Three-Phase Current Measurement
Freescale dedicated MCUs make it easy

Overview
Advanced motor control algorithms such as field-oriented control (FOC) and direct torque control (DTC) require sensing of motor phase currents. To reduce the number of sensors and overall cost of the solution, the phase currents can be measured by means of low-cost shunt resistors with a simple interface between the shunt resistors and MCU inputs. The phase current is measurable only at a certain instant and thus the current sensing based on the shunt resistors requires support from the MCU. Freescale dedicated motor control devices provide exceptional hardware support, allowing the user to solve specific application needs.

Figure 1: Three-Phase Inverter Topology

Figure 2: Current Sensing

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Electric motors are powered by inverters. Figure 1 depicts the typical topology of the three-phase inverter. The inverter consists of three half-bridge units with top and bottom transistors. The shunt resistors (R1, R2 and R3) used for current sensing are placed below the bottom transistors of the corresponding phase.

In some cases, it is possible to reconstruct the three-phase current just from a DC link shunt resistor \( R_{\text{dc}} \). A voltage drop on the shunt resistor is amplified by the operational amplifier and sampled and converted by the ADC peripheral module. Since the current flows through the shunt resistors when the bottom transistor is switched on (T2, T4, T6), an instant of ADC sampling must be precisely defined and synchronized with the switching conditions of inverter transistors and thus with the voltage generation peripheral module, which is the PWM module.

Detailed switching conditions of all inverter phases in the case of the complementary PWM mode are shown in figure 2.

**Freescale MCU Support for Current Sensing**

Freescale dedicated motor control MCUs provide wide flexibility for all possible current sensing configurations with shunt resistors. The Freescale MCU portfolio that supports the smart current sensing comprises MCUs based on DSCs, Qorivva MCUs (based on Power Architecture technology) and Kinetis solutions (based on the ARM core).

The current sensing mechanism requires synchronization between PWM and ADC peripheral modules. It is necessary to control the synchronization via hardware without software intervention. The PWM module generating the output voltage as the variable duty cycle signal also generates the synchronization signal. This synchronization signal is internally processed by a timer that defines delay between the synchronization signal and a signal triggering the ADC module. Once the timer value is set, the synchronization and ADC conversion work automatically. If needed, it is simple to manage the value in the timer register in runtime and thus the instant of ADC sampling. Another great feature of Freescale motor control MCUs is that the ADC module contains two independent AD converters with two independent sample and hold circuits. This feature allows the user to sample, hold and convert two analog signals, in this case currents, at the same time. This ADC operation is called the simultaneous operating mode. Since we always measure just two currents and the third is calculated from the following equation, \( i_a + i_b + i_c = 0 \), we can calculate the third current as precisely as possible.

**Current Sensing Using the MC56F84xxx DSC Family**

This very powerful DSC family provides flexible support for hardware triggering. ADC conversions can be synchronized by any module connected to the internal crossbar modules, such as PWM, timer modules, GPIO and comparators. Apart from the simple synchronization support, the MC56F84xxx DSC family also provides support for multitriggering modes with a programmable number of conversions on each trigger.
The typical configuration of internal peripheral modules allowing the hardware synchronization is shown in figure 3.

The eFlex PWM module is used for both the PWM output generation (PWM out 0, PWM out 1, ..., PWM out 6) and ADC sampling instant generation. The trigger events are connected through the crossbar switch module to the ADC module (internally two ADCs: ADC0 and ADC1). ADC0 and ADC1 run simultaneously and can convert not only the currents but also other analog signals such as VDC bus and temperature.

The principle of synchronization between the eFlex PWM module and ADC modules is shown in figure 4.

The PWM period is defined by two registers: init and compare value. The synchronization signal is generated at the beginning of the PWM period (SYNC signal).

Each eFlex PWM submodule has one counter and six compare registers. The compare registers that are not used for the PWM signal generation can be used for a synchronization purpose. When the eFlex PWM submodule counter reaches the compare value defining the trigger event, the trigger output from the eFlex PWM module is generated and starts the ADC conversion process. If the ADCs are set up for simultaneous operation then both ADCs are triggered at the same instant. In the case of the ADC module on the MC56F84xxx devices, the conversion times are as follows:

- Single conversion time: 425 ns
- Additional conversion time: 300 ns
- Eight conversions using parallel mode: 1.325 us, 16 results

Since the ADC module has 16 result registers, it is possible to convert up to 16 analog signals without reading the results. All 16 conversions can be triggered by one trigger or several triggers. The results can be read after the ADC conversion is complete using an interrupt service routine or DMA.

**Conclusion**

Freescale current sensing and analog signal measurement solutions allow the user to simplify the overall solution and reduce the system cost. The smart hardware synchronization provides extremely precise definition of the instant of sampling the analog signals (current, voltage, temperature, etc.). Moreover, the hardware synchronization increases MCU throughput.

Comprehensive information about the hardware synchronization for the corresponding device can be found at freescale.com. Here, you can find application notes and design reference manuals describing how to configure the current sensing, process ADC results, manage the synchronization in runtime and calculate or reconstruct motor phase currents.

Design reference manuals: DRM092, DRM102

Application notes: AN1930, AN3234, AN3731, AN1933, AN4410
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