

Dual Motor Control for PMSM with the Kinetis K70

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1 Introduction

This application note deals with the field-oriented control (FOC) of two permanent magnet synchronous motors (PMSM) with the Kinetis K70 microcontroller (MCU).

A dual motor control application requires a processor with high performance and the right set of peripherals for simultaneous control of two motors. The Kinetis K70 MCU satisfies both the requirements, with a performance margin for the application code.

The theoretical aspects of the dual motor control as well as a short introduction to all the hardware parts and their realization possibilities on the new K70 processor, are included in this application note.

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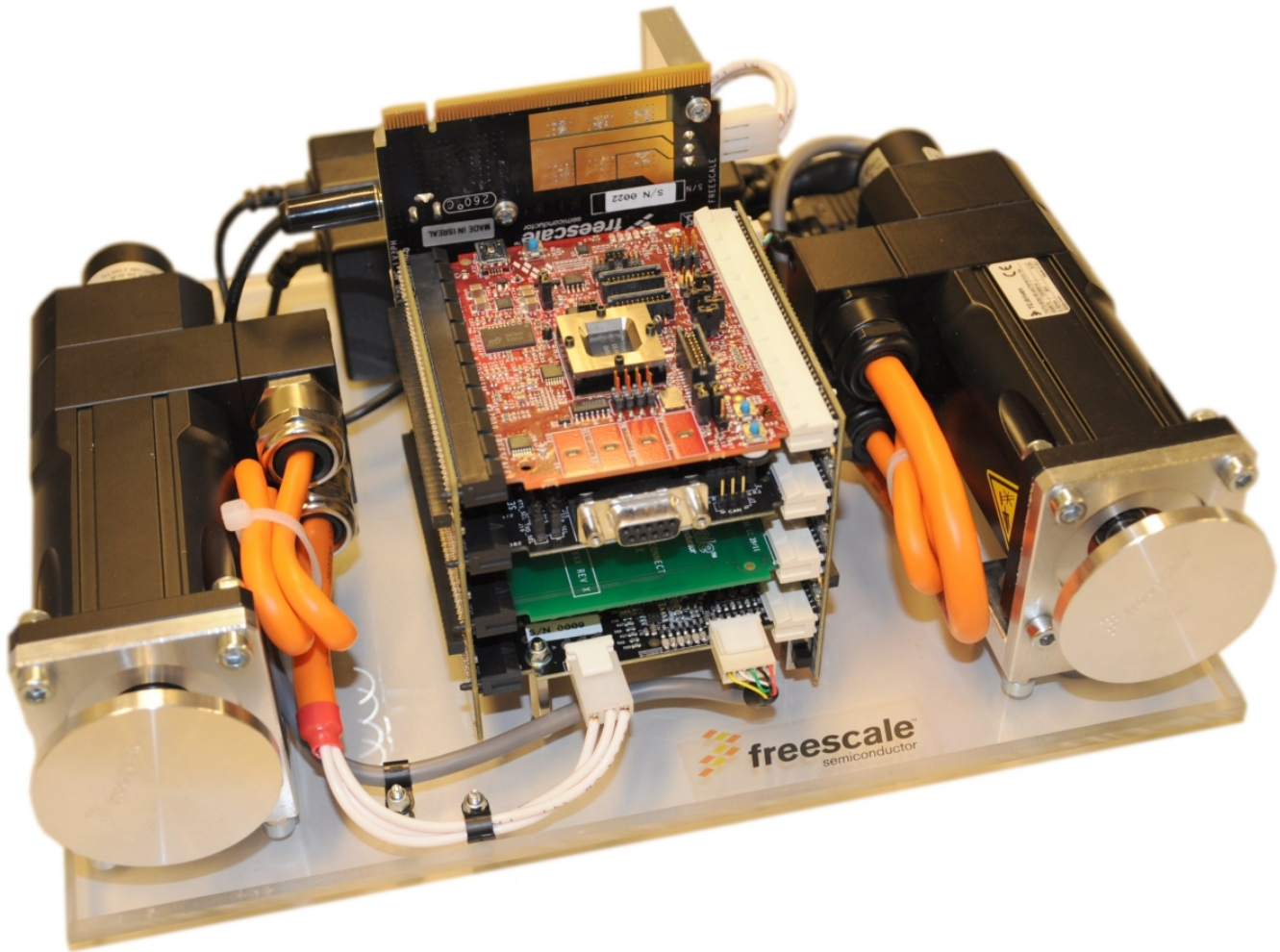


Figure 1. Dual motor control demo with K70 MCU

2 Kinetis portfolio and K70 family overview

Kinetis MCU is based on the ARM®Cortex™-M4 core. It gives the Kinetis portfolio, a unique position among similar MCUs. The Kinetis portfolio consists of five MCU families with over 200 pins, peripherals, and software-compatible devices. The features of the Kinetis MCU families can be summarized as follows:

- Each family offers excellent performance, memory, and feature scalability with common peripherals, memory maps, and packages, providing easy migration both within and between families.
- Kinetis MCUs are built from Freescale's innovative 90 nm Thin Film Storage flash technology with the unique FlexMemory.
- Kinetis MCU families combine the latest low-power innovations and high performance, high-precision mixed signal capability with a broad range of connectivity, human machine interface, and safety and security peripherals.
- Kinetis MCUs are supported by a market-leading enablement bundle from Freescale and numerous ARM third-party ecosystem partners.

3 Kinetic K70

The latest family member, the Kinetic K70, has a high performance, rich peripheral integration, and large internal memory. From a motor control perspective, the K70 MCU enables two high-end motor control algorithms to run in parallel, and a set of peripherals, namely the FlexTimer and analog-to-digital converters (ADC), enables an interface to the motor control power electronics. Here is a summary of the features of the Kinetic MK70FN1M0VMJ12 MCU:

- Core:
 - ARM Cortex-M4 Core / Floating point unit
 - CPU frequency: 120 MHz
- Memory:
 - 1 MB flash / 128 KB RAM / 16KB Cache
- Mixed-signal analogue:
 - Fast, high-precision 16-bit ADC, 12-bit digital-to-analog converters (DAC), programmable gain amplifiers (PGA), high-speed comparators (CMP), and an internal voltage reference
- Connectivity and Communications:
 - UART, IrDA, I2S, CAN, I2C, USB, and DSPI support
- Timing and Control:
 - Powerful FlexTimer (FTM)
 - Periodic interrupt timer (PIT)
 - Programmable delay block (PDB)
- System:
 - 5 V tolerant general-purpose input/output (GPIO) with pin interrupt functionality
 - Operational in 1.71-3.6 V voltage range and -40-105 °C temperature range
 - 256-pin MAPBGA package with 17x17 mm dimensions

4 Dual motor control—K70

The dual motor control algorithm controls two motors in parallel. The K70 MCU has only one core, therefore, it executes the algorithm for the first and the second motor, alternately. It reads the phase currents of each motor and detects the voltage of both inverters, and according to user interface, it generates the pulse-width modulation (PWM) signals of both inverters.

The application requires the correct set of MCU peripherals. For current and voltage measurement, ADCs are needed. At least two ADCs are required because for each motor, the control needs to measure two phase currents in parallel. Typically, shunt sensors are used. The measurement must be synchronized with the PWM pulses. For this purpose, the Kinetic family has a PDB, which synchronizes the ADC with the FTM and provides various delays between them. See [Figure 2](#). After the necessary delay, it runs the conversion of the two phases currents in parallel. This sequence runs alternately for the first and the second motor. The current measurement is a hardware process running without code. See [Figure 4](#) on how it works.

Each motor is supplied by its own inverter whose power part is a full bridge. Six PWM signals control the power devices in a full bridge. Therefore, two FTMs with at least six channels for each motor are required for sensing the mechanical quantities—rotor speed and the rotor position of each motor. The actual position is obtained by decoding the signals from an incremental sensor, and the rotor speed is calculated as the position change in time.

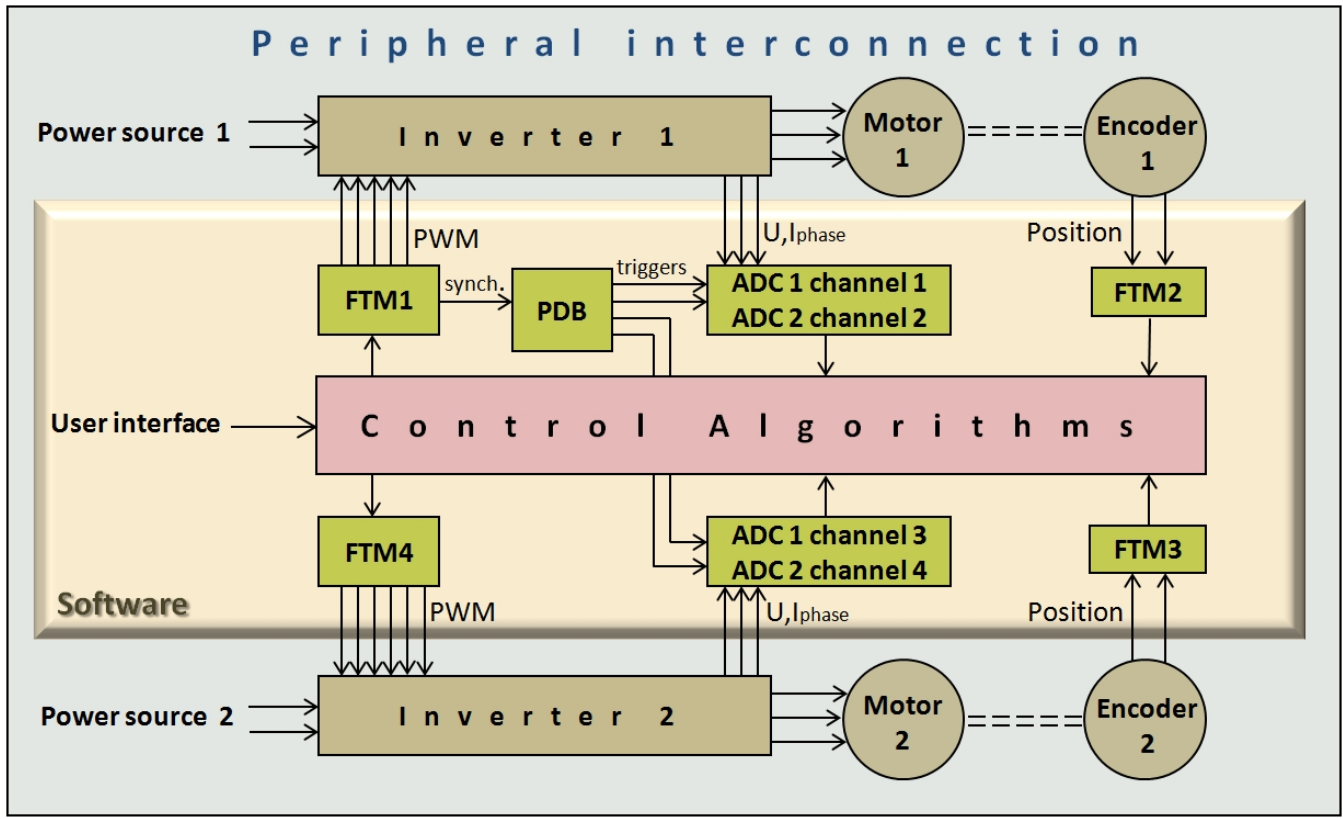


Figure 2. Topology of dual motor control

Table 1. Kinetis K70 peripherals overview for dual PMSM FOC

Group	Module	Submodule and channels available	Used in the application	Purpose
Timers	PIT	4 channels	1 channel	Time base for speed calculation and speed regulation
	FTM	FTM1: 8 channels	6 channels	Generation of 6 PWM channels for the first motor
		FTM2: 2 channels	2 channels	Quadrature encoder signals decoding for the first motor
		FTM3: 2 channels	2 channels	Quadrature encoder signals decoding for second motor
		FTM4: 8 channels	6 channels	Generation of 6 PWM channels for the second motor
	PDB	4 channels for triggering 4 ADCs. Two channels are multiplexed with two FTMs	2 channels	Triggering 2 ADC channels for phase currents measurement
		2 channels for DAC triggering		
		4 channels for CMP triggering		
	Analog	ADC	ADC1: 32 channels including 28 single-ended and 4 differential channels	4 single-ended channels
ADC2: 32 channels including 28 single-ended and 4 differential channels			4 single-ended channels	3 channels for phase current and 1 for DC bus voltage measurements of the second motor
ADC3: 32 channels including 28 single-ended and 4 differential channels				
ADC4: 32 channels including 28 single-ended and 4 differential channels				
CMP		4 channels		
DAC		2 channels		

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Table 1. Kinetis K70 peripherals overview for dual PMSM FOC (continued)

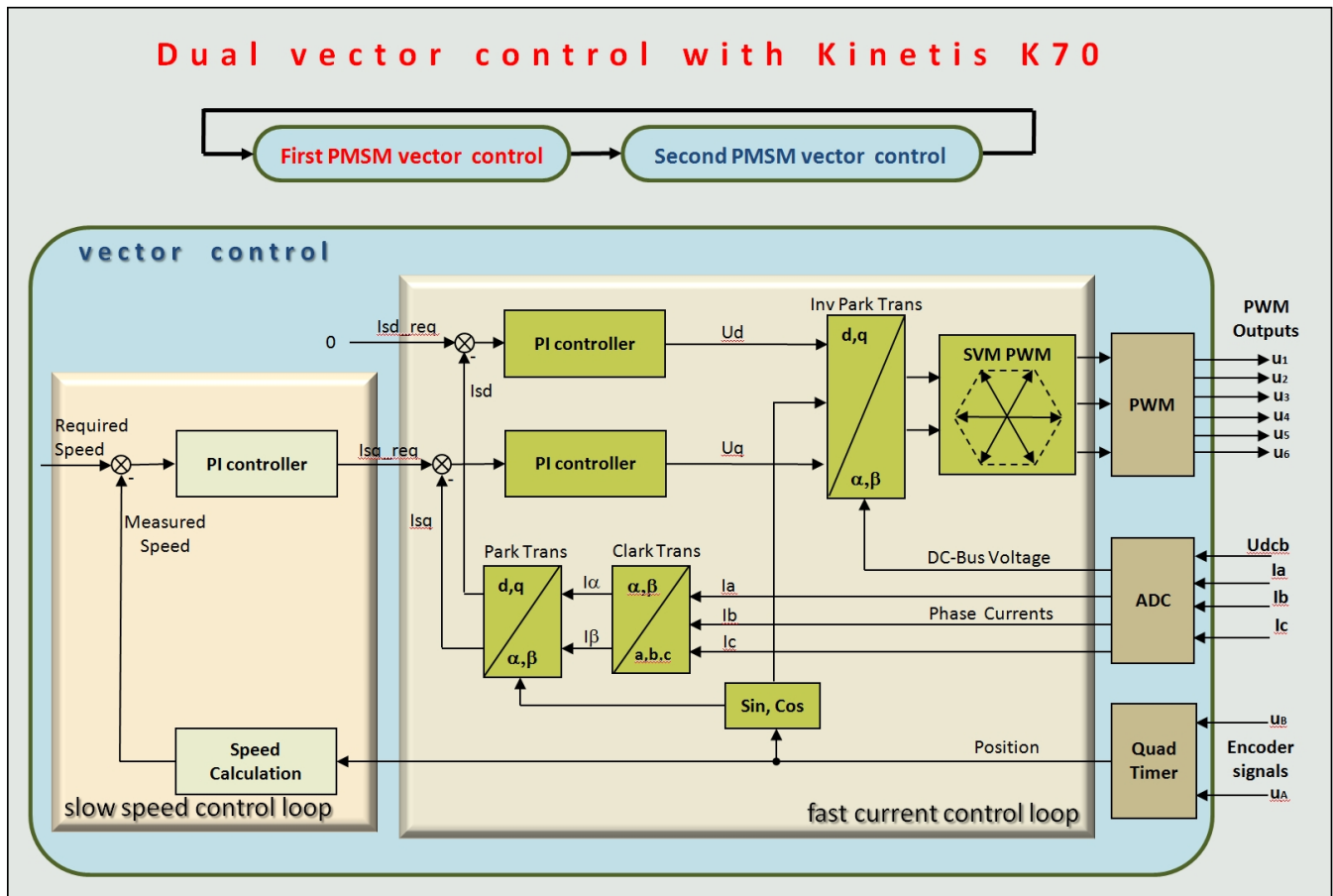
Group	Module	Submodule and channels available	Used in the application	Purpose
Communications	UART	6 channels	1 channel	FreeMASTER communication
	SPI	3 channels	1 channel with 2 chip selects	MOSFET driver communications
	I2C	2 channels		
	SDHC	1 channel		
	USB	1 channel		
	CAN	2 channel		
	Ethernet	1 channel		

5 Control algorithm

The dual motor control requires running two motor control algorithms in parallel. Figure 3 shows the field-oriented control (FOC) principle of a PMSM. The key to FOC is to control the motor torque and field excitation, or, the motor magnetic flux, independently and separately. The operating principles of the two control loops are discussed below:

- The current control loop: The following steps describe the working of this control loop:
 - a. The two phase currents must be measured in the stator three-phase system of coordinates.
 - b. The current vector in the stator two-phase system of coordinates, can be obtained using the Clark Transformation.
 - c. The following Park Transformation rolls the current vector into a rotating two-phase system of coordinates, according to the measured rotor position.
 - d. The differences between the measured and required current components are forced into the proportional-integral (PI) controller.
 - e. The voltage components obtained from the controllers must be again rolled using the Inverse Park Transformation.
 - f. The three components of the phase voltages for the PWM modulator are generated using the Space Vector Modulation block.
- The speed control loop: It is less complex and determines the deviation between the required speed and the real rotor speed calculated from the rotor position. The PI controller processes the deviation and creates the required torque current component.

The field weakening is not implemented, therefore, the required flux current component is kept at zero. A detailed description of the PMSM vector control application can be found in *PMSM Vector Control with Quadrature Encoder on Kinetis, Design Reference Manual (DRM)*, available at <http://www.freescale.com>.



6 Timing

The timing is the key for all motor control applications. The timing determines how the processor performance is utilized. For dual motor control, the processes for individual motors must overlap. It is convenient to set up the FTMs, so that the first FTM overflow will happen exactly in the middle of the second FTM cycle. See [Figure 4](#). This gives the same processing time for the fast loops of the first and second motors, so each motor has an available window equal to 50% of the total CPU time. It is important to prepare such a control algorithm in order to utilize the processor processing time properly. Also, the overlay enables a decrease in current stress of the DC-bus capacitors due to which the current peaks are spread.

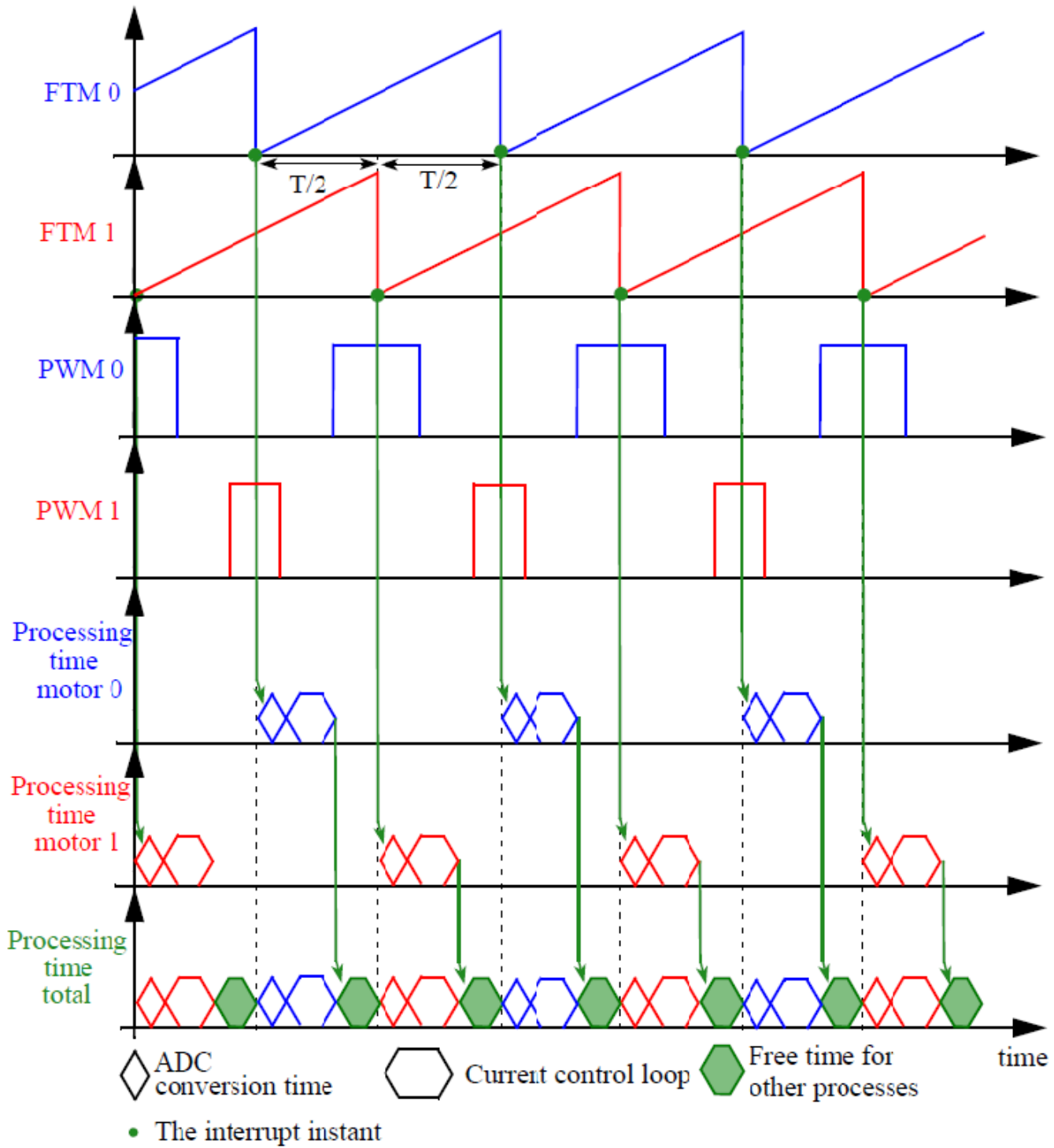


Figure 4. Dual motor control timing

7 Hardware of dual motor control

The tower system is a valuable asset of Kinetis MCUs. It is not possible to supply the motor from the MCU pins due to the voltage and current limitations, therefore, a full bridge consisting of powerful semiconductors is typically used to supply the motor. Freescale offers a low-level voltage power stage for the tower kits. This power stage not only includes the MOSFET power devices, but also a driver for the devices, measurement circuits, a protection unit, and power supply. This power stage fits the tower kit, and thus, a tower system, including the power stage, can be easily built.

The K70 MCU tower does not have natural support for dual motor control. A new tower interconnect board was proposed to connect selected signals from the secondary and the primary elevator into the connector where the second power stage is inserted.

Both power stages can be supplied independently from their own sources, or, it is possible to connect to one power supply through DC buses, in which case, the motors can change energy mutually.

8 References

- K70 Sub-Family Reference Manual, available at <http://www.freescale.com>.
- TWR-MC-LV3PH User's Manual, available at <http://www.freescale.com>.
- 3-Phase BLDC Motor Control on Kinetis, User's Guide, available at <http://www.freescale.com>.
- PMSM Vector Control with Quadrature Encoder on Kinetis, DRM, available at <http://www.freescale.com>.

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