LPS33K: MEMS pressure sensor with potted gel package

Introduction

This document is intended to provide usage information and application hints related to ST's LPS33K device.

The LPS33K is an ultra-compact piezo-resistive absolute pressure sensor which functions as a digital output barometer with a digital I²C serial interface standard output. Its operating pressure range is from 300 hPa to 1200 hPa and the device is capable of measuring pressure values with output data rates up to 75 Hz.

The LPS33K is available in a ceramic LGA package with metal lid. 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. Gel inside the IC protects the electrical components from harsh environmental conditions.

This document does not modify the content of the official datasheet. Please refer to the datasheet for parameter specifications.

1 Pin description

Figure 1. Pin connections

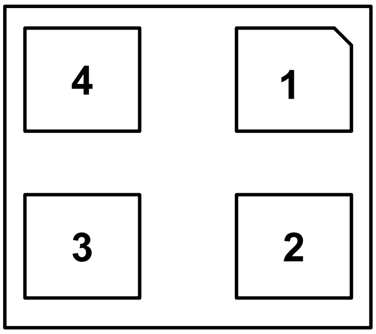


Table 1. Pin list, functions, and internal status

Pin number	Name	Function	Internal pin status
1	GND	0 V supply	
2	VDD	Power supply	
3	SCL	I²C serial clock	Default: Input without pull-up
4	SDA	I²C serial data	Default: Input without pull-up

2 Registers

Table 2. Registers

Register name	Address	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
WHO_AM_I	0Fh	1	0	1	1	0	0	0	1
CTRL_REG1	10h	0	ODR2	ODR1	ODR0	EN_LPFP	LPFP_CFG	BDU	0
CTRL_REG2	11h	BOOT	0	0	IF_ADD_INC	0	SWRESET	0	ONE_SHOT
RPDS_L	18h	RPDS7	RPDS6	RPDS5	RPDS4	RPDS3	RPDS2	RPDS1	RPDS0
RPDS_H	19h	RPDS15	RPDS14	RPDS13	RPDS12	RPDS11	RPDS10	RPDS9	RPDS8
RES_CONF	1Ah	0	0	0	0	0	0	reserved(1)	LC_EN
STATUS	27h	-	-	T_OR	P_OR	-	-	T_DA	P_DA
PRESS_OUT_XL	28h	POUT7	POUT6	POUT5	POUT4	POUT3	POUT2	POUT1	POUT0
PRESS_OUT_L	29h	POUT15	POUT14	POUT13	POUT12	POUT11	POUT10	POUT9	POUT8
PRESS_OUT_H	2Ah	POUT23	POUT22	POUT21	POUT20	POUT19	POUT18	POUT17	POUT16
TEMP_OUT_L	2Bh	TOUT7	TOUT6	TOUT5	TOUT4	TOUT3	TOUT2	TOUT1	TOUT0
TEMP_OUT_H	2Ch	TOUT15	TOUT14	TOUT13	TOUT12	TOUT11	TOUT10	TOUT9	TOUT8
LPFP_RES	33h	-	-	-	-	-	-	-	-

1. *The content of this bit must not be modified for proper operation of the device.*

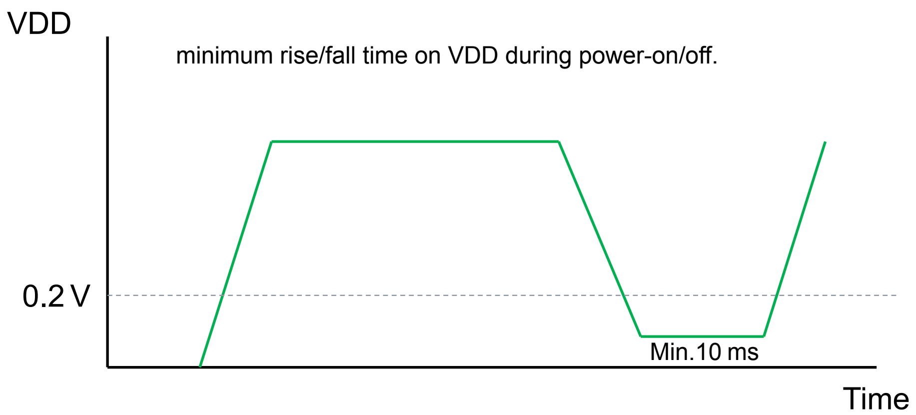
3 Operating / noise modes

The LPS33K features three operating modes:

- Power-down mode;
- One-shot mode;
- Continuous mode.

Basically, the LPS33K can read environmental data at the very moment the controlling MCU requires it, when configured in one-shot mode, or can keep reading data at predefined frequencies (fixed output data rates, ODRs), when configured in continuous mode. The device offers a wide VDD voltage range from 1.7 V to 3.6 V. In order to avoid potential conflicts, during the power-on sequence it is recommended to set the line connected to the device IO pin to high-impedance state on the host side. Furthermore, to guarantee proper device power-off and the next power-on reset sequence to be successful, it is recommended to drive the VDD line to GND (less than 0.2 V) and keep it at this level for at least 10 ms as illustrated in the figure below. Power timings and profiles need to be taken into account when managing the device power supply (VDD).

Figure 2. VDD power-on/off sequence



- VDD rise/fall time: 10 µs ~ 100 ms, these values represent the minimum and the maximum rise/fall time on VDD during power-on/off.
- VDD must be lower than 0.2 V for at least 10 ms during power-off sequence for correct POR.

After the power supply is applied, the LPS33K requires a boot procedure of 4 ms (maximum) to load the trimming parameters. After the boot is completed, the device is configured in Power-Down mode, ready to communicate with the host for register configurations and data measurements.

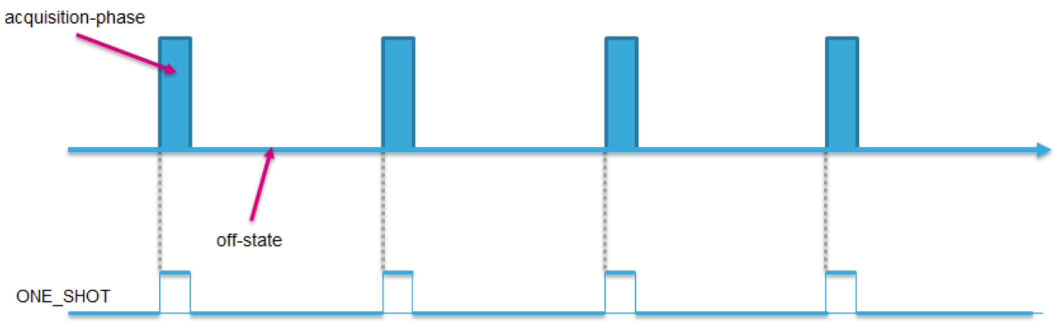
3.1 Power-down mode

Power-down mode is used to put the device in rest condition. When the device is in power-down mode, no data acquisition happens, almost all internal blocks of the device are switched off to minimize current drainage. In power-down mode the LPS33K can reach its lowest power consumption achievable while power supplied. While in power-down mode, I²C communication serial interface is kept active to allow communication with the device and setting configurations. The content of the configuration registers is preserved and the output data registers are not updated, keeping the last data sampled in memory before going into power-down mode. The device is in power-down mode when the ODR[2:0] bits of CTRL_REG1(@10h) register are set to ‘000’.

3.2 One-shot mode

One-shot mode is used to execute single data acquisitions at a desired pace. After the acquisition has been completed, the device automatically sets itself to power-down mode. One-shot mode has to be executed while the device is in power-down mode by setting the ONE_SHOT bit (default value '0') in CTRL_REG2(@11h) to ‘1’. When this happens, a single data acquisition is executed and read data are made available in the output registers and the STATUS(@27h) register is updated. Once the acquisition is completed and the output and status registers updated, the device automatically enters again power-down mode and the ONE_SHOT bit is self-cleared (to '0').

Figure 3. One-shot mode



One-shot mode is independent of the programmed output data rate (ODR). This mode depends on the frequency at which the ONE_SHOT bit is set to 1 by the microcontroller/application processor. The typical time needed for the generation of the new data and the maximum ODR frequency achievable in one-shot mode is given in the following table and strictly depends on the low-noise/low-current mode selected (please refer to Section 3.4 Low-noise / low-current mode configuration).

Table 3. Typical conversion time and maximum ODR in one-shot mode

Mode	Typical data conversion time [ms]	Maximum ODR [Hz]
Low noise	13.2	50
Low current	4.7	200

3.3 Continuous mode

Continuous mode is designed to keep reading data at a specific predefined selectable output data rate (ODR). Output registers are updated with fresher readings every given period according to the selected ODR frequency. Continuous mode ODR selection is made through bit range ODR[2:0], CTRL_REG1(@10h) register. When ODR[2:0] bits are set to a value different than ‘000’ (power-down mode), the device enters Continuous mode and immediately starts to sample pressure and temperature data and put them in the output registers at the selected frequency (Table 4).

Table 4. ODR selection

ODR[2:0]	ODR [Hz]
000	Power-down mode
001	1
010	10
011	25
100	50
101	75

3.4 Low-noise / low-current mode configuration

In continuous and one-shot mode a set of configuration options is available. The right trade-off among resolution, output data rate and power consumption has to be identified in order to make the sensor suitable for the specific design requirements. The bit LC_EN in the RES_CONF(@1Ah) register allows selecting two possible configurations:

- When the LC_EN bit is set to ‘0', low-noise mode is selected (default configuration);
- When the LC_EN bit is set to ‘1', low-current mode is selected

Note: For proper behavior of the pressure sensor, the LC_EN bit must be changed only when the device is in power-down.

In low-noise mode, the device is optimized to reduce the noise, while in low-current mode the device minimizes current consumption, as shown in Table 5.

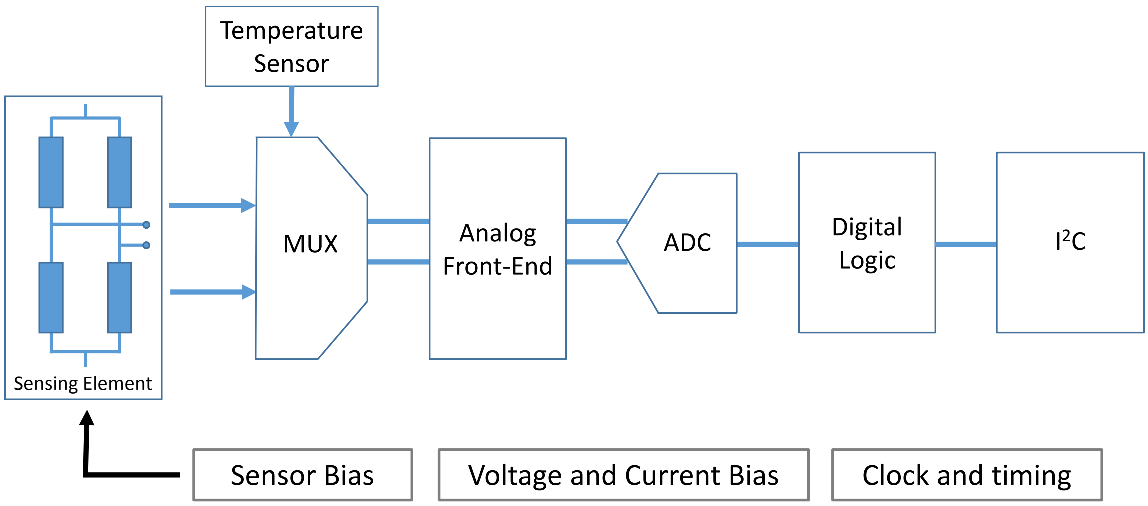
Table 5. Low-pass filter bandwidth, noise and power consumption

ODR [Hz]	Mode	LPF1 status	Device bandwidth	RMS noise [Pa] (Typical)	Current consumption [µA] (Typical)
1 Hz	Low noise	Disabled	ODR/2	2	15
		Enabled	ODR/9	1.2	15
		Enabled	ODR/20	0.8	15
	Low current	Disabled	ODR/2	5	4
		Enabled	ODR/9	2.8	4
		Enabled	ODR/20	1.6	4
10 Hz	Low noise	Disabled	ODR/2	2	111
		Enabled	ODR/9	1.2	111
		Enabled	ODR/20	0.8	111
	Low current	Disabled	ODR/2	5	33
		Enabled	ODR/9	2.8	33
		Enabled	ODR/20	1.6	33
25 Hz	Low noise	Disabled	ODR/2	2	276
		Enabled	ODR/9	1.2	276
		Enabled	ODR/20	0.8	276
	Low current	Disabled	ODR/2	5	80
		Enabled	ODR/9	2.8	80
		Enabled	ODR/20	1.6	80
50 Hz	Low noise	Disabled	ODR/2	2	550
		Enabled	ODR/9	1.2	550
		Enabled	ODR/20	0.8	550
	Low current	Disabled	ODR/2	5	159
		Enabled	ODR/9	2.8	159
		Enabled	ODR/20	1.6	159
75 Hz	Low noise	Disabled	ODR/2	2	768
		Enabled	ODR/9	1.2	768
		Enabled	ODR/20	0.8	768
	Low current	Disabled	ODR/2	5	181
		Enabled	ODR/9	2.8	181
		Enabled	ODR/20	1.6	181

4 Sampling chain

The LPS33K is a piezo-resistive absolute pressure sensor that works as a digital output barometer. The device comprises a sensing element and an IC interface that communicates through I²C serial protocol from the sensing element to the application.

Figure 4. LPS33K architecture block diagram



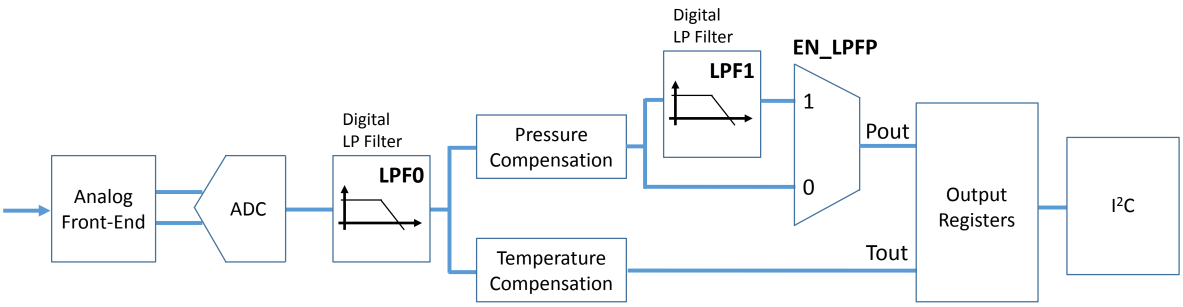
The sensing element, which detects absolute pressure, consists of a suspended membrane manufactured using a dedicated process developed by STMicroelectronics.

The following sections will focus on the "Digital Logic" block, describing the LPS33K filtering chain and the entire data path.

4.1 Digital low-pass filters

The LPS33K filtering chain embeds two digital low-pass filters. The first one is the LPF0 filter, which is applied to both temperature and pressure data. A second low-pass filter (LPF1) is also present. It can be applied optionally on the pressure readout path (temperature data are not filtered at this stage) when the device is in continuous mode. LPF1 affects data also when one-shot is used. Please note that LPF1 applies to pressure data only.

Figure 5. LPS33K digital LP filters block diagram



The LPF1 digital filter can be enabled by configuring the bit EN_LPFP, CTRL_REG1(@10h) register, and the overall device bandwidth can be configured acting on the bit LPFP_CFG, CTRL_REG1(@10h) register, as shown in Table 7. Setting EN_LPFP = 1 enables the filter and diverts its output to the pressure output registers. Setting EN_LPFP = 0 disables the filter. If the LPF1 digital filter is active, in order to avoid the transitory phase, the filter can be reset by reading the LPFP_RES(@33h) register. Every time the LPF1 digital filter is used, it is recommended to perform a reset of the filter immediately after the ODR has been set.

Table 6. Related registers and bit ranges of the LP filters

Register	Address	Bit	Bit range mask
CTRL_REG1	10h	EN_LPFP	00001000b = 08h
CTRL_REG1	10h	LPFP_CFG	00000100b = 04h

Table 7. Settings of the LP filters

EN_LPFP	LPFP_CFG	LPF1 filter status	Overall device bandwidth	Max overall settling time(1) without filter reset (samples to be discarded)	Max overall settling time(1) with filter reset (samples to be discarded)
0	x	Disabled	ODR/2 (LPF0 only)	0 (first sample correct)	0 (first sample correct)
1	0	Enabled	ODR/9	9	2
1	1	Enabled	ODR/20	20	2

1. *Settling time @ 99% of the final value.*

Table 7. Settings of the LP filters indicates the number of samples that should be discarded when the filter is enabled and/or after it's reset, before the filter reaches settling condition and output data can be considered meaningful.

5 Reading output data

Once the device has been power supplied, it automatically downloads the calibration coefficients from the embedded flash to the internal registers. When the boot procedure completes, i.e. after 4 milliseconds (maximum) from power-on, the sensor automatically enters power-down mode.

To turn on the sensor and gather pressure and temperature data through the I²C interface, it is necessary to select one of the operating modes through the ODR[2:0] bits in CTRL_REG1(@10h) register (continuous mode) or to set the ONE_SHOT bit to 1 in CTRL_REG2(@11h) (one-shot mode).

Data generated on board can be acquired by the controlling MCU by reads of the output registers.

Reading can be done:

- Asynchronously, polling the output registers at the proper pace;
- Synchronously, leveraging on the data-ready signal;

The basic startup sequence and the available options for data reading are described in the following paragraphs.

As a general rule, it is always recommended to read pressure and temperature samples from standard output (PRESS_OUT_x and TEMP_OUT_x) registers, starting from the lower address to the higher one without reading them in a different order.

5.1 Multi-read / write automatic address increment and rounding features

5.1.1 Automatic address increment feature

Available serial interfaces protocols allow executing single-read/write and multi-read/write register operations.

A single read/write operation is quite simple and requires specifying the register address that is going to be read/ written.

A multi-read/write operation allows easily and effectively executing a repeated read/write operation during a single bus transaction. Once the user knows the starting register and the desired number N of repetitions, according to two different behaviors:

- Read N times the same register at the address provided;
- Read a sequence of N registers starting from the address provided;

The IF_ADD_INC bit in CTRL_REG2(@11h) allows switching between the two behaviors by automatically incrementing the read/write address.

Setting IF_ADD_INC = 1 (default) enables automatic address increments in multi-read and multi-write register operations. This allows executing faster and more effective bus transactions to read/write adjacent registers.

For example, executing a multi-read operation of N=5 bytes starting from register PRESS_OUT_XL(@28h) will result in reading with a single transaction all standard output registers: from PRESS_OUT_XL(@28h) to TEMP_OUT_H(@2Ch), without the need for explicitly managing each single address involved.

Note: In order to read the data properly of multiple byte and single byte access, the recommended configuration for the LPS33K is the following:

- *For multiple byte access, synchronous data reading is only allowed with IF_ADD_INC = 1 and BDU = 0;*
- *For single byte access, either synchronous or asynchronous can be used with IF_ADD_INC = 0, but BDU has to be set to "1" for asynchronous data reading.*

5.1.2 Address rounding feature

Address rounding is another helpful feature available in the LPS33K, related to automatic address increment and designed to facilitate burst readings of standard output samples. It is always enabled when IF_ADD_INC = 1, CTRL_REG2(@11h).

It allows effectively reading multiple times the output register ranges by executing one single multi-read operation of M*5bytes;

It is available for the entire range of the output registers (PRESS_OUT_x, TEMP_OUT_x)(@28h-@2Ch).

Reading them starting from the initial register range to the final one results in the auto-increment feature providing, as the next address being read, the initial address range once the last address range has been read.

For example, a multi-read of 10 bytes (M=2, 2*5 bytes), starting at @28h will result in reading 2 times the standard output range (from @28h to @2Ch), as for the following sequence:

@28h→@29h→@2Ah→@2Bh→@2Ch→@28h→@29h→@2Ah→@2Bh→@2Ch

5.2 Startup sequence

To turn on the device and gather pressure/temperature data, it is necessary to select one of the operating modes. The following general-purpose sequence can be used to configure the LPS33K device:

1. Write CTRL_REG1(@10h) = 3Ch // ODR = 25 Hz, LPF (ODR/20)

5.3 Using the status register

The device is provided with a STATUS(@27h) register that should be polled to check when a new set of data (a pressure sample and a temperature sample) is available.

The P_DA bit is set to 1 whenever a new sample is available in the pressure output registers; the T_DA bit is set to 1 whenever a new sample is available in the temperature output registers.

The P_DA bit is cleared when the corresponding pressure sample is read (its most significant byte: PRESS_OUT_H(@2Ah).

The T_DA bit is cleared when the corresponding temperature sample is read (its most significant byte: TEMP_OUT_H(@2Ch).

The STATUS(@27h) register also includes the overrun flags: P_OR bit for pressure samples and T_OR bit for temperature samples. They are individually set to '1' when the corresponding sample is generated and the corresponding DA bit is already at 1, meaning the previous sample has been overwritten unread by the later generated new one, hence its value has been lost. The overrun bits are automatically cleared when all the data present inside the device have been read and new data have not been produced in the meantime.

The data-ready signals are represented by the P_DA and T_DA bits, STATUS(@27h) register.

Pressure and temperature data are synchronously generated; hence, bits P_DA and T_DA are synchronously rising at ‘1’ (unless one of the two isn’t already at ‘1’), but not synchronously resetting at ‘0’: it depends on when the respective data are read.

Reading the output registers before 1/ODR time period has expired allows acquiring the data and resetting P_DA and T_DA before an overwrite happens.

For the pressure sensor (for temperature sensor it is similar), the read operation of the output registers should be performed as follows:

1. Read STATUS(@27h);
2. If P_DA = 0, then go to 1;
3. Read PRESS_OUT_XL(@28h);
4. Read PRESS_OUT_L(@29h);
5. Read PRESS_OUT_H(@2Ah);
6. Data processing
7. Go to 1.

If the device is configured in one-shot mode instead of continuous mode, the routine will be stuck at step 1 after one execution, since the device performs a single measurement, sets the P_DA/T_DA bit high and returns to power-down mode. Please note that the ONE_SHOT bit is self-cleared when the device returns to power-down mode. It is possible to trigger another one-shot reading by setting the ONE_SHOT bit to 1 again.

5.4 Using the block data update (BDU) feature

If reading the data is particularly slow and cannot be synchronized (or it is not required to be) with either the P_DA/T_DA event bit in the STATUS(@27h) register, it is strongly recommended to set the BDU (block data update) bit to 1 in the CTRL_REG1(@10h) register.

This feature avoids reading values (XL, L and H parts of output data) related to different samples. In particular, when the BDU is activated, the output data registers always contain the most recent output data produced by the device, but, in case the read of a given part (e.g. pressure, starting from PRESS_OUT_XL(@28h)) is initiated, the refresh of the remaining bytes for that part (pressure), remains blocked until all XL, L and H parts of the data are read.

The same happens for the temperature section. If TEMP_OUT_L(@2Bh) is read, TEMP_OUT_H(@2Ch) content won't update until read.

BDU applies to both pressure data and temperature data, but manages them separately. When the BDU feature is enabled, pressure and temperature data are separately refreshed depending on when PRESS_OUT_H(@2Ah) / TEMP_OUT_H(@2Ch) is read.

Note: To guarantee the correct behavior of the BDU feature, PRESS_OUT_H(@2Ah) / TEMP_OUT_H(@2Ch), must be the last address read.

5.5 Understanding output data

5.5.1 Pressure data

The measured pressure data are sent to the PRESS_OUT_XL(@28h), PRESS_OUT_L(@29h), PRESS_OUT_H(@2Ah) registers. These registers contain, respectively, the least significant byte, the middle significant byte and the most significant byte of the pressure data.

The complete pressure data is given by the concatenation PRESS_OUT_H & PRESS_OUT_L & PRESS_OUT_XL and it is expressed as a binary number.

Pressure data is represented as 24-digit signed 2's complement binary numbers, (each digit referred to as LSB).

To translate the digital representation to its corresponding real number with its SI unit (Pa for pressure), a sensitivity parameter must be applied.

Each pressure sample must be divided by the proper sensitivity parameter (please refer to the datasheet) in order to obtain the corresponding value in hPa:

Psens = 4096 [LSB/hPa]

5.5.2 Example of pressure data

Hereafter is a simple example of how to get the pressure LSB data and transform it into hPa.

1. Get raw data from the sensor:
   - PRESS_OUT_XL(@28h): 1Ah
   - PRESS_OUT_L(@29h): 84h
   - PRESS_OUT_H(@2Ah): 3Eh
2. Do registers concatenation:
   - PRESS_OUT_H & PRESS_OUT_L & PRESS_OUT_XL: 3E841Ah
3. Calculate signed decimal value (from signed 2's complement 24-digit binary format):
   - P[LSB]: +4097050d
4. Apply Psens sensitivity:
   - P[hPa] = +4097050 / 4096 = +1000.2563

5.5.3 Temperature data

The measured temperature data are sent to the TEMP_OUT_L(@2Bh), TEMP_OUT_H(@2Ch) registers. These registers contain, respectively, the least significant byte and the most significant byte of the temperature data.

The complete temperature data is given by the concatenation of TEMP_OUT_H & TEMP_OUT_L registers and it is expressed as binary signed number by two's complement representation.

Temperature data is represented as 16-bit signed binary number, each digit referred to as LSB.

To translate the digital representation to its corresponding real number with its SI unit (°C, Celsius degrees, for temperature), a sensitivity parameter for temperature must be applied.

Each temperature sample must be divided by the proper sensitivity parameter (please refer to the datasheet) in order to obtain the corresponding value in °C:

Tsens = 100 [LSB/°C]

5.5.4 Example of temperature data

Hereafter is a simple example of how to get the temperature LSB data and transform it into °C.

1. Get raw data from the sensor:
   – TEMP_OUT_L(@2Bh): 7Bh
   – TEMP_OUT_H(@2Ch): FEh
2. Do register concatenation:
   – TEMP_OUT_H & TEMP_OUT_L: FE7Bh
3. Calculate signed decimal value (from 16-bit signed represented by two's complement format):
   – T[LSB]: -389d
4. Apply Tsens sensitivity:
   – T[°C] = -389 / 100 = -3.89

6 Reboot and software reset

After the device is powered up, the LPS33K performs a 4 ms (maximum) boot procedure to load the trimming parameters. After the boot is completed, the device is automatically configured in power-down mode. During the boot time the registers are not accessible.

After power-up, when the BOOT bit of the CTRL_REG2(@11h) register is set to 1, the trimming parameters are reloaded and the registers RPDS_L(@18h) and RPDS_H(@19h) are reset to 0.

No toggle of the device power lines is required. After the reboot is completed, the device enters in power-down mode (regardless of the selected operating mode) and the BOOT bit is self-cleared to '0'.

If the reset to the default value of the device registers is required, it can be performed by setting the SWRESET bit of the CTRL_REG2(@11h) register to 1. When this bit is set to 1, the CTRL_REG1(@10h) and CTRL_REG2(@11h) registers are reset to their default value.

The software reset procedure can take a few tens of μs; the status of the reset is signaled by the status of the SWRESET bit of the CTRL_REG2(@11h) register. Once the reset is completed, this bit is automatically set low.

In order to avoid conflicts, the reboot and the software reset must not be executed at the same time (do not set to 1 at the same time both the BOOT bit and SWRESET bit of the CTRL_REG2(@11h) register).

The flow must be performed serially as shown in the example below:

1. Set the BOOT bit of the CTRL_REG2(@11h) register to 1;
2. Wait 4 ms;
3. Set the SWRESET bit of the CTRL_REG2(@11h) register to 1;
4. Wait 50 μs (or wait until the SWRESET bit of the CTRL_REG2(@11h) register returns to 0).

7 Offset compensation (OPC - one-point calibration)

If, after the soldering of the component, a residual pressure offset is still present, it can be removed with a one-point calibration (OPC), leveraging on the RPDS registers which can store the residual offset value to be removed.

The calibration offset value is expected to be stored as a signed 16-bit value expressed as 2's complement in the RPDS_L(@18h) and RPDS_H(@19h) registers.

The default value for RPDS is 0 (zero).

The content of the RPDS registers is always automatically subtracted from the compensated pressure output and provided to the standard output pressure registers PRESS_OUT_x(@28h, 29h and 2Ah). It is provided as the difference between the measured pressure and the content of the RPDS registers (@18h, @19h) multiplied by 256.

Revision history

Table 8. **Document revision history**

Date	Version	Changes
21-May-2020	1	Initial release

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