Optimizing the I2C Bus for Hall B’s RICH-II Hardware Interlock System

Tyler Lemon, Mary Ann Antonioli, Peter Bonneau, Aaron Brown, Pablo Campero, Brian Eng, George Jacobs, Mindy Leffel, Marc McMullen, and Amrit Yegneswaran

Physics Division, Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
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For the RICH-II hardware interlock system, Sensirion SHT35 sensors will use inter-integrated circuit (I2C) communication to acquire humidity and temperature data. This note discusses the optimization of the I2C bus, i.e. determination of the pull-up resistor value, needed to acquire data in the standard mode.

Sensirion SHT35 sensors will acquire the RICH-II temperature and humidity data at ~1 Hz. A single temperature and humidity reading requires the sbRIO to transmit or receive ~100 bits; therefore, the I2C standard acquisition mode suffices, Table I.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-level input voltage</td>
<td>-0.5 V</td>
<td>0.3 x Vcc</td>
</tr>
<tr>
<td>High-level input voltage</td>
<td>0.7 x Vcc</td>
<td>Vcc + 0.5 V or 5.5 V (whichever is lower)</td>
</tr>
<tr>
<td>Data transfer rate</td>
<td>100 kbit/s</td>
<td></td>
</tr>
<tr>
<td>Signal rise time (tr)</td>
<td>1 μs</td>
<td></td>
</tr>
</tbody>
</table>

TABLE I. I2C standard acquisition mode specifications. For RICH-II, Vcc = 3.3 V.

RICH-II’s hardware interlock system devices on the I2C communication bus pull down the voltage of a signal line to the voltage level required by the I2C bus, Table II. To define the voltage of the signal line when it is in its quiescent state, at the bus voltage level Vcc, each signal line must be connected via a pull-up resistor to the bus voltage. The pull-up resistor, in addition to defining the signal line voltage, protects the devices on the signal lines from over-current.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Voltage [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I2C bus voltage Vcc</td>
<td>3.3</td>
</tr>
<tr>
<td>I2C low level</td>
<td>0.4</td>
</tr>
<tr>
<td>I2C high level</td>
<td>0.7 x Vcc (2.3)</td>
</tr>
</tbody>
</table>

TABLE II. I2C bus specifications for RICH-II devices.

The pull-up resistor’s minimum value required for communication with the PCA9600 buffer driver on the I2C bus is determined by the device specifications, Table III. The value is ~18 Ω for the buffer drivers on the I2C bus, determined by

\[ R_{\text{min}}[\Omega] = \frac{(V_{\text{cc}} - V_{\text{OL}})}{I_{\text{OL}}} \] (1)

The pull-up resistor’s maximum value depends on the signal rise time tr and on the capacitance C of the I2C bus,

\[ R_{\text{max}}[\Omega] = \frac{t_r}{(0.8473 \cdot C)} \] (2)

For standard mode data acquisition, the specified maximum tr is 1 μs.

To measure the capacitance of the CAT7 cable that will be installed for the hardware interlock system, the cable was used as a capacitor in an RC circuit, Fig. 1. Toggling the normally-open push button switch made the current flow through the 1-kΩ resistor, charging the cable. The oscilloscope triggered on the rising voltage. From the oscilloscope trace, Fig. 2, the circuit’s RC time constant r was determined.

Table IV shows r and the cable capacitance for each cable length tested. The measured capacitance of the CAT7 cable is ~27 pF/ft.

Equation 2 can be recast to be dependent on cable length L,

\[ R_{\text{max}}[\Omega] = 10^{4}/((0.8473 \cdot (27 \times 10^{-12}) \cdot L)) \]

\[ = 43710/L \] (3)
For RICH-II, the maximum cable length between the sbRIO (I2C controller) and SHT35 sensors is anticipated to be ~100 ft. From Eq. 3, this results in a maximum pull-up resistor value of ~440 Ω.

The pull-up resistor that will be used for RICH-II is 300 Ω. Using 300-Ω pull-up resistors ensures the I2C communication will work for cable lengths up to ~150 ft. and that the communication lines’ current will be below the current rating for the PCA9600 buffer driver.

In summary, for the optimization of the RICH-II hardware interlock system’s I2C communication to Sensirion SHT35 sensors, pull-up resistors of 300 Ω should be used; this value for the pull-up resistor makes I2C communication possible even for 150-ft. long cables.