New Motor Controllers Lead the Way
With Analog Circuit Integration
Agenda

- Introduction
- Typical FOC Sensorless Circuit Diagram with analog components
- Fairchild Smart Power Module (SPM)
- IR Intelligent Power Module (IPM)
- Melexis Integrated BEMF BLDC Motor Controller
- Microchip Integrated BEMF BLDC Motor Controller
- Microchip dsPIC33FJ16MC102 BEMF BLDC Circuit Diagram
- Microchip dsPIC33FJ64MC506 block diagram
- dsPIC33FJ64MC506 FOC Sensorless Circuit Diagram with Op Amps and Comparators
- Op Amp Code Configuration
- FOC Integration Approach Comparison
- Typical Stepper Motor Circuit Diagram with external comparators
- Microchip Stepper Motor Integrated Module (IPM)
- Freescale Integrated Stepper Motor Controller
- Stepper Motor Integration Approach Comparison
- Summary
Motor-drive component integration is the inevitable response to cost-reduction pressure:
- As new devices are introduced, the price of existing components decreases. In order to grow revenue, new solutions must be introduced.
- Power handling and heat elimination are the main obstacles blocking progress, due to processing limitations.

Three approaches to the integration problem:
- Integrated Power Module (IPM) approach—combine all the high-voltage components.
- Integrated DSC/MCU Approach—combine all the low-voltage components.
- Integrated Driver Approach—combine some of the components for a low-power BLDC or Stepper motor solution.
Typical FOC Sensorless Circuit Schematic With External Op Amp Circuits

- An IPM combines the MOSFETs with their gate drivers, and often the over-current protection circuit.
- New DSCs and MCUs combine Op Amps and Comparator circuits.
- For 12-volt BLDC BEMF Fan Control applications, the voltage regulator and LIN transceiver are integrated with the MCU and the Gate Drivers; and even the MOSFET.
Fairchild Smart Power Module (SPM)

- 600V/30A (FSBB30CH60)
- 3-phase IGBT Inverter Bridge
- Control ICs for gate drive and protection
- High-Side under-voltage (UV) protection (without fault signal output)
- Low-Side UV and short-circuit (SC) protection through external shunt resistor (with fault-signal output)
International Rectifier Integrated Power Module

- 600V/30A (IRAM136-3063B)
- Integrated gate drivers
- Temperature monitor and protection
- Overcurrent shutdown
- Under-voltage lockout for all channels
- Matched propagation delay for all channels
- 5V Schmitt-triggered input logic
- Cross-conduction prevention logic
MLX81200 Features and Benefits:

- 18V/11 mA (0.2 Watts)
- 16-bit MCU with Flash memory
- Gate drivers (NFET pre-driver with bootstrap)
- Voltage regulator
- RC/PLL oscillator
- Integrated LIN or PWM transceiver
- AEC-Q100 qualified up to 150° C ambient temperature
- Very robust, wide dynamic range
- Fast start up, accelerate and run under unknown load conditions
- Low-noise operation
- Block, trapezoidal and sinusoidal motor currents
- Delta and star motor configuration (no star point required)
Microchip Integrated BLDC Motor Controllers

- 14V/36 mA (0.5 Watt)
- Sinusoidal drive, for high efficiency and low acoustic noise
- BEMF sensorless drive
- Supports 2V to 14V power supplies (MTD6501C/D)
- Speed control through PAM and/or PWM
- Direction control pin (MTD6502B and MTD6505)
- Motor speed output (FG)
- Lockup protection and automatic recovery circuit (no external capacitor required)
- Over-current limitation, short-circuit and over-temperature protection
- Built-in thermal shutdown protection
- No external tuning required
- Boost mode (Optional BEMF pre-amplification in MTD6501D)
Previous Digital Signal Controllers (DSCs), such as the dsPIC33FJ16MC102 DSC, only incorporated comparators, which were used for over-current protection.

Newer DSC motor controllers, such as the dsPIC33EP families, integrate both comparators and op amps, leaving only the gate drivers and MOSFETs external.
dsPIC33EP64MC506 DSC

- 70 MIPS motor-control DSC
- 3 Op Amps for motor-control current feedback
- Price ~$2.75 @ 10 Ku
New dsPIC33E motor control DSCs integrate up to 3 Op Amps and up to 4 comparators.

Two op amps are used to read the current from two motor phases.

A third Op Amp is used to sum all three phases, and the output is routed internally to a comparator for over-current detection.

Dual-Shunt FOC Circuit Diagram
The op amp circuits multiply their input voltage difference by 15 times (depends on the value of the shunt resistor – 30 Ohms here) and center the result around 1.65 volts. The op amp output is fed into the A/D Converter. The digital value is translated into a phase current.

Kirchoff’s Law is used to calculate the 3rd motor-phase current.

One op amp sums the 3 motor-phase currents and feeds this to an on-chip comparator, to detect an over-current situation.
Op Amp Connections

- This diagram shows the signal connections for a 2-phase shunt current feedback for FOC control.

- An internal Op Amp and Comparator are used for Overcurrent detection.
To prevent negative motor-phase voltages on the dsPIC® DSC’s input pins (which would violate the spec.), the voltages are biased up by 1.65 Volts. The bias-voltage point is generated internally in the dsPIC DSC.
Op Amp & Comparator Configuration

/* Set up CVREF */
CVRCON = 0;
CVRCONbits.CVR2OE = 1; // CVREF20 output to pin enabled for VREF of 1.65V
CVRCONbits.CVRR = 0; // 1/32 step size
CVRCONbits.CVR = 15; // CVREF = (0.1031)*CVR + 0.825
CVRCONbits.CVREN = 1; // CVREF circuit on

/* Comparator enabled as op amp, op amp inputs CxIN1+/- */
CM1CON = 0x8C00;
CM2CON = 0x8C00;
CM3CON = 0x8C00;

/* Set up CMP4 */
CM4CON = 0;
CM4CONbits.CPOL = 0; // Comparator output non-inverted
CM4CONbits.EVPOL = 2; // Event generated on Low-to-high transition of comparator output
CM4CONbits.CREF = 1; // VIN+ input connects to internal CVREFIN voltage
CM4CONbits.CCH = 1; // VIN- input connects to CMP1 (source Ibus)
CM4CONbits.COE = 1; // Comparator output enabled
CM4CONbits.CON = 1; // Enable comparator
## FOC Integration Approach Comparison

<table>
<thead>
<tr>
<th>Approach</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Separate Components: Gate Drivers, MOSFETs and Op AMPS | • Lower cost than IPM, but higher cost than op amp-integrated DSC  
• Maximum flexibility | • Takes up the most board space  
• Must take care to match components |
| IPM                                           | • Smallest board space  
• Matched components  
• Overcurrent protection | • Highest cost (~$30 @ 10 Ku)  
• Still need op amps |
| DSC With Op Amps                               | • Saves cost over external op amps (~$1.50)  
• Saves board space | • Still needs an IPM or separate gate drivers and MOSFET |
| Integrated BLDC BEMF Devices (for fan control or for automotive applications) | • Can combine everything to save space  
• No user tuning required  
• Low cost (~$0.57) | • Not FOC (less efficient, lower, and slower torque response)  
• Very low power (<1/4 watt) |
- An IPM combines the MOSFETs with their gate drivers, and often the over-current protection circuit.

- New DSCs and MCUs combine op amps (used for current-mode control) and comparators (used for over-current protection).

- For 12-volt automotive-control applications, the LIN transceiver is integrated with the MCU, gate drivers, and the MOSFETS.
Microchip’s Stepper-Motor IPM

- MTS2916A
- Load voltage supply range 10V to 40V
- Output current up to 750 mA (each bridge)
- Internal fixed Toff-time PWM current control
- Built-in protection diodes
- Internal thermal shutdown
- Under-voltage lockout
- LS-TTL compatible logic inputs with pull-up resistors
- Low RON output resistance
- Low quiescent current
Freescale Integrated Stepper Motor Controller

- MC68HC908 MCU, integrated with gate drivers and MOSFETs (MM908E626)
- Voltage-mode control (no op amps)
- Over-current protection
- Lin transceiver
- 12V/20mA (0.24 watts)
## Stepper Integration Approach Comparison

<table>
<thead>
<tr>
<th>Approach</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate Components: Gate Drivers, MOSFETs and Op AMPS</td>
<td>• Lower cost than IPM, but higher cost than op amp-integrated DSC</td>
<td>• Takes up the most board space</td>
</tr>
<tr>
<td></td>
<td>• Maximum flexibility</td>
<td>• Must take care to match components</td>
</tr>
<tr>
<td>Stepper Motor IPM</td>
<td>• Smallest board space</td>
<td>• Higher cost (~$0.75 @ 10 Ku)</td>
</tr>
<tr>
<td></td>
<td>• Matched components</td>
<td>• Still need op amps for current-mode control</td>
</tr>
<tr>
<td></td>
<td>• Overcurrent Protection</td>
<td>• Still need MCU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Limited micro-stepping</td>
</tr>
<tr>
<td>DSC with Op Amps and Comparators</td>
<td>• Saves cost over external op amps/comparators (~$1.50)</td>
<td>• Still needs Gate Drivers and MOSFETS</td>
</tr>
<tr>
<td></td>
<td>• Saves board space</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Micro-stepping (down to 1/256)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Voltage &amp; current control mode options</td>
<td></td>
</tr>
<tr>
<td>Integrated Stepper Motor Driver (for automotive applications)</td>
<td>• Can combine everything except voltage regulators to save space</td>
<td>• Voltage-control mode, only (slower, noisier, less efficient)</td>
</tr>
<tr>
<td></td>
<td>• No user tuning required</td>
<td>• Very low power (&lt;1/4 watt)</td>
</tr>
</tbody>
</table>
Summary

• Three approaches to the integration problem:
  • Integrated Power Module (IPM) approach—combine all the high-voltage components
  • Integrated DSC/MCU approach—combine all the low-voltage components
  • Integrated Driver approach—combine some of (or all of) the components for a low-power BLDC or Stepper motor solution

• Motor-drive design engineers and the end customers will continue to benefit from lower costs, simplified circuit designs and more compact solutions.

Note: The Microchip name and logo, and dsPIC are registered trademarks of Microchip Technology Inc. in the U.S.A. and other countries. All other trademarks mentioned herein are property of their respective companies.