RX FAMILY
Renesas 32-Bit Microcontrollers
Mid-range 32-bit microcontrollers built around an exclusive CPU core developed by Renesas
Maintaining and Advancing the Renesas Tradition

The following new products have been added:
RX700 Series: RX72M, RX72N, RX72T
RX600 Series: RX66N, RX66T
RX200 Series: RX23W, RX23E-A
RX100 Series: RX13T

Information on the following solutions has been added:
Resolver position control solution
Cloud solutions
Information on the RXv3 core has been added.

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RX Family MCUs are built around advanced CPU cores packed with innovations unique to Renesas. Based on proprietary technology amassed over many years, they are designed to deliver improved responsiveness and power efficiency in all aspects while combining excellent operation performance and low power consumption. The RX Family brings together a variety of technical innovations from Renesas and aims to define the ultimate in 32-bit MCUs with on-chip flash memory for the industrial, home electronics, office automation, and ICT* fields.

Note: 1. ICT: Information and Communication Technology

Power and functionality poised to dominate the market:
The four powerful product series that compose the RX Family

The RX Family of 32-bit microcontrollers are built around Renesas’ exclusive RX CPU core and combine excellent operation performance with superior power efficiency.

The family consists of four product series: the flagship RX700 Series, with the fastest performance and most advanced functions; the mainstream RX600 Series; the RX200 Series, which delivers an optimal balance of power efficiency and high performance; and the entry-level RX100 Series, with extremely low power consumption. These four series encompass a range of products that provide seamless scalability from small-scale to large-scale applications.
With a proven track record and superior reliability, the RX family of 32-bit microcontrollers is suitable for a wide range of applications in the industrial and home electronics fields and supports the full lineup of customer products with a seamless range of operating frequencies from 32MHz to 240MHz.

Positioning of the RX Family

The flagship of the RX Family, with the highest speed and best performance

The mainstream of the RX Family, with high performance and an extensive product lineup

The best balance between power efficiency and high performance

The entry-level series designed for ultra-low power consumption

Features of the Four Series Composing the RX Family

**RX700 Series**
- Up to 240MHz
- 4MB Flash Max
- Dual Bank
- EtherCAT, IEE1588
- Ethernet
- USB, CAN
- SDHI, LCDC
- Security
- Safety
- Motor

**RX600 Series**
- Up to 160MHz
- 4MB Flash Max
- Dual Bank
- IEE1588
- Ethernet
- USB, CAN
- SDHI, LCDC
- Security
- Safety
- Motor

**RX200 Series**
- Up to 80MHz
- 1MB Flash Max
- 1.8 to 5.5V
- 0.12mA/MHz
- 0.8µA (stby)
- USB, CAN
- SDHI, Bluetooth
- Security
- Safety
- Motor
- Capacitive Touch
- IA Sensor

**RX100 Series**
- Up to 32MHz
- 512KB Flash Max
- 1.8 to 5.5V
- 0.35mA/MHz
- 0.35µA (stby)
- USB
- Segment LCD
- Security
- Motor
- Capacitive Touch

**Featured Products**

**RX72M/N**
- RX72T
- RX72Z

**RX66N**
- RX24U/T
- RX23T
- RX66T

**RX65N/1**
- RX23T
- RX23W

**RX231/0**
- RX13T

**RX130**
- RX23E-A

---

**Features of the Four Series Composing the RX Family**

- **Low Power**
  - Features: Ultra-low energy
  - Low pin count lineup available
  - Operating frequency: 20~32MHz
  - Applications: General-purpose, Sensor, Motor Control, LCD Display, Bluetooth* Low Energy, Sub-GHz Wireless Communication, Security

- **Power Efficiency**
  - Features: Superior power efficiency
  - High-capacity flash memories
  - Broad lineup
  - Operating frequency: 32~240MHz
  - Applications: General-purpose, Motor Control, Security, Capacitive Touch, Battery Powered, LCD Control, Industrial Network, Cloud Connectivity

- **Arm® Ecosystem**
  - Features: High efficiency
  - Security
  - Operating frequency: 48~200MHz
  - Applications: Motor Control, LCD Control, Network, Capacitive Touch, Security

- **Qualified Platform**
  - Features: Qualified software and tools
  - Operating frequency: 32~240MHz
  - Applications: Motor Control, Network, IoT Devices, Security

- **High Performance**
  - Features: Multi-core up to 8 cores
  - Linux or RTOS available
  - High-capacity on-chip RAM
  - DRP** image processing acceleration
  - Operating frequency: 125MHz~1.5GHz

*DRP: Dynamically Reconfigurable Processor
### RX Family Lineup

#### Flagship
**RX700**
- **RXv2**
  - RX71M
  - RX72M
  - 240MHz
  - Double Precision FPU
  - Register Bank Save
  - Up to 4MB Flash
  - EtherCAT

#### Mainstream
**RX600**
- **RXv2**
  - RX64M
  - 120MHz
  - Double Precision FPU
  - Register Bank Save
  - Up to 2MB Flash
- **RXv1**
  - RX63N, RX631, RX62N, RX621, RX630, RX610
  - 100MHz
  - 54MHz
  - Up to 512KB Flash
  - Bluetooth, Capacitive Touch
  - Security (Trusted Secure IP Lite)

#### Best Mix
**RX200**
- **RXv1**
  - RX210, RX220
  - 50MHz
  - 32MHz
  - For Bluetooth
  - RX23W
  - 54MHz
  - Up to 512KB Flash
  - Bluetooth, Capacitive Touch
  - Security (Trusted Secure IP Lite)

#### Entry
**RX100**
- **RXv1**
  - RX130
  - RX131, RX130
  - 32MHz
  - Up to 512KB Flash
  - 5V Support, Capacitive Touch
  - Common
  - USB/CAN

#### For Motor
**RX-T**
- **RXv1**
  - RX63T, RX62T, RX62G
  - 100MHz
  - 3-4 Motors
  - RX72T
  - 200MHz
  - Up to 1MB Flash
  - Register Bank Save, TFU
  - USB/CAN, PGA
  - Security (Trusted Secure IP Lite)
  - 4-4 Motors
  - RX66T
  - 160MHz
  - Up to 1MB Flash
  - USB/CAN, PGA
  - Security (Trusted Secure IP Lite)
  - 2-3 Motors
  - RX24T/RX24U
  - 80MHz
  - Up to 512KB Flash
  - CAN, PGA

- **RXv2**
  - RX231, RX230
  - 50MHz
  - 32MHz
  - For Sensor
  - RX23E-A
  - 32MHz
  - Up to 256KB Flash
  - High Precision AFE

- **RXv1**
  - RX110, RX111
  - 32MHz
  - Up to 128KB Flash
  - PGA

- **RXv1**
  - RX13T
  - 32MHz
  - Up to 128KB Flash
  - PGA

- **RXv1**
  - RX23T
  - 40MHz
  - Up to 128KB Flash

- **RXv1**
  - RX21A
  - 32MHz
  - RX113
  - Up to 128KB Flash
  - LCD

- **RXv1**
  - RX220
  - RX221
  - RX222

Common
- Dual Bank flash memory
- Ethernet
- USB/CAN
- LCD
- Security (Trusted Secure IP)

Next-Generation
- RX7xx
- RX6xx
- RX2xx
- RX1xx
- RXxxT
### RX Family Memory/Pin Lineup

#### Industrial, Home Appliances, and OA/ICT

<table>
<thead>
<tr>
<th>Memory</th>
<th>Pin</th>
<th>RX700</th>
<th>RX600</th>
<th>RX200</th>
<th>RX100</th>
</tr>
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<tbody>
<tr>
<td>4MB</td>
<td>36/40</td>
<td>✓</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3MB</td>
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<td></td>
</tr>
<tr>
<td>2.5MB</td>
<td>56</td>
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<td></td>
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<td></td>
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<tr>
<td>2MB</td>
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<td></td>
<td></td>
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<td>512KB</td>
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<td>384KB</td>
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<tr>
<td>256KB</td>
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<td>128KB</td>
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<td>224</td>
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#### Motor

<table>
<thead>
<tr>
<th>Memory</th>
<th>Pin</th>
<th>RX700</th>
<th>RX600</th>
<th>RX200</th>
<th>RX100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1MB</td>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>768KB</td>
<td>48</td>
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</tr>
<tr>
<td>512KB</td>
<td>52</td>
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<tr>
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<td>48KB</td>
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<td></td>
</tr>
<tr>
<td>32KB</td>
<td>144</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Contributing to the Development of Platforms in a Variety of Fields

Wide performance range from 32MHz to 240MHz, abundant peripheral functions for many applications, and excellent compatibility.
The RX Family is designed for compatibility across products in terms of CPU instructions, pin assignments, and functions.

- The instruction sets of the RXv1, RXv2, and RXv3 cores are intercompatible.
- The functions of RX Family MCUs are based on common IP cores, allowing for easy migration between RX products.
- The pin assignments of RX Family MCUs are fundamentally consistent with those of earlier Renesas products.
- Pin positions for digital peripheral functions can be selected from among multiple locations, simplifying the development of printed circuit boards.
- Compatibility among development environments has been enhanced, reducing the development burden and cost of tools while simplifying program management.

### RX Family Compatibility

<table>
<thead>
<tr>
<th>Pin assignments</th>
<th>Functions</th>
<th>Integrated development environments</th>
<th>On-chip debugging emulators</th>
<th>Compiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial in some cases</td>
<td>RX CPU</td>
<td>CS+/e² studio</td>
<td>E2 emulator/E2 emulator Lite</td>
<td>RX Compiler</td>
</tr>
<tr>
<td>Pin compatibility</td>
<td>FPU</td>
<td></td>
<td>E20 emulator</td>
<td></td>
</tr>
</tbody>
</table>

### Pin Compatibility between Series for Power Supply, Analog, and USB

Analog and USB pins are pin compatible. Power supply pins are compatible except in some devices which require additional pins.

### Existing Products and RX Extensibility

- The RX Family covers the performance range of a variety of CPU cores utilized in earlier Renesas products.
- Improved software reusability and unification of development environments allow the RX Family to provide seamless scalability when developing products over the entire model range from low- to high-end.
RX FUNCTIONAL SOLUTIONS

Functional Safety Solution for Industrial Automation

In the industrial equipment field the importance of “functional safety,” which aims to maintain safety even when malfunctions occur, is increasing as a way to prevent the adverse effect of breakdowns and accidents on plant operation, the adverse effect of injuries to personnel on society, and the associated economic losses. The European Union’s Machinery Directive also requires that equipment meet functional safety standards.

In response to the need for functional safety certification in a range of industrial fields, Renesas provides RX Functional Safety as a one-stop solution designed to reduce the burden on customers at the development and functional safety certification stages.

RX Functional Safety

IEC 61508 SIL 3 core technology comprises three components: self-test software kits, SIL3 system software kits, and functional safety certified compilers. A self-test software kit is an MCU self-diagnostic software product package for examining the CPU, ROM, and RAM internal to the MCU. An SIL3 system software kit is a functional safety platform software product package for mutual diagnostics in MCUs with redundant configurations or controlling the behavior of user applications.

IEC 61508 SIL 3 reference kits include the results of cases where Renesas has drawn up the safety specifications and implementation specifications, and then implemented a detailed design, failure analysis, and diagnostics for an MCU redundant configuration system based on these cases. Both reference documents and reference hardware are available. To assist customers’ efforts to obtain certification, Renesas provides a wide range of support to match every development stage and situation, from individual seminars to design consulting and contracted software development.

Solution Application Examples

Motor Control Application

Remote IO Application

Functional Safety Solution Products for Industrial Automation

Self-Test Software Kit

for CC-RX compiler
- for RX700 series product version free version RTX0EF005F27001JS
- for RX600 series product version free version RTX0EF005F26001JS
- for RX200 series product version free version RTX0EF005F22001JS
- for RX100 series product version free version RTX0EF005F21001JS

for IAR tool
- for RX700 series product version free version RTX0EF005F27001JS
- for RX600 series product version free version RTX0EF005F26001JS
- for RX200 series product version free version RTX0EF005F22001JS
- for RX100 series product version free version RTX0EF005F21001JS

(SIL3 System Software Kit)

for CC-RX compiler
- for RXv2 core product version RTX0EF0081F22001JS
- for RXv2 core evaluation version RTX0EF0081F32001JS

(The functions of the product version and evaluation version are identical, but the evaluation version software is not subject to functional safety certification.)

Reference Document

Full document set (total 19 volumes) common to all RX: RTX0EF0005Z11001JS
Set for concept phase (excerpts in 4 volumes) common to all RX: RTX0EF0031Z11001JS

Reference Hardware

for RX111-RX71M RTX0EF0058D01001SJ
for RXv2 core product version: RTX0EF0058D01001SJ

(19 v. documents total)

For more information, please refer to the RX Functional Safety Evaluation Kit User’s Manual.
In recent years, the creation of new added value for the Internet of Things (IoT) has been gaining attention. On the other hand, since IoT devices connect to the Internet, they are exposed to risks such as eavesdropping, tampering, and viruses, and such harmful incidents are also seeing an increase in number. Consequently, the demand for security features is increasing for devices that previously didn’t need them.

**Robust Security with Trusted Secure IP**

RX security solutions implement Root of Trust for IoT devices using encryption by key data that is protected by a strong Trusted Secure IP and an authentication program using a memory-protection function. By implementing security functions using an RX microcontroller (MCU), you can easily and strongly protect IoT devices against threats.

The RX65N and RX231 with Trusted Secure IP are CAVP certified under the FIPS 140-2 standard of the National Institute of Standards and Technology (NIST) of the United States, so the encryption algorithm employed can be used with confidence.

**Components of Communication Security Evaluation Kit**

Reference solutions for communication and security are available.

Start implementing security features in your project immediately using one of these one-stop solutions.

**Security Solutions**

The RX MCU provides a variety of security features.

**Hardware-Based Security Features of RX**

<table>
<thead>
<tr>
<th>MCU Group</th>
<th>Function</th>
<th>Encryption</th>
<th>Memory Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>RX23W/RX231</td>
<td>Trusted Secure IP</td>
<td>AES</td>
<td>Code Protect</td>
</tr>
<tr>
<td>RX66T/RX72T</td>
<td>RSA</td>
<td>TRNG</td>
<td>Area Protection</td>
</tr>
<tr>
<td>RX65N/RX66N/RX72M/RX72N</td>
<td>ECC</td>
<td>SHA</td>
<td>Memory Protection Unit</td>
</tr>
</tbody>
</table>

**Speed up Time-To-Market**

You can greatly speed up the time-to-market of your security and communication project using these ready-to-use security evaluation kits.

**Device Lifecycle Management (DLM) to Ensure Security from Manufacture to Decommissioning of IoT Devices**

In recent years it has become necessary to ensure security over the entire lifecycle of a product. This process is called Device Lifecycle Management (DLM). By making use of RX security functionality to implement a root of trust, customers can implement robust and sophisticated security management that extends over the entire lifecycle of a device.

For details, visit the following webpage: https://www.renesas.com/rx-security-solution
RX FAMILY SOLUTIONS

Motor Control Solutions

Renesas offers motor control solutions incorporating microcontrollers and analog products that are designed to enable reduced power consumption and quieter operation when driving brushless DC motors (permanent magnet synchronous motor) and stepping motors. Development tools optimized for each stage in the customer’s development workflow are available. They help shorten the time needed for development.

Development Workflow

Motor Control Starter Kit (Renesas Solution Starter Kit)

Just connect a power supply to get started checking your motor drive application.

This kit consists of a motor and an inverter board.*1

The provided “sample programs” are ideal for leaning about different control methods.

Motor Control Development Support Tool  Renesas Motor Workbench

Analyzer function reduces the debugging workload. Tuner function enables simple vector control, even if you have no specialized knowledge.

Motor control board (populated with MCU, power elements, etc.)

Target MCUs: RX23T, RX24T, RX24U, RX66T, RX72T, RX13T

Brushless DC motor (permanent-magnet synchronous motor, 24V)*2

Kit user’s manual and sample software are available on the website.

Available on website: Kit user’s manual, circuit diagrams, parts lists, application notes, sample software

Related URL

Renesas motor control solutions: https://www.renesas.com/solutions/motor

Notes:
1. The RX23T kit does not include the E1 or a power supply. These must be provided by the customer. The RX62T kit includes the E1.
2. The specifications of the supplied motor differ depending on the kit. For details, refer to the product specifications of specific kit.
Resolver Solution Features

- Low current consumption and low heat generation: Uses the minimum current necessary for torque control, and cuts current consumption in standby mode.
  - Reduced energy consumption, allowing for simplified cooling
- Low noise and low vibration: Server control reduces torque ripple, for reduced noise and vibration.
  - Ability to reduce cost of mechanical elements such as dampers
- Reduced motor size: Server control eliminates the need for a step-out margin and increases the usable torque.
  - Ability to achieve the same torque with a smaller motor

Position Sensor Comparison

<table>
<thead>
<tr>
<th>Comparison Item</th>
<th>Magnetic Encoder</th>
<th>Optical Encoder</th>
<th>Resolver + RDC IC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position resolution (P/R)</td>
<td>Average</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Environmental resistance</td>
<td>Average</td>
<td>Bad</td>
<td>Good</td>
</tr>
</tbody>
</table>
  (dust, vibration, impacts, magnetism, moisture/oil)
  Affected by magnetism from motor
  Susceptible to vibration, impacts, and dust
| Cost                             | Good             | Bad            | Good              |
  Magnet + magnetic sensor +
  magnetic shielding and housing
| Overall evaluation               | Average          | Cost and environmental resistance | Good |
  Suitable only for certain applications

Kit Information

Renesas Motor Workbench
Development Support Tool
RDC Driver
Motor Control
Sample Code

Position Control Solution Kit

Evaluation Board
Motor with resolver

Selected Products | Detail
--- | ---
MCU | RX24T 80/100-pin
RDC-IC | RAA3664002GFP LQFP48
S/W | - RDC Driver
   - Motor Control Certified Sample
H/W | Solution Board For evaluation Includes MCU, RDC, Inverter
Doc | Application Note
RX FAMILY SOLUTIONS

Capacitive Touch Solutions

RX Capacitive Touch Functionality

- Support for two capacitive touch technologies on a single chip:
  - Self-capacitance, which provides high sensitivity and proximity sensing, and mutual-capacitance, which provides superior water resistance.
  - Accurate touch input even in harsh environments and excellent design flexibility.
  - QE for Capacitive Touch program simplifies development by letting you easily adjust the sensitivity of touch sensors, previously a complex task, and control system operation.

<table>
<thead>
<tr>
<th>Features</th>
<th>Advantages for the User</th>
<th>Self-capacitance</th>
<th>Mutual-capacitance</th>
</tr>
</thead>
<tbody>
<tr>
<td>High sensitivity/Improved noise tolerance</td>
<td>Support for thick overlay panels or wood panels, operation when wearing gloves, and air gaps.</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Improved water resistance</td>
<td>Enables capacitive touch operation in wet environments or outdoors.</td>
<td>✓</td>
<td>—</td>
</tr>
<tr>
<td>Simple development</td>
<td>The development tool can generate detection programs automatically, provides self-calibration functions to shorten development time, and reduces resource requirements.</td>
<td>—</td>
<td>✓</td>
</tr>
</tbody>
</table>

Roadmap

- More products with capacitive touch functions will be added to the RX Family moving forward.
- The RX130 group with small ROM capacity and low pin count can handle input from multiple touch controls.
- The RX113 Group has integrated LCD functions that can be combined with a touch panel to create an HMI.
- The RX231 and RX230 Groups combine the RX2 core with enhanced DSP and FPU with low-power-consumption technology for superior power efficiency.
- RX23W Group with Bluetooth 5 (QE for Capacitive Touch support only).

Product Lineup

- Lineup of packages with pin counts from 48 to 100 pins to accommodate the number of touch controls required by the system and the mounting area.
- Many ROM size options ranging from 64KB to 512KB to match the required scale of system control.

Capacitive Touch Evaluation System with RX130 (RTK0EG0003S02001BJ)

Start evaluating your capacitive touch system right away. Evaluation of custom electrodes can be accomplished easily through development on the application board side. For details, refer to www.renesas.com/RTK0EG0003S02001BJ.

<table>
<thead>
<tr>
<th>ROM</th>
<th>RX230</th>
<th>RX231</th>
<th>RX23W</th>
<th>RX130</th>
<th>RX113</th>
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<td>64KB</td>
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</tr>
</tbody>
</table>

- CPU core
- 1st generation capacitive touch core
- Simple functions, 5V operation

Target applications

- Electric home appliances, measurement
- Electric home appliances, measurement, healthcare

Target applications

- Electric home appliances, measurement, healthcare

Roadmap

- More products with capacitive touch functions will be added to the RX Family moving forward.
- The RX130 group with small ROM capacity and low pin count can handle input from multiple touch controls.
- The RX113 Group has integrated LCD functions that can be combined with a touch panel to create an HMI.
- The RX231 and RX230 Groups combine the RX2 core with enhanced DSP and FPU with low-power-consumption technology for superior power efficiency.
- RX23W Group with Bluetooth 5 (QE for Capacitive Touch support only).
Cloud Solutions

Alongside the rapid pace of technical innovations in networking, the emergence of IoT devices is accelerating in an array of fields and applications. By making use of a variety of sensor technologies data can be managed device by device, and it is now possible to obtain more types of device data than ever before. On the other hand, cloud-based services have become essential in order to efficiently process the enormous volumes of data involved.

Many manufacturers are deploying new technology to implement communications with the cloud, but the barriers to development are considered high. Renesas offers solutions that enable customers to easily build and evaluate cloud-based communication environments, allowing even customers with little experience in the development of IoT devices to get started with development work without delay.

**Renesas RX65N Cloud Kit**

This all-in-one evaluation kit is intended for use in the development and evaluation of devices that communicate with Amazon Web Services (AWS). It includes a board mounted with three types of sensors and Wi-Fi communication functions as well as a standard software program for transmitting sensor data to the AWS cloud at regular intervals.

www.renesas.com/rx65n-cloud

1. Certified for FreeRTOS.
2. Available from Renesas sales agents.
3. Wireless communication using Silex Wi-Fi module.
4. Send three types of sensor data (temperature/humidity, brightness, and three-axis accelerometer) to the AWS cloud and view a graphical display on Renesas Dashboard.*

*Renesas Dashboard: A Renesas system that allows users to view data sent to the cloud in graphical format on a web browser.

**Renesas Starter Kit+ for RX65N-2MB**

Enables customers to evaluate the AWS cloud by programming FreeRTOS, an embedded OS provided by AWS for IoT devices, to the RSK.*

1. Certified for FreeRTOS.
2. Free download from GitHub.
3. Ethernet communication via wireless LAN.
4. Ability to use RX65N functions on RSK.*

*RSK: Renesas Starter Kit+ for RX65N-2MB

e² studio with FreeRTOS Support

Use e² studio, the integrated development environment from Renesas, to download the latest verified FreeRTOS projects from GitHub and get started with development work right away. www.renesas.com/e2studio

1. Generate and build the latest FreeRTOS sample projects from GitHub.
2. Provides assistance with network stack component library settings.
3. Easily add drivers and middleware to support USB, file systems, etc.
RX FAMILY SOLUTIONS

Human-Machine Interface (HMI) Solutions

RX231 HMI Evaluation Kit (R0K5RX231D000BR)

www.renesas.com/rx231hmi

This reference solution simplifies the process of developing user interfaces for home appliances, industrial equipment, healthcare equipment, or office equipment. It enables you to create attractive designs and user-friendly interfaces.

- Highly power efficient 32-bit RX231 microcontroller with integrated capacitive touch and USB functionality
- SAIC101 Smart Analog IC for controlling 16-bit A/D converter, amplifier gain, etc., allowing evaluation of the following functions:
  - Capacitive touch functions
  - Audio recording and playback functions (audio middleware)
  - LCD panel (character)
  - Pyroelectric infrared sensor, accelerometer

Release notes (User’s manual, circuit diagrams, parts lists, etc., are available for download on the Renesas website.)

RX65N/RX72N HMI Evaluation Kit (Envision kit)

www.renesas.com/envision

An all-in-one kit equipped with a WQVGA TFT-LCD makes it easy for customers to get started with GUI development.

- A debugger is provided, so a USB cable is all you need to perform debugging.
- Just launch the preinstalled demo to experience the capabilities of the 2D drawing engine.
- Segger emWin GUI tools are available for use free of charge.
- The RX72N version provides even higher performance and a larger memory capacity.
- Standard functions include onboard Wi-Fi, audio DSP, MEMS microphone, Ethernet, SD slot, and more.
- Includes sample code and video on GUI creation.

Visit the Renesas website for details.

Topics (Target Board for RX)

RX Evaluation Kit Entry Model (Target Board for RX130, RX231, RX23W, and RX65N)

www.renesas.com/rtxb

Two types of RX evaluation boards are available to match the needs of different users: a Renesas Starter Kit board or an RX Family target board. The RX Family target board is an entry model intended for new users of RX products and is mounted with an MCU and an on-chip debugger only. It can be used for inexpensive and simple RX MCU evaluation using free sample code such as FIT modules available on the Renesas website. In addition to the previously available RX130, RX231, and RX65N versions, a new RX23W version with Bluetooth® Low Energy has now been added to the lineup.

[RX23W Target Board]

- Built-in emulator circuit:
  There is no need for the E2 Emulator or E2 Emulator Lite to perform application development.
- Ability to access all MCU signal pins:
  Pin header through holes are provided, allowing access to all MCU signal pins.
- Arduino interface:
  Arduino interface pin headers are provided to ensure expandability.
RX CORE FEATURES

RX Core Roadmap

The need for increasing added value and system complexity demands higher microcontroller performance. At the same time, energy saving and longer battery life is also needed, so lower power consumption is also demanded. The RX core continues to evolve even further to meet these demands.

RX Family Features:

Comparison of RX Cores

<table>
<thead>
<tr>
<th>Item</th>
<th>RXv1</th>
<th>RXv2</th>
<th>RXv3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>32-bit CISC, Harvard architecture</td>
<td>Downward compatible with RXv1</td>
<td>Downward compatible with RXv1/RXv2</td>
</tr>
<tr>
<td>General purpose</td>
<td>32bit × 16ch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>registers</td>
<td></td>
<td><strong>Improved 5-stage pipeline</strong></td>
<td><strong>Improved 5-stage pipeline</strong></td>
</tr>
<tr>
<td>Compatibility</td>
<td>RXv1</td>
<td>109 instructions (90 RXv1 instructions + 19 instructions)</td>
<td>113 instructions (109 RXv2 instructions + 4 instructions)</td>
</tr>
<tr>
<td>Instruction set</td>
<td>90 instructions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipeline</td>
<td>5-stage</td>
<td><strong>Improved IPC through enhanced pipeline</strong></td>
<td><strong>Improved IPC through enhanced pipeline</strong></td>
</tr>
<tr>
<td>DSP function</td>
<td>Single-cycle MAC instructions (16-bit),</td>
<td>Single-cycle MAC instructions (16-bit, 32-bit), Accumulator × 2</td>
<td>Single-cycle MAC instructions (16-bit, 32-bit), Accumulator × 2</td>
</tr>
<tr>
<td>instructions</td>
<td>Accumulator × 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FPU</td>
<td>Single-precision floating-point operation instruction</td>
<td>Single-precision floating-point operation instruction</td>
<td>Single precision / double precision floating-point operation instruction (double precision is optional)</td>
</tr>
<tr>
<td>Performance</td>
<td>Up to 3.12 CoreMark/MHz</td>
<td>Up to 4.55 CoreMark/MHz</td>
<td>Up to 5.82 CoreMark/MHz</td>
</tr>
<tr>
<td>Others</td>
<td>-</td>
<td></td>
<td><strong>Register bank save function (optional)</strong></td>
</tr>
</tbody>
</table>

*Availability of optional functions depends on product specifications.*
### Feature 1: Original CPU That Inherits the Strengths of Its Predecessors

RX core combining advantages of CISC and RISC

- Combines the variable byte-length instructions of CISC with the general-purpose register machine, architecture, and pipelines of RISC. The RX CPU core brings together Renesas technology accumulated over many years.

- Variable-byte-length instructions
- Multiplier/divider and multiply-and-accumulate (MAC) units
- Register-relative addressing
- FPU
- 2 stack pointers

### Feature 2: RX CPU Core with Industry-Top-Class Performance

#### CoreMark score per operating frequency

<table>
<thead>
<tr>
<th>CoreMark/MHz</th>
<th>Cortex-M0</th>
<th>Cortex-M0+</th>
<th>Cortex-M3</th>
<th>Cortex-M4</th>
<th>Cortex-M7</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.12</td>
<td>2.33</td>
<td>2.45</td>
<td>3.34</td>
<td>3.42</td>
<td>5.01</td>
</tr>
</tbody>
</table>

- No.1

- RXv1
- RXv2
- RXv3

### CoreMark/MHz value = 5.82

Superior embedded performance and power efficiency

- CPU developed in-house for high operational efficiency.
- Five-stage superscalar architecture.
- Optimized for power efficiency and high performance.
- Processing capability and code efficiency on par with RISC.
- Improved interrupt responsiveness and FPU/DSP instructions.

### Feature 3: Pipeline Stage Configuration

- Harvard architecture enabling parallel execution of instruction fetches and data accesses.
- Five-stage pipeline configuration and out-of-order completion for even faster execution. (Allows no-wait execution of later instructions when there is no dependency between later and earlier instructions.)

#### Pipeline Stage Configuration

- 5-stage pipeline for faster processing
- Through benchmark testing of various types of application software, processing performance was more than doubled compared with earlier products.

#### Out-of-Order Completion

- Out-of-order completion boosts the efficiency and speed of instruction execution.

#### Harvard Architecture

- Instruction fetch stage (IF)
- Decode stage (D)
- Execution stage (E)
- Memory access stage (M)
- Write-back stage (WB)

#### Five Stage Pipeline

- Instruction fetch processing
- Instruction decode processing
- Operation processing, address calculation
- Memory access processing
- Write-back processing

- The memory access stage is only used when accessing the memory.

* Cortex®-M is the nominal value of Arm

### Performance Comparison

<table>
<thead>
<tr>
<th>No.1</th>
<th>RXv1</th>
<th>RXv2</th>
<th>RXv3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.82</td>
<td>5.01</td>
<td>4.55</td>
<td>3.34</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cortex®-M0</th>
<th>Cortex®-M0+</th>
<th>Cortex®-M3</th>
<th>Cortex®-M4</th>
<th>Cortex®-M7</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.12</td>
<td>2.33</td>
<td>2.45</td>
<td>3.34</td>
<td>3.42</td>
</tr>
</tbody>
</table>

### CoreMark/MHz

- CoreMark score per operating frequency
- CoreMark/MHz value
- Superior embedded performance and power efficiency
- RX core features
- CPU developed in-house for high operational efficiency.
- Five-stage superscalar architecture.
- Optimized for power efficiency and high performance.
- Processing capability and code efficiency on par with RISC.
- Improved interrupt responsiveness and FPU/DSP instructions.

### Performance Comparison Table

<table>
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<tr>
<th>CoreMark/MHz</th>
<th>No.1</th>
<th>RXv1</th>
<th>RXv2</th>
<th>RXv3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.82</td>
<td>5.01</td>
<td>4.55</td>
<td>3.34</td>
<td>3.42</td>
</tr>
</tbody>
</table>

### Conclusion

The RX core combines the advantages of CISC and RISC, providing superior performance and power efficiency compared to earlier products, thanks to its optimized architecture and advanced features.
RXv2 Core: CPU Block Diagram

Further enhancements while maintaining compatibility with the RXv1 core

- Improved pipeline for substantial increase in the number of instructions per cycle (IPC)
- Advanced fetch unit with improved interface to on-chip flash memory. Reduces re-fetching of instructions due to penalty imposed by branch instructions and reduces the number of flash memory accesses. Achieves improved CPU performance alongside reduced power consumption.
- Improved instructions for DSP and FPU functions.

Feature 1: Pipeline Enhancements

RXv2 Pipeline Processing Stage Configuration

- Improved pipeline processing and parallel execution of floating-point operations
  - Floating-point operations take place in parallel during execution stages and memory access stages.
  - Integer operation instructions and memory access or FPU instructions can execute at the same time.
  - Contributes to improved FPU execution speed and CPU performance.

Feature 2: FPU and DSP Enhancements

Enhanced FPU and DSP functions

- Reduced execution cycle count for existing instructions and addition of new instructions.
- The number of accumulators with dedicated buffers has been increased from one to two for more efficient DSP operations.
- Performance in filter operations has been boosted fourfold.

FPU functions (new instructions added, existing instructions speeded up)

<table>
<thead>
<tr>
<th>New instructions</th>
<th>Speed (cycles)</th>
<th>Single-cycle throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSQRT (√), FTOU, UTOF</td>
<td>FADD/FSUB: 4 cycles → 2 cycles</td>
<td>Pipelined FPU</td>
</tr>
</tbody>
</table>

| Improved formats | Improvements are shown in red. |

DSP functions (new instructions added, accumulator for operations added)

<table>
<thead>
<tr>
<th>Accumulator rounding instructions (16/32-bit, round off/down)</th>
<th>Accumulator added</th>
</tr>
</thead>
<tbody>
<tr>
<td>HULLH, MACLH, MSB (LH, HI, LO)</td>
<td>1 → 2</td>
</tr>
<tr>
<td>RDACW, RDACL, RACL</td>
<td></td>
</tr>
</tbody>
</table>

Downward compatible with RXv1 core

Pipeline improvements for increased instructions per cycle (IPC), up to 4.55 CoreMark/MHz

Improved CPU performance for fewer flash memory accesses and reduced current consumption

Improved DSP functions and instructions, addition of one more accumulator for total of two

Strengths of RXv2 core

RXv2 Pipeline Processing Stage Configuration

- Instruction fetch stage (IF)
- Decode stage (D)
- Execution stage (E)
- Memory access stage (M)
- Write-back stage (WB)

The memory access stage is only used when accessing the memory.
RXv3 CORE FEATURES

The successor to the RXv2 core, the RXv3 core boosts performance with new functions while adding a double-precision FPU and a register bank save function. These improvements enable it to achieve a score of 5.82 CoreMark/MHz on the EEMBC CoreMark® benchmark test, among the best CPU performance levels in the industry. The RXv3 core contributes to extremely fast and efficient operations in a wide array of applications requiring real-time processing.

**Feature 1: Register Bank Save Function**

- Dedicated memory for improved interrupt responsiveness
  - Faster saving/restoring data to/from CPU registers and improved interrupt responsiveness.
  - “Register save banks” provided as dedicated memory for register saves.
  - Dedicated instructions (SAVE and RSTR) for accessing the register save banks.
  - Number of register save bank areas: 16 (RX72T)*1

*Note: 1. Number of banks differs among products.*

Comparison with conventional product (saving data to all registers)

**Feature 2: Double-Precision FPU Support**

- First RX Family CPU core with a double-precision floating-point processor.
- Greatly improved processing performance in double-precision floating-point operations (up to eight times better).
## RX700/RX600 SERIES

### Features of RX700/RX600 Series

<table>
<thead>
<tr>
<th>High-performance, High-speed response</th>
<th>Large-capacity</th>
<th>Numerous peripheral functions</th>
<th>Various solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1396CoreMark @240MHz Double precision FPU coprocessor Trigonometric functions arithmetic unit Register bank save function</td>
<td>4MB Flash (Dual bank function) 1MB SRAM</td>
<td>Various communication interfaces 3-phase complementary PWM timer 12-bit A/D converter TFT LCD controller 2D rendering engine Trusted Secure IP</td>
<td>HMI Cloud Security Functional safety</td>
</tr>
</tbody>
</table>

### Main Applications of RX700 and RX600 Series

#### Industrial
- Robots, Machine tools
- Power conditioner
- HVAC controller
- General-purpose inverters
- PLC
- Security controller
- Smart meter

#### Office Automation
- Printers
- Copyers
- Security controller
- Projector

#### Consumer
- Air conditioner (outdoor unit, indoor unit)
- Audiovisual equipment
- Camera body

### Lineup of RX700 and RX600 Series

<table>
<thead>
<tr>
<th>RX72M</th>
<th>240MHz, 4MB Flash, 1MB SRAM 176/224-pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>RXv3</td>
<td>Double precision FPU Register bank save Trigonometric functions arithmetic unit IEEE1588 EtherCAT slave</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RX72N</th>
<th>240MHz, 4MB Flash, 1MB SRAM 100/144/145/176/224-pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>RXv3</td>
<td>Double precision FPU Register bank save Trigonometric functions arithmetic unit IEEE1588</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RX66N</th>
<th>120MHz, 4MB Flash, 1MB SRAM 100/144/145/176/224-pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>RXv3</td>
<td>Double precision FPU Register bank save</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RX65N/ RX651</th>
<th>120MHz, 2MB Flash, 64KB SRAM 64/100/144/145/178/177-pin</th>
</tr>
</thead>
<tbody>
<tr>
<td>RXv2</td>
<td>Single precision FPU</td>
</tr>
</tbody>
</table>

### Common functions

- Dual bank
- Quad SPI
- Ethernet
- GLCDC
- USB
- Trusted Secure IP
- CAN 12-bit ADC
- SD host I/F
RX72M and RX72N: Flagship Models with Support for a Variety of Industrial Networking Standards

- EtherCAT slave control* and high-precision time synchronization control for multiple industrial motors implemented on a single chip, enabling more compact product design.

- Full 1MB of on-chip SRAM. Enables high speed execution of middleware for TCP/IP, web server, file system, etc., without need for external memory.

- Supports a variety of industrial network protocol stacks in addition to EtherCAT. Flexible support for diversifying protocol requirements.

* EtherCAT slave controller (ESC) available on RX72M only.

Protocol stacks from Renesas and from partner vendors provide coverage for major industrial network standards.

RX66N: Successor to RX65N and RX651 with Enhanced CPU and On-Chip Memory

- The industry’s only MCU to combine 4MB of flash memory and 1MB of SRAM. Ability to implement a broad range of functions without external memory.

- Dual-plane SRAM (512KB + 512KB) configuration, allowing smooth display performance on WVGA (800×480, 8bpp) displays.

- The RXv3 core delivers excellent performance per unit of operating frequency, achieving performance when operating at 120MHz equivalent to that of competing MCUs operating at 200MHz.

RX65N and RX651: A Broad Lineup of Mainstream Models

- Broad lineup with 512KB, 768KB, 1MB, 1.5MB, or 2MB of flash memory and pin counts of 64, 100, 144, 145, 176, or 177 pins.

- Large memory capacity in a 4.5mm-square, 64-pin ultracompact package. Reduces the number of components required in compact IoT devices with limited mounting area.

- High-performance RXv2 core and state-of-the-art 40nm process deliver excellent performance and overwhelmingly superior power efficiency compared with competing MCUs.

All packages (other than 176-pin) are available in flash memory capacities ranging from 512KB to 2MB. (176-pin model is available in 1.5MB and 2MB versions only.)
RX200 SERIES

Features of RX200 Series

- Both low power consumption and high performance
  - 54MHz
  - 0.12mA/MHz operation

- Wide voltage range and external bus
  - 1.8-5.5V
  - 8/16-bit external bus

- Robust security and networking/sensors
  - Trusted secure IP
  - Bluetooth
  - Industrial sensor

- Various solutions
  - Functional safety
  - HMI
  - Capacitive touch

Main Applications of RX200 Series

Consumer (battery drive)
- Digital cameras
- Gadgets

Healthcare
- Wearable devices
- Blood glucose meter

Industrial
- Power meters
- Pressure, temperature, and flow volume meters
  - Inverters
  - Air conditioners

Home appliances
- Air conditioners
- Refrigerators
- Washing machines

Lineup of RX200 Series

<table>
<thead>
<tr>
<th>RXv2</th>
<th>Single precision FPU</th>
<th>CAN</th>
<th>USB</th>
<th>SDHI</th>
<th>Capacitive touch</th>
<th>Security</th>
<th>Bluetooth</th>
</tr>
</thead>
<tbody>
<tr>
<td>RX23W</td>
<td>54MHz, 512KB Flash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RX23E-A</td>
<td>32MHz, 256KB Flash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High-precision AFE</td>
</tr>
<tr>
<td>RX231</td>
<td>54MHz, 512KB Flash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RX230</td>
<td>54MHz, 256KB Flash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Excellent Balance of Low Power Consumption and High Performance

Excellent Balance of Low Power Consumption (0.12 mA/MHz) and High Performance (4.33 CoreMark/MHz)

Peripheral Functions for Home Electronics, Industrial, and IoT Applications

Equipped with functions suitable for capacitive touch, communication, and motor control applications. In addition to support for control and manipulation, implementation of IoT capabilities is simplified.
RX23W Concept and Platform

High Performance CPU, Security, and Wireless Communications on a Single Chip

www.renesas.com/rxble

High performance RXv2 core capable of controlling multiple systems, Trusted Secure IP implementing robust security functions, and Bluetooth 5.0 Low Energy with enhanced connectivity functions, all on a single chip.

High Performance RXv2 Core + Trusted Secure IP + Bluetooth 5.0 Low Energy Full Function = Implemented on a single chip

Application development platform

BLE software

Profiles GATT DB

BLE protocol stack

BLE Driver

Hardware

GATTBrowser

Smartphone app to communicate with RX23W

Also displays definition information exclusive to Renesas.

Evaluation of RF Performance: Certified Under Radio Law

Target Board

Includes on-chip debugger and provides access to all MCU signal pins.

Bluetooth Trial Tool Suite

Evaluation tool to control RX23W

RX23W Concept and Target

High-Precision AFE and High-Performance MCU on a Single Chip

- High-precision AFE ideal for industrial applications such as temperature and distortion measurement.
- High-performance MCU suitable for digital signal processing.
- Rich communication interface provides more freedom in system and board design.

RX23E-A Concept and Target

For Sensor Devices Demanding High-Precision Analog Characteristics

Sensor devices requiring an ADC with low noise, low drift, and high effective resolution are the target.

High-Precision AFE and High-Performance MCU on a Single Chip

- High-precision AFE ideal for industrial applications such as temperature and distortion measurement.
- High-performance MCU suitable for digital signal processing.
- Rich communication interface provides more freedom in system and board design.

Application Example (Force Sensor)

The amount and direction of force are calculated from data input from a distortion gauge and sent to the control system.
RX100 SERIES

Features of RX100 Series

- Power consumption among the lowest in the industry
  - 32MHz
  - 0.35μA standby
- 5V power supply support
- Segment LCD support
- Superior cost/performance ratio
  - Low-pin-count/
  - small-ROM-capacity versions
  - Integration of peripheral ICs
- Various solutions
  - Functional safety
  - Capacitive touch

Main Applications of RX100 Series

<table>
<thead>
<tr>
<th>Consumer (battery drive)</th>
<th>Healthcare</th>
<th>Home appliances</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor hubs (smartphones, game consoles, PCs, tablets), digital cameras, digital camcorders</td>
<td>Healthcare devices, wearable devices</td>
<td>Cooking appliances, water heaters</td>
<td>Power meters, detectors (smoke detectors, etc.), pressure gauges, thermostats</td>
</tr>
</tbody>
</table>

Lineup of RX100 Series

**RX130**
- 32MHz, 512KB Flash

<table>
<thead>
<tr>
<th>RXv1</th>
<th>12-bit A/D</th>
<th>Capacitive touch</th>
<th>5V</th>
</tr>
</thead>
</table>

**RX113**
- 32MHz, 512KB Flash

<table>
<thead>
<tr>
<th>RXv1</th>
<th>12-bit A/D</th>
<th>USB</th>
<th>Segment LCD</th>
<th>Capacitive touch</th>
</tr>
</thead>
</table>

**RX111**
- 32MHz, 512KB Flash

<table>
<thead>
<tr>
<th>RXv1</th>
<th>12-bit A/D</th>
<th>USB</th>
</tr>
</thead>
</table>

**RX110**
- 32MHz, 128KB Flash

<table>
<thead>
<tr>
<th>RXv1</th>
<th>12-bit A/D</th>
</tr>
</thead>
</table>

Power consumption among the lowest in the industry

Power consumption among the lowest in the industry

Superior cost/performance ratio

Various solutions

- 5V power supply support
- Segment LCD support

Main Applications of RX100 Series

Consumer (battery drive)
- Sensor hubs (smartphones, game consoles, PCs, tablets), digital cameras, digital camcorders

Healthcare
- Healthcare devices, wearable devices

Home appliances
- Cooking appliances, water heaters

Industrial
- Power meters, detectors (smoke detectors, etc.), pressure gauges, thermostats

Lineup of RX100 Series

**RX130**
- 32MHz, 512KB Flash

<table>
<thead>
<tr>
<th>RXv1</th>
<th>12-bit A/D</th>
<th>Capacitive touch</th>
<th>5V</th>
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**RX113**
- 32MHz, 512KB Flash

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<thead>
<tr>
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<th>12-bit A/D</th>
<th>USB</th>
<th>Segment LCD</th>
<th>Capacitive touch</th>
</tr>
</thead>
</table>

**RX111**
- 32MHz, 512KB Flash

<table>
<thead>
<tr>
<th>RXv1</th>
<th>12-bit A/D</th>
<th>USB</th>
</tr>
</thead>
</table>

**RX110**
- 32MHz, 128KB Flash

<table>
<thead>
<tr>
<th>RXv1</th>
<th>12-bit A/D</th>
</tr>
</thead>
</table>

Functional safety

Capacitive touch
Power Consumption Among the Lowest in the Industry

Ultralow current consumption during standby and during operation
- Standby current: 0.35μA
- Normal operation current: 0.1mA/MHz
- Recovery time: 4.8μs

Low-Power Timer (LPT) for Reduced Standby Current During Intermittent Operation
- LPT generates wakeup events to recover from standby mode.
- Current can be transitioned to standby state in standby periods during intermittent operation.

Comparison of Current Consumption in RX Family

Less current loss during recovery

Comparison with the Competitors

- Performance reduced to cut power consumption and lower costs.
- Lineup includes low-cost products with low pin count and small ROM capacity.
- Integration of peripheral functions reduces BOM cost.

Essential Peripheral Functions for Measuring Equipment and Household Appliances
- Integrates peripheral functions suitable for measuring equipment and household appliances, such as capacitive touch/LCD, communication, and 12-bit ADC.
- Support for applications ranging from system control in household appliances or industrial equipment to user interfaces for wet environments.

Superior Cost/Performance Ratio
- Functions and Lineup Selected for Enhanced Flexibility

Functions and Lineup Selected for Enhanced Flexibility

- 5V interface
- 12-bit ADC/DAC
- LCD / capacitive touch
- USB
- ROM 8KB to 512KB
- 4mm square package
- 36-pin to 100-pin
- Package with 0.8mm pin pitch

Notes:
1. Current value during all-peripheral operation at 32MHz on the RX130.
2. Current value including LPT operating current (0.37μA) on the RX130.
RX FOR MOTOR CONTROL (RX-T)

Features of RX for Motor Control (RX-T)

- **Broad lineup**
  - 32MHz to 200MHz
  - 1 motor to 4 motors
  - Highly compatible pin assignments

- **5V power supply support**
  - External bus

- **Analog circuit to extract full performance potential**
  - Three-channel simultaneous sample-and-hold circuit
  - PGA
  - Comparator

- **Specialized motor control functions**
  - Three-phase complementary PWM output
  - Timer output emergency stop
  - Trigonometric function unit

Main Applications of RX for Motor Control (RX-T)

<table>
<thead>
<tr>
<th>Robots, Machine tools</th>
<th>General-purpose inverters</th>
<th>Meters</th>
<th>Building automation</th>
<th>Office Automation</th>
<th>Home appliances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Copiers</td>
<td>Printers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Air conditioners</td>
<td>Refrigerators</td>
</tr>
</tbody>
</table>

Lineup of RX for Motor Control (RX-T)

**RX72T**
- 200MHz, 1MB Flash
- **RXv3**
  - Single precision FPU
  - Motors 3 to 4
  - Pseudo-differential PGA
  - Register bank save
  - Trigonometric functions arithmetic unit
  - CAN
  - USB
  - Security

**RX66T**
- 160MHz, 1MB Flash
- **RXv3**
  - Single precision FPU
  - Motors 3 to 4
  - Pseudo-differential PGA
  - CAN
  - USB
  - Security

**RX24U**
- 80MHz, 512KB Flash
- **RXv2**
  - Single precision FPU
  - Motors 2 to 3
  - Pseudo-differential PGA
  - CAN

**RX24T**
- 80MHz, 512KB Flash
- **RXv2**
  - Single precision FPU
  - Motors 2 to 3
  - PGA
  - CAN

**RX23T**
- 40MHz, 128KB Flash
- **RXv2**
  - Single precision FPU
  - Motors 1
  - CAN

**RX13T**
- 32MHz, 128KB Flash
- **RXv1**
  - Single precision FPU
  - Motors 1
  - PGA
RX for Motor Control (RX-T) Product Lineup

Allocation of Resources Specially for Motor Control

- Pin assignments that simplify design and layout
  - Six pins for three-phase complementary PWM output arranged side-by-side.
  - A/D converter input pins (with simultaneous three-channel sample-and-hold support) arranged side-by-side.
- Consistent approach to motor control–related pin assignments across all RX devices designed for motor control

Application Example Controlling Multiple Motors with a Single Chip

1. Control 3 inverters in a single chip
   - GPTW timer for multiple 3-phase complementary PWM outputs
   - MTU3d+GPTW available
2. Enable 3-shunt x 2 current detection at the same time
   - Can control 3-shunt inverters with 2 GPTW outputs
3. Less external parts required
   - Including reset circuit, E2PROM, op-amp, comparator
4. Designed to improve safety
   - Comparator’s 6ch for PWM forced cutoff
   - Output protection circuit dedicated to GPTW
5. Support function safety
   - Functions to support IEC60730 Safety Standard for Household Appliances class B (Fail-safe)
     - System fail-safe with less software load

Target Application:
- High-end air conditioner / washing machine,
- general-purpose inverter, robot, etc.
## RX FAMILY MOTOR CONTROL

### Motor Types and Recommended Microcontrollers

<table>
<thead>
<tr>
<th>Motors</th>
<th>Consumer/office equipment</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air conditioners</td>
<td>Washing machines</td>
<td>Refrigerators</td>
</tr>
<tr>
<td>Pumps</td>
<td>Fans</td>
<td>Surveillance cameras</td>
</tr>
<tr>
<td>IM</td>
<td>IM</td>
<td>IM</td>
</tr>
<tr>
<td>BLDC</td>
<td>BLDC</td>
<td>BLDC</td>
</tr>
<tr>
<td>RX200</td>
<td>RX100</td>
<td>RX200</td>
</tr>
<tr>
<td>RL78</td>
<td>RX100</td>
<td>RX100</td>
</tr>
<tr>
<td>RX200</td>
<td>RX200</td>
<td>RX200</td>
</tr>
<tr>
<td>RX600</td>
<td>RX600</td>
<td>RX600</td>
</tr>
<tr>
<td>RX700</td>
<td>RX700</td>
<td>RX700</td>
</tr>
<tr>
<td>R371</td>
<td>R371</td>
<td>R371</td>
</tr>
</tbody>
</table>

**Symbols:**
- BLDC: Brushless DC motor
- IM: AC induction motor
- STM: Stepping motor

---

### Motor Types, Control Methods, and Recommended RX Series

<table>
<thead>
<tr>
<th>Motor type</th>
<th>Control method</th>
<th>Necessary functions</th>
<th>Performance required by application and recommended RX microcontroller</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brushless DC motor</strong></td>
<td>Vector control (180-degree conducting control)</td>
<td>PWM × 6, dead time generation, POE, A/D converter (PWM link)</td>
<td>Compact industrial motors</td>
</tr>
<tr>
<td></td>
<td>Square wave control (120-degree conducting control)</td>
<td>PWM × 6, A/D converter</td>
<td>Refrigerators, fans, compact robots</td>
</tr>
<tr>
<td><strong>AC induction motor</strong></td>
<td>Vector control</td>
<td>PWM × 6, dead time generation, POE, A/D converter (PWM link)</td>
<td>Industrial pumps</td>
</tr>
<tr>
<td></td>
<td>V/F control</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stepping motor</strong></td>
<td>Pulse output</td>
<td>Port control or PWM control</td>
<td>Printers/multifunction units, surveillance cameras</td>
</tr>
<tr>
<td></td>
<td>Vector control (resolver)</td>
<td>PWM × 4, dead time generation, POE, A/D converter</td>
<td>Compact robots, carrier machine, textile machine, printers/multifunction units</td>
</tr>
</tbody>
</table>

**Note:**
- RX FAMILY MOTOR CONTROL
- BLDC: Brushless DC motor, IM: AC induction motor, STM: Stepping motor
**Motor Control by RX**

RX delivers high-speed arithmetic performance alongside MTU2 or MTU3, GPT timer, 12-bit A/D converter, and POE functions to simplify the process of implementing motor control.

### High-speed arithmetic operations (RX core)
- High-speed vector calculations
  - High-speed processing at 240MHz
  - FPU for high-speed floating point operations
  - TFU for high-speed trigonometric functions
  - Single-precision floating point
  - sin, cos, arctan, sqrt (x^2+y^2)
  - Fast/fixed cycle operation

### Waveform control/feedback control (MTU2 and MTU3, GPT, etc.)
- PWM waveform output
  - PWM output with 0 to 100% duty
  - 3-phase complementary PWM waveform output
  - Automatic insertion of dead time
  - A/D activation at user-defined timing for 1-shunt current detection

### Feedback control
- Acquisition of feedback information (position/rotation rate) from encoder

### Disable control output signals (POE)
- Disable output signals for the MTU and the GPT without using software.
- Forcibly disable complementary PWM output and realize fail-safe

### Feedback control (high-speed 12-bit A/D converter)
- Acquisition of feedback information using motor current
  - High-speed (1.0μs) 12-bit A/D converter
  - Simultaneous sampling of three tracks for 3-shunt current detection
  - Reduce BOM by using built-in comparator and PGA (some products)

### Examples of Motor Control Functions Provided by RX

<table>
<thead>
<tr>
<th>Description</th>
<th>For motor control</th>
<th>For General-Purpose, Sensor, and Network Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waveform output control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PWM output with 0 to 100% duty</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Synchronous output on multiple channels</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Chopping or level waveform output in AC synchronous motor drive mode</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>3-phase complementary PWM output with dead time (left-right symmetric dead time amplitude)</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>3-phase complementary PWM output with dead time (left-right asymmetric dead time amplitude)</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>High-resolution PWM output</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Feedback detection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase counting mode</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>High-speed 12-bit A/D converter using sequential conversion</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>A/D converter activation requests at user-defined timing (for 1-shunt current detection)</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>12-bit A/D converter double-trigger function (storage of data from two conversions in separate registers)</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>12-bit A/D converter with simultaneous sampling of three tracks</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Acceleration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compare match and A/D conversion start request skipping function</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>FPU for high-speed arithmetic operations</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Double buffering function (provision of two register buffer stages for compare match operation)</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Safety functions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error detection and PWM output auto-cutoff using port output enable</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compare match/input capture</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>5V power supply</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>32-bit counter support</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Trigonometric functions arithmetic unit</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>
Renesas supports all stages of the development of RX applications by supplying integrated development environments, real-time OSes, middleware, and programming tools that dramatically enhance the development process. Renesas integrated development environments enable you to accomplish coding, building, and debugging tasks quickly and easily, helping to reduce system development time.

### Introduction

- **Free evaluation versions**
  - Free evaluation versions of tools, sample software, application notes
- **Low price.**
  - Target board with emulator
- **Renesas Cloud Kit for testing AWS**
- **A growing selection of starter kits you can start using immediately**

### Development

Renesas offers two integrated development environments to match the customer’s system.

#### Integrated development environment e² studio

- Provides a large number of functions. Development environment based on Eclipse. Supports compilers from IAR Systems and the GNU Project in addition to Renesas. Now supports FreeRTOS.

#### Integrated development environment CS+

- A stable, proprietary Renesas development environment initially developed nearly a decade ago. Supports Renesas compiler. Will continue to support Renesas devices in the years ahead.

### Build

- **Renesas C/C++ Compiler Package for RX Family (CC-RX)**
  - (node locked and floating license versions)
  - Compiler from IAR Systems
  - GNU compiler

### Coding (OS)

- **Embedded OS with the best established track record in Japan and conformant with μTORN standard (RI600V4 and RI600PX)**
  - FreeRTOS, which supports connecting to AWS

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**URLs:**
- Free Evaluation Versions: [https://www.renesas.com/tool_evaluation](https://www.renesas.com/tool_evaluation)
- e² studio: [https://www.renesas.com/e2studio](https://www.renesas.com/e2studio)
- CC-RX Compiler: [https://www.renesas.com/rx_c](https://www.renesas.com/rx_c)
- CS+: [https://www.renesas.com/cs+](https://www.renesas.com/cs+)
- Real-time OS/Middleware: [https://www.renesas.com/mw](https://www.renesas.com/mw)
Software tools that make development even faster

[Smart configurator]
Tool that automatically generates device drivers

[On-chip debugging emulators]
Choose from the low-cost E2 Emulator Lite; the E2 Emulator, which lets you measure current consumption right on the emulator; and the E20 Emulator, with advanced functions.

Renesas Flash Programmer
flash memory programming software

[Quick and Effective tool solutions]
Tools suitable for a variety of applications

[ Middleware]
Support for communication environments, security, image processing, and signal processing

[QE for Current Consumption]
Using just the E2 Emulator you can measure current consumption and detect abnormal current flows.

[QE for Capacitive Touch]
Supports embedded systems employing capacitive touch sensors. Easily implement touch and slider operations in applications.

Smart Configurator
https://www.renesas.com/smart-configurator

QE
https://www.renesas.com/qe

RX Driver Package
https://www.renesas.com/rdp

OCD Emulator
https://www.renesas.com/oecd

PG-FP6
https://www.renesas.com/pg-fp6
RX FAMILY DEVELOPMENT TOOLS

Software and Support Tools You Can Use Immediately with the RX Family

Available software packages include board-specific programs, peripheral function drivers, middleware, and documents and application examples illustrating usage procedures. Users can also use Smart Configurator to easily incorporate the above Renesas software components into their own projects, automatically generate I/O drivers for MCU peripheral functions, and more. This makes it possible to boost the efficiency of the development process overall.

### Searching for Information in Sample Code or Manuals
From within the integrated development environment you can search for and display sample code, middleware, and Renesas product information on the web, as well as downloading and installing sample code.

### Making Complex Pin Settings and Embedding Drivers
You can add and verify middleware and drivers for USB, file system, and other functions from within the integrated development environment. You can also make complex and time-consuming pin settings from the built-in GUI, and when conflicts are detected you can resolve them with a single click.

### Assistance for Coding and Debugging
From within the integrated development environment you can reference register information and perform coding and debugging. The development knowhow that allows you to begin development of a variety of applications with a few simple settings can significantly reduce overall development time.

### RX Family Middleware Driver Package (RX Driver Package)

The RX Driver Package is a software package that enables use of basic functions such as MCU visualization, flash self-programming, timer control, UART communication, and A/D conversion, as well as applied functions such as USB and Ethernet.

- Makes it possible to start using RX MCU peripheral functions right away, greatly reducing the time customers must spend considering prototypes.
- Applications that make use of Firmware Integration Technology (FIT) can be reused on MCUs across the RX Family. This significantly reduces the software development cost burden for customers extending their product lines.

**URL** https://www.renesas.com/rdp

### RX Driver Package

<table>
<thead>
<tr>
<th>Middleware</th>
<th>Socket API</th>
<th>FTP Server</th>
<th>DNS Client</th>
<th>QSPI/SCI Flash memory</th>
<th>ADPCM (M3S-S2_Tiny)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>M3S-T4-Tiny I/F Conversion Module</td>
<td>File Driver Module for Server</td>
<td>Memory Driver I/F Module</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Communication**: SCI, SCIF, Simple I2C, RTIC, Ethernet, EPTPC, EtherCAT, USB, RSPI
- **Device Driver**: QSPI, IrDA, CAN, CANopen, BLE
- **Analog**: DAC, S12AD, Unique ID, Unique ID
- **System**: Sound / Audio, SRC, SSI, LCDC, LCDC, Image Capture, PDC, Flash
- **Timer**: LVDT, VBATT, IR, GPIO, MPC, RTC, LPC, HMI
- **Other**: MTU, CMT, CMTW, CMT, LPT, Capacitive Touch, BYTEQ, LONGQ

**Board Support Package**

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**Renesas Middleware Usage Examples**

### Medical and Healthcare Devices
TCP/IP, voice recording and playback, FAT file system, SPI serial EEPROM, I2C serial EEPROM, SD memory card driver, drivers for various memory types, etc.

### Industrial Devices
TCP/IP, voice recording and playback, DSP, FAT file system, SPI serial EEPROM, I2C serial EEPROM, SD memory card driver, drivers for various memory types, etc.

### Information Terminals
Graphics, FAT file system, SD memory card driver, etc.

### Digital AV
AAC encoder/decoder, aacPlus decoder, MP3 encoder/decoder, FAT file system, SD memory card driver, encryption, etc.

### Home Networks
TCP/IP, HTTP server, FTP server, SMTP/POP3, DHCP client, file system, encryption, security, etc.

### Security Systems
Encryption, security, graphics, audio, communication, file system, etc.
**Convenient Development Support Tools**

**Smart Configurator**
Smart Configurator provides functionality that makes it easy for users to incorporate Renesas drivers into their projects. The following functions support driver integration:

- **Importing sample code (FIT)**
  Download and import sample code, and use it in combination with generated driver code.

- **Generating driver code**
  Enter peripheral function settings via the GUI, and driver code is generated automatically according to the settings.

- **Checking for pin conflicts**
  Check in real time for conflicts among pins used by the driver code and FIT modules.

**Plenty of Convenient Functions to Assist Application Development**

**QE Development Support Tools for Many Application Types**

“I’ve imported this application but it doesn’t work! What should I do?” Has this ever happened to you? QE development support tools add development knowhow (functionality) to applications within the integrated development environment, helping to minimize the application development workload.

**QE for BLE Development Support Tool for Bluetooth® Low Energy Applications**

This development support tool is designed for embedded systems employing Bluetooth® Low Energy. It is compatible with the e² studio integrated development environment and allows users to try out communication functions based on the Bluetooth® specification without delay. Devices using BLE for communication must use the same profile, but QE for BLE makes it a simple matter to define the correct profile.

**QE for Display Development Support Tool for Display Applications**

Using QE for Display for embedded system development utilizing the image display functions of the RX Family’s graphic LCD controller (GLCDC) greatly simplifies initial screen calibration of the display, reducing the time required for development.

**QE for Capacitive Touch Development Support Tool for Capacitive Touch Sensor Applications**

Using QE for Capacitive Touch in the development of embedded systems that utilize the capacitive touch sensor functions of RX Family MCUs simplifies making initial touch interface settings and tuning sensitivity, reducing the time required for development.
## RX FAMILY PACKAGE LINEUP

<table>
<thead>
<tr>
<th>Pin-type:</th>
<th>Size:</th>
<th>Pitch:</th>
<th>Thickness:</th>
<th>Group:</th>
</tr>
</thead>
<tbody>
<tr>
<td>32-LQFP</td>
<td>7 x 7 mm</td>
<td>0.80 mm</td>
<td>1.70 mm</td>
<td>RX13T</td>
</tr>
<tr>
<td>36-WFLGA</td>
<td>4 x 4 mm</td>
<td>0.50 mm</td>
<td>0.80 mm</td>
<td>RX111, 110</td>
</tr>
<tr>
<td>40-HWQFN</td>
<td>6 x 6 mm</td>
<td>0.50 mm</td>
<td>0.80 mm</td>
<td>RX23E-A, 111, 110</td>
</tr>
<tr>
<td>48-HWQFN</td>
<td>7 x 7 mm</td>
<td>0.50 mm</td>
<td>0.80 mm</td>
<td>RX231, 230, 130, 111, 110</td>
</tr>
<tr>
<td>48-LQFP</td>
<td>7 x 7 mm</td>
<td>0.50 mm</td>
<td>1.70 mm</td>
<td>RX63T, 631, 23E-A, 231, 230, 220, 210, 131, 130, 111, 110</td>
</tr>
<tr>
<td>52-LQFP</td>
<td>10 x 10 mm</td>
<td>0.65 mm</td>
<td>1.70 mm</td>
<td>RX23T</td>
</tr>
<tr>
<td>56-HVOFN</td>
<td>7 x 7 mm</td>
<td>0.40 mm</td>
<td>0.90 mm</td>
<td>RX23W</td>
</tr>
<tr>
<td>64-HWQFN</td>
<td>9 x 9 mm</td>
<td>0.50 mm</td>
<td>0.80 mm</td>
<td>RX231, 230</td>
</tr>
<tr>
<td>64-LQFP</td>
<td>10 x 10 mm</td>
<td>0.50 mm</td>
<td>1.70 mm</td>
<td>RX66T, 630, 24T, 210</td>
</tr>
<tr>
<td>64-TFBGA</td>
<td>4.5 x 4.5 mm</td>
<td>0.50 mm</td>
<td>1.20 mm</td>
<td>RX651</td>
</tr>
<tr>
<td>64-TFLGA</td>
<td>8 x 8 mm</td>
<td>0.50 mm</td>
<td>1.05 mm</td>
<td>RX631</td>
</tr>
<tr>
<td>64-TFBGA</td>
<td>5.5 x 5.5 mm</td>
<td>0.50 mm</td>
<td>1.20 mm</td>
<td>RX23W</td>
</tr>
<tr>
<td>64-TFLGA</td>
<td>7 x 7 mm</td>
<td>0.50 mm</td>
<td>1.05 mm</td>
<td>RX631</td>
</tr>
<tr>
<td>80-LQFP</td>
<td>12 x 12 mm</td>
<td>0.50 mm</td>
<td>1.70 mm</td>
<td>RX66T, 630, 24T, 21A, 210, 130</td>
</tr>
<tr>
<td>85-TFBGA</td>
<td>7 x 7 mm</td>
<td>0.50 mm</td>
<td>1.20 mm</td>
<td>RX630, 231, 230, 210</td>
</tr>
<tr>
<td>85-TFLGA</td>
<td>7 x 7 mm</td>
<td>0.50 mm</td>
<td>1.05 mm</td>
<td>RX630, 231, 230, 210</td>
</tr>
<tr>
<td>100-LQFP</td>
<td>14 x 14 mm</td>
<td>0.50 mm</td>
<td>1.70 mm</td>
<td>RX72T, 72N, 71M, 66T, 66N, 65N, 651, 64M, 63T, 63N, 631, 630, 62T, 62N, 62G, 621, 24U, 24T, 231, 230, 220, 21A, 210, 130, 131, 113</td>
</tr>
<tr>
<td>100-TFLGA</td>
<td>5.5 x 5.5 mm</td>
<td>0.50 mm</td>
<td>1.05 mm</td>
<td>RX630, 231, 230, 210</td>
</tr>
<tr>
<td>112-LQFP</td>
<td>20 x 20 mm</td>
<td>0.50 mm</td>
<td>1.70 mm</td>
<td>RX66T, 63T, 62T, 62G</td>
</tr>
<tr>
<td>120-LQFP</td>
<td>16 x 16 mm</td>
<td>0.50 mm</td>
<td>1.70 mm</td>
<td>RX63T</td>
</tr>
<tr>
<td>144-LQFP</td>
<td>20 x 20 mm</td>
<td>0.50 mm</td>
<td>1.70 mm</td>
<td>RX72T, 72N, 71M, 66T, 66N, 65N, 651, 64M, 63T, 63N, 631, 630, 62N, 621, 24U, 24T, 231, 230, 220, 21A, 210, 130, 131</td>
</tr>
<tr>
<td>145-TFLGA</td>
<td>9 x 9 mm</td>
<td>0.50 mm</td>
<td>1.20 mm</td>
<td>RX23N, 621</td>
</tr>
<tr>
<td>145-TFLGA</td>
<td>13 x 13 mm</td>
<td>0.80 mm</td>
<td>1.40 mm</td>
<td>RX72M, 72N, 71M, 66N, 65N, 651, 64M, 63N, 631, 630, 62N, 621, 610</td>
</tr>
<tr>
<td>176-LFBGA</td>
<td>24 x 24 mm</td>
<td>0.50 mm</td>
<td>1.70 mm</td>
<td>RX72M, 72N, 71M, 66N, 65N, 651, 64M, 63N, 631, 630, 62N, 621, 610</td>
</tr>
<tr>
<td>177-TFLGA</td>
<td>0 x 0 mm</td>
<td>0.50 mm</td>
<td>1.05 mm</td>
<td>RX71M, 65N, 651, 64M, 63N, 631, 630</td>
</tr>
<tr>
<td>224-LFBGA</td>
<td>13 x 13 mm</td>
<td>0.80 mm</td>
<td>1.40 mm</td>
<td>RX72M, 72N, 66N</td>
</tr>
</tbody>
</table>
Example of product information for RX72M (176-pin), product No. R5F572MNHGFC#V0

This guide lists the values for individual product numbers. For information on the actual product lineup, refer to the relevant user’s manual.

Note: 1. This information is different for each RX group. Refer to the relevant user’s manual for details.
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