Build high-performance, miniaturized power tools and fan motor applications that the market demands

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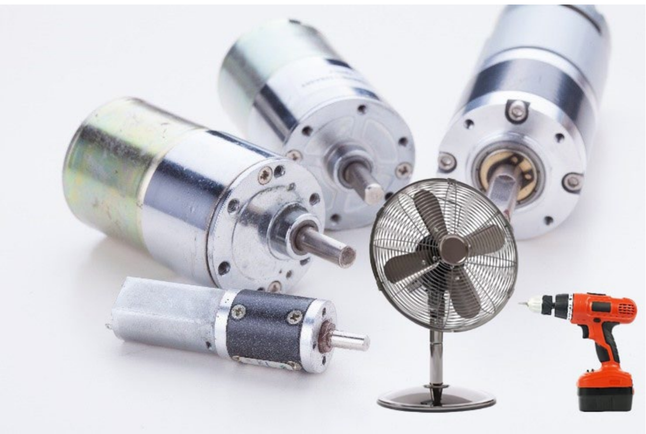
Overview



In recent years, increased investment in residential and commercial infrastructure has driven up the demand for power tools used in construction. As shipments rise, these tools are evolving with advancements in miniaturization, energy density, and overall performance. Similarly, motors are widely adopted in fan applications within home appliances and housing equipment—such as fans, air conditioners, ventilation systems, air purifiers, vacuum cleaners, and hair dryers—where there is a growing need for quieter operation, higher speeds and output, and more compact designs.

While the requirements for motor control in power tools and fan applications vary, both demand high performance and efficiency—such as high-speed rotation, high torque, and fast responsiveness—alongside lower power consumption. At the same time, designers face the added pressure of maintaining cost competitiveness through circuit miniaturization and system cost reduction. Achieving a well-balanced system design is therefore critical.

This whitepaper outlines the key motor control challenges in these applications and explores how the new RA2T1 microcontroller from the Renesas RA family can help address them.

Challenges in Power Tool Applications and How the RA2T1 MCU Can Help

Power tools generally fall into two categories: DIY and professional use. These typically utilize one of two motor types—brushed motors or brushless motors (permanent magnet synchronous motors). In professional-grade tools, there is a strong market preference for brushless motors due to their compact size, light weight, high output, and low maintenance. However, controlling brushless motors is more complex than brushed motors, making microcontroller-based control the industry standard.

Currently, 120-degree conduction control using Hall sensors is commonly employed for brushless motor control in power tools. Hall sensors enable detection of the rotor's position, allowing the motor to deliver high torque across a wide speed range—from startup to high-speed operation—while also simplifying control software. However, this method tends to produce high peak currents and torque fluctuations, which can lead to challenges such as reduced battery efficiency and the need for greater voltage margins when selecting components.

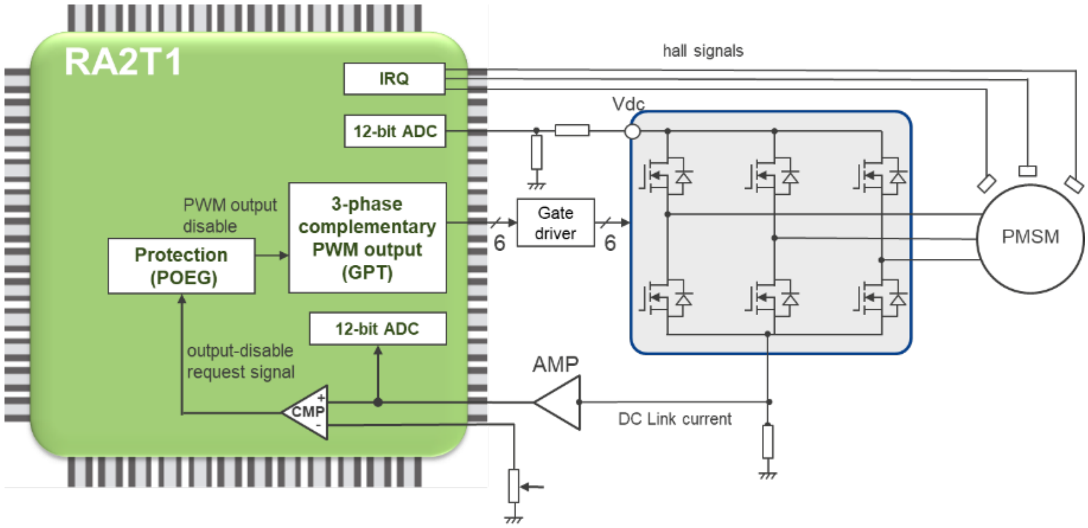


Figure 1: Example of a control block using a Hall sensor

One effective way to address these challenges is by adopting vector control.

Unlike 120-degree conduction control, which switches current every 60 degrees across six commutation steps, vector control enables much finer and more continuous control of the rotor's position. This results in reduced peak currents and minimized torque ripple, allowing designers to lower the voltage margin requirements for inverter components. Since the applied voltage waveform approaches an ideal sine wave, harmonic distortion is greatly reduced, leading to improved battery efficiency. Vector control requires accurate current sensing. This can be achieved using the existing DC link current detection circuit typically employed for overcurrent protection on the PCB. This method, known as the 1-shunt current detection technique, relies on detecting motor current via a single shunt resistor placed in the DC link. However, precise timing is critical: current must be sampled exactly at moments when it can be uniquely determined—specifically, when two motor phases are ON and one is OFF, or vice versa.

The RA2T1 MCU simplifies this with its GPT timer and A/D trigger coordination. The RA2T1 features a GPT (General Purpose Timer) that can trigger A/D conversion at freely defined timing points. This allows the system to capture current flowing through the shunt resistor at the optimal moment, based on the PWM duty cycle. When the GPT controls inverter switching, it generates PWM signals using a symmetrical triangular waveform in complementary PWM mode. However, certain 3-phase PWM waveforms may not provide enough ON-time for accurate current sampling. To solve this, the RA2T1's GPT supports asymmetric PWM generation, which shifts the timing of the PWM edges to extend ON-time for each switching element—ensuring accurate current detection. Furthermore, the RA2T1 is equipped with a built-in comparator and POEG (Port Output Enable for GPT), which together enable immediate PWM shutoff in case of overcurrent, enhancing system safety and reliability.

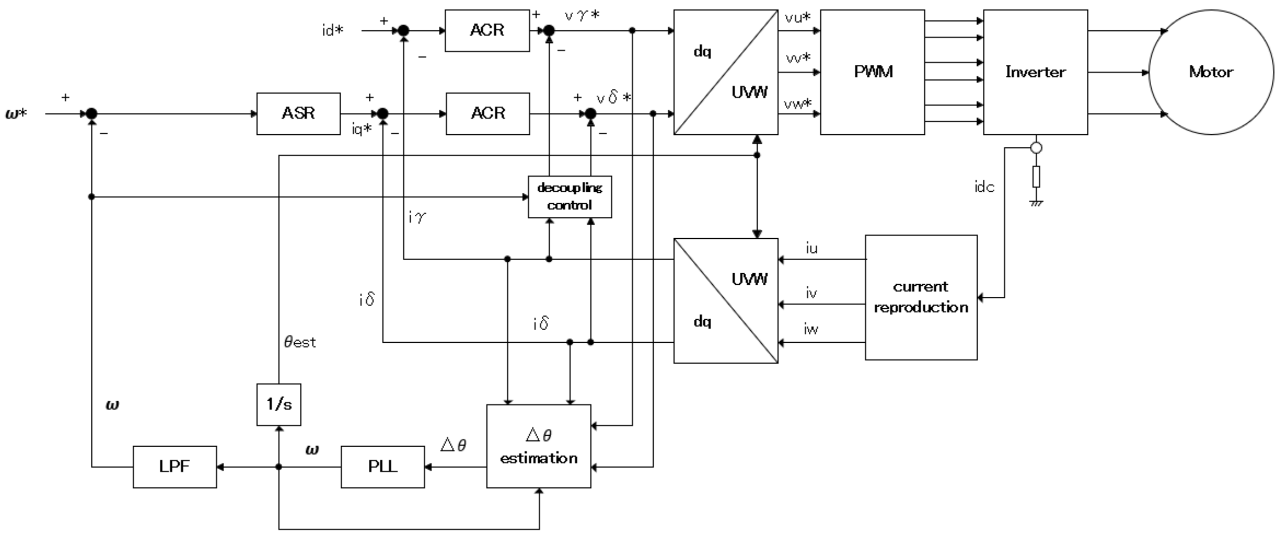


Figure 2: Example of a one-shunt current sensing vector control system block diagram

Fan Application Challenges and the Value of RA2T1 MCUs

Fan motors are widely used in devices such as air conditioners and air purifiers, which often operate year-round. To ensure low maintenance and long-term reliability, these applications commonly adopt induction motors or brushless motors, which do not require brush replacement. With growing demands for energy efficiency and smaller designs, brushless motors are increasingly replacing induction motors.

When controlling brushless motors in fan applications, power consumption and quiet operation become especially important. Inexpensive fan products typically use scalar control, while higher-end models adopt vector control for greater performance. Since vector control relies on accurate motor current information, a 3-shunt or 2-shunt current detection method is often used to measure the low-distortion current flowing through the motor's phases.

When detecting three-phase currents, A/D conversion is required—and the timing of this conversion is critical. Ideally, all three currents should be sampled simultaneously. However, in systems where the A/D converter is not optimized for motor control, a single A/D module typically converts three channels sequentially. This introduces delays between samples, resulting in discrepancies between the detected current values.

As motor speeds increase, this discrepancy has a growing impact on control performance. Today's fan motors are often driven at higher speeds to maintain airflow despite smaller form factors. Devices such as vacuum cleaners and hair dryers can exceed speeds of 100,000 rpm. At these speeds, the current waveform cycles become shorter and change rapidly, meaning that even small detection delays can cause significant errors. In vector control systems, this results in phase shifts, potentially reducing power efficiency and causing unstable motor control.

To address this issue, the RA2T1 MCU integrates a dedicated three-channel sample and hold circuit within its A/D converter. This enables simultaneous sampling of all three-phase currents, eliminating timing discrepancies caused by sequential A/D conversion. The result is more accurate current detection, which enhances both the responsiveness and stability of the control algorithm. Additionally, the need for software-based current compensation is eliminated, reducing the processing load and further improving control accuracy.

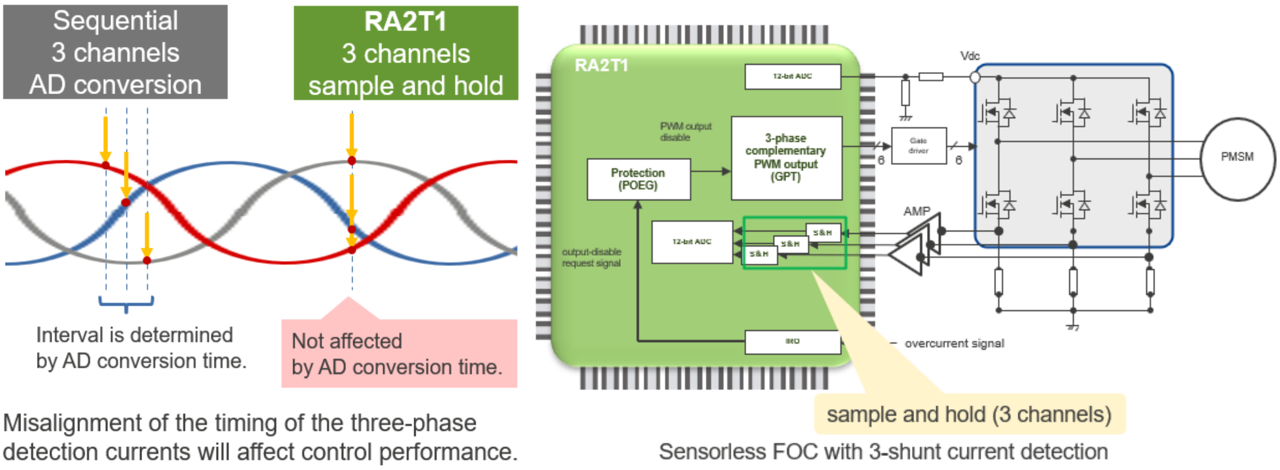


Figure 3: Example of RA2T1 A/D converter sample-and-hold function

Motor Control MCU RA2T1

Renesas has a long-standing history of developing a wide range of microcontrollers for motor control. Building on this expertise, the company introduces the RA2T1 group as the first motor control ASSP (Application-Specific Standard Product) in the RA2 Series based on the Arm® Cortex®-M23 core. The RA2T1 is specifically optimized for single-motor applications such as compact fan control, power tools, and refrigerator compressors—addressing the growing demand for higher efficiency and miniaturization in consumer motor-driven devices.

The RA2T1 integrates a suite of features tailored to solve the challenges discussed in the previous section. These include: - A GPT timer supporting symmetric and asymmetric complementary PWM waveform generation with built-in dead-time insertion - A 12-bit A/D converter with three independent sample-and-hold circuits for accurate and simultaneous current sensing - A trigger coordination function between the GPT timer and A/D converter for precise current sampling timing - Two high-speed comparators for fast signal processing. Additionally, for system protection, the RA2T1 includes a POEG (Port Output Enable for GPT) function that shuts off PWM output in response to overcurrent conditions—enhancing reliability and safety in motor control designs.

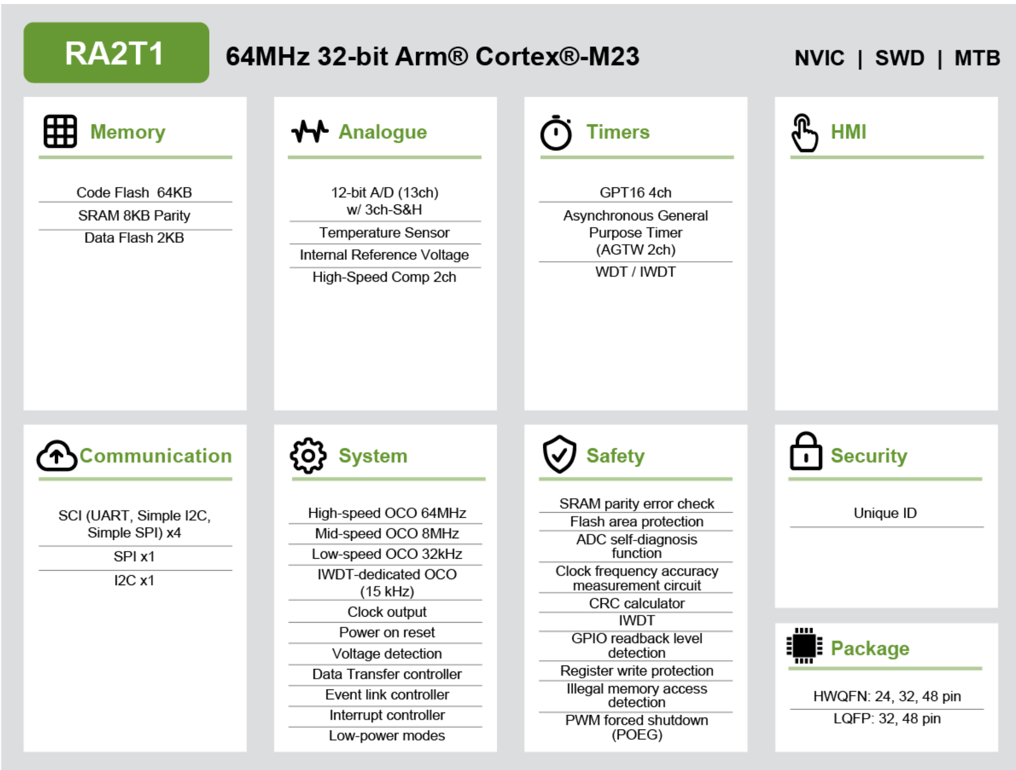


Figure 4: RA2T1 Functional Block Diagram

A wide variety of package options are available, including compact 24-pin QFN packages. The RA2T1 also supports a broad operating temperature range from -40°C to 125°C, making it ideal for applications in harsh thermal environments, space-constrained designs, and systems requiring a low bill of materials (BOM).

Code Flash/ RAM / Data Flash	Operating Temperature (Ta)	24-pin	32-pin		48-pin	
64KB / 8KB / 2KB	-40 to +105℃	RA2T1	RA2T1	RA2T1	RA2T1	RA2T1
	-40 to +125℃	RA2T1	RA2T1	RA2T1	RA2T1	RA2T1
Pin Count Package Size Pitch		24pin HWQFN 4x4mm 0.5mm	32pin LQFP 7x7mm 0.8mm	32pin HWQFN 5x5mm 0.5mm	48pin LFQFP 7x7mm 0.5mm	48pin HWQFN 7x7mm 0.5mm
Package view		4 mm × 4 mm 0.5 mm pitch	7 mm × 7 mm 0.8 mm pitch	5 mm × 5 mm 0.5 mm pitch	7 mm × 7 mm 0.5 mm pitch	7 mm × 7 mm 0.5 mm pitch

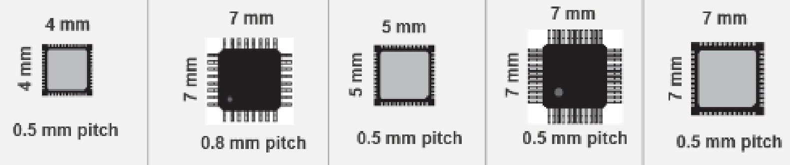


Figure 5: RA2T1 Package Lineup

In addition, the RA2T1 supports a 5V power supply—a common requirement in motor control applications. This ensures excellent noise immunity and a wide dynamic range for analog input signals. As a result, designers can achieve higher control accuracy while continuing to leverage existing 5V power system assets.

Motor Control Development Environment

To accelerate motor control development, the RA2T1 is supported by a comprehensive development environment. Both application examples introduced earlier can be developed and evaluated using RA2T1. By utilizing available development tools, designers can significantly reduce development time and effort.

MCK-RA2T1 Motor control kit

The MCK-RA2T1 serves as an evaluation kit specifically for motor control using the RA2T1 MCU. It includes a CPU board equipped with RA2T1, an inverter board connected via a dedicated connector, and a brushless DC (BLDC) motor—all bundled in one package. With everything pre-integrated, users can start spinning the motor right out of the box.

Figure 6: MCK-RA2T1 kit

The inverter board included in the kit allows easy switching between 1-shunt and 2/3-shunt current sensing configurations. This enables users to quickly evaluate a wide range of motor control applications tailored to specific needs, including Hall sensor or sensorless 120-degree conduction control and sensorless vector control.

Application Notes and Sample Programs for Motor Control

RA2T1 is supported by a comprehensive suite of application notes and sample code for various motor control method. These resources—available for download from the Renesas website—are tailored to specific control algorithms.

Application Notes: The documentation covers control implementations such as sensorless vector control for permanent magnet synchronous motors. It also provides guidance on using Renesas Motor Workbench, the dedicated motor control development tool. Each guide details functions and control flows, providing developers with valuable insights for streamlined evaluation and development.

Sample Program: Every application note includes sample code that can be downloaded directly to the MCU. These examples leverage the RA2T1's driver libraries and are designed for the MCK-RA2T1 evaluation kit. Key focus areas include control algorithms, system control, PWM management, and A/D conversion routines.

Currently, several motor control applications for single-motor use are available, and more content is planned to further support user development.

For instance, the sensorless vector control sample program for PMSM motors implements: - 1-shunt current detection using the GPT timer and A/D conversion trigger coordination (as described in the "Power Tool Applications" section), and - 3-shunt current detection for sensorless vector control (as introduced in the "Fan Applications" section).

These programs are based on fixed-point arithmetic and incorporate scaling parameters, making them especially valuable for development on the Arm Cortex-M23 core, which does not include an FPU (floating-point unit). This allows developers to build and evaluate efficient control systems even in resource-constrained environments.

Renesas Motor Workbench

Renesas Motor Workbench (RMW) is a specialized debugging tool for motor control applications. Its Analyzer function enables real-time monitoring, waveform visualization, and read/write access to internal MCU variables. Traditionally, motor control debugging is performed using tools like J-Link debuggers and e² studio IDE, which are not electrically isolated between the PC and target board. This poses risks: inverter circuits often operate at high voltages that exceed the MCU’s input range. When USB and board grounds are shared, it can lead to noise issues or even damage due to unintentional behavior during early evaluation stages. Additionally, breakpoints in traditional debugging halt the CPU, which can interrupt the GPT timer’s dead-time generation, possibly causing unintended PWM outputs that may damage the inverter. To mitigate these risks, RMW offers a dedicated communication board (MC-COM) that electrically isolates the PC from the inverter circuitry while allowing evaluation to proceed with the CPU running. This setup ensures safe, accurate debugging without risk of unintentional hardware damage. Renesas Motor Workbench is available for download on the official Renesas website.

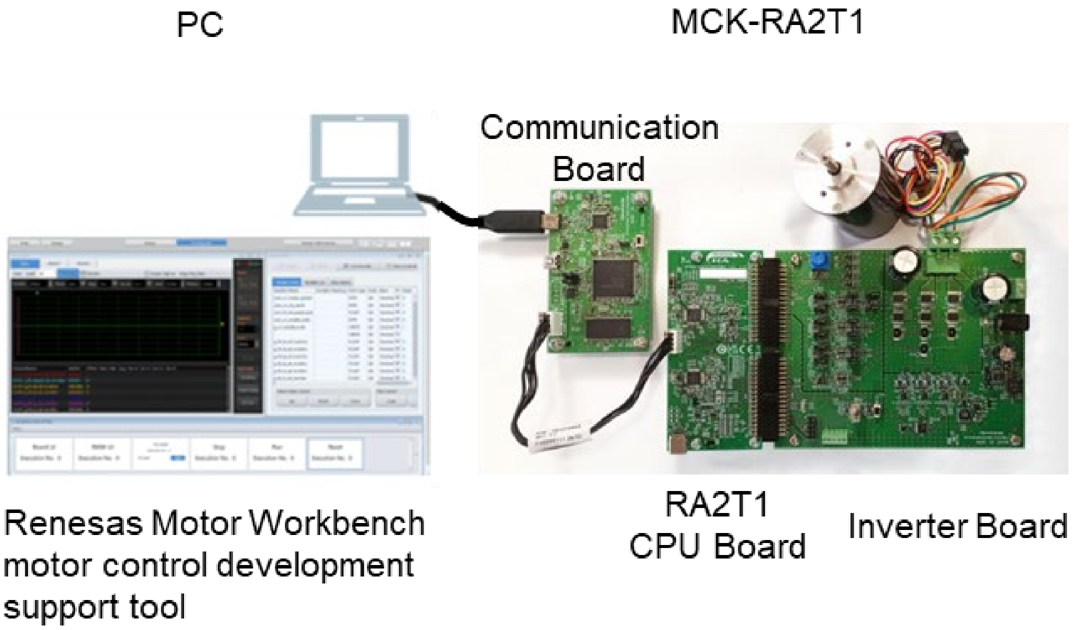


Figure 7: Example of connecting Renesas Motor Workbench to MCK-RA2T1

QE for Motor: Simplifying Motor Development

QE for Motor is a development support tool that enables easy implementation of Renesas motor solutions by simply following a guided workflow. Available as a free extension for the e² studio integrated development environment, it can be downloaded from the Renesas website. QE for Motor also integrates seamlessly with Renesas Motor Workbench (RMW)—automating its configuration so that users can access its functions with just a click through the graphical user interface.

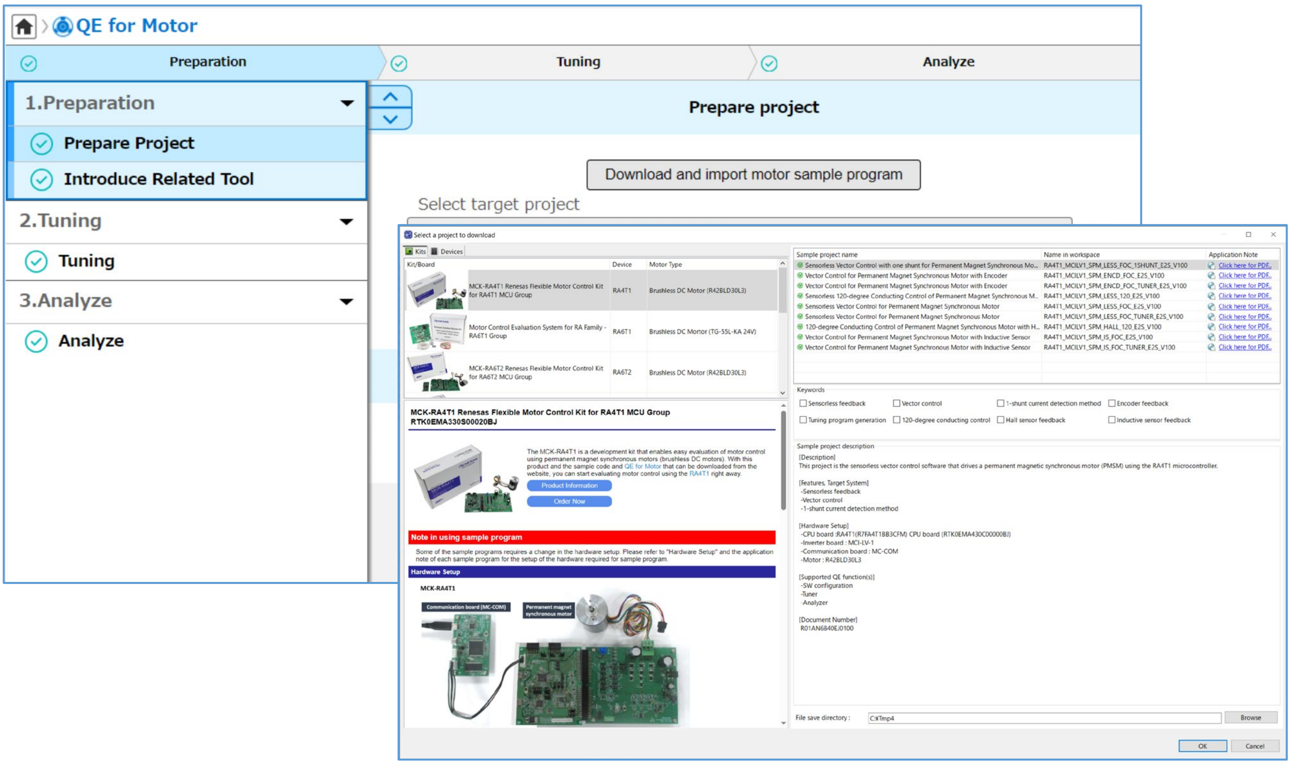


Figure 8: Example of QE for Motor screen

Summary

This whitepaper introduces a configuration based on sensorless vector control, highlighting the use of the GPT timer and its coordination with A/D conversion start triggers for 1-shunt current detection, as well as the sample & hold function of the A/D converter, which is effective for 2-shunt and 3-shunt current detection.

The RA2T1 MCU is purpose-built for single-motor control and features: - 125°C temperature tolerance - A compact 24-pin QFN package - 5V operation, ideal for robust motor control in noisy environments. In addition, the RA2T1 supports fixed-point arithmetic, making it highly suitable for systems based on the Arm® Cortex®-M23 core, which lacks a floating-point unit (FPU). Coupled with robust development tools like QE for Motor and RMW, this enables efficient, low-overhead development even in resource-constrained environments.

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The RA2T1's capabilities are not limited to power tools and fan motors—it is a flexible solution suitable for a wide range of motor control applications. As modern systems demand both higher performance and increasingly compact, cost-effective designs, the approaches introduced in this document provide a practical foundation for next-generation product development. We encourage you to take advantage of the tools, reference designs, and control strategies introduced here to streamline your development process and meet the evolving demands of your motor control applications.

Additional Details

- RA2T1 : 64MHz Arm Cortex-M23 Motor Control Microcontroller
- MCK-RA2T1 : Renesas Flexible Motor Control Kit for RA2T1 MCU Group
- Renesas Motor Workbench : Motor Control Development Support Tool
- QE for Motor : Development support tool for motor

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