An Unofficial SoftWire User's Guide, Version 1.0.0

By R. G. Sparber

Purpose

Provide an understanding of SoftWire that will enable you to go from a device's spec sheet to a set of SoftWire function calls. This journey takes you from timing diagrams through voltage waveshapes and into software. Then I take a sample spec sheet and turn it into a driver.

This document is a work in progress. I welcome your comments and suggested corrections.

Overview

SoftWire provides the functions to

- place information into a transmit buffer,
- process the transmit buffer as it sends this information to a designated slave,
- request information from a slave,
- collect that information and put it into a receive buffer,
- and read information from this receive buffer

Ways to Use This Document

If you wish to have the same understanding of SoftWire as I do, read this document sequentially. If you just want to create I2C device drivers, read the Creating a Driver section. If anything is confusing, refer to the corresponding section. If that doesn't help, contact me at rgsparber@AOL.com.

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Creating a Driver

These steps should guide you in creating a driver for your selected device. Reading the example on page 33 may help you see how this works.

1. Find the spec sheet for the I2C device you wish to drive.
2. Identify if it expects 5 volt or 3.3 volt logic levels. Only connect it to an I2C bus with devices from the same voltage family. Furthermore, be sure that the total pull-up resistance is around 4.7K. Some breakout boards include optional pull-up resistors; you do not want more than one pair active on a bus.
3. Study the spec sheet carefully to find
   a. The device's 7 bit address. This is sometimes called its base address.
   b. What commands must you send the device, and how many bytes are returned? For example, a command to read temperature may return two bytes.
   c. I assume your spec sheet contains one or more sequence diagrams showing what must pass between master and slave to accomplish the stated task. If it is in text, draw your sequence diagrams.
4. For each sequence diagram
   a. Match the sequence of a SoftWire command to a segment of your sequence diagram. Pay close attention to the TransmissionInProgress flag state.
   b. Form a list of these commands.
   c. Place these commands into your code with tests, as needed, to prevent a faulty sensor from stopping execution.

Background

I have never liked using libraries that I don't understand. Recently, I needed to interface with an I2C device using SoftWire. Finding a library that included my device wasn't difficult, but it was designed for the built-in hardware I2C bus. I looked at the code, but it used many programming techniques that were foreign to me. I wanted to find a more straightforward and understandable way. I tried to use the functions defined for SoftWire.

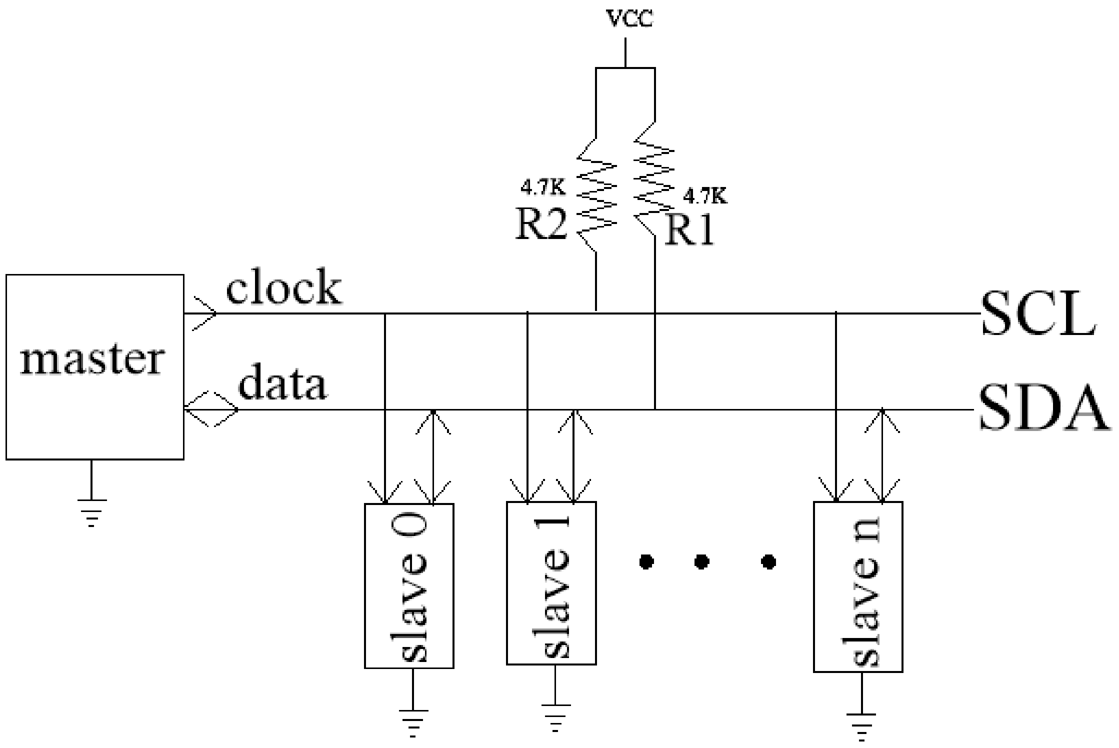
The Reference section of Arduino provides a list of SoftWire functions, but I could not find anything like a User's Guide, so here is my attempt. It is based on studying the SoftWire.cpp and SoftWire.h files, plus applying this understanding to a driver for an I2C temperature sensor. All software was developed on a Sparkfun Pro Micro using the Arduino Integrated Development Environment. I used Notepad++ for code editing.

If you are unfamiliar with I2C, I suggest you read this excellent document.

If you go to SoftWire, you will find a lot of software development-focused documentation. Maybe I missed it, but I couldn't find anything telling me how to use these functions to control an I2C device. Thankfully, SoftWire.h and SoftWire.cpp were clear enough for me to follow, given my level of software sophistication. The acid test was when I successfully applied this newfound understanding to writing a driver for the Si17021 Humidity and Temperature sensor that would read back temperature.

Contents

The Physical Layer

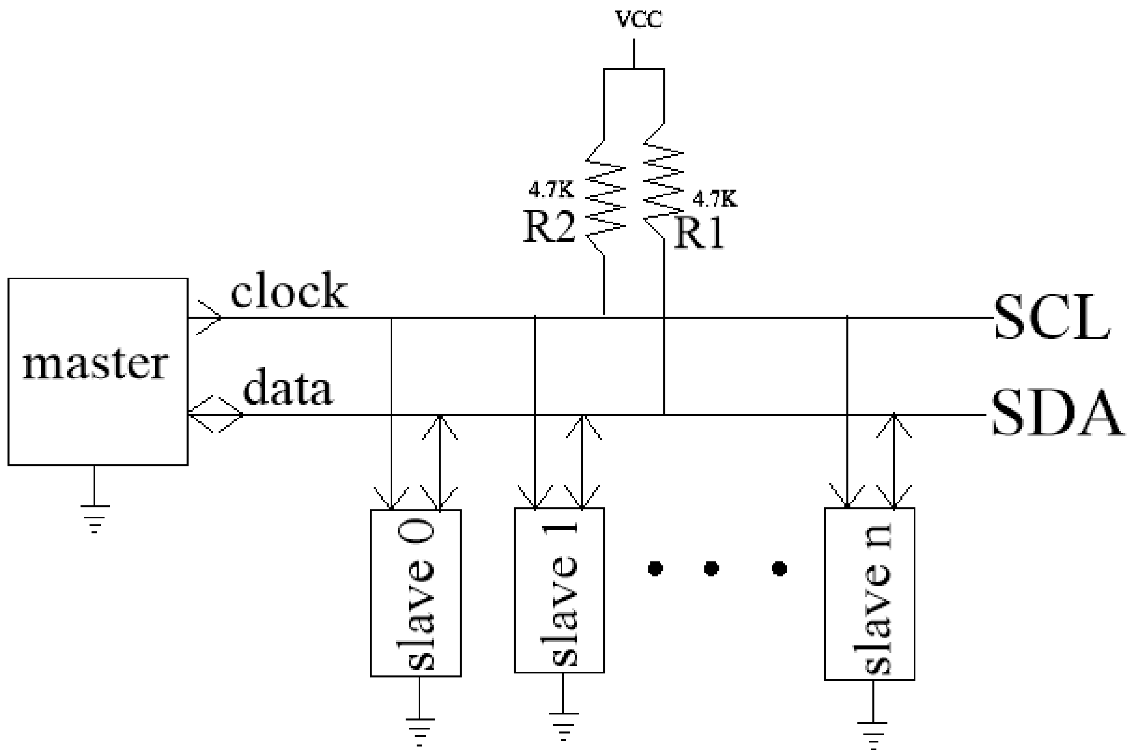


The I2C bus consists of a Serial Clock lead (SCL) and a Serial Data lead (SDA). If any boxes pull down on a lead, a logic 0 results. If no boxes are pulling down, you get a logic 1.

At any given time, there can only be one “master.” During a communication session, the master sources clock to all “slaves” as shown by the arrows going from the master to all the slaves. The master can dialog with any slave by calling the unique address built into each slave. When called upon, any slave can use the clock to place data on the SDA line.

From a software standpoint, a maximum of 127 slaves can exist on one I2C bus. Due to electrical[2] and failure mode constraints[3], this number is typically fewer than 10.

[2] The longer the wires carrying clock and data, the more capacitance exists from each conductor to ground. This capacitance and its related pull-up resistor form an RC circuit. If you try to run the clock too fast, the resistor cannot charge up the capacitance fast enough to reach a logic 1. See Appendix I, page 34 for details.
[3] You can image the difficulty of find which of 127 devices was pulling down on the clock or data lead because it was faulted.



From an electrical standpoint, when the master or a slave wants to send a logic 0, it pulls that lead to ground. When the master and all slaves are not pulling to ground, the lead can rise up to a logic 1 thanks to the pull-up resistors R1 and R2, which connect to a voltage source, VCC.

You may find that some I2C breakout boards have pull-up resistors with the option of disconnecting them. You do not want more than one set of pull-up resistors on a given I2C bus.

Notice that the pull-up resistors connect to VCC, usually the symbol for the device's power supply. In most cases, the voltage used to set logic 1 via the pull-ups is the same as the device's power supply voltage. For example, you can have a 5 volt powered device, and it expects to see a logic 1 equal to 5 volts. Consult the spec sheet for your device to be sure.

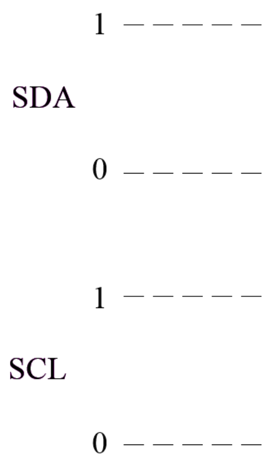
All I2C devices recognize ground as a logic 0 regardless of the supply voltage.

What do you do if some devices need 5 volt logic and the rest need 3.3 volt logic? You will need two I2C buses.

What do you do if you have two slaves with the same address? You will need two I2C buses to prevent them from responding simultaneously.

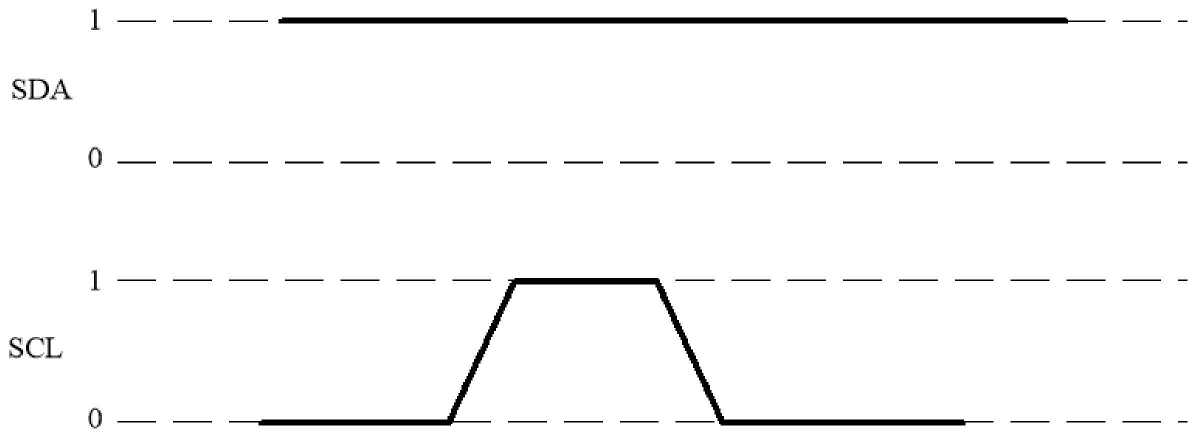
Most Arduino-compatible computers have only one hardware-based I2C bus, so you may be looking into SoftWire for extra I2C busses. It permits you to have many I2C buses. For every two GPIO pins, you get one I2C bus. You can only have one of these buses active at a time, but that is a small price to pay.

Ones, Zeros, and More

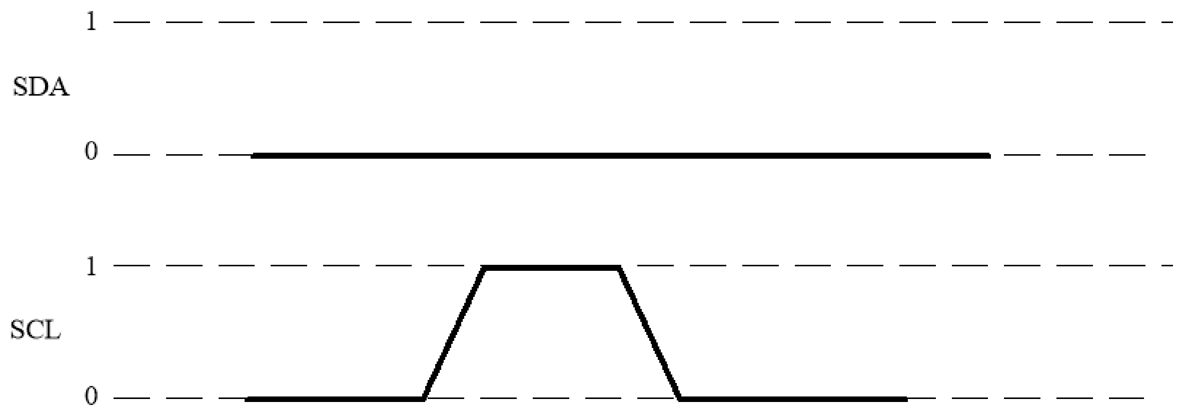


Serial Clock and Serial Data can each have only two values in the world of digital hardware: logic 0 or logic 1.

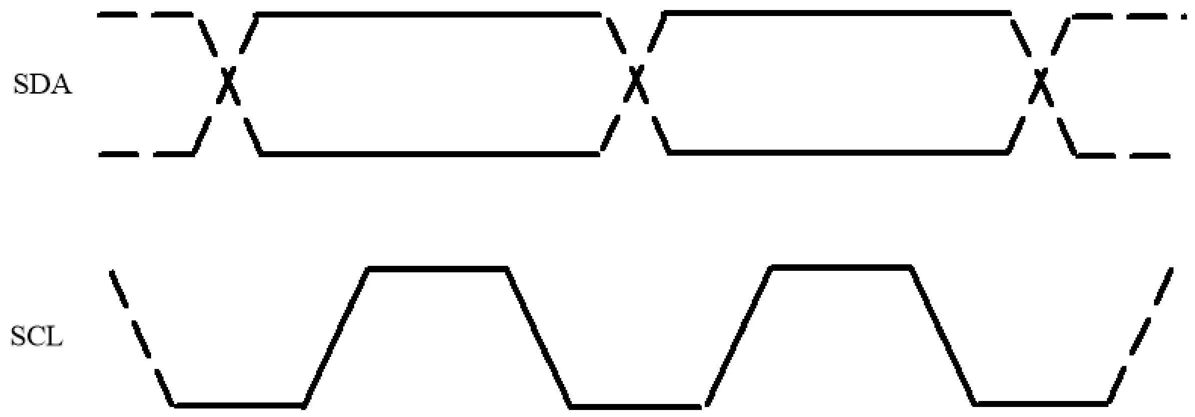
We use SDA's and SCL's logic 0 and 1 states to convey bits. A 1 is present when SDA is at logic 1, and SCL goes through the sequence logic 0 – logic 1 – logic 0. This sequence on SCL is called a clock pulse.



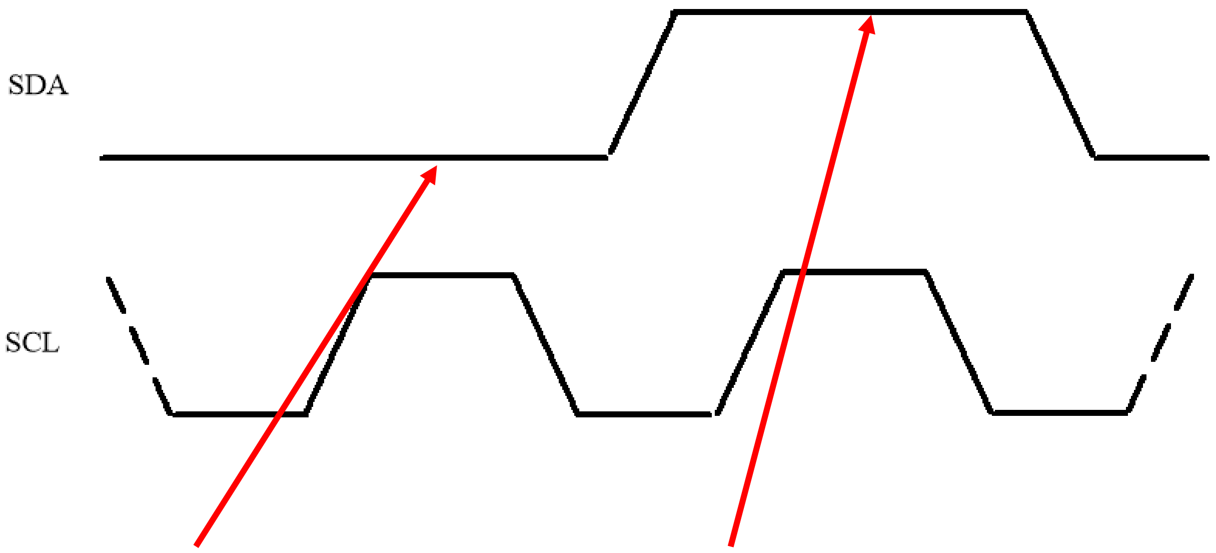
If SDA was at logic 0 during a clock pulse, a 0 is present.



The digital value only exists when the clock is at logic 1. During this time, SDA must be steady. SDA changes when SCL is at logic 0.

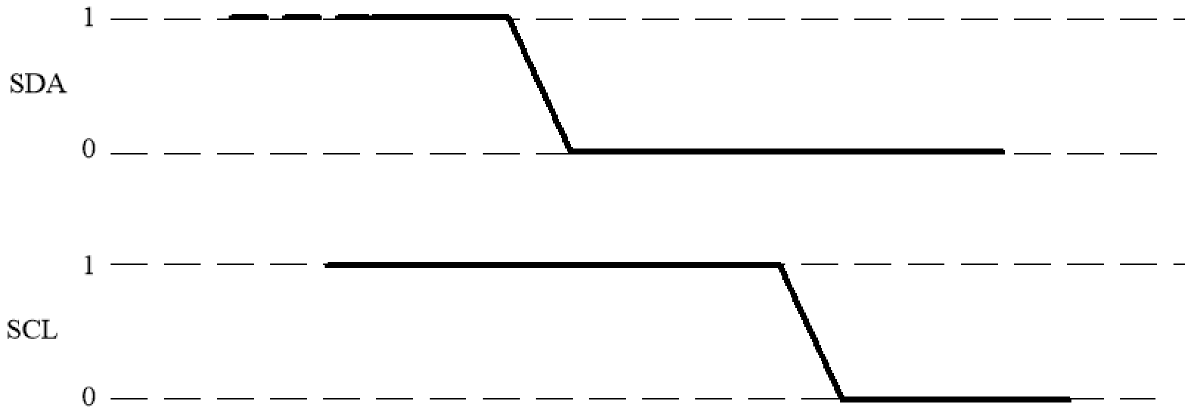


To transmit 01, we would see

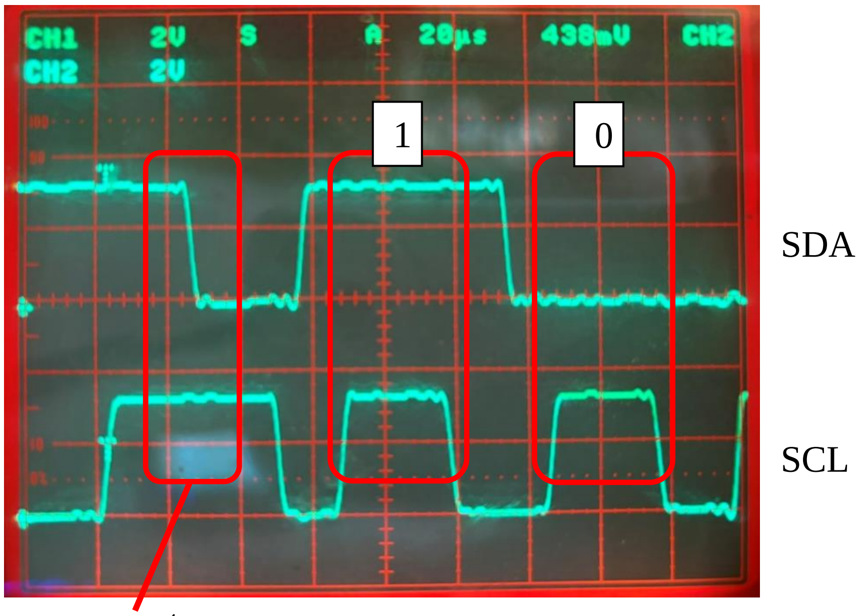


SDA is at logic 0 for the first clock pulse and logic 1 for the second. If you understand the rules so far, you know that SDA will not change while SCL is high.

To signal the start of a series of bits, we use a "START condition."



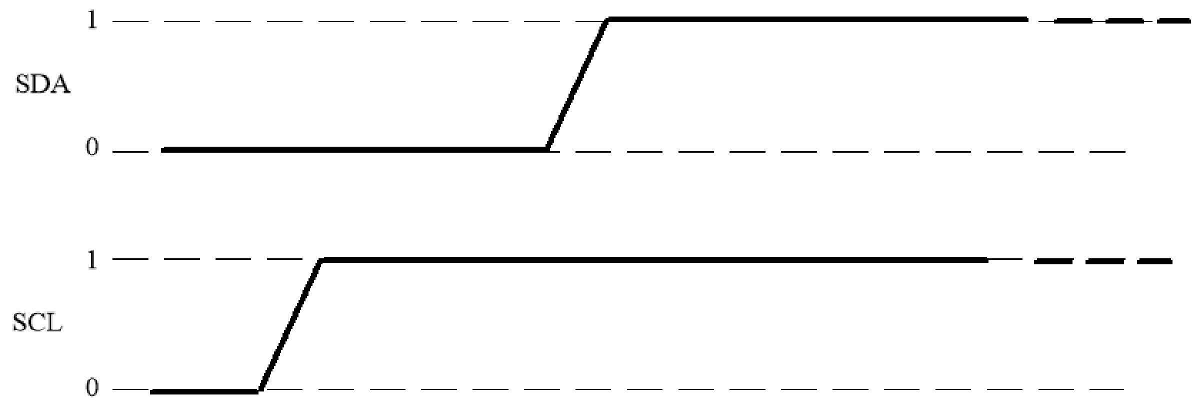
When SDA changes from logic 1 to logic 0 while SCL is high, we get a START condition. In the standards, START is marked with an "S." If subsequent START conditions occur, they can be marked with "Sr" or simply "S."



First[4], we have the START condition. Followed by 10.

[4] The picture was taken with an iPhone of a Tektronix 2430A osilloscope.

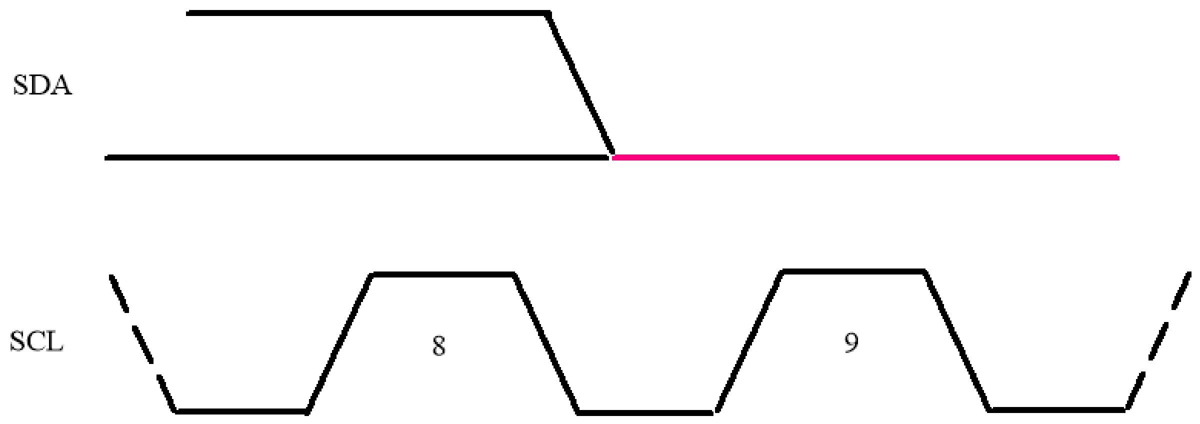
Similarly, we need a way to signal the end of a series of bits, a STOP condition.



When SDA changes from a logic 0 to a logic 1 while SCL is at logic 1, we have a STOP condition.

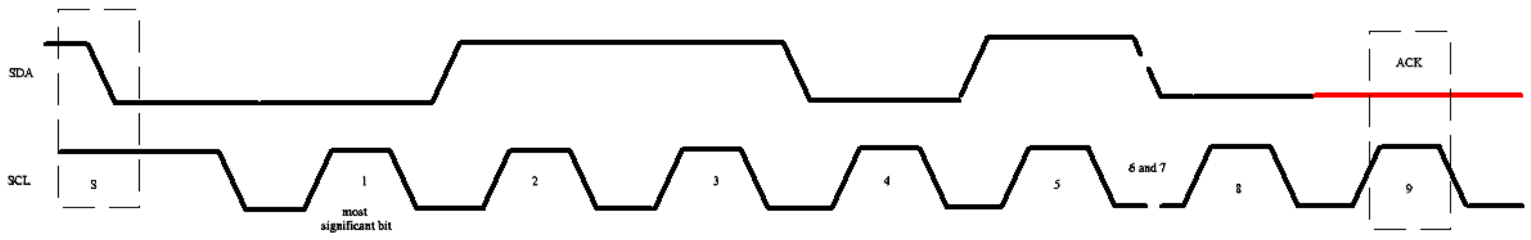
In the standards, STOP is designated with a "P."

There is one more piece to this puzzle. After eight bits, the receiver takes control of the SDA lead for an acknowledgment (ACK) that it received the previous byte.



During clock pulse 8, SDA can be a logic 0 or 1. Then, whoever sent those bits changes from driving the SDA line to listening to it. The end that received the byte changes to driving the SDA line (in red) and sets it to logic 0 to indicate ACK. If the receiver doesn't successfully receive the byte, it is clueless, so it remains in the listening mode, causing the pull-up resistors to put a logic 1 on SDA. This is called No-ACK or NACK.

Time to put this all together.



Before bits start to fly, SDA and SCL are sitting at logic 1 because neither the master nor any slaves pull it down to logic 0. Then, the master pulls SDA to logic 0 while leaving SCL high to give us a START condition. Then, the most significant bit arrives. In our example, SDA is at logic 0, so the first bit is a 0. During clock pulse 2, SDA is at logic 1, so a 1 exists. SDA remained at logic 1 during clock pulse 3, so we get another 1. During clock pulse 4, SDA has transitioned to a logic 0 so we get a 0. Clock pulse 5 witnesses a logic 1, so we get a 1. Skipping clock pulses 6 and 7 because I think you get it by now, we arrive at clock pulse 8, our least significant bit. SDA is at logic 0, so our last bit is a 0. The master then changes from driving SDA to listening to it, while the slave changes from listening to SDA to driving it and puts out a logic 0. This is the ACK, which remains low until clock pulse 9 is gone.

We would then either receive another byte of data followed by another ACK or, if done, receive a STOP condition as shown on the previous page.

To recap, we have the following pieces that will be used to build I2C messages

- START
- Data: 0 or 1
- ACK or NACK after each byte of data
- STOP

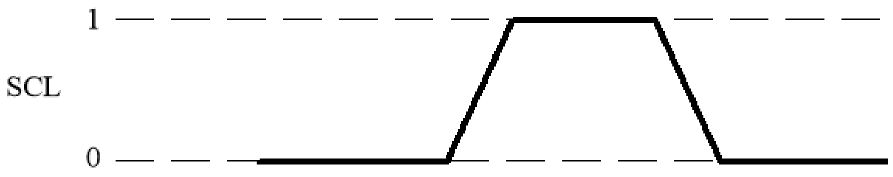
In a spec sheet you may see START, DATA, and ACK represented like this:

S	DATA	A

You will see these concepts again as we talk about SoftWire.

SoftWire

The SoftWire library consists of SoftWire.h and SoftWire.cpp. This code performs what is commonly called “bit banging.” While Wire accomplishes I2C by having hardware change the state of SDA and SCL, in SoftWire, it is all in the code.



To generate a clock cycle we stat start with SCL at logic 0, they write a 1 to the SCL port, wait $\frac{T}{2}$ microseconds, write a 0, and $\frac{T}{2}$ again. The clock “period” is then T microseconds.

If every clock cycle passed one bit of data, the baud rate would equal the reciprical of the clock period. For example, if the clock was at logic 1 for 20 microseconds and then low for 20 microseconds, the baud rate would be $(\frac{1}{40\ microseconds})$ = 25,000 bits per second or $\frac{25{,}000\ bits\ per\ second}{8\ bits\ per\ byte}$ = 3125 bytes per second.

But since each byte is accompanied by an acknowledgment, which takes one clock cycle, the baud rate is reduced to $\frac{25{,}000\ bits\ per\ second}{\mathbf{9}\ bits\ per\ byte}$ = 2778 bytes per second.

I will introduce you to the commands and then detail each one. Then, I will show you how they fit together to satisfy the interface of a specific I2C device.

The SoftWire Functions

begin()

beginTransmission( )

write( )

endTransmission( )   This is a big one.

requestFrom( )

read()

available()

stop()

Currently, I'm not addressing the clock stretching feature.

At the bottom of each description is a list of return values.

Key Low-Level Elements

TransmissionInProgress is a flag that tells various commands how to behave.

The Transmit Buffer is an array that holds bytes to be sent to the designated slave.

The Receive Buffer is an array that holds bytes read from the designated slave.

Functional Descriptions of Each Function

begin()

begin(void) sends a STOP condition plus sets the TransmissionInProgress flag to false. It returns a value of 0. It is typically only in setup() and called once per bus. For example, if I want two SoftWire busses:

```
sw0.begin();
sw1.begin();
```

Return value: It does not return anything.

beginTransmission( )

beginTransmission(<slave's address>) prepares for a new transmission by clearing the transmit buffer. This address is 7 bits. It saves the slave address for other functions to use. It does not modify the TransmissionInProgress flag.

Return value: It does not return anything.

write( )

We have two flavors:

- write(<byte>) puts the byte into the transmit buffer.
- write(<an array's name>, <number of bytes>) reads the array and puts the specified number of bytes into the transmit buffer. For example, say we have the array Qaz[33] and want to put the first two elements into the transmit buffer. Then we would enter `write(Qaz, 2).` It does not modify the TransmissionInProgress flag.

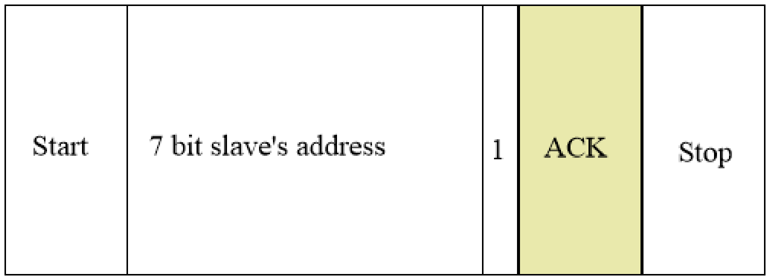
Return value: If the transmit buffer is full, it returns 0. If data was written, it returns a 1.

endTransmission( )

We have a few possible behaviors:

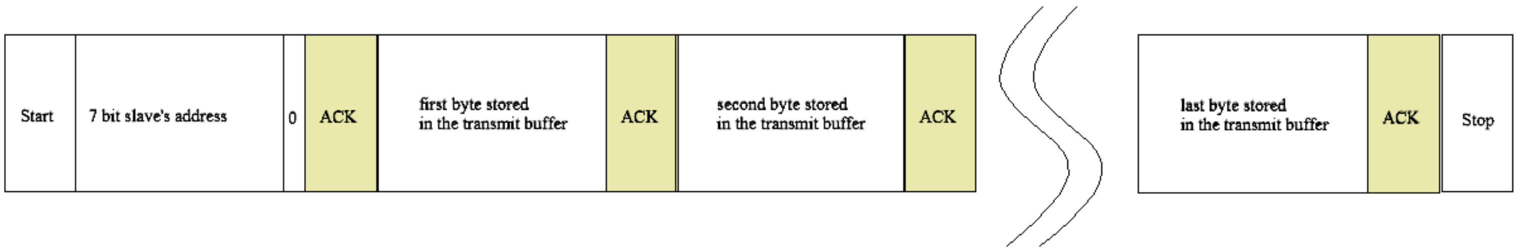
- endTransmission(true) first looks at the TransmissionInProgress flag.
  - If the TransmissionInProgress flag is true, it puts out
    - START,
    - the slave's 7 bit address is concatenated with a 1. This "1" signifies a read.
    - It then looks for an ACK from the slave. At this level of detail, assume the ACK was received.
    - It then sends STOP.

  In graphical form:



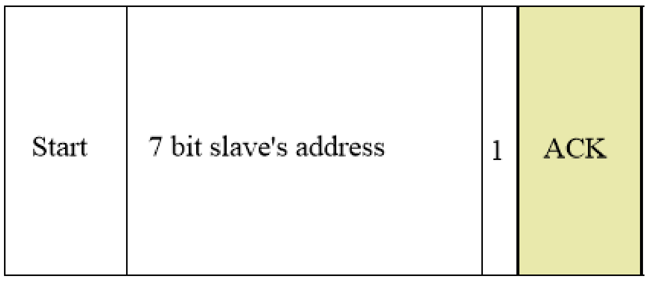
  - If the TransmissionInProgress flag is false, it puts out
    - START,
    - the slave's 7 bit address is concatenated with a 0. This "0" signifies a write.
    - It then looks for an ACK. At this level of detail, assume the ACK was received.
    - Then it puts all bytes stored in the transmit buffer on the bus looking for ACK between each byte.
    - It then sends STOP.

  In graphical form:


Start
7 bit slave's address
0
ACK
first byte stored in the transmit buffer
ACK
second byte stored in the transmit buffer
ACK
last byte stored in the transmit buffer
ACK
Stop

- endTransmission(**false**)
  - If the TransmissionInProgress flag is **true**, it puts out
    - START,
    - the slave's 7 bit address is concatenated with a 1. This "1" signifies a read.
    - It then looks for an ACK. At this level of detail, assume the ACK was received.

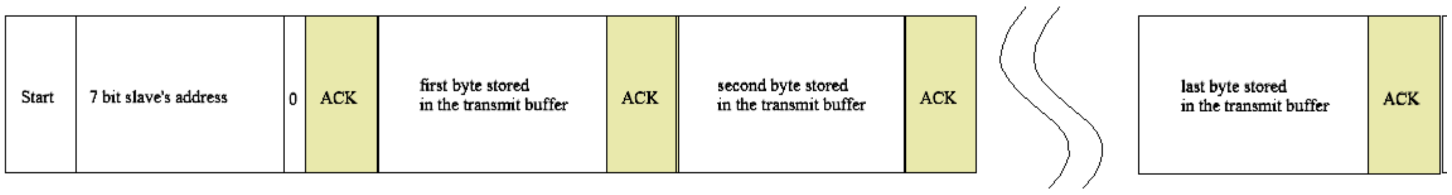
In graphical form:



Notice that no Stop exists on the end.

  - If the TransmissionInProgress flag is **false**, it puts out
    - START,
    - the slave's 7 bit address concatenated with a 0. This "0" signifies a write.
    - It then looks for an ACK. At this level of detail, assume the ACK was received.
    - Then it puts all bytes stored in the transmit buffer on the bus, looking for ACK between each byte.
    - It then sets the TransmissionInProgress flag to **true**.

In graphical form:


Start
7 bit slave's address
0
ACK
first byte stored in the transmit buffer
ACK
second byte stored in the transmit buffer
ACK
last byte stored in the transmit buffer
ACK

Notice that no Stop exists on the end.

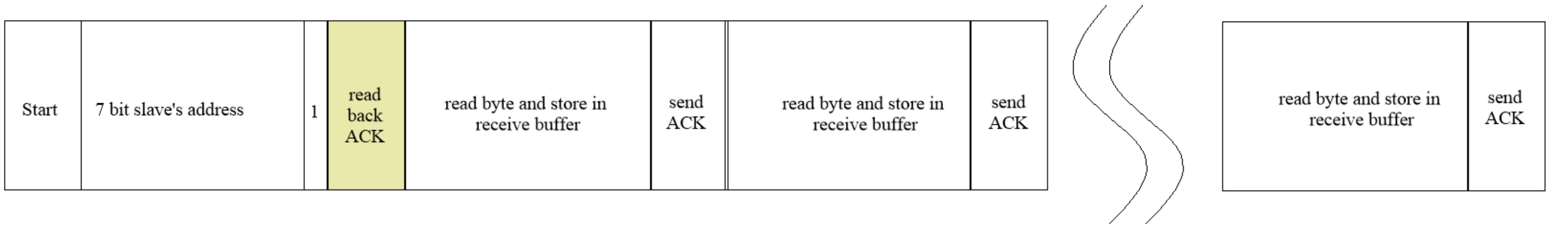
Return value: If it doesn't receive anything from the slave during the ACK clock cycle, it returns a NACK which is 2. Timeout is related to clock stretching and isn't covered in this document.

requestFrom( )

requestFrom( ) has a few possible behaviors:

- requestFrom(<slave's address>, <quantity>, **false**[5]) has two possible behaviors:
    - If the TransmissionInProgress flag is **true**,
        - It clears the receive buffer
        - The 7 bit <slave's address> is concatinated with a "1", which means read, to become "Addr+1"
        - It puts out onto the bus
            - START
            - Addr+1
        - look for an ACK. At this level of detail, assume the ACK was received.
        - For each byte specified by <quantity>
            - Read back from the bus a bytes
            - send an ACK to the slave
            - put received byte into the receive buffer.
        - requestFrom( ) returns the number of bytes read

In graphical form:

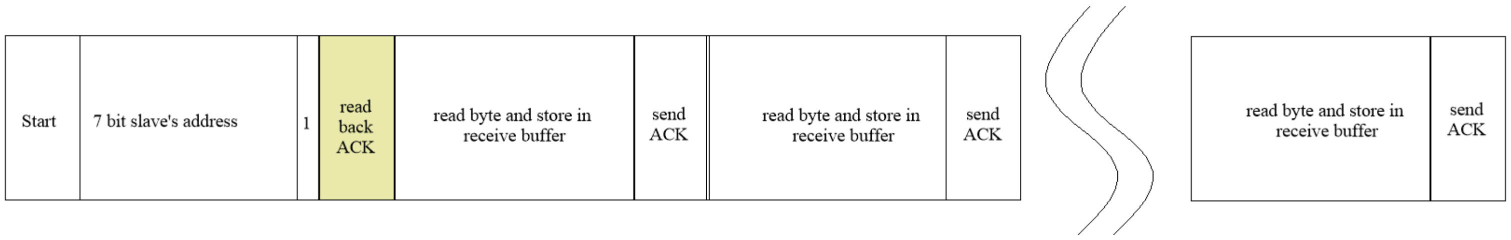

Start
7 bit slave's address
1
read back ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK

[5] This is the sendStop flag, so making it false means we do not want to send a STOP condition.

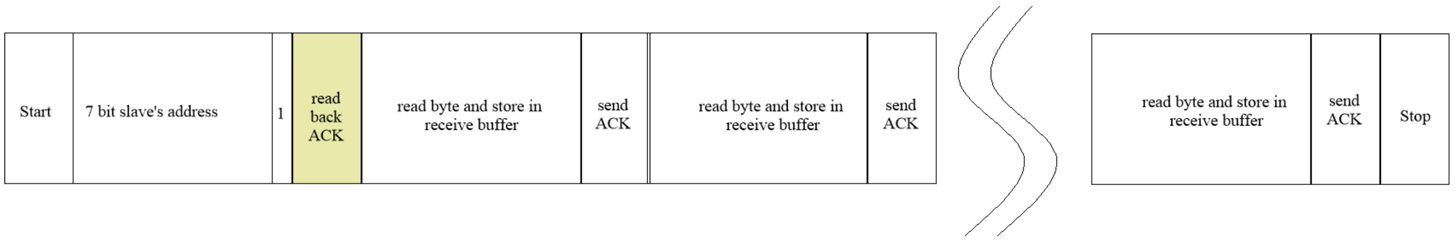
requestFrom(<slave's address>, <quantity>, **false**) continued

- If the TransmissionInProgress flag is **false**,
  - It clears the receive buffer
  - The 7 bit <slave's address> is concatinated with a "1", which means read, to become "Addr+1"
  - It puts out onto the bus
    - START
    - Addr+1
  - look for an ACK. At this level of detail, assume the ACK was received.
  - For each byte specified by <quantity>
    - Read back from the bus a bytes
    - send an ACK to the slave
    - put received byte into the receive buffer.
  - It then sets the TransmissionInProgress flag to **true**.
  - requestFrom( ) returns the number of bytes read

In graphical form:


Start
7 bit slave's address
1
read back ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK

- requestFrom(<slave's address>, <quantity>, **true**[6]) has two possible behaviors:
    - If the TransmissionInProgress flag is **true**,
        - It clears the receive buffer
        - The 7 bit <slave's address> is concatinated with a "1", which means read, to become "Addr+1"
        - It puts out onto the bus
            - START
            - Addr+1
        - look for an ACK. At this level of detail, assume the ACK was received.
        - For each byte specified by <quantity>
            - Read back from the bus a bytes
            - send an ACK to the slave
            - put the received byte into the receive buffer.
        - Put STOP onto the bus
        - It then sets the TransmissionInProgress flag to **false**[7].
        - requestFrom( ) returns the number of bytes read
- In graphical form:

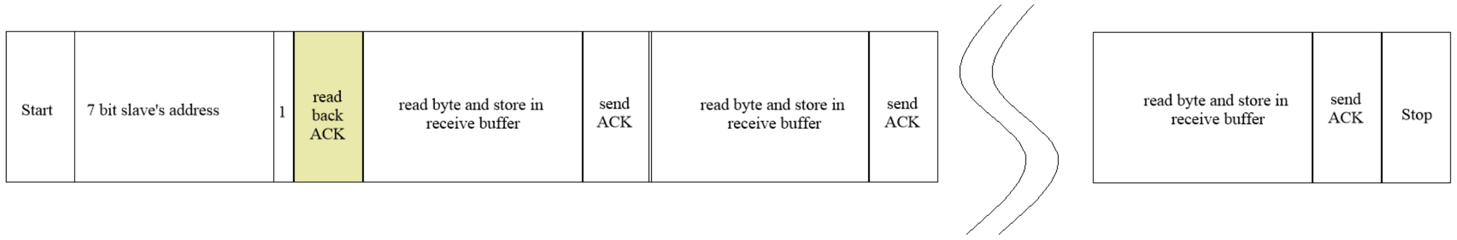

Start
7 bit slave's address
1
read back ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK
Stop

[6] This is the sendStop flag, so making it true means we want to send a STOP condition.
[7] Since we are sending a STOP condition, it means a transmission is not in progress so we set the TransmissionInProgress flag to false. Other functions need to know this.

requestFrom(<slave’s address>, <quantity>, **true**) continued

- If the TransmissionInProgress flag is **false**,
    - It clears the receive buffer
    - The 7 bit <slave’s address> is concatinated with a “1”, which means read, to become “Addr+1”
    - It puts out onto the bus
        - START
        - Addr+1
    - look for an ACK. At this level of detail, assume the ACK was received.
    - For each byte specified by <quantity>
        - Read back from the bus a bytes
        - send an ACK to the slave
        - put received byte into the receive buffer.
    - Put STOP onto the bus
    - It then sets the TransmissionInProgress flag to **true**.
    - requestFrom( ) returns the number of bytes read

In graphical form:


Start
7 bit slave's address
1
read back ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK
Stop

Return value: the total number of bytes read

read()

Return value: This function return one byte from the receive buffer and decrements the buffer pointer. This is a first in, first out buffer. If no byte is present, it returns -1.

Example:

Given you are expecting to get up to 16 bytes:

```
int qaz[16];
for(byte j = 0;j < 15; j++)
{
    qaz[i]  = read();
    if(qaz[i] < 0) break; //if nothing in buffer, stop
reading from it
}
```

available()

Return value: This function returns the number of bytes not yet read from the receive buffer.

Example:

```
if(available() = 2) //I am expecting 2 bytes
{
    byte qaz = read();
    byte wsx = read();
}
```

Now, available() will return 0.

stop(false)[8]

This function puts a STOP condtion on the bus and sets the TransmissionInProgress flag to **false**.

Return value: 0 unless it is doing clock stretch and has a failure.

[8] The function stop(true) involves clock stretching which I'm not addressing in this version of the document.

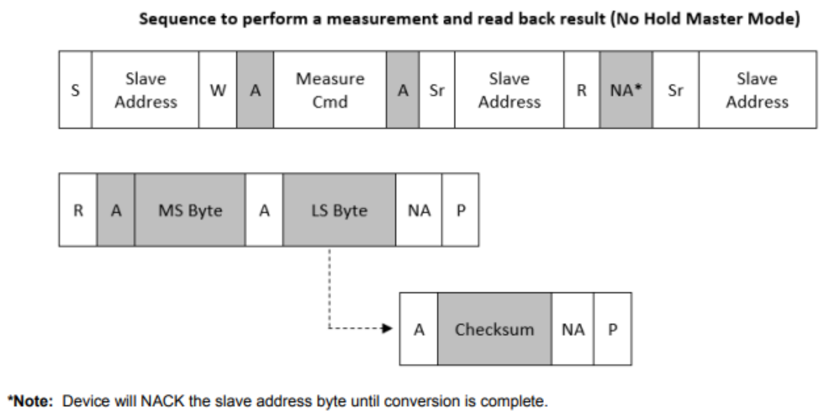
Example: The Si7021 Humidity and Temperature Sensor

I will periodically refer to this spec sheet from SILICON LABS.

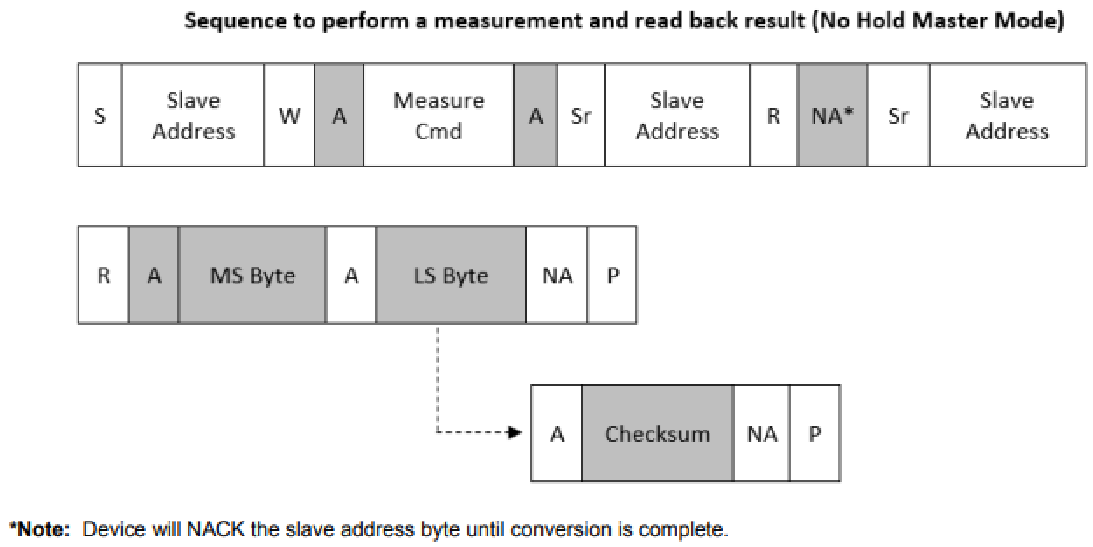
Table 2 shows that it can take up to 10.8 milliseconds to do a 14-bit temperature conversion. Table 3 shows the I2C interface specs, but we will not be nearly this fast using SoftWire. Table 5 says the accuracy is within +/- 1 °C from -40 °C to +115 °C. Between -10 °C and 85 °C is is +/- 0.4 °C maximum.

From Table 7, the storage temperature is from -65 °C to 150 °C, so it will survive my application where it will see -55 °C even though the accuracy will suffer at this temperature. It also specifies the supply voltage to be a maximum of 4.2V while the voltage on any input pin is no more than the supply voltage plus 0.3V. We will run at 3.3V, so no input pin should get above 3.6V. **Note that 5 volts on the I2C pull-up resistors violates the spec and can cause damage.**

From section 5, we get the I2C Interface specs. The 7 bit slave address is **0x40**. To measure temperature without "Hold Master Mode," we will use command code **0xF3**. Hold Master Mode is tied to clock stretching, which I won't be using. Instead, I will wait the maximum time before asking for a reading.

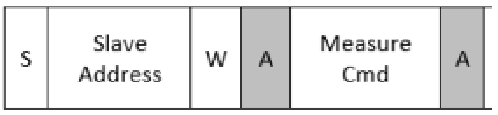

Sequence to perform a measurement and read back result (No Hold Master Mode)
S
Slave Address
W
A
Measure Cmd
A
Sr
Slave Address
R
NA*
Sr
Slave Address
R
A
MS Byte
A
LS Byte
NA
P
A
Checksum
NA
P
*Note: Device will NACK the slave address byte until conversion is complete.

From section 5.1, we get the required details of a transaction. They are using terminology consistent with the I2C standards.

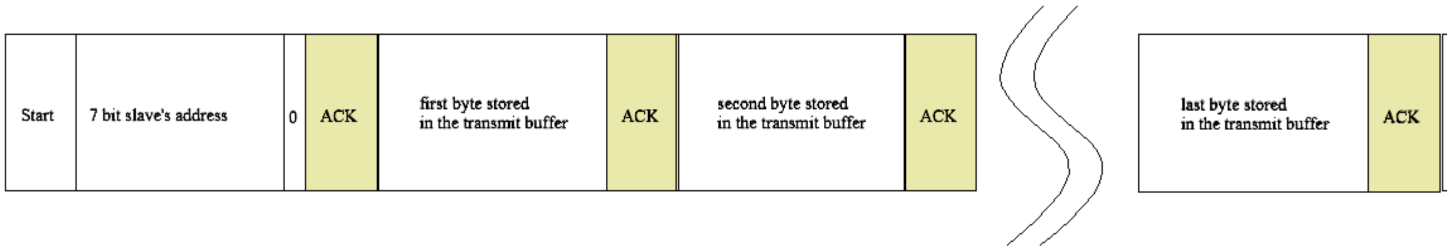

Sequence to perform a measurement and read back result (No Hold Master Mode)
S
Slave Address
W
A
Measure Cmd
A
Sr
Slave Address
R
NA*
Sr
Slave Address
R
A
MS Byte
A
LS Byte
NA
P
A
Checksum
NA
P
*Note: Device will NACK the slave address byte until conversion is complete.

The white boxes are what the master sends, and the gray boxes are what the sensor sends.

First, we must send START, the slave address, 0x40, a write bit, wait for an ACK, and then the measurement command, 0xF3, and receive another ACK. "W" means a write bit, so it has the value of 0.

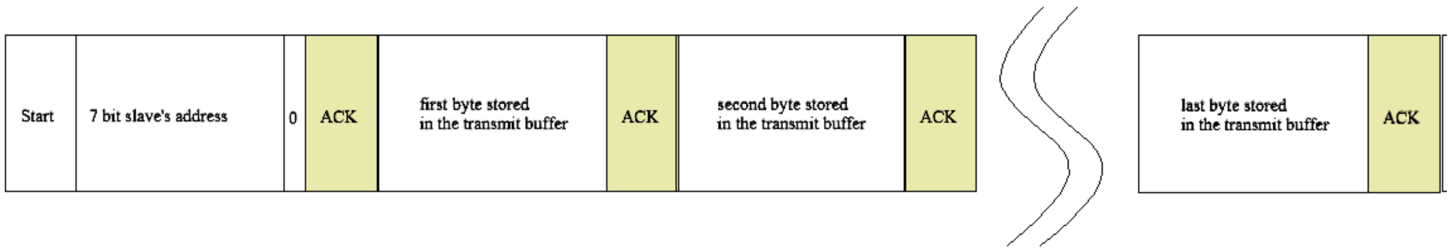


Looking through the graphical forms, I found


Start
7 bit slave's address
0
ACK
first byte stored in the transmit buffer
ACK
second byte stored in the transmit buffer
ACK
last byte stored in the transmit buffer
ACK

I only need to send one byte, the Measurement command, which is 0xF3. This graphic corresponds to:

endTransmission(**false**)
TransmissionInProgress flag is **false**


Start
7 bit slave's address
0
ACK
first byte stored in the transmit buffer
ACK
second byte stored in the transmit buffer
ACK
last byte stored in the transmit buffer
ACK

But before we can call endTransmission(**false**), we need to put the Measurement command into the transmit buffer. The command write(<byte>) will do the trick.

So far, we have:

```
write (0xF3);
endTransmission(false);
```

Don't forget that we need to have the TransmissionInProgress flag set to **false.**

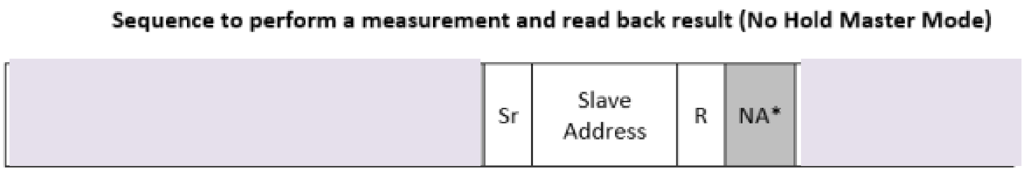
`begin()` goes into setup(), where it will only be called once and will set the TransmissionInProgress flag set to **false.**

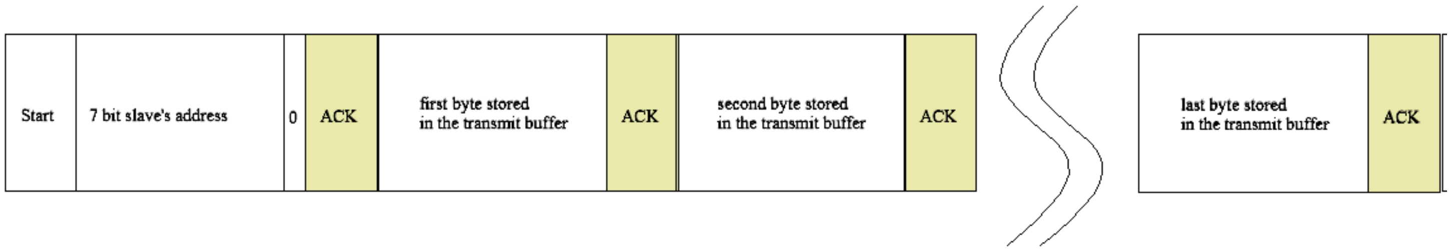
`beginTransmission(0x40)` clears the receive buffer and saves the slave address for other functions to use.

This brings us to:

```
Setup()
{
     begin();//sets TransmissionInProgress to false
}

void TempSensor()
{
     beginTransmission(0x40); //sets TransmissionInProgress false
     write (0xF3);//has no effect on the TransmissionInProgress flag
     endTransmission(false);// TransmissionInProgress flag is false
```

This tells the sensor we want a temperature reading.


Sequence to perform a measurement and read back result (No Hold Master Mode)
Sr
Slave Address
R
NA*


Start
7 bit slave's address
0
ACK
first byte stored in the transmit buffer
ACK
second byte stored in the transmit buffer
ACK
last byte stored in the transmit buffer
ACK

This matches, except we expect an ACK from the sensor, and the spec sheet says "NA*." Following the aesthetic brings us to

*Note: Device will NACK the slave address byte until conversion is complete.

In other words, we will get a NACK until the sensor is done with its conversion. When the conversion is done, we will get our ACK. We just have to be sure our timer tolerates this delay in receiving an ACK. Using `setTimeout(1000)` when we set up the bus, we can tolerate up to a 1000 millisecond delay in receiving ACK. This delay will be compatible with all known sensors yet not delay a failed sensor's detection by more than 1 second.

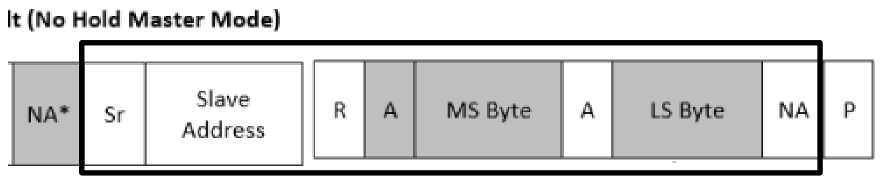
The above graphic comes from `endTransmission(`**`false`**`) on page 18`.

So now we have:

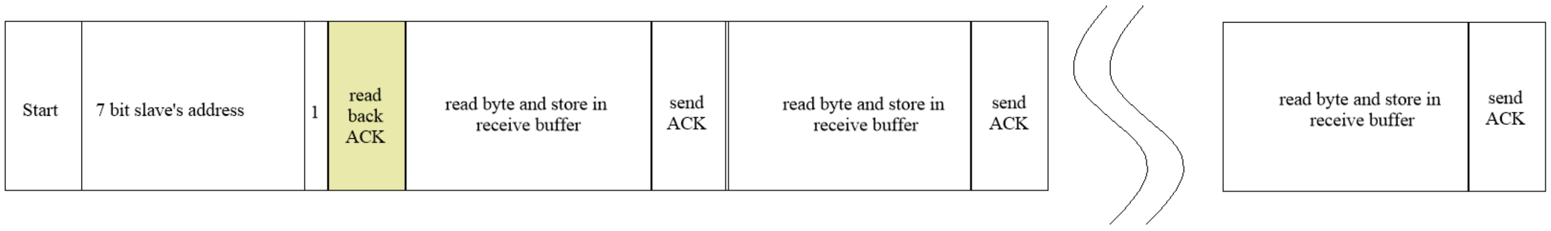
```
Setup()
{
      begin();//sets TransmissionInProgress to false
}

void TempSensor()
{
      beginTransmission(0x40); //sets TransmissionInProgress false
      write (0xF3);//has no effect on the TransmissionInProgress flag
      endTransmission(false);// TransmissionInProgress flag is true
```

Next, we need to ask for that two byte temperature reading.

Recall that R means we output a 1.



On page 19,18 I found:


Start
7 bit slave's address
1
read back ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK
read byte and store in receive buffer
send ACK

These match, except that the spec sheet will send a NACK after reading back the second byte, while SoftWire will send an ACK. Both then expect the master to send a STOP condition. This is not a serious discrepancy as was confirmed during my testing.

The corresponding command is

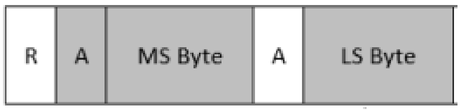
requestFrom(0xF3, 2, **false**) with the TransmissionInProgress flag **true**.

We now have

```
Setup()
{
      begin();//sets TransmissionInProgress to false
}

void TempSensor()
{
      beginTransmission(0x40); //sets TransmissionInProgress false
      write (0xF3);//has no effect on the TransmissionInProgress flag
      endTransmission(false);// TransmissionInProgress flag is false
      requestFrom(0xF3,2,false);//TransmissionInProgress flag is true.
```

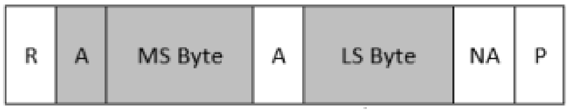
We should now have two bytes in our receive buffer.

We read the two bytes by calling read() twice. Notice that the first byte into the buffer was the Most Significant byte, and the second byte was the Least Significant byte. We read out in the same order.



```
byte MSB  = read();//first in, first out buffer
byte LSB =  read();
```

The final action is to end the conversation between the master and the slave. This is done with a STOP condition, designated “P” in the spec sheet.



All we need to do is call stop(**false**). It also sets the TransmissionInProgress flag to **false**.

Sample Code: Si7021 Device

Before setup():

```
#include <SoftWire.h>
#include <AsyncDelay.h> //used by SoftWire
int sda0Pin = 8;//define logical pins used for bus 0
int scl0Pin = 9;
int sda1Pin = 16; //define logical pins used for bus 1
int scl1Pin = 10;
SoftWire sw0(sda0Pin, scl0Pin);//define the two I2C busses
SoftWire sw1(sda1Pin, scl1Pin);
// These buffers must be at least as large as the largest read or write you
perform.
char sw0TxBuffer[16];//used by SoftWire bus 0
char sw0RxBuffer[16]; //used by SoftWire bus 0
char sw1TxBuffer[16];//used by SoftWire bus 1
char sw1RxBuffer[16]; //used by SoftWire bus 1
AsyncDelay readInterval;//required by SoftWire docs
byte Si7021AddressByte = 0x40;//this is the 7 bit address of our sensor
byte measureTempByte = 0xF3;//this is the 8 bit command for reading temp
```

The first #include brings in SoftWire header file which defines functions and variables within SoftWire.cpp which it includes. SoftWire uses AsyncDelay so that is our second #include.
Next, define which logical pins on our Pro Micro processor will be used for each of the two SoftWire buses. Then, we make two copies of SoftWire. One is called sw0 with its SDA and SCL, while the other is called sw1 with its SDA and SCL. Next, the transmit and receive buffers for each I2C bus are defined.

We make one copy of AsyncDelay, which we included, and call it readInterval. The last two lines are specific to the I2C device we will drive.

In setup()

```
setup()
{
	sw0.setTxBuffer(sw0TxBuffer, sizeof(sw0TxBuffer));//set up bus 0
	sw0.setRxBuffer(sw0RxBuffer, sizeof(sw0RxBuffer));
	sw0.setDelay_us(5);//from SoftWire docs
	sw0.setTimeout(1000);//from SoftWire docs
	sw0.begin();//called only once, at setup

	sw1.setTxBuffer(sw1TxBuffer, sizeof(sw1TxBuffer)); //set up bus 1
	sw1.setRxBuffer(sw1RxBuffer, sizeof(sw1RxBuffer));
	sw1.setDelay_us(5);
	sw1.setTimeout(1000);
	sw1.begin();

	readInterval.start(2000, AsyncDelay::MILLIS); //from SoftWire docs
}
```

SoftWire requires the next block of code. I didn't change any of it. Notice that I used the same commands for each bus, only changing the bus name.

Then comes our first SoftWire operational command: begin( ). It sets the initial conditions on each bus by sending out a STOP condition and setting the TransmissionInProgress flag to false.

Although we have set up two I2C buses, SoftWire can only operate one at a time.

This last line is required by SoftWire.

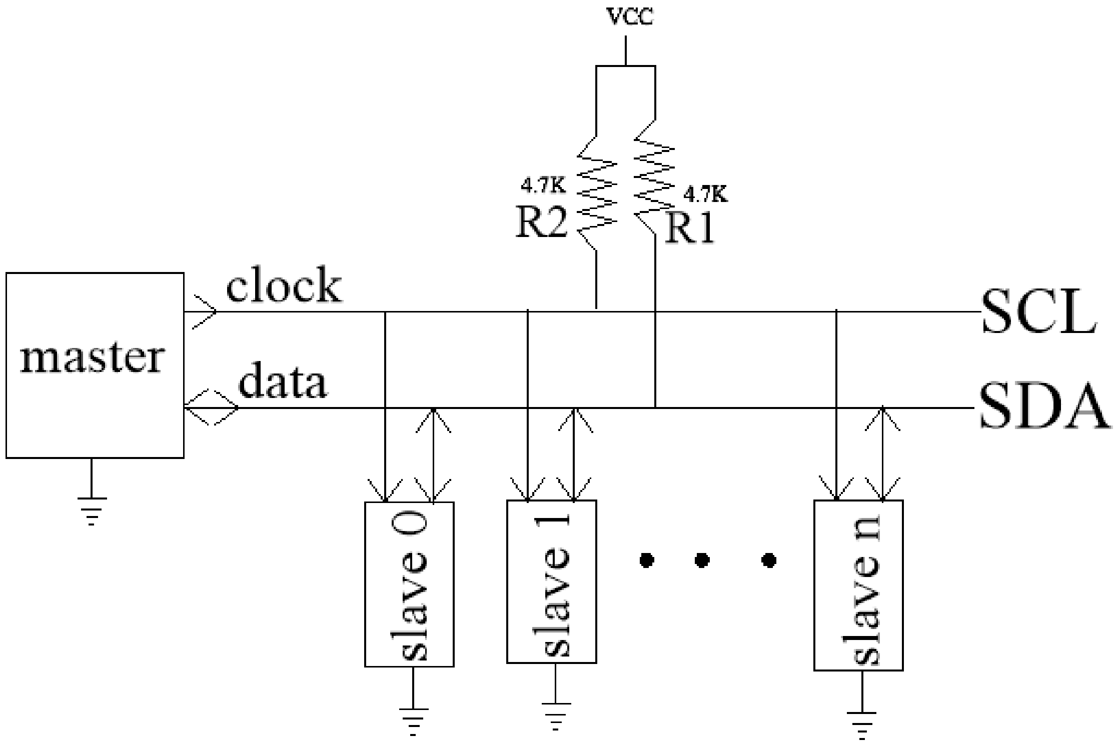
This concludes the setting up of the environment to run my I2C sensor driver.

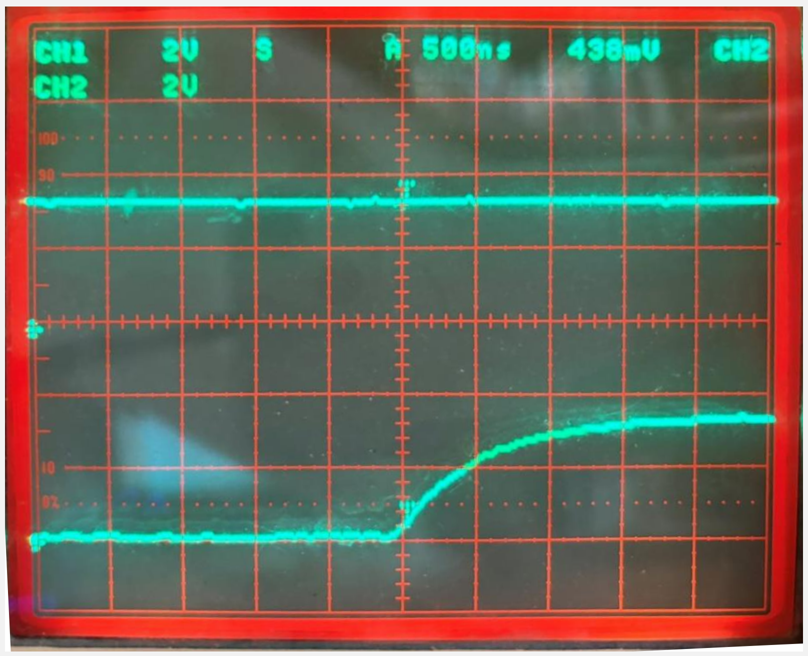
The I2C Driver

I am driving a Si7021 Humidity and Temperature sensor connected to SoftWire bus 0. I will read the temperature and place the raw result into an array.

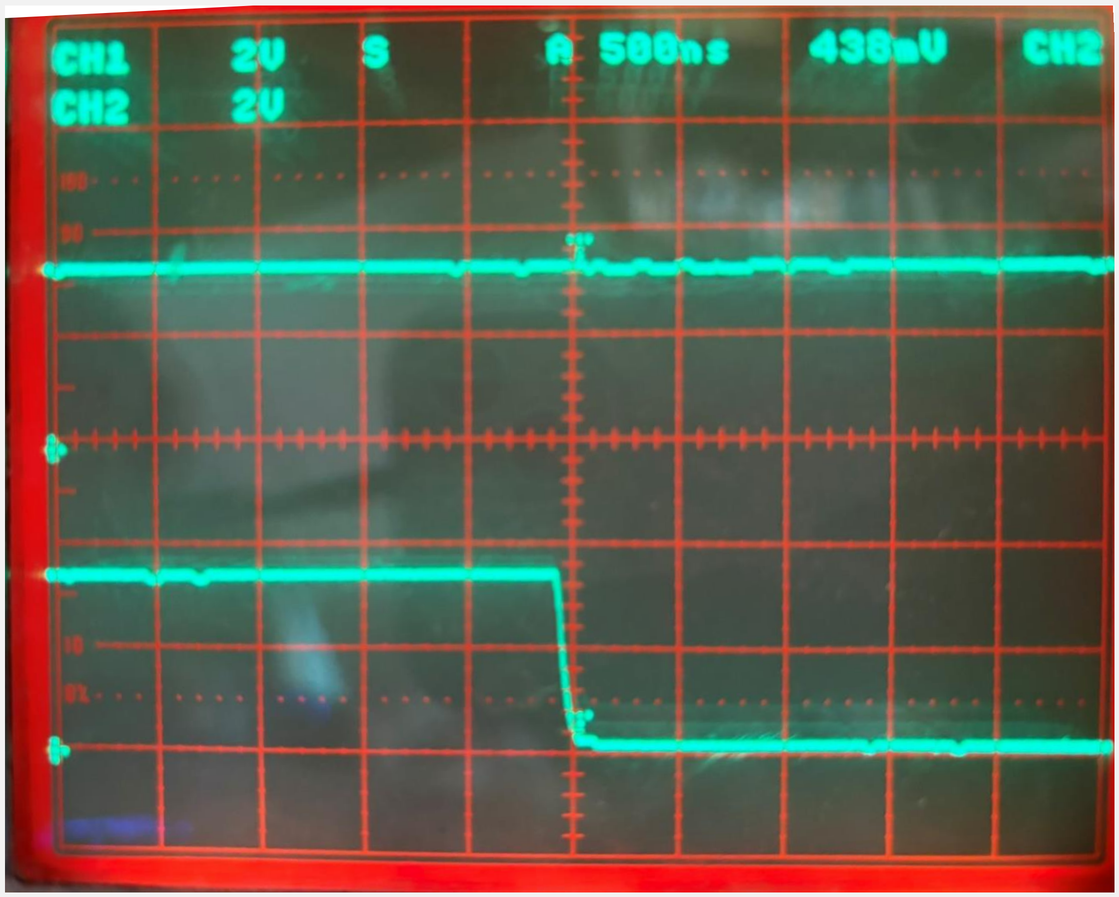
```
void Si7021Driver()
{
sw0.beginTransmission(Si7021AddressByte);//bus 0. Sensor address is 0x40
            if(!sw0.write(measureTempByte))//returns 0 for fault and 1 if OK
            {
                  receivedDataByte[16] = failedByte;//populate status byte
with failure
                  return;
            }
            if(sw0.endTransmission(false) != 0)
            {;//send slave address, write and measurement command
                  receivedDataByte[16] = failedByte;//populate status byte
with failure
                  return;
            }

            delay(20);//time for sensor to take a reading plus software
overhead
            sw0.requestFrom(Si7021AddressByte,2, false);//command a read of 2
bytes of data
            unsigned long startTimeULong = millis();
            byte byteCountByte = 0;
            while(1)
            {//read the MS Byte and LS Byte
                  if(sw0.available() >= 2)
                  {//our two bytes are waiting to be read
                        receivedDataByte[0] = sw0.read();//MSB
                        receivedDataByte[1] = sw0.read();//LSB
                        receivedDataByte[16] = successByte;//set status byte
                        return;
                  }else
                  {
                        if((millis() - startTimeULong) > 200)
                        {//we timed out waiting for our temp reading
                              receivedDataByte[16] = timedOutByte;//4
                              return;//give up on sensor after waiting 200 ms
                        }
                  }
            }
            sw0.stop(false);
}
```

Appendix I: Analog Aspects of I2C





The slow rise time due to the capacitance of the SCL lead and the 4.7K pull-up are evident here. It takes about 1.5 microseconds to go from a logic 0 to a logic 1.



Here, we see the negative edge of the clock. The Pro Micro is pulling down to a logic 0 and discharging the capacitance of the line. It can sink up to about 40 mA, so the transition from logic 1 to 0 takes place in about 100 ns.

We can reduce our rise time by using smaller pull-up resistors but this will reduce the available current during the fall time because the device must sink both the capacitive and pull-up current.

As a rough check, note that on rise time, we have $\underline{v = 3.3e^{-\frac{t}{\tau}}\, volts.}$ Note that we are at 2 volts after 400 ns. This gives us a $\tau = 800\ ns$ which equals $R\ \times C$. With R = 4.7k, this means the total capacitance on the node is 170 *pf.*

The initial fall time is about 2 volts in 50 ns and is approximately linear so that we can say $I = C\frac{dv}{dt} = 170\ pf\,\frac{2V}{50\ ns}$ = 6.8 mA which is sunk by the Pro Micro. Note that that is far less than the maximum rated current of 40 mA.

Acknowledgments

Thanks to the authors of SoftWire for writing code that I could comprehend.

I welcome your comments and questions.

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