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

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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 [1, 2, 3, 4, 5, 6]. 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 [7] suffices, Table I.

Specification	Minimum	Maximum
Low-level input voltage	-0.5 V	0.3 x V_{CC}
High-level input voltage	0.7 x V_{CC}	V_{CC} + 0.5 V or 5.5 V (whichever is lower)
Data transfer rate		100 kbit/s
Signal rise time (t_r)		1 µs

TABLE I. I²C standard acquisition mode specifications. For RICH-II, V_{CC} = 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 V_{CC}, 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.

Specification	Voltage [V]
I²C bus voltage V_{CC}	3.3
I²C low level	0.4
I²C high level	0.7 x V_{CC} (2.3)

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

The pull-up resistor's minimum value required for communication with the PCA9600 buffer driver [8] 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

$$R_{min}[\Omega] = (V_{CC} - V_{OL}) / I_{OL}. \quad (1)$$

Specification	Value
Voltage when pulling output low (V_{OL})	1 V
Current sink when pulling output low (I_{OL})	130 mA
Supply voltage (V_{CC})	3.3 V

TABLE III. PCA9600 buffer driver specifications.

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

$$R_{max}[\Omega] = t_r/(0.8473 \cdot C). \quad (2)$$

For standard mode data acquisition, the specified maximum t_r 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 τ was determined.

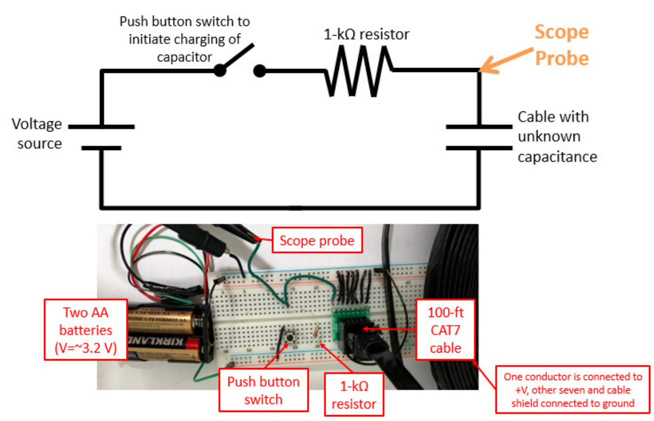

FIG. 1. RC circuit used to determine cable capacitance. Top is schematic diagram. Bottom is realization. Test circuit was verified to result in correct capacitance by testing with capacitors of known values of 10 nF and 10 µF.

Table IV shows τ 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,

$$R_{max}[\Omega] = 10^{-6}/(0.8473 \cdot (27\times10^{-12}) \cdot L) = 43710/L. \quad (3)$$

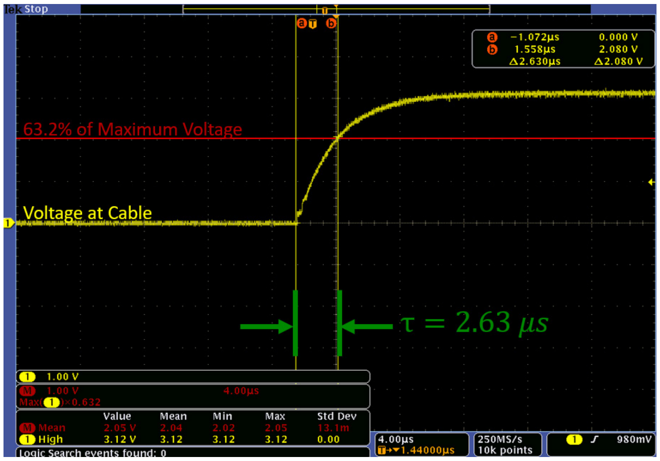

FIG. 2. Screenshot from oscilloscope showing voltage trace of cable as it is being charged.

Cable length [ft]	τ [µs]	Capacitance [nF]
1	0.0286	0.0286
50	1.26	1.26
100	2.63	2.63

TABLE IV. Observed τ and calculated cable capacitance.

Figure. 3 is a plot of pull-up resistor values vs. cable length.

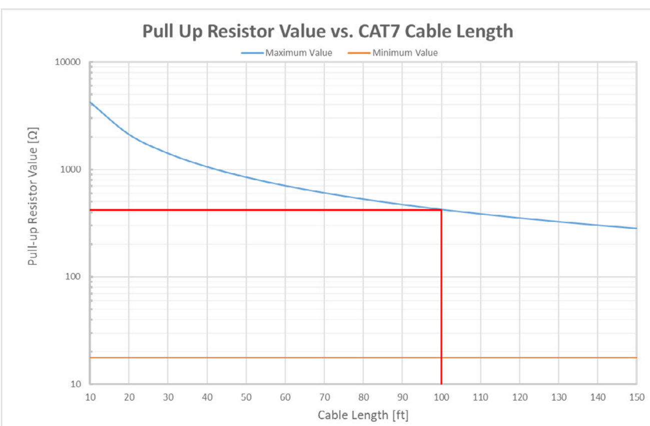

Fig. 3. Plot of maximum and minimum pull-up resistor values vs. CAT7 cable length. The plot of maximum value, blue line, is created using Eq. 3. The plot for the minimum value, orange line, is created using Eq. 1.

For RICH-II, the maximum cable length between the sbRIO (I^2C 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 I^2C 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 I^2C communication to Sensirion SHT35 sensors, pull-up resistors of 300 Ω should be used; this value for the pull-up resistor makes I^2C communication possible even for 150-ft. long cables.

[1] Peter Bonneau et al., *Proposed Integrated Temperature and Humidity Digital Sensor for the RICH Detector*, DSG Note 2019-12, 2019.

[2] Peter Bonneau, et al., *Proposed Controller for the Readout of the Temperature and Humidity Digital Sensors Sensirion SHT85 Envisioned for the RICH Detector*, DSG Note 2019-27, 2019.

[3] Peter Bonneau, et al., *Development of Data Acquisition to Read out Sensirion SHT85 Temperature and Humidity Sensors for the RICH Detector*, DSG Note 2019-31, 2019.

[4] Peter Bonneau, et al., *FPGA Command Engine Development for the RICH Hardware Interlock System*, DSG Note 2020-02, 2020.

[5] Peter Bonneau, et al., Data Acquisition System for the Sensirion Humidity and Temperature Sensors, DSG Note 2020-10, 2020.

[6] Peter Bonneau, et al., *Proposed Temperature and Humidity Digital Sensors for Interlock System of Detector Hardware*, DSG Note 2020-28, 2020.

[7] NXP Semiconductors, *I^2C-bus Specification and User Manual – Rev. 6*, 4/ 2014.

[8] NXP Semiconductors, *PCA9600 Dual Bidirectional Bus Buffer – Rev. 6*, 9/2015.