An Exploration of Ultra-Low Cost Motor Drive Design

By

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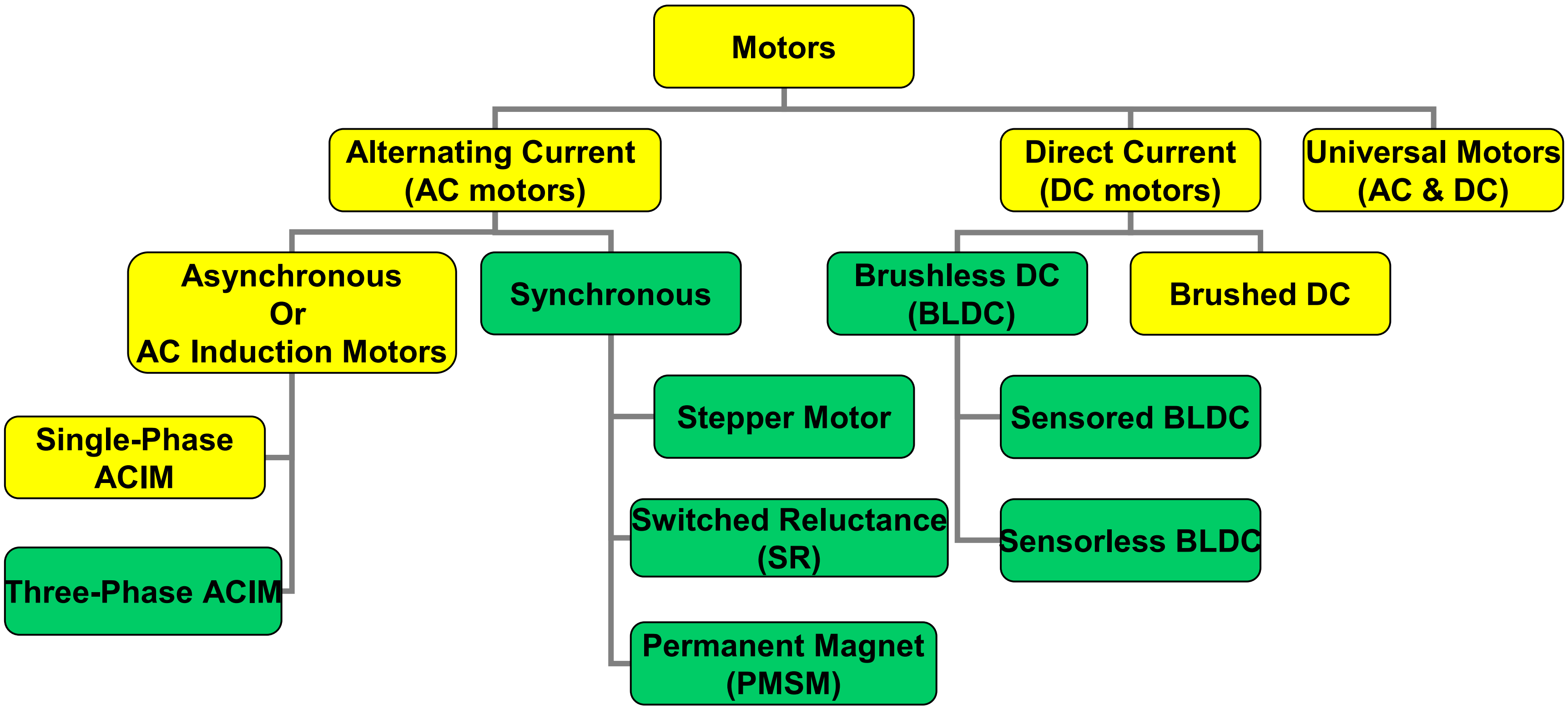
Agenda

- **Explore the design trade-offs associated with creating ultra-low cost motor drives, without compromising control techniques, energy efficiency or safety**

- **Examine three designs:**
  - dsPICDEM™ MSCM—a simple stepper-motor drive
  - dsPICDEM™ MCLV—a standard low-voltage sensorless drive
  - dsPICDEM™ MCHV—a complex isolated high-voltage drive

- **Compare the actual Bill of Material (BOM) costs, control techniques, energy efficiency and safety features of the three designs**

Targeted Motor Types



While many different types of motors exist, we focused on supporting the motors in the green blocks. The motors in the yellow blocks can be run without any intelligent control.

Targeted Motor-Control Algorithms

Motor Type	Algorithm
Stepper Motor	Full and Microstepping, Position Control
	Open Loop and Current Control Closed Loop
BLDC and PMSM	Trapezoidal Drive, Hall-Effect Sensor Commutation
	Sinusoidal Drive, Hall-Effect Sensor Commutation
	Trapezoidal Drive, Sensorless BEMF Commutation
	Field Oriented Control, Sensorless Commutation
ACIM	Open Loop Volts/Hertz
	Field Oriented Control with a Shaft Encoder
	Field Oriented Control, Sensorless
	Power Factor Correction (PFC)

Our goal was to support the most common algorithms and the most common hardware feedback circuits.

Efficiency Considerations

Motor	Improve Efficiency by	Circuit Requirements
Stepper	Using closed-loop current control	• 2 current shunt-resistor circuits for current feedback • DSC with motor-control PWMs and fast Analog-to-Digital Converter (DSC)
BLDC	Moving from trapezoidal to sensorless Field-Oriented Control (FOC)	• 2 current shunt-resistor circuits for current feedback • DSC with motor-control PWMs and fast ADC
PMSM	Moving to dual-shunt Sensorless FOC with field weakening	• 2 current shunt-resistor circuits for current feedback • DSC with motor-control PWMs and fast ADC
ACIM	Moving to FOC with field weakening and Power Factor Correction (PFC)	Current Feedback: • 2 current shunt-resistor circuits for current feedback • DSC with motor-control PWMs and fast ADC PFC: • Boost inductor, MOSFET and driver circuit • 2-Voltage reference and op amp circuit • Current shunt-resistor circuit for current feedback • Zero-cross detection for V_{AC} circuit

Safety Considerations

Issue	Improve Safety With	Circuit Requirements
Motor Bus, PFC and Gate Driver Over-Current	PWM fault shutdown	● Current shunt-resistor or a current transformer, and current reference and comparator circuit ● DSC with PWM fault-shutdown input
Motor Bus, PFC and Gate Driver Over-Voltage	PWM fault shutdown	● Over-voltage reference and comparator circuit ● DSC with PWM fault-shutdown input
Gate Driver Under-Voltage	PWM fault shutdown	● Under-voltage reference and comparator circuit ● DSC with PWM fault-shutdown input
User Interface	Isolation from high voltages	● Isolation transformer circuit for digital power and ground ● Opto-isolator for each signal

Note that one fault pin can be used for all fault conditions.

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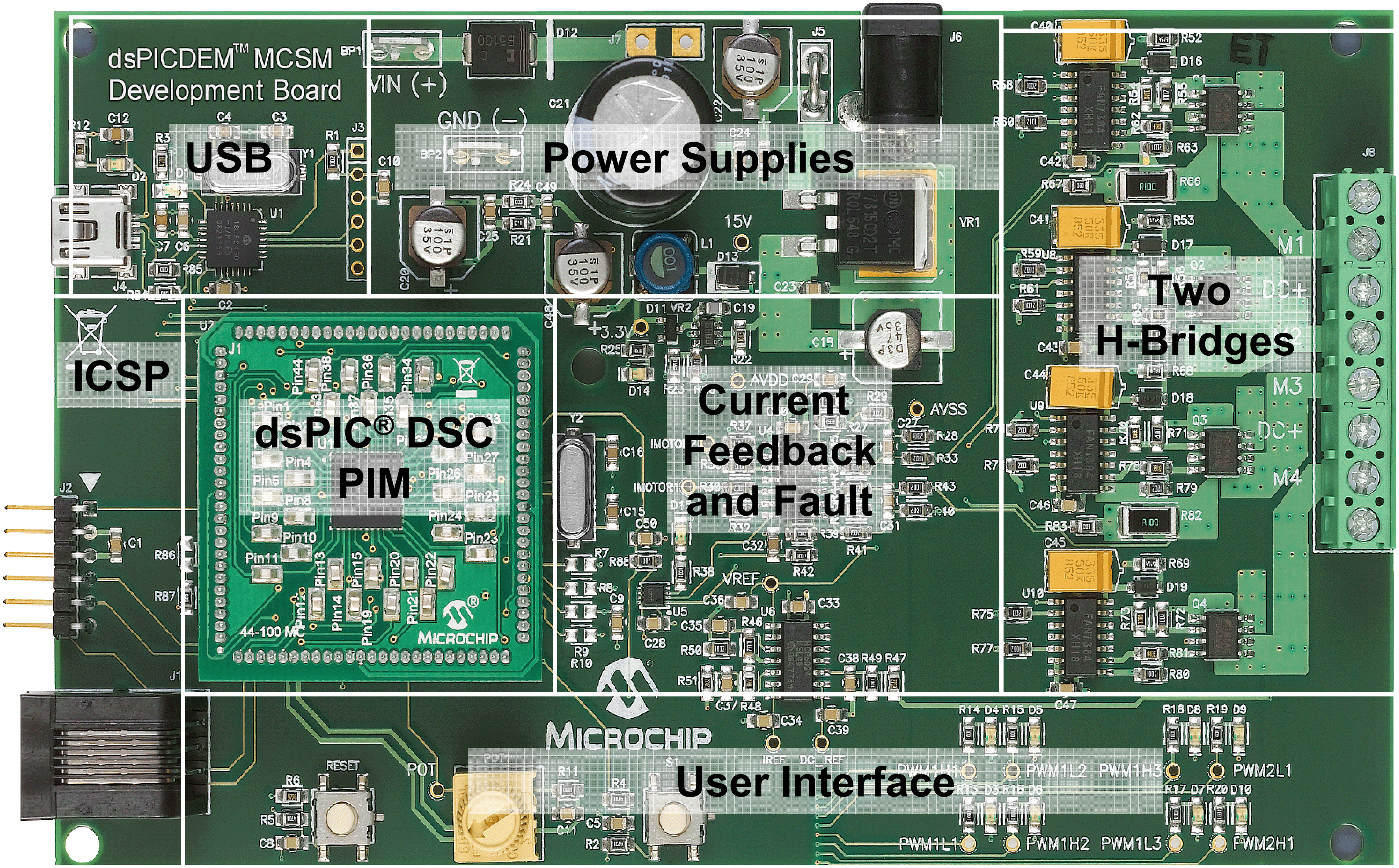
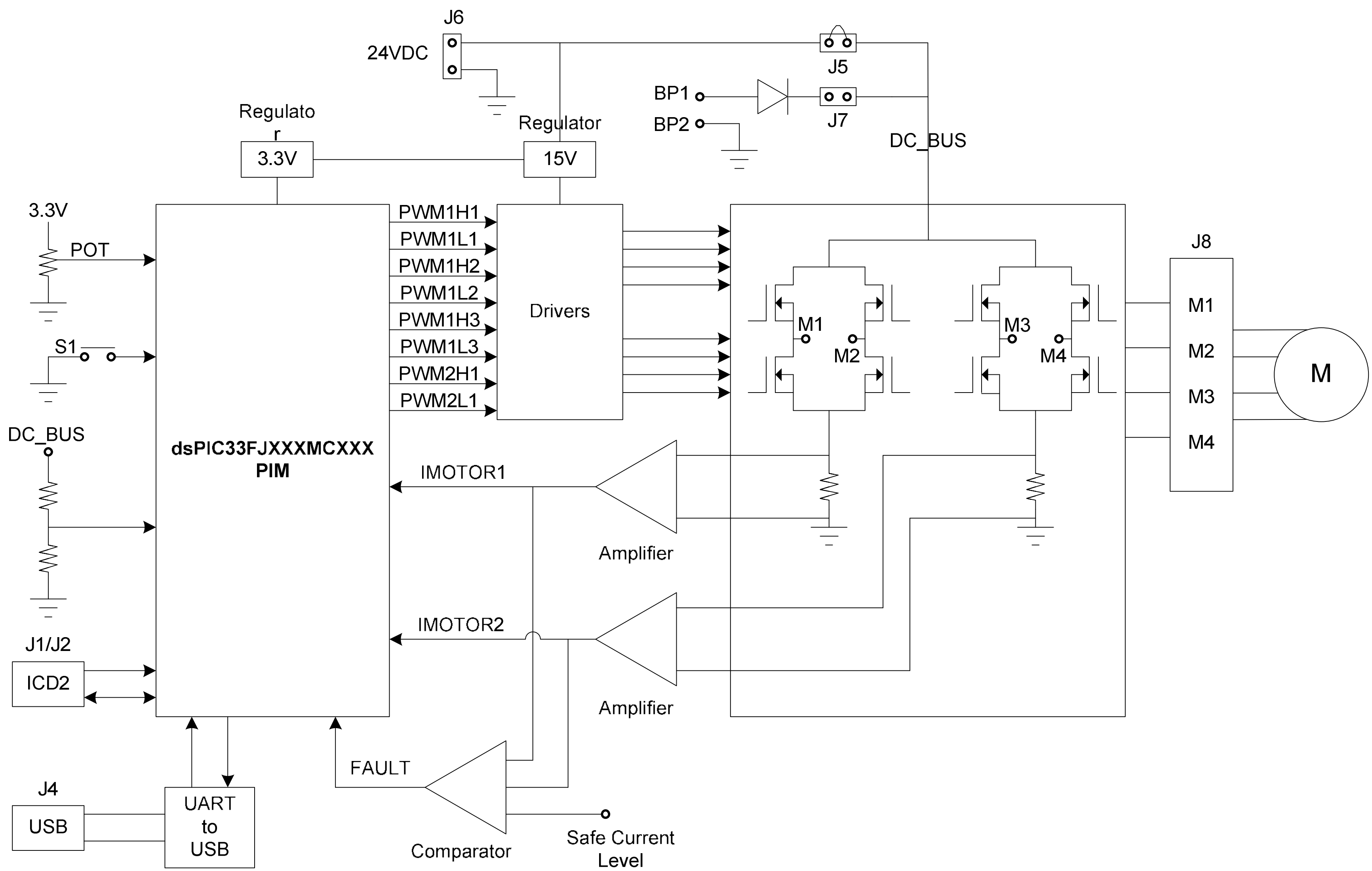
MCSM Specifications

Voltage:	0V to 24V
Peak Current:	20 A
Cont. Current:	12 A
Power:	100 W
Estimated Resell:	$130

MCSM Board Layout



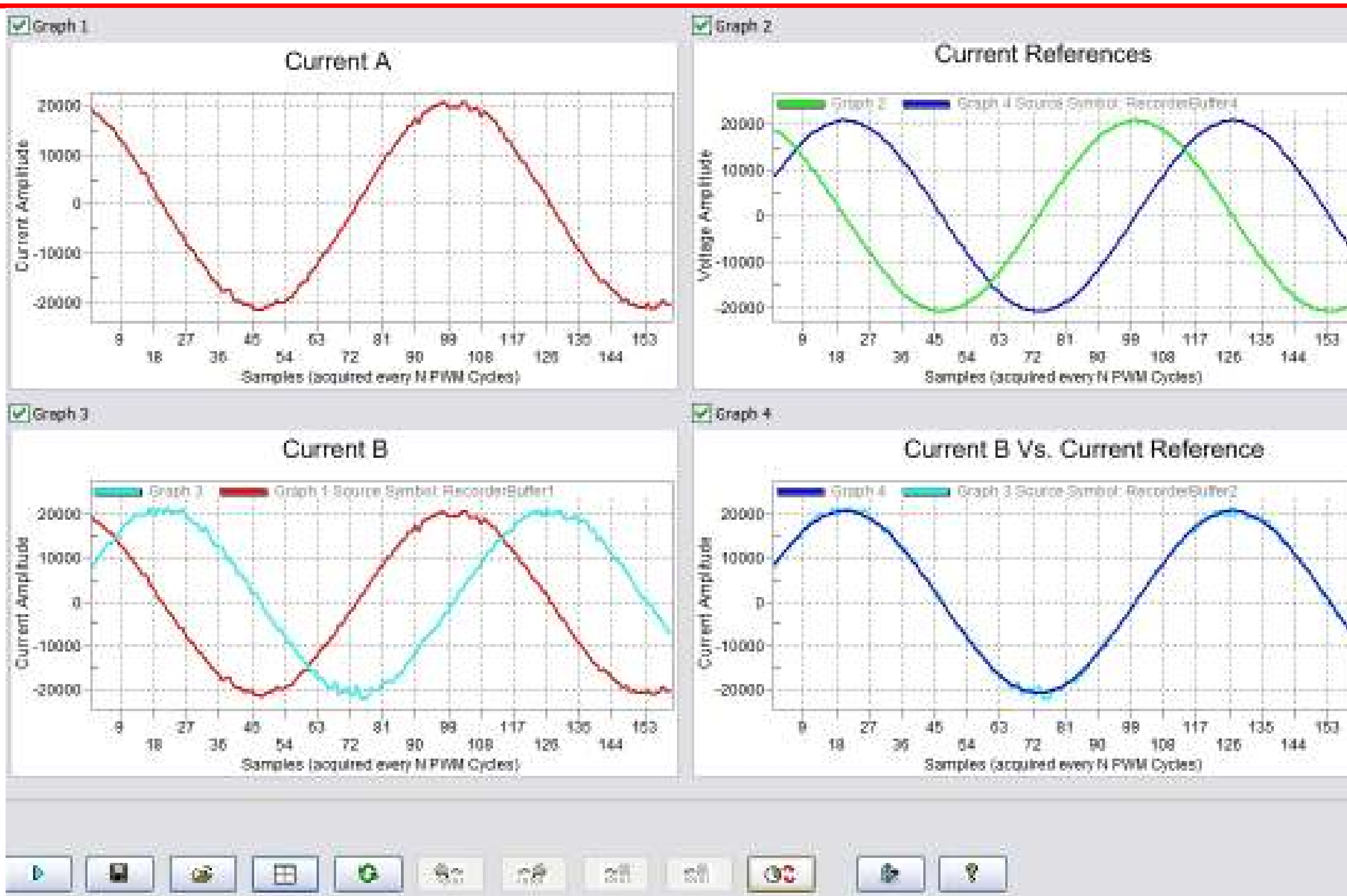
MCSM Block Diagram



Stepper Motor Control Algorithms

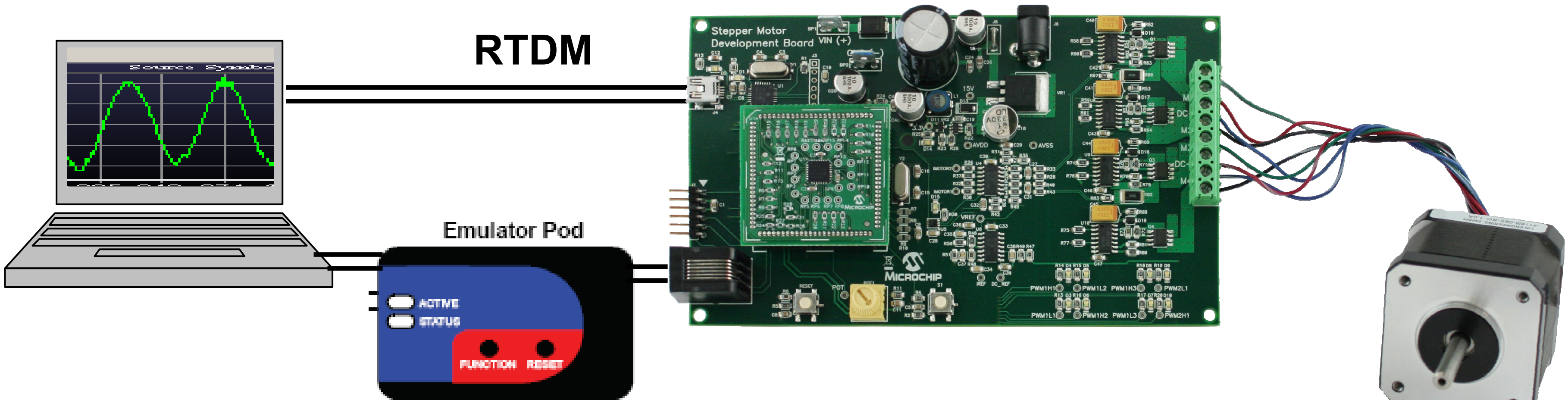
Motor	Control Technique Used by dsPIC® Digital Signal Controller (DSC)	Benefits
Unipolar, Bipolar	Full Stepping, Half Stepping, Micro-Stepping, Position **- Open Loop Control (Fixed Voltage or Fixed Current)**	Easiest
Unipolar, Bipolar	Full Stepping, Half Stepping, Micro-Stepping, Position **- Closed Loop Current PI Control Loop**	Faster Speed, Quieter, Smoother Most Efficient

Test Results



Closed-loop control is more efficient than open loop. Here, you can see that the actual measured motor current (in cyan) closely tracks the reference current commanded by the dsPIC® DSC software (in blue).

Development Environment With Real-Time Data Monitoring

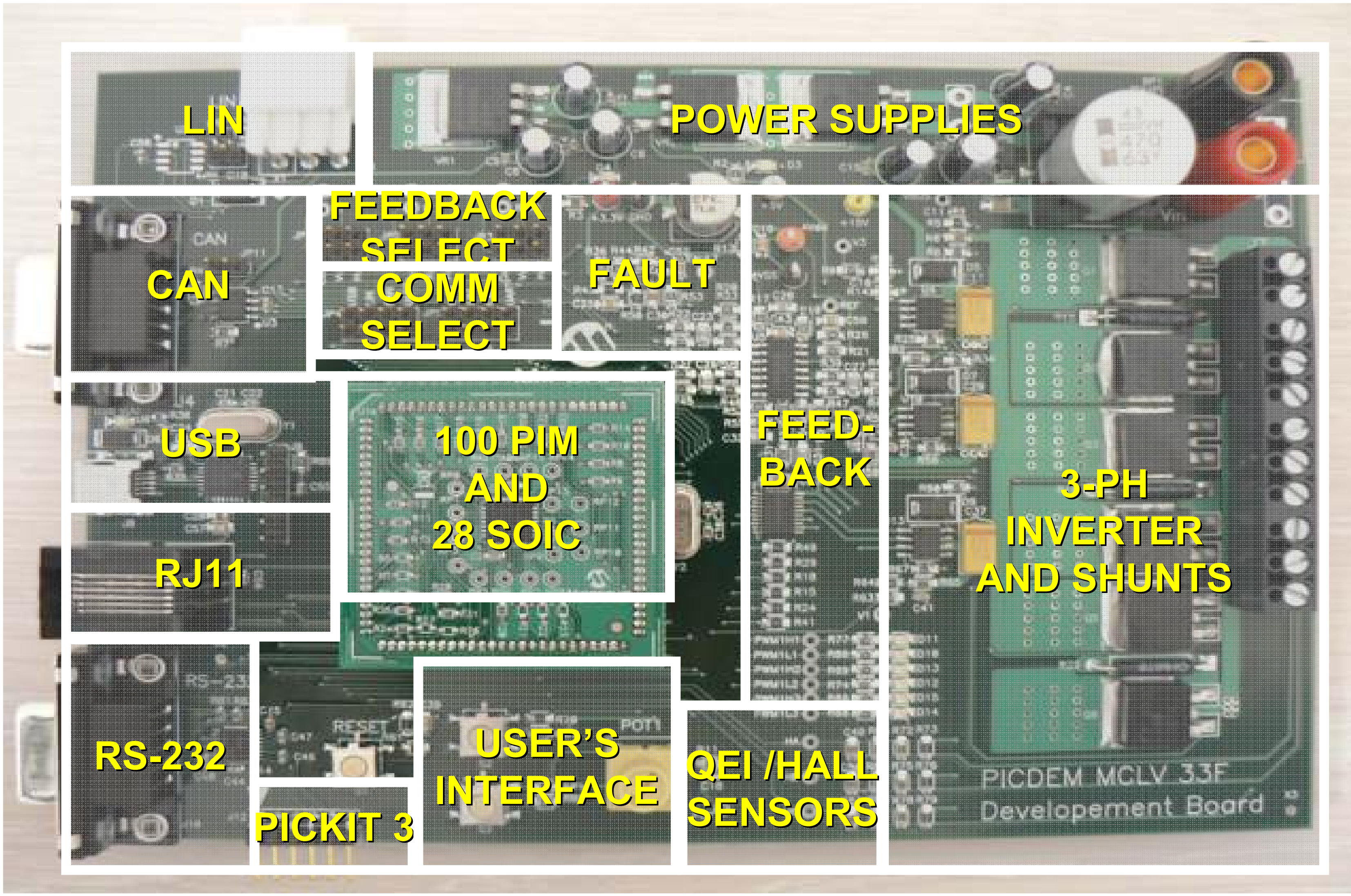


Using the MPLAB® IDE Data-Monitoring and Control Interface (DMCI) with Real-Time Data Monitoring (RTDM), the motor operating mode changes, micro-stepping and position control can be done without stopping the motor, or stopping to rebuild and reprogram the dsPIC® DSC.

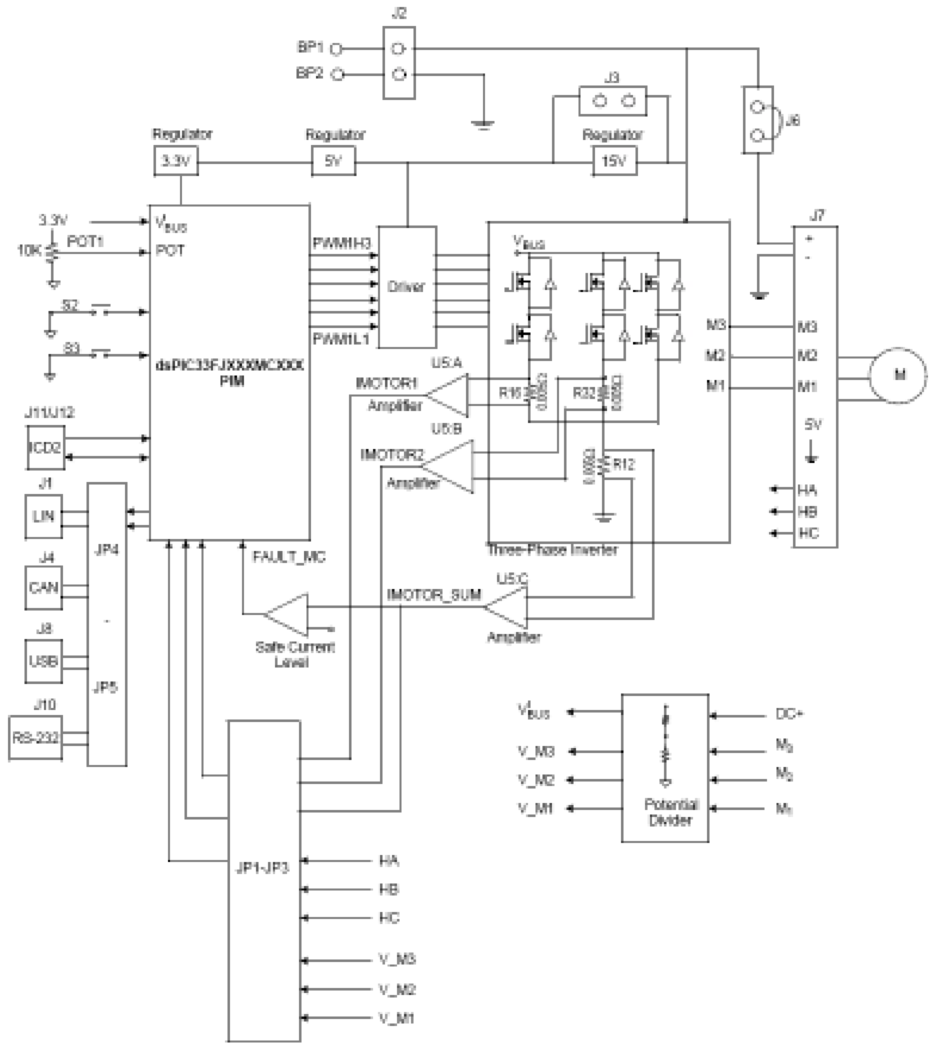
MCLV Specifications

Voltage:	0V to 48V
Peak Current:	20 A
Cont. Current:	12 A
Power:	200 W
Estimated Resell:	$150

MCLV Board Layout



MCLV Block Diagram

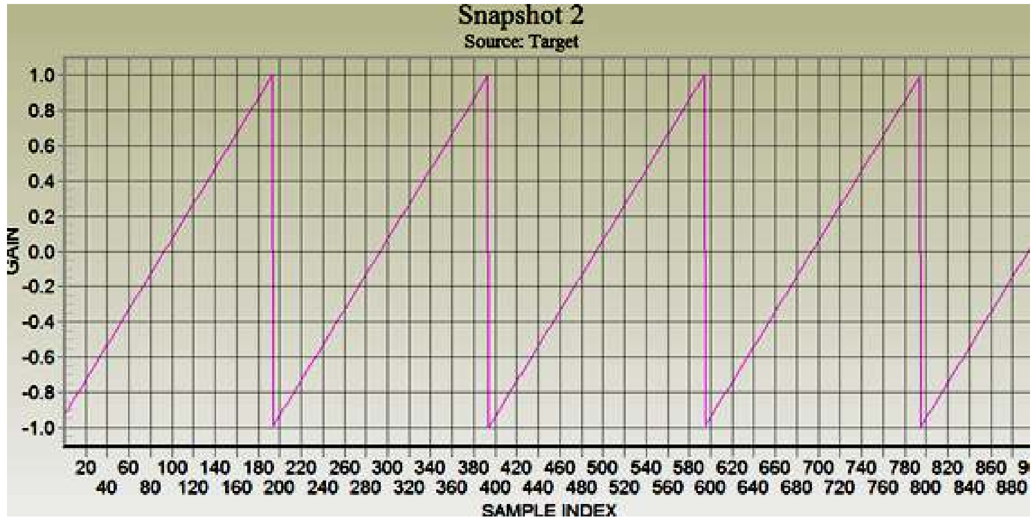


Low-Voltage Motor Control Algorithms

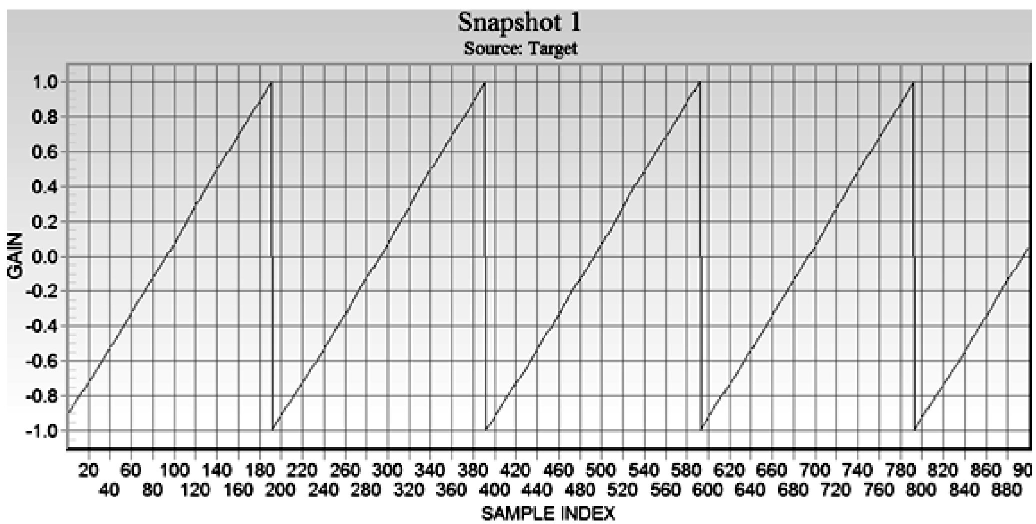
Motor	Control Technique Used by dsPIC® DSC	Benefits
BLDC	Sensored (Hall Effect) (Trapezoidal/120º) **- High-speed operation (5 to 20K RPM)** **- Rapid load changes requiring fast torque response** **- Fast or high accuracy on a servo-position response**	Better Torque Control than BDC
BLDC/PMSM	Sensored (Hall Effect) (Sinusoidal/180º)	Lower Noise
BLDC	Sensorless (requires moderate tuning) (Trapezoidal/120º) **- Back EMF with ADC** **- FIR filtered BEMF with ADC** **- FIR filtered BEMF with ADC and Majority Detect function**	Lower Cost
PMSM	Sensorless (requires advanced tuning) **- FOC with single- or dual-shunt circuits** **- Sliding Mode Observer (SMO) or PLL Estimator** **- Field Weakening, Adaptive Filters, PFC**	Highest Efficiency, Best Torque Control

Sensorless SMO FOC for PMSM Measured Results

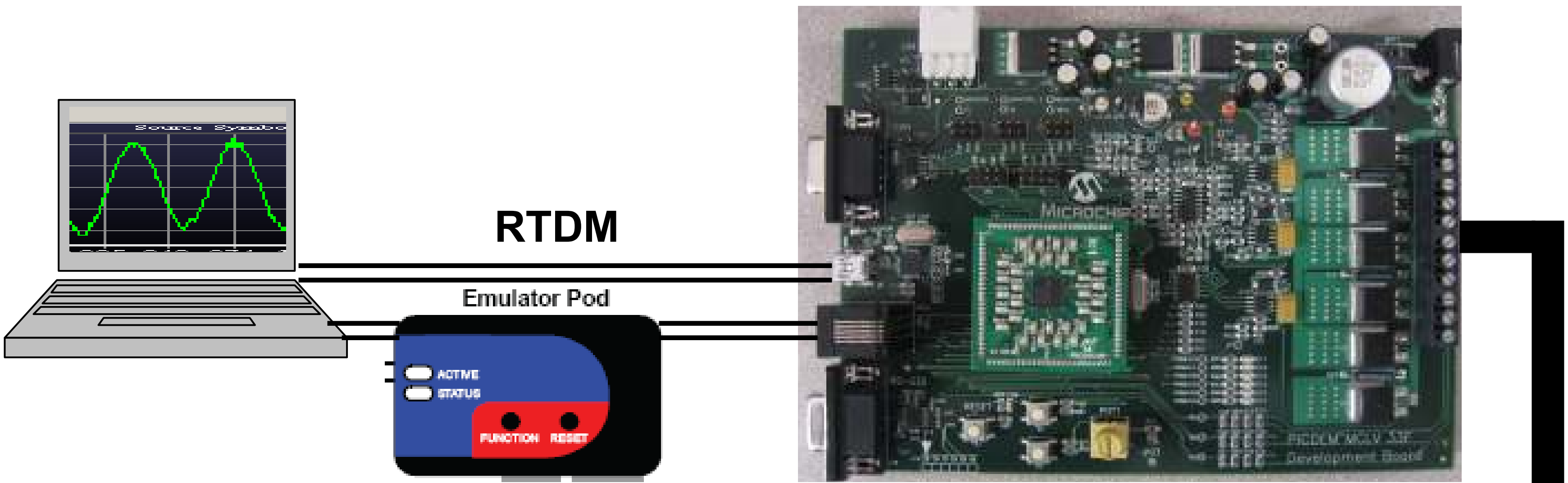
- **Actual Rotor Position**

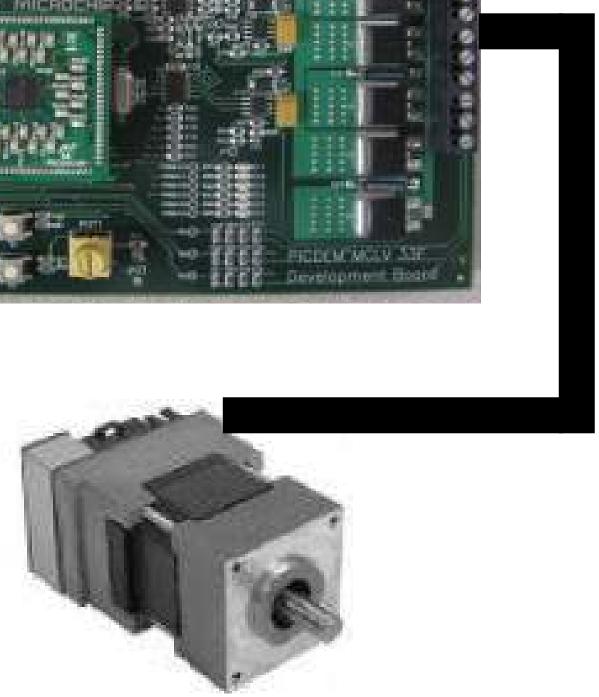


- **Estimated Rotor Position**



Development Environment With Real-Time Data Monitoring





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MCHV Specifications

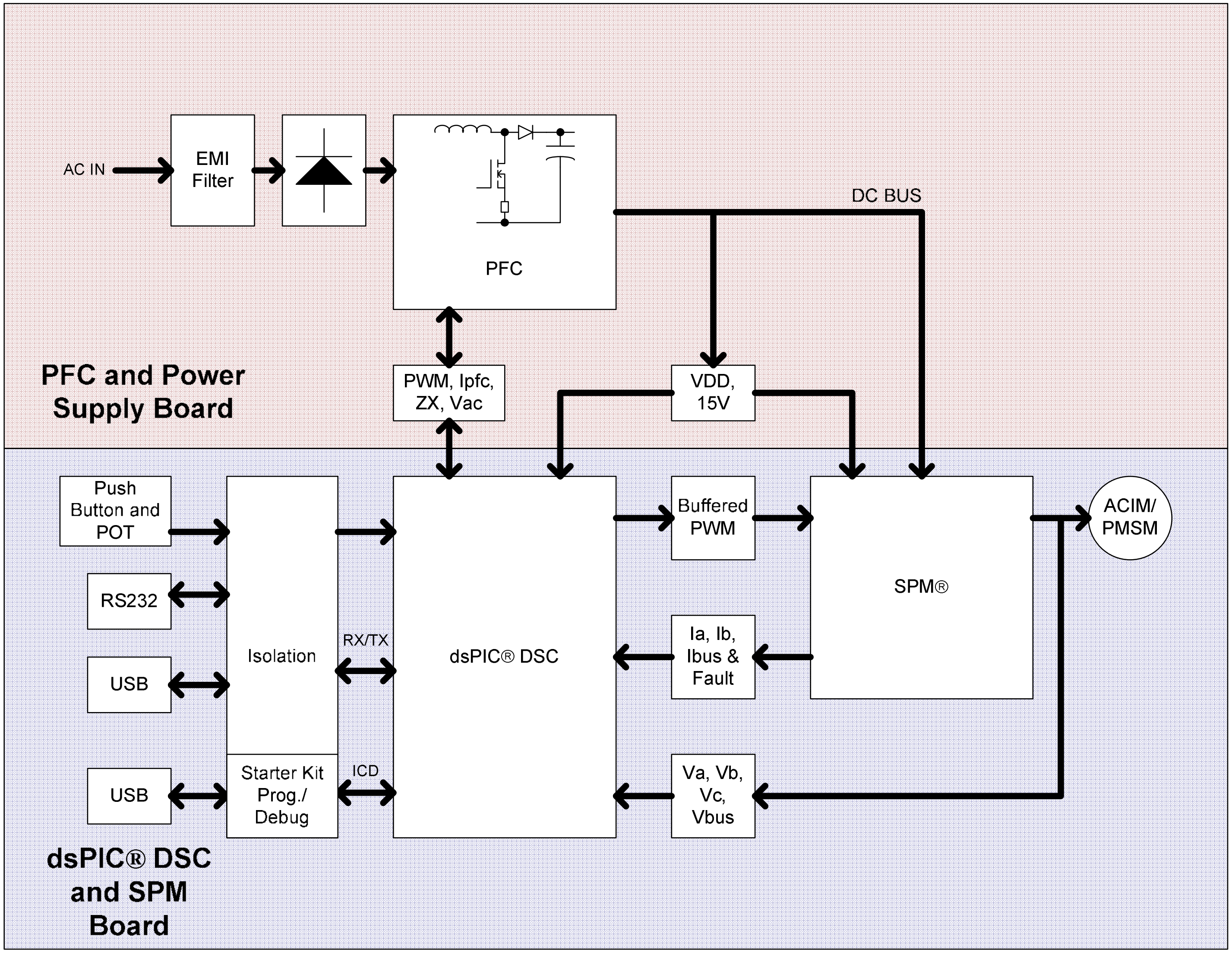
- **PFC Stage**

Parameter	Min	Typical	Max.	Units
DC Bus	90	380	400	VDC
Current	0.1	2.6	3.5	A
Power Rating	9	1000	1400	Watts
Switching Freq.	0	50	100	kHz

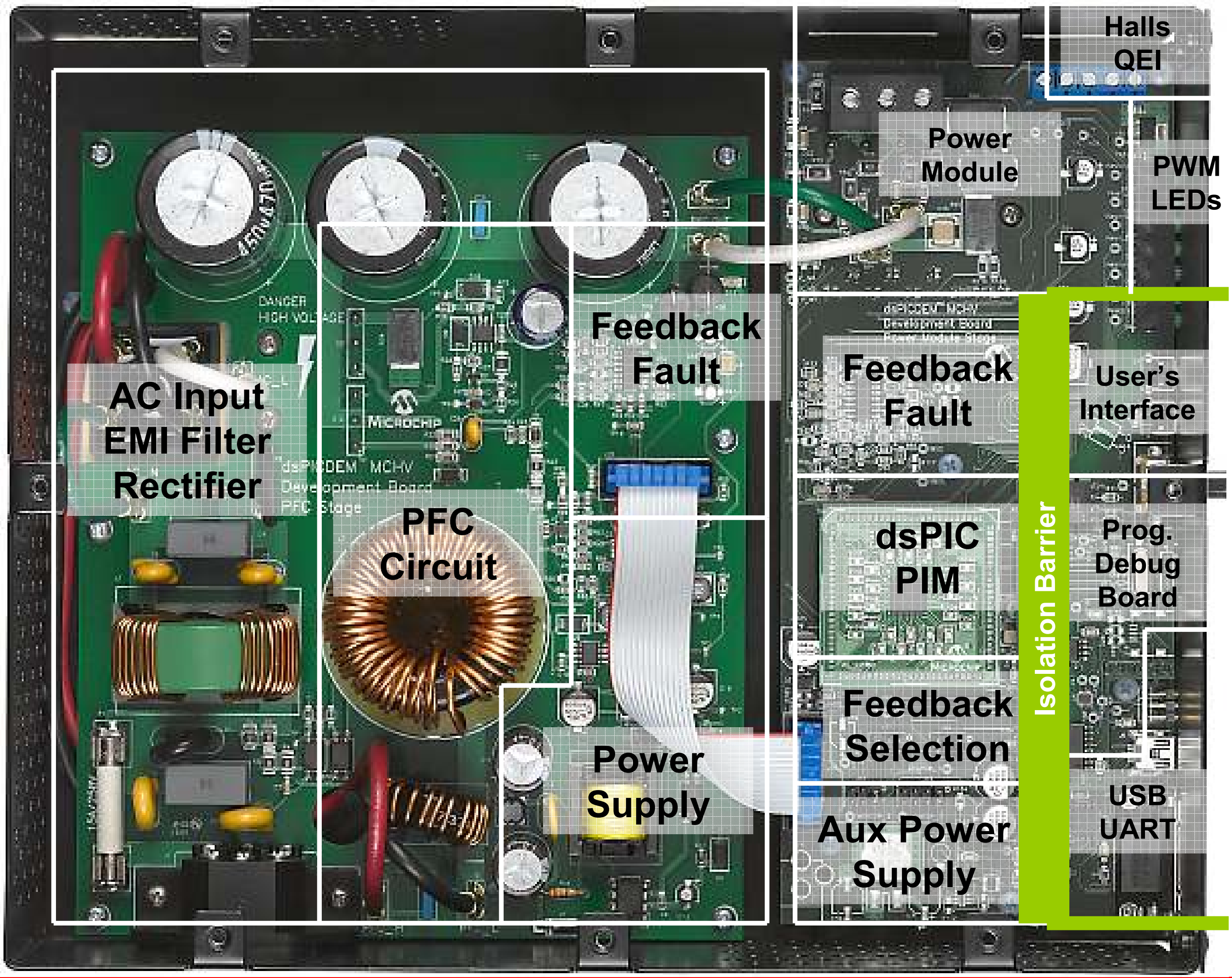
- **Inverter Stage**

Parameter	Min	Typical	Max.	Units
DC Bus	40	310	400	VDC
Current	0.1	6.5	10	A
Power Rating	4	2015	4000	Watts
Switching Freq.	0	-	20	kHz

MCHV Block Diagram



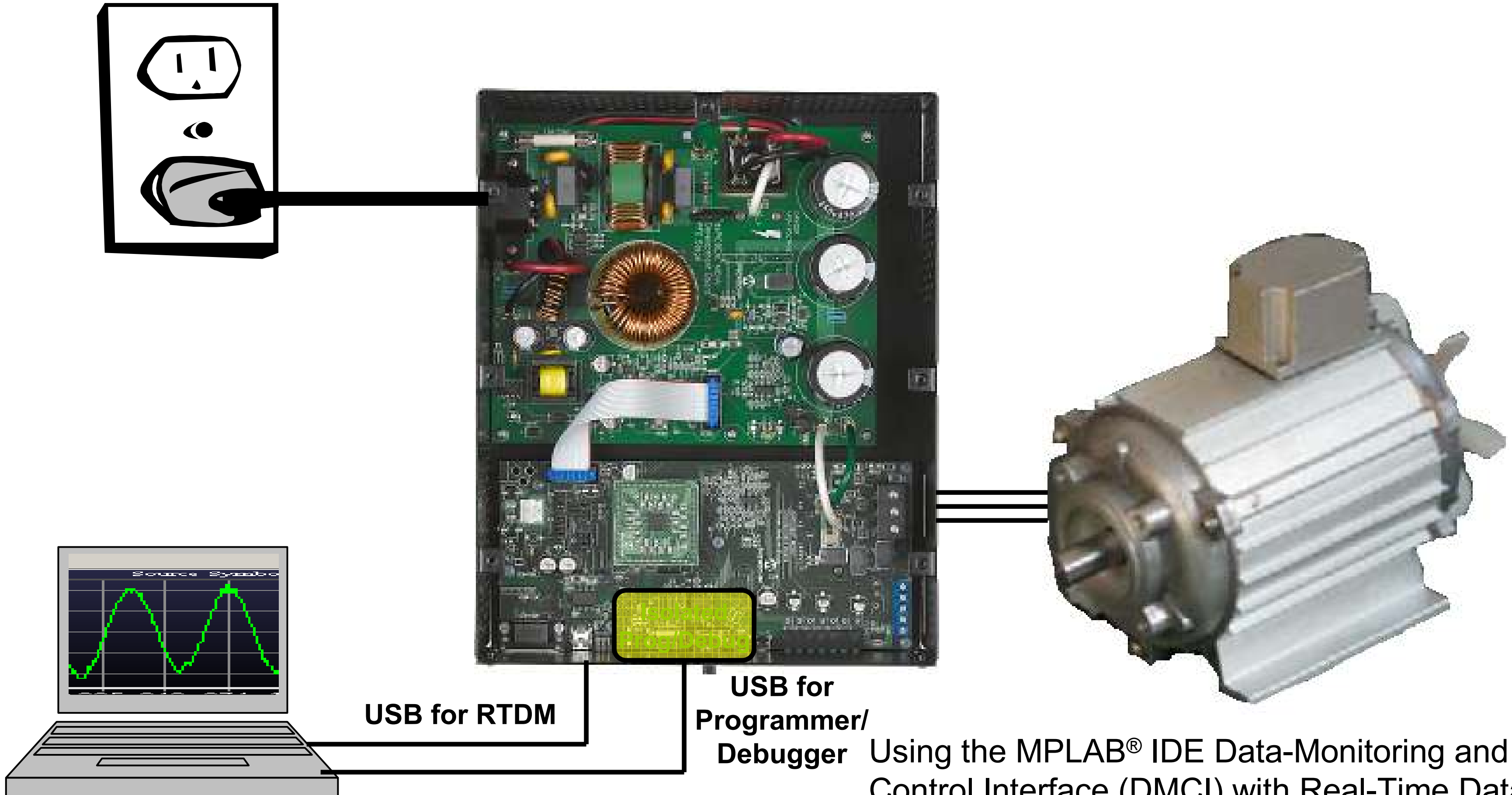
MCHV Board Layout



High-Voltage Motor Control Algorithms

Motor	Best Control Technique Used by dsPIC® DSC	Benefits
3-phase ACIM	Open Loop (V/F) with variable speed	Low Cost
3-phase ACIM	Closed Loop **- Sensored (QEI)** **- Sensorless FOC (Vector Control/180º) with PLL estimator and dual shunts**	Better Control
BLDC	Sensored (Hall Effect) (Trapezoidal/120º) **- High speed operation (5 to 20K RPM)** **- Rapid load changes requiring fast torque response** **- Fast or high accuracy on a servo position response**	Better Torque Control than ACIM
BLDC/PMSM	Sensored (Hall Effect) (Sinusoidal/180º)	Lower Noise
BLDC	Sensorless (requires moderate tuning) (Trapezoidal/120º) **- Back EMF with ADC** **- FIR filtered BEMF with ADC** **- FIR filtered BEMF with ADC and Majority Detect function**	Lower Cost
PMSM	Sensorless (requires advanced tuning) **- FOC with single- or dual-shunt circuits, PLL or SMO estimator and field weakening**	Highest Efficiency, Best Torque Control

Development Environment With Real-Time Data Monitoring



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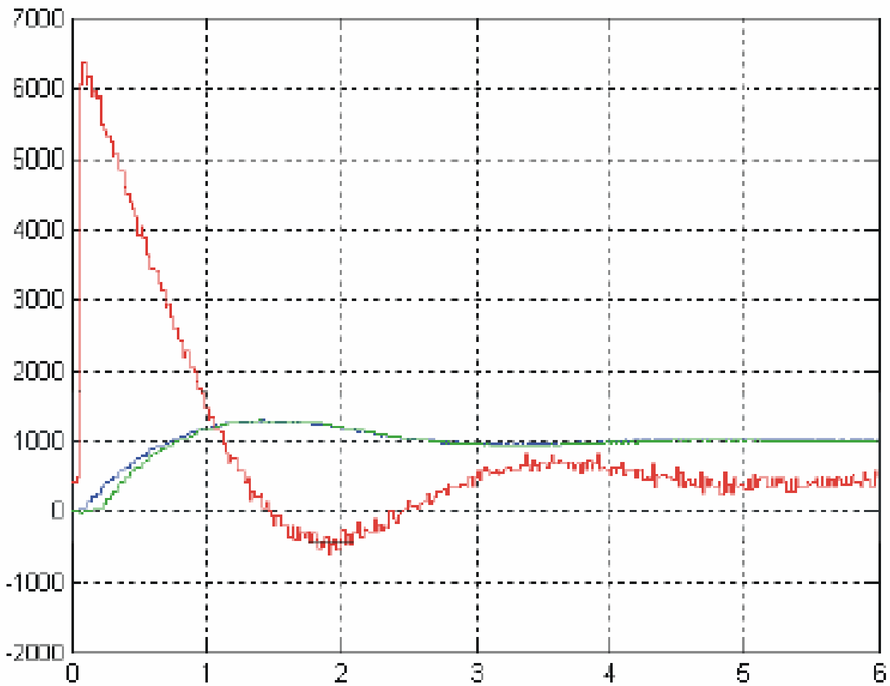
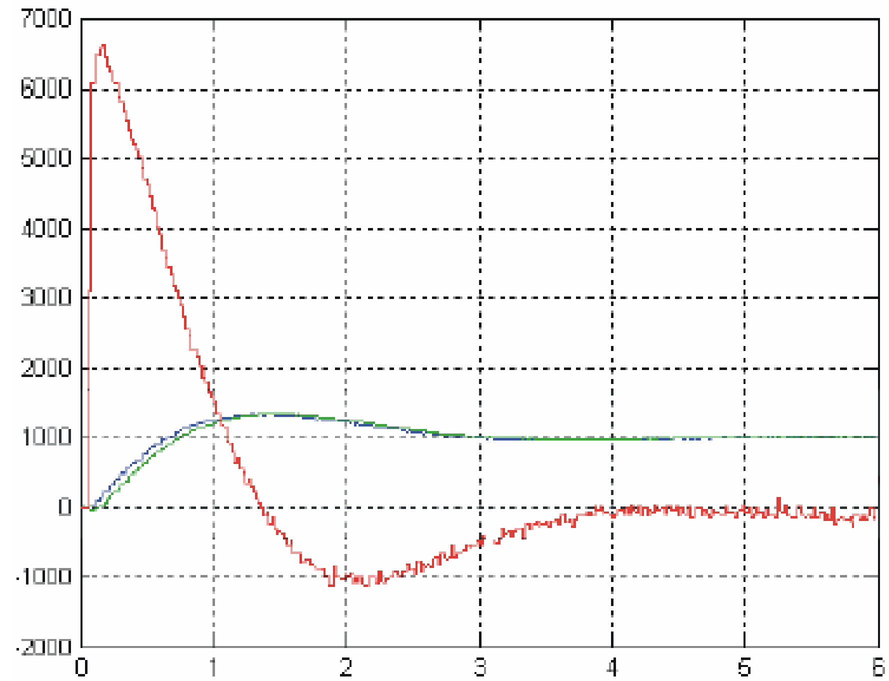
Sensorless PLL FOC for ACIM Step Response

Sensored



Sensorless



Estimated Torque
Actual Torque
Measured Speed

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Summary of Motor-Control Algorithms

Motor	Control Technique Used	Benefits
3-phase ACIM	Open Loop (V/F) with variable speed	Low Cost
3-phase ACIM	Closed Loop **- Sensored (QEI)** **- Sensorless FOC (Vector Control/180º) with PLL estimator and dual shunts**	Better Control
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PMSM	Sensorless (requires advanced tuning) **- FOC with single or dual shunt circuits, PLL or SMO estimator and field weakening**	Highest Efficiency, Best Torque Control
Stepper	Full Stepping, Half Stepping, Micro-Stepping, Position Control - Open Loop Control (Fixed Voltage or Fixed Current) - Closed Loop Current PI Control Loop	Easiest Faster Speed, Most Efficient

dsPIC® DSC Motor Control Application Notes

Motor Type	App. Note	Description
Stepper Motor	AN907	Stepper Motor Fundamentals
	AN1307	dsPIC33F Stepper Motor Control
Brushed DC Motor	AN905	Brushed DC Motor Fundamentals
BLDC and PMSM	AN857	Brushless DC Motor Control Made Easy
	AN885	Brushless DC (BLDC) Motor Fundamentals
	AN901	Sensorless Control of BLDC Motor using dsPIC30F6010
	AN992	Sensorless Control of BLDC Motor using dsPIC30F2010
	AN957	Sensored Control of BLDC Motor using dsPIC30F2010
	AN1017	Sinusoidal Control of PMSM Motors with dsPIC30F
	AN1083	Sensorless Control of BLDC with Back-EMF Filtering
	AN1078	Dual Shunt Sensorless FOC for PMSM
	AN1160	Sensorless BLDC Control with Back-EMF Filtering Using a Majority Function
	AN1208	Integrated PFC and Sensorless FOC System
	AN1292	Dual Shunt Sensorless FOC PSMS PLL Field Weakening
	AN1299	Single Shunt Sensorless FOC PMSM SMO
AC Induction Motor	AN887	AC Induction Motor Fundamentals
	AN908	Using the dsPIC30F for Vector Control of an ACIM
	AN984	Introduction to ACIM Control using the dsPIC30F
	AN1162	Sensorless Field Oriented Control (FOC) of an ACIM
	AN1206	Field Weakening Sensorless FOC for ACIM
Other	AN1106	Power Factor Correction on dsPIC® DSC
	AN1229	Meeting IEC 60730 Class B Compliance with dsPIC® DSC

Low-Cost Development Tools

Stepper →

dsPICDEM™ MCSM
(DM330022)
$130 (resell)

BLDC →

dsPICDEM™ MCLV
(DM330021)
$150 (resell)

ACIM →
(or high-voltage BDC/BLDC/PMSM)

dsPICDEM™ MCHV
(DM330023)
$650 (resell)

Drive Comparison

Drive	Motor Types	Control Techniques	Feedback Circuits	Safety	Benefits/ Efficiency	BOM Cost (@ 100 units)
MCSM	Stepper • Unipolar • Bipolar - Series • Bipolar - Parallel • Bipolar - Half-Winding	• Open-Loop Fixed Voltage • Open-Loop Fixed Current • Closed-Loop Current PI Control Loop • Multiple Decay Modes	• 2 current shunt-resistor circuits for current feedback	• Over-current protection	• Optimized for torque, high-speed and noise • One drive platform supports multiple motor types and control techniques	$32
MCLV	3-Phase BLDC & PMSM	Sensored Trapezoidal or Sinusoidal, Sensorless Back EMF or Field Oriented Control with Field Weakening	• 2 current shunt-resistor circuits for current feedback • Resistor divider chain for voltage feedback	• Over-current protection	• Efficiency ≤ 95% • One drive platform supports multiple motor types and control techniques	$55
MCHV	3-Phase ACIM or High-Voltage BLDC or PMSM	Open-Loop Volts/Hertz, Sensored Vector Control or Sensorless FOC with single or dual shunts, PFC and Field Weakening	• 2 current shunt-resistor circuits for current feedback • Resistor divider chain for voltage feedback PFC: • Inductor, MOSFET and driver circuit • Voltage reference and op amp circuit • Current shunt-resistor circuit for current feedback • Zero Cross Detection for Vac circuit	• Over-voltage protection • Over-current protection • Gate Driver under-voltage protection • Isolated digital power and ground • Opto-isolated user interface	•Efficiency ≤ 95% • One drive platform supports multiple motor types and control techniques plus PFC	$215

Resources

- For more information please download the User Guide (includes schematics) and the application notes (includes source code) from:
- http://www.microchip.com/dscmotor
- For actual Bill Of Materials, please contact us directly:
  - daniel.torres@microchip.com
  - patrick.heath@microchip.com

Conclusion

- We have met our goals of designing a trio of ultra low-cost but safe drive hardware for the most common types of motors—stepper, low-voltage BDLC or PMSM, and high-voltage ACIM or BLDC/PMSM.
- These drives support all of the common control algorithms and feedback circuits.
- Additionally, we have shown that low-cost does not mean skimping on efficiency or benefits. DSCs such as the Microchip dsPIC33F are competitively priced and provide the processing capabilities needed to run the most efficient control algorithms.