

Level Shifting Between 1.8V and 3.3V Using I2C Buffers

As the trend in low voltage microcontrollers migrates to 1.8V logic levels, I<sup>2</sup>C bus systems will need logic level shifting to communicate with 3.3V I<sup>2</sup>C slave devices. Without level shifting, the output logic levels of mixed voltage devices are not capable of properly driving the input logic thresholds of the I<sup>2</sup>C devices on the bus. A common solution uses an I<sup>2</sup>C buffer with level shifting capability to translate the 1.8V signals to levels compliant with the slave devices with the higher supply voltage. Level shifting I<sup>2</sup>C buffers have two supply pins (e.g. V<sub>CC1</sub> and V<sub>CC2</sub>); one connects to the higher voltage for slave devices and the other to the lower voltage for the microcontroller supply. Internally, the I<sup>2</sup>C buffer level shifts the I<sup>2</sup>C signals between the two supply voltages.

While there are new I<sup>2</sup>C buffers in the market that are capable of operating down to 1.8V, some buffers are not. These buffers may be of an older design that is not operational down to 1.8V but they may include desirable features not available in the new buffers (e.g. rise time accelerators that actively drive the bus to the logic high levels). Rise time accelerators provide an active source current to improve rise times, allowing longer bus lengths or higher bus capacitances. This method is preferred over using smaller pull-up resistors to increase rise times as the accelerator current is only active during a low to high transition. A pull-up resistor must sink its load current the entire time the I<sup>2</sup>C bus drives low.

Whether the I<sup>2</sup>C bus designer does not want to replace every 3.3V I<sup>2</sup>C buffer in the system due to cost or legacy compliance reasons or because the special features of a 3.3V buffer are desired, an interface to the 1.8V microcontroller is needed. A simple application solution can achieve the 1.8V logic level shifting while keeping the I<sup>2</sup>C buffer within its operating voltage range. A zener voltage regulator is used to drop the 3.3V bus down to the minimum operating voltage of the buffer specified in the datasheet. A few design considerations are necessary to prevent the rise time accelerators from over driving the 1.8V supply rail.

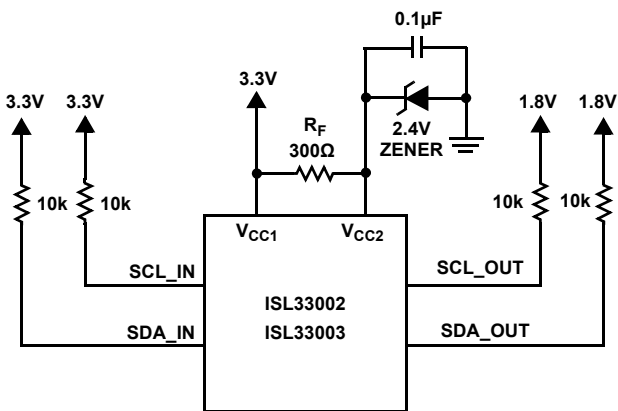


FIGURE 1. APPLICATION CIRCUIT

For example, Intersil's ISL33002 and ISL33003 (FN7560) are two channel I<sup>2</sup>C buffers with rise time accelerators and logic level shifting. Their minimum operating supply voltage is 2.3V so they cannot directly level shift down to 1.8V. Using a standard 2.4V zener diode to voltage regulate off the 3.3V bus while using bus pull-up resistors to 1.8V allows the buffer to level shift 1.8V to 3.3V. See Figure 1. Operating at 2.4V minimizes the overvoltage drive the rise time accelerators place on the 1.8V bus. Some design considerations for the bus designer are:

1. Sizing the current limiting resistor (Rf) for the zener regulator to operate beyond the knee voltage while sourcing enough current to power the buffer. The voltage variation of the zener regulator must handle the static and dynamic current on the 2.4V supply to the I<sup>2</sup>C buffer. The proper Rf resistor guarantees the voltage will not go below the minimum operating supply voltage of the I<sup>2</sup>C buffer.
2. Ensuring the voltage compliance of the 1.8V and 3.3V bus will not cause faulty operation of the I<sup>2</sup>C communication. The zener regulator must withstand the power supply variations of the 3.3V supply rail.
3. Providing protection on the 1.8V microcontroller against the potential overcurrent caused by the rise time accelerators on the buffer. A critical concern is the rise time accelerator from the I<sup>2</sup>C buffer damaging the 1.8V microcontroller. ESD diodes internal to the microcontroller are forward biased at ~0.5V above its supply rail. While the rise time accelerators drive the bus to 2.4V, they are active for only ~500ns (see Figure 2). If overcurrent is a concern, a series resistor on the I<sup>2</sup>C SDA (Data) and SCL (Clock) lines of 10Ω limits the current to protect the microcontroller. Assuming a worse cast 0V diode conduction, the peak current is limited by the capability of the rise time accelerator circuit on the buffer, in this case 5mA. From a voltage stand-point a 1.8V to 3.3V microcontroller has an absolute maximum voltage in the 3.6V range, much less than the 2.4V from the accelerator drive.

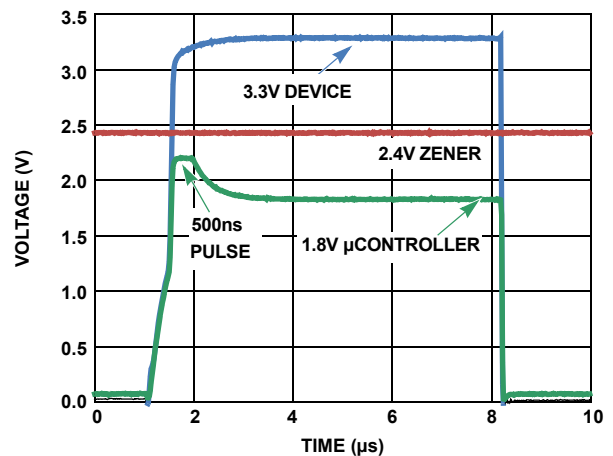


FIGURE 2. 1.8V TO 3.3V LEVEL SHIFTING

Another consideration when choosing the right buffer is that some devices similar to the ISL33002 and ISL33003 have a 2.7V minimum operating voltage. A 2.7V zener regulator is required, but the rise time accelerator over drive voltage is now 0.9V above the 1.8V rail, enough to fully turn on the ESD diode inside the microcontroller. The Intersil ISL33002 and ISL33003 I<sup>2</sup>C buffers with their lower minimum operating voltage of 2.3V allow a standard 2.4V zener diode regulator while reducing the rise time accelerator over drive voltage to the 1.8V microcontroller compared to competitor equivalent I<sup>2</sup>C buffers.

For applications that will use both 3.3V and 5V I<sup>2</sup>C devices in a mixed voltage bus system, the same application circuit will work. For direct level shifting between a 5V and 1.8V bus, the zener regulator will need a change to resistor  $R_F$  to limit the higher supply voltage. See Figure 3. However the best solution is to power the ISL33002/ISL33003 with 3.3V and zener regulate the second supply pin to 2.4V. I<sup>2</sup>C bus pull-up resistors to 1.8V on the microcontroller side and pull-up resistors to 5V on the slave side perform the logic level shifting while the buffer provides the isolation from each bus. See Figure 5. The ISL33002 and ISL33003 SDA/SCL pins are overvoltage compliant up to 5.5V regardless of the power supply level. In this circuit, the buffer actively drives the high voltage bus to 3.3V, then the pull-up resistors passively drive it to the 5V rail. See Figure 4. This allows all of the buffers on the board to be powered by a single supply instead, simplifying the design and layout.

For more information on ISL33002/ISL33003, including Intersil's family of I<sup>2</sup>C Buffer and other related products, visit [intersil.com](http://intersil.com).

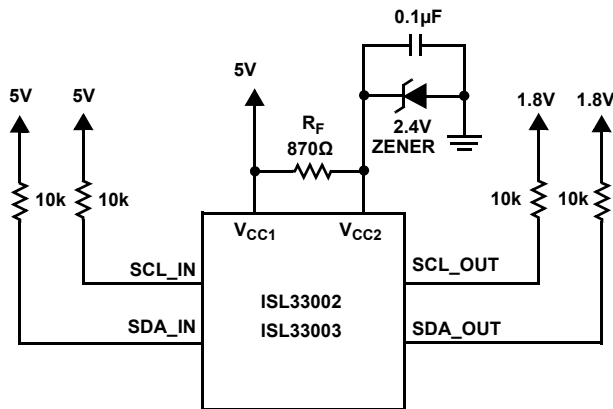


FIGURE 3. 1.8V TO 5V LEVEL SHIFTING WITH 5V SUPPLY

## Related Literature

- See [FN7560](#), ISL33001, ISL33002, ISL33003 Datasheet, "I<sup>2</sup>C Bus Buffer with Rise Time Accelerators and Hot Swap Capability"
- See [FN6492](#), ISL3034E, ISL3035E, ISL3036E Datasheet, "4-Channel And 6-Channel High Speed, Auto-direction Sensing Logic Level Translators"
- See [AN1543](#), "ISL33001MSOPEVAL1Z, ISL33002MSOPEVAL1Z, ISL33003MSOPEVAL1Z Evaluation Board User's Manual"

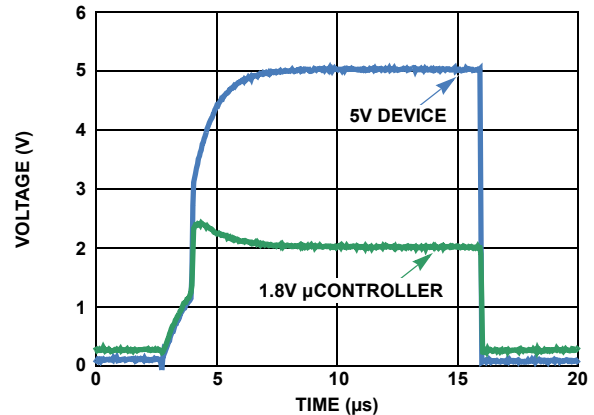


FIGURE 4. 1.8V TO 5V LEVEL SHIFTING WITH 3.3V SUPPLY

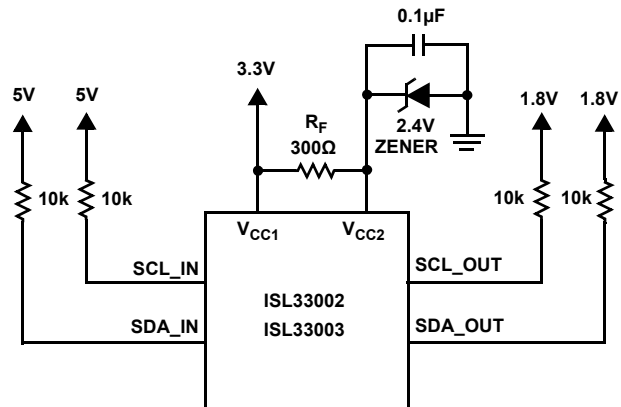


FIGURE 5. 1.8V TO 5V LEVEL SHIFTING WITH 3.3V SUPPLY

## Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.
2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.
3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
4. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.
5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The intended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.  
"Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.  
"High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.  
Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user's manual or other Renesas Electronics document.
6. When using Renesas Electronics products, refer to the latest product information (data sheets, user's manuals, application notes, "General Notes for Handling and Using Semiconductor Devices" in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.
7. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or danger to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.
8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
9. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.
10. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.
11. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.  
(Note 1) "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its directly or indirectly controlled subsidiaries.  
(Note 2) "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.

(Rev.4.0-1 November 2017)



### SALES OFFICES

Renesas Electronics Corporation

<http://www.renesas.com>

Refer to "<http://www.renesas.com/>" for the latest and detailed information.

**Renesas Electronics America Inc.**  
1001 Murphy Ranch Road, Milpitas, CA 95035, U.S.A.  
Tel: +1-408-432-8888, Fax: +1-408-434-5351

**Renesas Electronics Canada Limited**  
9251 Yonge Street, Suite 8309 Richmond Hill, Ontario Canada L4C 9T3  
Tel: +1-905-237-2004

**Renesas Electronics Europe Limited**  
Dukes Meadow, Millboard Road, Bourne End, Buckinghamshire, SL8 5FH, U.K  
Tel: +44-1628-651-700, Fax: +44-1628-651-804

**Renesas Electronics Europe GmbH**  
Arcadiastrasse 10, 40472 Düsseldorf, Germany  
Tel: +49-211-6503-0, Fax: +49-211-6503-1327

**Renesas Electronics (China) Co., Ltd.**  
Room 1709 Quantum Plaza, No.27 ZhichunLu, Haidian District, Beijing, 100191 P. R. China  
Tel: +86-10-8235-1155, Fax: +86-10-8235-7679

**Renesas Electronics (Shanghai) Co., Ltd.**  
Unit 301, Tower A, Central Towers, 555 Langao Road, Putuo District, Shanghai, 200333 P. R. China  
Tel: +86-21-2226-0888, Fax: +86-21-2226-0999

**Renesas Electronics Hong Kong Limited**  
Unit 1601-1611, 16/F., Tower 2, Grand Century Place, 193 Prince Edward Road West, Mongkok, Kowloon, Hong Kong  
Tel: +852-2265-6688, Fax: +852-2886-9022

**Renesas Electronics Taiwan Co., Ltd.**  
13F, No. 363, Fu Shing North Road, Taipei 10543, Taiwan  
Tel: +886-2-8175-9600, Fax: +886-2-8175-9670

**Renesas Electronics Singapore Pte. Ltd.**  
80 Bendemeer Road, Unit #06-02 Hyflux Innovation Centre, Singapore 339949  
Tel: +65-6213-0200, Fax: +65-6213-0300

**Renesas Electronics Malaysia Sdn.Bhd.**  
Unit 1207, Block B, Menara Amcorp, Amcorp Trade Centre, No. 18, Jln Persiaran Barat, 46050 Petaling Jaya, Selangor Darul Ehsan, Malaysia  
Tel: +60-3-7955-9390, Fax: +60-3-7955-9510

**Renesas Electronics India Pvt. Ltd.**  
No.777C, 100 Feet Road, HAL 2nd Stage, Indiranagar, Bangalore 560 038, India  
Tel: +91-80-67208700, Fax: +91-80-67208777

**Renesas Electronics Korea Co., Ltd.**  
17F, KAMCO Yangjae Tower, 262, Gangnam-daero, Gangnam-gu, Seoul, 06265 Korea  
Tel: +82-2-558-3737, Fax: +82-2-558-5338