

## FEATURES

- Improves I<sup>2</sup>C Bus Rise Time Transition
- Ensures Data Integrity with Multiple Devices on the I<sup>2</sup>C Bus.
- Wide Supply Voltage Range: 1.6V to 5.5V
- Improves Low State Noise Margin
- Up to 400kHz Operation
- Auto Detect Low Power Standby Mode
- Low (<5 $\mu$ A) Supply Current Shutdown
- Does Not Load Bus When Disabled or Powered Down
- Strong Slew Limited Pull-up Current
- $\pm$ 8kV Human Body Model ESD Ruggedness
- 2mm  $\times$  2mm DFN and SC70 Packages

## APPLICATIONS

- Notebook and Palmtop Computers
- Portable Instruments
- Battery Chargers
- Industrial Controls
- TV/Video Products
- ACPI SMBus Interface

## DESCRIPTION

The LTC<sup>®</sup>4311 is a dual I<sup>2</sup>C active pull-up designed to enhance data transmission speed and reliability for bus loading conditions well beyond the 400pF I<sup>2</sup>C specification limit. The LTC4311 operates at supply voltages from 1.6V to 5.5V and is also compatible with SMBus.

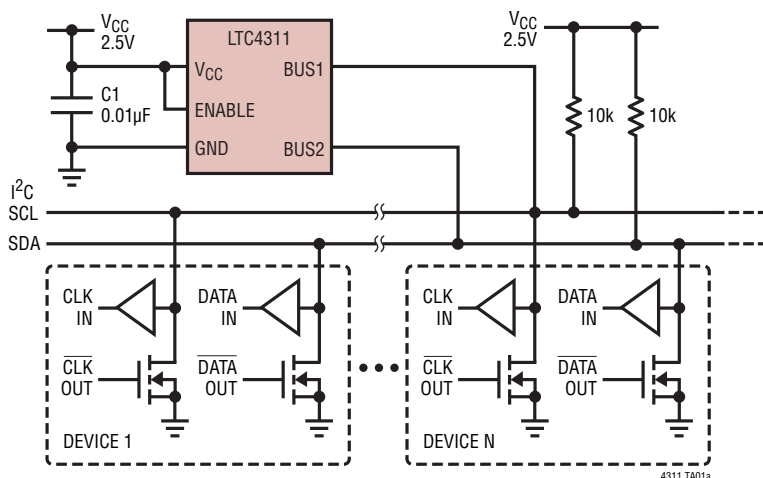
The LTC4311 allows multiple device connections or a longer, more capacitive interconnect, without compromising slew rates or bus performance, by using two slew limited pull-up currents.

During positive bus transitions, the LTC4311 provides slew limited pull-up currents to quickly slew the I<sup>2</sup>C or SMBus lines to the bus pull-up voltage. During negative transitions or steady DC levels, the currents are disabled to improve negative slew rate, and improve low state noise margins. An auto detect standby mode reduces supply current if both SCL and SDA are high. When disabled, the LTC4311 goes into low (<5 $\mu$ A) current shutdown.

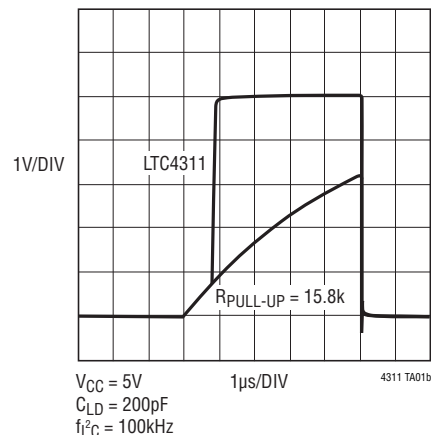
The LTC4311 is available in the 2mm  $\times$  2mm  $\times$  0.75mm DFN, and SC70 packages.

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## TYPICAL APPLICATION



Comparison of I<sup>2</sup>C Waveforms for the LTC4311 vs Resistor Pull-Up



# LTC4311

## ABSOLUTE MAXIMUM RATINGS (Notes 1, 2)

|                                 |               |                                        |                |
|---------------------------------|---------------|----------------------------------------|----------------|
| $V_{CC}$ to GND .....           | -0.3 to 6V    | Storage Temperature Range (DFN) .....  | -65°C to 125°C |
| BUS1, BUS2, ENABLE Inputs ..... | -0.3 to 6V    | Storage Temperature Range (SC70) ..... | -65°C to 125°C |
| Operating Temperature           |               | Lead Temperature (Soldering 10, sec)   |                |
| LTC4311C .....                  | 0°C to 70°C   | SC70 .....                             | 300°C          |
| LTC4311I .....                  | -40°C to 85°C |                                        |                |

## PIN CONFIGURATION

|                                                                                                                                                                                                                                            |                                                                                                                                                               |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>TOP VIEW</p> <p>DFN PACKAGE<br/>6-LEAD (2mm × 2mm) PLASTIC DFN<br/><math>T_{JMAX} = 125^{\circ}\text{C}</math>, <math>\theta_{JA} = 102^{\circ}\text{C/W}</math><br/>EXPOSED PAD (PIN 7) PCB CONNECTION TO GND IS OPTIONAL (Note 3)</p> | <p>TOP VIEW</p> <p>SC70 PACKAGE<br/>6-LEAD PLASTIC SC70<br/><math>T_{JMAX} = 125^{\circ}\text{C}</math>, <math>\theta_{JA} = 150^{\circ}\text{C/W}</math></p> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|

## ORDER INFORMATION

### Lead Free Finish

| TAPE AND REEL (MINI) | TAPE AND REEL     | PART MARKING* | PACKAGE DESCRIPTION             | TEMPERATURE RANGE |
|----------------------|-------------------|---------------|---------------------------------|-------------------|
| LTC4311CDC#TRMPBF    | LTC4311CDC#TRPBF  | LCNG          | 6-Lead (2mm × 2mm) Plastic DFN  | 0°C to 70°C       |
| LTC4311IDC#TRMPBF    | LTC4311IDC#TRPBF  | LCNG          | 6-Lead (2mm × 2mm) Plastic DFN  | -40°C to 85°C     |
| LTC4311CSC6#TRMPBF   | LTC4311CSC6#TRPBF | LCNF          | 6-Lead (2mm × 2mm) Plastic SC70 | 0°C to 70°C       |
| LTC4311ISC6#TRMPBF   | LTC4311ISC6#TRPBF | LCNF          | 6-Lead (2mm × 2mm) Plastic SC70 | -40°C to 85°C     |

TRM = 500 pieces. \*Temperature grades are identified by a label on the shipping container.

Consult LTC Marketing for parts specified with wider operating temperature ranges.

Consult LTC Marketing for information on lead based finish parts.

For more information on lead free part marking, go to: <http://www.linear.com/leadfree/>

For more information on tape and reel specifications, go to: <http://www.linear.com/tapeandreeel/>

# ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{CC} = 3.3\text{V}$ , unless otherwise noted.

| SYMBOL                   | PARAMETER                                | CONDITIONS                                                                                        |   | MIN  | TYP  | MAX  | UNITS |
|--------------------------|------------------------------------------|---------------------------------------------------------------------------------------------------|---|------|------|------|-------|
| V <sub>CC</sub>          | Positive Supply Voltage                  |                                                                                                   | ● | 1.6  |      | 5.5  | V     |
| I <sub>CC</sub>          | Supply Current                           | V <sub>CC</sub> = 5.5V, ENABLE = 5.5V, V <sub>BUS1</sub> = V <sub>BUS2</sub> = 0V                 | ● |      | 200  | 300  | μA    |
| I <sub>CC_STANDBY</sub>  | Supply Current, Standby Mode             | V <sub>CC</sub> = 5.5V, ENABLE = 5.5V, V <sub>BUS1</sub> = V <sub>BUS2</sub> = 5.5V               | ● |      | 26   | 45   | μA    |
| I <sub>CC_DISABLED</sub> | Supply Current, Disabled                 | V <sub>CC</sub> = 5.5V, ENABLE = 0V, V <sub>BUS1</sub> = V <sub>BUS2</sub> = 5.5V                 | ● |      |      | ±5   | μA    |
| I <sub>PULLUPAC</sub>    | Transient Boosted Pull-up Current        | Positive Transition on Bus, Slew Rate = 0.5V/μs<br>V <sub>CC</sub> = 1.8V, BUS > V <sub>THR</sub> | ● | 2.5  | 5    |      | mA    |
| I <sub>BUS(IN)</sub>     | BUS1,BUS2, Input Leakage Current         | V <sub>CC</sub> = 0V, V <sub>BUS1</sub> = V <sub>BUS2</sub> = 5.5V                                | ● |      |      | ±5   | μA    |
| I <sub>ENABLE(IN)</sub>  | ENABLE Input Leakage Current             | V <sub>CC</sub> = 0V, V <sub>ENABLE</sub> = 5.5V                                                  | ● |      |      | ±10  | μA    |
| V <sub>THR</sub>         | Bus Input Threshold Voltage              | V <sub>CC</sub> = 1.8V                                                                            | ● | 0.45 | 0.55 | 0.65 | V     |
|                          |                                          | V <sub>CC</sub> = 2.5V                                                                            | ● | 0.65 | 0.75 | 0.85 | V     |
|                          |                                          | V <sub>CC</sub> = 2.7V to 5.5V                                                                    | ● | 0.68 | 0.78 | 0.88 | V     |
| V <sub>THR_ENABLE</sub>  | ENABLE Threshold Voltage                 | V <sub>CC</sub> = 1.6V, 5.5V                                                                      | ● | 0.4  | 1    | 1.5  | V     |
| SR <sub>THRESH</sub>     | Slew Rate Detector Threshold             | BUS > V <sub>THR</sub> , V <sub>CC</sub> = 1.8V, 5.5V                                             | ● |      | 0.2  | 0.5  | V/μs  |
| t <sub>r</sub>           | Fast Mode I <sup>2</sup> C Bus Rise Time | Bus Capacitance = 400pF, V <sub>CC</sub> = 3V (Note 4)                                            | ● |      |      | 300  | ns    |
| f <sub>MAX</sub>         | Bus Maximum Operating Frequency          | (Note 5)                                                                                          | ● | 400  |      |      | kHz   |

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

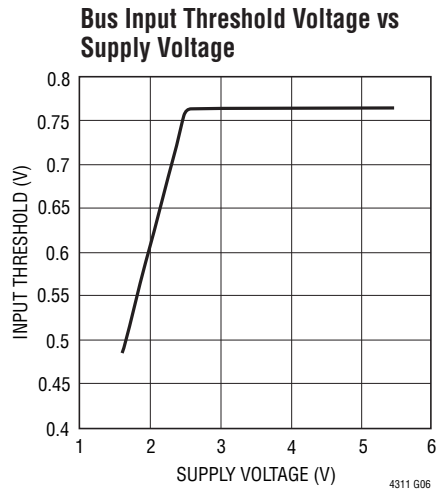
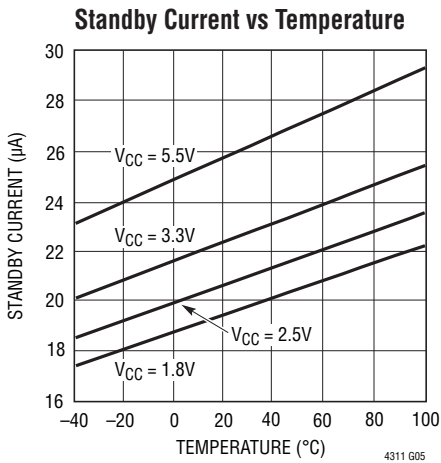
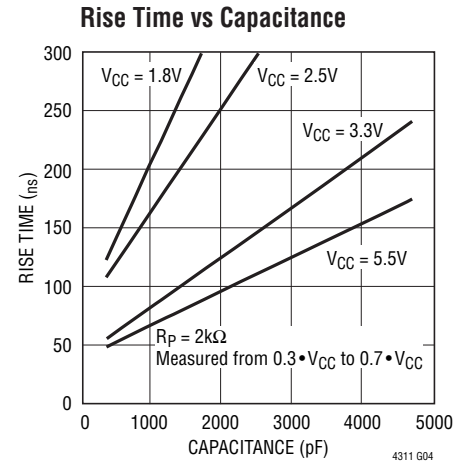
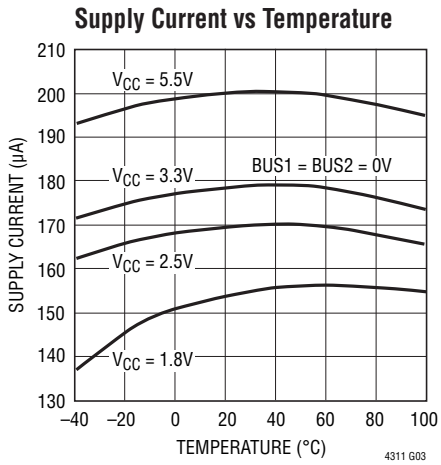
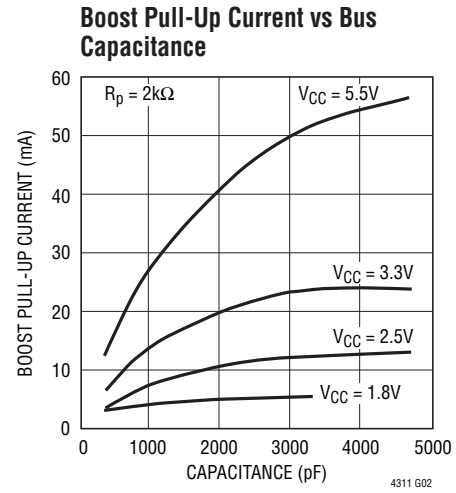
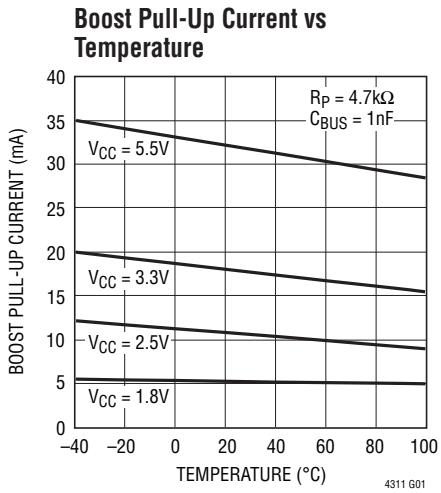
**Note 2:** All currents into pins are positive. All voltages are referenced to GND unless otherwise specified.

**Note 3:** Thermal characteristics are determined with exposed pad soldered to GND plane. If the exposed pad is left open, thermal characteristics can be drastically different.

**Note 4:** The rise time of an I<sup>2</sup>C bus line is calculated from  $V_{IL(MAX)}$  to  $V_{IH(MIN)}$  or  $0.9\text{V}$  to  $2.1\text{V}$  (with  $V_{CC} = 3\text{V}$ ). This parameter is guaranteed by design and not tested. With a minimum boosted pull-up current of  $2.5\text{mA}$ : Rise Time =  $(2.1\text{V} - 0.9\text{V}) \cdot 400\text{pF} / 2.5\text{mA} = 0.19\mu\text{s}$ .

**Note 5:** Determined by design, not tested in production.

## TYPICAL PERFORMANCE CHARACTERISTICS ( $T_A = 25^\circ\text{C}$ , unless otherwise indicated)



## PIN FUNCTIONS

**BUS1:** Active Pull-up for Bus. Connect to either clock line or data line for 2-wire bus.

**BUS2:** Active Pull-up for Bus. Connect to either clock line or data line for 2-wire bus.

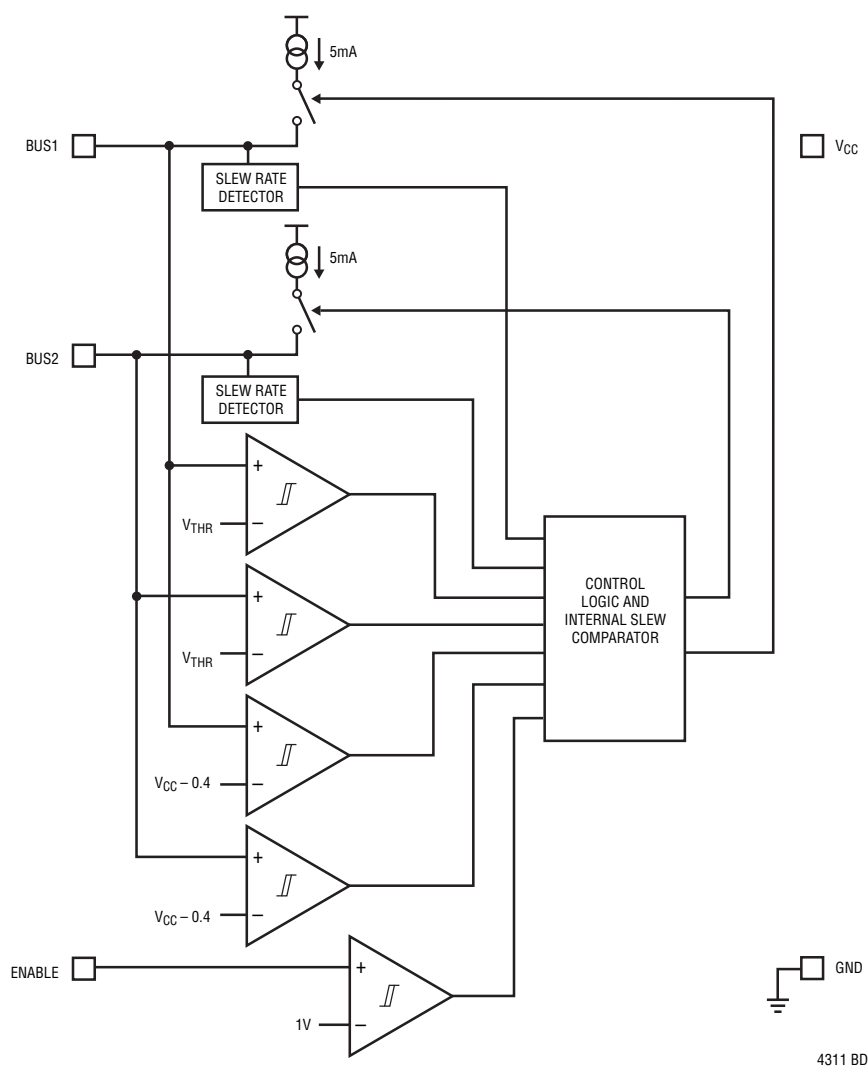
**ENABLE:** Device Enable Input. This is a 1V nominal digital threshold input pin. For normal operation drive ENABLE to a voltage greater than 1.5V. Driving ENABLE below the 0.4V threshold puts the device in a low ( $<5\mu\text{A}$ ) current shutdown mode and puts the BUS pins in a high impedance state. If unused, connect to  $V_{CC}$ .

**EXPOSED PAD (DFN Package Only):** Exposed Pad may be left open or connected to device ground.

**GND:** Device Ground. Connect this pin to a ground plane for best results.

**$V_{CC}$ :** Supply Voltage Input. Connect this pin to bus supply and place a bypass capacitor of at least  $0.01\mu\text{F}$  close to  $V_{CC}$  for best results.

## BLOCK DIAGRAM



## OPERATION

### I<sup>2</sup>C and SMBus Overview

The I<sup>2</sup>C communication protocol employs open-drain pull-down drivers with resistive or current source pull-ups. This protocol allows multiple devices to drive and monitor the bus without bus contention. The simplicity of resistive or fixed current source pull-ups is offset by the slow rise times resulting when bus capacitance is high. Rise times can be improved by using lower pull-up resistor values or higher fixed current source values, but the additional current increases the low state bus voltage, decreasing noise margins. Slow rise times can seriously impact data reliability, enforcing a maximum practical bus speed well below the established I<sup>2</sup>C or SMBus maximum transmission rate.

The LTC4311 overcomes these limitations by providing a boosted pull-up current only during positive bus transitions to quickly slew large bus capacitances. Therefore, rise time is dramatically improved, especially with maximum or out of specification I<sup>2</sup>C or SMBus loading conditions.

The LTC4311 has separate but identical circuitry for each BUS output pin. The circuitry consists of a positive edge slew rate detector and a voltage comparator. The voltage comparator has a supply dependent threshold. At supply voltages below 2.7V the comparator threshold is  $0.3V_{CC}$ , and at higher voltages the comparator threshold is a constant 0.8V. This allows the rise time accelerator to be used in non-compliant systems where the bus thresholds

are optimized for low voltage operation, while still meeting standard thresholds for compliant I<sup>2</sup>C and SMBus systems.

The slew limited pull-up current is only turned on if the bus line voltage is greater than the supply dependent comparator threshold voltage and the positive slew rate of the bus line is greater than the typical 0.2V/μs threshold of the slew rate detector. The pull-up current remains on until the voltage on the bus line is within 0.4V of  $V_{CC}$  or the slew rate drops below 0.2V/μs.

The pull-up current is slew limited to maintain signal integrity for busses that have very little capacitive load. In a lightly loaded system a strong pull-up could result in fast edge rates that cause reflections on the bus. These reflections can be detected by devices on the bus as extra clock edges, could result in erroneous data, or cause a stuck bus. An internal slew limit comparator limits the rate the pull-up current can slew the bus lines to 100V/μs.

### Auto Detect Standby Mode and Shutdown Mode

When BUS1 and BUS2 are both high the LTC4311 reduces the standby supply current. Internal comparators detect when the bus pins are within 400mV of  $V_{CC}$ , and reduce the supply current to 26μA. When the ENABLE pin is grounded, the LTC4311 enters a low (<5μA) supply current shutdown mode. Both bus pins are high impedance in shutdown, regardless of the bus pin voltage.

## APPLICATIONS INFORMATION

### Selecting the values of $R_S$ and $R_P$

The typical configuration for the data bus for a 2-wire bus is shown in Figure 1. The parameters  $R_P$  and  $R_S$  should be chosen carefully. A description of the process for choosing the values of  $R_P$  and  $R_S$  follows.

An external pull-up resistor  $R_P$  is required in each bus line to supply a steady state pull-up current if the bus is at logic zero. This pull-up current is used for slewing the bus line during the initial portion of the positive transition in order to activate the LTC4311 pull-up current.

Using an external pull-up resistor  $R_P$  to supply steady state pull-up current provides the freedom to adjust rise time versus fall time as well as defining the low state logic-level ( $V_{OL}$ ).

For I/O stage protection from ESD and high voltage spikes on the bus, a series resistor  $R_S$  (Figure 1) is sometimes added to the open drain driver of the bus agents.

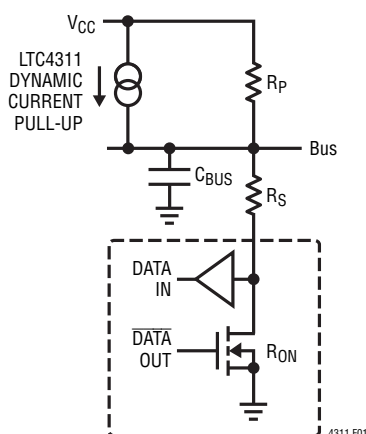


Figure 1. Typical 2-Wire Bus Configuration

Both the values of  $R_P$  and  $R_S$  must be chosen carefully to meet the low state noise margin and all bus timing requirements.

A discussion of the electrical parameters affected by the values of  $R_S$  and  $R_P$ , as well as the general procedure for selecting the values of  $R_S$  and  $R_P$  follows.

### Low State Noise Margin

A low value of  $V_{OL}$ , the low state logic level, is desired for good noise margin.  $V_{OL}$  is calculated as follows:

$$V_{OL} = \frac{R_L \cdot V_{CC}}{R_L + R_P} \quad (1)$$

$R_L$  is the series sum of  $R_S$  and  $R_{ON}$ , the on resistance of the open-drain driver.

Increasing the value of  $R_P$  decreases the value of  $V_{OL}$ . Increasing  $R_L$  increases the value of  $V_{OL}$ .

### Initial Slew Rate

The initial slew rate, SR, of the bus is determined by:

$$SR = \frac{V_{CC} - V_{OL}}{R_P \cdot C_{BUS}} \quad (2)$$

SR must be greater than  $SR_{THRESH}$ , the LTC4311 slew rate detector threshold ( $0.5V/\mu s$  max), in order to activate the pull-up current.

### I<sup>2</sup>C Rise and Fall Time

Rise time of an I<sup>2</sup>C line is derived using equation 3.

$$t_r = -R_P \cdot C_{BUS} \cdot \ln \left\{ \frac{V_{IHMIN} - V_{CC} - R_P \cdot I_{PULLUPAC}}{V_{ILMAX} - V_{CC} - R_P \cdot I_{PULLUPAC}} \right\} \quad (3)$$

Fall time of an I<sup>2</sup>C line is derived using equation 4.

$$t_f = R_T \cdot C_{BUS} \cdot \ln \left\{ \frac{\frac{V_{IHMIN}}{V_{CC}} \cdot (R_P + R_L) - R_L}{\frac{V_{ILMAX}}{V_{CC}} \cdot (R_P + R_L) - R_L} \right\} \quad (4)$$

where  $R_T$  is the parallel equivalent of  $R_P$  and  $R_L$ .

## APPLICATIONS INFORMATION

For an I<sup>2</sup>C system with fixed input levels,  $V_{ILMAX} = 1.5V$  and  $V_{IHMIN} = 3V$ . For I<sup>2</sup>C systems with  $V_{CC}$  related input levels,  $V_{ILMAX} = 0.3V_{CC}$  and  $V_{IHMIN} = 0.7V_{CC}$ .

$C_{BUS}$  is the total capacitance of the I<sup>2</sup>C line.

### SMBus Rise and Fall Time

Rise time of a SMBus line is derived using equations 5, 6 and 7.

$$t_r = t_1 + t_2 \quad (5)$$

$t_1$  is the time from when the bus crosses the lower slew rate measurement point, until the bus reaches  $V_{THR}$  and the accelerators fire. The time from when the accelerators fire until the bus reaches the upper slew rate measure point is given by  $t_2$ . Equations for  $t_1$  and  $t_2$  are given here:

$$t_1 = -R_P \cdot C_{BUS} \cdot \ln \left\{ \frac{V_{THR} - V_{CC}}{V_{ILMAX} - 0.15V - V_{CC}} \right\} \quad (6)$$

If  $(V_{ILMAX} - 0.15V) > V_{THR}$ , then  $t_1 = 0$

$$t_2 = -R_P \cdot C_{BUS} \cdot \ln \left\{ \frac{V_{IHMIN} + 0.15V - V_{CC} - R_P \cdot I_{PULLUPAC}}{V_{THR} - V_{CC} - R_P \cdot I_{PULLUPAC}} \right\} \quad (7)$$

Fall time of an SMBus line is derived using equation 8:

$$t_f = R_T \cdot C_{BUS} \cdot \ln \left\{ \frac{\frac{V_{IHMIN} + 0.15V}{V_{CC}} \cdot (R_P + R_L) - R_L}{\frac{V_{ILMAX} - 0.15V}{V_{CC}} \cdot (R_P + R_L) - R_L} \right\} \quad (8)$$

For an SMBus system,  $V_{ILMAX} = 0.8V$  and  $V_{IHMIN} = 2.1V$ .

$C_{BUS}$  is the total bus capacitance of the SMBus line.

A general procedure for selecting  $R_P$  and  $R_L$  is as follows:

1.  $R_L$  is first selected based on the I/O protection requirement. Generally, an  $R_S$  of  $100\Omega$  is sufficient for high voltage spikes and ESD protection.  $R_{ON}$  is determined by the size of the open-drain driver, a large driver will have a lower  $R_{ON}$ .
2. The value of  $R_P$  is determined based on the  $V_{OL}$  and minimum slew rate requirements. The  $V_{OL}$  will determine the smallest resistance value that can be used in a system, and the minimum slew requirement will bound the resistance on the upper end. Generally the largest value of resistance that meets the minimum slew rate with some margin will be selected.
3. For I<sup>2</sup>C systems incorporating the LTC4311, the rise times are met under most loading conditions, due to the strong accelerator current. The pull-down drivers are typically low impedance, and therefore fall times are not generally an issue. Rise and fall time requirements must be verified using equations 3 and 4 (for an I<sup>2</sup>C system) or equations 5 to 8 (for an SMBus system). The value chosen for  $R_P$  must ensure that both the rise and fall time specifications are met simultaneously.

### I<sup>2</sup>C Design Example

Given the following conditions and requirements:

$$\begin{aligned} V_{CC} &= 3.3V \text{ NOMINAL} \\ V_{OL} &= 0.4V \text{ MAXIMUM} \\ C_{BUS} &= 600pF \\ V_{ILMAX} &= 0.99V, V_{IHMIN} = 2.31V \\ t_r &= 0.3\mu s \text{ MAXIMUM}, t_f = 0.3\mu s \text{ MAXIMUM} \end{aligned} \quad (9)$$

If an  $R_S$  of  $100\Omega$  is used and the max  $R_{ON}$  of the driver is  $200\Omega$ , then  $R_L = 200\Omega + 100\Omega = 300\Omega$ . Use equation 1 to find the required  $R_P$  to meet  $V_{OL}$ .

$$\begin{aligned} R_P &= \frac{300\Omega \cdot (3.3V - 0.4V)}{0.4V} \\ R_P &= 2.175k \end{aligned} \quad (10)$$

## APPLICATIONS INFORMATION

This is the lowest resistor value that may be chosen and still meet  $V_{OL}$ . Next calculate the largest value of  $R_P$  that will satisfy SR, the minimum slew rate requirement. Using  $V_{OL} = 0.4V$  and  $SR = 0.5V/\mu s$  calculate the value of  $R_P$  with equation 2.

$$R_P = \frac{3.3V - 0.4V}{600pF \cdot 0.5V/\mu s}$$

$$R_P = 9.667k \quad (11)$$

This is approximately the largest value of  $R_P$  that will satisfy the minimum slew rate requirement. Since  $R_P$  is larger than 2.175k the  $V_{OL}$  will be below 0.4V, and the slew rate will actually be faster than calculated. Choosing  $R_P = 10k$ ,  $V_{OL}$  and SR are recalculated.

$$V_{OL} = \frac{300\Omega \cdot 3.3V}{300\Omega + 10k\Omega} = 96mV$$

$$SR = \frac{3.3V - 96mV}{10k\Omega \cdot 600pF} = 0.534V/\mu s \quad (12)$$

The rise and fall times need to be verified using equations 3 and 4.

$$t_r = -10k\Omega \cdot 600pF \cdot \ln \left\{ \frac{2.31V - 3.3V - 10k\Omega \cdot 2.5mA}{0.99V - 3.3V - 10k\Omega \cdot 2.5mA} \right\} = 0.297\mu s$$

$$t_f = 291\Omega \cdot 600pF \cdot \ln \left\{ \frac{\frac{2.31}{3.3V} \cdot (10k\Omega + 300\Omega) - 300\Omega}{\frac{0.99V}{3.3V} \cdot (10k\Omega + 300\Omega) - 300\Omega} \right\} = 0.158\mu s \quad (13)$$

$$t_f = 291\Omega \cdot 600pF \cdot \ln \left\{ \frac{\frac{2.31}{3.3V} \cdot (10k\Omega + 300\Omega) - 300\Omega}{\frac{0.99V}{3.3V} \cdot (10k\Omega + 300\Omega) - 300\Omega} \right\} = 0.158\mu s \quad (14)$$

Both the rise and fall times meet the  $0.3\mu s$   $I^2C$  requirement and the  $V_{OL}$  is satisfied, while meeting the minimum slew rate requirement, so  $R_P$  is chosen to be 10k.

If  $t_r$  is not met,  $R_P$  should be decreased and if  $t_f$  is not met then  $R_P$  should be increased.

### SMBus Design Example

Given the following conditions and requirements for a low power SMBus system:

$$V_{CC} = 3.3V \text{ NOMINAL}$$

$$V_{OL} = 0.4V \text{ MAXIMUM}$$

$$C_{BUS} = 400pF$$

$$V_{ILMAX} = 0.8V, V_{IHMIN} = 2.1V$$

$$t_r = 1\mu s \text{ MAXIMUM}, t_f = 0.3\mu s \text{ MAXIMUM} \quad (15)$$

If an  $R_S$  of  $100\Omega$  is used and the max  $R_{ON}$  of the driver is  $200\Omega$ , then  $R_L = 200\Omega + 100\Omega = 300\Omega$ . Use equation 1 to find the required  $R_P$  to meet  $V_{OL}$ .

$$R_P = \frac{300\Omega \cdot (3.3V - 0.4V)}{0.4V}$$

$$R_P = 2.175k \quad (16)$$

Calculate Maximum  $R_P$  from equation 2.

$$R_P = \frac{3.3V - 0.4V}{400pF \cdot 0.5V/\mu s}$$

$$R_P = 14.5k \quad (17)$$

Choose  $R_P = 13k$  and recalculate  $V_{OL}$  and SR.

$$V_{OL} = \frac{300\Omega \cdot 3.3V}{300\Omega + 13k\Omega} = 74mV$$

$$SR = \frac{3.3V - 74mV}{13k\Omega \cdot 400pF} = 0.62V/\mu s \quad (18)$$

The rise and fall times need to be verified using equations 5 to 8.

$$t_r = -13k\Omega \cdot 400pF \cdot \ln \left\{ \frac{0.9V - 3.3V}{0.8V - 0.15V - 3.3V} \right\} = 0.515\mu s \quad (19)$$

## APPLICATIONS INFORMATION

$$t_2 = -13\text{k}\Omega \cdot 400\text{pF} \cdot \ln \left\{ \frac{2.1\text{V} + 0.15\text{V} - 3.3\text{V} - 13\text{k}\Omega \cdot 2.5\text{mA}}{0.9\text{V} - 3.3\text{V} - 13\text{k}\Omega \cdot 2.5\text{mA}} \right\} = 0.205\mu\text{s} \quad (20)$$

$$t_r = t_1 + t_2 = 0.515\mu\text{s} + 0.205\mu\text{s} = 0.72\mu\text{s} \quad (21)$$

$$t_f = 293\Omega \cdot 400\text{pF} \cdot \ln \left\{ \frac{\frac{2.1\text{V} + 0.15\text{V}}{3.3\text{V}} \cdot (13\text{k}\Omega + 300\Omega) - 300\Omega}{\frac{0.8\text{V} - 0.15\text{V}}{3.3\text{V}} \cdot (13\text{k}\Omega + 300\Omega) - 300\Omega} \right\} = 0.156\mu\text{s} \quad (22)$$

The rise time meets the 1 $\mu\text{s}$  SMBus requirement and the fall time meets the 0.3 $\mu\text{s}$  requirement. The  $V_{OL}$  is satisfied while meeting the minimum slew rate requirements, so  $R_P$  is chosen to be 13k $\Omega$ . If the rise time was not met due to a large  $t_1$ , equation 6 can be used to calculate a maximum value of  $R_P$  that will meet the rise time requirements.

## ACK Data Setup Time

Care must be taken in selecting the value of  $R_S$  (in series with the pull-down driver) to ensure that the data setup time requirement for ACK (acknowledge) is fulfilled. An acknowledge is the host releasing the SDA line (pulling

high) at the end of the last bit sent and the slave device pulling the SDA line low before the rising edge of the ACK clock pulse.

The LTC4311 5mA pull-up current is activated when the host releases the SDA line, allowing the voltage to rise above the LTC4311's comparator threshold ( $V_{THR}$ ). If a slave device has a high value of  $R_S$ , a longer time is required for the slave device to pull SDA low before the rising edge of the ACK clock pulse. To ensure sufficient data setup time for ACK, slave devices with high values of  $R_S$  should pull the SDA low earlier.

An alternative is the slave device can hold the SCL line low until the SDA line reaches a stable state. Then, SCL can be released to generate the ACK clock pulse.

## Multiple LTC4311s in Parallel

In very heavily loaded systems, stronger pull up current may be desired. Two LTC4311's may be used in parallel to increase the total pull up current to meet rise time requirements.

## Notes on Using the LTC4311 in LTC1694 Applications

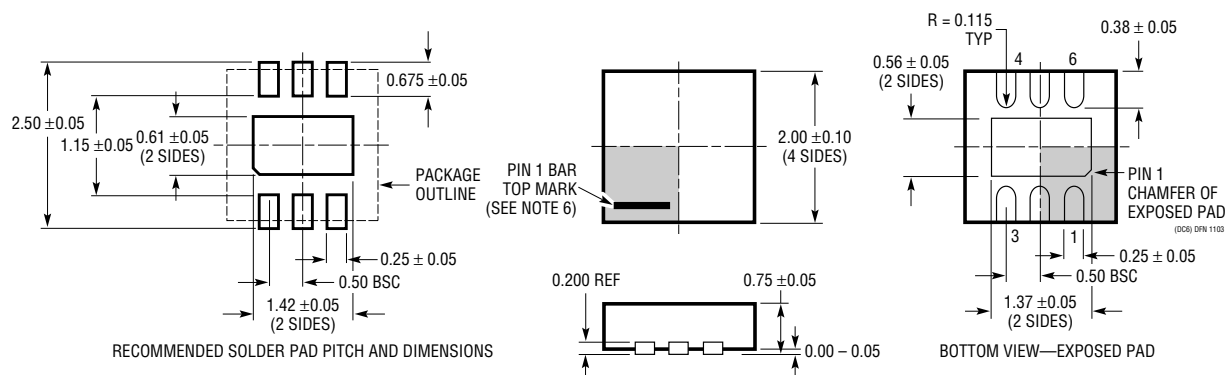
Although the LTC1694 and LTC4311 are functionally similar accelerators for I<sup>2</sup>C, SMBus, and other comparable open drain/collector bus applications, the LTC4311 offers a lower power, higher performance solution in a smaller package as compared to the LTC1694. These and other differences are listed in Table 1 and must be accounted for if using the LTC4311 in LTC1694 applications.

Table 1. Differences Between LTC1694 and LTC4311

| SPECIFICATION                   | LTC1694          | LTC4311               | COMMENTS                                                                      |
|---------------------------------|------------------|-----------------------|-------------------------------------------------------------------------------|
| Enable Pin (typ)                | N/A              | 1V                    | Allows the LTC4311 to be Disabled, Consuming Less than 5 $\mu\text{A}$        |
| $V_{CC}$                        | 2.7V – 6V        | 1.6V – 5.5V           | Lower Operating Supply Voltage for Low Voltage Systems                        |
| $I_{CC}$ (typ), BUS1, BUS2 High | 60 $\mu\text{A}$ | 26 $\mu\text{A}$      | Lower Standby Current to Conserve Power                                       |
| $V_{THRES}$ (typ)               | 0.65V            | Dependent on $V_{CC}$ | Tighter, Higher Noise Margins and Improved Rise Times                         |
| $I_{PULL-UP}$ (typ)             | 2.2mA            | 5mA                   | Stronger Slew-Limited Source Current for Slewing Higher Bus Capacitances      |
| $f_{MAX}$                       | 100kHz           | 400kHz                | Higher Operating Frequency for I <sup>2</sup> C's Fast Mode Bus Specification |

## PACKAGE DESCRIPTION

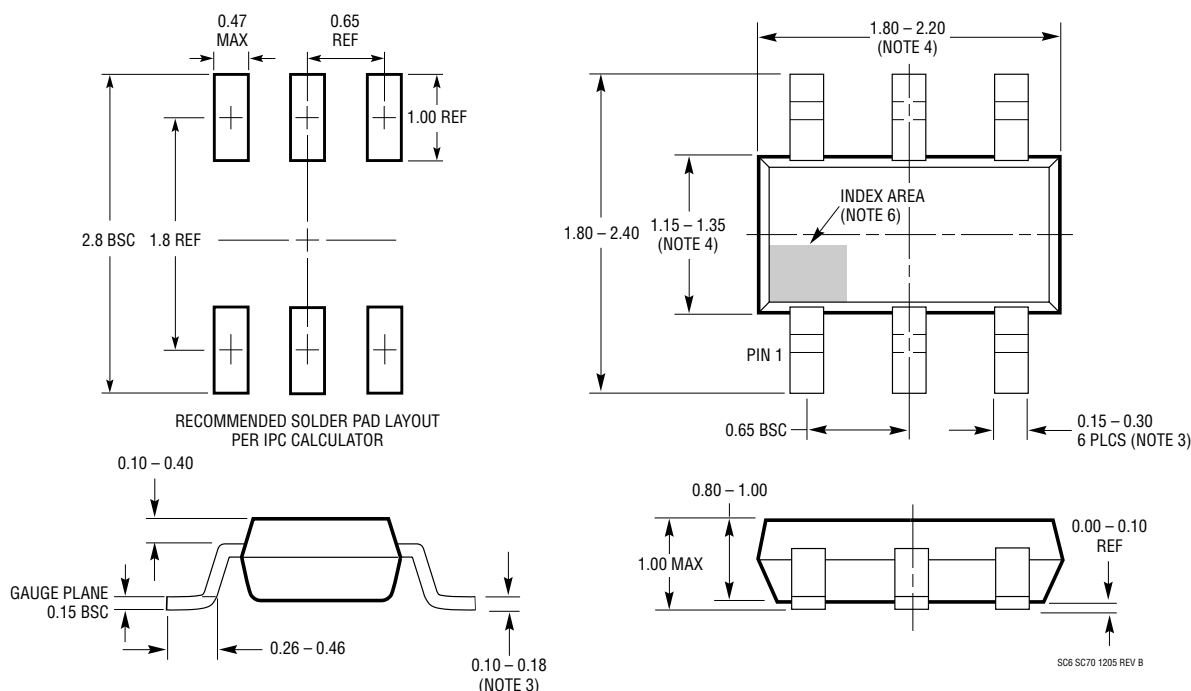
### DC Package 6-Lead Plastic DFN (2mm × 2mm) (Reference LTC DWG # 05-08-1703)



#### NOTE:

1. DRAWING TO BE MADE A JEDEC PACKAGE OUTLINE MO-229 VARIATION OF (WCCD-2)
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. DIMENSIONS OF EXPOSED PAD ON BOTTOM OF PACKAGE DO NOT INCLUDE MOLD FLASH. MOLD FLASH, IF PRESENT, SHALL NOT EXCEED 0.15mm ON ANY SIDE
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON THE TOP AND BOTTOM OF PACKAGE

### SC6 Package 6-Lead Plastic SC70 (Reference LTC DWG # 05-08-1638 Rev B)

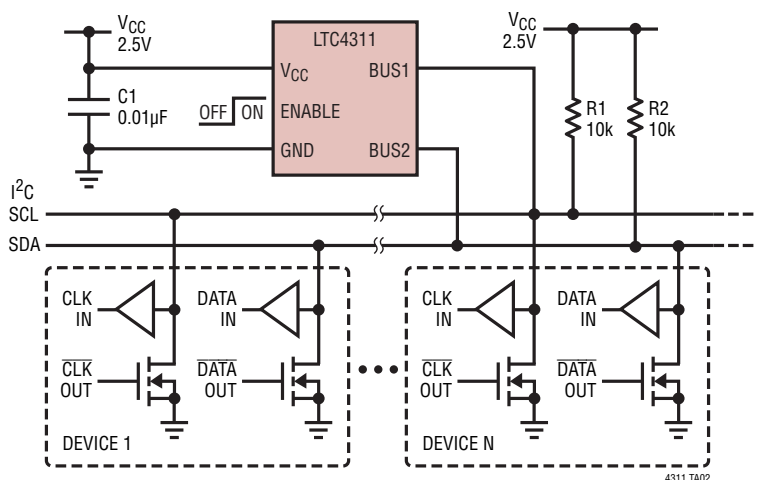


#### NOTE:

1. DIMENSIONS ARE IN MILLIMETERS
2. DRAWING NOT TO SCALE
3. DIMENSIONS ARE INCLUSIVE OF PLATING
4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
5. MOLD FLASH SHALL NOT EXCEED 0.254mm
6. DETAILS OF THE PIN 1 IDENTIFIER ARE OPTIONAL, BUT MUST BE LOCATED WITHIN THE INDEX AREA
7. EIAJ PACKAGE REFERENCE IS EIAJ SC-70
8. JEDEC PACKAGE REFERENCE IS MO-203 VARIATION AB

## TYPICAL APPLICATION

Application Utilizing Low Current Shutdown



## RELATED PARTS

| PART NUMBER                              | DESCRIPTION                                                                   | COMMENTS                                                                                                                                       |
|------------------------------------------|-------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| LTC1380/LTC1393                          | Single-Ended 8-Channel/Differential 4-Channel Analog MUX with SMBus Interface | Low $R_{ON}$ : 35Ω Single-Ended/70Ω Differential, Expandable to 32 Single or 16 Differential Channels                                          |
| LTC1427-50                               | Micropower, 10-Bit Current Output DAC with SMBus Interface                    | Precision 50µA $\pm$ 2.5% Tolerance Over Temperature, 4 Selectable SMBus Addresses, DAC Powers Up at Zero or Midscale                          |
| LTC1623                                  | Dual High Side Switch Controller with SMBus Interface                         | 8 Selectable Addresses/16 Channel Capability                                                                                                   |
| LTC1663                                  | SMBus Interface 10-Bit Rail-to-Rail Micropower DAC                            | DNL < 0.75 LSB Max, 5-Lead SOT-23 Package                                                                                                      |
| LTC1694/LTC1694-1                        | SMBus Accelerator                                                             | Improved SMBus/I <sup>2</sup> C Rise-Time, Ensures Data Integrity with Multiple SMBus/I <sup>2</sup> C Devices                                 |
| LT1786F                                  | SMBus Controlled CCFL Switching Regulator                                     | 1.25A, 200kHz, Floating or Grounded Lamp Configurations                                                                                        |
| LTC1695                                  | SMBus/I <sup>2</sup> C Fan Speed Controller in ThinSOT™                       | 0.75Ω PMOS 180mA Regulator, 6-Bit DAC                                                                                                          |
| LTC1840                                  | Dual I <sup>2</sup> C Fan Speed Controller                                    | Two 100µA 8-Bit DACs, two Tach Inputs, Four GPIO                                                                                               |
| LTC4300A-1/<br>LTC4300A-2/<br>LTC4300A-3 | Hot Swappable 2-Wire Bus Buffers                                              | -1: Bus Buffer with READY, ACC and ENABLE<br>-2: Dual Supply Bus Buffer with READY and ACC<br>-3: Dual Supply Bus Buffer with READY and ENABLE |
| LTC4301                                  | Supply Independent Hot Swappable 2-Wire Bus Buffer                            | Supply Independent                                                                                                                             |
| LTC4301L                                 | Hot Swappable 2-Wire Bus Buffer with Low Voltage Level Translation            | Allows Bus Pull-Up Voltages as Low as 1V on SDAIN and SCLIN                                                                                    |
| LTC4302-1/<br>LTC4302-2                  | Addressable 2-Wire Bus Buffer                                                 | Address Expansion, GPIO, Software Controlled                                                                                                   |
| LTC4303/4                                | Hot Swappable 2-Wire Bus Buffers with Stuck Bus Recovery                      | Provides Automatic Clocking to Free Stuck I <sup>2</sup> C Busses                                                                              |
| LTC4305/6                                | 2 or 4-Channel, 2 Wire Bus Multiplexers with Capacitance Buffering            | 2 or 4 Selectable Downstream Buses, Stuck Bus Disconnect, Rise Time Accelerators, Fault Reporting, $\pm$ 10kV HBM ESD Tolerance                |
| LTC4307                                  | Low Offset Hot Swappable 2-Wire Bus Buffer with Stuck Bus Recovery            | 60mV Buffer Offset with 30ms Stuck Bus Timeout                                                                                                 |

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