TMPM4K Motor Control Microcontroller for High-Performance PMSM Drive Systems at Lower Cost

Permanent magnet synchronous motors (PMSMs) have become widely disseminated in the consumer and industrial fields in recent years. Progress has been made in enhancing the performance of PMSM drive systems through the introduction of vector control to secure high efficiency while reducing noise. However, the application of vector control to PMSM drive systems is hindered by issues associated with increased costs. These costs arise owing to either the necessity for expensive sensors, including current sensors and position sensors for vector control, or the necessity for advanced technology on the user's side if a sensorless control method for PMSM is employed in order to eliminate the requirement for expensive sensors.

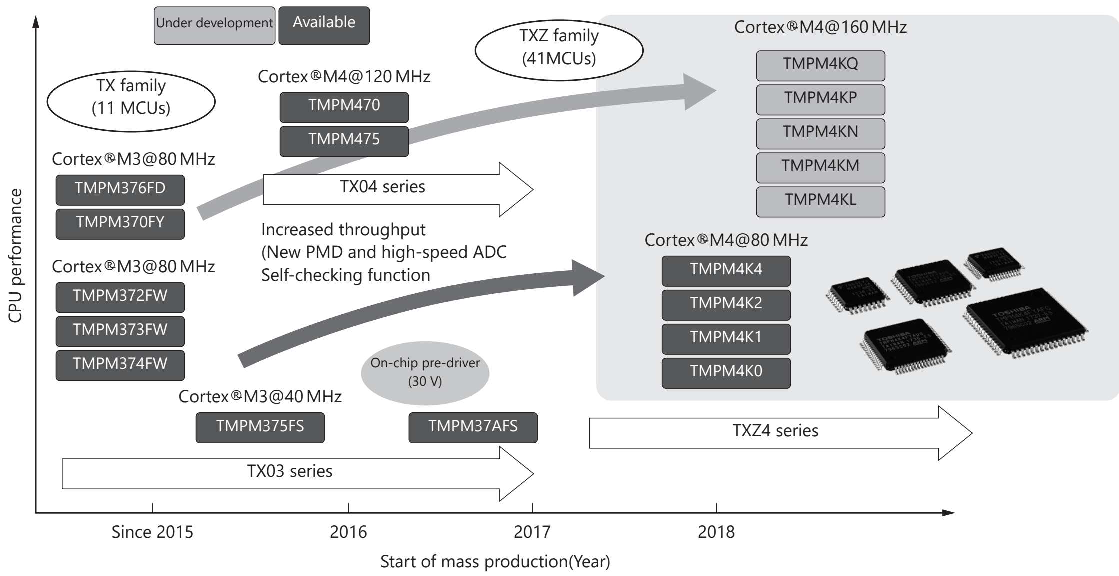
In response to users' needs for the easy introduction of vector control into motor drive systems, the Toshiba Group has been developing and supplying motor control microcontrollers that feature a vector engine (VE) incorporating certain vector control functions as hardware. We have now commercialized the TMPM4K, a motor control microcontroller suitable for PMSM drive systems equipped with an improved VE and an advanced programmable motor driver (A-PMD) to generate inverter control pulse signals. The TMPM4K is expected to offer high performance due to increased processing speed while reducing costs because of the smaller number of parts required.

1.Introduction

PMSMs are coming into widespread use for many consumer and industrial applications because they provide higher efficiency than induction motors. In particular, in the field of consumer products, in Japan the enforcement of the Top Runner System based on the Law on the Rational Use of Energy (Energy Saving Act) has increased the demand for energy saving, and highly efficient PMSMs are required. Although the technique called vector control is effective for driving PMSMs with high efficiency and low acoustic noise, its use has been restricted to industrial applications because the vector control algorithm is complicated.

Under these circumstances, the Toshiba Group has released the TX03 and TX04 Series of microcontroller units (MCUs) for consumer motor control applications incorporating a VE, which implements part of the vector control algorithm as hardware to simplify the use of vector control[1] (**Figure 1**). Of the complex mathematical calculations required for vector control, the vector engine implements, as hardware, the routine processes that do not vary considerably according to the application, offloading the central processing unit (CPU) and thereby increasing overall processing speed. This hardware implementation also facilitates the use of vector control for motor control applications (**Figure 2**).

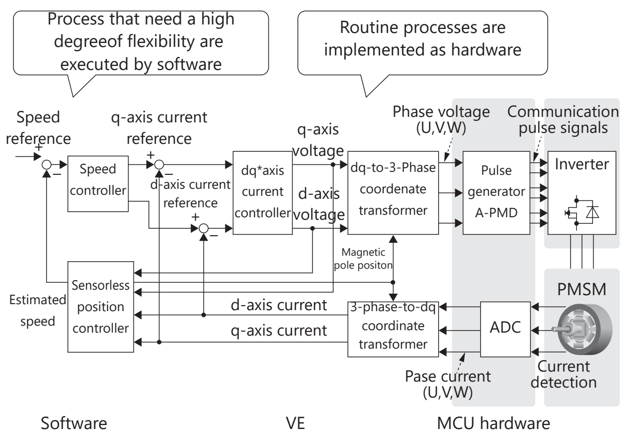
The Toshiba Group has now developed the TXZ4 Series (TMPM4K Group) of new motor control MCUs with new enhancements and higher processing speed than that of the TX03 and TX04 Series. This article describes the new enhancements added to the MCUs of the TMPM4K Group as well as motor control techniques using these enhancements.



*This feature includes MCUs under development and is therefore subject to change without notice.

Figure 1. Roadmap of Toshiba motor control microcontrollers for consumer applications

From the first-generation TX03 series equipped with VE, we have further improved the processing and developed the TXZ4 series equipped with new functions.



*Coordinate system where the d-axis is the magnetic pole direction of motor's rotor and the q-axis is the direction orthogonal to it.

Figure 2. Configuration of VE

VE implements routine processes for PMSM control as hardware, reducing the CPU software workload and thereby increaseing overall prosessing speed.

2.Features of TMPM4K Motor Control MCUs

2.1 High-speed Arm® Cortex®-M4 core and extensive MCU lineup

Table 1 shows the functional specifications of the MCUs of the TMPM4K Group, which incorporate the Cortex®-M4 CPU core from Arm Limited operating at clock frequencies of up to 160 MHz. The Arm® Cortex®-M4 core contains a floating-point unit (FPU), providing great convenience for designers.

Table1. Specifications of TMPM4K microcontroller

Part No.			M4K0	M4K1	M4K4	M4KL	M4KN	M4KQ
Basic functions	CPU		Arm® Cortex®-M4(FPU with FPU)					
	Max frequency	(MHz)	80			160		
	Data flash memory	(Ki bytes)	-			32		
	Number of I/O ports		22	34	52	51	87	131
Timers	32 (16)- bit timers	(ch)	6(12)			5(10)	6(12)	6(12)
	Watchdog timer		Y			Y		
	32(16)-bit PWM generators	(ch)	2(2)	5(6)	6(7)	5(9)	6(11)	6(12)
Analog circuitry	12-bit ADC (input ch/units)		6/1	10/1	13/1	14/3	22/3	32/3
	Op-amps	(ch)	1	3		3	3	3
Commu-nication units	UART	(ch)	2	2	4	3	4	4
	TSPI(SPI/SIO)	(ch)	1	2	4	2	2	2
	I^2C	(ch)	-	1	1	2	2	2
	CAN		-			-	1	1
Other peripheral circuits	Advanced Vector Engine Plus (A-VE+)	(ch)	1			1	1	1
	DMAcontroller (ch/units)		32/1			32/1	32/1	32/1
	A-PMD (3-phase complementary PWM generators)	(ch)	1		2	3	3	3
	Advanced encoder input circuits	(ch)	1			1	3	3
Supply voltage		(V)	2.7 to 5.5			2.7 to 5.5		

FPU: floating -point unit
Ki byte: kibibyte. 2^{10} bytes
ch: channel
PWM: pulse-width modulation
UART: Universal Asynchronous Receiver Transmitter
TSPI: Twin Serial Peripheral Interface
SPI: Serial Peripheral Interface
SIO: Serial Input / Output
I^2C: Inter-Integrated Circuit
CAN: Controller Area Network
DMA:Direct Memory Access

*This table includes MCUs under development and is therefore subject to change without notice.

Housed in 32-pin to 144-pin packages, the TMPM4K Group is available with different numbers of analog-to-digital converters (ADCs), general-purpose input/output (I/O) ports, and other peripheral functions, allowing different numbers of motors to be controlled simultaneously. The MCUs of the TMPM4K Group incorporate self-checking functions for ROM, RAM, ADCs, and CLOCK to make it possible to satisfy the functional safety requirements.

2.2 A-PMD

The Programmable Motor Driver (PMD) is a circuit generating commutation pulse signals for an inverter. **Figure 3** shows the functional block diagram of the newly developed A-PMD. As a result of current control by vector control, a voltage command value is input to the A-PMD as a modulation signal corresponding to the ratio of the on state of the switching element. The A-PMD compares modulation signals with reference waveform (called carriers) to generate commutation pulse signals. Reference waveform signals of various waveforms are used such as triangle and sawtooth waveforms. However, the conventional PMD can use only the same reference signal for all three phases.
In contrast, the A-PMD contained in the TMPM4K Group allows the use of different reference waveforms, even those with a phase difference, for different phases. Therefore, A-PMD provides greater flexibility in generating commutation pulse signals in various waveforms, enabling advanced control of PMSMs.

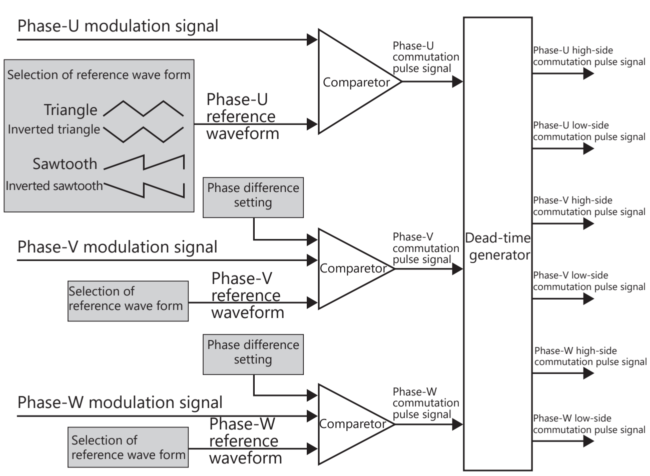
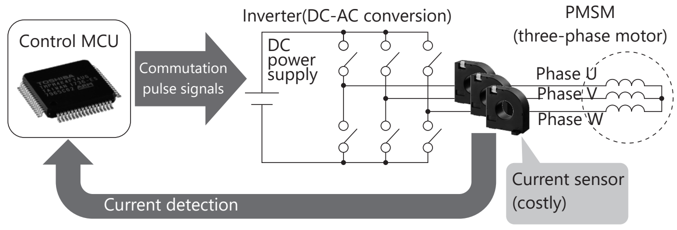
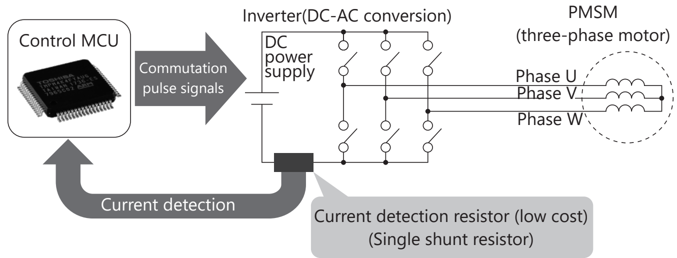


Figure 3. Pulse signal generation in A-PMD

A-PMD provides great flexibility in generating commutation pulse signals since it allows separate selection of reference waveform for each phase.



(a) Configuration using Current sensors



(b) Configuration of single-shunt current detection circuit

Figure 4. Configuration of PMSM Control schemes with different current detection circuits

A typical PMSM drive system comprises an inverter, current sensors, and a control MCU.

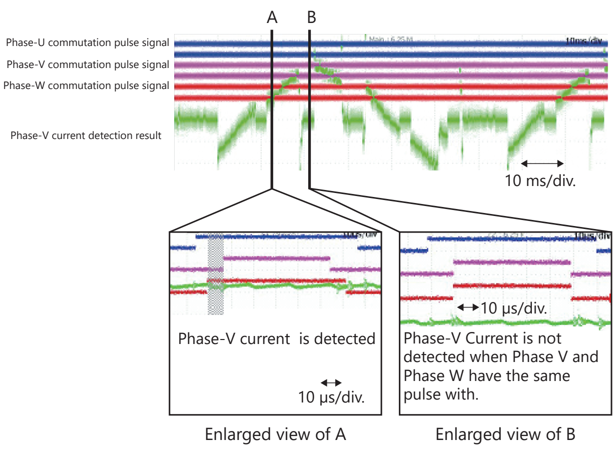
3. Advanced Motor Control Using TMPM4K

3.1 Single-shunt current detection technique

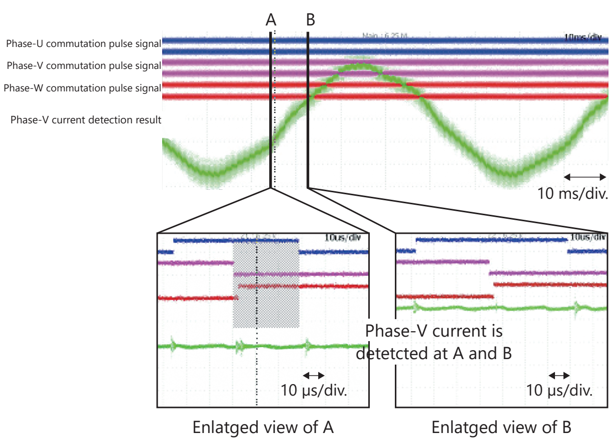
For vector control, it is necessary to detect phase currents flowing to a PMSM. Typically, current sensors are connected to the wires between the inverter outputs and the PMSM as shown in **Figure 4**(a). In consumer applications, however, all the three phase currents are detected using a single shunt resistor connected to the DC link of an inverter as shown in Figure 4(b) so as to meet the small-form-factor and low-cost requirements. Because current flows through the shunt resistor according to the switching of the inverter, phase current detection is considerably affected by the commutation pulse signals applied to the inverter.
The A-PMD in the TMPM4K is capable of generating various patterns of commutation pulse signals, simplifying the generation of commutation pulse signals suitable for single-shunt current detection.
Figure 5(a) shows the patterns of commutation pulse signals that can be generated by the TMPM4K and the corresponding current detection characteristics.
In the case of commutation pulse signals with a typical pattern, the detection rate of the phase current decreases in the low-/mid-speed region. On the other hand, consisting of

Commutation pulse signal pattern			Current detection rate		
Pattern	Reference waveform	Commutation pulse singnal	Low speed	Mid speed	high speed
Typocal pattern	Triangle Triangle Triangle	Phase U Phase V Phase W Detection timing	Low	Medium	High
Pattern 1	Triangle Inverted Triangle Triangle	Phase U Phase V Phase W Detection timing	Low	High	Medium
Pattern 2	Triangle Inverted sawtooth Sawtooth	Phase U Phase V Phase W Detection timing	High	High	Medium

(a) Patterns of commutation pulse available with TMPM4K and current detection characteristics



(b) Single-shunt current detection using commutation pulse signals of typical pattern



(c) Single-shunt current detection using commutation pulse sighals of pattern 2

div. : division

Figure 5. Patterns of pulse signals and characteristics of single-shunt current detection circuit of TMPM4K

The TMPM4K provides different single-shunt current detection characteristics, depending on the patterns of commutation pulse signals. Pattern 2 provides a high detection rate at low to medium speed.

a combination of 3-phase reference wave signals, such as triangular wave, reverse triangular wave, sawtooth wave,and reverse sawtooth wave, pattern 1 has high detection rate of phase current in the mid-speed region, and pattern 2 has a high detection rate in the low- and mid-speed regions(2). Figure 5(b) and Figure 5(c) compare current detection characteristics in the low-output-voltage region, showing that commutation pulse signals of pattern 2 help increase the rate of phase current detection.

Furthermore, the VE of the TMPM4K Group allows selection of reference waveform and the ADC timing so as to generate commutation pulse signals for single-shunt current detection. This single-shunt current detection technique can be utilized via simple setting.

3.2 Sensorless position control at low speed region

For vector control, phase currents are detected to control the commutation pulse signals flowing to an inverter according to the position of a motor's magnetic pole. It is therefore necessary to detect the position of a PMSM's magnetic pole. Typically, a resolver or an encoder is employed as a position sensor. However, there is a growing need for sensorless position control in order to improve the maintainability and reduce the cost of PMSM applications.

Generally, at the zero and low-speed regions, sensorless position control relies on the magnetic saliency of a PMSM, i.e., the magnetic reluctance and inductance variation according to the position of the magnetic pole, which depends on the stator structure of the PMSM. Therefore, the position of the magnetic pole can be estimated based on the inductance calculated from voltage and current.

Conventional sensorless position control techniques apply a test voltage for inductance detection at the low-speed region, which causes an acoustic noise problem due to the resulting high-frequency current pulsation (**Figure 6**).

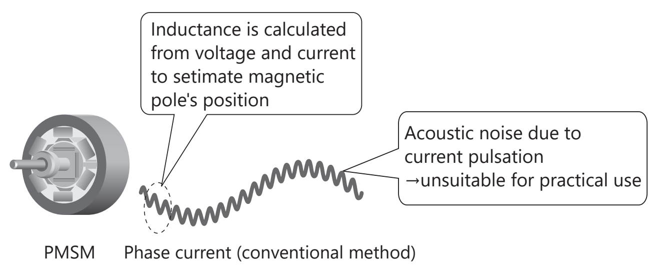


Figure 6. Problem of conventional sensorless position control in low-speed region

The conventional technique requires application of high-frequency test voltage, causeing acousticnoise due to current pulsation.

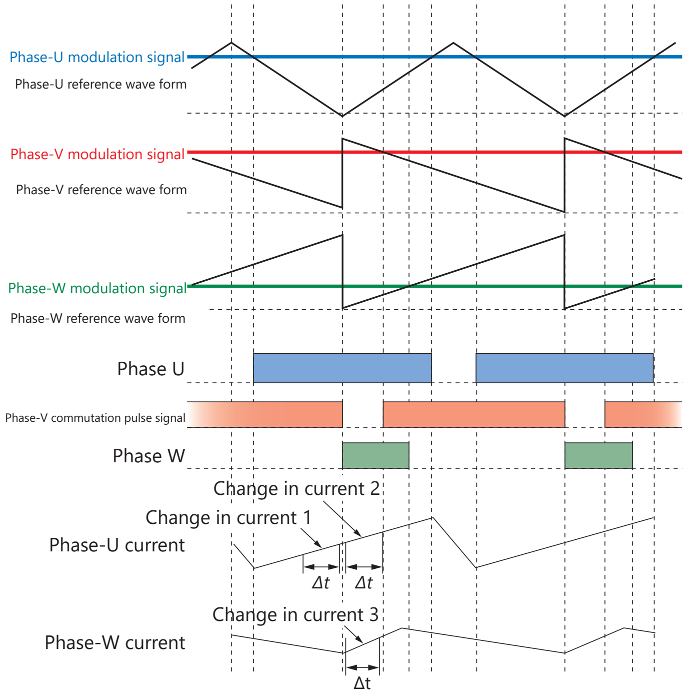
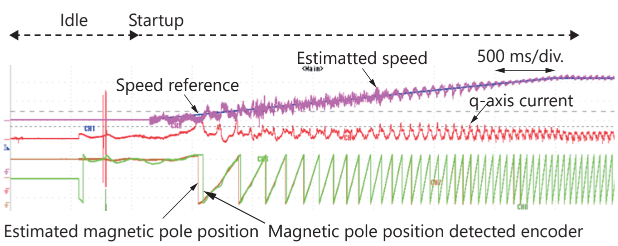
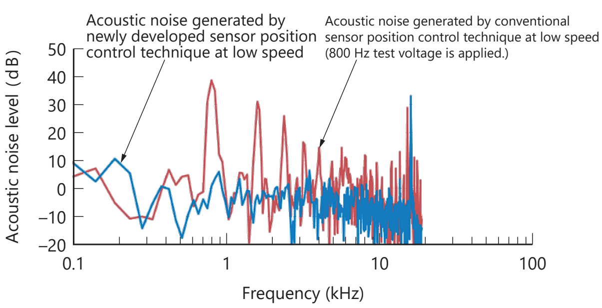


Figure 7. Commutation pulse signals for sensorless position control generated by A-PMD

This figure shows the phase current waveforms and ADC timing when commutation pulse signals generated from three deiierent refernce wave froms are used.
The position of the magnetic pole can be estimated from changes in current durting commutation.



(a) Magnetic pole position estimation from speed



(b) Reduction in acoustic noise

Figure 8. Reduction in acoustic noise by sensorless position control at low speed

The newly developed technique helps reduce acoustic noise since test voltage is not applied.

To solve this problem, the MCUs of the TMPM4K Group generate commutation pulse waveforms as shown in **Figure 7** to estimate the magnetic pole position from changes in current during commutation[3]. With the A-PMD, such commutation pulse waveforms can be generated simply by selecting a reference waveform. **Figure 8**(a) compares the estimated magnetic pole position with the position detected by an encoder for reference at the startup of a PMSM. It indicates that the newly developed technique provides accurate estimates even at zero speed. **Figure 8**(b) compares acoustic noise levels between the conventional and newly developed technique, showing that the newly developed technique generates less acoustic noise because it does not require the application of a test voltage.

4.Conclusion

We have released the TMPM4K Group of motor control MCUs for consumer applications that provide an increased performance and new enhancements. The MCUs of the TMPM4K Group reduce the number of external components required and help achieve motor control at low cost. We received the Kanto Region Invention Award in 2017 and 2018 from the Japan Institute for Promoting Invention and Innovation in recognition of the incorporation of these vector control functions into MCUs[4][5].

In view of the prevalence of PMSMs, the requirements for MCUs are expected to become increasingly stringent. We will continue to develop MCUs with even higher performance and greater ease of use.

References

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