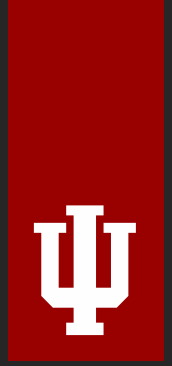


E210 Engineering Cyber-Physical Systems (Spring 2021)

LPS331AP Pressure Sensor

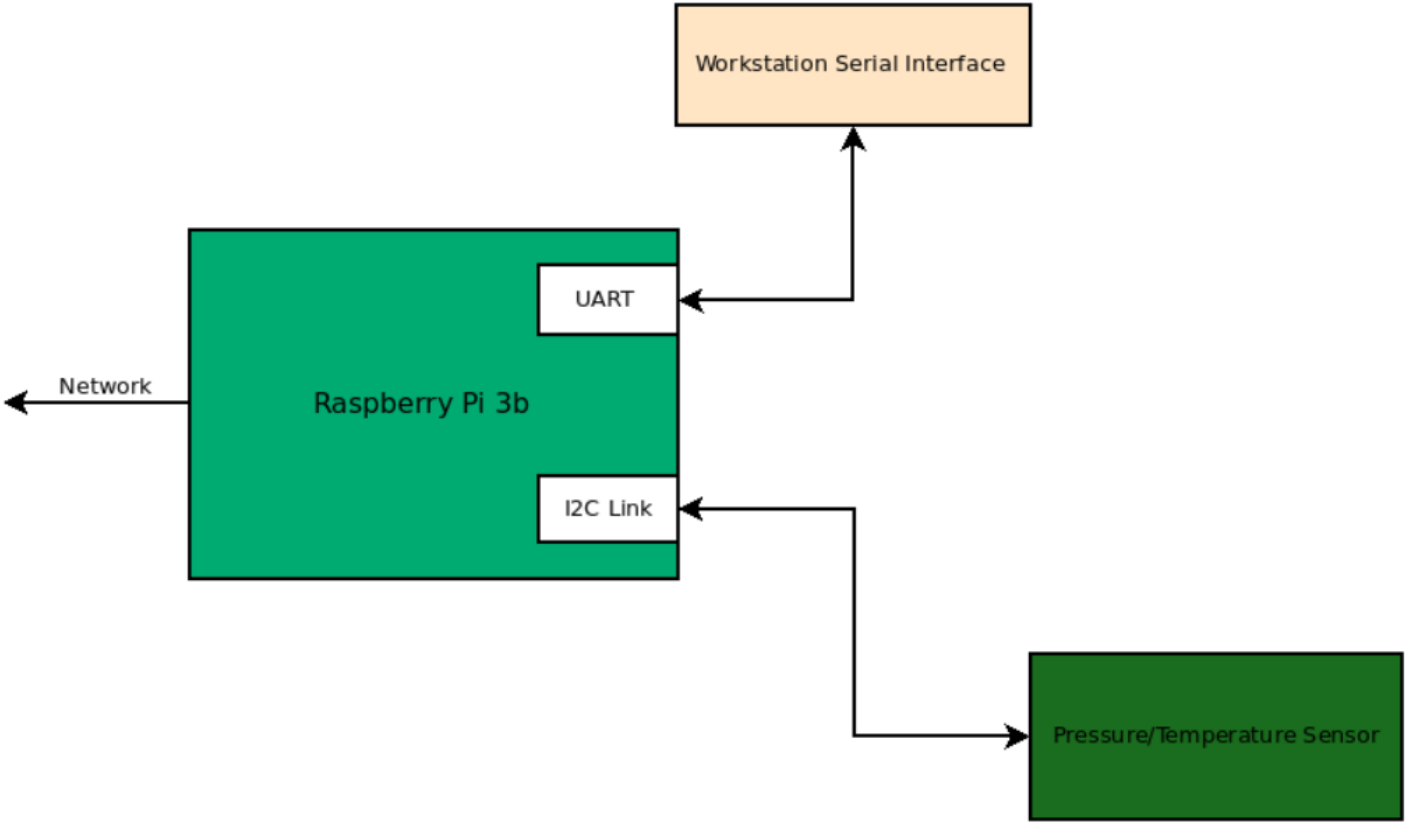
Bryce Himebaugh

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



LPS331AP Pressure Sensor

Component Datasheet

1. Provided by Manufacturer
2. Written for many roles
   - Computer Engineer
   - Programmer
   - Circuit Board Designer
   - Mechanical Engineer
   - System Engineer

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 I^2C interfaces
- Supply voltage: 1.71 to 3.6 V
- High shock survivability: 10,000 *g*
- Small and thin package
- ECOPACK® lead-free compliant

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

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.

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.

Table 1. Device summary

Order codes	Temperature range [°C]	Package	Packing
LPS331APY	-40 to +85	HCLGA-16L	Tray
LPS331APTR			Tape and reel

https://engr210.github.io

3/10	Wednesday	Raspberry Pi Intro	

Cyber-Physical Systems Introduction

Reading References:

1. Introduction to Embedded Systems - A Cyber-Physical Systems Approach
2. Pro Git Book
3. Sparkfun I2C Tutorial
4. Python Classes
5. ST LPS331 Pressure Sensor
6. Sparkfun SPI Tutorial
7. Cyber-Physical Systems - a Computational Perspective
8. Dive Into Python 3

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Overview Page

High Level List of Features

Uses envisioned by the manufacturer

High Level Functionality

LPS331AP

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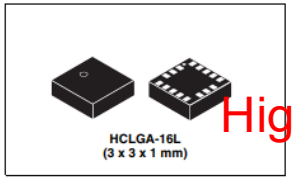

HCLGA-16L
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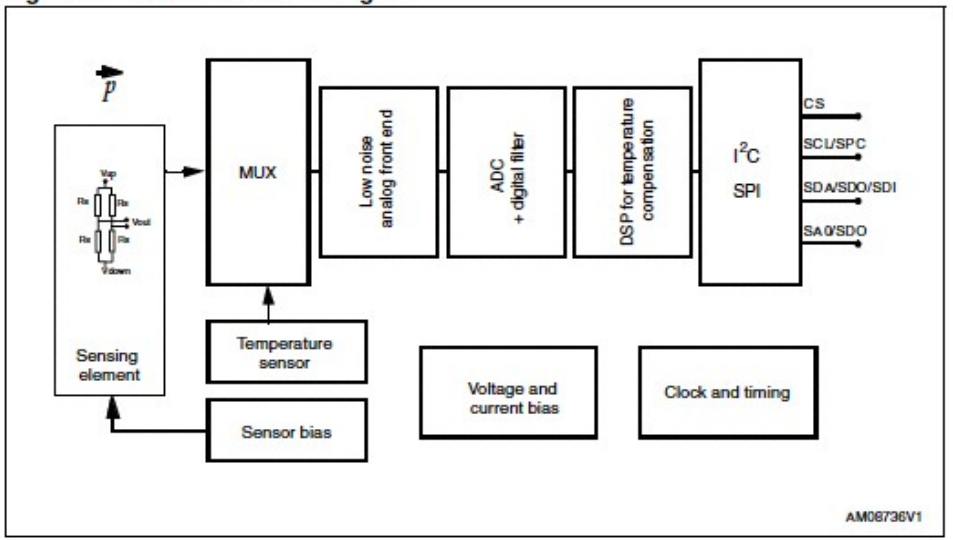
Block Diagram

1 Block diagram and pin description

1.1 LPS331AP block diagram

Figure 1. LPS331AP block diagram

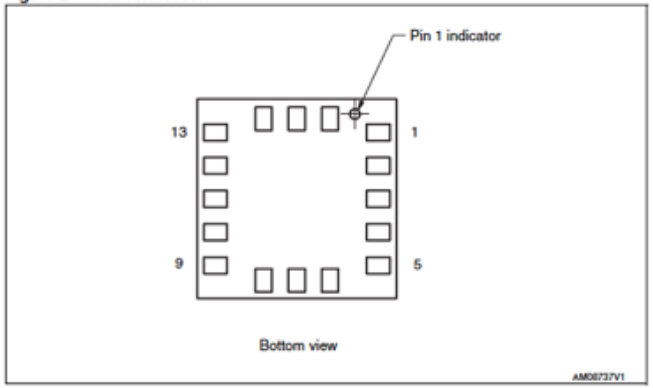


Pin Description

Table 2. Pin description

Pin#	Name	Function
1	Vdd_IO	Power supply for I/O pins
2	NC	Not connected
3	NC	Not connected
4	SCL SPC	I^2C serial clock (SCL) SPI serial port clock (SPC)
5	GND	0 V supply
6	SDA SDI SDO	I^2C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
7	SDO SA0	SPI serial data output (SDO) I^2C less significant bit of the device address (SA0)
8	CS	SPI enable I^2C/SPI mode selection (1: I^2C mode; 0: SPI enabled)
9	INT2	Interrupt 2 (or data ready)
10	Reserved	Connect to GND
11	INT1	Interrupt 1 (or data ready)
12	GND	0 V supply
13	GND	0 V supply
14	VDD	Power supply
15	VCCA	Analog power supply
16	GND	0 V supply

Figure 2. Pin connection



Environmental Requirements

2.1 Mechanical characteristics

Table 3. Mechanical characteristics

Symbol	Parameter	Test condition	Min.	Typ.(1)	Max.	Unit
Top	Operating temperature range		-40	–	85	°C
Tfull	Full accuracy temperature range		0	–	80	°C
Pop	Operating pressure range		260	–	1260	mbar
Pbits	Pressure output data		–	24	–	bits
Pres	Pressure sensitivity		–	4096	–	LSB/ mbar
Paccrel	Relative accuracy over pressure(2)	P = 800 to 1100 mbar T= 25°C	–	±0.1	±0.2	mbar
PaccT	Absolute accuracy pressure over temperature(3)	P = 800 to 1100 mbar T = 0 →+80 °C	- 3.2	±2	2.6	mbar
Pnoise	Pressure noise		See *Table 17.*			mbar RMS
Tbits	Temperature output data		–	16	–	bits
Tres	Temperature sensitivity		–	480	–	LSB/°C
Tacc	Absolute accuracy temperature	T= 0~+80 °C	–	±2	–	°C

1. Typical specifications are not guaranteed.
2. Characterization data. Parameter not tested at final test
3. Embedded pwl compensation.

V_O	Vss to VDD	Vss to VDD	
Total Power Dissipation			
P_D (T_A=85°C)		60	mW
Temperatures			
Operating Temperature	-40	+85	°C
Storage Temperature	-40	+125	°C

Absolute Maximum Ratings

Table 6. Absolute maximum ratings

Symbol	Ratings	Maximum value	Unit
Vdd	Supply voltage	-0.3 to 4.8	V
Vdd_IO	I/O pins supply voltage	-0.3 to 4.8	V
Vin	Input voltage on any control pin	-0.3 to Vdd_IO +0.3	V
P	Overpressure	20	bar
T_{STG}	Storage temperature range	-40 to +125	°C
ESD	Electrostatic discharge protection	2 (HBM)	kV

Electrical Properties

Electrical characteristics

Table 4. Electrical characteristics

Symbol	Parameter	Test condition	Min.	Typ.(1)	Max.	Unit
Vdd	Supply voltage		1.71	–	3.6	V
Vdd_IO	IO supply voltage		1.71	–	3.6	V
Idd	Supply current @ ODRp 1 Hz and ODRt = 1Hz		see *Table 5*			µA
IddPdn	Supply current in power-down mode T = 25 °C		–	0.5	–	µA

1. Typical specifications are not guaranteed.

Table 5. Supply current at ODRp 1 Hz, ODRt 1 Hz

Symbol	RES_CONF (hex)	Min.	Typ.	Max.	Unit
Idd	73	–	5.5	–	µA
	75	–	6.6	–	
	77	–	11.5	–	
	78	–	17.5	–	
	7A	–	30.0	–	

Interfacing Options

5 Digital interfaces

5.1 I²C serial interface

The registers embedded in the LPS331AP may be accessed through both the I²C and SPI serial interfaces. The latter may be SW configured to operate either in 3-wire or 4-wire interface mode.

The serial interfaces are mapped onto the same pads. To select/exploit the I²C interface, CS line must be tied high (i.e. connected to Vdd_IO).

Table 7. Serial interface pin description

Pin name	Pin description
CS	SPI enable I²C/SPI mode selection (1: I²C mode; 0: SPI enabled)
SCL/ SPC	I²C serial clock (SCL) SPI serial port clock (SPC)
SDA/ SDI/ SDO	I²C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
SA0/ SDO	I²C less significant bit of the device address (SA0) SPI serial data output (SDO)

I2C Interface

5.2 I²C serial interface

The LPS331AP I²C is a bus slave. The I²C is employed to write data into registers whose content can also be read back.

The relevant I²C terminology is given in *Table 8.*

Table 8. Serial interface pin description

Term	Description
Transmitter	The device which sends data to the bus
Receiver	The device which receives data from the bus
Master	The device which initiates a transfer, generates clock signals and terminates a transfer
Slave	The device addressed by the master

There are two signals associated with the I²C bus: the serial clock line (SCL) and the serial data line (SDA). The latter is a bi-directional line used for sending and receiving the data to/from the interface. Both lines have to be connected to Vdd_IO through pull-up resistors.

The I²C interface is compliant with fast mode (400 kHz) I²C standards as well as with the normal mode.

5.2.1 I²C operation

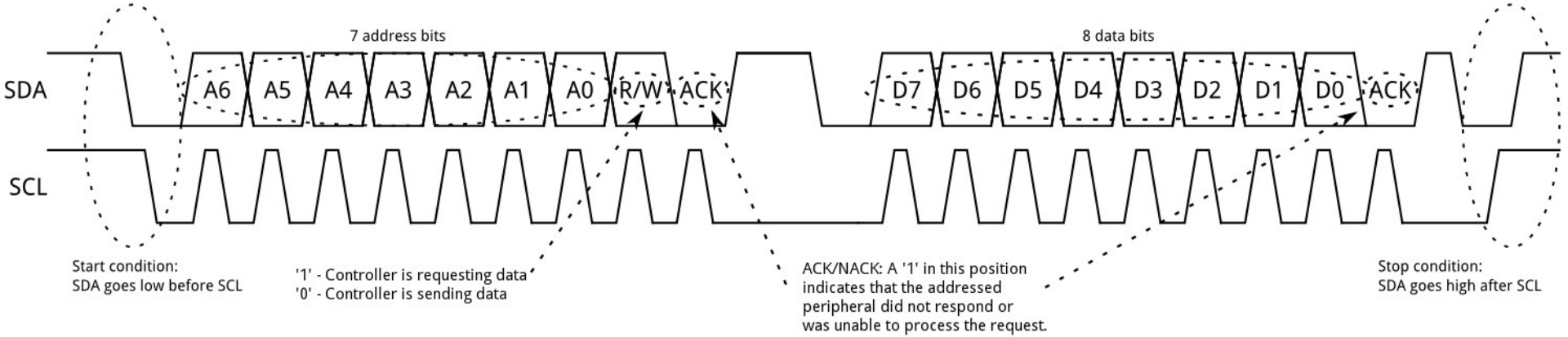
The transaction on the bus is started through a START (ST) signal. A start condition is defined as a HIGH to LOW transition on the data line while the SCL line is held HIGH. After this has been transmitted by the master, the bus is considered busy. The next byte of data transmitted after the start condition contains the address of the slave in the first 7 bits and the eighth bit tells whether the master is receiving data from the slave or transmitting data to the slave. When an address is sent, each device in the system compares the first seven bits after a start condition with its address. If they match, the device considers itself addressed by the master.

The slave address (SAD) associated to the LPS331AP is 101110xb. The **SDO**/**SA0** pad can be used to modify the less significant bit of the device address. If the SA0 pad is connected to voltage supply, LSb is '1' (address 1011101b), otherwise if the SA0 pad is connected to ground, the LSb value is '0' (address 1011100b). This solution permits to connect and address two different LPS331APs to the same I²C lines.

Data transfer with acknowledge is mandatory. The transmitter must release the SDA line during the acknowledge pulse. The receiver must then pull the data line LOW so that it remains stable low during the HIGH period of the acknowledge clock pulse. A receiver which has been addressed is obliged to generate an acknowledge after each byte of data received.

The I²C embedded in the LPS331AP behaves like a slave device and the following protocol

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

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

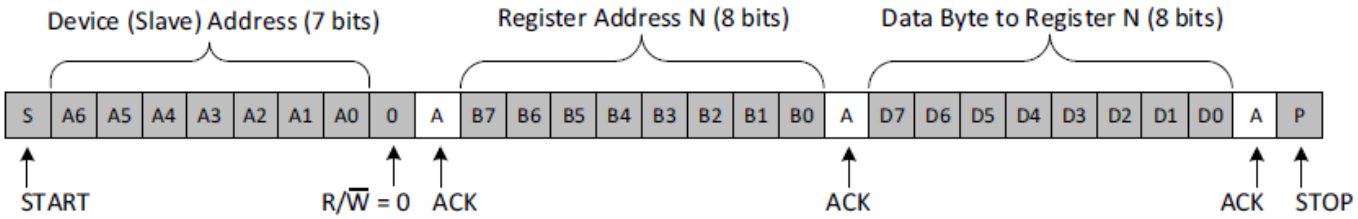


Figure 8. Example I²C Write to Slave Device's Register

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

Writing Data to Device

I2C Address of LPS331AP

Register Address within LPS331AP

Data to be written

Table 10. Transfer when master is writing one byte to slave

Master	ST	SAD + W		SUB		DATA		SP
Slave			SAK		SAK		SAK	

Acknowledgement

Start and Stop Bits

Read Peripheral Register from Controller

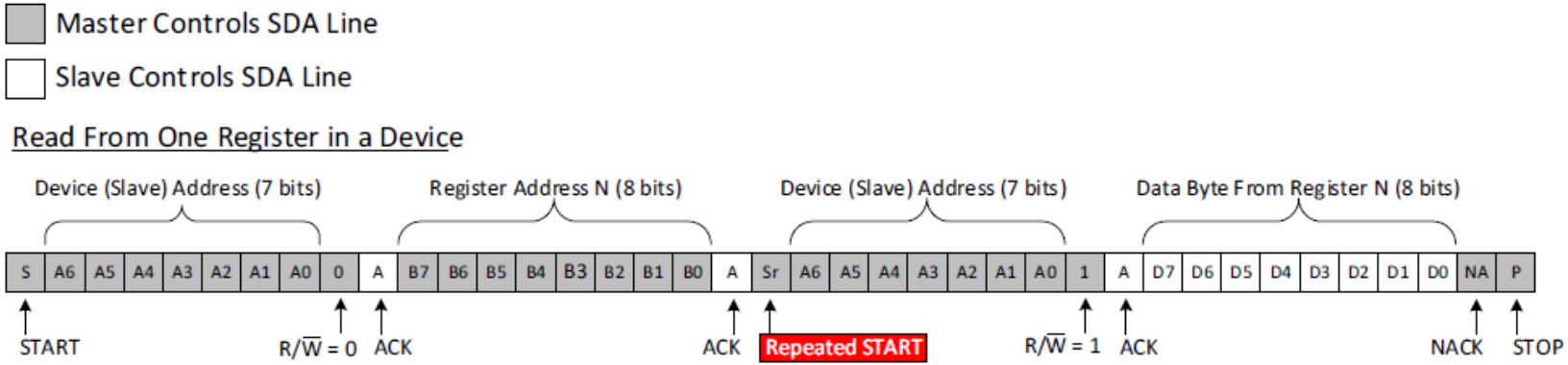


Figure 9. Example I²C Read from Slave Device's Register

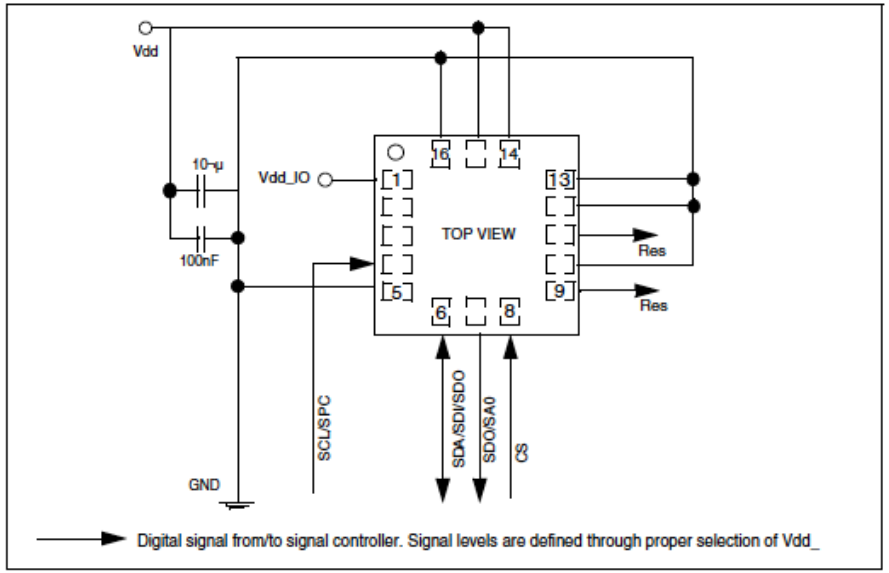
Reading Data From Device

Table 12. Transfer when master is receiving (reading) one byte of data from slave

Master	ST	SAD + W		SUB		SR	SAD + R			NMAK	SP
Slave			SAK		SAK			SAK	DATA		

Example Connections

Figure 3. LPS331AP electrical connection



Register Map

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

Registers marked as Reserved must not be changed. The writing to these registers may

Register Descriptions

WHO_AM_I — **Device identification**

7	6	5	4	3	2	1	0
1	0	1	1	1	0	1	1

Address: 0Fh

Type: R

Description: This read-only register contains the device identifier that, for LPS331AP, is set to BBh.

CTRL_REG1 — **Control register 1**

7	6	5	4	3	2	1	0
PD	ODR2	ODR1	ODR0	DIFF_EN	DBDU	DELTA_EN	SIM

Address: 20h

Type: R/W

Description: Control register.

[7] PD: power down control.
Default value: 0
(0: power-down mode; 1: active mode)

[6:4] ODR2, ODR1, ODR0: output data rate selection.
Default value: 00
(see *Table 18*)

[3] DIFF_EN: Interrupt circuit enable.
Default value: 0
(0: interrupt generation disabled; 1: interrupt circuit enabled)

[2] BDU: block data update.
Default value: 0
(0: continuous update; 1: output registers not updated until MSB and LSB reading)

[1] DELTA_EN: delta pressure enable
(1: delta pressure registers enabled. 0: disable)

[0] SIM: SPI Serial Interface Mode selection.
Default value: 0
(0: 4-wire interface; 1: 3-wire interface)

PD bit allows to turn on the device. The device is in power-down mode when PD = '0' (default value after boot). The device is active when PD is set to '1'.

ODR2- ODR1 - ODR0 bits allow to change the output data rates of pressure and temperature samples. The default value is "000" which corresponds to "one shot configuration" for both pressure and temperature output. ODR2, ODR1 and ODR0 bits can be configured as described in *Table 18*.

Note: *Before changing the ODR it is necessary to power down the device (CTRL_REG1[7]).*

Register Descriptions

CTRL_REG2 — **Control register 2**

7	6	5	4	3	2	1	0
BOOT	RESERVED				SWRESET	AUTO_ZERO	ONE_SHOT

Address: 21h

Type: R/W

Description: Control register.

[7] BOOT: Reboot memory content. Default value: 0
(0: normal mode; 1: reboot memory content)

[6:3] RESERVED

[2] Software reset. Default value: 0
(0: normal mode; 1: software reset)

[1] Autozero enable. Default value: 0
(0: normal mode; 1: autozero enable)

[0] One shot enable. Default value: 0
(0: waiting for start of conversion; 1: start for a new dataset)

BOOT bit is used to refresh the content of the internal registers stored in the Flash memory block. At the device power-up the content of the Flash memory block is transferred to the internal registers related to trimming functions to permit a good behavior of the device itself. If for any reason, the content of the trimming registers is modified, it is sufficient to use this bit to restore the correct values. When BOOT bit is set to '1' the content of the internal Flash is copied inside the corresponding internal registers and is used to calibrate the device. These values are factory trimmed and they are different for every device. They permit good behavior of the device and normally they should not be changed. At the end of the boot process the BOOT bit is set again to '0'.

BOOT bit takes effect after one ODR clock cycle.

SWRESET is the software reset bit. The device is reset to the power on configuration if the SWRESET bit is set to '1' and BOOT is set to '1'.

AUTO_ZERO, when set to '1', the actual pressure output is copied in the REF_P_H & REF_P_L & REF_P_XL and kept as reference and the PRESS_OUT_H & PRESS_OUT_L & PRESS _OUT_XL is the difference between this reference and the pressure sensor value.

ONE_SHOT bit is used to start a new conversion when ODR1-ODR0 bits in CTRL_REG1 are set to "000". In this situation a single acquisition of temperature and pressure is started when ONE_SHOT bit is set to '1'. At the end of conversion the new data are available in the output registers, the STAUS_REG[0] and STAUS_REG[1] bits are set to '1' and the ONE_SHOT bit comes back to '0' by hardware.

Register Descriptions

PRESS_OUT_XL — **Pressure data (LSB)**

7	6	5	4	3	2	1	0
POUT7	POUT6	POUT5	POUT4	POUT3	POUT2	POUT1	POUT0

Address: 28h

Type: R

Reset: 00h

Description: Pressure data.

[7:0] POUT7 - POUT0: Pressure data LSB

PRESS_OUT_L — **Pressure data**

15	14	13	12	11	10	9	8
POUT15	POUT14	POUT13	POUT12	POUT11	POUT10	POUT9	POUT8

Address: 29h

Type: R

Reset: 80

Description: Pressure data.

[15:8] POUT15 - POUT8: Pressure data

PRESS_OUT_H (2Ah) — **Pressure data (MSB)**

24	23	22	21	20	19	18	17
POUT23	POUT22	POUT21	POUT20	POUT19	POUT18	POUT17	POUT16

Address: 2Ah

Type: R

Reset: 2F

Description: Pressure data are expressed as PRESS_OUT_H & PRESS_OUT_L & PRESS_OUT_XL in 2's complement. Values exceeding the operating pressure Range (see Table 3) are clipped.
Pressure output data: Pout(mbar)=(PRESS_OUT_H & PRESS_OUT_L & PRESS_OUT_XL)[dec]/4096

[24:17] POUT23 - POUT16: Pressure data MSB

Temperature Descriptions

TEMP_OUT_L (2Bh) **Temperature data (LSB)**

7	6	5	4	3	2	1	0
TOUT7	TOUT6	TOUT5	TOUT4	TOUT3	TOUT2	TOUT1	TOUT0

Address: 2Bh
Type: R
Reset: 00h

[7:0] TOUT7 - TOUT0: temperature data LSBI

TEMP_OUT_H (2Ch) **Temperature data (MSB)**

15	14	13	12	11	10	9	8
TOUT15	TOUT14	TOUT13	TOUT12	TOUT11	TOUT10	TOUT9	TOUT8

Address: 2Ch
Type: R
Reset: 00h

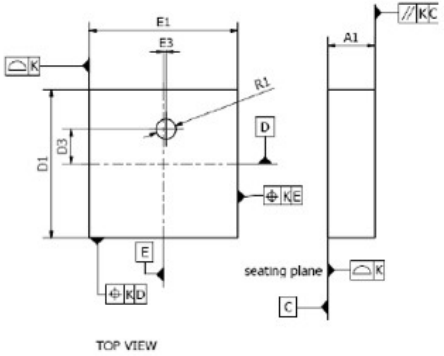
[15:8] TOUT15 - TOUT8: temperature data MSB.

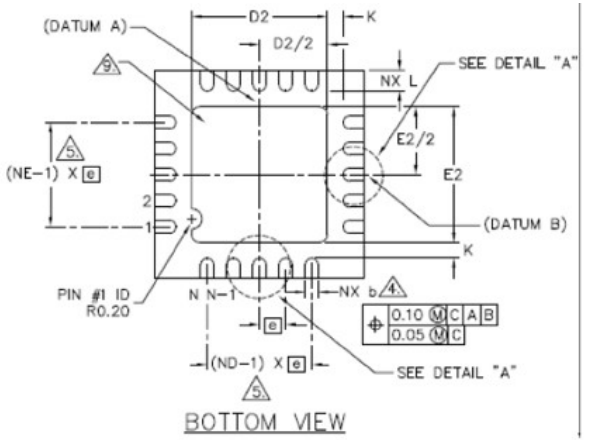
Temperature data are expressed as TEMP_OUT_H & TEMP_OUT_L as 2's complement numbers.

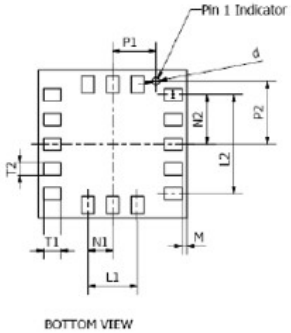
Temperature output data:

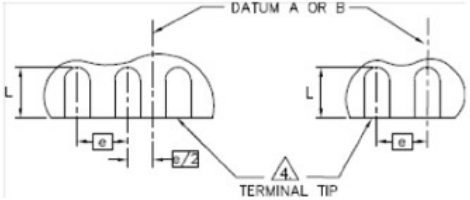
T(degC) = 42.5 + (Temp_OUTH & TEMP_OUT_L)[dec]/480

Packaging


E1
E3
A1
R1
D
D1
D3
E
seating plane
C
TOP VIEW

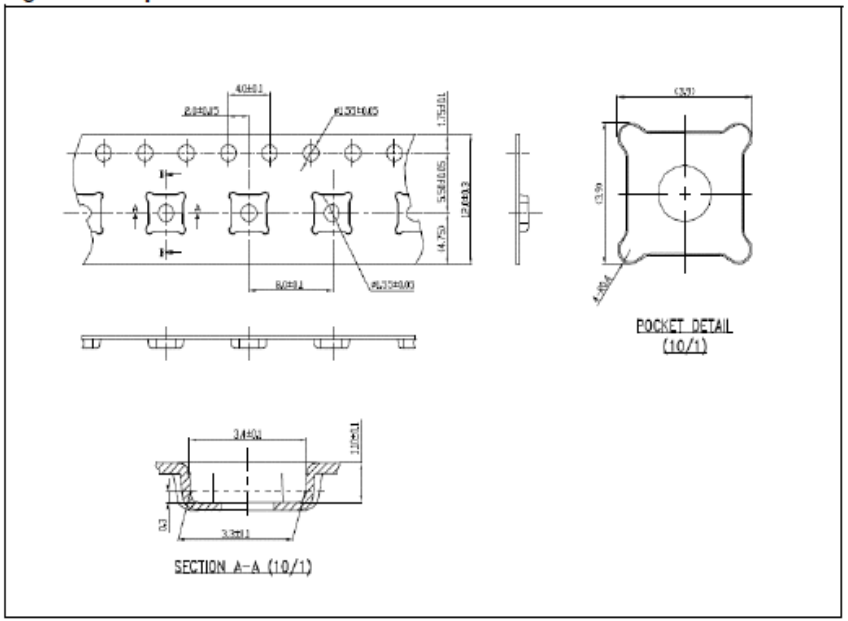

(DATUM A)
D2
K
D2/2
SEE DETAIL "A"
NX L
E2/2
E2
(NE-1) X e
(DATUM B)
K
PIN #1 ID
R0.20
N N-1
NX b
0.10 M C A B
0.05 M C
(ND-1) X e
SEE DETAIL "A"
BOTTOM VIEW


Pin 1 Indicator
P1
d
E1
N2
P2
L2
T2
T1
N1
M
L1
BOTTOM VIEW


DATUM A OR B
L
L
e
e/2
TERMINAL TIP

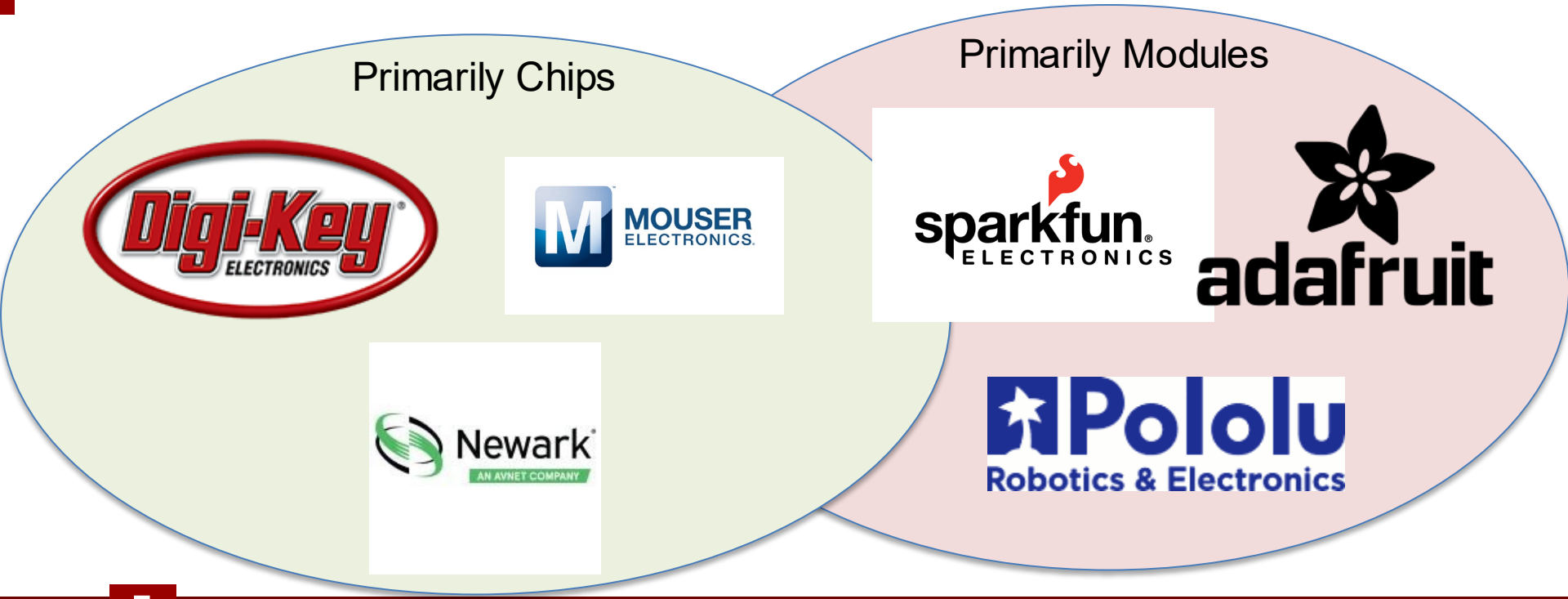
Production Packaging

Figure 13. Tape information



Chips vs Modules

Chip Vendors vs Module Vendors



LPS331AP

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

Datasheet – production data

Features

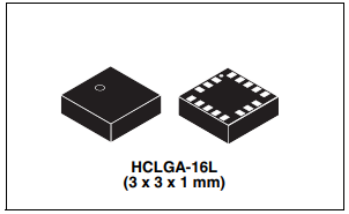
- 260 to 1260 mbar absolute pressure range
- High-resolution mode: 0.020 mbar RMS
- Low power consumption:
  - Low resolution mode: 5.5 µA
  - High resolution mode: 30 µA
- High overpressure capability: 20x full scale
- Embedded temperature compensation
- Embedded 24-bit ADC
- Selectable ODR from 1 Hz to 25 Hz
- SPI and I^2C 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.

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

COVID-19 impact: We are still operating and shipping all orders! We are operating with a reduced staff, so for

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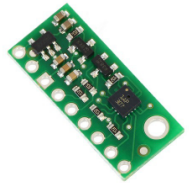
LPS331AP Pressure/Altitude Sensor Carrier with Voltage Regulator

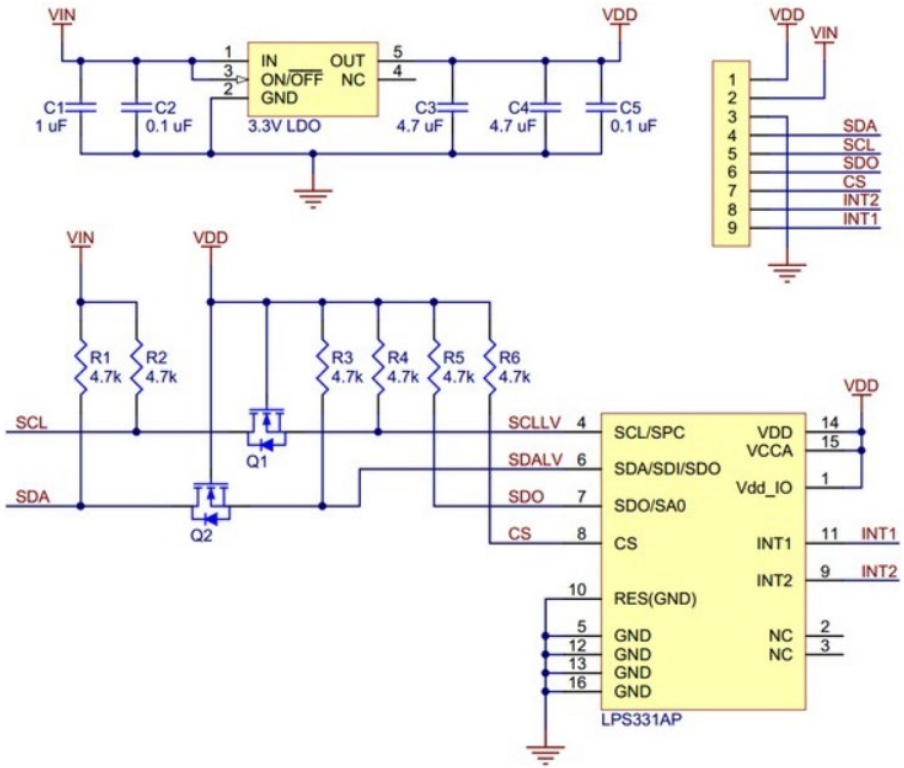


Pololu item #: 2126 — 181 in stock
Brand: Pololu
Status: Clearance
✓ RoHS 3

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

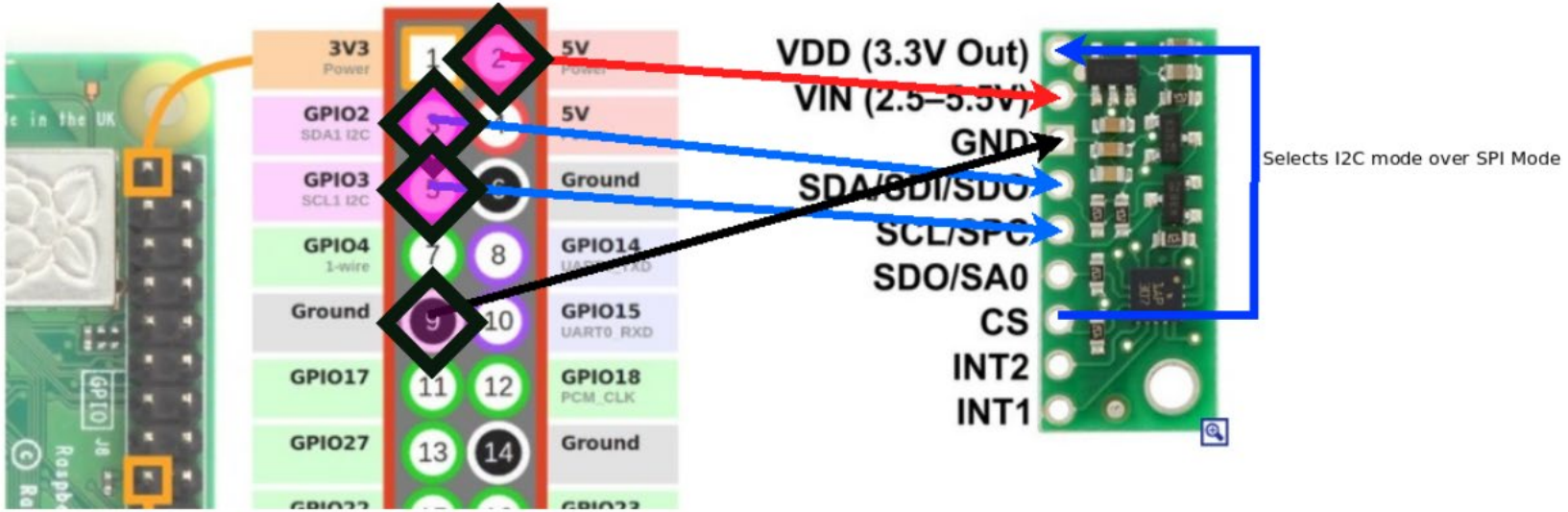
This carrier for ST's LPS331AP digital barometer measures pressures from 260 mbar to 1260 mba
±2 mbar (0.2 kPa) and typical RMS noise of 0.02 mbar (0.002 kPa) in high-resolution mode. The
regulator and integrated level shifters that allow it to work over an input voltage range of 2.5 V t



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

Board Connections

Raspberrry Pi Connections



Physical Connections