White Paper

Shorten Multi-Motor Control Development for Industrial Machinery

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Abstract

Systems using motors these days are steadily improving in performance, and with better performance, the rising of BOM cost emerges as a problem at the same time. In addition, the safety implementation due to breakdowns is an issue for industrial machinery, and there is an urgent need to comply with functional safety (IEC61508), but the increase in development costs is a factor bothering developers.

In this whitepaper, we will introduce how we can solve the above problems with both devices and solutions.

- **Introduction of microcontroller for motor control**
  ASSP microcontroller for motor control (RX66T/RX72T series) of RX family can realize multiple motor control with a single microcontroller

- **Introduction of motor control development solution**
  - **Evaluation System for BLDC Motor**
    A kit mainly composed of an inverter board that can easily evaluate a permanent magnet synchronous motor (brushless DC motor)
  - **Motor control application note**
    Detailed information on implementation method, including knowledge necessary for motor control and source code to facilitate evaluation
  - **Renesas Motor Workbench 2.0**
    A powerful development tool reducing development time

- **Introduction of functional safety solution for industrial machinery**
  A solution that significantly reduces the functional safety certification process and reduces the development workload.

Do you have any of the following problems in motor control development?

1. We want to realize multiple motor control with a single microcontroller in order to reduce BOM cost.
2. We want to easily build a development environment to implement multiple motor control.
3. To improve safety, we would like to develop a system supporting functional safety (IEC61508).

Below are the methods to solve these problems.

1. A microcontroller that realizes multiple motor control

In order to realize multiple motor control with a single microcontroller, it is imperative to overcome the following hurdles:

A. It is not possible to control multiple motors in the first place if the number of three-phase complementary PWM output timers is not equal to the number of drive motors.

B. In order to control multiple motors, CPU processing power (computing power) needs to be equal to the number of drive motors required.

C. In order to control multiple motors, feedback functions (position detection) for the number of multiple motors are required. There are 1 to 3 shunt methods, resolver methods, and encoder methods for feedback, each of which requires multiple A/D converters and phase counting functions.

The ASSP microcontroller for motor control (RX66T/RX72T series) of the RX Family can satisfy these A.B.C. functions. As shown in Figure 1, you can build a system with a single microcontroller.

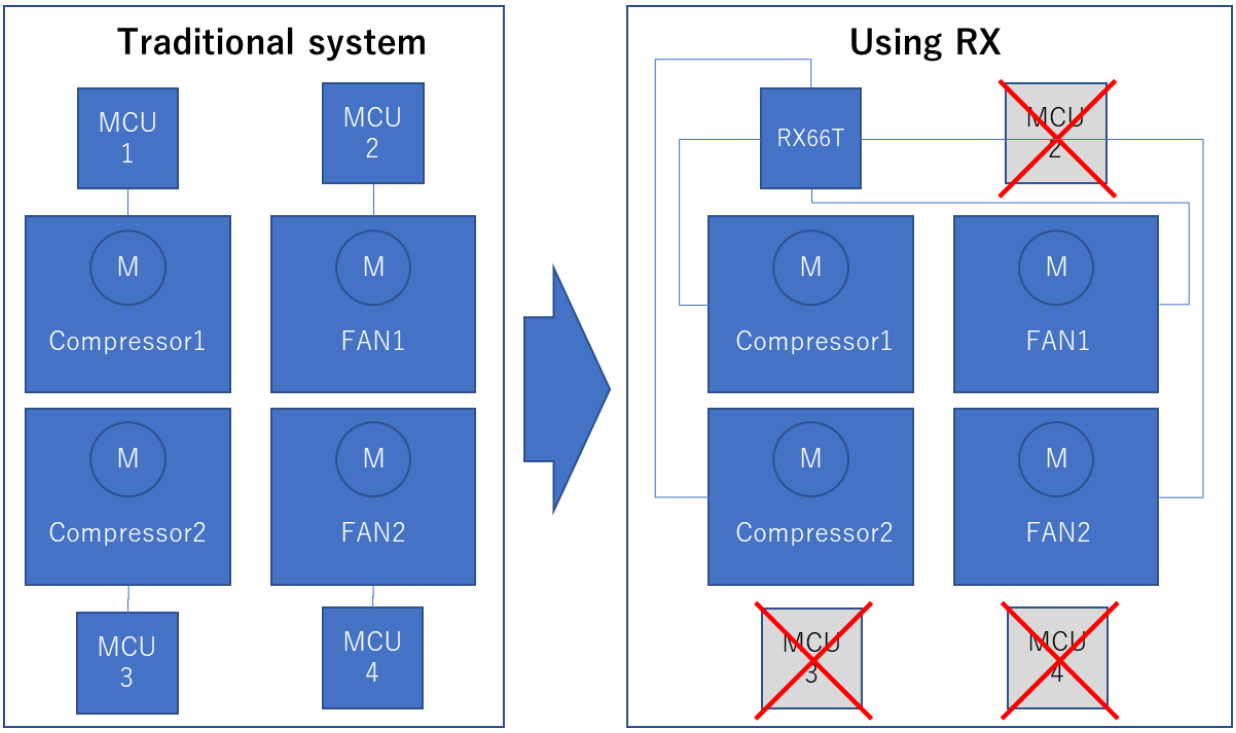


Figure 1: System Comparison – Traditional System vs. System Using RX Family

Next, find out more on the feature functions of the RX Family that can control multiple motors.

A. Three-phase complementary PWM timer

The functions for three-phase complementary PWM output in the RX66T/RX72T series include the MTU3 timer and GPTW timer shown in Figure 2 below. It is a timer that can output multiple three-phase complementary PWMs. Equipped with a feature function reducing the software load when outputting multiple three-phase complementary PWMs.

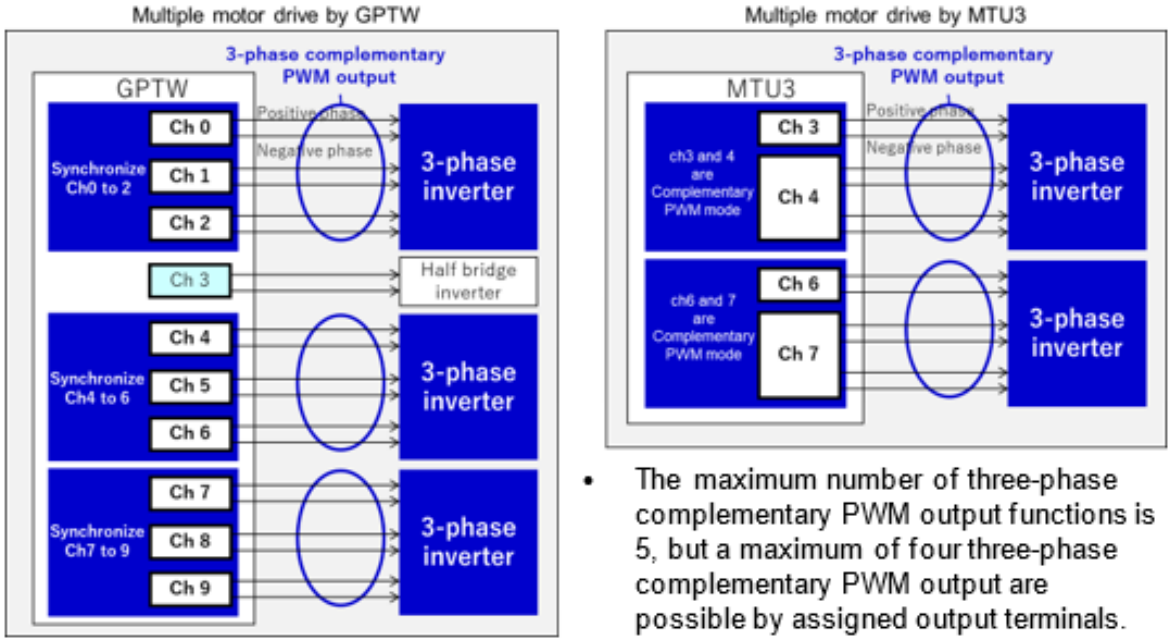


Figure 2: The Number of Three-Phase Complementary PWM Timer

- **Three-phase complementary PWM timer – Feature 1 (Double Buffer Function)**

The buffer registers for up-counting and down-counting of the up-down counter, enabling left-right asymmetric complementary PWM, which is required for current detection during 1 shunt control. In addition, the number of interrupts can be reduced by half (software intervention is reduced by 50%), and by reducing software intervention, a large amount of CPU resources can be used for time-consuming motor control operations.

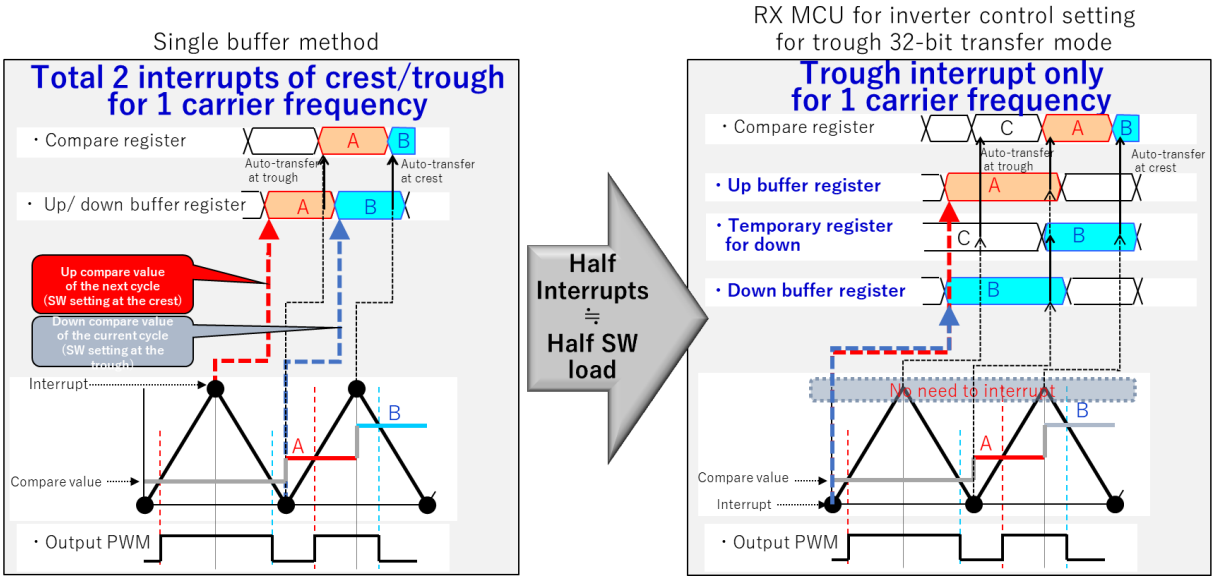


Figure 3: Double Buffer Function of Three-Phase Complementary PWM Timer

- **Three-phase complementary PWM timer – Feature 2 (Thinning function of interrupt & A/D conversion)**

When controlling multiple motors, there is a possibility that processing may not be in time. In the past, software was used to thin out interrupts, but there were problems such as interrupt overhead and calculation interruption due to CPU intervention. Also, since A/D conversion is performed even when the A/D conversion result is discarded, there is a problem of waiting if you want to use it elsewhere during A/D conversion.

On the other hand, the thinning function has its own thinning counter for interrupts and A/D conversion start triggers. Unnecessary interrupts and A/D conversion start triggers are automatically reduced, only through setting the thinning counter. Since it can be processed without using CPU resources, it is the best function for controlling multiple motors.

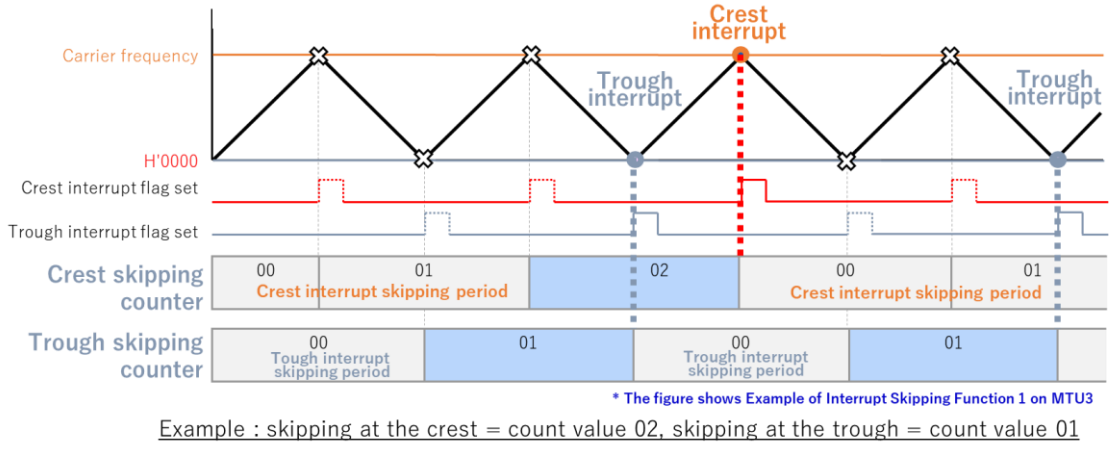


Figure 4: Interrupt Thinning Function of Three-Phase Complementary PWM Timer

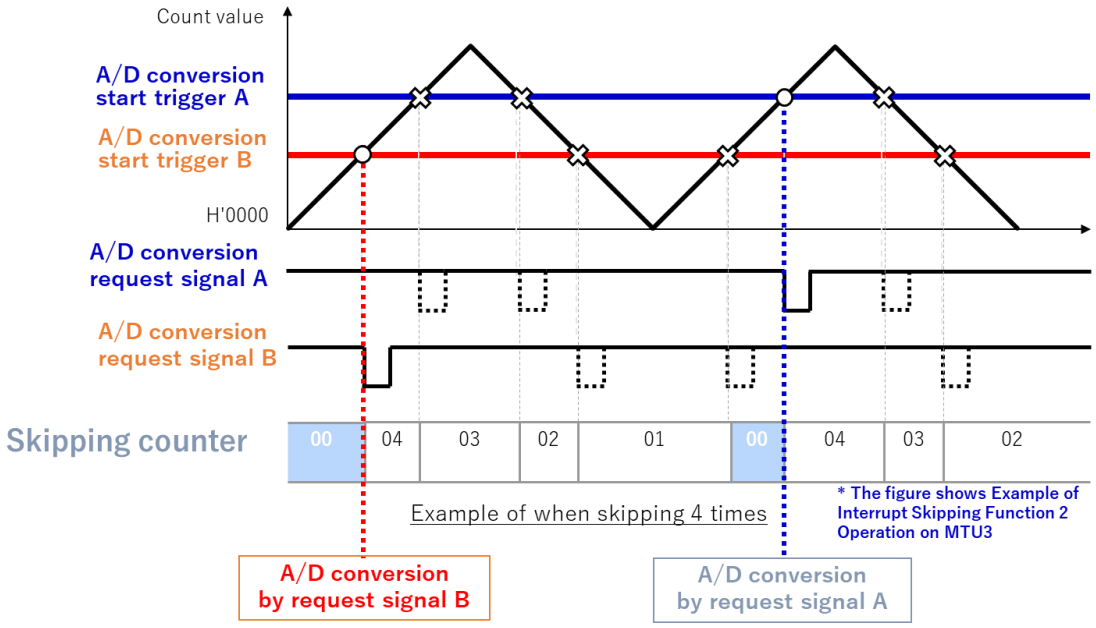


Figure 5: A/D Conversion Thinning Function of Three-Phase Complementary PWM Timer

- **Three-phase complementary PWM timer – Feature 3 (PWM output protection function)**

The fail-safe function essential for motor control is the PWM output protection function. If a problem occurs during motor control, it is a function to stop the motor drive quickly, and the RX66T/RX72T series can forcibly shut off multiple motor drives individually.

- ✓ GPT and MTU3 output can be stopped under various conditions without software intervention.
- ✓ It can be stopped regardless of the operating status of the timer, contributing to the realization of a strong fail-safe.
- ✓ Not only can the timer output be cut off, but it can also be switched to general-purpose I / O.
- ✓ When the abnormal voltage is detected by the comparator and the voltage abnormality disappears, the forced cutoff is automatically released.

Trigger factor	Trigger contents
POE# input terminal	Detect level due to low edge/sampling
Oscillation stop	Detect oscillation stop of main clock oscillator
complementary PWM output level comparison	Positive/Negative output are active at the same time
Comparator detection	Detect comparator output
Software	When controlled by register write

Table 1: Trigger Factors for Three-Phase

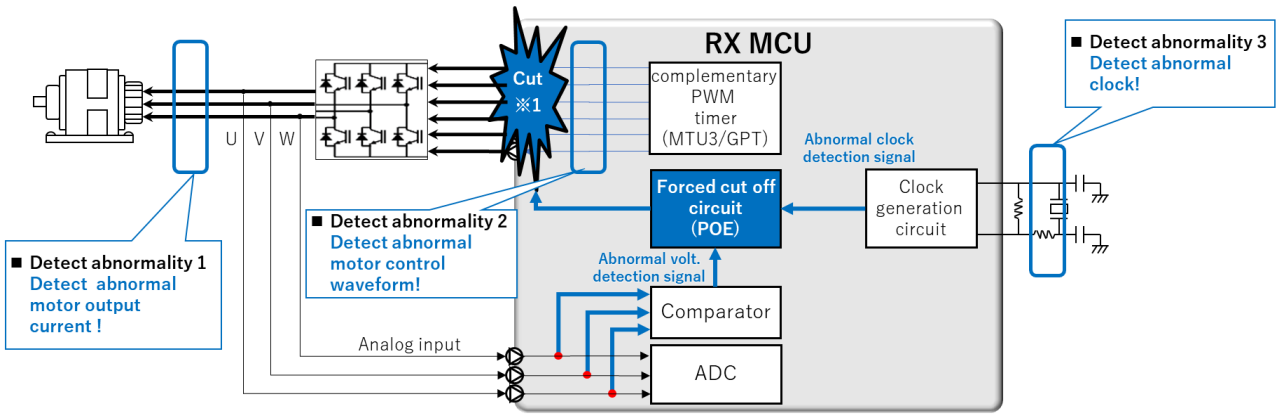


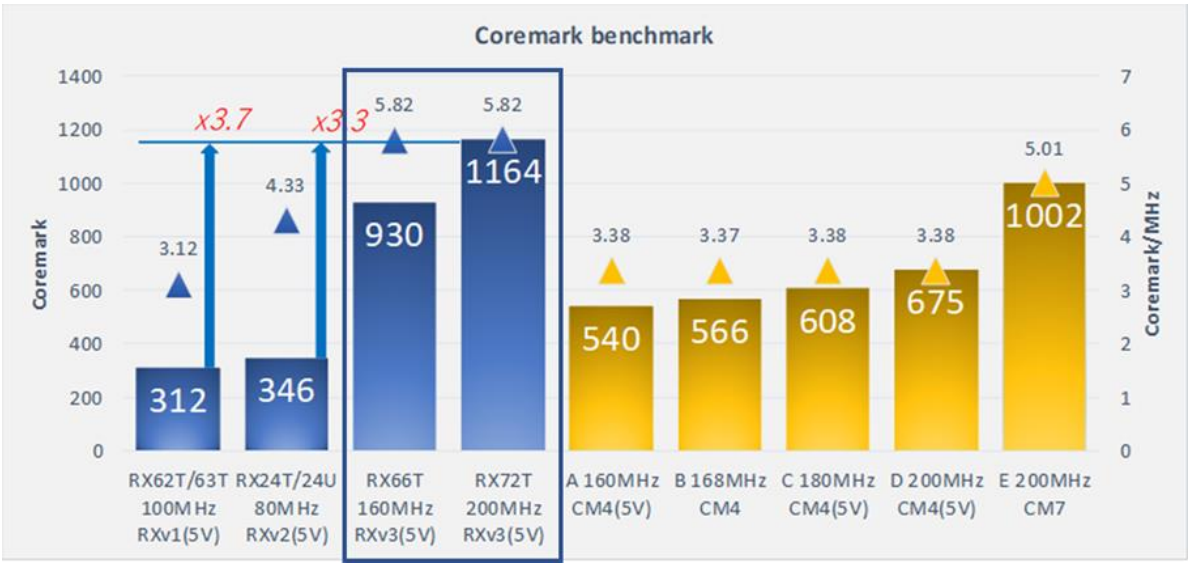
Figure 6: PWM Output Protection Function

B. Computing power

- **CPU power**

With CPU performance surpassing that of competitors, multiple motor control calculations can be performed smoothly. The RX66T/RX72T series is equipped with the latest RXv3 core, raising the performance of RX72T @ 200MHz to be higher than RX62T @ 100MHz. RX66T shows about 1.7 times higher performance of competitors' ARM core microcontroller (Cortex-M4 (CM4)) @ 160MHz with the same frequency. Hence, it is possible to show the same performance as competitors' microcontrollers without raising the operating frequency, which is also contributing to lower power consumption.

✓ RX72T Maximum 1160 CoreMark is 3.7 times that of RX62T and 3.3 times that of RX24T/U, surpassing competitors' products in the same frequency band.
✓ With the highest level of performance as a 5V compatible product, it contributes to system performance, functionality, and responsiveness.

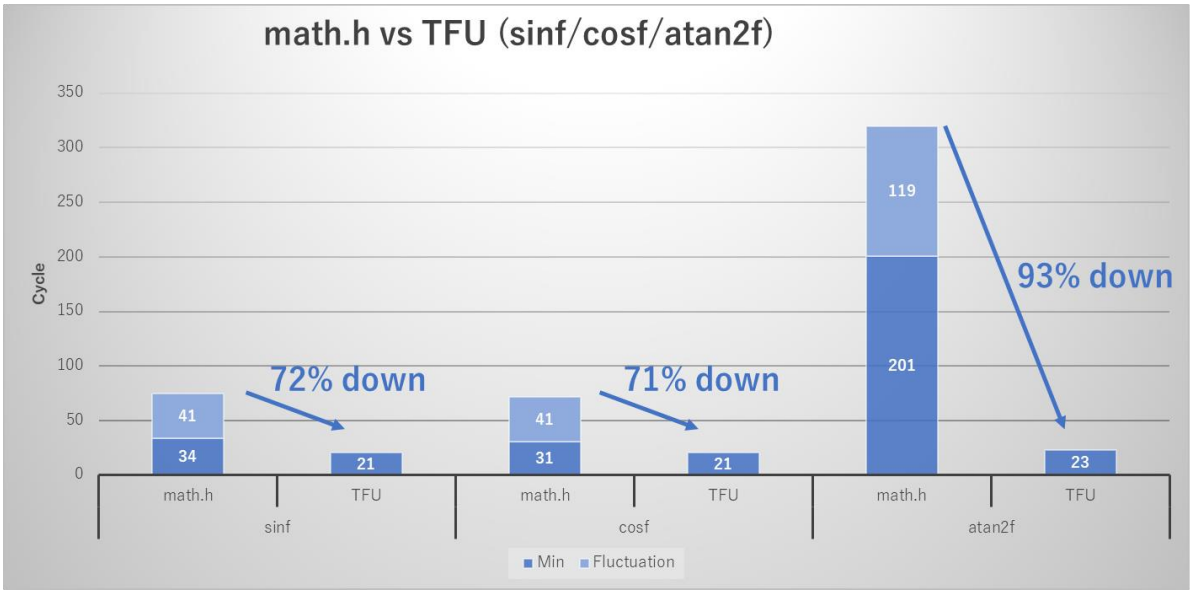


*EEMBC / manufacturer's nominal value

Figure 7: Coremark Benchmark Comparison

- **Trigonometric Accelerator (TFU)**

The RX72T is equipped with a trigonometric function accelerator executing trigonometric function operations required for FOC control at high speed. The processing reduced time effect when using TFU is up to 72% for the “sin” function; up to 71% for the “cos” function; and up to 93% for the “atan” function compared to “math.h” in the standard library. CPU processing can be significantly reduced while the RX72T demonstrates performance to withstand multiple motor controls.



This result is reference value measured by CC-RX V3.01 and this is not an exhaustive input value.

Figure 8: Effect of TFU math.h vs. TFU

- **Register bank save function**

Since many interrupt processing is performed in multiple motor control, interrupt handler processing becomes a heavy load. The interrupt handler processing time can be significantly reduced to 50% or more by using the register bank save function equipped in the RX72T.

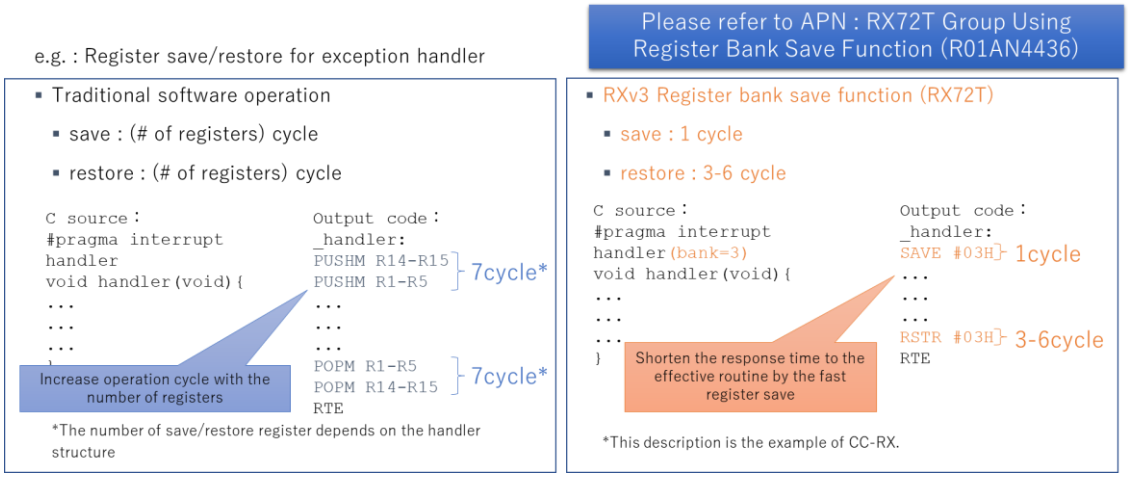


Figure 9: Effect of the Register Bank Save Function – Traditional Microcontroller vs. RX72T

C. Feedback function for motor (A/D converter, Encoder)

The RX66T/RX72T series is equipped with a function to acquire multiple motor feedback information. In particular, the A/D converter is equipped with a maximum of 3 units, and a maximum of 2 units of 3ch simultaneous sample and hold for the 3-shunt method. Compared to the traditional scan conversion, there is no shift of the current acquisition point and the correction processing by software is not needed. It is also equipped with a data duplication register that can hold the conversion result for each conversion triggers of the 1-shunt method, therefore it can convert-two points with single analog path. This enables easier board design and reduces overhead interrupts. In addition, 6 channels of Pseudo differential input type operational amplifiers are equipped to acquire shunt current. The conventional single-ended type is affected by common noise and the external circuit configuration becomes complicated, but the pseudo differential input type operational amplifier can solve such a problem and lead to the reduction of external operational amplifiers. The encoder function is equipped with a mode supporting various encoder outputs and can be directly imported into the microcontroller without conversion by an external circuit. It is a flexible system.

- **A/D converter function**

Improved analog functions of existing products. Easier to use.

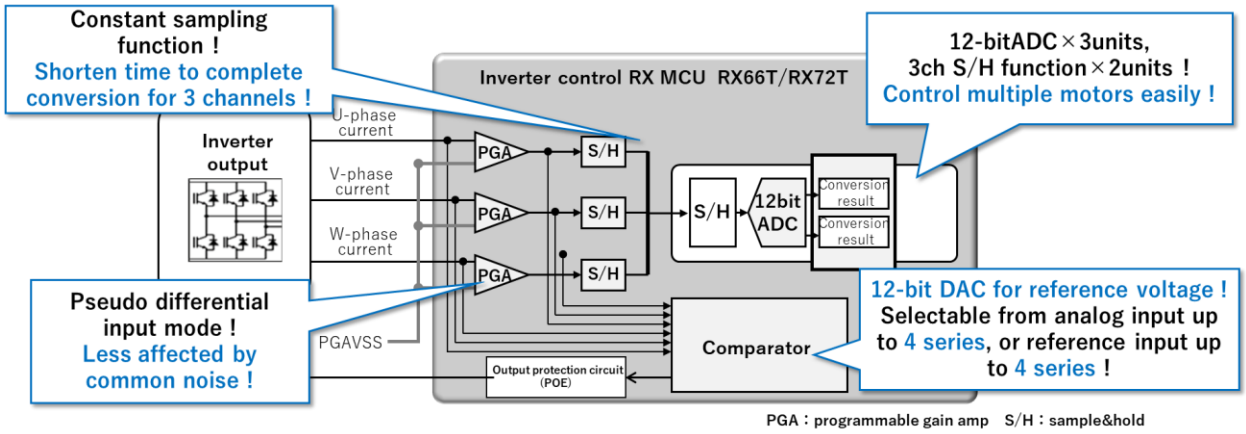


Figure 10: Features of the A/D Converter Equipped in the RX66T/RX72T Series

- **Encoder function**

Best suitable for measuring 2-phase encoder and pulse input. Input 2 pulse signals with phase difference into MTCLKA (MTCLKC, GTIOCnA) and MTCLKB (MTCLKD, GTIOCnB) terminals, and count (add/subtract) the number of edges. Phase counting has 5 modes supporting various encoder/pulse input types.

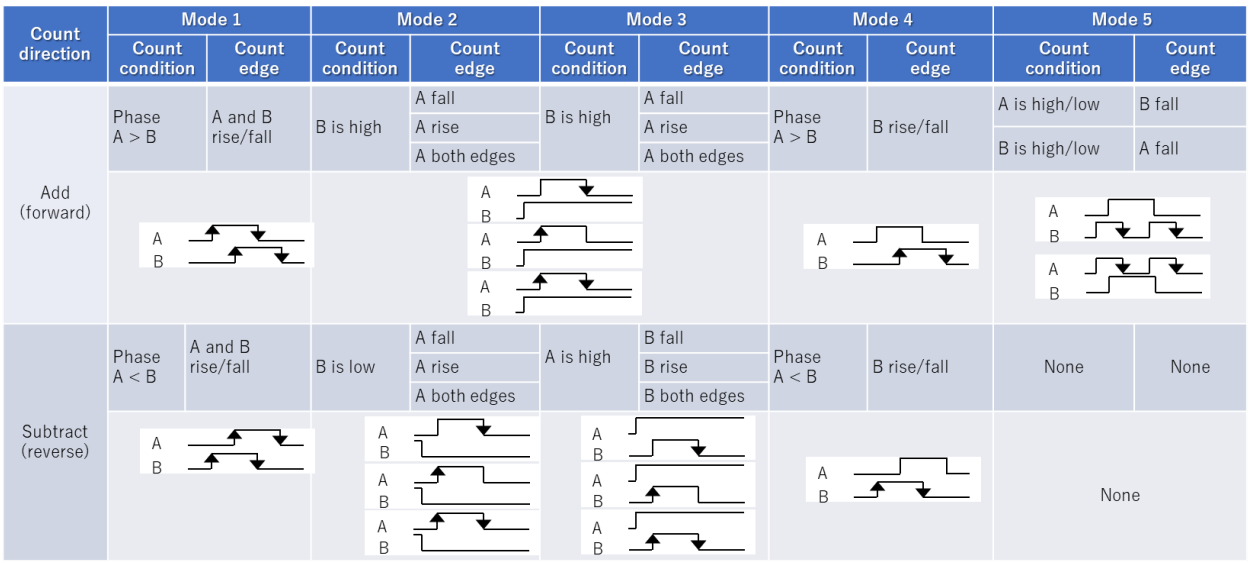


Figure 11: Features of the Encoder Function Equipped in the RX66T / RX72T Series

2. Development environment for motor control

System development goes through various processes from specification review to testing. In the specification review process, we will consider whether or not the function and performance of the microcontroller is satisfactory, in order to realize the required specification for the system. The Renesas application note provides all the information necessary for motor control. Next, in the software development process, it is necessary to build a hardware platform (board development). Renesas provides a solution (Evaluation System for BLDC Motor) that can be used as a hardware platform. You can also use the provided circuit information as a reference when developing hardware. Also, in software development, visualization of operations has a strong advantage for development efficiency. Previously, customers need to prepare original tools (RAM monitors, etc.), but now, Renesas provides the “Renesas Motor Workbench 2.0” (RAM monitors, parameter changes, waveform display) as an alternative to those tools. In this way, Renesas has the solutions required for each development process, and system development can be realized quickly, efficiently, and at low cost.

- **Evaluation System for BLDC Motor**

This kit mainly consists of an inverter board that can easily evaluate permanent magnet synchronous motors (brushless DC motors). With the boards, motors and web-downloadable software included in the kit, you can start evaluating immediately after purchasing the kit and the CPU card. This kit is a hardware that can be used as a reference board and platform.

Kit features:

- Supports 48V / 5A and can be evaluated immediately after purchase
- Various microcontroller can be evaluated by changing the CPU card
- Supports 2-motor control (2 kits required)

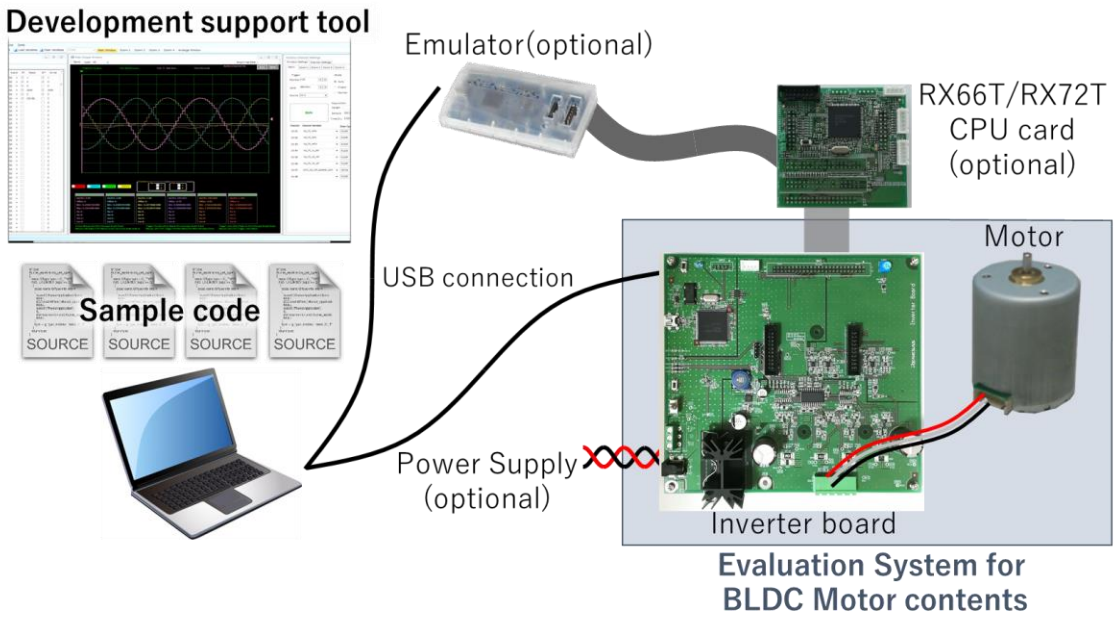


Figure 12: Configuration of Evaluation System for BLDC Motor

- **Motor control application notes**

  Renesas has the algorithm explanations to realize the system functions, sample code of various functions, implementation guidance, etc. We provide the knowledge necessary for motor control and the source code that can be easily evaluated.

  Application note features:

- Complete with 120-degree energization control and FOC control (hall sensor, encoder, sensorless) software for each microcontroller
- Explain the control method in each application note
- Software that even beginners of motor control can handle, compatible with the motor control development support tool
- Ideal for checking the initial settings of motor control registers
- RX66T/RX72T series software can select the output of three-phase complementary PWM from MTU3 and GPTW
- RX72T software uses trigonometric function arithmetic unit (TFU) to process FOC control at high speed

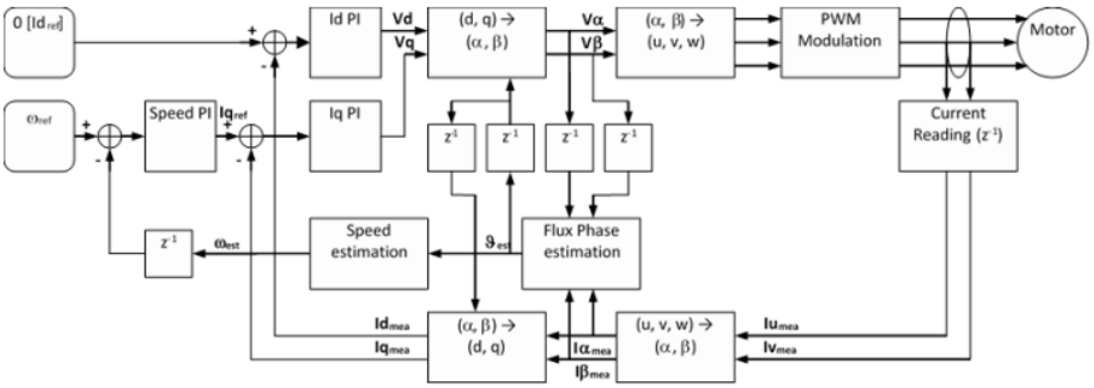


Figure 13: FOC Algorithm Configuration

Supply		Target MCU	Method of providing	Charged/ free
Software (Motor Control Software & Application Note)				
Field Oriented Control using encoder (CS+ version, e2studio version)		RX23T, RX24T, RX24U, RX66T, RX72T	From the Web DL	Free of charge
Association Document	Application Notes-Algorithms			
	Application Notes-Implementation			
Sensorless Field Oriented Control (CS+ Edition, e2studio Edition)		RX13T, RX23T, RX24T, RX24U, RX66T, RX72T		
Association Document	Application Notes-Algorithms			
	Application Notes-Implementation			
Sensorless 120-degree conducting control (CS+ Edition, e2studio Edition)		RX23T, RX24T		
Association Document	Application Notes-Algorithms			
	Application Notes-Implementation			
120-degree conducting control using hole sensor (CS+ Edition, e2studio Edition)				
Association Document	Application Notes-Algorithms			
	Application Notes-Implementation			

Table 2: Application Note List

- **Renesas Motor Workbench 2.0 (RMW)**

RMW is a software tool that can be easily incorporated into user projects and does not require dedicated hardware. In the traditional development method, the internal variables of the microcontroller (A/D conversion result, etc.) are output to the outside by serial communication, etc. and the control status is confirmed. Then the motor parameter correction, program change and compilation are performed, and the operation is evaluated repeatedly. RMW has the functions of dynamically reading and writing variables, displaying variable waveforms, and outputting waveform display data such as an oscilloscope while operating the motor, without modifying and compiling the program. In addition, it has a function to automatically identify the motor parameters and control gain required for FOC control, which is a required

know-how, and the results can be generated as a PDF file or header file. RMW is a powerful development tool that significantly reduces your development time.

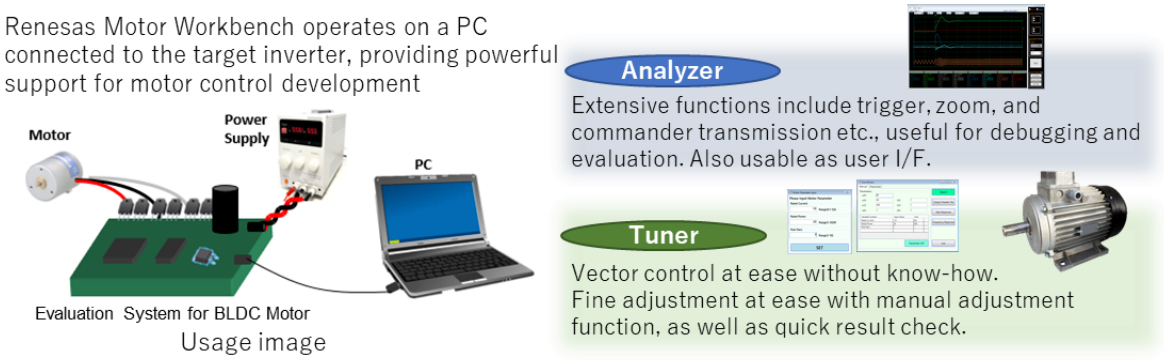


Figure 14: Feature of Renesas Motor Workbench 2.0

- **Analyzer function**

  - Variables can be read and written dynamically while driving the motor
  - Variable waveforms can be displayed dynamically while driving the motor
  - Trigger settings and various display settings can be set for the waveform display
  - It is possible to create an operation sequence in advance for any variable and send it
  - Equipped with batch processing buttons that can be defined and used by the user

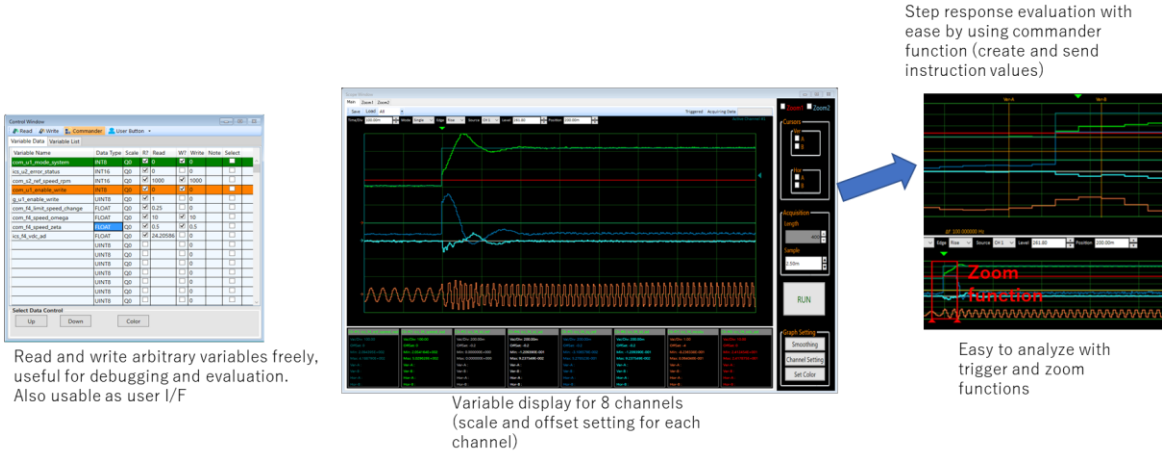
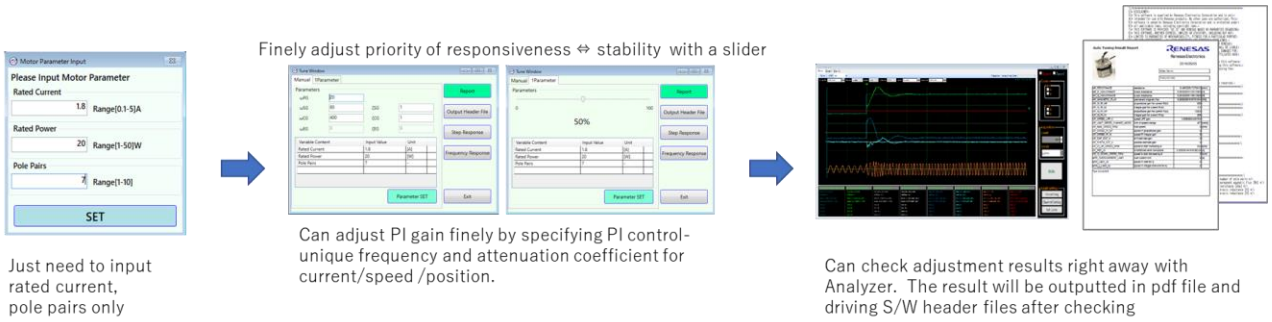


Figure 15: Analyzer Function of Renesas Motor Workbench 2.0

- **Tuner function**

  - Automatic measurement of motor-specific parameters (resistance, inductance, induced voltage constant, inertia)
  - Automatically adjusts current, speed, and position PI control gains
  - Automatic adjustment of estimated gain for sensorless FOC control
  - Each PI control can be fine-tuned by manual tuning
  - The result can be generated as a PDF file or a header file for the drive software



*Works on Evaluation System for BLDC Motor

Figure 16: Tuner function of Renesas Motor Workbench 2.0

- **How to implement Renesas Motor Workbench 2.0**

In order to use Renesas Motor Workbench 2.0, the contents to be set on the user program are only the following simple changes.

A. User program changes
- DTC setting RAM area used setting
- Interrupt setting SCI TX, RX interrupt setting
- Call the "ics2_init" initialization function in the main process
- Call the "ics2_watchpoint" data transfer function in the specified interrupt processing

B. Compile the Renesas Motor Workbench 2.0 communication library with your program

```
#include "ics_RX23T.h"
#pragma section DTCTBL
unsigned long dtc_table[256]; // caution alignment 0x000
#pragma section
void main（void)
{
ics2_init（（void*) dtc_table, port, level, speed, mode);
}
```

```
void int_TM100u（void) /* 100usec 間隔 */
{
if （3 <= g_u1_cnt_decimation) /*decimation of ICS call */
{
g_u1_cnt_decimation = 0;
ics2_watchpoint（); /* data transfer */
}
g_u1_cnt_decimation++;
}
```

3. Functional safety for industrial machinery (IEC61508)

Obtaining IEC61508 certification takes a lot of time and money. It is necessary to carry out various tasks as follows for the process from the start of development, to the acquisition of certification. To reduce this work, Renesas provides “functional safety solutions for industrial machinery” to equip microcontrollers with safety functions and further shorten the authentication process. Renesas supports customer development with these solutions.

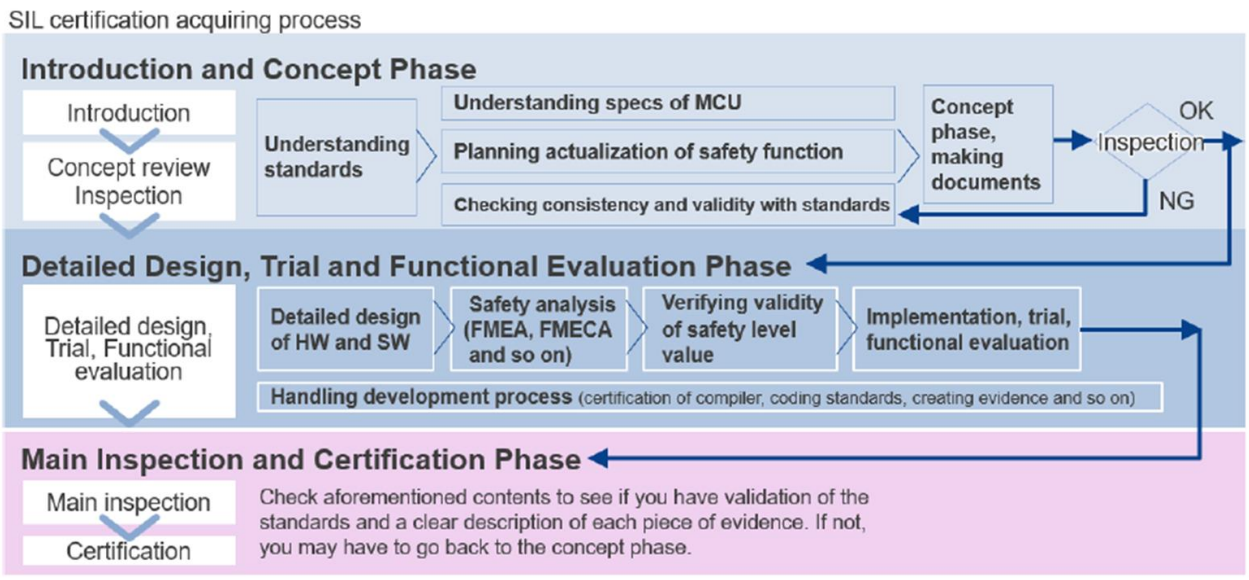
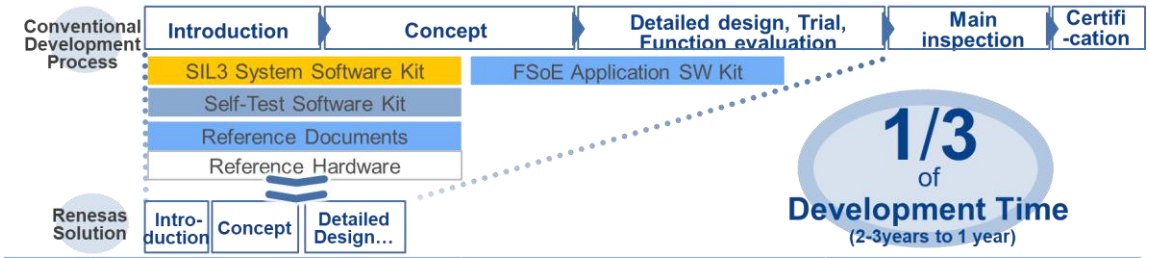


Figure 17: Functional Safety System Development Process

- **Applied development of functional safety solutions for industrial machinery**

Starting the development of a system that applies functional safety on a zero basis will lead to a significant cost increase. Renesas provides “functional safety solutions for industrial machinery” that can significantly reduce the functional safety certification process, and significantly reduces the development load of functional safety systems for industrial machinery.

Please also refer to this white paper for details on Renesas' functional safety initiatives and solutions. For details, please see the functional safety webpage for industrial machinery.



Functional Safety Software and Documents	RX Family			RA Family	
	RXv1	RXv2	RXv3	RA4M1, RA6M1, M2, M3	
1. SIL3 System Software Kit		✓	✓ New		
2. Self-Test Software Kit	✓	✓	✓ New	✓	New
3. Functional Safety over EtherCAT Stack		✓ New	✓ New		
4. Reference Documents	✓	✓	✓	✓	
5. Reference Hardware Board	✓	✓	✓ New		
6. Safety Compilers	✓	✓	✓	✓	New

Figure 18: Effect of Renesas Functional Safety Solution for Industrial Machinery Application

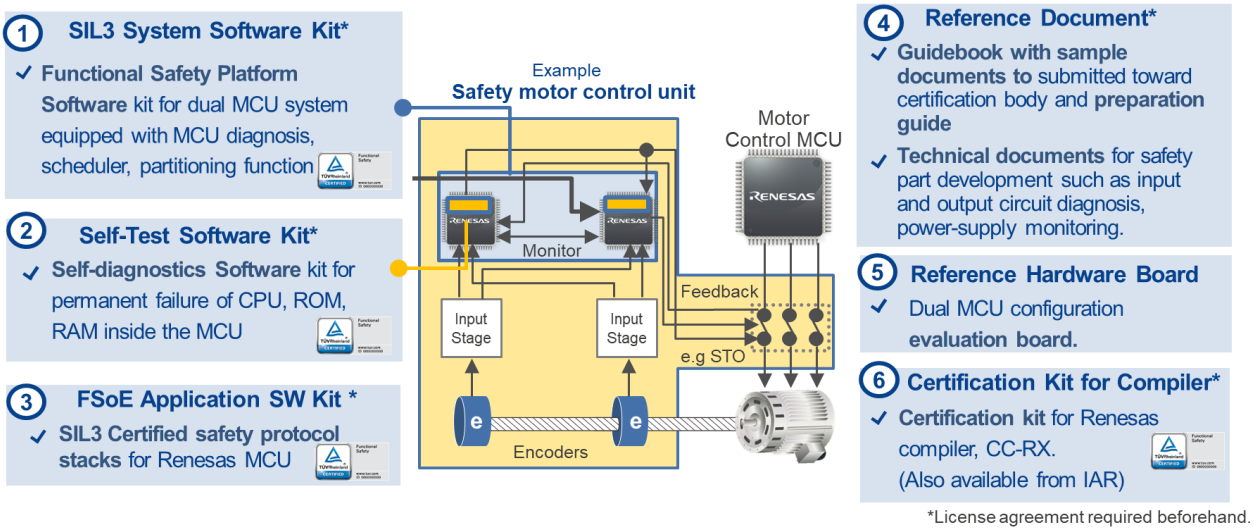


Figure 19: Renesas Functional Safety Solution

Conclusion

The RX66T/72T is equipped with the latest RXv3 core (CPU) and trigonometric function accelerator that improves performance by 3.7 times over the conventional MCU. It is also equipped with peripheral devices that are ideal for controlling multiple motors (up to 4 motors at one time). Furthermore, it has encryption keys (AES and RSA) used for communication data encryption processing, and encryption functions such as read protection of ROM data. You can easily build a secure environment with the MCU alone.

Shorten time from prototyping to development and debugging by using the inverter evaluation board, sample software, and debug tool of the motor control development solution. For the development of functional safety, the IEC61508 SIL3 compliant "Functional Safety Solution for Industrial Machines" can reduce functional safety development time by 60% or more, compared to the conventional development method.

Renesas contributes to reducing the BOM cost of customer systems, improving functionality, and improving development efficiency.

Learn More

1. RX66T: 32-bit motor control microcontroller MCU / 64 to 144 pin
   160MHz / Up to 1MB Flash / USB / CAN / PGA / Security
2. RX72T: 32-bit motor control microcontroller MCU / 100 to 144 pin
   200MHz / Up to 1MB Flash / USB / CAN / PGA / Security / Register bank save / TFU
3. RX Motor Control Solution
4. Functional Safety Solution for Industrial Machinery