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Moving Motor-Control Design Forward

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Advances in embedded processing are driving the emergence of higher performing and more open platforms for building intelligent motor controls.

Introduction: Harnessing Embedded Progress

As appliance energy ratings have become increasingly important selection criteria for appliances such as washing machines, refrigerators and air conditioners, intelligent motor controls offering increased efficiency have evolved from high-end signal-processing applications to adopt a more hardware-centric architecture based on general-purpose microcontrollers. Now, with the arrival of new high-performing and cost-effective embedded processors such as the 32-bit ARM® Cortex™-M family, the scene is set for a more flexible and open firmware-based approach.

The ARM Cortex embedded processor architecture, which offers 32-bit performance and improved processing efficiency at traditional 8-bit or 16-bit price points, is enabling new generations of microcontrollers (MCUs) capable of hosting high-performance applications.

Among the emerging classes of devices using the Cortex processor, motor-control MCUs that implement important IP blocks not as dedicated hardware but rather as firmware can provide the basis for a cost-effective and customisable high-performing solution. As firmware, the motor-control IP allows developers the flexibility to use only the functions they need, without having to accept high silicon overheads. Operating alongside, the Cortex core has enough processing capacity to support value-added features and functions such as motor emergency stop or advanced user interface features in addition to performing basic motor-control calculations that support the firmware.

Moving into Firmware

Toshiba motor-control MCUs such as the TMPM374, which features the ARM Cortex-M3 embedded CPU, implement a Vector Engine (VE) and Programmable Motor Drive (PMD) as customisable firmware. Together, these functions execute a Field Oriented Control (FOC), also called Vector Control (VC), algorithm. This provides the basis for smooth and responsive control without the high demand on compute power imposed by traditional sinusoidal control techniques at high rotor speeds. Figure 1 illustrates how FOC is partitioned in the TMPM374.

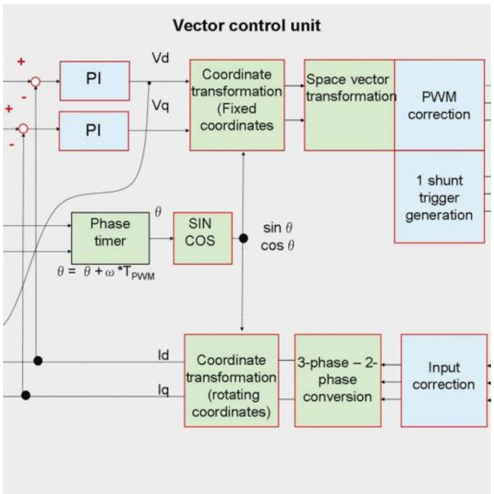

Figure 1. Vector Control firmware in the TMPM374 MCU.

The FOC algorithm manipulates the motor currents and voltages with reference to the rotor axes by ensuring the stator field remains constant and in quadrature with the rotor field. The sensed stator currents are transformed into two vectors acting in line with the rotor (D) and in quadrature (Q).

For maximum torque, the D vector is compared with zero and the Q vector is compared with the torque requested by the application. The resulting error signals drive a Proportional-Integral (PI) function that calculates signals referenced to the rotor axes. These are then transformed into the stator domain to generate the corresponding PWM signal for each phase. This approach to FOC is independent of any bandwidth limitations of the PI controllers, and hence allows the motor to deliver maximum torque even at high rotor speeds.

Microcontroller Architecture in Depth
Toshiba's PMD block implements a 3-phase PWM generator, dead-time controller, protection circuit and ADC timing network. Working in combination with these functions, the VE enhances efficient motor control by offloading resource-hungry computations from the main CPU. Within the VE block, a scheduler for event and priority control, a calculation core and decoder, an operation unit, a multiply-accumulate unit and vector control modules handle processing of the 3-phase current input from the MCU's ADC and perform the FOC algorithm.

With only a few simple register settings required, the PMD and VE firmware work together to manage all of the functions needed to control a motor, including three-phase PWM waveform generation at 16-bit resolution, speed control and position estimation. The MCU integrates multiple analogue op-amp and comparator channels, as well as a 12-bit ADC providing high-speed PWM-synchronised analogue-to-digital conversion. The on-board programmable amplifiers allow flexible gain setting for the phase currents.

Implementing these functions in firmware gives developers the freedom to blend elements provided in the PMD block with any preferred or proprietary motor control IP as required. Unlike a conventional hardware-based approach, the PMD firmware leaves no unused silicon if the developer chooses such an approach.

The complete family of Toshiba TMPM370 ARM Cortex-M3 MCUs in fact provides a choice of devices supporting this firmware-based approach when designing either single-motor or dual-motor applications. In North American markets, dual-motor devices are essential to address large opportunities for air conditioning units. On the other hand, the majority of appliances sold within Europe are single-motor designs that are best served by cost-effective single-channel MCUs such as the TMPM374.

The new family of motor-control MCUs also carries over important peripheral functions from previous generations, such as Toshiba's proven Oscillation Frequency Detector (OFD). The OFD is a hardware block that simplifies clock monitoring for the detection of abnormal clock activity. This is a useful technique for verifying correct processor operation and hence enabling the system to manage fault conditions safely in accordance with the IEC 60730 safety standard for domestic appliances.

By increasing the accessibility of high-performance motor controls using FOC, this new generation of motor-control MCUs will also help developers meet emerging European directives, as eco-design regulations move to encompass motors above 750 Watts. FOC helps to minimise both audible noise and EMI, which are key concerns throughout European markets. In addition, the firmware-based approach allows developers to use CPU sleep modes most effectively to minimise energy consumed by the control circuitry.

Updating the Ecosystem
Accompanying this evolution in motor-control design using advanced MCUs, low-cost software tools are also emerging. A typical example is the development, code analysis and test automation toolchain from Atollic. Tools such as these enable designers to realise the maximum potential savings in cost and time. The Atollic toolchain includes the TrueSTUDIO® editor and C/C++ compiler and debugger, as well as TrueANALYZER® and TrueINSPECTOR® code analysis tools. These support static and dynamic analysis with reporting and code metrics. TrueVERIFIER® test automation is also part of this tightly integrated IDE. Powerful features are available free of charge. The professional configuration is around one-quarter the price of traditional tools.

Despite the disruptive influence ARM embedded cores have had on motor-control processing, the design of the power section tends to evolve more slowly. As the all-important link translating the results of the FOC loop into high-voltage signals for driving the motor phases, a proven and reliable design for the power stage is a valuable asset.

Semiconductor vendors traditionally have offered tightly coupled processing and power electronic IP that provides little or no option for customers to take advantage of improved microcontroller architectures without also investing in a new power section. The main cause is a lack of flexibility in typical hardware development platforms provided.

To overcome such restrictions and give customer design teams the freedom to maintain and evolve their own power design independently, if required, hardware supporting the TMPM370 family provides access to the MCU PWM signals. This allows designers to connect the microcontroller to almost any preferred power section. Figure 3 illustrates this more open platform for motor-control evaluation and prototyping.

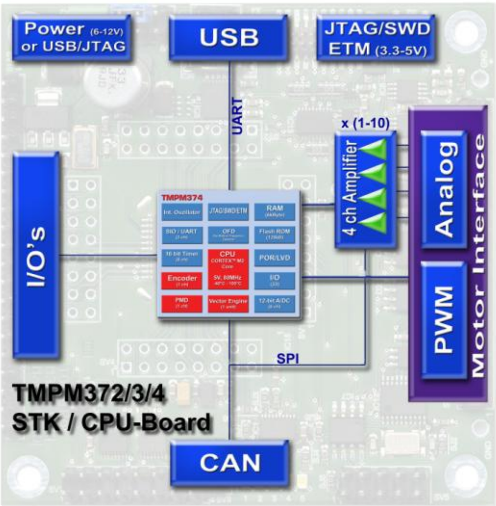

Figure 2. Open motor-control architecture.

Conclusion
The game-changing price/performance proposition offered by today's advanced embedded processors is opening new possibilities to create energy-efficient appliances featuring intelligent motor control. Accompanying improvements in microcontroller features, motor-control IP and software tools, as well as more open system architecture and development hardware, will help to translate these possibilities into innovative new products achieving today's best energy ratings.

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