

I2C Bus Pullup Resistor Calculation

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ABSTRACT

Pullup resistor calculation for I2C interface is a commonly asked question. In this application note we show how to use simple equations for this calculation.

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1 Introduction

I2C communication standard is the mostly widely used **inter-chip communication standard** in today's electronic systems. It is an **open-drain/open-collector communication standard** which implies integrated circuits (IC's) **with different voltage supply rails** can be connected for communication. Pullup resistors need to be connected from the I2C lines to the supply to enable communication as shown in [Figure 1](#). The pullup resistors pull the line high when it is not driven low by the open-drain interface. The value of the pullup resistor is an important design consideration for I2C systems as an incorrect value can lead to signal loss. In this article we show **the simple equations** for the pullup resistor calculation which the system designer can use to do quick calculations for their design.

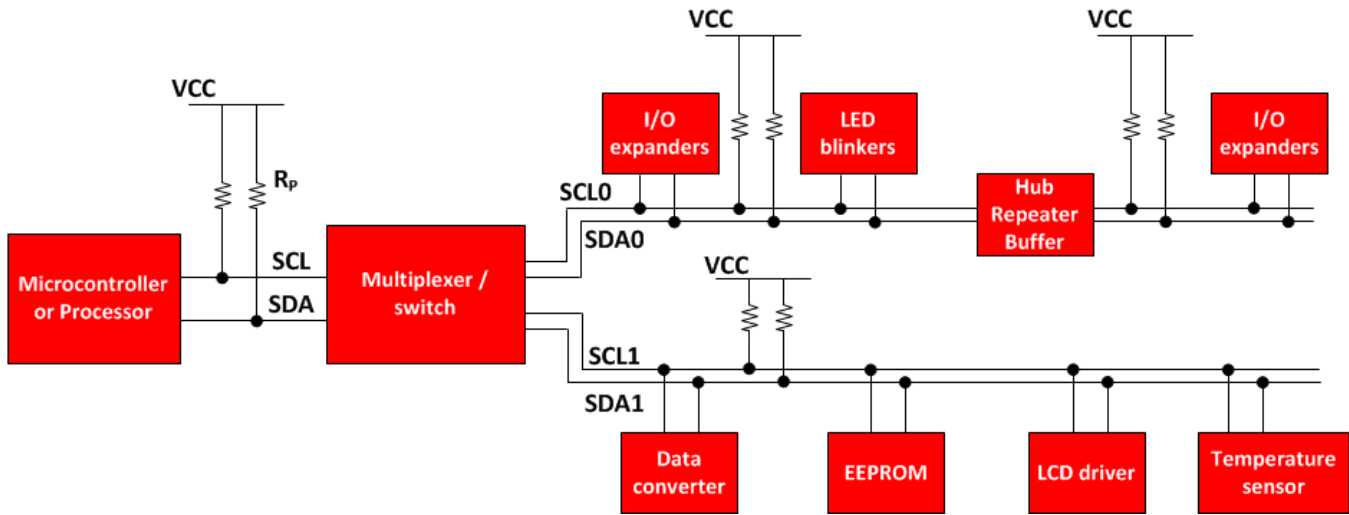


Figure 1. Application Example Showing I2C Communication Between the Different IC's on a System and With Pullup Resistors on I2C Bus

2 Pullup Resistor Calculation

A strong pullup (small resistor) prevents the I2C pin on an IC from being able to drive low. The V_{OL} level that can be read as a valid logical low by the input buffers of an IC determines the minimum pullup resistance $[R_P(\min)]$. $R_P(\min)$ is a function of V_{CC} , $V_{OL}(\max)$, and I_{OL} :

$$R_P(\min) = \frac{(V_{CC} - V_{OL}(\max))}{I_{OL}} \quad (1)$$

The maximum pullup resistance is limited by the bus capacitance (C_b) due to I2C standard rise time specifications. If the pullup resistor value is too high, the I2C line may not rise to a logical high before it is pulled low. The response of an RC circuit to a voltage step of amplitude V_{CC} , starting at time $t = 0$ is characterized by time constant RC . The voltage waveform can be written as:

$$V(t) = V_{CC} \times \left(1 - e^{-\frac{t}{RC}}\right) \quad (2)$$

For $V_{IH} = 0.7 \times V_{CC}$:

$$V_{IH} = 0.7 \times V_{CC} = V_{CC} \times \left(1 - e^{-\frac{t_1}{R_P \times C_b}}\right) \quad (3)$$

For $V_{IL} = 0.3 \times V_{CC}$:

$$V_{IL} = 0.3 \times V_{CC} = V_{CC} \times \left(1 - e^{-\frac{t_2}{R_P \times C_b}}\right) \quad (4)$$

The rise time for the I2C bus can be written as:

$$t_r = t_2 - t_1 = 0.8473 \times R_P \times C_b \quad (5)$$

The maximum pullup resistance is a function of the maximum rise time (t_r):

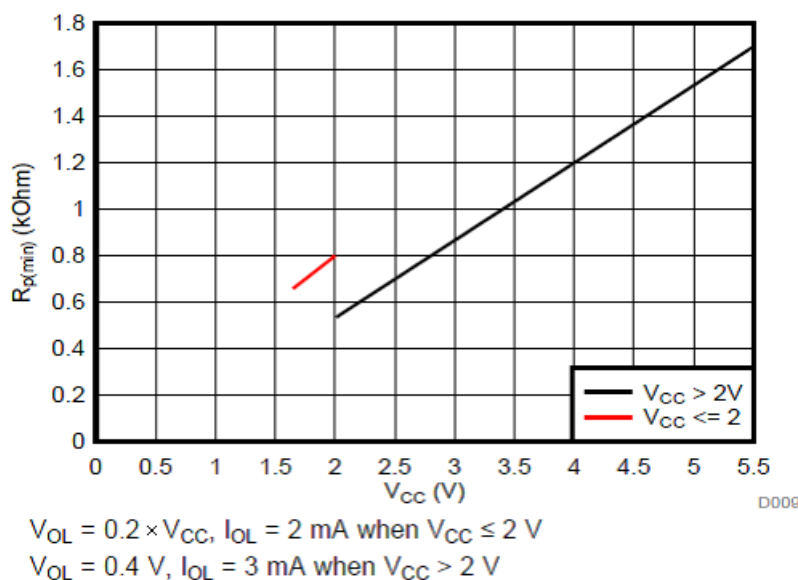
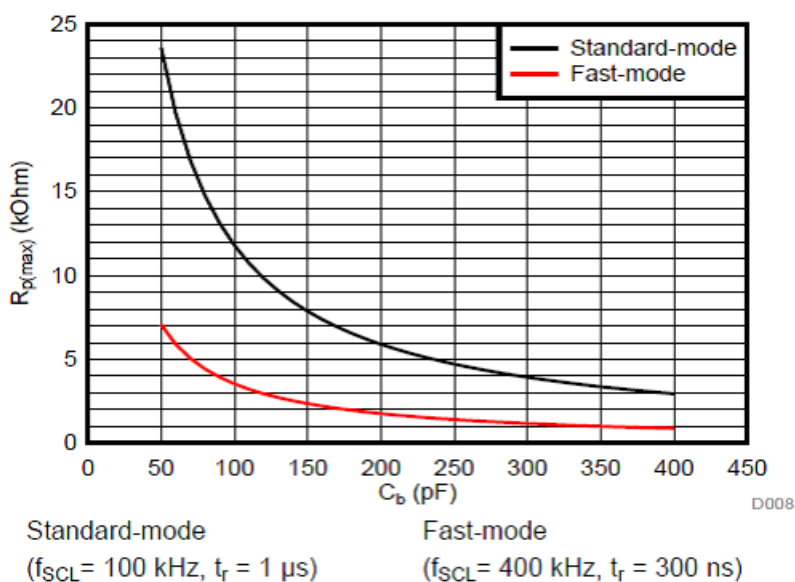
$$R_P(\max) = \frac{t_r}{(0.8473 \times C_b)} \quad (6)$$

where parametrics from I2C specifications are listed in [Table 1](#).

Table 1. Parametrics from I2C specifications

| Parameter | | Standard Mode (Max) | Fast Mode (Max) | Fast Mode Plus (Max) | Unit |
|-----------|--|---------------------|---------------------|----------------------|------|
| t_r | Rise time of both SDA and SCL signals | 1000 | 300 | 120 | ns |
| C_b | Capacitive load for each bus line | 400 | 400 | 550 | pF |
| V_{OL} | Low-level output voltage (at 3 mA current sink, $V_{CC} > 2$ V) | 0.4 | 0.4 | 0.4 | V |
| | Low-level output voltage (at 2 mA current sink, $V_{CC} \leq 2$ V) | – | $0.2 \times V_{CC}$ | $0.2 \times V_{CC}$ | V |

The R_p (min) is plotted as a function of V_{CC} in Figure 2. The R_p (max) is plotted as a function of C_b in Figure 3 for standard-mode and fast-mode I2C.


Figure 2. Minimum Pullup Resistance [R_p (min)] vs Pullup Reference Voltage (V_{CC})

Figure 3. Maximum Pullup Resistance [R_p (max)] vs Bus Capacitance (C_b)

3 Speed Versus Power Trade-off

Once the minimum and maximum value of the pullup resistor has been selected, the decision for the value of resistor can be made based on trade-off between the speed and power budget. A smaller resistor will give a higher speed because of smaller RC delay, and a larger resistor will give lower power consumption.

4 Example

For Fast-mode I2C communication with the following parameters, calculate the pullup resistor value.

$$C_b = 200 \text{ pF}, V_{CC} = 3.3 \text{ V}$$

Solution:

Taking the values from [Table 1](#):

$$R_P(\text{max}) = \frac{t_r}{(0.8473 \times C_b)} = \frac{(300 \times 10^{-9})}{(0.8473 \times 200 \times 10^{-12})} = 1.77 \text{ k}\Omega \quad (7)$$

$$R_P(\text{min}) = \frac{V_{CC} - V_{OL}(\text{max})}{I_{OL}} = \frac{(3.3 - 0.4)}{(3 \times 10^{-3})} = 966.667 \text{ }\Omega \quad (8)$$

Therefore, we can select any available resistor value between 966.667 Ω and 1.77 k Ω . The value of the pullup resistor can be selected based on the trade-off for the power consumption and speed.

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