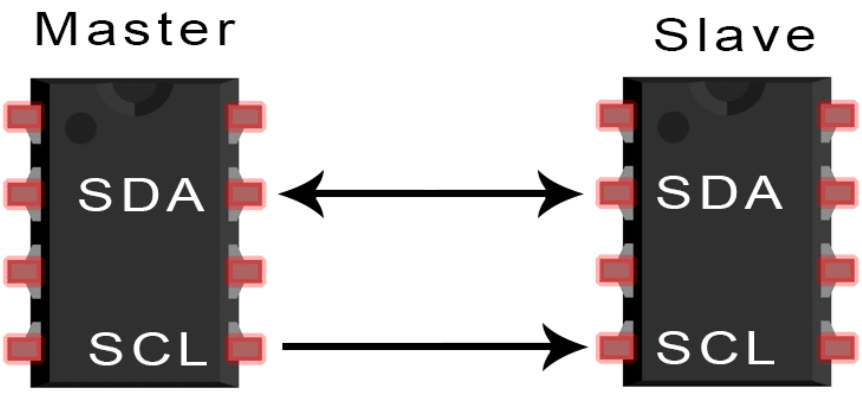
BASICS OF THE I2C COMMUNICATION PROTOCOL

Posted by Scott Campbell | DIY Electronics | 57



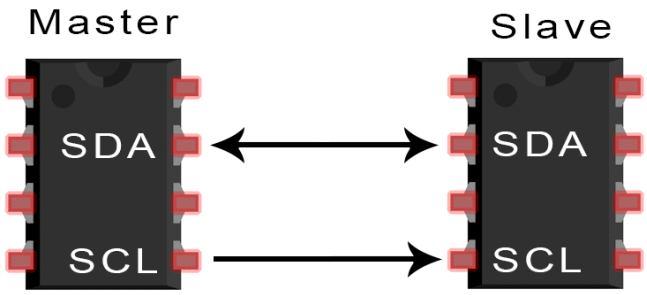
So far, we've talked about the basics of SPI communication and UART communication, so now let's go into the final protocol of this series, the Inter-Integrated Circuit, or I2C.

You'll probably find yourself using I2C if you ever build projects that use OLED displays, barometric pressure sensors, or gyroscope/accelerometer modules.

INTRODUCTION TO I2C COMMUNICATION

I2C combines the best features of SPI and UARTs. With I2C, you can connect multiple slaves to a single master (like SPI) and you can have multiple masters controlling single, or multiple slaves. This is really useful when you want to have more than one microcontroller logging data to a single memory card or displaying text to a single LCD.

Like UART communication, I2C only uses two wires to transmit data between devices:



SDA (Serial Data) – The line for the master and slave to send and receive data.

SCL (Serial Clock) – The line that carries the clock signal.

I2C is a serial communication protocol, so data is transferred bit by bit along a single wire (the SDA line).

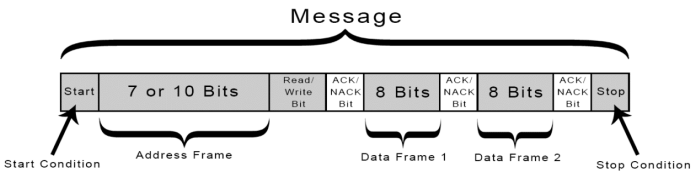
Like SPI, I2C is synchronous, so the output of bits is synchronized to the sampling of bits by a clock signal shared between the master and

the slave. The clock signal is always controlled by the master.

Wires Used	2
Maximum Speed	Standard mode= 100 kbps
	Fast mode= 400 kbps
	High speed mode= 3.4 Mbps
	Ultra fast mode= 5 Mbps
Synchronous or Asynchronous?	Synchronous
Serial or Parallel?	Serial
Max # of Masters	Unlimited
Max # of Slaves	1008

HOW I2C WORKS

With I2C, data is transferred in *messages*. Messages are broken up into *frames* of data. Each message has an address frame that contains the binary address of the slave, and one or more data frames that contain the data being transmitted. The message also includes start and stop conditions, read/write bits, and ACK/NACK bits between each data frame:



Start Condition: The SDA line switches from a high voltage level to a low voltage level *before* the SCL line switches from high to low.

Stop Condition: The SDA line switches from a low voltage level to a high voltage level *after* the SCL line switches from low to high.

Address Frame: A 7 or 10 bit sequence unique to each slave that identifies the slave when the master wants to talk to it.

Read/Write Bit: A single bit specifying whether the master is sending data to the slave (low voltage level) or requesting data from it (high voltage level).

ACK/NACK Bit: Each frame in a message is followed by an acknowledge/no-acknowledge bit. If an address frame or data frame was successfully received, an ACK bit is returned to the sender from the receiving device.

ADDRESSING

I2C doesn't have slave select lines like SPI, so it needs another way to let the slave know that data is being sent to it, and not another slave. It does this by *addressing*. The address frame is always the first frame after the start bit in a new message.

The master sends the address of the slave it wants to communicate with to every slave connected to it. Each slave then compares the address sent from the master to its own address. If the address matches, it sends a low voltage ACK bit back to the master. If the address doesn't match, the slave does nothing and the SDA line remains high.

READ/WRITE BIT

The address frame includes a single bit at the end that informs the slave whether the master wants to write data to it or receive data from it. If the master wants to send data to the slave, the read/write bit is a low voltage level. If the master is requesting data from the slave, the bit is a high voltage level.

THE DATA FRAME

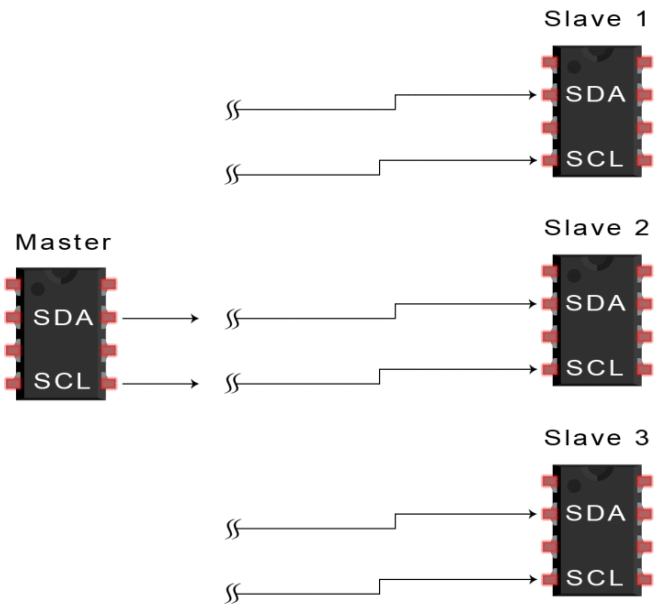
After the master detects the ACK bit from the slave, the first data frame is ready to be sent.

The data frame is always 8 bits long, and sent with the most significant bit first. Each data frame is immediately followed by an ACK/NACK bit to verify that the frame has been received successfully. The ACK bit must be received by either the master or the slave (depending on who is sending the data) before the next data frame can be sent.

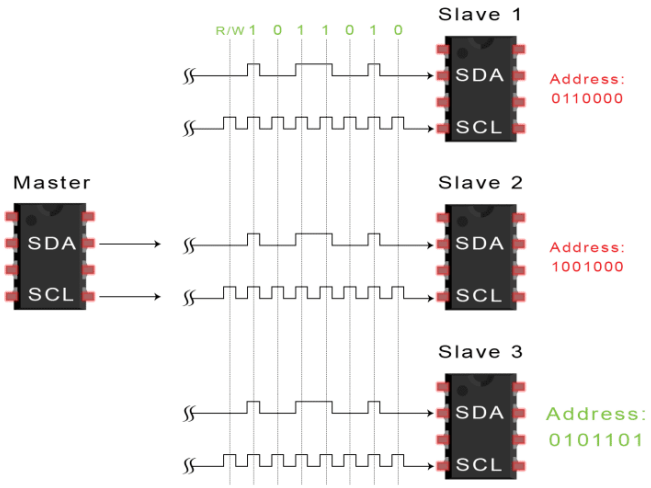
After all of the data frames have been sent, the master can send a stop condition to the slave to halt the transmission. The stop condition is a voltage transition from low to high on the SDA line after a low to high transition on the SCL line, with the SCL line remaining high.

STEPS OF I2C DATA TRANSMISSION

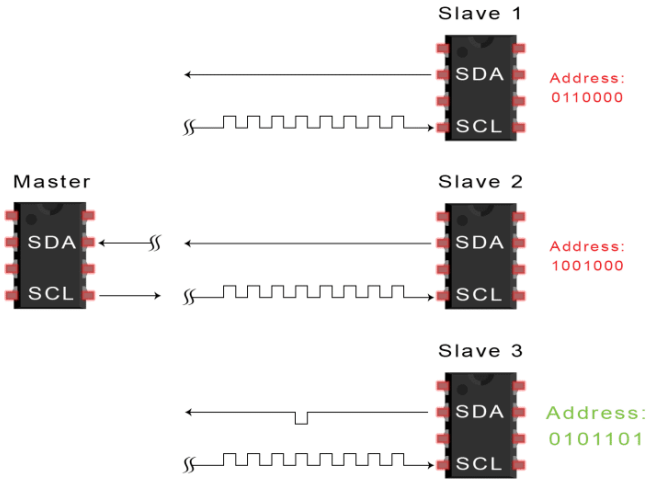
1. The master sends the start condition to every connected slave by switching the SDA line from a high voltage level to a low voltage level *before* switching the SCL line from high to low:



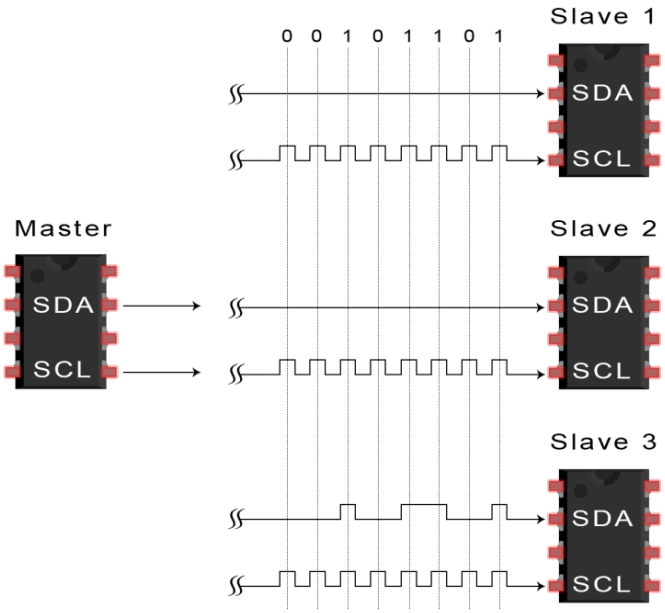
2. The master sends each slave the 7 or 10 bit address of the slave it wants to communicate with, along with the read/write bit:



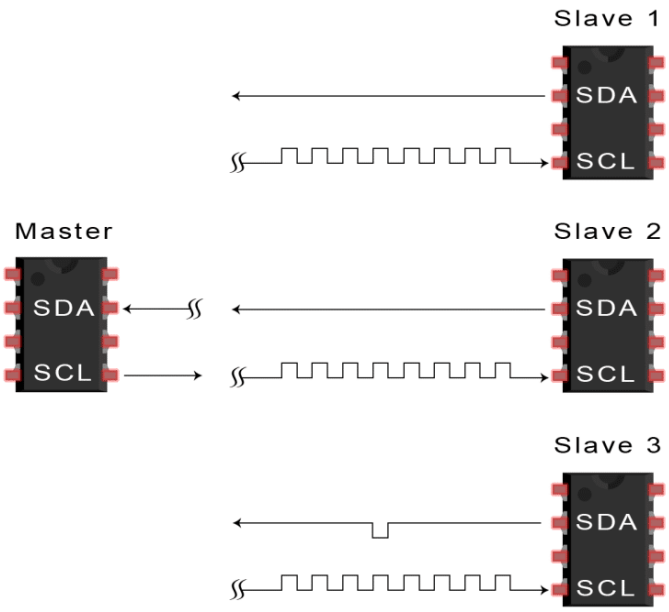
3. Each slave compares the address sent from the master to its own address. If the address matches, the slave returns an ACK bit by pulling the SDA line low for one bit. If the address from the master does not match the slave's own address, the slave leaves the SDA line high.



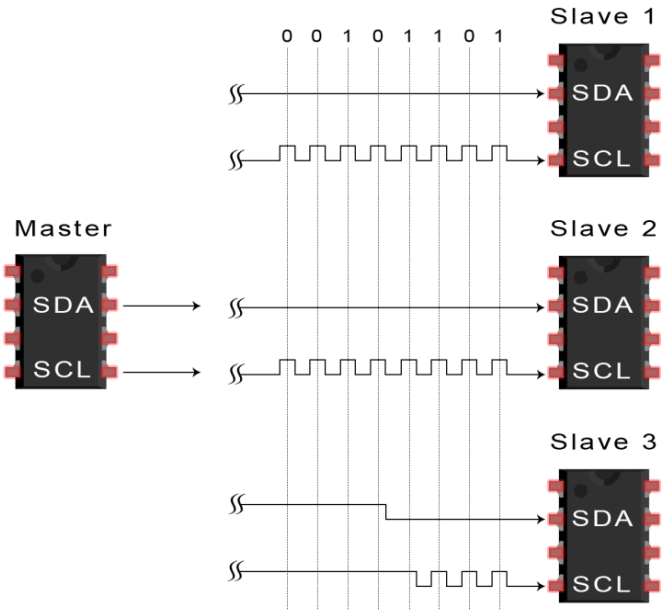
4. The master sends or receives the data frame:



5. After each data frame has been transferred, the receiving device returns another ACK bit to the sender to acknowledge successful receipt of the frame:

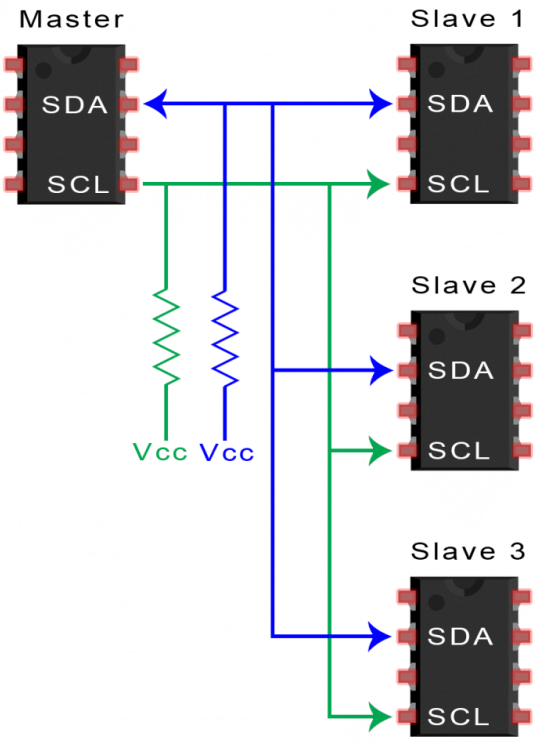


6. To stop the data transmission, the master sends a stop condition to the slave by switching SCL high before switching SDA high:



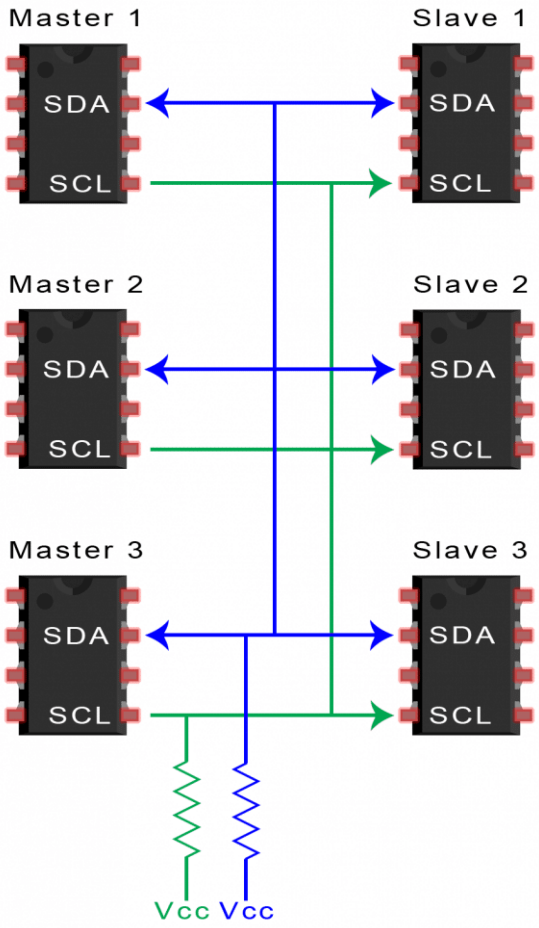
SINGLE MASTER WITH MULTIPLE SLAVES

Because I2C uses addressing, multiple slaves can be controlled from a single master. With a 7 bit address, 128 (2^7) unique address are available. Using 10 bit addresses is uncommon, but provides 1,024 (2^{10}) unique addresses. To connect multiple slaves to a single master, wire them like this, with 4.7K Ohm pull-up resistors connecting the SDA and SCL lines to Vcc:



MULTIPLE MASTERS WITH MULTIPLE SLAVES

Multiple masters can be connected to a single slave or multiple slaves. The problem with multiple masters in the same system comes when two masters try to send or receive data at the same time over the SDA line. To solve this problem, each master needs to detect if the SDA line is low or high before transmitting a message. If the SDA line is low, this means that another master has control of the bus, and the master should wait to send the message. If the SDA line is high, then it's safe to transmit the message. To connect multiple masters to multiple slaves, use the following diagram, with 4.7K Ohm pull-up resistors connecting the SDA and SCL lines to Vcc:



ADVANTAGES AND DISADVANTAGES OF I2C

There is a lot to I2C that might make it sound complicated compared to other protocols, but there are some good reasons why you may or may not want to use I2C to connect to a particular device:

ADVANTAGES

- Only uses two wires
- Supports multiple masters and multiple slaves
- ACK/NACK bit gives confirmation that each frame is transferred successfully
- Hardware is less complicated than with UARTs
- Well known and widely used protocol

DISADVANTAGES

- Slower data transfer rate than SPI
- The size of the data frame is limited to 8 bits
- More complicated hardware needed to implement than SPI

Thanks for reading! Hope you learned something from this series of articles on electronic communication protocols. In case you haven't read them already, part one covers the SPI communication protocol, and part two covers UART driven communication.

If you have any questions or have anything to add, feel free to leave a comment below. And be sure to subscribe to get more articles like this in your inbox!

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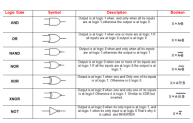

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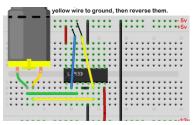

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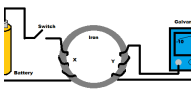

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57 COMMENTS

rjsheperd on February 13, 2016 at 9:52 pm

Great series of posts. Thanks for sharing this!

REPLY

harry on February 14, 2016 at 1:32 pm

Thanks for this,u are a genius,i need simple circuit for invater and power Bank circuit

REPLY

Dani on February 22, 2016 at 7:18 am

Many thanks. Working with this – while knowing how it actually works makes it so much better. Thank you for taking the time to explain it so well

REPLY

Sachin Gupta on February 24, 2016 at 5:46 am

Thanks very nice information. I liked all your articles and the way you explained all.

Please add for PCIe communication as well.

REPLY

Manuel Antonio Nava on March 30, 2016 at 2:51 pm

Simple and easy to understand. I suggest some example to put in practice

REPLY

再地郎 on March 31, 2016 at 12:31 am

GOOD JOB!

REPLY

Phil Howard on July 3, 2016 at 7:52 am

@TheArduinoGuy not bad, although the multi-master arbitration part is very, see; https://t.co/2msABa9WxH

REPLY

Mitek on July 4, 2016 at 8:30 am

Thanks, but can't find any about correct I2C initialization (as describe in NXP document)

REPLY

Nigel on July 5, 2016 at 7:51 am

Great post. Thank you very much !!

REPLY

RAVI on November 22, 2016 at 5:48 pm

SIR THIS IS VERY USEFUL FOR BEGINERS PLEASE ALSO SEND

THE CAN PROTOCOL ALSO
PLEASE
PLEASE
PLEASE ….infinite TIMES….

REPLY

haleem on December 12, 2016 at 10:02 am

Please share CAN article also

REPLY

Bri on August 19, 2020 at 8:14 pm

Here's a intro tutorial on CAN: https://www.circuitcrush.com/can-networking-tutorial/

REPLY

ArchonOSX on December 18, 2016 at 2:38 pm

Step 1 confuses me. You say "1. The master sends the start condition to every connected slave by leaving SCL high and switching SDA to low:" and yet the diagram shows the SDA line going from low to high. Am I seeing this correctly?

REPLY

ArchonOSX on December 18, 2016 at 2:45 pm

Step 6 is similarly confusing as you say "6. To stop the data transmission, the master sends a stop

condition to the slave by switching SCL high before switching SDA high:" The diagram shows both lines high already with SDA going low before SCL. I follow your written explanation but I don't think your diagrams do.

REPLY

Circuit Basics on March 24, 2017 at 6:45 am

You're right, step 1 could have been written better. I re-wrote it and hopefully cleared it up a bit... In step 6, I think it's the direction the bits are being sent that might be a little confusing. In the diagrams, picture the bits travelling from left to right, so in step 6, the SCL line switches high before the SDA line switches high.

REPLY

ArchonOSX on December 18, 2016 at 2:48 pm

Otherwise good articles and helpful explanations. Thanks for the work.

REPLY

Hello World on February 2, 2017 at 9:13 pm

Where is information about clock stretching? Very useful feature

REPLY

ktr on April 4, 2017 at 10:02 am

awsome article

REPLY

amlendra Kumar on May 11, 2017 at 1:56 pm

Good article on I2C.

REPLY

M Tilak on June 5, 2017 at 7:12 pm

Really helpful

REPLY

Debabrata Ghosh on July 20, 2017 at 3:36 pm

DtcInstall

REPLY

Brian on September 23, 2017 at 9:12 am

Thanks. This is a very interesting article. I'm not fully understanding point 4 however. When master is transmitting to its chosen slave would the sda line of all slaves not be pulled high as they are all sharing the same line?

REPLY

Johnny on January 23, 2019 at 10:24 am

Have the same question. It's like all the other slaves will also receive the data which

is not meant for them. If it is correct, is it possible to transmit data to only one specific slave with I2C?

REPLY

Imraan on June 1, 2019 at 4:45 am

I also have this same question. It seems like it's possible for devices that are not selected to also read the SDA pin because they're on the same line. Is this protocol on the assumption that all slaves and masters are part of one system and so none are trying to steal data?

REPLY

Colin on September 11, 2019 at 5:58 am

The SDA line, like the SCLK line, is indeed common to all devices and so will always be the same. The key thing is that only the slave device with the matching address actions a write command and drives the SDA line for a read command.

I'm sure the OP drew the diagrams this way to show the actual data transfer between the addressed device and the master for clarity.

REPLY

chandan bhargav on October 30, 2017 at 7:11 am

good article .i think it is better to explain about arbitration clock stretching /synchronization about why pull ups ....

REPLY

Dodutils on November 21, 2017 at 7:14 am

@framboise314 excellent !

REPLY

Dodutils on November 21, 2017 at 7:26 am

Did I miss it or do you talk about how to handle communication with multiple I2C modules that use same Address ?

You could add a chapter about I2C multiplexing and how to handle it for example with a TCA9548A .

REPLY

chandu on April 16, 2018 at 11:02 am

woow superb ..... its a really basic concepts of i2c.....

thanks for this website....
go head yaaar.

superb ,nice ,great .....

REPLY

Monica Patil on September 3, 2018 at 12:03 pm

This article is very good for beginner to study the serial communication protocols. The concepts are easily understood.

REPLY

david on February 18, 2019 at 2:36 pm

Hi Nice article. But waveform of Start and End conditions need to be switched :)

REPLY

Vedaant Arya on March 23, 2019 at 8:43 am

Great article! One thing though: Under “Single Master With Multiple Slaves”, while describing how using a 7-bit or a 10-bit address frame, it’s written so: 128 (27) and 1024 (210), while it should be 128 (2^7) and 1024 (2^(10)). I was stuck there for a while ._.

REPLY

Jack on March 28, 2019 at 4:33 pm

When you state the SCL goes “high” or “low”, does this basically mean it is “ON” or “OFF”? It’s just a clock signal at a specific frequency based on a crystal? No data is sent over this line; it’s just the set clock frequency? And what is a typical frequency?

Since polarity and phase cannot be set as with SPI, would this not be a disadvantage? Are these parameters sometimes adjusted for better communication, and thus SPI might be a better choice over I2C ?

REPLY

George Whitaker on March 30, 2019 at 11:55 pm

HI: I have spent several day trying to get the I2C network to work with no luck. I am trying to connect a RTC 3231 and a 16X2 lcd display.Each will work seperatly but when I connect both of them, the RTC works but the display doesn't.
Appreciate any help you can offer.
George Whitaker
gmwhjt@frontier.com

REPLY

Sreedhar on April 8, 2019 at 6:11 pm

Explanation is very good. But in I2C, 7-BIT addressing, 10-BIT Addressing Explanation is not there.

REPLY

rANOJAN on May 16, 2019 at 8:04 pm

NICE

REPLY

KRuPA on June 9, 2019 at 8:57 am

Great work. Can you please post such articles on CAN?

REPLY

Abdul Haseeb on July 10, 2019 at 8:34 am

Grateful information...

REPLY

KETUL on September 4, 2019 at 6:33 am

Nice article. But waveform of Start and End conditions need to be switched :)

REPLY

Anurag on September 22, 2019 at 4:19 pm

Simple and great article. thanks

REPLY

Madhav on October 7, 2019 at 5:23 pm

Can you add I3C as well. i3C is very new . But just want to glimpse of it.

REPLY

Mallika on November 12, 2019 at 11:28 am

Very useful information.Very clear and perfect.
Thank u for posting this topic

REPLY

Dinesh on November 25, 2019 at 11:38 am

Very Useful Stuff.
I need the know how to trigger the sensors using I2C commands also need clarification to set the delay using I2C in my project.
Please share your response.
Thank you !!!

REPLY

Ankit Satpati on December 30, 2019 at 6:49 am

what about usb protocol?

REPLY

Ramendra Hazarika on January 16, 2020 at 2:18 am

Sir, my humble thanks for a tremendous article. Great piece of Technical knowledge dissemination. Request you as well as other knowledgeable members to advise how to know target device address. Does the target device, in my case, a memory ic, an eeprom of 25 series, have a fixed address, or is given one? Pls help me out. Thanks

REPLY

Curie Gupta on April 16, 2020 at 10:04 am

Very nicely explained. Kudos to the author!

REPLY

Arslan Ahmed on April 25, 2020 at 8:34 am

nice article on i2c communication

REPLY

Hariprasad Bhat on June 29, 2020 at 5:03 am

In the Start & STOP cases, the SDA line is represented wrongly
Start: SDA goes high to low (In the diagram, it is low to high)
Stop: SDA goes from low to high(In the diagram, it is high to low)

REPLY

Junters on December 29, 2020 at 11:31 am

Notice the direction of transmission. In the diagram,the right is ahead of the left.

REPLY

Maulik solanki on August 14, 2020 at 9:35 am

Nice Article about I2C communication, I have used it in my college time.
Its very helpful for my metro project.

Thanks
Aakash patel

REPLY

gamage on February 8, 2021 at 11:48 am

Nice article & got the clear understanding of the I2C protocol. thank you a lot....

REPLY

frank on March 29, 2021 at 6:42 pm

In step 1) – Both SCL and SDA are going from low to high. But explanation says the opposite. Am I not reading the signals correctly. Could you please explain it.

REPLY

thesegotoeleven on August 1, 2021 at 2:03 pm

Read the signal from right to left. In this article, the waveforms are shown in the opposite sense that you would see on an oscilloscope. I had the same issue.

REPLY

Mousa on December 13, 2021 at 7:44 pm

Thanks for this information.

REPLY

ojoshiro on February 22, 2022 at 8:51 pm

Much appreciated. Very helpful. thank you very much!

REPLY

artur ferenc on June 20, 2023 at 3:51 pm

thank you – very useful

REPLY

Rapturot on August 29, 2023 at 6:08 am

The content was concise and I could grasp it in one reading, also the diagrams were of great help. Much appreciated.

REPLY

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