Application Guidelines for LPS331AP Atmospheric Pressure Sensor

Version 1.5
Educational part: What is pressure? Atmospheric pressure sensor types, Altitude, What are the key parameters in pressure sensing? …

LPS331AP: Overview of the key product features

Hardware Design: Schematic, PCB layout, Soldering, …

Embedded Software: Offset calibration, Temperature Compensation, Digital Filter, Low level driver

Documentation & Support Tools
What is Pressure

- **Pressure** is the ratio of force to the area over which that force is distributed.

\[ p = \frac{F}{A} \]

- **Units**
  - pascal (Pa) is SI unit, 1 Pa = 1N/m²
  - non-SI units: **bar**, **psi** (pounds per square inch)
  - In meteorology: hPa is often used which is equivalent to millibar (mbar)

\[ 1 \, Pa = 10 \, \mu\text{bar} = 0.145 \, \text{psi} \]

- **Absolute pressure** is measured relative to a perfect vacuum. An example is atmospheric pressure.

- **Differential pressure** is the difference in pressure between two points of measurement.

- **Gauge pressure** is measured relative to ambient pressure.
Atmospheric Pressure sensor types

Pressure types
- Fluid pressure (water, *atmospheric* etc.)
- Surface pressure
- Vapor pressure
- Kinematic pressure

Pressure measurement principles
- **Piezoresistive** – LPS331AP
- Capacitive
- Electromagnetic
- Piezoelectric
- Optical
- Potentiometric
- Resonant
- Thermal
- Ionization

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LPS331AP is piezoresistive atmospheric pressure sensor
As altitude increases, atmospheric pressure decreases.

Pressure drops by 1 mbar approx. every 8.3 meters. Pressure changes with weather, therefore it is used for **weather forecasting**.

Terminology is very delicate for altitude. There is not one altitude, there are many.

Earth mean **sea level pressure** is defined as 1013.25 hPa (or mbar)

**Pressure altitude** - the simplest and widely used barometer (altitude) formula comes from the US Standard Atmosphere, 1976 edition.

\[
\text{Altitude}\,[\text{ft}] = (1 - (\text{Pressure}\,[\text{mbar}] / 1013.25)^{0.190284}) \times 145366.45
\]

**Density altitude** – is pressure altitude adjusted to non-standard temperature and humidity

The **GPS altitude** is different than the pressure altitude or density altitude.
Key parameters in pressure sensing

- **The accuracy** is the difference between the real pressure value and the output of the pressure sensor.
- **The pressure noise** is indicated usually by its RMS i.e. the standard deviation of the noise.
- Noise is important to define the minimum resolution.
  - For example: although if the output is 24 bits if the noise is big the less significant bits are submerged by the noise and useless.
- In the altimeter application it is important to define the minimum altitude detectable.

- The absolute accuracy takes in account any possible non idealities (temperature span, pressure non linearity).
- **The sensitivity** describes the gain of the sensor per LSB.
Barometric Sensor

- Pressure and Temperature inputs
- Analog to Digital Conversion (ADC)
- Embedded Filtering & Compensation
- I²C or SPI Digital output

Factory calibrated System on a Chip!
LPS331AP Applications [1/3]
Consumer and Mobile

- Key parameter for **Consumer and Mobile** are: Size, Power consumption, Resolution, Price
  - Main application needs: half meter altitude variations ~ 60ubar
  - Measurement mode: automatic mode (ODR ~ 10Hz)
  - Sensor Usage: Measurement of altitude
- Example applications:
  - Indoor and Outdoor Navigation System (Smartphone & Tablet), Pedestrian Navigation System, Enhanced/Handed GPS, GPS navigation enhancement

![Figure 24: Height Output Comparison](image-url)
LPS331AP Applications [2/3]
Healthcare, Wellness and Fitness

• Key parameters for **Healthcare** are: Resolution, Accuracy, Long-term stability, Hysteresis
  • Main application needs: high resolution
  • Measurement mode: automatic update (frequent at least 10Hz)
  • Sensor Usage: Measurement of change of pressure or altitude
  • Example applications: Respiratory Equipment, Anesthesia Unit Monitor, Ventilators and Respirators, A novel application one of our customers is working on is a bandage that uses pressure readings to monitor suction, to improve the healing process for deep wounds

• Key parameters for **Wellness and Fitness** are: Size, Power consumption, Resolution, Accuracy
  • Main application needs: atmospheric pressure range i.e. 20-110 kPa measurement range or high resolution (for activity measurement)
  • Measurement mode: one shot mode or automatic updates
  • Sensor Usage: measurement of absolute atmospheric pressure
  • Example applications: Sport Watches, Bike Computers, Altimeter, Activity measurement
• Key parameters for **Home Appliance** are: Resolution, Long-term Stability
  • Main application needs: high resolution or atmospheric pressure range i.e. 20-110 kPa
  • Measurement mode: one shot mode
  • Sensor Usage: measurement of absolute atmospheric pressure or measurement of change of pressure
  • Example applications: Weather Station (OK for LPS331AP), Fan power control, Vacuum cleaner

• LPS331AP product is not useful in many of these applications, since in many cases there are requirements like i.e. Industrial high pressure measurement, differential pressure measurement, pressure measurement with the risk to get material into the hole of the package, like water, …).”
Hardware Design

- Schematic aspects
- PCB design rules and Soldering
- Application Design considerations
Schematic Aspects [1/2]

• Power supply
  - Separated Vdd and Vdd_IO lines (ultra low drop, low noise LDO)
  - Supply voltage range: 1.71 to 3.6V for both, VDD_IO <= VDD

• LPS331AP is capable to communicate over 2 digital serial interfaces
  - SPI 3-wire(CS, SPC, SDI/O) or 4-wire (CS, SPC, SDI, SDO)
  - I²C (SCL, SSA) with slave address selectable by SA0 pin
  - CS pin is used to select between SPI and I²C

• Device setup and data acquisition is done by accessing registers of LPS331AP

• INT1 and INT2 interrupts push-pull pins have programmable functionality
  (pressure high, pressure low, data ready)
Key notes:

- SDA and SCL pull-up resistors should be connected to VDD_IO
- VDD_IO should be same or lower than VDD (use level shifters otherwise)
- If VDD_IO is higher than VDD, high non-destructive current may occur
- If there is choice and interface is I2C, use SA0 = VDDIO slave address by default.
PCB design and soldering

• PCB design rules
  • The area below the sensor must be defined as keepout area.
  • Mechanical stress coming from PCB board should be avoided
    • Place the pressure sensor at the edge of PCB where the PCB warpage is minimal, avoid placement in long and narrow PCB area, warp free area
  • The whole package surface + air should have minimum temperature gradient
  • Localized air pressure stability (unwanted fast air pressure variation, fans)

• Soldering
  • There should be no cleaning process performed on the pressure sensors.
  • LGA packages for pressure sensor are qualified for soldering heat resistance according to JEDEC J-STD-020, in MSL3 condition.
Hardware Design Considerations [1/2]

• Power-up sequence

Power sequence is similar to ST accelerometers. Vdd_IO is always recommended to rise before (or at the same time) with Vdd.

It is advised that Vdd_IO rise no later than 1 msec after Vdd.
Hardware Design Considerations [2/2]

• Self test
  • There is not self-test function similar to the one often seen in motion MEMS
  • There are other means how to test the devices:
    • Reading WHO_AM_I register - I2C communication test
    • When pressure is always fixed to out of range value (760 mbar), check proper averaging and ODR settings. If it does not help device has been damaged.
    • A very big or "negative" pressure could come from bonding wire being cut by mishandling of the device
    • An example of C type self-test function is available

• Light, humidity and dust protection
  • The LPS331AP has an opening on top of the package
  • To avoid losing accuracy of measurements, following suggestions should be followed:
    • Avoid strong electrical field / light source
    • Avoid dust and water exposure/condensation
    • Consider: gore-tex protection, Parylene, etc.
STM8/ STM32 Software Overview

Low level drivers

Pressure Sensor offset calibration

Sensor absolute accuracy
  temperature compensation

IIR Digital filter
STM8 / STM32 Software [1/2]

• Pressure sensor offset calibration - soldering drift reduction
  • Reflow soldering may cause an additional spread of the device population, the spread is PCB construction, assembly and layout specific.
  • Beware that normal sockets and board warpage can cause absolute accuracy errors.
  • “1 point calibration” in the end of customer’s production line could be implemented.

• Pressure measurement accuracy compensation in temperature
  • The LPS331AP devices are trimmed at final test and have embedded Piece-line wise temperature compensation with a typical absolute accuracy of +/-2mb
  • LPS331AP devices may have higher absolute accuracy by implementing an extra SW pressure temperature compensation algorithm, which is called "quadratic pressure compensation in temperature"
STM8 / STM32 Software [2/2]

• **SW filtering – Digital filters**
  - If higher precision is required or air pressure/flow is unstable, SW filter could be implemented:
    - Moving average – simple, but uses extra RAM, has slower response time
    - IIR filter – more advanced
    - Pressure variation limiter – define maximum pressure variation to limit high-frequency noise
    - Sensor fusion – for indoor navigation use information from all sensors
  - We strongly suggest to propose this SW algorithms to any customer based on the fact that our main competitor also needs external SW compensation and filtering

• **LPS331AP Low level Drivers**
  - Provides a set of functions needed to manage the communication between MCU I2C master and LPS331AP I2C slave

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**LPS331AP low level drives, quadratic temperature compensation algorithm, filter functions and self-test functions are available on request from** [AMS-support-EMEA@st.com](mailto:AMS-support-EMEA@st.com) *(no NDA)*
Pressure Sensor offset calibration

- Process called “One point calibration” - Pressure offset drift reduction (drift caused by soldering)

- LPS331AP has a dedicated register to implement the one point calibration
  - Value stored in the register is add/subtracted to the pressure output
  - Use a high precision barometer, and store in the application a SW compensation offset, which could also take into account ageing test results.
Piece-line wise Temperature Compensation

• Embedded in LPS331AP
  • LPS331AP is calibrated at 3 different temperature. Calibration coefficients are stored in the embedded memory during production in ST factory.
  • The compensation algorithm uses the embedded temperature sensor to compensate the non linear piezoresistor behavior vs. temperature

![Resistor vs. Temperature Diagram](image)

![Accuracy Diagram](image)
Quadratic Temperature Compensation

- LPS331AP is calibrated at 3 different temperatures. Using the 3 calibration coefficients sets it is possible implement a quadratic temperature compensation improving the accuracy over temperature.

- Quadratic compensation also solves the problem of three point temperature compensation: change of sign of pressure accuracy in the middle of usual measurement range.
- Why? Noise reduction by using SW IIR filter (Infinite Impulse Response) – Increasing the sensor absolute resolution

RMS noise = 0.054 mbar (0.33 mbar Peak-to-Peak ~ 3.0 meter resolution) Quadratic compensation only
RMS noise = 0.02 mbar (0.06 mbar Peak-to-Peak ~ 0.6 meter resolution) Quadratic compensation + IIR
Software Design Considerations

• Resolution
  • Resolution is selectable by RES_CONF register:
  • Depending on number of averaged samples, RMS noise is decreased and the resolution is increased:

<table>
<thead>
<tr>
<th>RES_CONF (hex)</th>
<th>RMS noise(^{(1)})</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>0.450</td>
<td></td>
</tr>
<tr>
<td>71</td>
<td>0.320</td>
<td></td>
</tr>
<tr>
<td>72</td>
<td>0.230</td>
<td></td>
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<tr>
<td>73</td>
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<td>75</td>
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<td>76</td>
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<td>77</td>
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<tr>
<td>78</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>7A(^{(2)})</td>
<td>0.020</td>
<td></td>
</tr>
</tbody>
</table>

T_{RES} = b[6..4]@0x10
T_{av}   | P_{RES} = b[3:0]@0x10 | P_{av} |
--- | --- | --- |
0 | 1   | 0   |
1 | 2   | 1   |
2 | 4   | 2   |
3 | 8   | 3   |
4 | 16  | 4   |
5 | 32  | 5   |
6 | 64  | 6   |
7 | 128 | 7   |
8 | 256 | 8   |
9 | 384 | 9   |
A | 512 | A   |

• One shot mode vs. Auto mode
  • In one shot mode, the device automatically goes stand by when measurement is completed.
  • In Auto mode, pressure and temperature is refreshed with selectable ODR (Output data rate)

• Conversion time and Power consumption are proportional to selected resolution and ODR:
  
  Typical conversion time ≈ 62.5 \times (P_{av} + T_{av}) + 1545 \mu s
  
  \[ I_{cc} = [1 \, \mu A/Hz + 48 \, nA/Hz \times P_{av}] \times \text{ODRP} + 32 \, nA/Hz \times T_{av} \times \text{ODRT} \]
Documentation & Support Tools

- Datasheet, Application / Design Notes & Tips
- Evaluation Boards
- PC Graphical User Interface
- Technical Support
• LPS331AP Product Website

• LPS331AP: Datasheet

• Application Note AN4159 for LPS331AP

• Technical Note TN0018 on PCB design and package surface mounting

• Design tip DT0004 on How to interpret the LPS331AP pressure and temperature readings
Evaluation boards

STEVAL-MKI109V2

STM32-based MEMS motherboard compatible with ST MEMS adapters

- Firmware upgrades are possible via DFU
- Source codes available including low level drivers for STM32

Daughter boards available:

LPS331AP
STEVAL-MKI1120V1

LSM303DLHC + L3GD20 + LPS331AP =
STEVAL-MKI124V1

Note: Schematics and Gerber files are available under evaluation boards webpages in internet
Unico Evaluation software

• **Unico** is Graphical User Interface (GUI) **for PC** (Windows based)

• Designated to be used with STEVAL-MKI109V2 and any MEMS adapter board

• Connection
  - USB
  - Bluetooth – with STEVAL-MKI132V1

• LPS331AP in Unico
  - Register setup
  - Pressure and temperature data reading
  - Quadratic pressure compensation and IIR filter results shown

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