

Application Note

Using Renesas GreenFET Load Switches in Super Capacitor Applications

AN-CM-246

Abstract

This application note describes some common problems caused by powering up on high capacitive loads. Using GreenFET Load Switches it is easy to power up from very small capacitance to relatively high value super capacitors.

Using Renesas GreenFET Load Switches in Super Capacitor Applications

Contents

Abstract	1
Contents	2
Figures.....	2
1 Terms and Definitions.....	3
2 References	3
3 Introduction.....	4
4 Design Description.....	5
5 Start-up Inrush Current Considerations	6
6 Capacitive Load Operation.....	7
7 Conclusion	9
Revision History	9

Figures

Figure 1: Two Charged Conductive Plates Separated with Dielectric Layer	4
Figure 2: A Supercapacitor Structure and Charge Distribution	5
Figure 3: Typical Application Diagram of SLG59M1717V	5
Figure 4: SLG59M1717V's Equivalent Slew-rate Control Loop Circuit.....	6
Figure 5: Typical Power up Operation Waveform for $V_{DD} = V_{IN} = 4\text{ V}$, $R_{SET} = 40\text{ k}\Omega$, $C_{SLEW} = 10\text{ nF}$, $R_{LOAD} = 100\ \Omega$, $C_{LOAD} = 10\ \mu\text{F}$	7
Figure 6: Active Current Limit and Thermal Protection Operation During Power Up on High Capacitive Load Caused by Improper GreenFET Load Switch Slew Rate Settings for $V_{DD} = V_{IN} = 4\text{ V}$, $I_{ACL} = 5.7\text{ A}$, $R_{SET} = 40\text{ k}\Omega$, $C_{SLEW} = 10\text{ nF}$, $C_{LOAD} = 0.66\text{ F}$, $R_{LOAD} = 100\ \Omega$	8
Figure 7: Typical Power Up for High Capacitive Load with Proper GreenFET Load Switch Slew Rate Settings for $V_{DD} = V_{IN} = 4\text{ V}$, $I_{ACL} = 5.7\text{ A}$, $R_{SET} = 40\text{ k}\Omega$, $C_{SLEW} = 2\ \mu\text{F}$, $C_{LOAD} = 0.66\text{ F}$, $R_{LOAD} = 100\ \Omega$	8

Using Renesas GreenFET Load Switches in Super Capacitor Applications

1 Terms and Definitions

ACL	Active Current Limit
IC	Integrated Circuit
PCB	Printed Circuit Board

2 References

- [1] SLG59M1717V, Datasheet, Renesas Electronics
- [2] AN-1068 GreenFET and High Voltage GreenFET Load Switch Basics, Application Note, Renesas Electronics

Author: Andrii Hrypa and Petro Zeykan

Using Renesas GreenFET Load Switches in Super Capacitor Applications

3 Introduction

Capacitance is the ability of a system to store an electric charge (Figure 1). Capacitance value is the ratio of the charge accumulated on conductive plates to the applied voltage:

$$C = \frac{Q}{V}$$

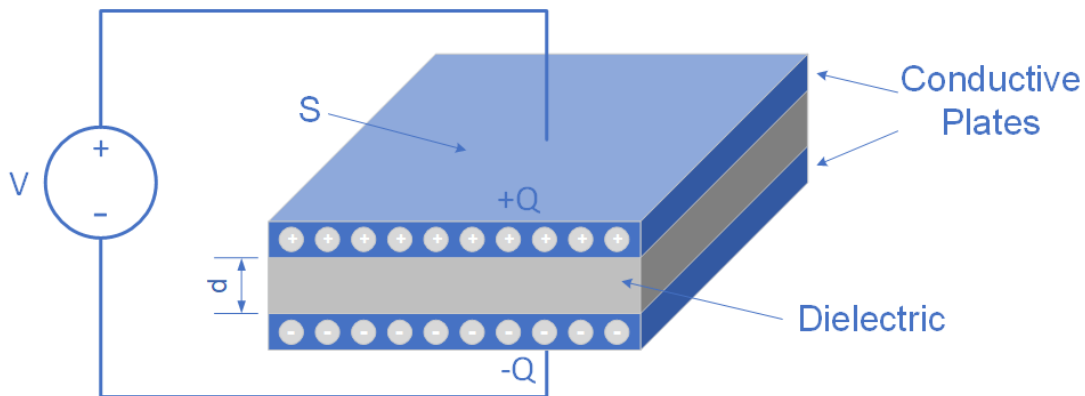


Figure 1: Two Charged Conductive Plates Separated with Dielectric Layer

The capacitance of a parallel plate system is proportional to the plate area S and inversely proportional to the distance d between these two conductive plates.

$$C = \frac{\epsilon S}{d} \quad (1)$$

where

ϵ - an absolute permittivity of the dielectric material;

S - a square of conductive plate;

d - a distance between two conductive plates.

A component designed to store electric charge is called capacitor. In electronic circuits, capacitors can be used in a variety of different ways: coupling and decoupling effects, smoothing output signal of rectifiers, as a timing element, etc.

A capacitor which can store a great amount of charge is called a supercapacitor or ultracapacitor. Supercapacitor's electrodes are made of the materials that have a high surface area. This allows to hold much more charge without increasing capacitor's size.

Supercapacitors have an electrolyte inside and when the electrodes are charged, the electrolyte polarizes according to the charge of the electrodes (Figure 2). This charge separation creates two oppositely charged layers. Such system behaves like two conventional capacitors attached in series. These capacitors have plate separation distances that are a few nanometers thick.

Using Renesas GreenFET Load Switches in Super Capacitor Applications

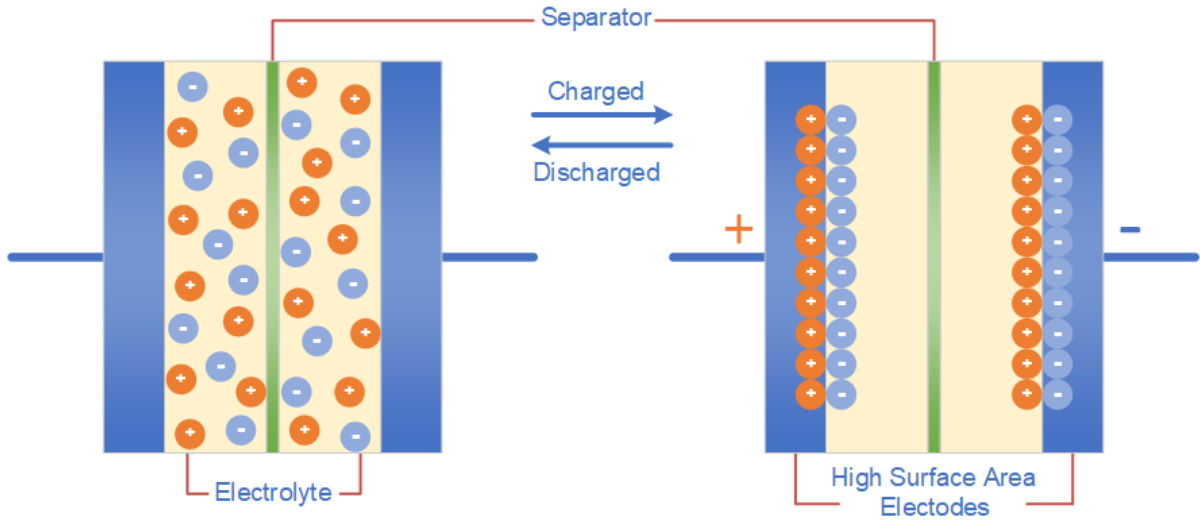


Figure 2: A Supercapacitor Structure and Charge Distribution

The combination of the increased surface area and the small plate separation distance increases the capacitance and the energy stored in the supercapacitor.

4 Design Description

In this application note, we will describe how to apply nFET SLG59M1717V load switch to power up into super-capacitor or very high capacitive loads. To implement a very large capacitive load, (3) 5 V, 0.22 F supercapacitors were connected in parallel. The SLG59M1717V is a high-performance, 4 mΩ, 5 A single-channel, feature-rich nFET load switch designed for all 0.8 V to 5.5 V power rail applications. In addition to its world-class RDS_{ON}, the SLG59M1717V incorporates two-stage overcurrent protection: (1) resistor-adjustable Active Current Limit and (2) a fixed 1.6 A Short-circuit Current Limit.

A typical connection of SLG59M1717V in capacitive/resistive load applications is illustrated in Figure 3.

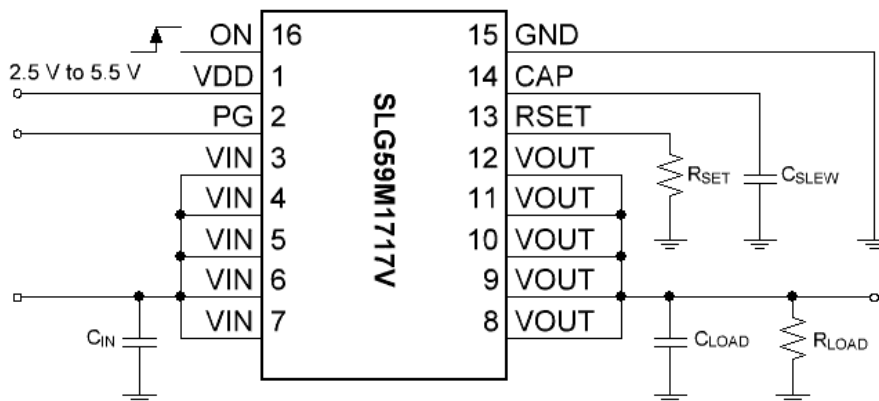


Figure 3: Typical Application Diagram of SLG59M1717V

Using Renesas GreenFET Load Switches in Super Capacitor Applications

5 Start-up Inrush Current Considerations

When a voltage is applied to a discharged (or an uncharged) capacitor, a large initial current may flow through a GreenFET load switch. This current is called inrush current and can be calculated by equation below:

$$\text{Inrush Current, } I = C \frac{dV}{dt}$$

where

C - is the total load capacitance;

$\frac{dV}{dt}$ - the load switch V_{OUT} slew rate during voltage ramp up.

To reduce inrush current for a given load capacitance, it is necessary to decrease the V_{OUT} slew rate of the load switch. An equivalent circuit of the SLG59M1717V's slew rate control loop with capacitors at its V_{IN} and V_{OUT} pins is shown in Figure 4:

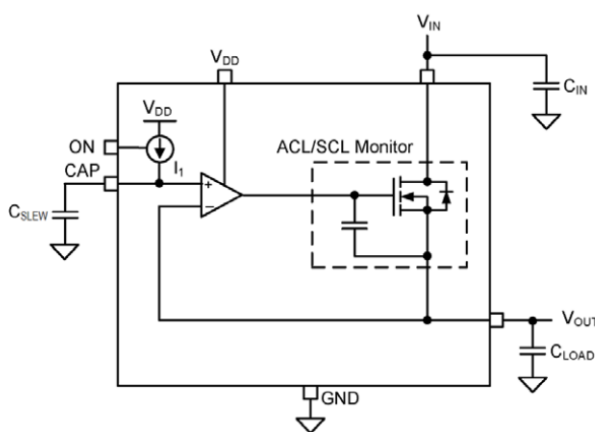


Figure 4: SLG59M1717V's Equivalent Slew-rate Control Loop Circuit

For a desired $V_{OUT(SR)}$, a corresponding C_{SLEW} value is selected. At the V_{OUT} pin and with $ON = LOW$, the internal FET is OFF, V_{OUT} is initially at 0 V, and there is no stored charge on C_{LOAD} . When a low-to-high transition is applied to the IC's ON pin, an internal current source (I_1) is enabled which, in turn, charges the external slew rate capacitor, C_{SLEW} . The SLG59M1717V's internal micropower op amp sets the circuit's $V_{OUT(SR)}$ based on the slew rate of the nodal voltage at its non-inverting pin (the voltage at the CAP pin).

Using Renesas GreenFET Load Switches in Super Capacitor Applications

6 Capacitive Load Operation

In Figure 5, a typical SLG59M1717's power up behavior for resistive and capacitive load is illustrated. As can be observed, output voltage and current through the GreenFET load switch are changing linearly.

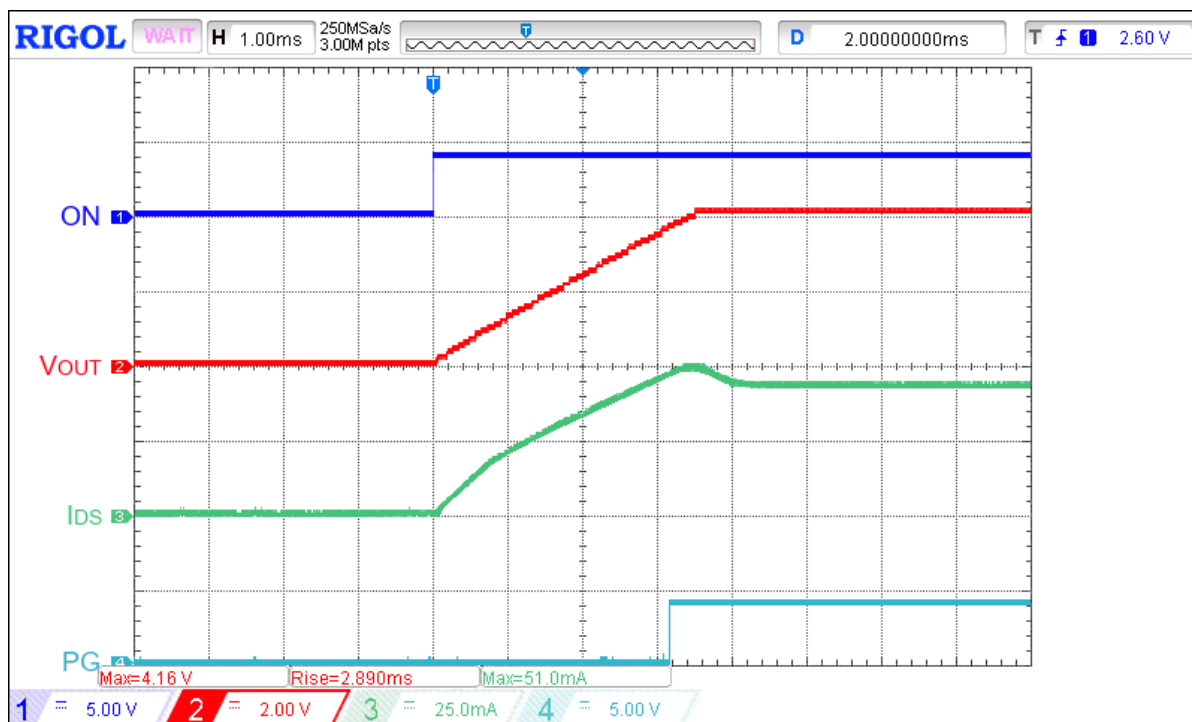


Figure 5: Typical Power up Operation Waveform for $V_{DD} = V_{IN} = 4\text{ V}$, $R_{SET} = 40\text{ k}\Omega$, $C_{SLEW} = 10\text{ nF}$, $R_{LOAD} = 100\text{ }\Omega$, $C_{LOAD} = 10\text{ }\mu\text{F}$

In this example, a 10 nF C_{SLEW} capacitor sets the slew rate to approximately 1.1 V/ms , thus inrush current is only 11 mA . In using a 0.66F supercapacitor, the resultant inrush current is dramatically increased and a non-linear ramp is observed during power up (see Figure 6). Since the inrush current is higher than the GreenFET load switch's I_{ACL} threshold (set by external R_{SET} resistor), the load switch's internal overcurrent protection is activated. To keep the load capacitor's charging current from exceeding the load switch's I_{ACL} threshold, the ACL monitor increases the FET resistance. However, if the overload condition persists where the die temperature rises because of the increased FET resistance, the GreenFET load switch's internal Thermal Shutdown Protection circuit will be activated. If the die temperature exceeds $150\text{ }^\circ\text{C}$ the load switch's internal Thermal Shutdown Protection circuit shuts the FET completely OFF, thereby allowing the die to cool. When the die cools to the load switch's lower $130\text{ }^\circ\text{C}$ temperature threshold, the FET is automatically turned back on. This process may repeat as long as the output current overload condition persists.

According to the above, charging supercapacitors with high currents leads to continuously switching ON/OFF load switch and a "saw" appears on the V_{OUT} (see Figure 6). To charge up such a large load capacitor, a $2\text{ }\mu\text{F}$ capacitor was chosen for C_{SLEW} . It sets the slew rate to 5.75 V/s and thus limits the inrush current to 3.8 A (see Figure 7).

Even if C_{SLEW} is chosen and protection circuits are not triggered during power up, we recommend to check package-case temperature as well. If during power up, the package case temperature rises higher than $20\text{ }^\circ\text{C}$ to $30\text{ }^\circ\text{C}$, we recommend increasing C_{SLEW} value until case temperature rise is less than $30\text{ }^\circ\text{C}$ (or lower), otherwise frequent overheating cycles may impact the load switch's long-term reliability.

Using Renesas GreenFET Load Switches in Super Capacitor Applications

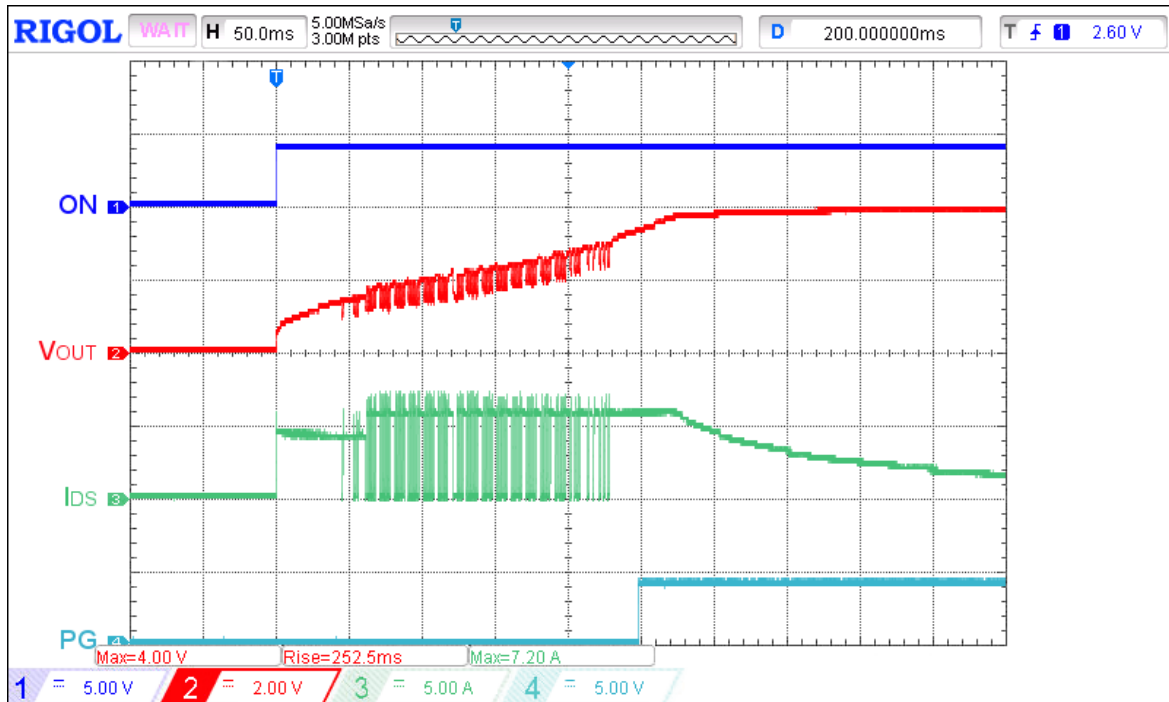


Figure 6: Active Current Limit and Thermal Protection Operation During Power Up on High Capacitive Load Caused by Improper GreenFET Load Switch Slew Rate Settings for $V_{DD} = V_{IN} = 4\text{ V}$, $I_{ACL} = 5.7\text{ A}$, $R_{SET} = 40\text{ k}\Omega$, $C_{SLEW} = 10\text{ nF}$, $C_{LOAD} = 0.66\text{ F}$, $R_{LOAD} = 100\ \Omega$

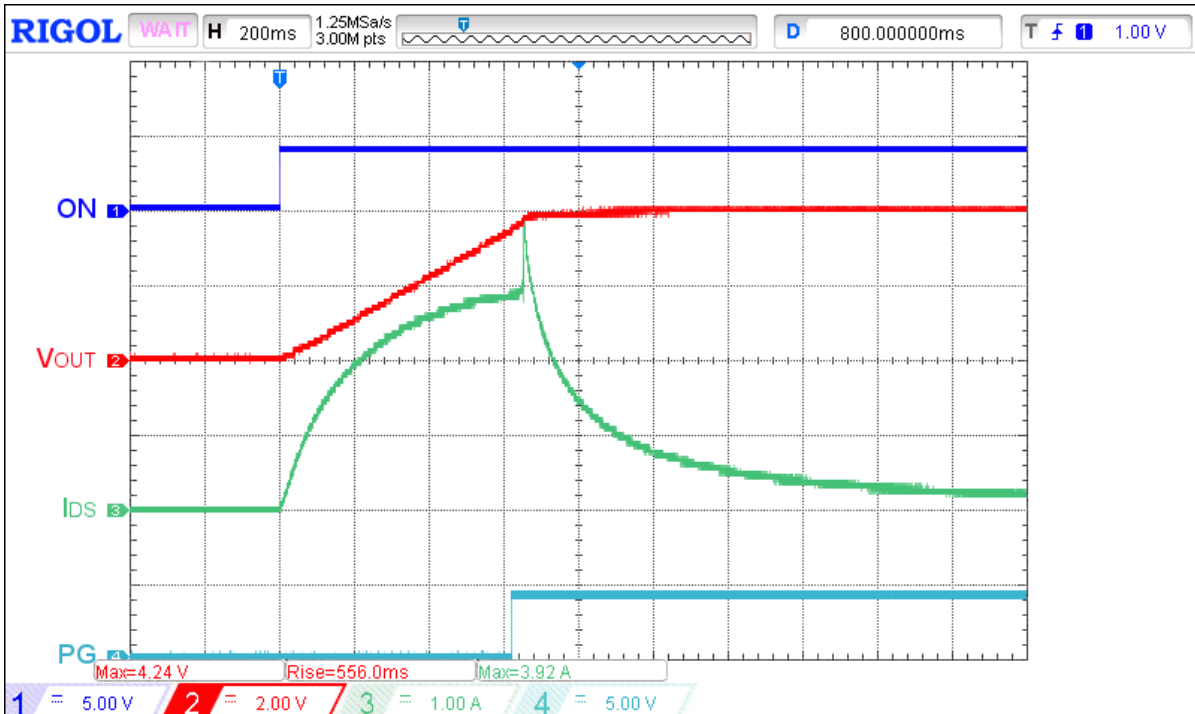


Figure 7: Typical Power Up for High Capacitive Load with Proper GreenFET Load Switch Slew Rate Settings for $V_{DD} = V_{IN} = 4\text{ V}$, $I_{ACL} = 5.7\text{ A}$, $R_{SET} = 40\text{ k}\Omega$, $C_{SLEW} = 2\ \mu\text{F}$, $C_{LOAD} = 0.66\text{ F}$, $R_{LOAD} = 100\ \Omega$

Using Renesas GreenFET Load Switches in Super Capacitor Applications

7 Conclusion

Charging high capacitive loads without any control may cause large inrush currents which can severely damage a load switch as well as any circuits downstream of the load switch. In addition, the charging of large capacitive loads may cause frequent over-heating cycles that can affect any load switch's long-term reliability. To solve this problem, Renesas Electronics offers a wide range of high-performance nFET load switches with at least one or more protection features like adjustable inrush current control, active current limit, thermal shutdown protection.

Revision History

Using Renesas GreenFET Load Switches in Super Capacitor Applications

Revision	Date	Description
1.0	03-Jul-2018	Initial Version

IMPORTANT NOTICE AND DISCLAIMER

RENESAS ELECTRONICS CORPORATION AND ITS SUBSIDIARIES (“RENESAS”) PROVIDES TECHNICAL SPECIFICATIONS AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, WITHOUT LIMITATION, ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for developers skilled in the art designing with Renesas products. You are solely responsible for (1) selecting the appropriate products for your application, (2) designing, validating, and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. Renesas grants you permission to use these resources only for development of an application that uses Renesas products. Other reproduction or use of these resources is strictly prohibited. No license is granted to any other Renesas intellectual property or to any third party intellectual property. Renesas disclaims responsibility for, and you will fully indemnify Renesas and its representatives against, any claims, damages, costs, losses, or liabilities arising out of your use of these resources. Renesas' products are provided only subject to Renesas' Terms and Conditions of Sale or other applicable terms agreed to in writing. No use of any Renesas resources expands or otherwise alters any applicable warranties or warranty disclaimers for these products.

(Rev.1.0 Mar 2020)

Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

Contact Information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit:
www.renesas.com/contact/

Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.