Application Report
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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.

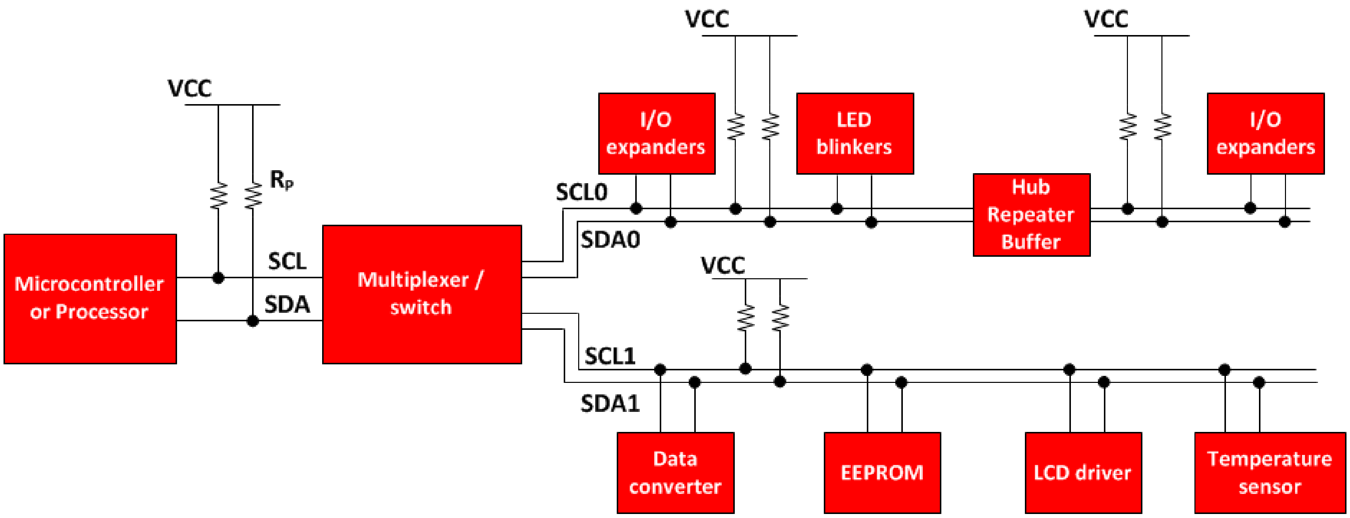

Figure 1. Application Example Showing I2C Communication Between the Different IC's on a System and With Pullup Resistors on I2C Bus

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}:

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

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:

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

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

$$V_{IH} = 0.7 \times V_{CC} = V_{CC} \times \left(1 - e^{\frac{-t1}{R_P \times C_b}}\right) \tag{3}$$

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

$$V_{IL} = 0.3 \times V_{CC} = V_{CC} \times \left(1 - e^{\frac{-t2}{R_P \times C_b}}\right) \tag{4}$$

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

$$t_r = t_2 - t_1 = 0.8473 \times R_p \times C_b \tag{5}$$

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

$$R_p(\text{max}) = \frac{t_r}{(0.8473 \times C_b)} \tag{6}$$

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.

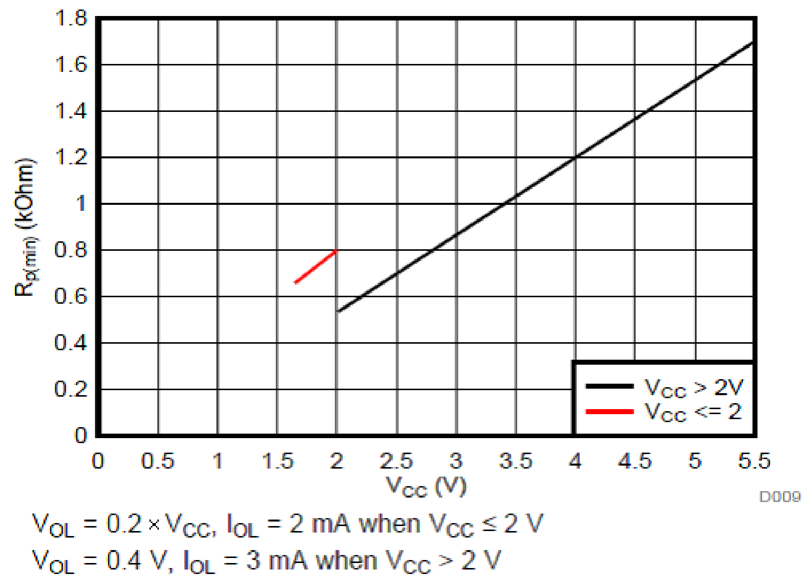

Figure 2. Minimum Pullup Resistance [R_P (min)] vs Pullup Reference Voltage (V_{CC})

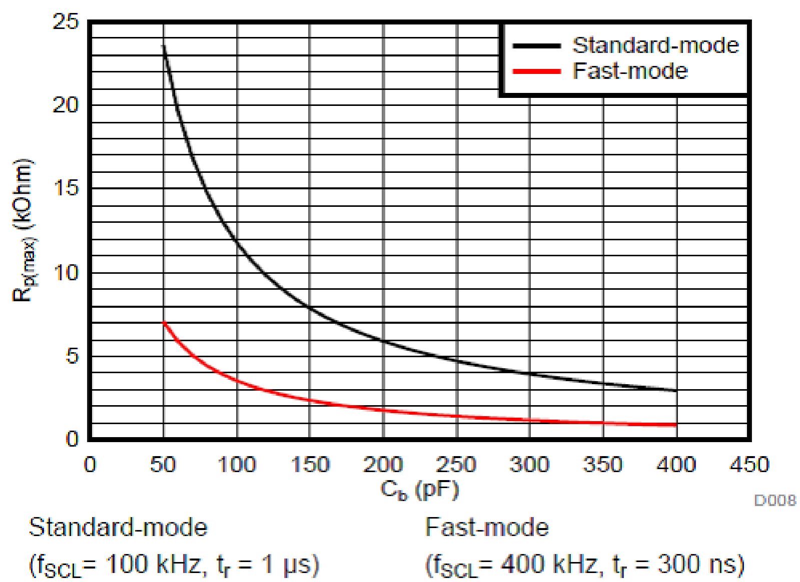

Figure 3. Maximum Pullup Resistance [R_P (max)] vs Bus Capacitance (C_b)

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 pF, V_{CC} = 3.3 V

Solution:

Taking the values from Table 1:

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

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

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

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