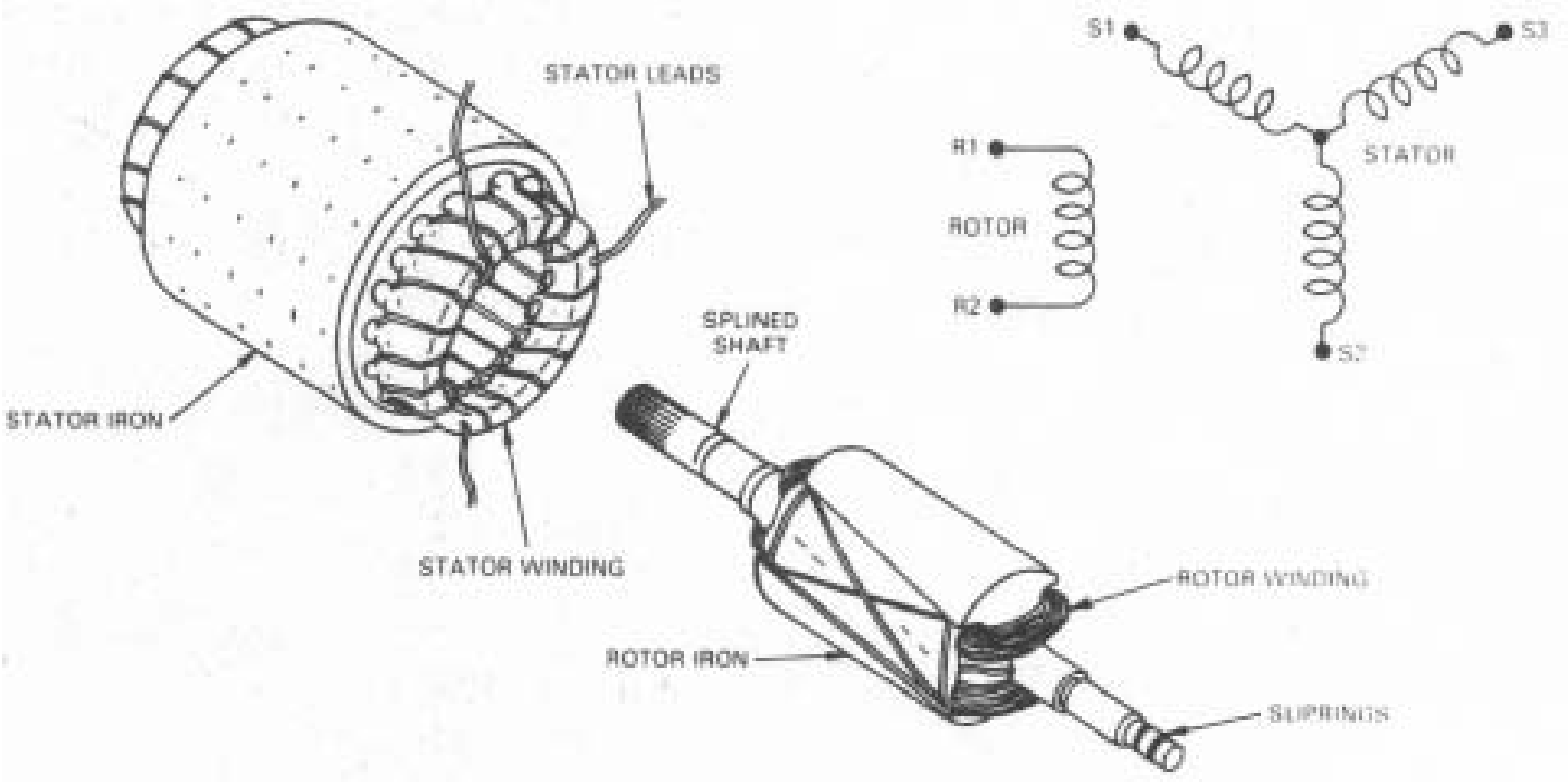
Simultaneous Sampling

$$V_R(t)=V_R*\sin(\omega t)$$
$$V_S(t)=V_S*\sin(\omega t+120°)$$
$$V_T(t)=V_T*\sin(\omega t-120°)$$
$$I_R(t)=I_R*\sin(\omega t-\phi_1)$$
$$I_S(t)=I_S*\sin(\omega t+120°-\phi_2)$$
$$I_T(t)=I_T*\sin(\omega t-120°-\phi_3)$$

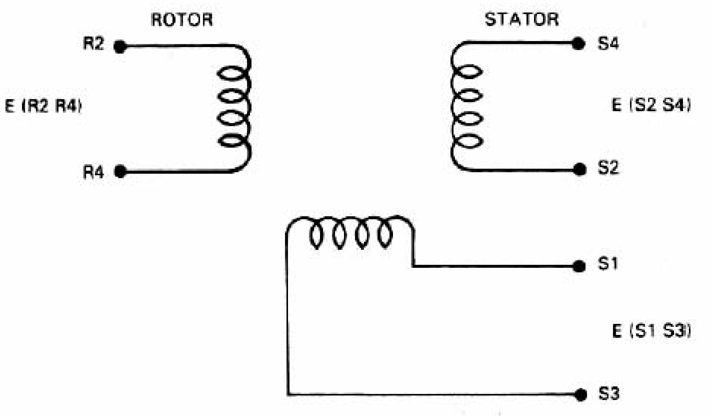
Simultaneous measurement of six signals needed for correct power measurement:

$$P_R(t)=V_R(t)*I_R(t)$$
$$P_S(t)=V_S(t)*I_S(t)$$
$$P_T(t)=V_T(t)*I_T(t)$$

Internal structure of a Synchro Control transmitter

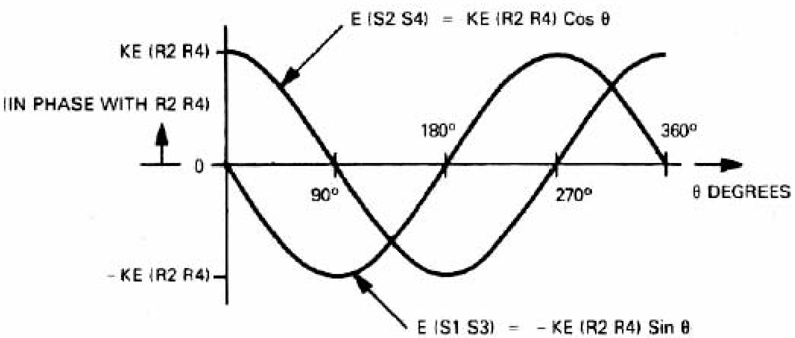


Resolver (2 Phase) and Synchro (3 Phase) Connection Convention

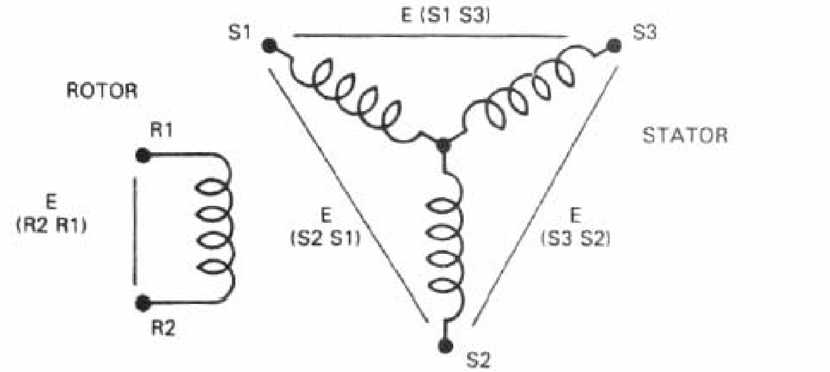


E (S1 S3) = − KE (R2 R4) Sin θ
E (S2 S4) = KE (R2 R4) Cos θ

WHERE R2 = R_H
AND R4 = R_{LO} ON CONVERTERS

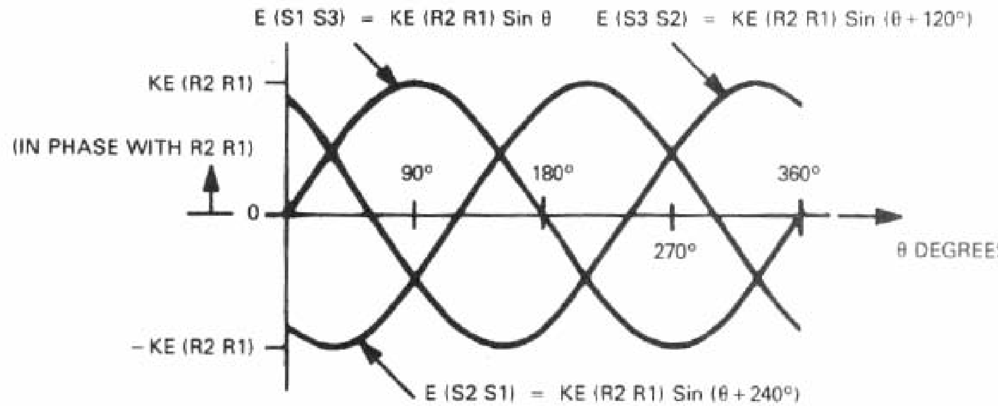


OUTPUTS AS A FUNCTION OF INCREASING ANGLE (FROM ELECTRICAL ZERO) FROM A STANDARD RESOLVER TRANSMITTER OR



E (S1 S3) = KE (R2 R1) Sin θ
E (S3 S2) = KE (R2 R1) Sin (θ + 120°)
E (S2 S1) = KE (R2 R1) Sin (θ + 240°)

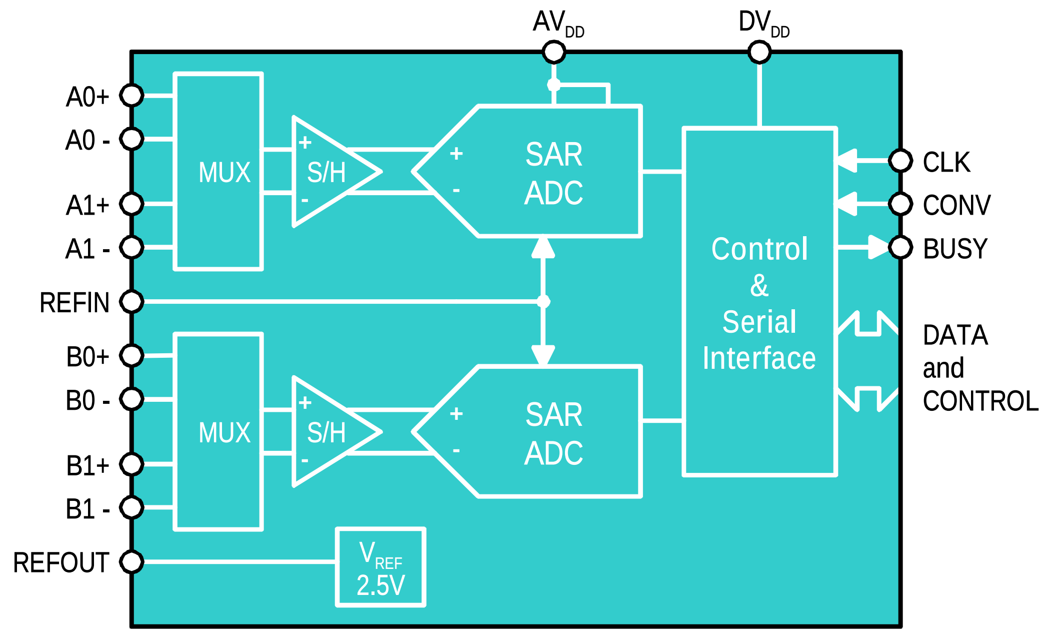
WHERE R1 = R_H
R2 = R_{LO} ON CONVERTERS



OUTPUTS AS A FUNCTION OF INCREASING ANGLE (FROM ELECTRICAL ZERO)

ADS8361

16bit 500kSPS, 4 ch. Simultaneous Sampling SAR ADCs



Features:

- 4 Fully Differential Inputs
- 2 Independent 16-Bit ADCs
- 500kSPS Sample Rate per ADC
- 2 Sample and Holds
- Internal VREF (+2.5V)
- Serial Data-Bus
- Power - 200mW max
- 24 pin SSOP and QFN 32 (5x5)

Key Differentiators:

- 16-Bit Upgrade to the 12-Bit ADS7861
- Pin Compatible With the ADS7861
- Low price 1Ku $8.75

Applications:

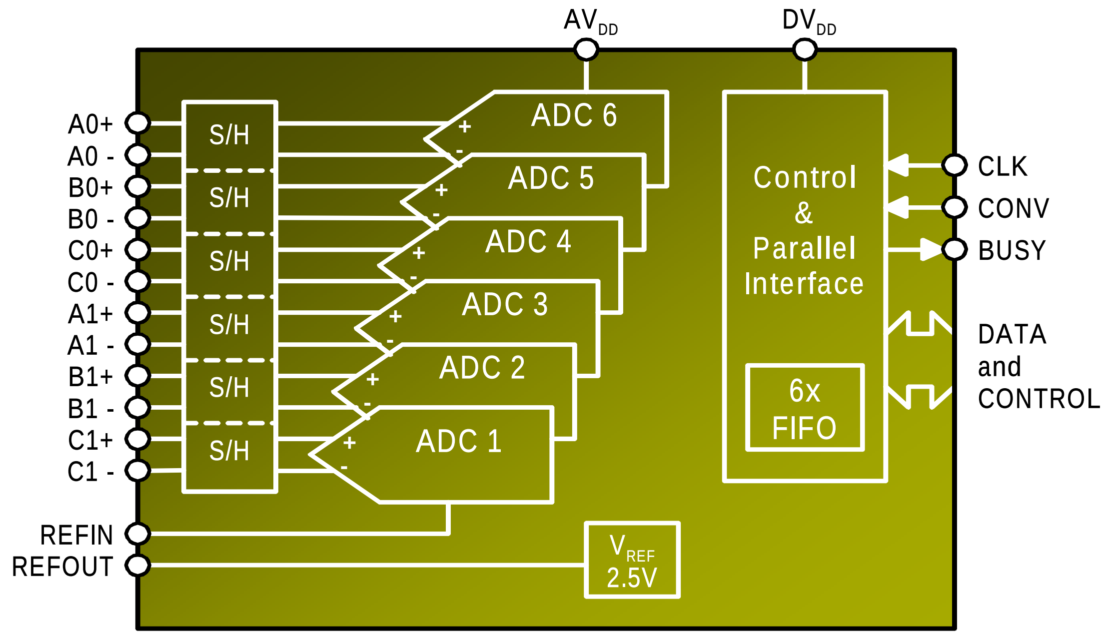
- Closed-Loop Servo Control
- Machine and Motion Control
- Multi-Axis Positioning
- 3-Phase Power Control
- Motor Control

ADS8364

16-bit 250kSPS, 6 ch. Simultaneous Sampling SAR ADCs

Key Features

- 6 Fully Differential Inputs
- 6 Independent 16-bit ADCs
- 250kSPS Sample Rate per ADC
- 6 Sample and Holds
- 6 FIFO Registers
- Internal VREF (+2.5V)
- Power - 470mW max
- 64 pin TQFP



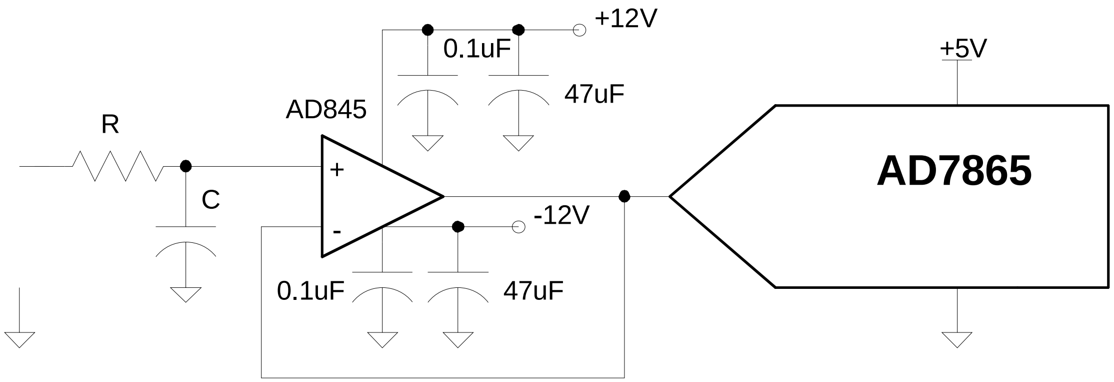
Key Differentiators

- First In Industry – 6 Channels
- Low price
  - ASD8364 1Ku $17.23
- Functional Compatible 16-Bit Upgrade for ADS7864.

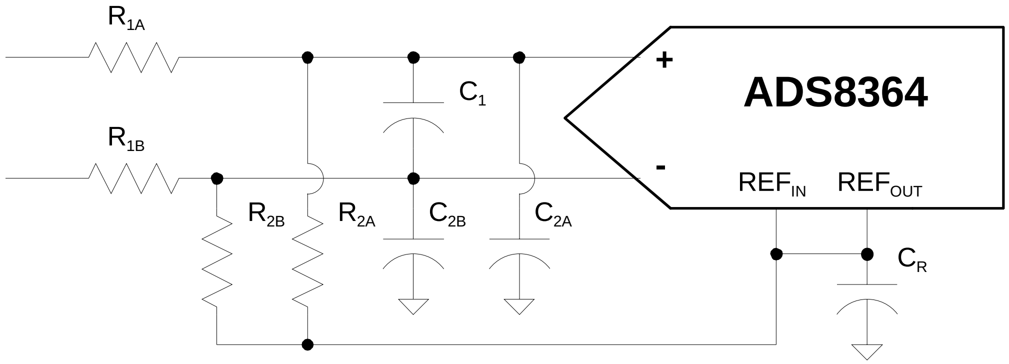
Applications

- Closed-Loop Servo Control
- Machine and Motion Control
- Multi-Axis Positioning
- 3-Phase Power Control
- Motor Control

Competitive Comparison

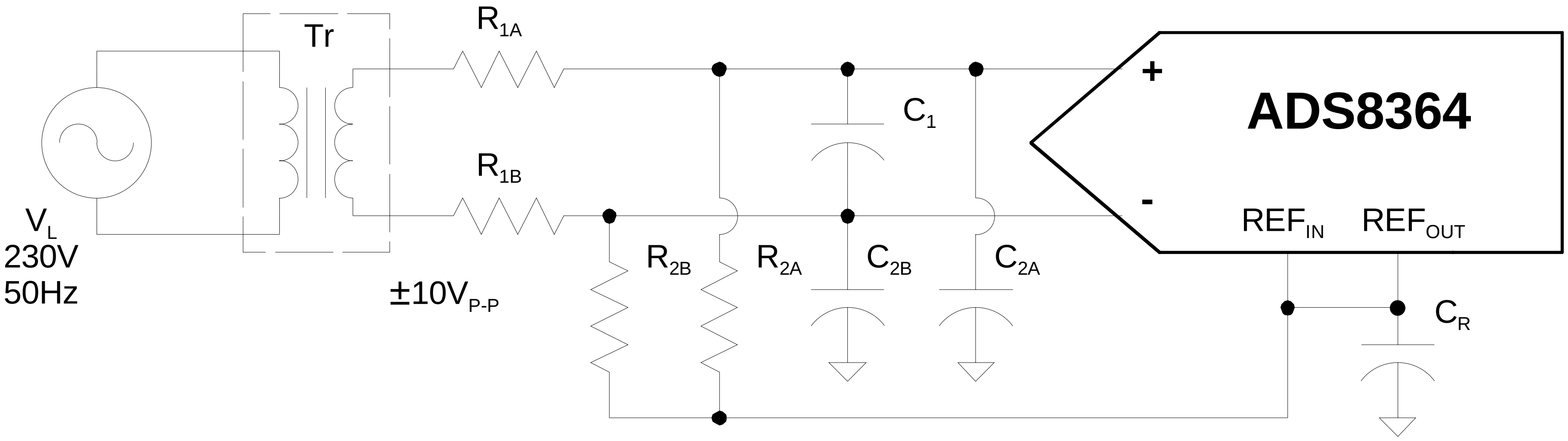


- Requires additional operational amplifier
- Requires two additional analog power supplies
- Single ended input, poor CMVR
- Additional errors due to op amp characteristics



- Differential input, high CMVR
- Only one power supply
- Optimum performances

Differential Signal Measurement with ADS8364

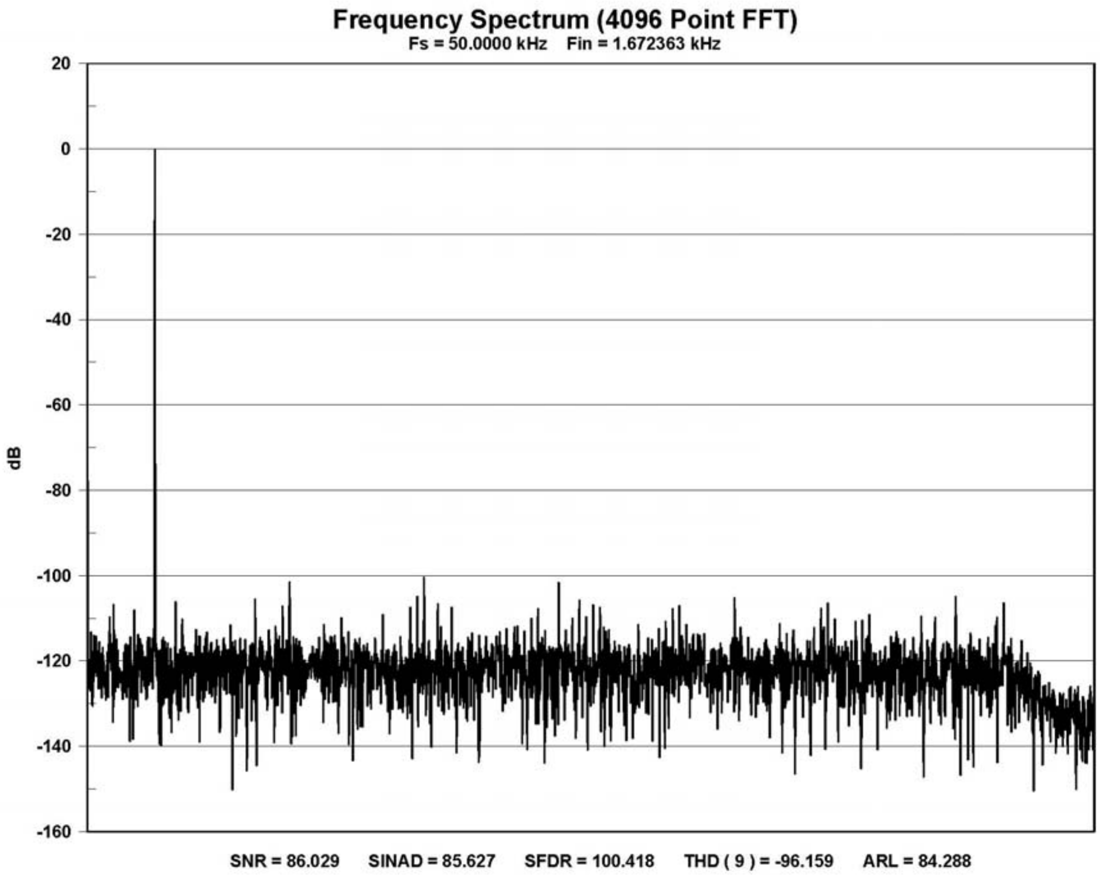


ADS8364 Example:
- **Clock 3.8MHz**
- **38kSPS**
- **Sampling time 21.84μs**
- **Conversion time 4.47μs**

$R_{1A} = R_{1B} = 4k\Omega$
$R_{2A} = R_{2B} = 1k\Omega$
$C_1 = 1.8nF$
$C_{2A} = C_{2B} = 0.18nF$

ADS8364 Example Measurement Results
Fs = 50kHz, Fin = 1.7kHz

SNR = 86dB
SINAD = 85.6dB
SFDR = 100.4dB
THD = -96.2dB



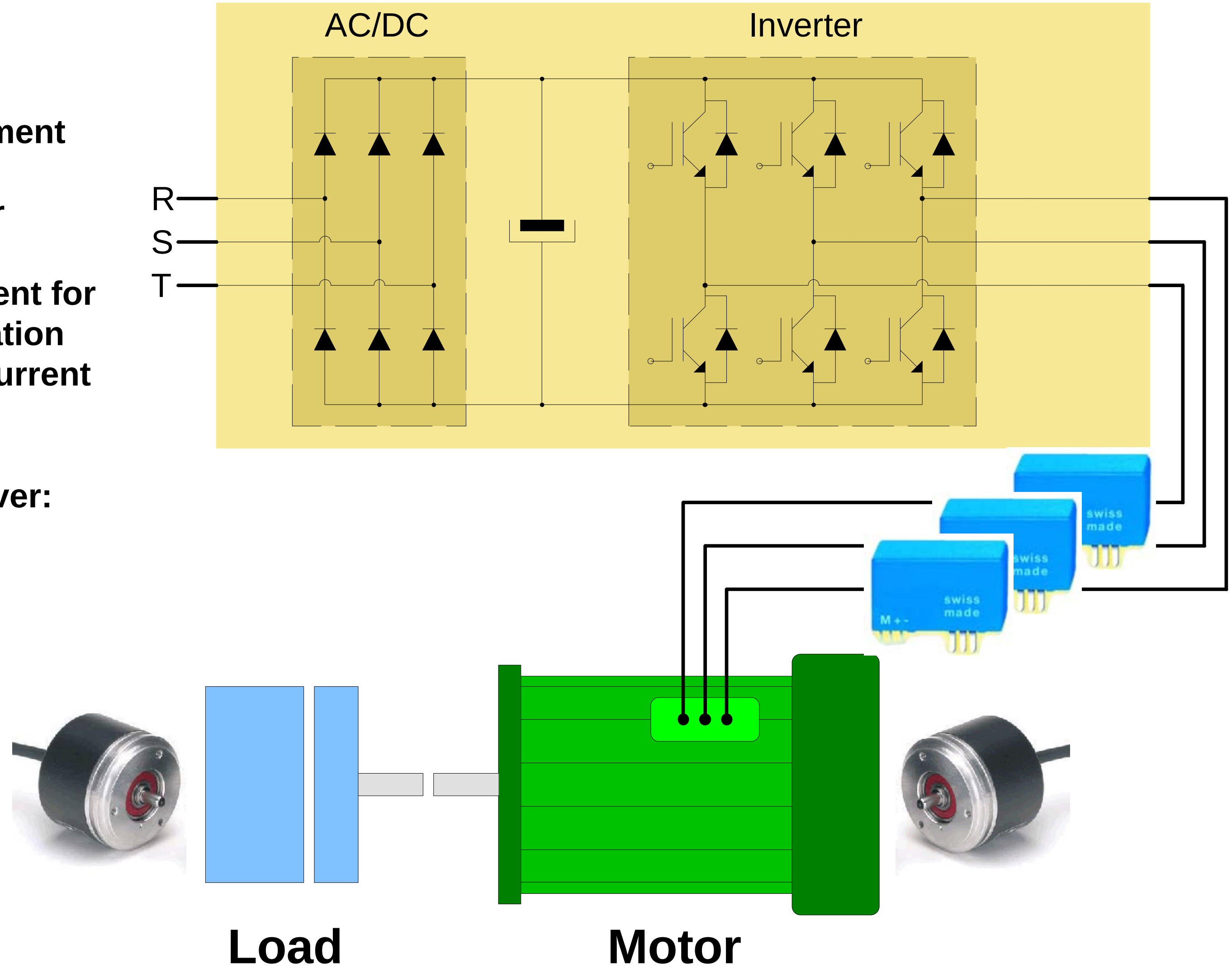
Measurements for Servo Application

Motor Current Measurement (2-Phase or 3-Phase):
- **Motor current value for control algorithm**
- **Sign of the phase current for "dead time" compensation**
- **Over-Load and Over Current protection**

Motor Encoder or Resolver:
- **Rotor Speed**
- **Rotor Position**

Load Encoder:
- **Load Position**

- **DC-Link voltage**
- **Temperature**
- **Etc…**

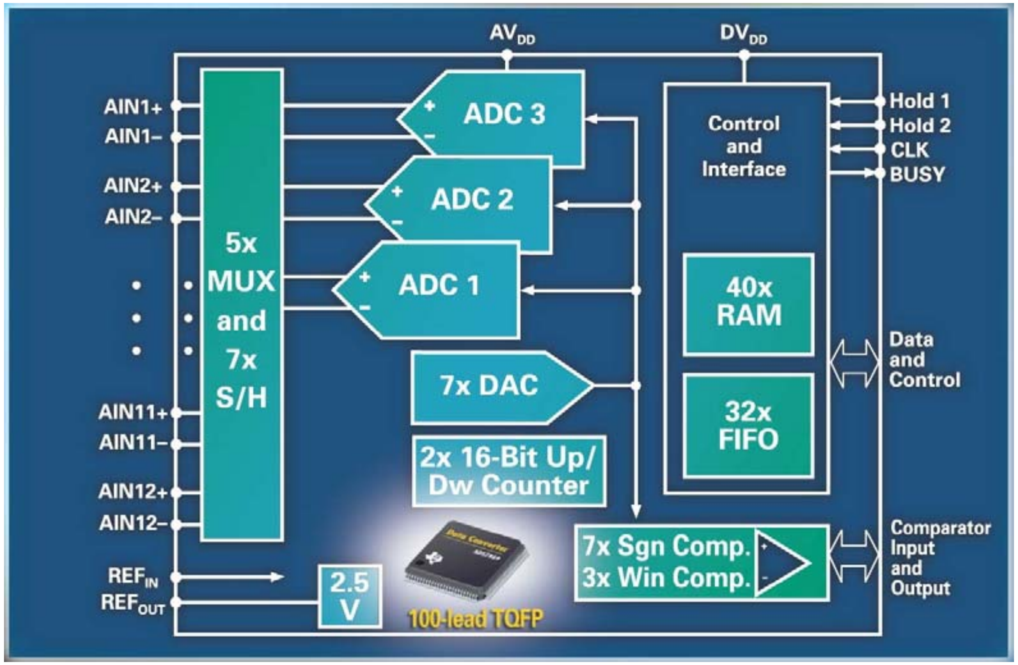


ADS7869

12-bit 1MSPS, 12 ch. Simultaneous Sampling SAR ADCs

Key Features

- 12 Fully Differential Inputs
- 3 Independent 12-bit ADCs
- 1MSPS sample rate per ADC
- 7 Sample and Holds
- 5 Multiplexers
- 7 Sign and 3 Win. Comparator
- 2 Up/Down 16-Bit Counters
- 100 pin TQFP



Key Differentiators

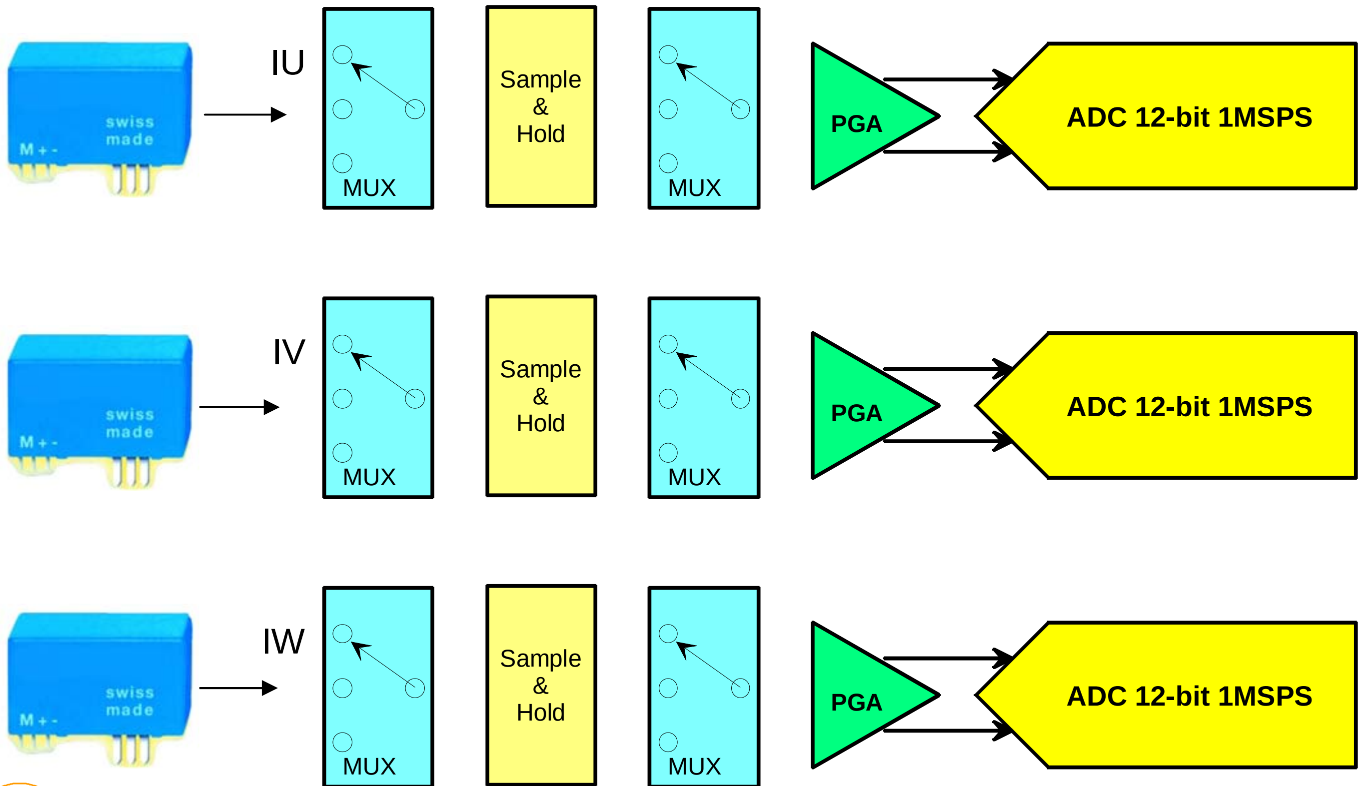
- First In Industry –
  Complete Motor Control Front End
- Low price
  - ADS7869 1Ku $14.56

Applications

- Closed-Loop Servo Control
- Machine and Motion control
- Multi-Axis Positioning
- Motor Control

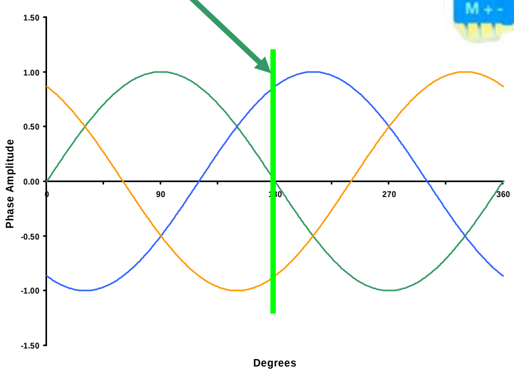
Motor Current Measurement with ADS7869

Three:
- **Sample & Hold**
- **12BIT ADC 1MSPS**
- **PGA**



iu(t)=IU sin(ωt)
iv(t)=IV sin(ωt+120°)
iw(t)=IW sin(ωt-120°)

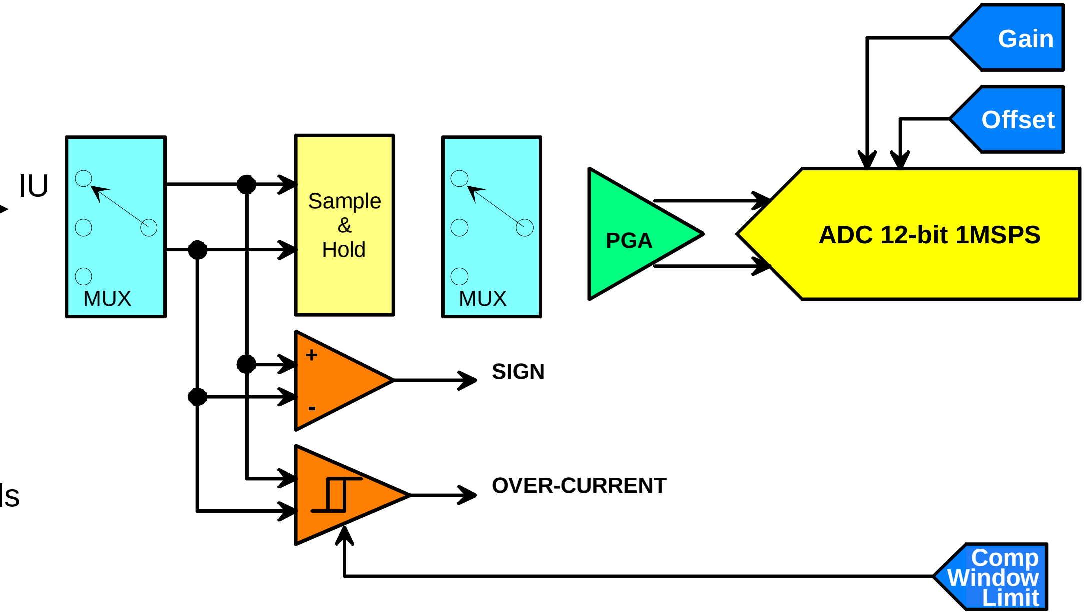
Simultaneous Sampling



Motor Current Measurement with ADS7869

3X :

- **Sample & Hold**
- **12BIT ADC 1MSPS**
- **PGA**
- **Sign Comparators**
- **Window Comp.**



Three simultaneous sampling inputs
- No time difference error in sampling of signals

Three differential inputs
- High CMRR for noisy environment

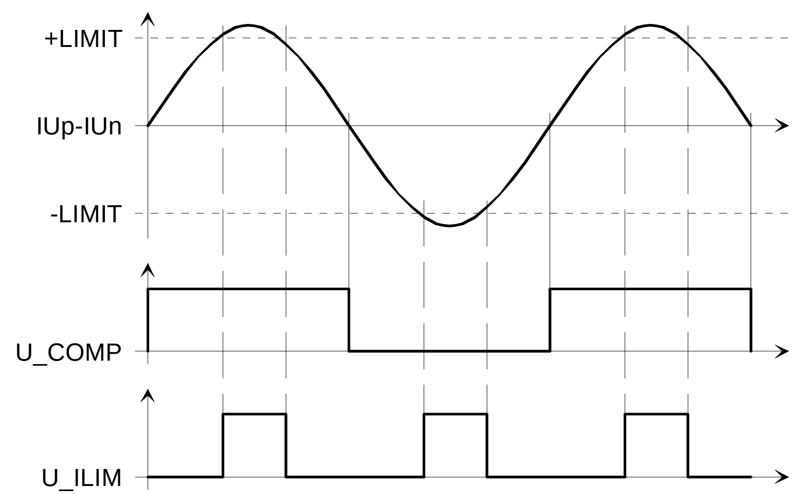
Three PGA are simultaneously scaling inputs
- Same HW for different power range

Three 12 bits 1MSPS ADCs
- Low delay in control algorithm

Three sign comparators
- SW Lockout time compensation

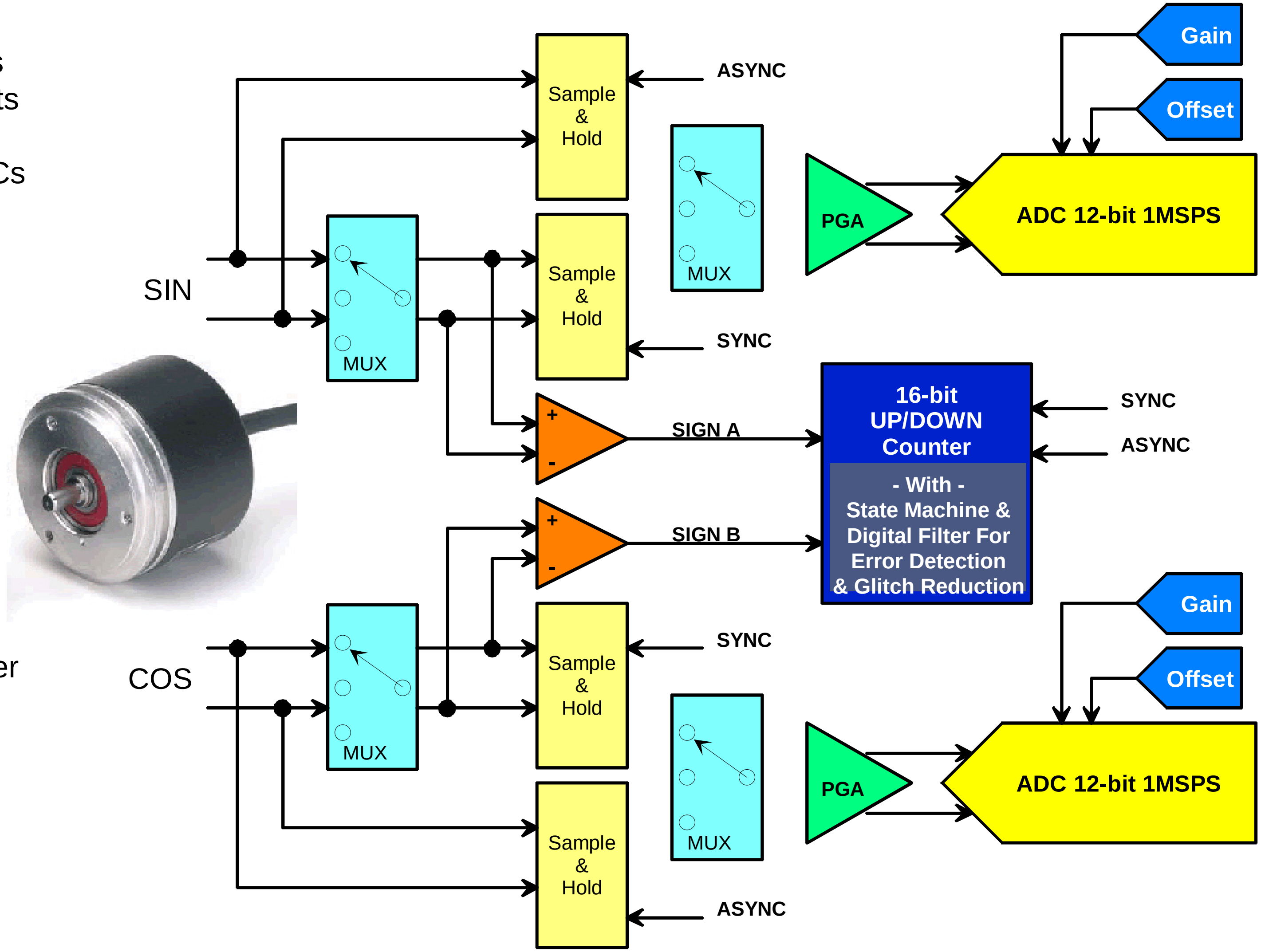
One 8 bit DAC for set up of current limit
- Dynamic control of motor acceleration

Three programmable window comparators
- Separate control of motor phases over-current



Incremental Encoder Measurement with ADS7869

Two Synchronous inputs
Two Asynchronous inputs
Differential inputs
Two 12 bits 1MSPS ADCs
20% Gain correction
20% Offset correction



Two Sign Comparators
16-bit UP/DOWN Counter
State Machine
Digital Filter
4 Registers
26-bit total resolution

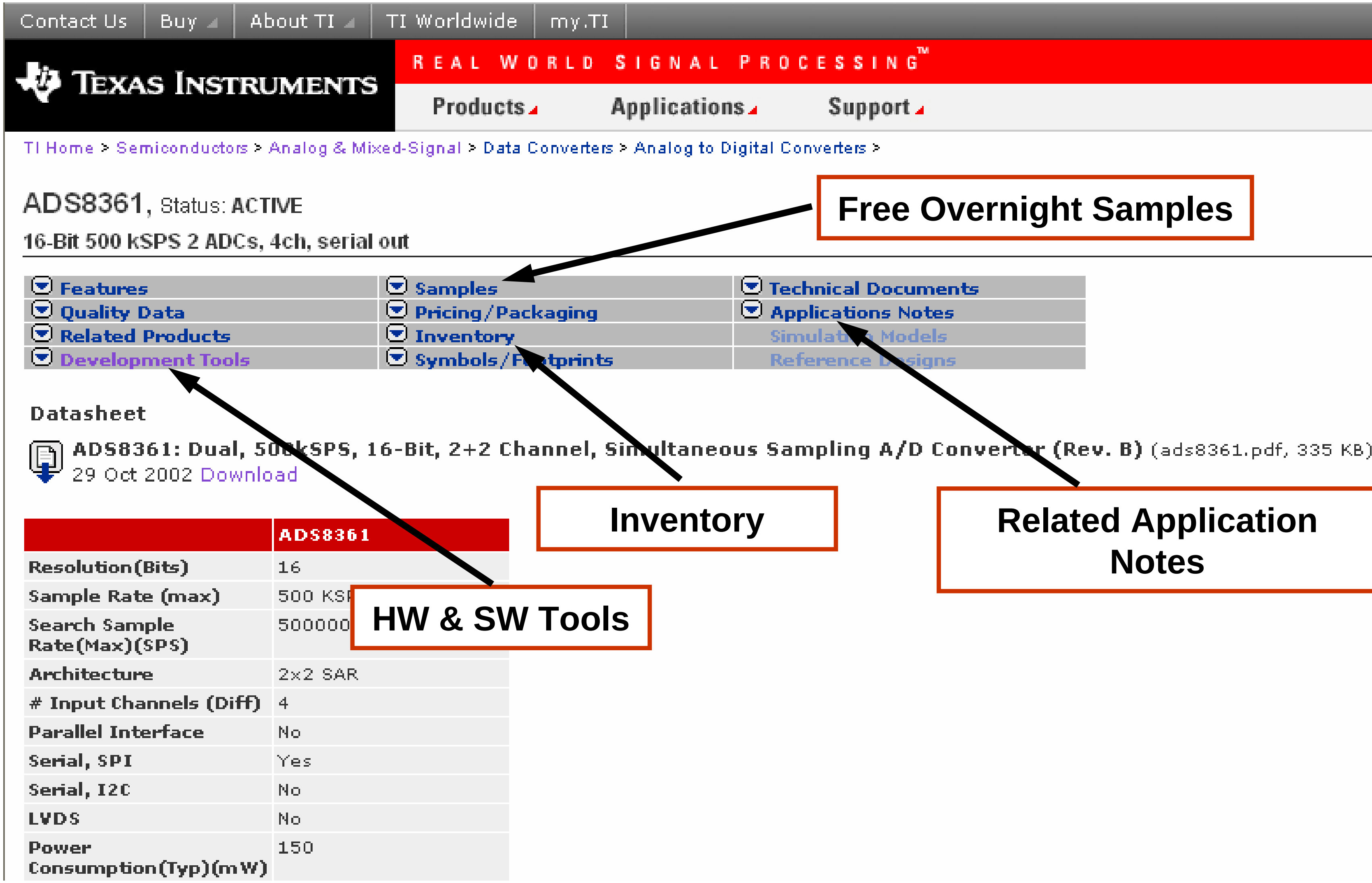
Getting Started: analog.ti.com

Product Listing

HW & SW Tools

Application Notes

Samples, Development Tools and more



Data Converter Software Plug-In

Data Converter Software support

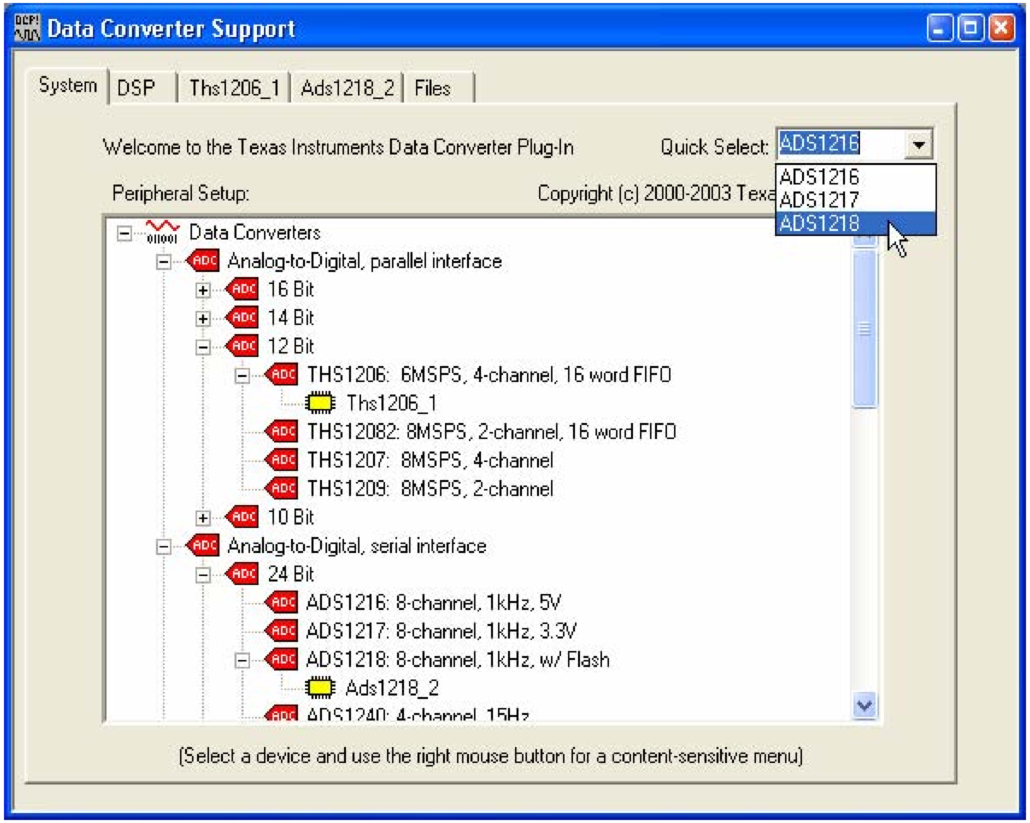
embedded into

Code Composer Studio (CCS)

Software for Data Converters?

- **Today's data converters need software support due to:**
  - On-chip features like
    - Selectable input channels
    - On-chip filters
    - Integrated FIFOs
    - Adjustable gain
  - Complex configuration
    - Some parts have more than 40 registers and 640 control-bits
    - Coding of registers is tedious and error prone
- **Customer benefits:**
  - Faster system time to market
  - Reduced development cost
- **Software support helps:**
  - The DSP software developer:
    - No need to learn "that crazy analog part"
  - The analog designer:
    - No need to learn DSP programming just to test "this neat data converter"

Software Support: The Converters



Supports 117 devices:

- 4 devices on the C2800 DSP platform
- 86 devices on the C5400 DSP platform
- 26 devices on the C5500 DSP platform
- 75 devices on the C6200/C6700 DSP platform
- 21 devices on the C6400 DSP platform

- **Select:**
  - Virtually any number of data converters
  - Nearly every combination (limitation is the DSP)
- **Supports:**
  - Analog to Digital converters
  - Digital to Analog converters
  - Codecs
  - For a complete list of supported devices, visit http://www.ti.com/sc/dcplug-in
- **Not hardware specific:**
  - Can be used on the analog EVMs or with the customer’s own hardware, as long as there is no special hardware setup necessary (e.g. controlling a multiplexer)

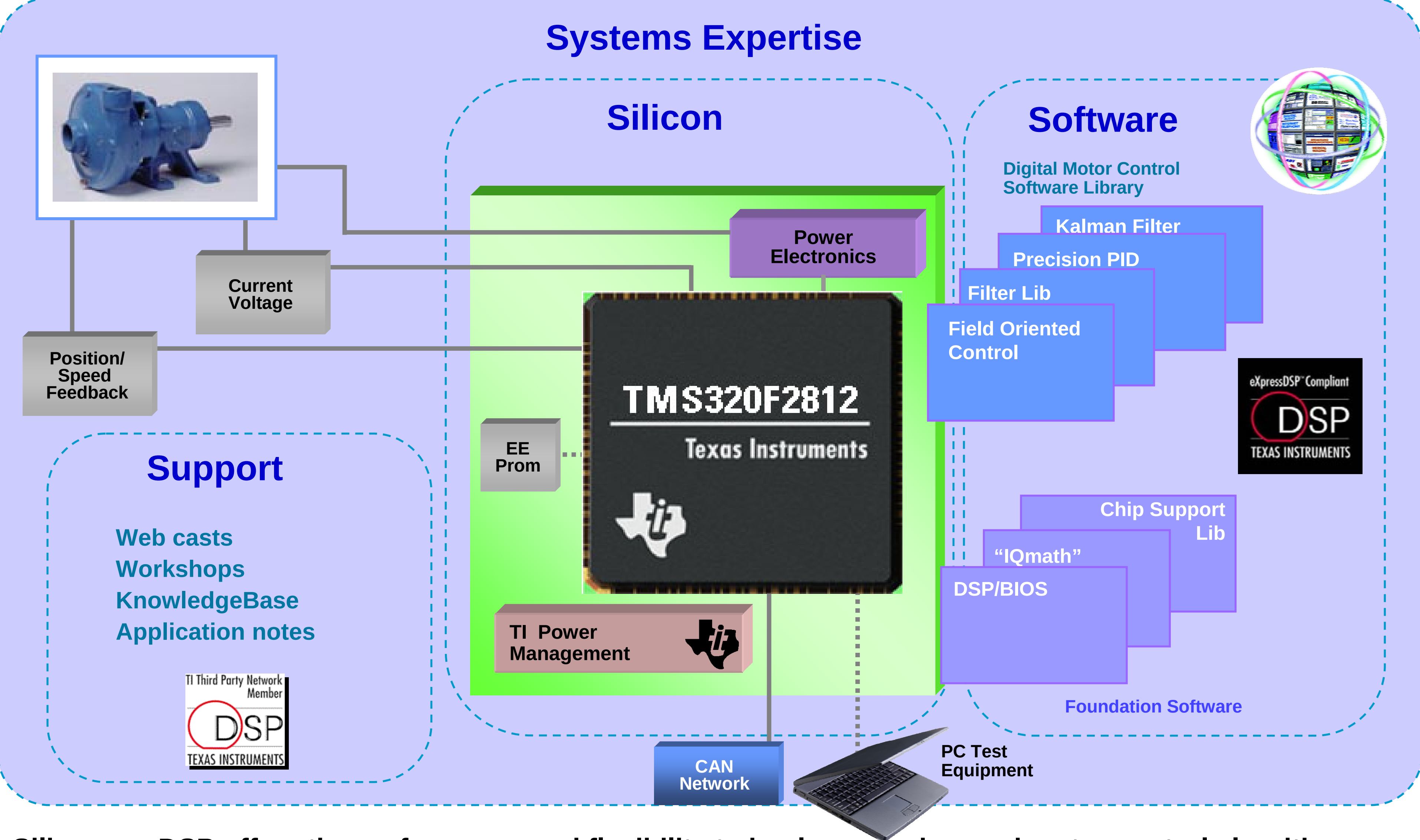
High Performance Analog for Motor Control

Application Collateral

- Evaluation Boards complete with User's Guide, Schematic, & BOM on web
- Device specific application notes – linked directly from product folder!
- Code Composer Studio Example Projects for C2000, C5000, C6000 DSPs
- Complete "Signal Chain" prototyping system for C2x processors coming soon!
- EVMs available for purchase at www.ti-estore.com

Related Application Notes

- Using a SAR A/D Converter for Current Measurement in Motor Control Applications (sbaa081.htm)
- Understanding the CAN Controller on the TMS320C24x DSP Controller (spra500.htm)
- RS-485 for Digital Motor Control Applications (slla143.htm)
- Interfacing the ADS8361 to the TMS320F2812 DSP (slaa167.htm)
- Interfacing the ADS8364 to the TMS320F2812 DSP (slaa163.htm)



Silicon: DSP offers the performance and flexibility to implement advanced motor control algorithms
Software: Modular software reduces time-to-market
Tools: Advanced Development Tools make development easy
Analog: Offers a broad selection of signal conditioning and power management