I²C Translator Pull-up Resisters: Internal vs. External?

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It is difficult to resist choosing an I²C translator with internal pull-up resisters (R_p) vs. external pull-up resisters. At first glance, an I²C translator with internal pull-up resisters reduces BOM and PCB space. However, a more critical examination of the I²C specification (UM10204 rev 03 – 19 June 2007) supports an argument for not integrating pull-up resisters into an I²C translator.

The I²C Specification:

The I²C specification (UM10204 Rev. 03 – 19, June 2007) defines the following fast-mode (400kbit/s) limits:

1. Maximum rise time of 300ns (30% - 70%)

2. Maximum number of I²C devices cannot exceed 400pF.

3. Maximum bus capacitance is 400pF.

4. Minimum IOL of 3mA during valid VOL's.

Meanwhile, the I2C specification <u>does not</u> define a minimum or maximum pull-up resister value.

$R_{P(max)}$ Sizing & I²C Bus Capacitance:

Unlike push-pull drivers, an I²C driver "let's go" for a logic high, and "pulls down" for a logic low. So, a low to high (LH, or rise time) transition is highly dependent on the RC time constant of the bus. Since bus capacitance is synonymous with the maximum number of slaves, you want the I²C segment capacitance to be able to grow (up to 400pF). So,

in order to add slaves (capacitance) to the bus, theoretically, you need lower R_p, or else you run the risk of exceeding the max rise time spec of 300ns.

Figure 29, of the I²C specification provides the relationship between bus capacitance and R_p. For example, a fast-mode (400 kbit/s) I²C bus segment with a fixed pull-up resistance of 10K ohm theoretically can't drive any capacitance at all without exceeding the 300ns maximum rise time, while a 2K R_p value can drive 200pF and 1K R_p permits 400pF. So, in terms of maximizing the number of I²C slaves per segment, a large R_p severely limits the number of I²C devices. In reality, the pull-up resister is a critical knob to optimize your I²C segment for bus capacitance vs. edge rate.

Summary

The I²C specification does not specify a min or max R_p value. This is because the I²C specification guides users to view the R_p as a knob for optimizing the I²C segment. As you increase the number of I²C slaves, the bus capacitance will increase. As the bus capacitance increases, the rise times increase, because open drain driver rise times are dominated by the RC time constant. In order to keep your rise times below 300ns, if the number of slaves is increasing, you need to lower the pull-up resister values. R_p flexibility is paramount. Therefore, it is preferable to choose I²C translators without integrated pull-up resisters.
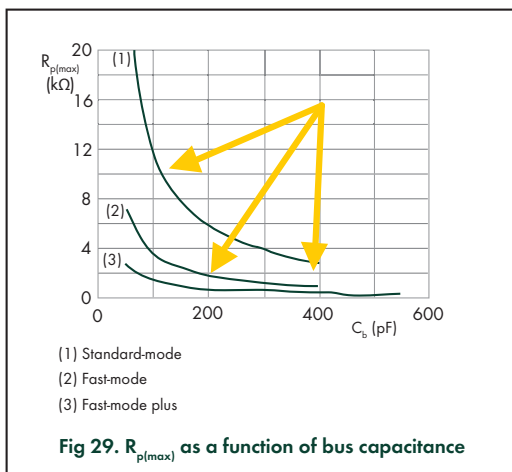

Fig 29. $R_{p(max)}$ as a function of bus capacitance

(1) Standard-mode
(2) Fast-mode
(3) Fast-mode plus