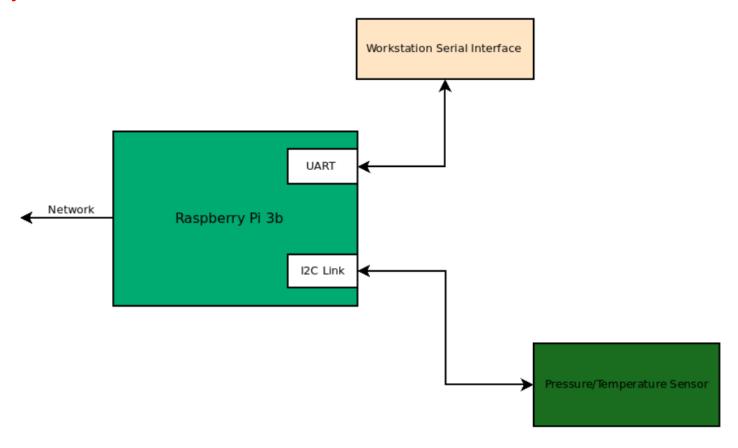


E210 Engineering Cyber-Physical Systems

LPS331AP Pressure Sensor

Weekly Focus	Reading	Monday	Wed	Lab
CPS Intro/UART		1/10: CPS Introduction	1/12: Pi Intro/UART Bus	Project 0 Raspberry PI Setup
I2C Bus		1/17: MLK Day	1/19: I2C Bus Overview	Project 1 I2C Pressure/Temperature Sensor
I2C and SPI Bus		1/24: Pressure Sensor	1/26: SPI Bus Overview	Project 2 SPI Accelerometer
SPI/Networking		1/31: Accelerometer	2/2: Networking Overview	Project 3 Flask Web Server
Networking		2/7: Flask	2/9: Redis/matplotlib	Project 3 Continued
Web Server		2/14: CPS Wrapup	2/16: Exam Review	P5 Demultiplexer
Evaluation		2/21: Exam 1	2/23: CE Intro/ Logic	P6 ALU

Raspberry I2C Link



LPS331AP Pressure Sensor

Component Datasheet

- Provided by Manufacturer
- 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 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.

Table 1. Device summary



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 monosilicon 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 stooper.

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.

Order codes	Temperature range [°C]	Package	Packing
LPS331APY	LPS331APY -40 to +85 HCLGA-16L		Tray
LPS331APTR	-40 to +65	HOLOX-TOL	Tape and reel

March 2012 Doc ID 022112 Rev 7 1/36

This is information on a product in full production.

www.st.com



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

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

Overview Page

High Level List of Features

Uses envisioned by the manufacturer



LPS331AP

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Datasheet -production data

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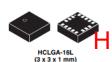
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High Level Functionality

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LPS331APTR	-40 10 +05	TIOLGA-TOL	Tape and reel

March 2012 Doc ID 022112 Rev 7 1/3

This is information on a product in full production

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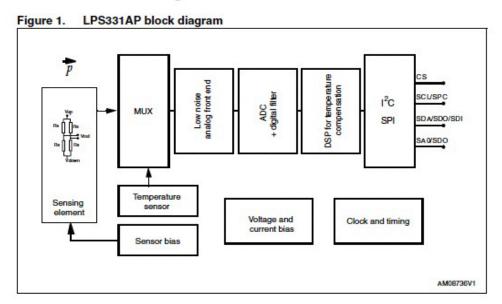


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1 Block diagram and pin description

1.1 LPS331AP block diagram

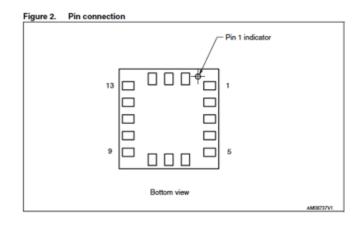
Block Diagram



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 ² C serial clock (SCL) SPI serial port clock (SPC)
5	GND	0 V supply
6	SDA SDI SDO	I ² C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
7	SDO SA0	SPI serial data output (SDO) I ² C less significant bit of the device address (SA0)
8	cs	SPI enable I ² C/SPI mode selection (1: I ² C 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



Environmental Requirements

2.1 Mechanical characteristics

Table 3. Mechanical characteristics

able 3.	Mechanical Characterist	lus .				
Symbol	Parameter	Test condition	Min.	Typ.(1)	Max.	Unit
Тор	Operating temperature range		-40	E20	85	°C
Tfull	Full accuracy temperature range		0	-	80	°C
Pop	Operating pressure range		260	-	1260	mbar
Pbits	Pressure output data		1_1	24		bits
Pres	Pressure sensitivity		1-3	4096	-	LSB/ mbar
Paccrel	Relative accuracy over pressure ⁽²⁾	P = 800 to 1100 mbar T= 25°C	178	±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		Se	ee Table	17.	mbar RMS
Tbits	Temperature output data		-	16	-	bits
Tres	Temperature sensitivity		123	480	200	LSB/°C
Tacc	Absolute accuracy temperature	T= 0~+80 °C	128	±2	<u> =</u>	°C

Typical specifications are not guaranteed.

2. Characterization data. Parameter not tested at final test

Embedded pwl compensation.

l vo	งลล เก งกก	งรุร เก งกก	
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	٧
Vdd_IO	I/O pins supply voltage	-0.3 to 4.8	٧
Vin	Input voltage on any control pin	-0.3 to Vdd_IO +0.3	٧
Р	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		٧	
Vdd_IO	IO supply voltage		1.71 - 3.6		٧	
ldd	Supply current @ ODRp 1 Hz and ODRt = 1Hz		see Table 5		μА	
IddPdn	Supply current in power-down mode T = 25 °C		-	0.5	-	μА

^{1.} Typical specifications are not guaranteed.

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

Symbol	RES_CONF (hex)	Min.	Тур.	Max.	Unit
	73	-	5.5	-	
	75	-	6.6	-	
ldd	77	-	11.5	-	μА
	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 $\rm I^2C$ 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	I ² C serial clock (SCL) SPI serial port clock (SPC)
SDA/ SDI/ SDO	I ² C serial data (SDA) SPI serial data input (SDI) 3-wire interface serial data output (SDO)
SA0/ SDO	I ² C less significant bit of the device address (SA0) SPI serial data output (SDO)

12C 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

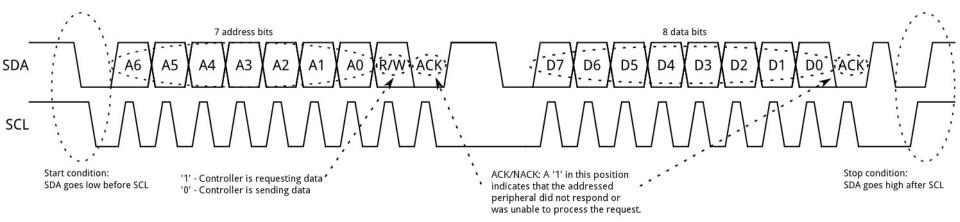
The transaction on the bus is started through a START (ST) signal. A start condition is defined as a HIGH to LOW transition on the data line while the SCL line is held HIGH. After this has been transmitted by the master, the bus is considered busy. The next byte of data transmitted after the start condition 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



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

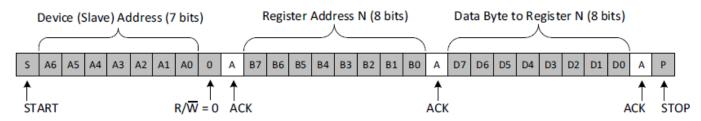


Figure 8. Example I²C Write to Slave Device's Register

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

Writing Data to Device

Data to be written

I2C Address of LPS331AP

Register Address within LPS331AP

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

Master Controls SDA Line

Slave Controls SDA Line

Read From One Register in a Device

Device (Slave) Address (7 bits)

Register Address N (8 bits)

Device (Slave) Address (7 bits)

Data Byte From Register N (8 bits)

START

R/W = 0 ACK

Repeated START

R/W = 1 ACK

NACK STOP

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

Reading Data From Device

I2C Address of LPS331AP

Data From Sensor

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		

Register Address within LPS331AP

Start and Stop Bits

Example Connections

TOP VIEW SDA/SDVSDO Digital signal from/to signal controller. Signal levels are defined through proper selection of Vdd_

LPS331AP electrical connection

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Register Map

Table 14. Registers address map

Name	Tomas	Register	Address	Default	Function and	
Name	Type	Hex	Binary	Delault	comment	
Reserved (Do not modify)		00-07 0D - 0E			Reserved	
REF_P_XL	R/W	08	0001000	00000000		
REF_P_L	RW	09	0001001	00000000		
REF_P_H	R/W	0A	0001010	00000000		
WHO_AM_I	R	oF	0001111	10111011	Dummy register	
RES_CONF	R/W	10	0010000	011111010	7	
Reserved (Do not modify)	4	11-1F			Reserved	
CTRL_REG1	RW	20	010 0000	00000000		
CTRL_REG2	RW	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	RW	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	

Desisters and and an Occasional most be absenced. The mosting to those anxiety many



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	ODRO	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

/	0	5	4	3	2	1	U
BOOT		RESER	RVED		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)

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 sense healt to '1' bit heretized.

Register Descriptions

PRESS OUT H (2Ah)

Pressure data (MSB)

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

Address: Type:

2Ah

2F

Reset:

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

PRESS OUT XL

Pressure data (LSB)

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

Address:

Type:

Reset: 00h

Description: Pressure data.

28h

[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 R

Type:

Reset:

Description:

Pressure data.

[15:8] POUT15 - POUT8: Pressure data

Temperature Descriptions

TEMP	Δ	L (2Bh)	
IEIVIE	OUI	L (ZDII)	

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
Ī	TOUT15	TOUT14	TOUT13	TOUT12	TOUT11	TOUT10	TOUT9	TOUT8

Address: 2Ch
Type: R
Reset: 00h

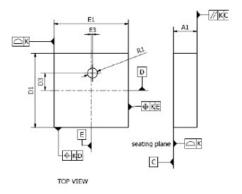
[15:8] TOUT15 - TOUT8: temperature data MSB.

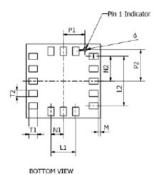
Temperature data are expressed as TEMP_OUT_H & TEMP_OUT_L as 2's complement numbers.

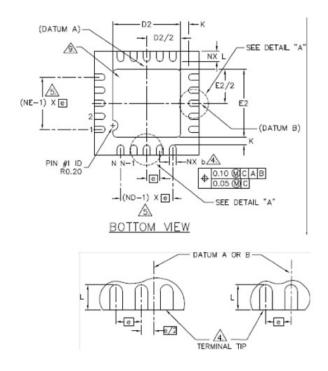
Temperature output data:

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

Packaging

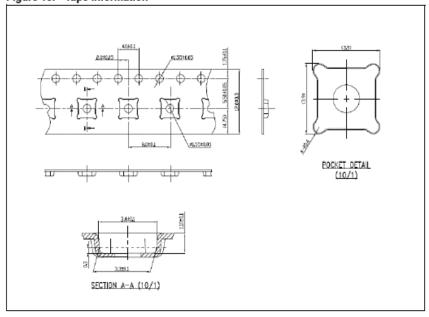






Production Packaging

Figure 13. Tape information



Chips vs Modules

Chip Vendors vs Module Vendors

Primarily Chips







Primarily Modules









LPS331AP

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

Datasheet -production data

Features

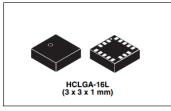
- 260 to 1260 mbar absolute pressure range
- High-resolution mode: 0.020 mbar RMS
- Low power consumption:
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- High overpressure capability: 20x full scale
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- Embedded 24-bit ADC
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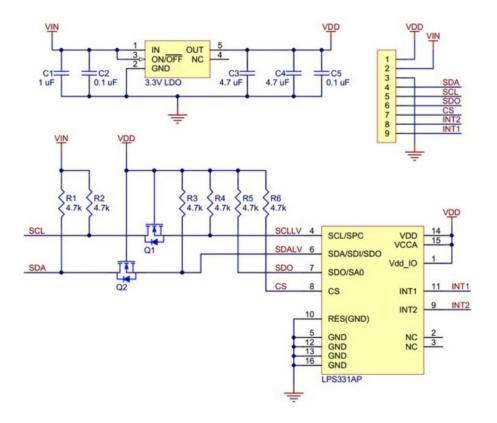
Battery Holders

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



This carrier for ST's LPS331AP digital barometer measures pressures from 260 mbar to 1260 mbar ±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.1

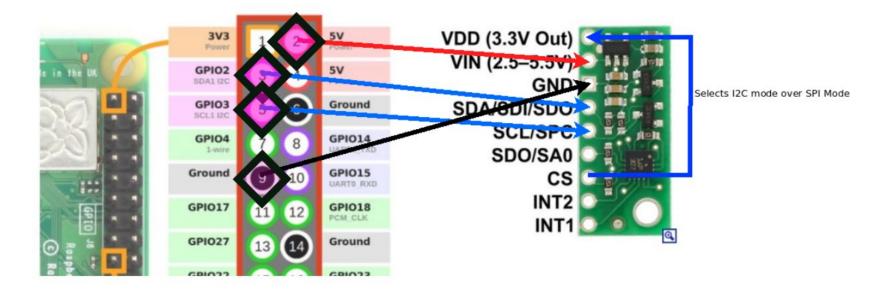
About





Board Connections

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Physical Connections

