Application Report
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Advantages and Design Considerations of the TCA980x Family

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ABSTRACT

The TCA980x family of I^2C level-shifters have many new and exciting features which help improve signal integrity, communication with more non-compliant I^2C devices, improve power consumption, support lower supply voltages, and reduce BOM cost.

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1 Advantages of the TCA980x Family Over a Traditional Buffer

The TCA980x family of level-translating buffers have many features to improve the system reliability and cost.

1.1 Integrated Current Source

Figure 1 shows the internal block diagram of the TCA980x family, highlighting the internal B-side current source.

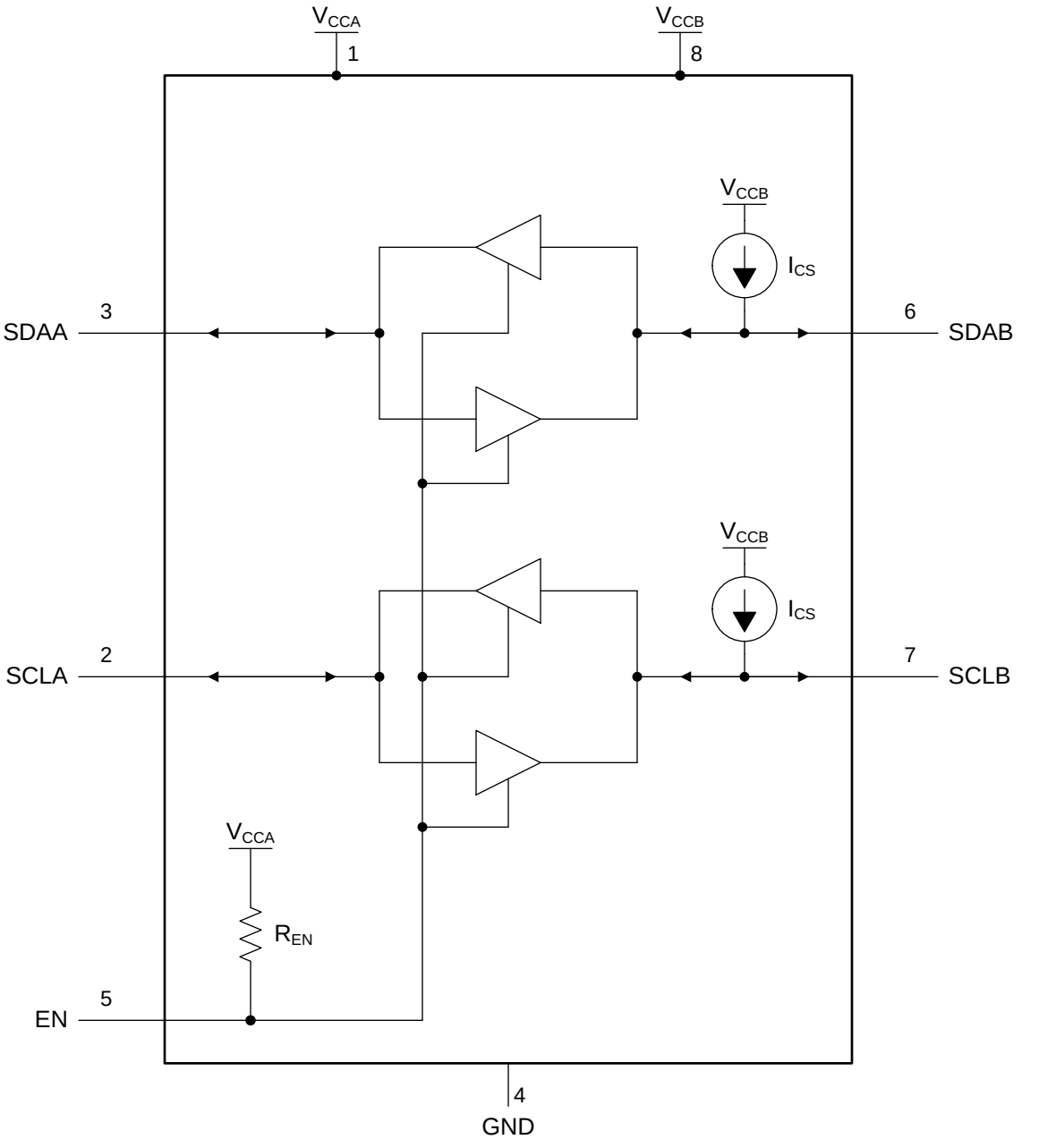

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Figure 1. Internal Block Diagram of the TCA980x

By integrating a current source into the B-side pins, the rise time of the bus is faster and flatter compared to using a pullup resistor. For more information and examples, see Section 2.1.

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1.2 Output Low Voltage (V_{OL})

A common issue with I^2C peripherals is that the output low voltage (V_{OL}) may not be low enough on a device to meet the input low voltage (V_{IL}) requirement of another peripheral. Figure 2 shows a plot of standard I^2C input voltage thresholds. The solid gray regions are valid areas, and the red region in the middle is the invalid area. Input state is undefined inside of the striped red region, so make sure that the signals to the peripheral are within the allowed range.

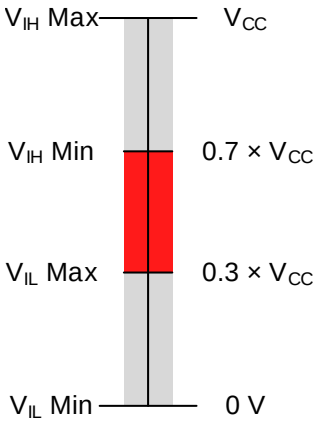

Figure 2. Normal I^2C Input Thresholds

It is desirable to have an output high signal (V_{OH}) from a peripheral be as close to the V_{CC} of the receiving peripheral as possible, and likewise with a output low signal (V_{OL}) as close to 0 V as possible. Figure 3 shows a 0.5 V V_{OL} of an example device on top of the input threshold region graphic. For this specific example, the assumption is that V_{CC} = 1.8 V, where 30% is 0.6 V. This system operation is valid, because the V_{OL} from another device is within the V_{IL} region of the receiving device. Note that while this operation is within the recommended conditions, it is marginal, with only 0.1 V of margin between the V_{IL} maximum and the V_{OL}.

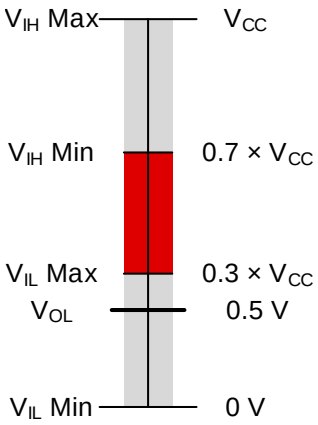

Figure 3. V_{OL} Within Valid V_{IL} Region

VOL communication issues may occur when the V_{OL} (or V_{OH}) are not within their valid V_{IL} or V_{IH} regions. In I^2C, it is most common with V_{OL}, since the peripheral attempting to transmit a low must pull the entire bus low. There are two main reasons that a V_{OL} would be outside of the valid V_{IL} region:

- V_{OL} of the transmitting peripheral is high, it might be higher than the V_{IL} max of the device.
- V_{IL} max of the receiving peripheral is low, it might be lower than the V_{OL} of the transmitting device.

With some receiving peripherals, this V_{IL} max is set artificially low (0.4 V), and can cause issues with any device that transmits a V_{OL} > 0.4 V. Figure 4 shows such an example where the V_{IL} max of the receiving device is at a fixed threshold, and somewhat low. In this situation, there is likely to be communication issues between the transmitting and receiving devices because the V_{OL} is in the undetermined region.

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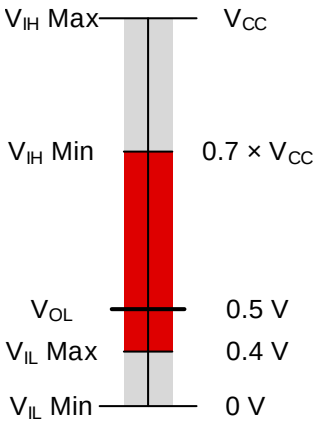

Figure 4. V_{OL} Outside of Valid V_{IL} Region

This V_{OL} and V_{IL} mis-match is common, especially when a buffer device with a voltage offset is used. Most of these common buffers will have a fixed V_{OL} output of 0.5 V. The TCA980x helps with these issues by providing a very low V_{OL} signal on both the A and B sides. The A-side typical value is below 0.1 V and the B side typical V_{OL} is 0.2 V

1.3 Power Consumption

Power consumption is a growing concern among system designers, who require more speed, but are also expected to improve battery life. The TCA980x family features a significant improvement in power consumption.

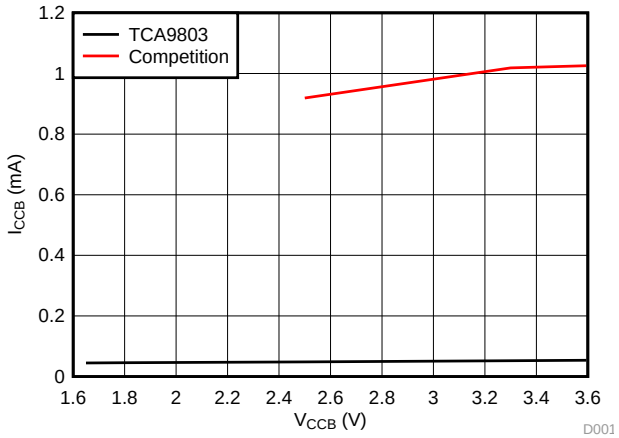

Figure 5. Typical Idle Supply Current (I_{CCB}) Across V_{CCB}

Figure 5 shows the I_{CCB} curve of the TCA9803 and a common competitor device for an idle bus. There is a significant power consumption difference shown by the plot, which also shows that the TCA980x family can operate down to 1.65 V.

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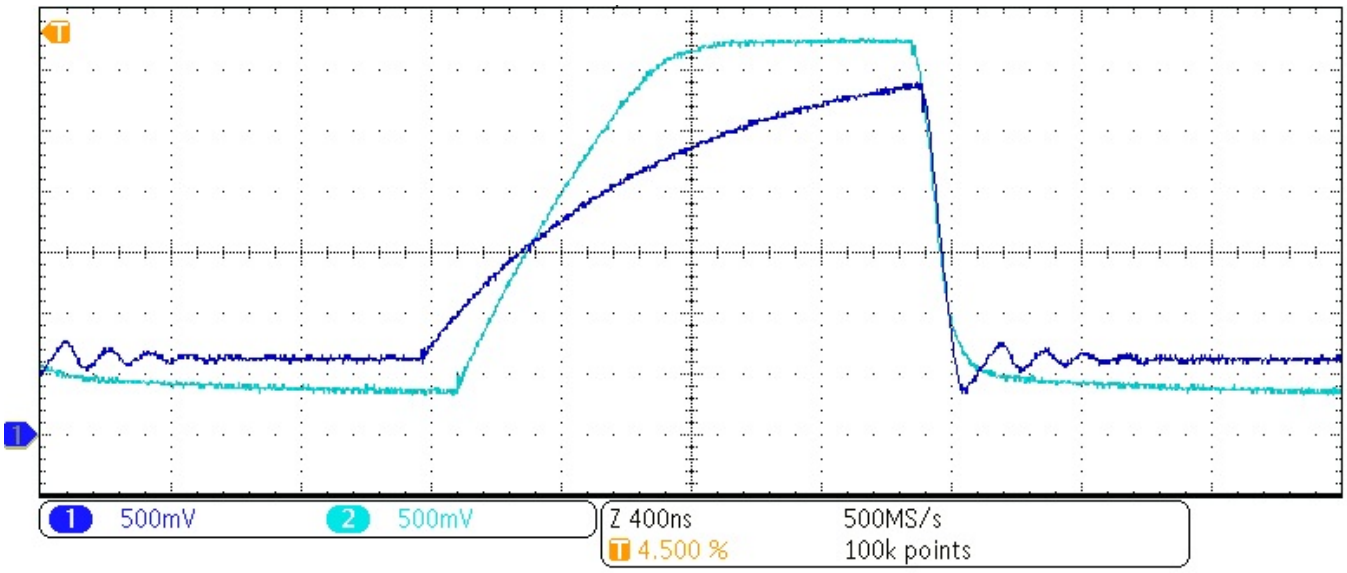
2 Common I²C Bus Design Issues

This section deals with some common issues while designing an I²C system.

2.1 Buffering High Capacitance Load Causing Slow Rise Times

In a large I²C system with many peripherals or a long board trace, the large capacitance load can slow down the rising edge, since a pullup resistor will pull the bus high. As shown in Figure 1, the TCA980x family integrates a current source. Normally, this can be corrected by decreasing the pullup resistor value, increasing the input low level (I_{OL}) current. A trade-off to increasing the I_{OL} current is that the output low voltage (V_{OL}) of the system is generally increased, since total current flowing through the bus is increased to drive the higher capacitance. Notably, when VOL increases, the possibility of communication issues increases, as explained in Section 1.2. With a constant current source, the signal rises faster as compared to an equivalent pullup resistor value, since the drive current is constant.



(1) TCA9802 channel 2 (light blue); Competition channel 1 (dark blue)

(2) C_L = 400 pF for both devices

(3) R_{PU} = 1.8 kΩ for competition device only

(4) f_{SCL} = 400 kHz

(5) V_{CC} = 3.3 V

Figure 6. TCA9802 vs Competition (With Pullup Resistor)

As shown in Figure 6, the light blue trace (channel 2) is the TCA9802, and the dark blue trace (channel 1) is a competition solution using a pullup resistor. While the load and nominal drive strength of the devices are similar, the waveforms are very different. The constant current waveform models straight line up to the rail voltage quickly. In this waveform, the t_r for TCA9802 is about 270 ns, and about 700 ns for the pullup resistor competition device. The I²C specification limits the rise time to no slower than 300 ns for 400 kHz operation. Also note that the pullup resistor competition solution does not meet the I²C specification rise time, or high time requirements.

Another thing to note as a difference in the waveform, is that the falling edge of the TCA980x on the B-side has slew rate control

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3 TCA980x Family Considerations

3.1 FET or Pass-Gate Translators

Some translators are based on pass-gates for translation support. In most of the use cases, external pullup resistors are required to pull the bus to the voltage rail.

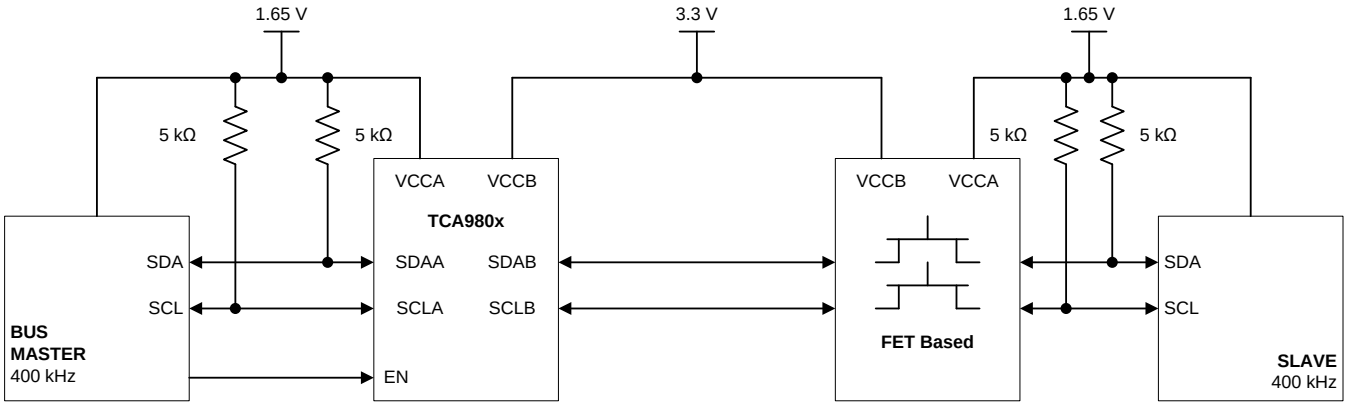

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Figure 7. Incorrect B-Side Pass-Gate Based Translator Use Case

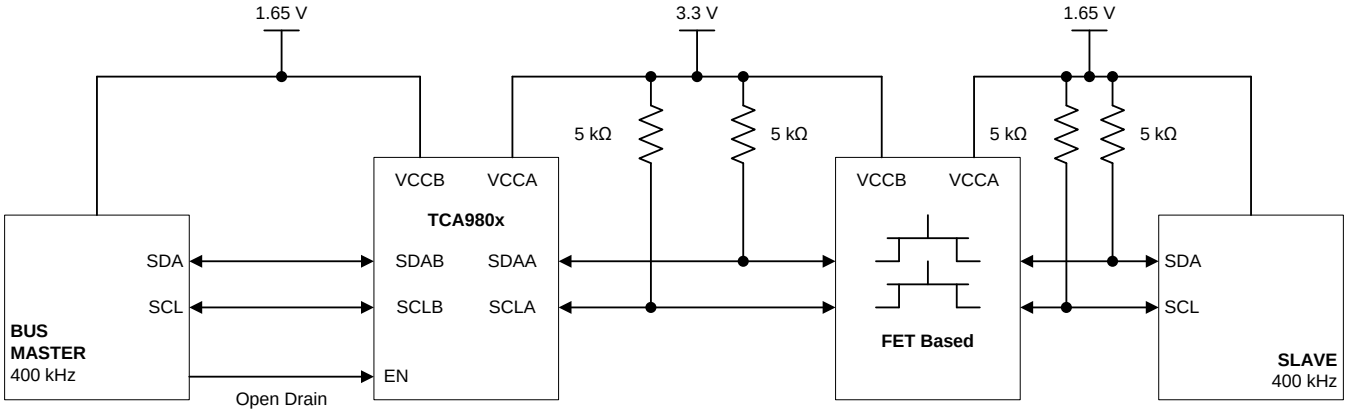

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Figure 8. A-Side Pass-Gate Based Translator Use Case

As shown in Figure 7, it may appear that this use case is valid, but actually it is not. When either the TCA980x B-side or the slave pull down on the bus, the FET isolating the bus closes (low R_{DS_ON}) and current from the 5-kΩ resistor is observed by the TCA980x, violating I_{EXT-I}. See the TCA980x datasheet for more information.

Figure 8 shows the correct way to pair with a FET base translator (connecting to the A-side).

Rather than using a FET-based translator, using a buffered translator is recommended, such as another TCA980x or a TCA9517. See the TCA980x datasheet for more information on concerns with B-side connections to buffered translators.

3.2 Buffered Translators and Level-Shifters

The TCA980x family supports connections with buffered translators, but care must be taken to ensure that no operating conditions be violated. In a general sense, the following must be avoided on the B-side ports of the TCA980x:

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- Sources of current other than the individual TCA980x (B-side of the other TCA980x, external pullup resistors, current sources, rise time accelerators, and so forth)
- Static-voltage offset buffer outputs (B-side of the TCA9517, and so forth)
- Outputs with R_{ILC} (equivalent pull-down resistance) > 150 Ω

Importantly, these special operating requirements apply only to the B-side ports of the TCA980x. For example, the TCA9517 B-side can be safely connected to the A-side of the TCA980x, but not to the B-side of the TCA980x. However, the A-side of the TCA9517 can be connected to the B-side (or A-side) of the TCA980x, because the A-side does not have a static voltage offset based output.

Figure 9 shows an example of the incorrect connection on the B-side to a buffer with a static voltage offset output. The reason this is unacceptable is because the equivalent output resistance of the output buffer is greater than the maximum R_{ILC} allowed. See the TCA980x datasheet for more information.

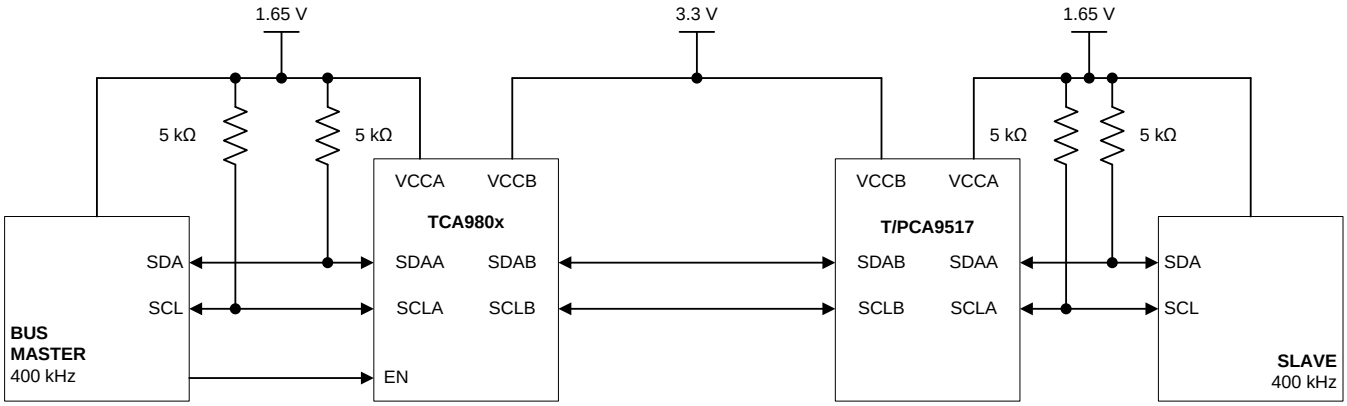

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Figure 9. Incorrect B-Side Static Voltage Offset Buffer Connection

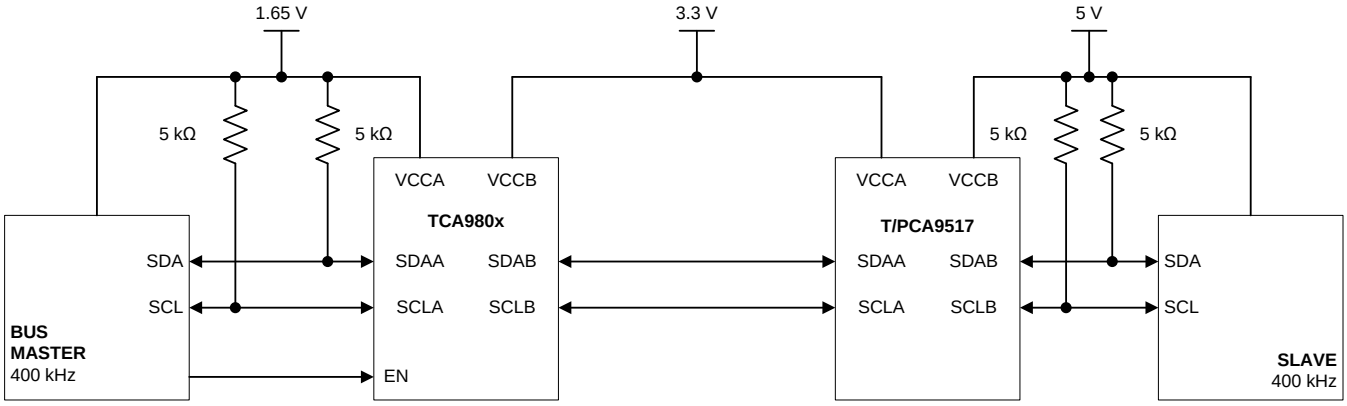

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Figure 10. Correct Connection With Other Buffers

NOTE: Decoupling capacitors are not shown to keep the illustration simple. Decoupling capacitors (1 µF and 0.1 µF) must be placed close to each power supply pin.

As shown in Figure 10, this connection is acceptable for use on the B-side ports of the TCA980x, because the equivalent R_{ILC} of the A-side of this example buffer is less than 150 Ω.

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