Photo courtesy Allegro Microsystems

Silicon takes on MOTION CONTROL

ICs ARE STEADILY ASSUMING MORE FUNCTIONS IN MOTOR-CONTROL APPLICATIONS, EASING YOUR DESIGN TASK AND MAKING CONTROL MORE EFFICIENT.

Motor control is by no means a trivial consideration. You must take into account a host of parameters—commutation, speed, acceleration, deceleration, and torque, to name a few—when designing a motor-control system. In times past, you would assemble a breadboard with a bunch of logic ICs, comparators, and an H-bridge or a half-bridge output using discrete MOSFET or insulated-gate bipolar-transistor (IGBT) drivers. Now, you have access to several sophisticated motor-drive ICs and modules that incorporate virtually all logic and drive functions. In addition to the ICs that directly drive the motor, a number of dedicated, motor-drive DSP chips are available. These ICs perform the complex math and control functions necessary in motion control. The motor-control and DSP chips replace what were once entire boards full of components.

Pulse-width modulation (PWM) provides an efficient means of controlling dc motors. You can control torque, speed, acceleration, and braking (deceleration) by controlling the duty cycle and phase of the PWM drive. The method is efficient from the viewpoints of power consumption and thermal performance, because the drivers in the output bridge are either fully on or fully off. Moreover, the technique lends itself to flexible digital control of all parameters. Allegro Microsystems uses PWM control of DMOS-based full-bridge (also called H-bridge) drivers in its recently announced family of motor-drive ICs. Model 3958, for example, handles continuous currents of ±2A at operating voltages to 50V. The DMOS output transistors have a typical low on-resistance ($R_{DS(ON)}$) of 270 mΩ.

SIMPLIFY MOTOR CONTROL

Figure 1 shows the internal structure of the $2.27 (1000)

3958. The IC has a three-wire serial port that accepts clock, strobe, and data signals. The data signal uses a 20-bit word for programming motor-control parameters. Two bits control current-sense-comparator blank time. When a source driver turns on, a current spike results because of reverse-recovery currents in the clamp diodes, switching transients related to distributed capacitance in the load, or both. To prevent this spike from erroneously resetting the source-enable latch, you blank the comparator for a period of $4/f_{osc}$ to $24/f_{osc}$, according to the digital input. Five bits select the off time of the PWM waveform. Four more bits determine the portion of the off time that operates in fast-decay mode versus slow-decay mode. You can select fast-, slow-, and mixed-decay modes with these 4 bits. A synchronous-rectification function reduces DMOS power dissipation and can eliminate the need for external clamping diodes. When the IC enters a PWM off cycle, load current continues to recirculate according to the selected decay mode. The synchronous-rectification feature turns on the opposite pair of DMOS outputs during the current decay and effectively shorts out the body diodes with the low-$R_{DS(ON)}$ driver.

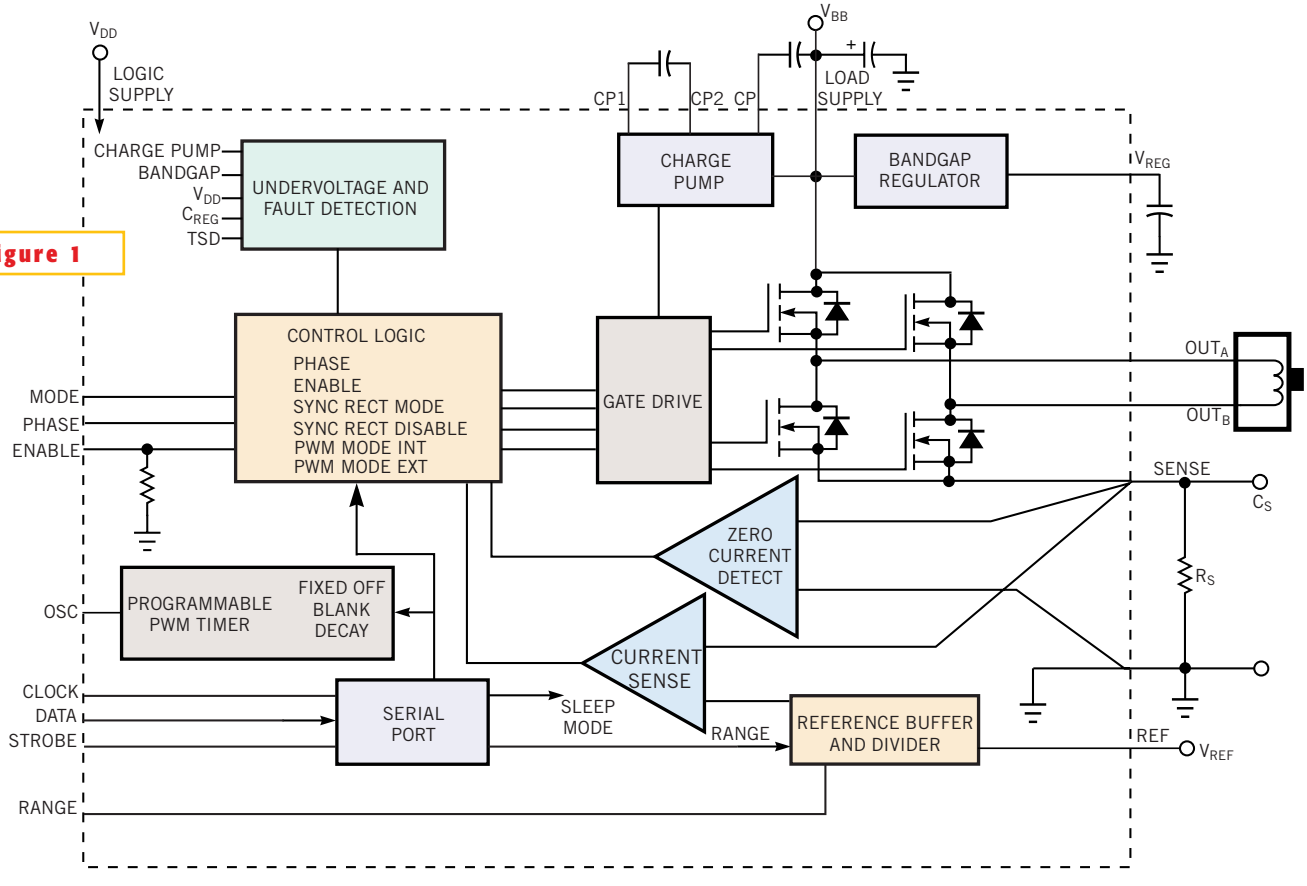
AT A GLANCE

- Motor-driver ICs cut size, power, and heat.
- Digital controls make motor drive easy.
- Motion-control DSP chips are powerful math engines.

Allegro offers several variations of the 3958. The 3972, for example, contains all the functions of the 3958, only twice—it's a dual-channel, stepping-motor driver. It also adds two 6-bit D/A converters to generate microstepping in 1.56% increments for the stepping motor. Another variation of the 3958, the 3971, is a dual full-bridge driver that works essentially like the 3958 but with less elaborate digital controls. Allegro is also introducing a three-phase power-MOSFET controller. The 3932 drives external MOSFETs for controlling brushless-dc motors. It provides commutation logic for Hall-effect sensors mounted with 120° spacing in the motor. The 3932 also offers the synchronous-rectification feature of the 3958 to minimize power dissipation in the MOSFETs and eliminate the need for clamping diodes.

A heftier motor driver from Composite Modules Inc handles 20A continuous and 45A peak and operates from a single 18 to 35V supply (**Figure 2**). The CMI-5015-28 module uses an ASIC for commutation, cross-conduction protection, automatic braking, undervoltage lockout, and cycle-by-cycle current limiting. Speaking of cross-conduction,

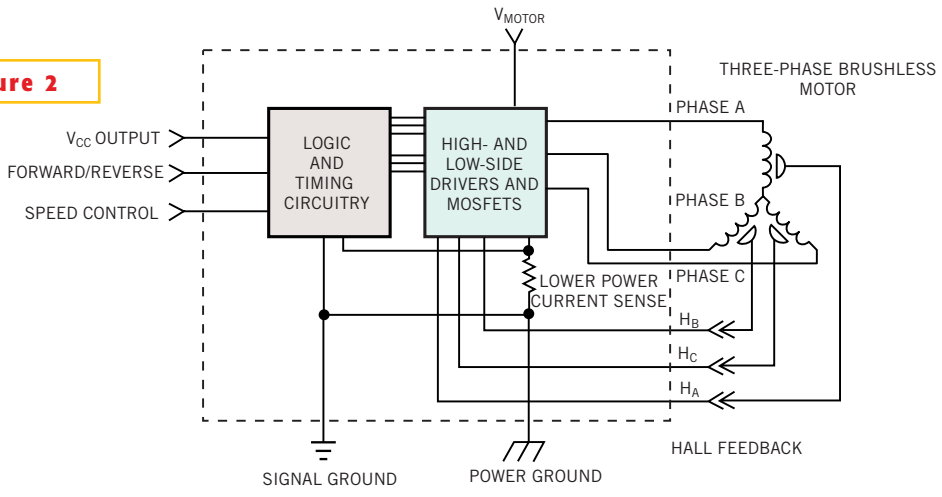
Figure 1



The 3958 motor driver from Allegro uses a 20-bit command word to execute a variety of functions.

most ICs and modules on the market incorporate "dead time," during which the upper and lower drivers are both off. Otherwise, simultaneous conduction of both drivers could produce huge current spikes. The CMI-5015-28 driver works with three external Hall-effect sensors that sense motor-shaft position. The module uses n-channel MOSFETs in the output stages and incorporates high-side drivers that allow operation to zero speed without the loss of high-side drive. A speed-control input accepts a 1.25 to 5V-dc input for variable-speed control; at less than 1.2V, a braking circuit provides deceleration. The 2×2.5×0.375-in. module costs $375 (1000).

Figure 2



The CMI 5015-28 brushless-dc motor driver uses a custom ASIC, including a proprietary high-side driver.

THREE-PHASE DRIVER USES EXTERNAL FETs

A family of bridge drivers from Intersil uses external, bridge-configured MOSFETs. The HIP4086 is a three-phase driver that targets PWM motor-control applications. It uses internal charge-pump circuitry to generate the gate drive for the high-side FETs. The IC has shoot-through (cross-conduction) protection with programmable dead time, and you can override the shoot-through protection. The override is beneficial when driving switched-reluctance motors. An undervoltage-shutdown feature prevents the MOSFETs from turning on if the bias-supply voltage is less than a preset level. Intersil provides an evaluation board for development purposes.

So far, this article has discussed motor-drive devices that target dc motors. International Rectifier (IR) has developed a series of ICs for use in 115, 230, and 460V-ac motor drives. **Figure 3** illustrates IR's conception of the functions and requirements in high-power motor-drive applications. The company maintains, for example, that the IGBT gate-drive and protection functions must be synchronized and that the feedback-sensing, regulator-control, and PWM functions must match. The IR1110 fulfils the soft-start function. According to IR, the IC is the first to make SCR phase control of the bus-charging current of a PWM inverter drive practical. SCR phase-control-charging ramps up the dc bus faster than resistive charging does. The IC works by controlling the phase of an SCR bridge, advancing the phase angle of the SCR firing pulses to increase the bus voltage in a controlled series of steps.

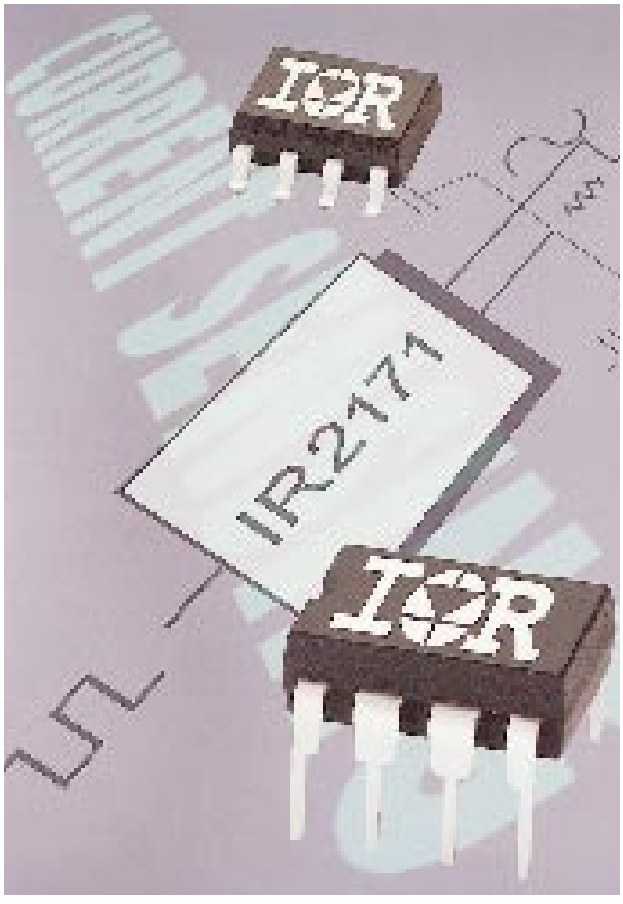
A current-sensing IC fulfils the feedback-sensing function in **Figure 3**. IR's IR2171 is a 600V IC that integrates all motor phase-current measurement, A/D conversion, noise filtering, and a feedback interface to the µC. According to IR, precision measurement of motor-phase current is a challenge because of the small differential-mode signal that rides on the large, common-mode ac voltage driving the motor phase. The IR2171 can accommodate common-mode voltages as great as 600V on its sensing inputs. It senses current by measuring the voltage drop across a resistor in series with the

A family of DSP motor-control ICs from Analog Devices incorporates flash memory.

motor phase. A third IC in the family fulfils the gate-drive and IGBT-protection functions. The 600V IR2237 driver optimizes IGBT turn-on and -off characteristics for optimum IGBT performance. In the event of an overcurrent condition that causes high-side desaturation, the IC initiates a soft-shutdown sequence, in which all six IGBTs turn off together. A 1200V version, the IR2237, is also available.

FAN-CONTROL ICs GET SMART

A fan-control IC with a remote temperature sensor from Maxim Integrated Products lets you adjust fan speed via an SMBus two-wire serial interface. The Max1669 uses a remote temperature sensor that consists of a diode-connected pnp transistor. Remote-sensing accuracy is ±3°C for transistors from multiple manufacturers, with no calibration needed. The IC provides a logic output that drives external power components connected to a dc brushless fan. The controller operates in a 20- to 60-Hz PWM mode, intended for driving the fan motor, and a high-impedance mode that generates a variable dc-control voltage. In PWM mode, you can synchronize the fan-drive frequency to an external clock. The Max1669 contains overtemperature and undertemperature alarms that alert you of extreme conditions.



A three-phase bridge driver from International Rectifier can withstand 600V common-mode voltage.

The US79 fan-driver IC from Melexis is unique in that it requires no external components. The three-lead IC reduces component count in motor-drive systems from eight to one, according to Melexis. It also has no power-supply pins for ESD to creep in, because it derives its power from the motor coils. The coils also provide ESD filtering and overvoltage and reverse-voltage protection. ESD tolerance of the US79 is 3000 to 7000V, and ESD tolerance of a complete fan/IC assembly is 15,000 to 25,000V. The device contains a Hall-effect sensor for motor commutation and features overtemperature protection, RFI suppression, output inductive-spike clamping, and locked-rotor protection.

MOTION MATHEMATICIANS

So far, this discussion has centered on devices that connect to, drive, and control motors. These circuits have varying amounts of digital intelligence. Another class of devices serves as motion-control mathematicians. These devices are powerful, programmable DSP engines that handle the myriad aspects of motion-control systems. They are the heart of

FOR MORE INFORMATION...

For more information on motion-control ICs such as those discussed in this article, enter the appropriate numbers at www.ednmag.com/infoaccess.asp. When you contact any of the following manufacturers directly, please let them know you read about their products in *EDN*.

Allegro Microsystems Inc
www.allegromicro.com
Enter No. 301

Analog Devices Inc
www.analog.com/motorcontrol
Enter No. 302

Composite Modules Inc
www.cmodules.com
Enter No. 303

International Rectifier
www.irf.com
Enter No. 304

Intersil Corp
www.intersil.com
Enter No. 305

Maxim Integrated Products
www.maxim-ic.com
Enter No. 306

Melexis Inc
www.melexis.com
Enter No. 307

Performance Motion Devices Inc
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Technosoft
www.technosoft.ch
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Texas Instruments
www.ti.com
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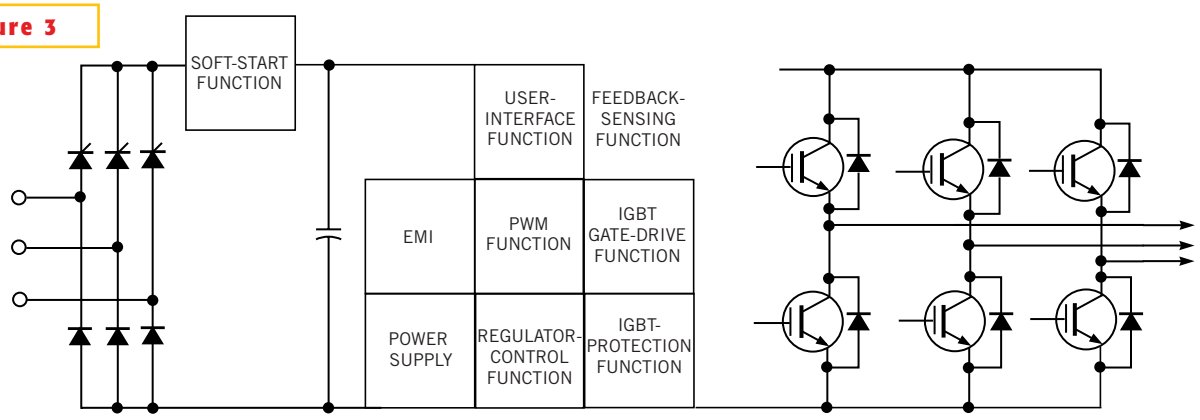
SUPER CIRCLE NUMBER
For more information on the products available from all of the vendors listed in this box, enter No. 311 at www.ednmag.com/infoaccess.asp.

Figure 3



International Rectifier's conception of high-power motor drive includes nine basic modules and functions.

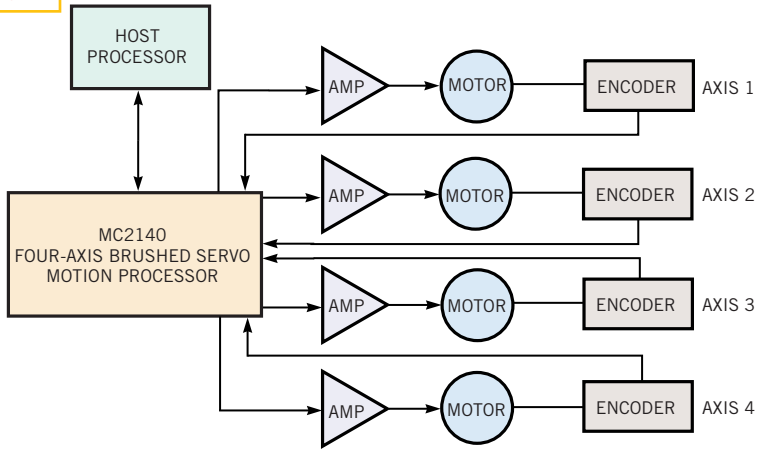
most motion-control boards. An example is the MC2000 Series (dubbed the Navigator family) of motion processors from Performance Motion Devices. **Figure 4** shows a typical motor-control configuration. The ICs are available in one-, two-, and four-axis versions and in single- and multiple-motor types. The MC2100 Series controls brushed servo motors; the MC2300 Series controls brushless servo motors, and the MC2400 and MC2500 Series controls stepping motors. The MC2800 Series controls both brushed and brushless servo motors.

The MC2000 devices are loaded with motion-control intelligence. Motion profiles include S-curve, trapezoidal, velocity contouring, and electronic gearing. For the trapezoidal profile, you can custom-program asymmetric acceleration and deceleration characteristics. The devices accommodate an encoder rate of 5 million counts/sec, thereby allowing the use of high-resolution feedback devices. For those who are used to industrial programming, the MC2000 Series accommodates PLC-style programmable inputs and outputs, including a per-axis programmable input and output. The motion controller accepts input parameters such as position, velocity, and acceleration from the host via an 8- or 16-bit bidirectional parallel port. You can choose a 10-bit, 20-kHz PWM signal or a linear 16-bit D/A converter output. The instruction set for the MC2000 series includes more than 130 commands.

An extensive range of DSP-based motion-control chips is available from Analog Devices. The company's DashDSP family of 28-pin motor controllers uses the 20-MIPS ADSP-21xx programmable DSP circuit as a core. The devices offer a 16-bit, three-phase PWM output to drive a power stage and an internal A/D converter to process current-feedback signals. The chip accepts six 10-bit analog inputs and has nine digital-I/O lines. The IC accepts position feedback from either an encoder or a resolver. The ADMCF326, 327, and 328 incorporate 4k×24-bit flash memory for program instructions. They also include 512×24-bit program-memory RAM, 512×16-bit data-memory RAM, and 4k×24-bit program-memory ROM. The ADMC326 has the same complement of RAM and ROM but has no flash memory. You can order DashDSP versions with derivatives optimized for brushless-dc, ac-induction, or switched-reluctance motors. The ICs cost $2.95 (OEM).

Analog Devices offers a $395 RAM-based emulation kit for the ADM32x Series. The emulation board uses RAM for easy software development and debugging. The software, the Windows-based Motion Control Debugger, includes all the necessary compilers, linkers, and assemblers. All DashDSP chips contain an on-chip ROM kernel that provides full access to the controller's state via the cited software. In addition, an on-chip

Figure 4



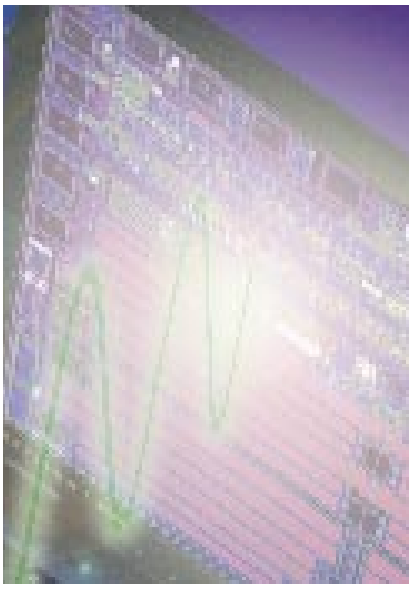
Motion-control ICs from Performance Motion Devices are powerful math processors.

ROM library contains preprogrammed math and motor-control utilities that you can call by application code. The ROM-based motor-control functions also support an interactive mode in which the emulator receives and processes commands from a host. In the interactive mode, the host can access both the internal DSP core and the peripheral motor-control registers. The host can also read and write to both program and data memory, implement breakpoints, and perform single-step and run/halt operations as part of the program-debugging cycle.

Another family of DSP-based motion controllers from Analog Devices also uses the company's ADSP-21xx (the 26-MIPS 2171) as a core. The ADMC401 is optimized for the control of ac-induction, permanent-magnet synchronous, brushless-dc, and switched-reluctance motors. The IC integrates an eight-channel, simultaneous-sampling A/D-conversion block, with conversion time of less than 2 μsec and SNR greater than 70 dB. The output is a 16-bit, three-phase PWM signal. Other features include an encoder-interface circuit with programmable input filtering, 12 lines of programmable digital I/O, two auxiliary PWM outputs, a 16-bit watchdog timer, two 16-bit interval timers, a power-on-reset circuit, and a programmable interrupt controller that manages peripheral interrupts. A $395 development kit for the ADMC401 includes the Windows-based Motion Control Debugger software. The ADMC401 comes in a 144-pin TQFP and costs $15 to $18 (OEM).

DSP CHIP COMES IN 13 FLAVORS

Another company devoting extensive efforts to DSP-based motion control is Texas Instruments. Its $2.95 (10,000) TMS320C24x family of 16-bit DSP chips comprises 13 members. Instruction-processing speed is 20 or 30 MIPS, depending on the version. Various memory options are available: RAM ranges from 544 bits to 2.5 kbits; ROM, from 4 to 32 kbits; and flash memory, from 8 to 32 kbits. Versions are available with eight, 12, or 16 PWM output channels and with two, eight, or 16 10-bit A/D inputs. The MCK240 motion-control development kit includes a DSP chip, a brushless motor with a 500-line quadrature encoder and Hall-effect sensors, ready-to-run software for serial communication, a processor evaluation, a reference generator, control implementation, data acquisition, motion-control examples, and motion-application analysis and development. The development board offers a universal I/O interface for connection to various power amplifiers, such as an IGBT inverter bridge. Software includes MCWIN, which includes a monitor for serial communication with downloading/uploading functions and debugging facilities. MCWIN also includes a Windows integrated-device-electronics drive for assistance in performance evaluation of motor-control applications. The MCK240 kit also includes the BLAC/BLDC (brushless-ac and brushless-dc) software package, which contains ready-to-run examples of ac and dc brushless-motor speed control, processor-evaluation software, and an advanced graphical tool.



AS IN VIRTUALLY ALL DISCIPLINES, SILICON HAS ENTERED THE MOTION-CONTROL ARENA WITH A VENGEANCE, MAKING YOUR MOTION-CONTROL DESIGN TASK EASIER.

You can reach Senior Technical Editor Bill Travis at 1-617-558-4471, fax 1-617-558-4470, e-mail b.travis@cahners.com.

The latest member of TI's motion-control family is the 400-MIPS C28x Series. The devices use a 32-bit architecture and can perform 32- and 64-bit math operations. The ICs are code-compatible with C24x chips. Extended addressing supports as much as 8 Mbytes of program memory and 8 Gbytes of data memory. The device's instruction set includes one-cycle read-modify-write operations, plus special I/O and branching operations. According to TI, these μC-like instructions simplify the programming of control routines and make the code compact. The C28x will be available in sample quantities in the fourth quarter of this year. Emulation tools will also be available at that time from TI and from third-party-network companies that work closely with TI in developing DSP tools.

Apropos of third-party developers, the Swiss company Technosoft offers a number of development kits (including the cited MCK240) for the C24x motion controllers. The company has also developed a C24x-based IC, dubbed the MotionChip, that uses ROM to store motor-control algorithms for various motor parameters. The chip works in stand-alone, master/slave, and single- or multiple-axis modes. It controls brushless, induction, and stepping motors. The $35.95 (1000) MotionChip provides interfaces to encoders, Hall-effect sensors, resolvers, and tachometers. Communications protocols include scalable coherent interface (SCI), controller-area network, and parallel I/O. Technosoft offers various development tools for the MotionChip, as well as several compatible power-amplifier packages that drive various motor types.

As in virtually all disciplines, silicon has entered the motion-control arena with a vengeance. Motor-driver ICs cut parts count and circuit size and alleviate thermal problems. Sophisticated DSP chips perform the calculations to determine and control motor parameters. Most important, these chips make your motion-control design task easier.□