Electric drivetrain control

New control methodologies for three-phase AC motors are enhancing safety of electric parts

Electrical three-phase AC-motors, such as permanent magnetic synchronous motors (PMSM) and induction machines, have a long history in industrial control systems. In automotive applications, however, they are relatively new, and are now emerging as an addition to or replacement for the IC engine.

Three-phase sinusoidal distributed and mechanically displaced windings are the main characteristic of PMSMs. Three-phase sinusoidal and time-displaced currents result in a rotating magnetic field, and this rotating field turns the motor and is caused by current switched in the motor windings via MOSFETs/IGBTs. The field-oriented control (FOC) algorithm generates the PWM pattern for the current control of the motor. The rotor position and current are continuously sensed. Efficient FOC systems, based on high-performance microcontrollers, lead the path to safe and highly efficient solutions to drive electric and hybrid vehicles.

Infineon's 32bit AUDO MAX microcontroller family is equipped with a main core (TriCore CPU) and also a fast co-processor, called PCP (see Figure 1). This asymmetric architecture allows for the efficient handling of the peripherals using PCP without interrupting the processing of the main algorithm that runs on the TriCore CPU. As such, the PCP takes care of the real time and critical interrupt loads, and therefore offloads the CPU.

For generation of the PWM to drive the inverter, two options are possible. The GPTA enables every sophisticated PWM pattern generation. As a result, this includes asymmetric dead-time generation or customized patterns. As a lower-end option, the peripheral module CCU6 can be used for generation of center-aligned and edge-aligned PWM. Compared with the GPTA, the generation of the PWM signals is directly supported with low software overhead and does not require the configuration of multiple timer cells.

Both modules – CCU6 and GPTA – offer trigger functionalities that allow latency-free, time-equidistant synchronization between the PWM-signal and the A/D current measurements. As an additional safety feature within the system, every GPTA module is equipped with an emergency mode stop signal that can be used to set up a safety switch. In addition for all TriCore AUDO MAX microcontrollers, a safety platform (based on PRO-SIL) is available that covers hardware (safety watchdog CIC61508) and software (SafeTcore driver) for scalable ASIL B-D requirements.

Two motor phase currents are measured in the given example and converted by use of an A/D converter. Based on Successive Approximation Register (SAR), the analog/digital conversion offers high precision (12bit resolution) and a conversion time smaller than one microsecond. Out of two known phase currents, the third can be derived by calculation. For increased safety requirement levels, the redundant measurement of the third motor phase current is recommended. In such a case a microcontroller with a third A/D module is available.

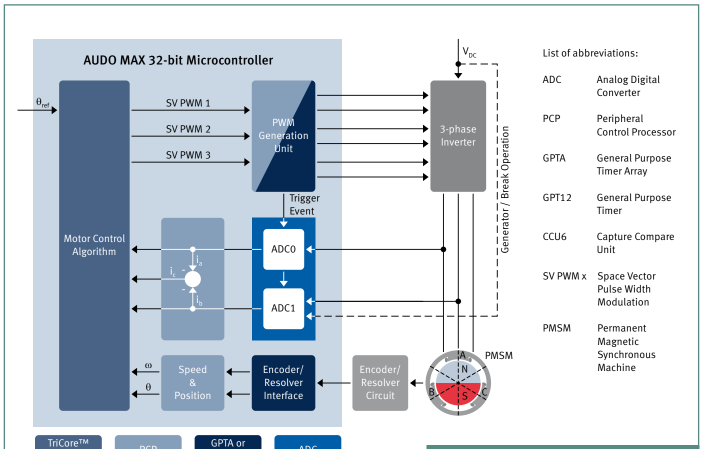

Figure 1: The 32-bit TriCore running in FOC mode

A resolver converts the angle position of the PMSM rotor into an electrical value. Essentially, the rotor angle is derived from two signals (sine/cosine) with the use of an additional circuitry that applies tangent function. The signal of the resolver circuitry is given to the SPI bus. Alternatively, the resolver sine and cosine signals are directly read by the microcontroller. Another alternative is the encoder signal that is then conditioned in the encoder interface that runs on the GPT12 of the microcontroller and is fed back to the control algorithm.

Over the last few years, both automotive software and communication has been standardized via OSEK, AUTOSAR, and FlexRay. Besides standardized

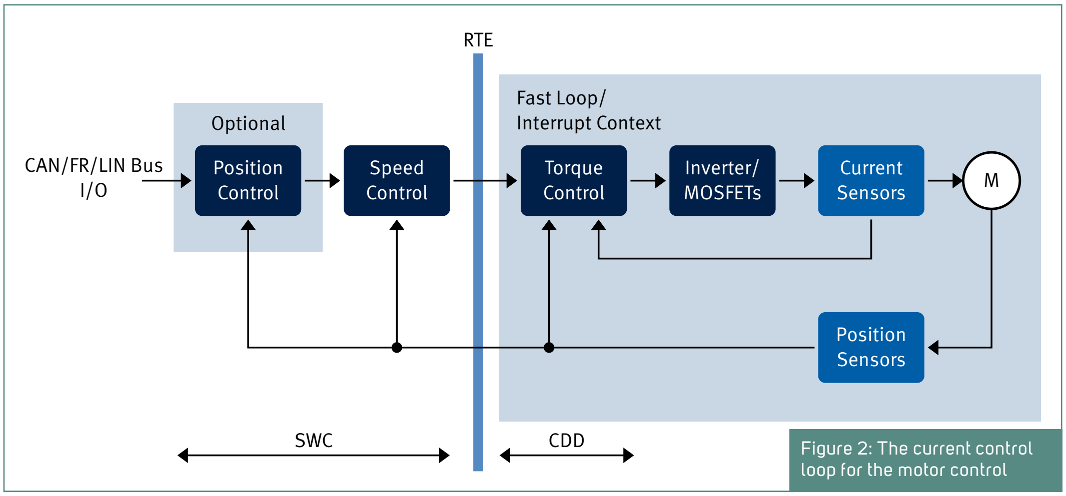

Figure 2: The current control loop for the motor control

		AUDO MAX
Basic features		▪ Control up to 4 PMSM motors via FOC ▪ Control up to 4 BLDC motors via block commutation
FOC mode	Sensors	▪ Incremental encoder / Hall sensors ▪ Resolver ▪ Direct resolver mode (without resolver IC) ▪ Sensorless FOC
	Current measurement	▪ 3-Phase ▪ 2-Phase ▪ DC link
Block commutation mode	Sensors	▪ Hall sensors ▪ Sensorless back EMF
	Current measurement	▪ DC link

Figure 3: The MC-ISAR eMotor operation modes

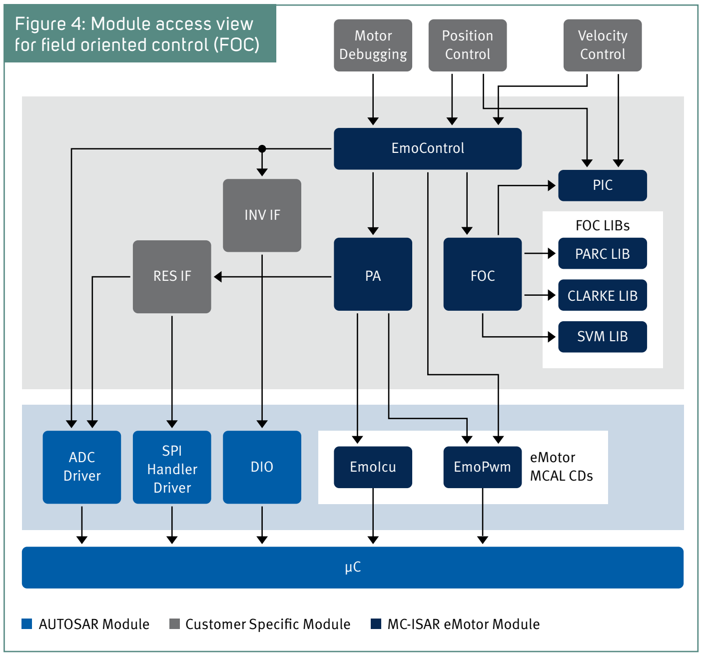

Figure 4: Module access view for field oriented control (FOC)

software components, automotive systems are using control algorithms that can be reused amongst a variety of applications. The control of electrical motors is increasingly handled within ECUs located within the powertrain.

The MC-ISAR eMotor driver is abstracting the common feature of current control for three-phase electric motor applications. It has been designed to support multiple-position acquisition modes and inverter-control devices.

Infineon's AUDO MAX family is highly suitable for the control of electrical motors. The TriCore architectures and MC-ISAR eMotor driver provide the power to control multiple three-phase motors, with their sophisticated control strategies for block commutation of brushless DC (BLDC) motors and FOC of PMSM.

Even the mixed control of BLDC and PMSM motors from one microcontroller device is supported. The advantages of FOC controlled PMSM motors in comparison to other motor types enables more energy efficiency levels, shows less attrition and enables exact control and positioning. It's important to remember that the support for linear torque control is the baseline for its use in the hybrid and electric drivetrain technologies.

Figure 2 shows the current control loop of the MC-ISAR eMotor driver on the right side as complex device driver (CDD). On this occasion, the time-critical current control loop is handled in an interrupt context manner within a range of 50 microseconds. On the left side there are additional software components for position and speed control that are provided from the application code.

To further support the precise positioning requirements, the MC-ISAR eMotor (Figure 3) applies the typical high-resolution sensor modes via hall sensors plus incremental encoder and resolver. In addition to this, the sensorless FOC may be used for failsafe modes. For cost-sensitive implementation, the direct resolver mode is provided for the AUDO MAX family via software implementation and discrete components to avoid the need for external resolver ICs. Such a setup enables a cost reduction of around US$2 per control unit – a key point during a time when budgets and cost reduction are playing an important role in the automotive industry around the world.

The software partitioning in Figure 4 is split into hardware-independent and hardware-dependant components. Hardware-independent modules are for EmoControl, position acquisition PA and FOC. Therefore EmoControl is the main module to control the direction and the current via FOC. The currents given to the motor defines the torque. Towards the application, the MC-ISAR eMotor driver returns position and speed information of the motor. The position acquisition PA module captures the angle form the resolver and encoder signals. The FOC with its park, clarke and space vector modulation is the main part to set the new current via sensing the current and position.

Hardware adaptation is provided via modules that are either reused from the AUTOSAR MCAL drivers, or dedicated models for PWM generation and encoder interface. The customer code for position and velocity control can be added as standard software components and subsystems, such as the ones provided by the AUTOSAR development package.

To further support safety-compliant applications, it is vital to consider all safety requirements from the beginning when designing software components. The application-specific requirements are to be defined during ECU development, and as such, they may differ from one application to another. For example, the MC-ISAR eMotor has been developed and based upon an ISO 26262-aligned software process and allows three-phase current measurement, which supports and enhances safety aspects.

The Infineon AUDO MAX family and MC-ISAR eMotor driver enables control of up to four PMSM or BLDC motors in parallel and provides performance for controlling the application task. Furthermore, the MC-ISAR eMotor is integrated with the standard AUTOSAR MCAL drivers under the same configuration tool.

As a result of such a setup, configuring the microcontroller resources for the AUTOSAR MCAL and MC-ISAR eMotor driver is supported within one user interface and enables seamless configuration of the different software modules. ECU developers can focus on the application that's relevant to the control of the electrical motor and do not need to reprogram the motor control algorithm. To reduce systems costs, the direct-resolver mode is supported and this function eliminates the need for the resolver IC. The AUDO MAX family and MC-ISAR eMotor driver are designed to support safety applications. ◉

CONTACT
Guenter Hank and Thomas Hafner at Infineon Technologies
T. 0(0)800 951 951 951 (toll-free)
W. www.infineon.com