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COVER STORY: Field Oriented Control for motor drives using an optimized 8-bit MCU

Field Oriented Control

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Field-oriented control for motor drives using an optimised 8-bit MCU

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This article decribes field-oriented control (FOC) implemented on the 8-bit XC886/8 microcontroller by combining a high-performance 8051 core and a "vector computer" coprocessor core, which performs 16-bit arithmetic operations.

■ Field-oriented control (FOC), a technique for operating electric motors that results in smooth and energy efficient operation at all speeds, is increasingly being adopted for consumer and industrial motor control. Achieving this efficient method of control with an optimised 8-bit microcontroller redefines the economic models for developers of appliances and other motor-controlled products such as fans and HVAC control. FOC is implemented on the 8-bit XC886/8 MCU by combining a high-performance 8051 core and a "vector computer" coprocessor core, which performs 16-bit arithmetic operations. This vector computer is build by two parallel operating units. The MDU, a 16-bit multiply and divide unit, and the CORDIC, a 16-bit coprocessor dedicated for vector rotation and angular calculations. Unlike most competitive FOC implementations that are hard-coded, XC886/8 microcontroller based solution offers the added benefit of software reprogrammability to give the developers more versatile application options.

A sensorless FOC offers the full benefits of sinusoidal commutation at a minimum system cost. There is just one shunt in the DC link necessary to aquire the three phase currents. Figure 1 shows the block diagram of the sensorless FOC with speed control of a permanent magnet synchronuous motor (PMSM). From a control point of view, the FOC is comparable with that of a DC motor. The basic concept is a cascade control with the important difference that the electrical variables (V_d, I_d, V_q and I_q) are turning with the rotor. Thus the currents measured at the stator (I_α and I_β) have to be transformed into the rotor coordinates (I_d and I_q). The controller for the currents is realised in the rotating system as PI-controller, whereas the field exciting d-component and the torque exciting q-component is controlled separately. The speed controller adjusts - as for DC motors - the reference value for the torque exciting current I_q. Due to the permanent magnets at the rotor, the reference value for the field-exciting current I_d is set to zero. The output of the current controllers represents the reference voltages (V_d and V_q) in the rotor coordinates. These values are transformed into the stator coordinates (V_α and V_β) in order to calculate the polar coordinates (norm and angle). Using space vector pulse-width modulation, the norm and angle values are converted in three-phase currents by modulating the high-side and low-side switches of the power inverter accordingly.

A space vector is a sinusoid whose center is able to "float" in space. Inactive states are used as an off-time during the switching period when creating the space vector. A three-phase space vector is represented by a hexagon which can be divided in six sectors. Any desired voltage-space vector will consist of a "real" voltage from one of the phases and an "imaginary" right-angle voltage created from the other two phases. Figure 3 shows the sinusoidal output current I_U, I_V and I_W which are phase shifted each by 120° as well as the hexagon of the space vector representation with the six sectors labeled from A to

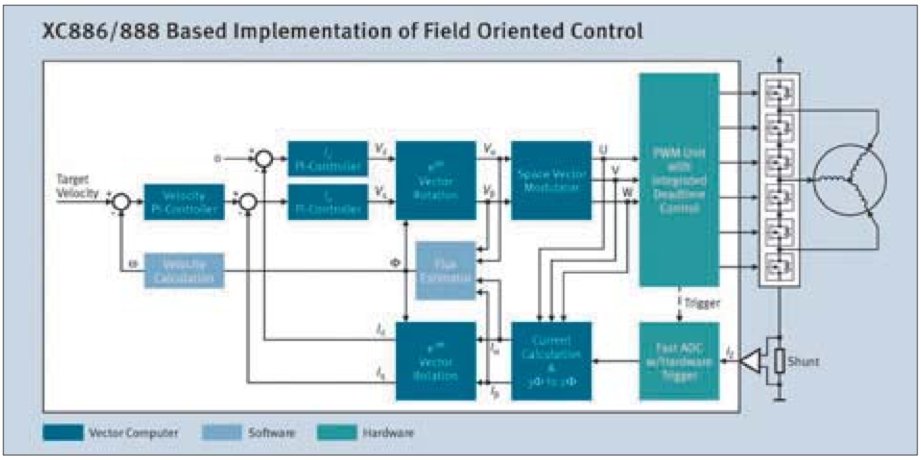

Figure 1. Sensorless Field-oriented control of PMSM motor

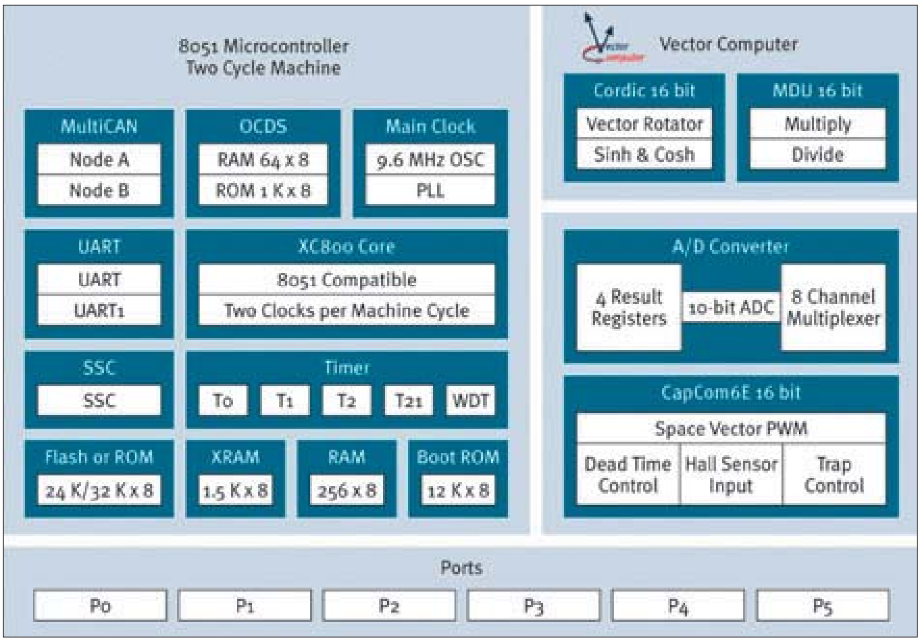

Figure 2. Block diagram of 8-bit microcontroller XC886/888 with vector computer

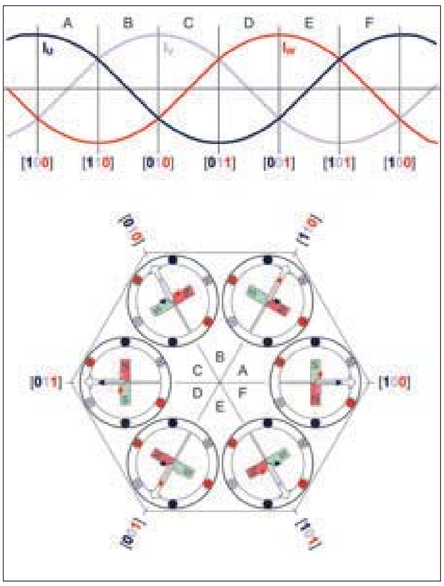

Figure 3. Sinusoidal output current and three-phase space vector, represented by a hexagon

F. The magnetic field is a superposition of the fields generated by the coils of the stator. In figure 3, e.g. the blue coil generates the a magnetic field in the direction of the blue arrow. The superpostion of the fields is represented by the white arrow. Please note that the white arrow is rotating, whereas the red, blue and pink arrows are fixed. It is the superposition of the three stator fields which causes the rotation. The FOC algorithm has to make sure that the magnetic field of the stator is always oriented rectangularly to the permanent magnets of the rotor. In figure 3, this magnetic field is represented by a dipole (N and S). In order to estimate the rotor position by a single shunt measurement, the PWM pattern generation and the triggering of the ADC for current measurement must be very fast and accurate. Any jitter in the trigger point will influence the actual rotor's angle estimation. As a result, the total harmonic distortion of the sinusoidal current signals will increase.

The XC886/888C(L)M implements the above requirement using an event-based hardware trigger from the PWM unit CapCom6E towards the ADC. The event-based trigger eliminates any interrupt latency and enables fast and accurate current measurement The ADC provides in total four result registers, from which two are used to hold the appropriate DC-link current values I_{DClink}. The ADC sample time is as low as 250ns.

Sensorless FOC execution on Infineon's 8-bit microcontrollers XC886 and XC888 (for instance with 15kHz PWM frequency and 133µs current control response time) requires only 58% of the CPU's performance providing plenty of headroom for application-specific functionality. This efficient programming of the sensorless FOC algorithm in 16-bit arithmetic can only be realised by a nested utilization of the vector computer - MDU and CORDIC - and the 8051 compatible CPU core itself. The resulting sinusoidal waveform of this implementation results in low-noise operation of the motor. The system costs are reduced by using an 8-bit standard microcontroller, using just one shunt in the DC-link for acquiring the three-phase currents and using a FOC algorithm that makes expensive Hall sensors obsolete. One of the key benefits of the solution is the software reprogrammability which enables an optimised start-up phase of the motor by programming a controlled ramp using any signal of the algorithm. The implementation of a field weakening method can easily be done by controlling the field-exciting I_d component of the FOC algorithm. When changing the reference value from zero to a negative value, the motor will exceed its nominal speed.

A FOC drive application kit which provides customers with a cost-effective method of evaluating and developing sensorless brushless DC (BLDC) motor control applications using the sensorless field-oriented control technique. The kit features the CANmotion evaluation board which integrates the XC886CM MCU (TQFP-48) and a 3-phase power inverter providing all the necessary functions to control a 24V BLDC motor. The complete sensorless FOC source code with a comprehensive documentation allows the users to jump start with FOC development.

A CAN to USB bridge, built by using the XC886CM again, is available in the kit for hex code download and parameter adjustments. A CAN message-based user interface enables the users to set and modify all motor control parameters for speed and current control. The unique CAN-based monitoring offers real-time control of the motor control application. The 24V BLDC motor and a plug-in power supply make the kit ready-to-use.

The pre-compiled demos provide a platform for easy evaluation and performance measurement of the FOC algorithm. The complete development environment including a free tool chain allows the users to advance to the next stage of application development and customisation using the same application kit.

Internet Links:

FOC Drive Application Kit	**http://www.infineon.com/XC800-FOC**
XC800 8-bit microcontroller	**http://www.infineon.com/XC800**
Datasheet and usermanual XC886	**http://www.infineon.com/XC886**
Datasheet and usermanual XC888	**http://www.infineon.com/XC888**