E210 Engineering Cyber-Physical Systems (Spring 2021)

I2C Introduction

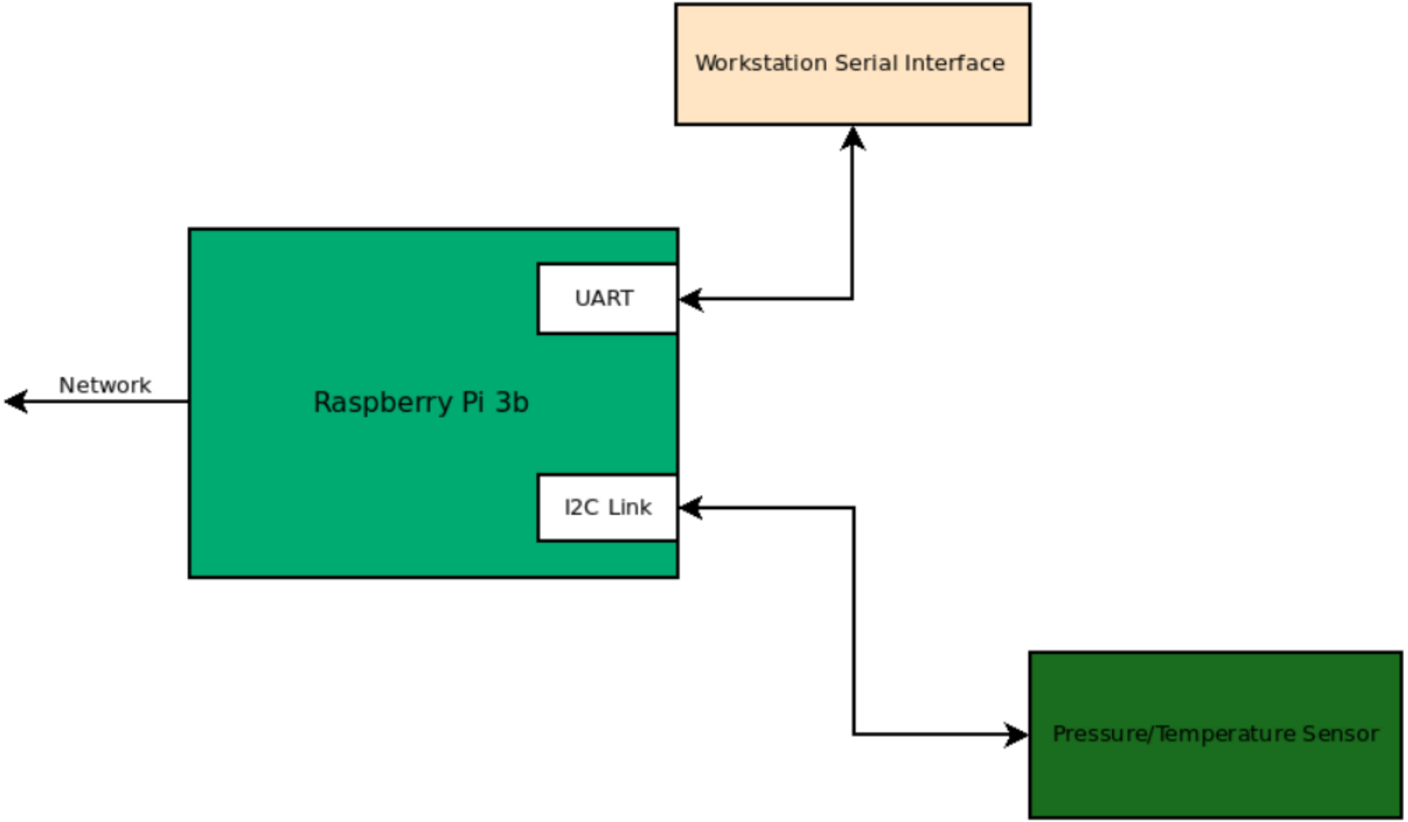
Bryce Himebaugh

Weekly Focus	Reading	Monday	Wed	Lab
Exam/CPS Introduction	Ref 1 Chapter 1	**3/8:** Exam 1	**3/10:** CPS Introduction	**Project 5 Raspberry PI Setup**
Raspberry Pi	Ref 2 Chapter 1-3	**3/15:** Pi Intro/UART Bus	**3/17:** Git/Github	
I2C Bus	Ref 3	**3/22:** I2C Bus	**3/24:** Wellness Day	**Project 6 I2C Pressure Sensor**
Python/Sensor	Ref 4, Ref 5	**3/29:** Classes/Modules	**3/31:** Pressure Sensor	
SPI	Ref 6	**4/5:** SPI Bus Overview	**4/7:** SPI HDL Design	**Project 7 SPI Connected I/O**
SPI	Ref 7 Chapter 1	**4/12:** SPI HDL Design	**4/14:** Sensor Memory	
Network Interface	Ref 7 Chapter 2	**4/19:** Ethernet Interface	**4/21:** MQTT	**Project 8 Network Interface**
MQTT/Flask	Ref 7 Chapter 14	**4/26:** Flask	**4/29:** Open Topic	

Final Exam Tues 5/4 10:10-12:10

https://engr210.github.io/

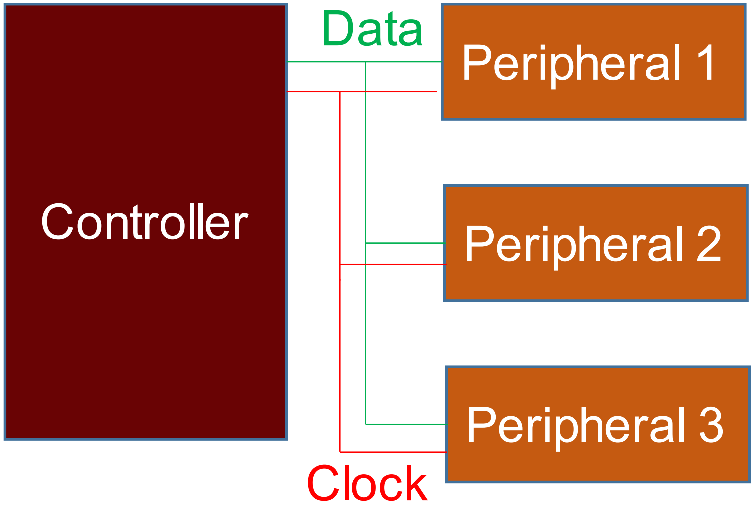
Raspberry I2C Link



I2C Overview

What is I2C?

- Synchronous Serial Link
- 2 Wire Bus
  - Open Collector
  - Half Duplex
- Devices are Individually Addressable
- Multiple Bus Controllers Possible



History of I2C

- Internally developed by Phillips Semiconductor in 1982
  - 100khz
  - 7-bit addresses: 128 devices on bus (practically 112)
- Public Specification in 1992
  - 400khz
  - 10-bit addresses possible
- Today
  - 5Mhz bus speeds

Comparison to UART

Category	I2C	UART
Clock	Synchronous	Asynchronous
Speed	400K Baud (5M Baud Max)	115K Baud
Transmission Mode	Half Duplex	Full Duplex
Number of Devices	112 (1024 possible)	2
Number of Pins	2 (Data, Clock)	2* (Rx, Tx), Optional (CTS,RTS)
Baud Rate Accuracy Requirement	N/A	~3% Baud Rate Accuracy
Development Complexity	More than UART	Less than I2C

Device Naming Conventions

[1] **Note:** You may be familiar with the terms "master" and "slave" to represent the relationship between devices on an I^2C bus. The terms are considered obsolete and are now replaced with the terms "controller" and "peripheral," respectively.

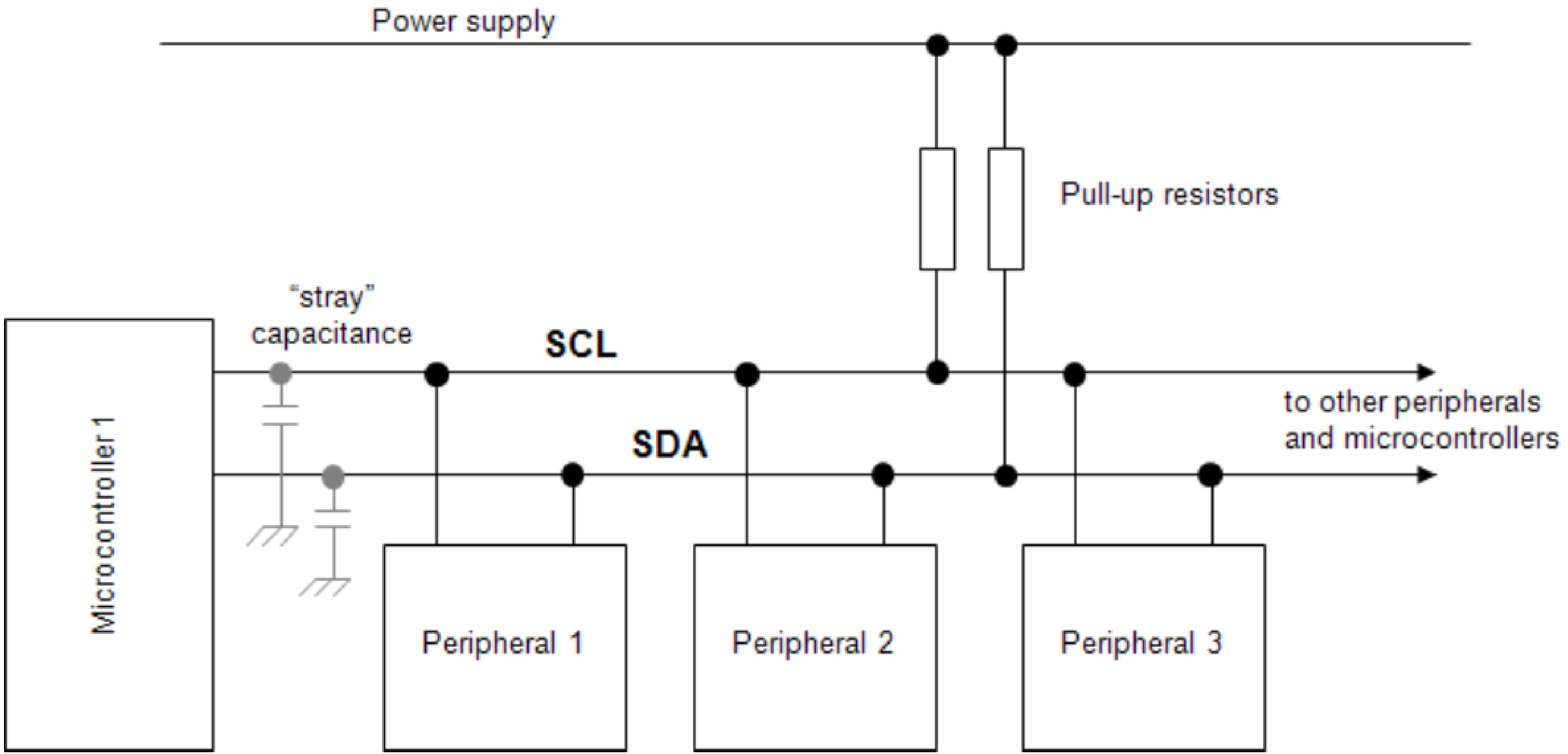
Obsolete Name	Replacement Name
Master	Controller
Slave	Peripheral

The naming convention may vary depending on manufacturer, programming language, companies, or organizations (e.g. main/secondary, initiator-responder, source/replica, etc.). For more information, check out the following links.

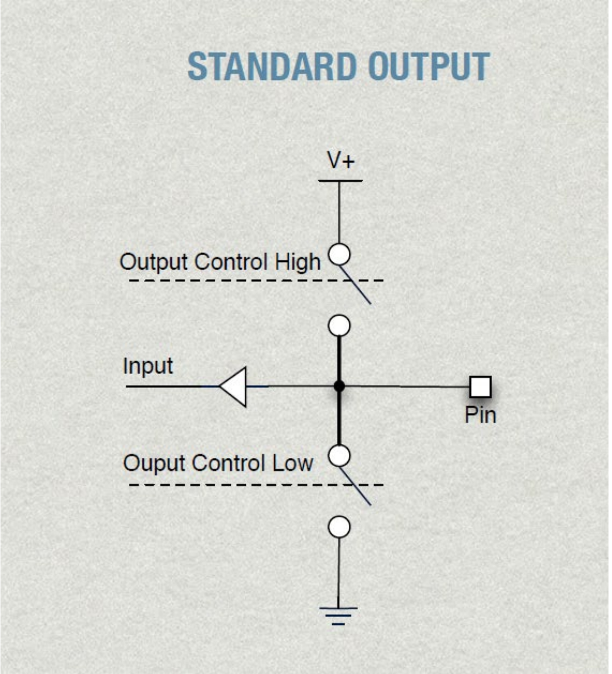
- Wikipedia: Terminology Concerns
- OSHWA: A Resolution to Redefine SPI Signal Names

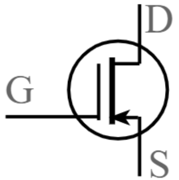
https://learn.sparkfun.com/tutorials/i2c/all

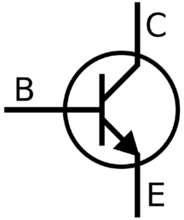
Bus Connections


Power supply
Pull-up resistors
"stray"
capacitance
SCL
SDA
to other peripherals
and microcontrollers
Microcontroller 1
Peripheral 1
Peripheral 2
Peripheral 3

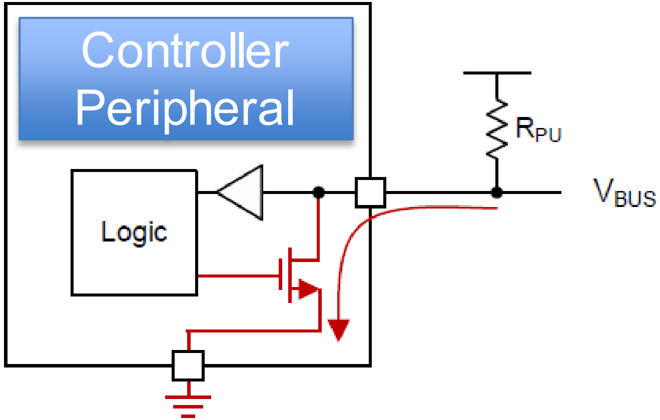
Standard vs Open-Collector Output



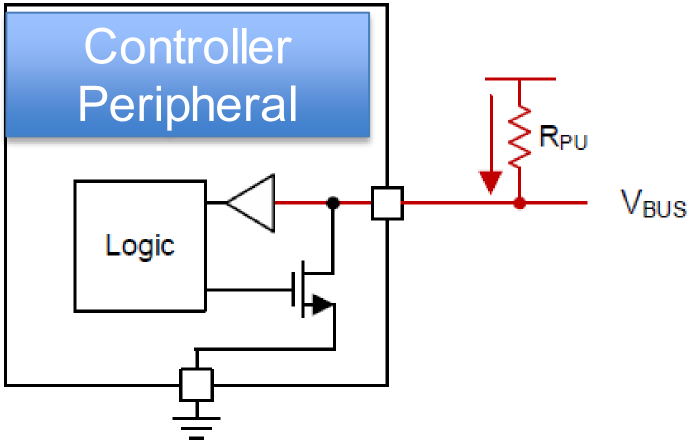


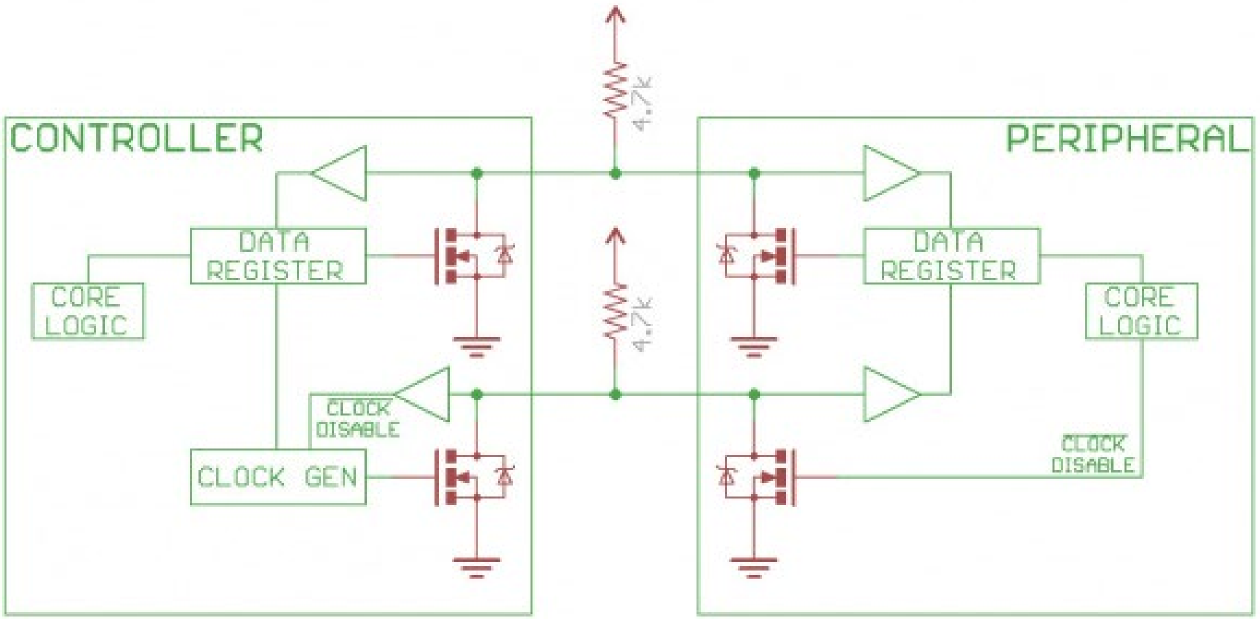


Output a 0



Output a 1

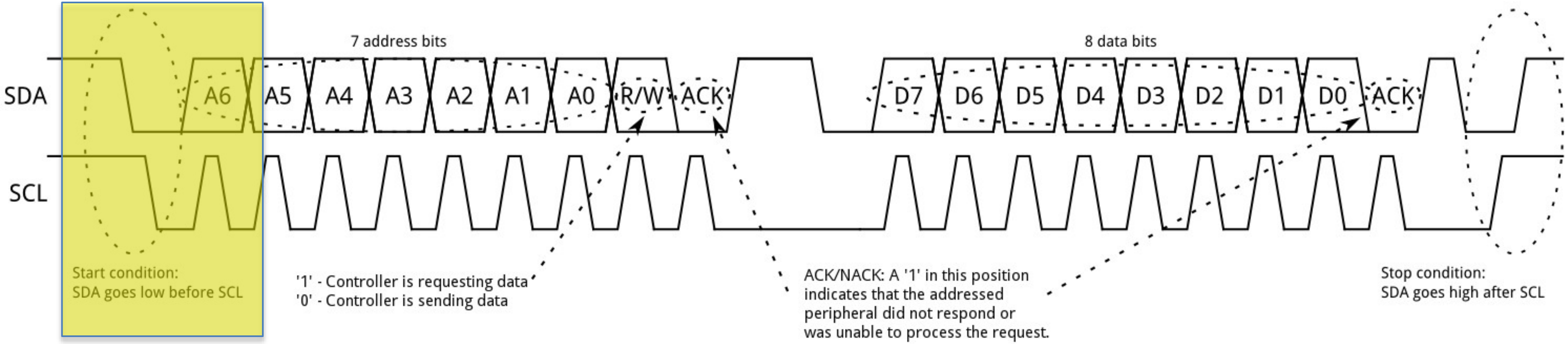




Notice the two pull-up resistors on the two communication lines.

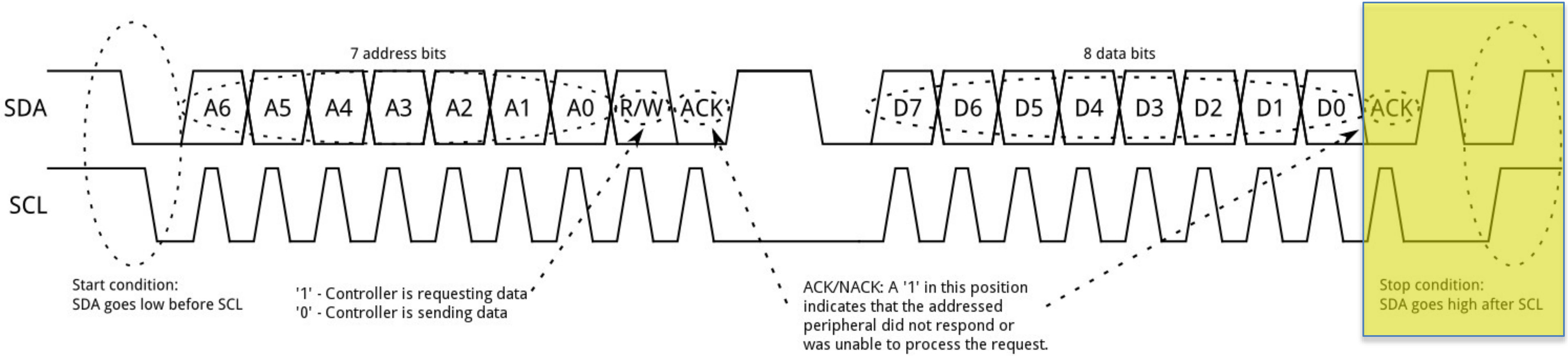
https://learn.sparkfun.com/tutorials/i2c/all

Waveform



7 address bits
8 data bits
SDA
SCL
A6
A5
A4
A3
A2
A1
A0
R/W
ACK
D7
D6
D5
D4
D3
D2
D1
D0
ACK
Start condition:
SDA goes low before SCL
'1' - Controller is requesting data
'0' - Controller is sending data
ACK/NACK: A '1' in this position
indicates that the addressed
peripheral did not respond or
was unable to process the request.
Stop condition:
SDA goes high after SCL

Waveform



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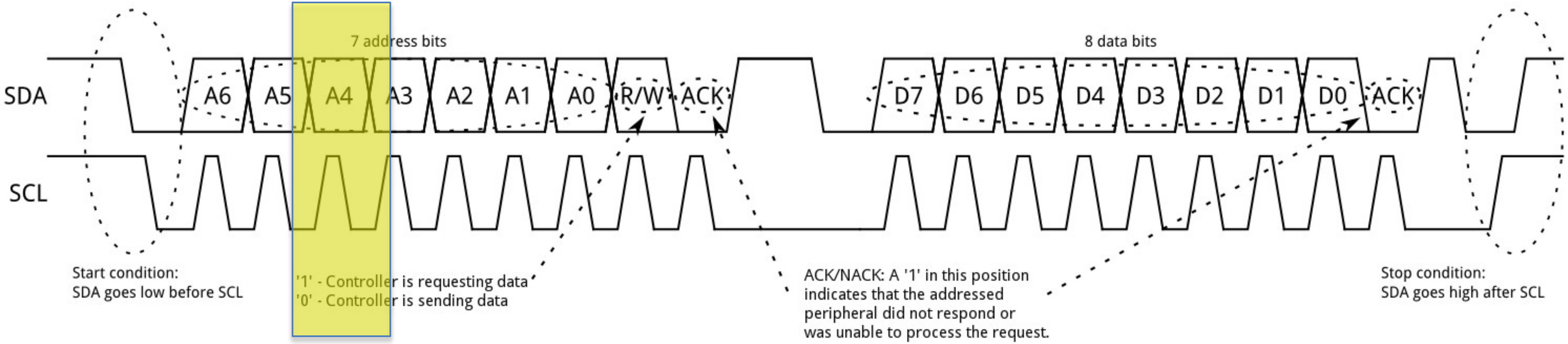

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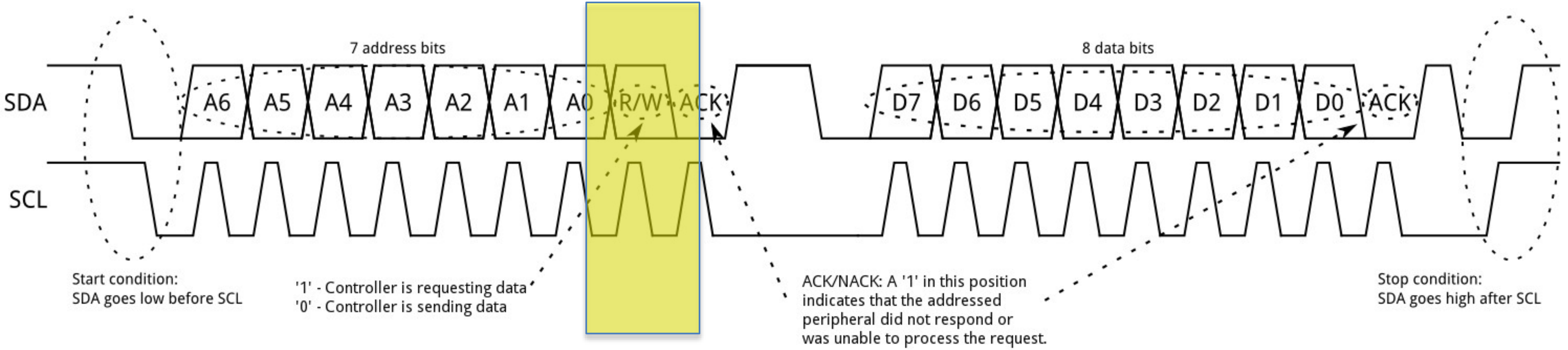
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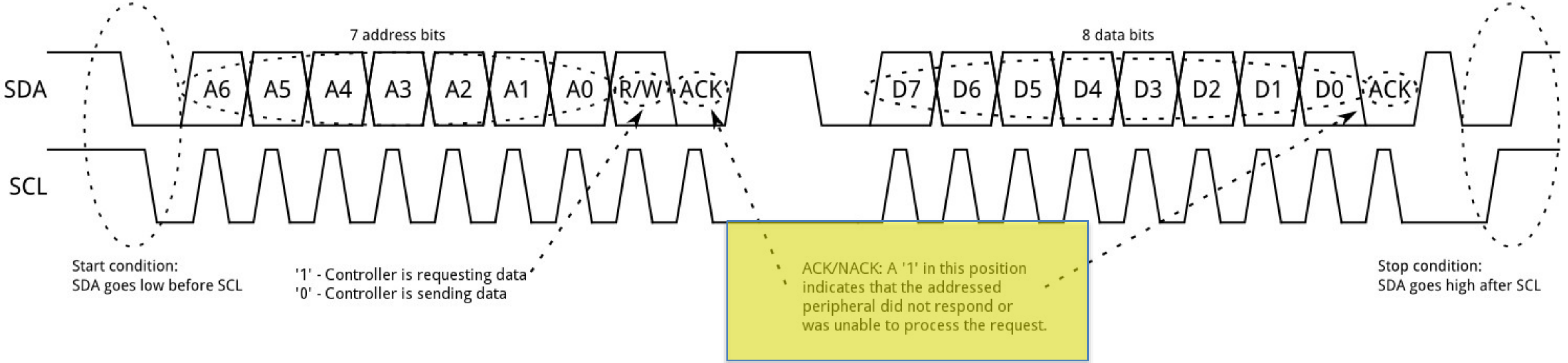
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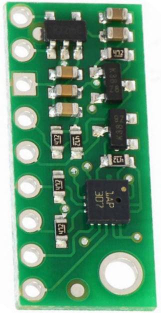
Peripheral Addressing

Bus Address vs Register Address

I2C Connections



Device Address: 0x5C or 0x5D
Depending on External Pin

Table 14 provides a list of the 8-bit registers embedded in the device and the related addresses.

Table 14. Registers address map

Name	Type	Register Address		Default	Function and comment
		Hex	Binary		
Reserved (Do not modify)		00-07 0D - 0E			Reserved
REF_P_XL	R/W	08	0001000	00000000	
REF_P_L	R/W	09	0001001	00000000	
REF_P_H	R/W	0A	0001010	00000000	
WHO_AM_I	R	0F	0001111	10111011	Dummy register
RES_CONF	R/W	10	0010000	011111010	
Reserved (Do not modify)		11-1F			Reserved
CTRL_REG1	R/W	20	010 0000	00000000	
CTRL_REG2	R/W	21	010 0001	00000000	
CTRL_REG3	R/W	22	010 0010	00000000	
INT_CFG_REG	R/W	23	0100011	00000000	
INT_SOURCE_REG	R	24	0100100	00000000	
THS_P_LOW_REG	R/W	25	0100101	0000000	
THS_P_HIGH_REG	R/W	26	0100110	0000000	
STATUS_REG	R	27	010 0111	00000000	
PRESS_POUT_XL_REH	R	28	010 1000	output	
PRESS_OUT_L	R	29	010 1001	output	
PRESS_OUT_H	R	2A	010 1010	output	
TEMP_OUT_L	R	2B	010 1011	output	
TEMP_OUT_H	R	2C	010 1100	output	
Reserved (Do not modify)		2D-2F			Reserved
AMP_CTRL	R/W	30	011 0000		Partially reserved

LPS331 Registers

Table 14 provides a list of the 8-bit registers embedded in the device and the related addresses.

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REF_P_L	R/W	09	0001001	00000000	
REF_P_H	R/W	0A	0001010	00000000	
WHO_AM_I	R	0F	0001111	10111011	Dummy register
RES_CONF	R/W	10	0010000	011111010	
Reserved (Do not modify)		11-1F			Reserved
CTRL_REG1	R/W	20	010 0000	00000000	
CTRL_REG2	R/W	21	010 0001	00000000	
CTRL_REG3	R/W	22	010 0010	00000000	
INT_CFG_REG	R/W	23	0100011	00000000	
INT_SOURCE_REG	R	24	0100100	00000000	
THS_P_LOW_REG	R/W	25	0100101	0000000	
THS_P_HIGH_REG	R/W	26	0100110	0000000	
STATUS_REG	R	27	010 0111	00000000	
PRESS_POUT_XL_REH	R	28	010 1000	output	
PRESS_OUT_L	R	29	010 1001	output	
PRESS_OUT_H	R	2A	010 1010	output	
TEMP_OUT_L	R	2B	010 1011	output	
TEMP_OUT_H	R	2C	010 1100	output	
Reserved (Do not modify)		2D-2F			Reserved
AMP_CTRL	R/W	30	011 0000		Partially reserved

Communication Protocol

Write from Controller to Peripheral

Figure 8 shows an example of writing a single byte to a slave register.

Master Controls SDA Line

Slave Controls SDA Line

Write to One Register in a Device

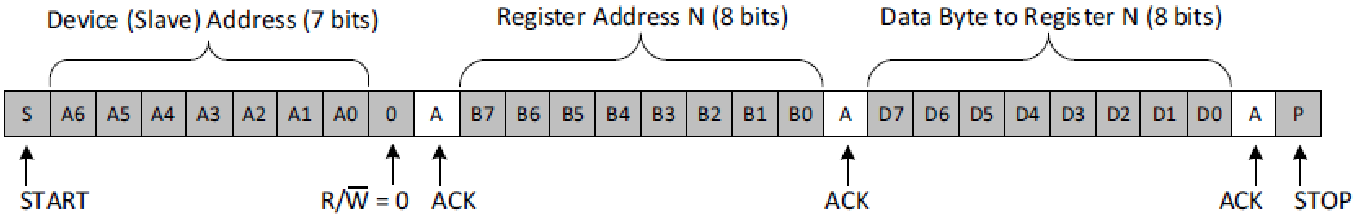


Figure 8. Example I²C Write to Slave Device's Register

https://www.ti.com/lit/an/slva704/slva704.pdf

Read Peripheral Register from Controller

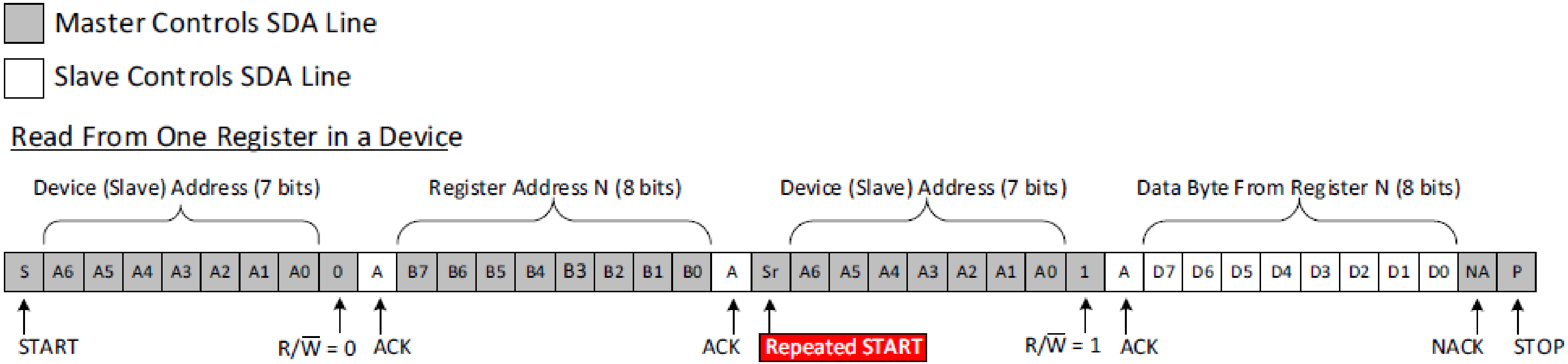


Figure 9. Example I^2C Read from Slave Device's Register

LPS331AP Pressure Sensor

LPS331AP

MEMS pressure sensor: 260-1260 mbar absolute digital output barometer

Datasheet —production data

Features

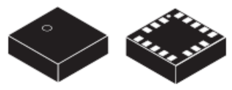
- 260 to 1260 mbar absolute pressure range
- High-resolution mode: 0.020 mbar RMS
- Low power consumption:
  - Low resolution mode: 5.5 μA
  - High resolution mode: 30 μA
- High overpressure capability: 20x full scale
- Embedded temperature compensation
- Embedded 24-bit ADC
- Selectable ODR from 1 Hz to 25 Hz
- SPI and I²C interfaces
- Supply voltage: 1.71 to 3.6 V
- High shock survivability: 10,000 *g*
- Small and thin package
- ECOPACK® lead-free compliant

Applications

- Indoor and outdoor navigation
- Enhanced GPS for dead-reckoning
- Altimeter and barometer for portable devices
- Weather station equipment
- Sport watches

Description

The LPS331AP is an ultra compact absolute piezoresistive pressure sensor. It includes a monolithic sensing element and an IC interface able to take the information from the sensing element and to provide a digital signal to the external world.



HCLGA-16L (3 x 3 x 1 mm)

The sensing element consists of a suspended membrane realized inside a single mono-silicon substrate. It is capable to detecting pressure and is manufactured using a dedicated process developed by ST, called *VENSENS*.

The *VENSENS* process allows to build a mono-silicon membrane above an air cavity with controlled gap and defined pressure. The membrane is very small compared to the traditionally built silicon micromachined membranes. Membrane breakage is prevented by an intrinsic mechanical stopper.

The IC interface is manufactured using a standard CMOS process that allows a high level of integration to design a dedicated circuit which is trimmed to better match the sensing element characteristics.

The LPS331AP is available in a small holed cap land grid array (HCLGA) package and it is guaranteed to operate over a temperature range extending from -40 °C to +85 °C. The package is holed to allow external pressure to reach the sensing element.

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https://www.pololu.com/product/2126

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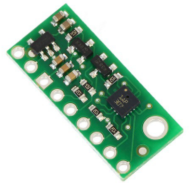
LPS331AP Pressure/Altitude Sensor Carrier with Voltage Regulator



Pololu item #: 2126 **181** in stock

Brand: Pololu

Status: Clearance

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Price break	Unit price (US$)
1	3.95
5	3.63
25	3.34
100	3.08

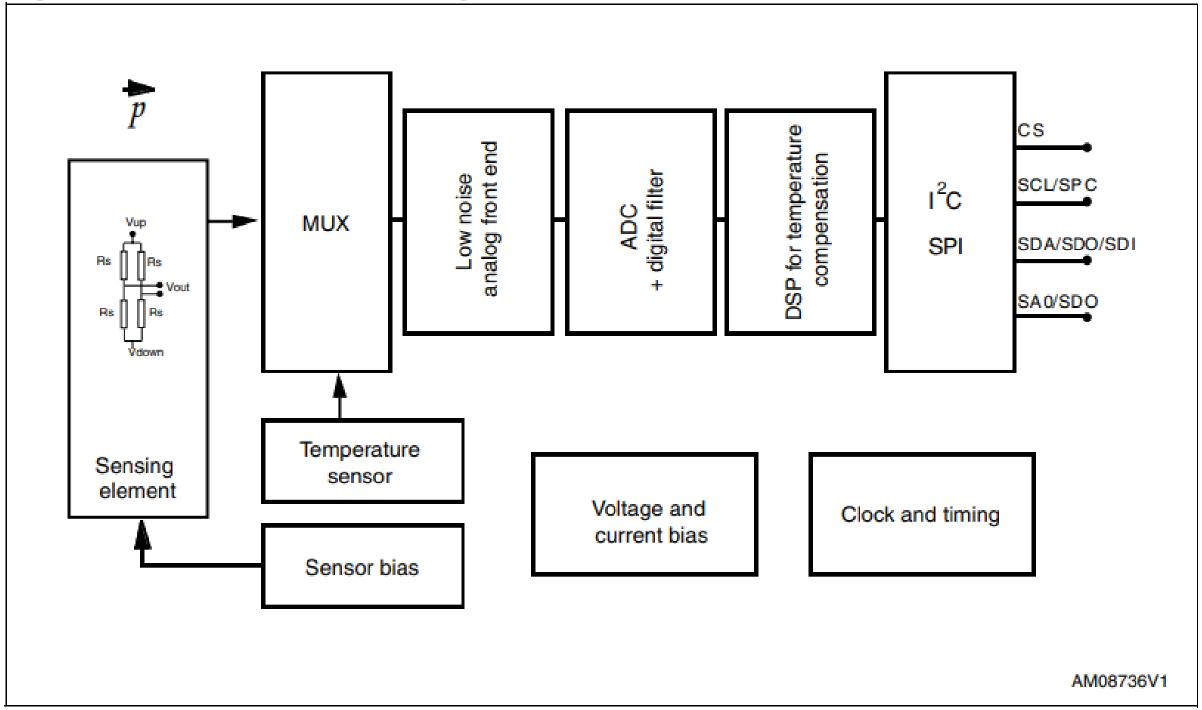
Quantity: 1 Add to cart

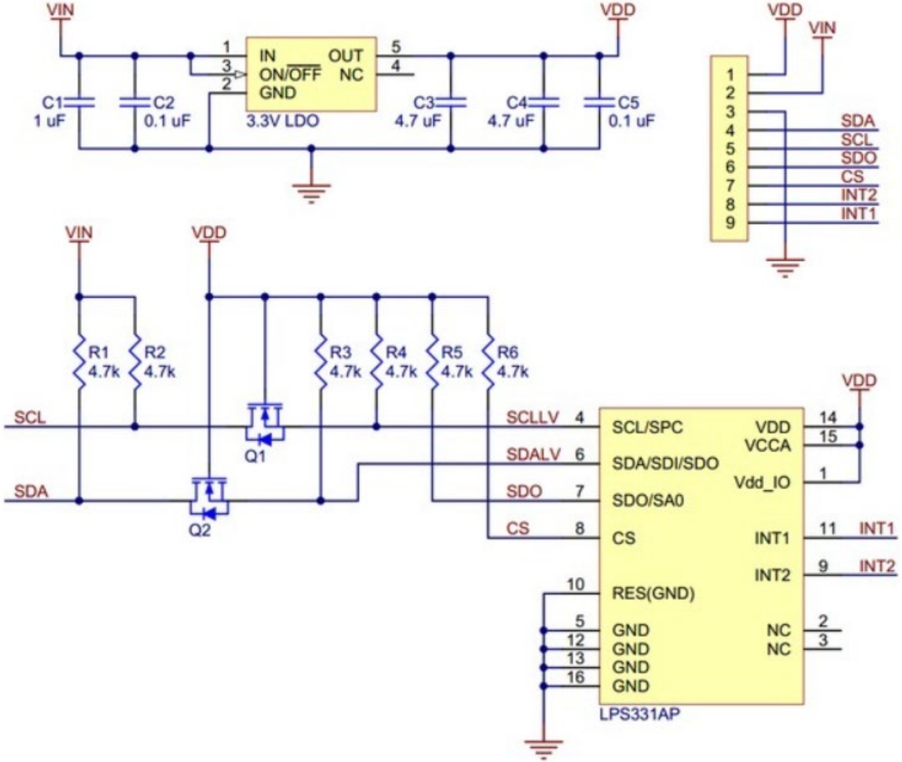
backorders allowed Add to wish list

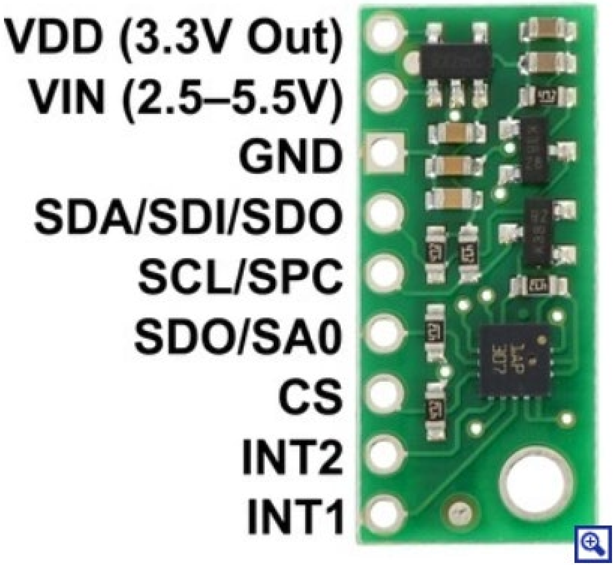
This carrier for ST's LPS331AP digital barometer measures pressures from 260 mbar to 1260 mba ±2 mbar (0.2 kPa) and typical RMS noise of 0.02 mbar (0.002 kPa) in high-resolution mode. The regulator and integrated level shifters that allow it to work over an input voltage range of 2.5 V t

1.1 LPS331AP block diagram

Figure 1. LPS331AP block diagram




VIN
VDD
IN
OUT
ON/OFF
NC
GND
3.3V LDO
C1 1 uF
C2 0.1 uF
C3 4.7 uF
C4 4.7 uF
C5 0.1 uF
SDA
SCL
SDO
CS
INT2
INT1
R1 4.7k
R2 4.7k
R3 4.7k
R4 4.7k
R5 4.7k
R6 4.7k
Q1
Q2
SCLLV
SDALV
SCL/SPC
SDA/SDI/SDO
SDO/SA0
RES(GND)
VCCA
Vdd_IO
LPS331AP


VDD (3.3V Out)
VIN (2.5–5.5V)
GND
SDA/SDI/SDO
SCL/SPC
SDO/SA0
CS
INT2
INT1