



## Miniature SPI Digital Barometer

The MPL115A1 is an absolute pressure sensor with a digital SPI output targeting low cost applications. A miniature 5 x 3 x 1.2 mm LGA package is ideally suited for the space constrained requirements of portable electronic devices. Low current consumptions of 5  $\mu$ A during Active mode and 1  $\mu$ A during Shutdown (Sleep) mode are essential when focusing on low-power applications. The wide operating temperature range spans from -40°C to +105°C to fit demanding environment conditions.

The MPL115A1 employs a MEMS pressure sensor with a conditioning IC to provide accurate pressure measurements from 50 to 115 kPa. An integrated ADC converts pressure and temperature sensor readings to digitized outputs via a SPI port. Factory calibration data is stored internally in an on-board ROM. Utilizing the raw sensor output and calibration data, the host microcontroller executes a compensation algorithm to render *Compensated Absolute Pressure* with  $\pm 1$  kPa accuracy.

The MPL115A1 pressure sensor's small form factor, low power capability, precision, and digital output optimize it for barometric measurement applications.

### Features

- Digitized pressure and temperature information together with programmed calibration coefficients for host micro use.
- Factory calibrated
- 50 kPa to 115 kPa absolute pressure
- $\pm 1$  kPa accuracy
- 2.375V to 5.5V supply
- Integrated ADC
- SPI Interface
- Monotonic pressure and temperature data outputs
- Surface mount RoHS compliant package

### Application Examples

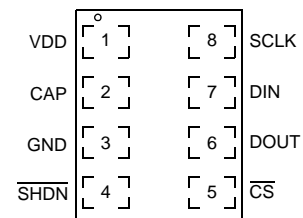
- Barometry (portable and desktop)
- Altimeters
- Weather stations
- Hard-disk drives (HDD)
- Industrial equipment
- Health monitoring
- Air control systems

**MPL115A1**  
50 to 115 kPa



**LGA Package**  
5.0 mm x 3.0 mm x 1.2 mm

#### Top View



#### Pin Connections

### ORDERING INFORMATION

Device Name	Package Options	Case No.	# of Ports			Pressure Type			Digital Interface
			None	Single	Dual	Gauge	Differential	Absolute	
MPL115A1	Tray	2015	•					•	SPI
MPL115A1T1	Tape & Reel (1000)	2015	•					•	SPI

# 1 Block Diagram and Pin Descriptions

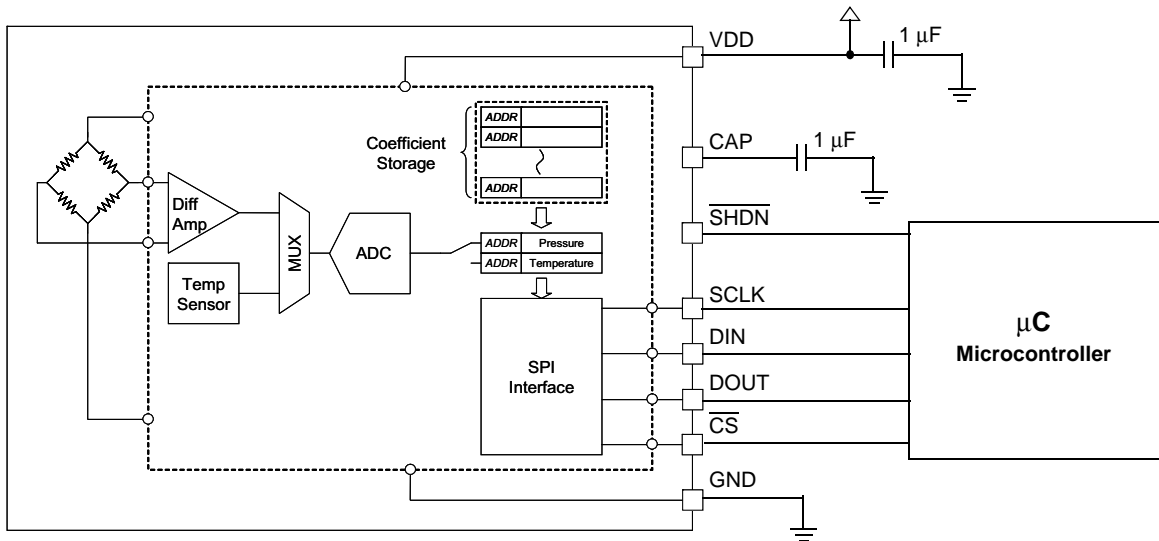


Figure 1. Block Diagram and Pin Connections

Table 1. Pin Description

Pin	Name	Function
1	VDD	VDD Power Supply Connection: VDD range is 2.375V to 5.5V.
2	CAP	External Capacitor: Output decoupling capacitor for main internal regulator. Connect a 1 $\mu$ F ceramic capacitor to ground.
3	GND	Ground
4	$\overline{\text{SHDN}}$	Shutdown: Connect to GND to disable the device. When in shut down the part draws no more than 1 $\mu$ A supply current and all communications pins ( $\overline{\text{CS}}$ , SCLK, DOUT, DIN) are high impedance. Connect to VDD for normal operation.
5	$\overline{\text{CS}}$	$\overline{\text{CS}}$ : Chip Select line.
6	DOUT	DOUT: Serial data output
7	DIN	DIN: Serial data input
8	SCLK	SPI: Serial Clock Input.

## 2 Mechanical and Electrical Specifications

### 2.1 Maximum Ratings

Voltage (with respect to GND unless otherwise noted)

$V_{DD}$ .....	-0.3 V to +5.5 V
$\overline{\text{SHDN}}$ , SCLK, $\overline{\text{CS}}$ , $D_{IN}$ , $D_{OUT}$ .....	-0.3 V to $V_{DD}+0.3$ V
Operating Temperature Range .....	-40°C to +105°C
Storage Temperature Range .....	-40°C to +125°C
Overpressure .....	1000 kPa

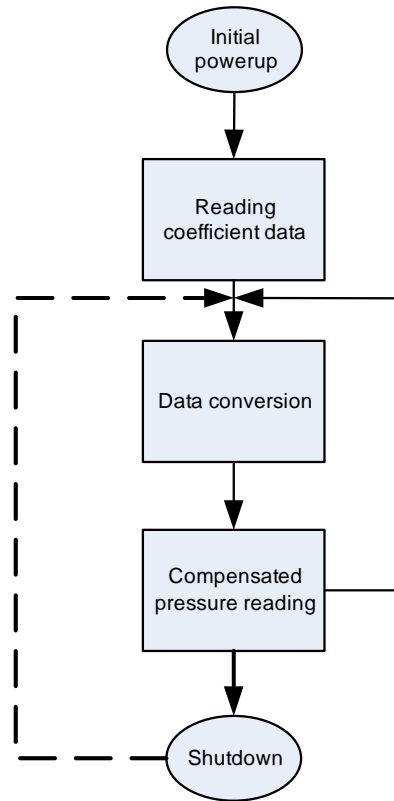
### 2.2 Operating Characteristics

( $V_{DD}$  = 2.375 V to 5.5 V,  $T_A$  = -40°C to +105°C, unless otherwise noted. Typical values are at  $V_{DD}$  = 3.3 V,  $T_A$  = +25°C.)

Ref	Parameters	Symbol	Conditions	Min	Typ	Max	Units
1	Operating Supply Voltage	$V_{DD}$		2.375	3.3	5.5	V
2	Supply Current	$I_{DD}$	Shutdown ( $\overline{\text{SHDN}}$ = GND)	—	—	1	$\mu\text{A}$
			Standby	—	3.5	10	$\mu\text{A}$
			Average – at one measurement per second	—	5	—	$\mu\text{A}$
<b>Pressure Sensor</b>							
3	Range			50	—	115	kPa
4	Resolution			—	0.15	—	kPa
5	Accuracy		-20°C to 85°C	—	—	$\pm 1$	kPa
6	Conversion Time (Start Pressure and Temperature Conversion)	$t_c$	Time between start convert command and data available in the Pressure and Temperature registers	—	1.6	3	ms
7	Wakeup Time	$t_w$	Time between leaving Shutdown mode ( $\overline{\text{SHDN}}$ goes high) and communicating with the device to issue a command or read data.	—	3	5	ms
<b>SPI Inputs: SCLK, <math>\overline{\text{CS}}</math>, <math>D_{IN}</math></b>							
8	SCLK Clock Frequency	$f_{\text{SCLK}}$	<sup>(1)</sup>	—	—	8	MHz
9	Low Level Input Voltage	$V_{IL}$		—	—	$0.3V_{DD}$	V
10	High Level Input Voltage	$V_{IH}$		$0.7V_{DD}$	—	—	V
<b>SPI Outputs: <math>D_{OUT}</math></b>							
11	Low Level Output Voltage	$V_{OL1}$	At 3 mA sink current	0	—	0.4	V
		$V_{OL2}$	At 6 mA sink current	0	—	0.6	
12	High Level Output Voltage	$V_{OH1}$	At 3 mA source current	$V_{DD} - 0.4$ V	—	—	V

1. Nominal maximum SPI clock frequency.

### 3 Overview of Functions/Operation



**Figure 2. Sequence Flow Chart**

The MPL115A interfaces to a host (or system) microcontroller in the user's application. All communications are via SPI. A typical usage sequence is as follows:

#### **Initial Power-up**

All circuit elements are active. SPI port pins are high impedance and associated registers are cleared. The device then enters standby mode.

#### **Reading Coefficient Data**

The user then typically accesses the part and reads the coefficient data. The main circuits within the slave device are disabled during read activity. The coefficients are usually stored in the host microcontroller local memory but can be re-read at any time. Reading of the coefficients may be executed only once and the values stored in the host microcontroller. It is not necessary to read this multiple times because the coefficients within a device are constant and do not change. However, note that the coefficients will be different from device to device, and cannot be used for another part.

#### **Data Conversion**

This is the first step that is performed each time a new pressure reading is required which is initiated by the host sending the CONVERT command. The main system circuits are activated (wake) in response to the command and after the conversion completes, the result is placed into the Pressure and Temperature ADC output registers.

The conversion completes within the maximum conversion time,  $t_c$  (see [Row 6](#), in the Operating Characteristics Table). The device then enters standby mode.

#### **Compensated Pressure Reading**

After the conversion has been given sufficient time to complete, the host microcontroller reads the result from the ADC output registers and calculates the Compensated Pressure, a barometric/atmospheric pressure value which is compensated for changes in temperature and pressure sensor linearity. This is done using the coefficient data from the MPL115A and the raw sampled pressure and temperature ADC output values, in a compensation equation (detailed later). Note that this is an absolute pressure measurement with a vacuum as a reference.

From this step the host controller may either wait and then return to the Data Conversion step to obtain the next pressure reading or it may go to the Shutdown step.

## Shutdown

For longer periods of inactivity the user may assert the  $\overline{\text{SHDN}}$  input by driving this pin low to reduce system power consumption. This removes power from all internal circuits, including any registers. In the shutdown state, the Pressure and Temperature registers will be reset, losing any previous ADC output values.

This step is exited by taking the  $\overline{\text{SHDN}}$  pin high. Wait for the maximum wakeup time,  $t_w$  (see [Row 7](#), in the Operating Characteristics Table), after which another pressure reading can be taken by transitioning to the data Conversion step.

**Table 2. Device Memory Map**

Address	Name	Description
0x00	Padc_MSB	10-bit Pressure ADC output value MSB
0x01	Padc_LSB	10-bit Pressure ADC output value LSB
0x02	Tadc_MSB	10-bit Temperature ADC output value MSB
0x03	Tadc_LSB	10-bit Temperature ADC output value LSB
0x04	a0_MSB	a0 coefficient MSB
0x05	a0_LSB	a0 coefficient LSB
0x06	b1_MSB	b1 coefficient MSB
0x07	b1_LSB	b1 coefficient LSB
0x08	b2_MSB	b2 coefficient MSB
0x09	b2_LSB	b2 coefficient LSB
0x0A	c12_MSB	c12 coefficient MSB
0x0B	c12_LSB	c12 coefficient LSB
0x0C	Reserved*	—
0x0D	Reserved*	—
0x0E	Reserved*	—
0x0F	Reserved*	—
0x10	Reserved	—
0x11	Reserved	—
0x12	CONVERT	Start Pressure and Temperature Conversion

\*These registers are set to 0x00. These are reserved, and were previously utilized as Coefficient values, c11 and c22, which were always 0x00.

For values with less than 16 bits, the lower LSBs are zero. For example, c12 is 14 bits and is stored into 2 bytes as follows:

$$c12 \text{ MS byte} = c12[13:6] = [c12_{b13}, c12_{b12}, c12_{b11}, c12_{b10}, c12_{b9}, c12_{b8}, c12_{b7}, c12_{b6}]$$

$$c12 \text{ LS byte} = c12[5:0] \ \& \ "00" = [c12_{b5}, c12_{b4}, c12_{b3}, c12_{b2}, c12_{b1}, c12_{b0}, 0, 0]$$

### 3.1 Pressure, Temperature and Coefficient Bit-Width Specifications

The table below specifies the initial coefficient bit-width specifications for the compensation algorithm and the specifications for Pressure and Temperature ADC values.

Pressure, Temperature and Compensation Coefficient Specifications						
	a0	b1	b2	c12	Padc	Tadc
<b>Total Bits</b>	16	16	16	14	10	10
<b>Sign Bits</b>	1	1	1	1	0	0
<b>Integer Bits</b>	12	2	1	0	10	10
<b>Fractional Bits</b>	3	13	14	13	0	0
<b>dec pt zero pad</b>	0	0	0	9	0	0

### Example Binary Format Definitions:

a0 Signed, Integer Bits = 12, Fractional Bits = 3 :	Coeff a0 = S I <sub>11</sub> I <sub>10</sub> I <sub>9</sub> I <sub>8</sub> I <sub>7</sub> I <sub>6</sub> I <sub>5</sub> I <sub>4</sub> I <sub>3</sub> I <sub>2</sub> I <sub>1</sub> I <sub>0</sub> · F <sub>2</sub> F <sub>1</sub> F <sub>0</sub>
b1 Signed, Integer Bits = 2, Fractional Bits = 13 :	Coeff b1 = S I <sub>1</sub> I <sub>0</sub> · F <sub>12</sub> F <sub>11</sub> F <sub>10</sub> F <sub>9</sub> F <sub>8</sub> F <sub>7</sub> F <sub>6</sub> F <sub>5</sub> F <sub>4</sub> F <sub>3</sub> F <sub>2</sub> F <sub>1</sub> F <sub>0</sub>
b2 Signed, Integer Bits = 1, Fractional Bits = 14 :	Coeff b2 = S I <sub>0</sub> · F <sub>13</sub> F <sub>12</sub> F <sub>11</sub> F <sub>10</sub> F <sub>9</sub> F <sub>8</sub> F <sub>7</sub> F <sub>6</sub> F <sub>5</sub> F <sub>4</sub> F <sub>3</sub> F <sub>2</sub> F <sub>1</sub> F <sub>0</sub>
c12 Signed, Integer Bits = 0, Fractional Bits = 13, dec pt zero pad = 9 :	Coeff c12 = S 0.000 000 000 F <sub>12</sub> F <sub>11</sub> F <sub>10</sub> F <sub>9</sub> F <sub>8</sub> F <sub>7</sub> F <sub>6</sub> F <sub>5</sub> F <sub>4</sub> F <sub>3</sub> F <sub>2</sub> F <sub>1</sub> F <sub>0</sub>
Padc Unsigned, Integer Bits = 10 :	Padc U = I <sub>9</sub> I <sub>8</sub> I <sub>7</sub> I <sub>6</sub> I <sub>5</sub> I <sub>4</sub> I <sub>3</sub> I <sub>2</sub> I <sub>1</sub> I <sub>0</sub>
Tadc Unsigned, Integer Bits = 10 :	Tadc U = I <sub>9</sub> I <sub>8</sub> I <sub>7</sub> I <sub>6</sub> I <sub>5</sub> I <sub>4</sub> I <sub>3</sub> I <sub>2</sub> I <sub>1</sub> I <sub>0</sub>

**NOTE:** Negative coefficients are coded in 2's complement notation.

## 3.2 Compensation

The 10-bit compensated pressure output, Pcomp, is calculated as follows:

$$P_{comp} = a_0 + (b_1 + c_{12} \cdot T_{adc}) \cdot P_{adc} + b_2 \cdot T_{adc} \quad \text{Eqn. 1}$$

Where:

- Padc is the 10-bit pressure ADC output of the MPL115A
- Tadc is the 10-bit temperature ADC output of the MPL115A
- a0 is the pressure offset coefficient
- b1 is the pressure sensitivity coefficient
- b2 is the temperature coefficient of offset (TCO)
- c12 is the temperature coefficient of sensitivity (TCS)

Pcomp will produce a value of 0 with an input pressure of 50 kPa and will produce a full-scale value of 1023 with an input pressure of 115 kPa.

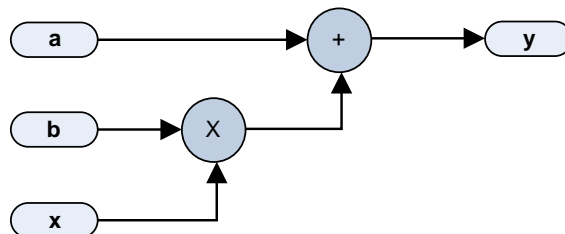
$$\text{Pressure (kPa)} = P_{comp} \cdot \left[ \frac{115 - 50}{1023} \right] + 50 \quad \text{Eqn. 2}$$

## 3.3 Evaluation Sequence, Arithmetic Circuits

The following is an example of the calculation for Pcomp, the compensated pressure output. Input values are in **bold**.

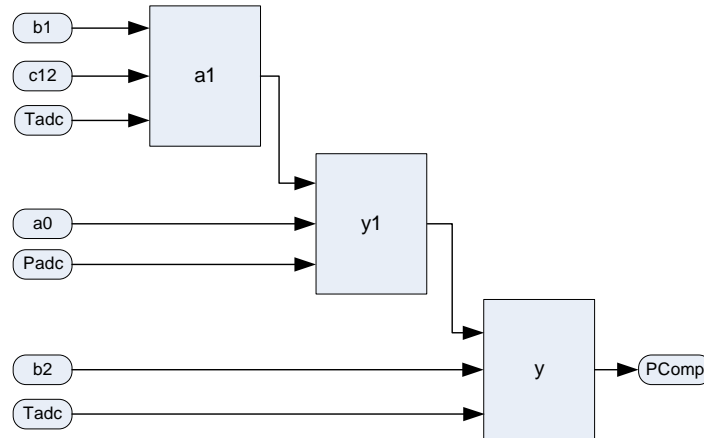
- c12x2 = **c12** \* Tadc
- a1 = **b1** + c12x2
- a1x1 = a1 \* **Padc**
- y1 = **a0** + a1x1
- a2x2 = **b2** \* Tadc
- Pcomp = y1 + a2x2

This can be calculated as a succession of Multiply Accumulates (MACs) operations of the form  $y = a + b * x$ :



The polynomial can be evaluated (Equation 1) as a sequence of 3 MACs:

$$P_{comp} = a_0 + (b_1 + c_{12} \cdot T_{adc}) \cdot P_{adc} + b_2 \cdot T_{adc}$$



Please refer to Freescale application note AN3785 for more detailed notes on implementation.

### 3.4 SPI Device Read/Write Operations

All device read/write operations are memory mapped. Device actions e.g. “Start Conversions” are controlled by writing to the appropriate memory address location. All memory address locations are 6-bit (see Table 2).

The 8-bit command word comprises:

- the most significant bit which is the Read/Write identifier which is '1' for read operations and '0' for write operations.
- the 6-bit address (from Table 2);
- the least significant bit which is not used and is don't care (X).

The device write commands are shown in Table 3.

**Table 3. SPI Write Command**

Command	Binary	HEX <sup>(1)</sup>
Start Conversions	0010010X	0x24

X = don't care

1. The command byte needs to be paired with a 0x00 as part of the SPI exchange to complete the passing of *Start Conversions*.

The actions taken by the part in response to each command are as follows:

**Table 4. SPI Write Command Description**

Command	Action Taken
Start Conversions	Wake main circuits. Start clock. Allow supply stabilization time. Select pressure sensor input. Apply positive sensor excitation and perform A to D conversion. Select temperature input. Perform A to D conversion. Load the Pressure and Temperature registers with the result. Shut down main circuits and clock.

SPI Read operations are performed by sending the required address with a leading *Read* bit set to '1'. SPI operations require that each byte be addressed individually. All data is transmitted most significant bit first.

**Table 5. Example SPI Read Commands**

Command	Binary	HEX <sup>(1)</sup>
Read Pressure MSB	1000000X	0x80
Read Pressure LSB	1000001X	0x82
Read Temperature MSB	1000010X	0x84
Read Temperature LSB	1000011X	0x86
Read Coefficient data byte 1	1000100X	0x88

X = don't care

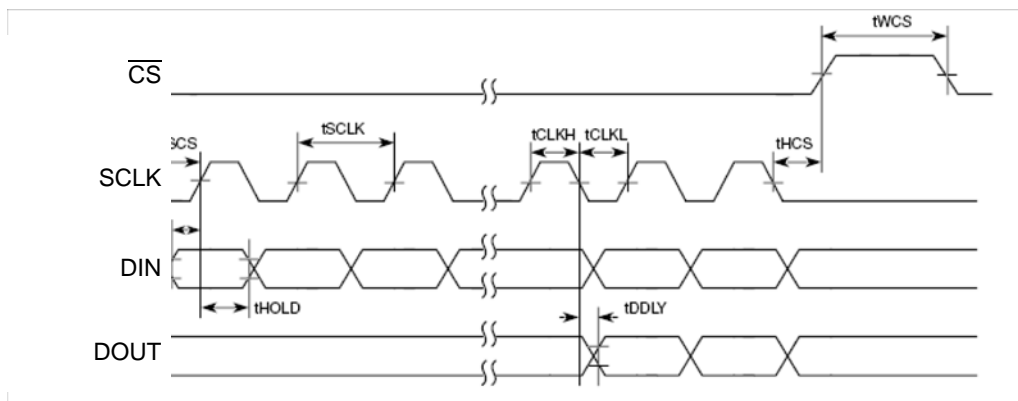
1. The command byte needs to be paired with a 0x00 as part of the SPI exchange to complete the passing of stated command.

### 3.5 SPI Timing

Table 6 and Figure 3 describe the timing requirements for the SPI system.

**Table 6. SPI Timing**

Ref	Function	Symbol	Min	Max	Unit
1	Operating Frequency	$f_{of}$	—	8	MHz
2	SCLK Period	$t_{SCLK}$	125	—	ns
3	SCLK High time	$t_{CLKH}$	62.5	—	ns
4	SCLK Low time	$t_{CLKL}$	62.5	—	ns
5	Enable lead time	$t_{SCS}$	125	—	ns
6	Enable lag time	$t_{HCS}$	125	—	ns
7	Data setup time	$t_{SET}$	30	—	ns
8	Data hold time	$t_{HOLD}$	30	—	ns
9	Data valid (after SCLK low edge)	$t_{DDLY}$	—	32	ns
10	Width CS High	$t_{WCS}$	30	—	ns



**Figure 3. SPI Timing Diagram**



### 3.6 Example of SPI Reading of Coefficients

These are MPL115A1 SPI commands to read coefficients, execute Pressure and Temperature conversions, and to read Pressure and Temperature data. The sequence of the commands for the interaction is given as an example to operate the MPL115A1. Utilizing this gathered data, an example of the calculating the Compensated Pressure reading is given in floating point notation.

#### SPI Commands (simplified for communication)

- Command to Write "Convert Pressure and Temperature" = 0x24
- Command to Read "Pressure ADC High byte" = 0x80
- Command to Read "Pressure ADC Low byte" = 0x82
- Command to Read "Temperature ADC High byte" = 0x84
- Command to Read "Temperature ADC Low byte" = 0x86
- Command to Read "Coefficient data byte 1 High byte" = 0x88

#### Read Coefficients:

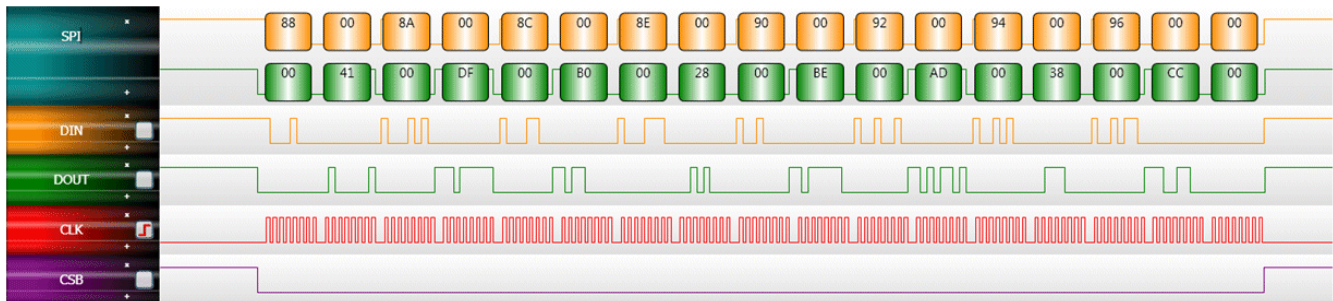
[CS=0], [0x88], [0x00], [0x8A], [0x00], [0x8C], [0x00], [0x8E], [0x00], [0x90], [0x00], [0x92], [0x00], [0x94], [0x00], [0x96], [0x00], [0x00], [CS=1]

#### Start Pressure and Temperature Conversion, Read raw Pressure:

[CS=0], [0x24], [0x00], [CS=1], [3 ms Delay]

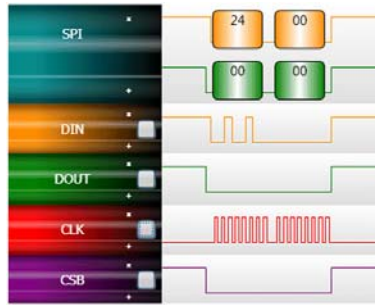
[CS=0], [0x80], [0x00], [0x82], [0x00], [0x84], [0x00], [0x86], [0x00], [0x00], [CS=1]

**NOTE:** Extra [0x00] at the end of each sequence to output the last data byte on the slave side of the SPI.



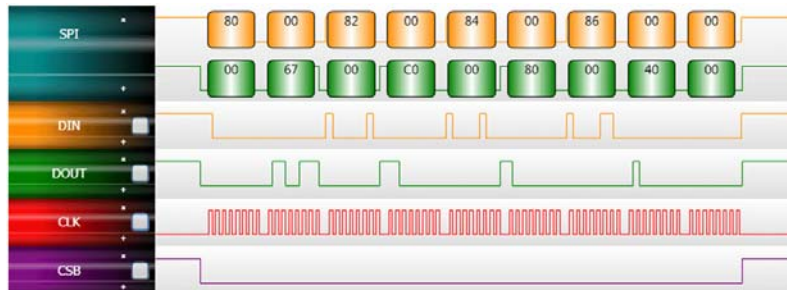
**Figure 4. SPI Read Coefficient Datagram**

- a0 coefficient MSB = 0x41
- a0 coefficient LSB = 0xDF    a0 coefficient = 0x41DF = 2107.875
  
- b1 coefficient MSB = 0xB0
- b1 coefficient LSB = 0x28    b1 coefficient = 0xB028 = -2.49512
  
- b2 coefficient MSB = 0xBE
- b2 coefficient LSB = 0xAD    b2 coefficient = 0xBEAD = -1.02069
  
- c12 coefficient MSB = 0x38
- c12 coefficient LSB = 0xCC    c12 coefficient = 0x38CC = 0.00086665



**Figure 5. SPI Start Conversion Datagram**

Command to Start Pressure and Temperature Conversion, 0x24



**Figure 6. SPI Read Results Datagram**

Pressure MSB	=	0x67			
Pressure LSB	=	0xC0	Pressure	=	0x67C0 = 0110 0111 11 00 0000
					= 415 ADC counts
Temperature MSB	=	0x80			
Temperature LSB	=	0x40	Temperature	=	0x8040 = 1000 0000 01 00 0000
					= 513 ADC counts

### 3.7 Example of Pressure Compensated Calculation in Floating-point Notation

a0 coefficient = 2107.875  
 b1 coefficient = -2.49512  
 b2 coefficient = -1.02069  
 c12 coefficient = 0.00086665

Pressure = 415 ADC counts  
 Temperature = 513 ADC counts

Pressure Compensation:

$$P_{comp} = a_0 + (b_1 + c_{12} \cdot T_{adc}) \cdot P_{adc} + b_2 \cdot T_{adc}$$

Using the evaluation sequence shown in Section 3.3:

$$\begin{aligned}c12x2 &= c12 * Tadc = 0.00086665 * 513 &= 0.44459 \\a1 &= b1 + c12x2 = -2.49512 + 0.44459 &= -2.05052 \\a1x1 &= a1 * Padc = -2.05052 * 415 &= -850.96785 \\y1 &= a0 + a1x1 = 2107.875 + (-850.96785) &= 1256.90715 \\a2x2 &= b2 * Tadc = -1.02069 * 513 &= -523.61444 \\PComp &= y1 + a2x2 = 1256.90715 + (-523.61444) &= 733.29270\end{aligned}$$

$$\begin{aligned}\text{Pressure (kPa)} &= P_{\text{comp}} \cdot \left[ \frac{115 - 50}{1023} \right] + 50 \\&= 733.29 \cdot \left[ \frac{115 - 50}{1023} \right] + 50 \\&= 96.59 \text{ kPa}\end{aligned}$$

## 4 Solder Recommendations

1. Use SAC solder alloy (i.e., Sn-Ag-Cu) with a melting point of about 217°C. It is recommended to use SAC305 (i.e., Sn-3.0 wt.% Ag-0.5 wt.% Cu).
2. Reflow
  - Ramp up rate: 2 to 3°C/s.
  - Preheat flat (soak): 110 to 130s.
  - Reflow peak temperature: 250°C to 260°C (depends on exact SAC alloy composition).
  - Time above 217°C: 40 to 90s (depends on board type, thermal mass of the board/quantities in the reflow).
  - Ramp down: 5 to 6°C/s.
  - Using an inert reflow environment (with O<sub>2</sub> level about 5 to 15 ppm).

**NOTE:** The stress level and signal offset of the device also depends on the board type, board core material, board thickness and metal finishing of the board.

## 5 Handling Recommendations

It is recommended to handle the MPL115A pressure sensor with a vacuum pick and place tool. Sharp objects utilized to move the MPL115A pressure sensor increase the possibility of damage via a foreign object/tool into the small exposed port.

The sensor die is sensitive to light exposure. Direct light exposure through the port hole can lead to varied accuracy of pressure measurement. Avoid such exposure to the port during normal operation.

## 6 Soldering/Landing Pad Information

The LGA package is compliant with the RoHS standard. It is recommended to use a no-clean solder paste to reduce cleaning exposure to high pressure and chemical agents that can damage or reduce life span of the Pressure sensing element.

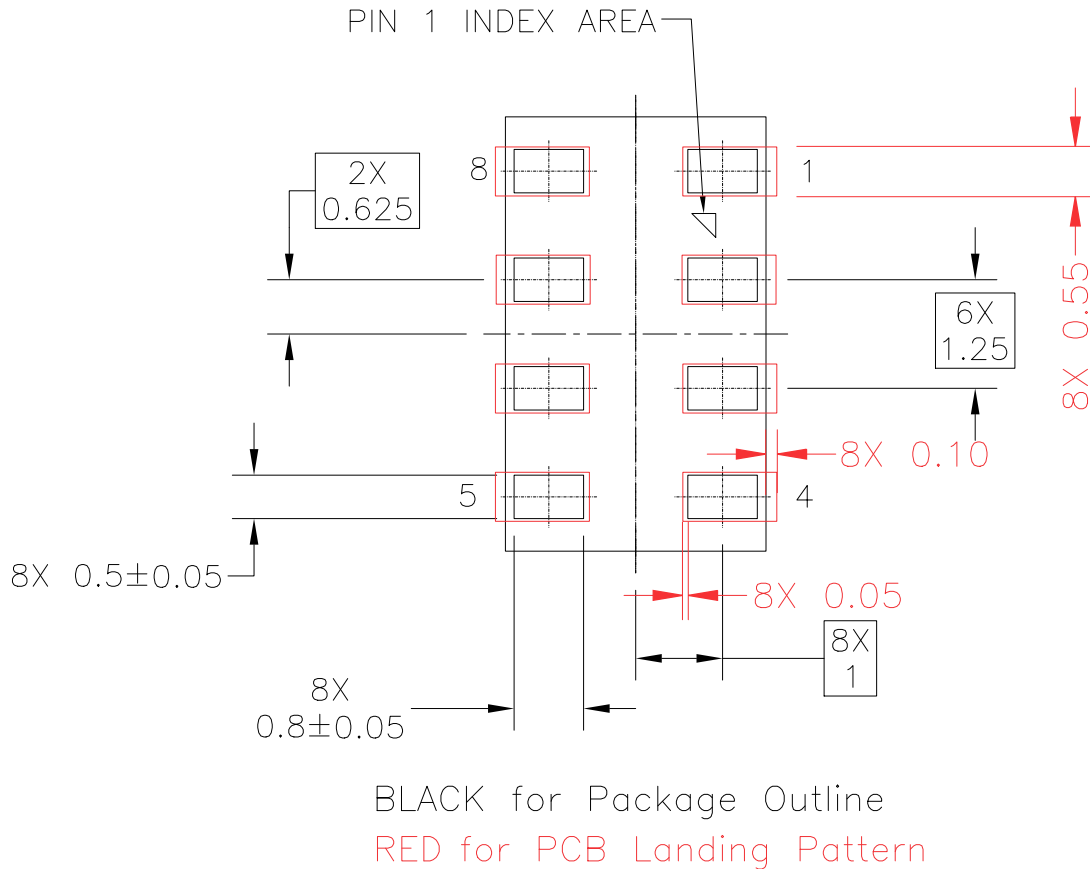


Figure 7. MPL115A1 Recommended PCB Landing Pattern

## 7 Tape and Reel Specifications

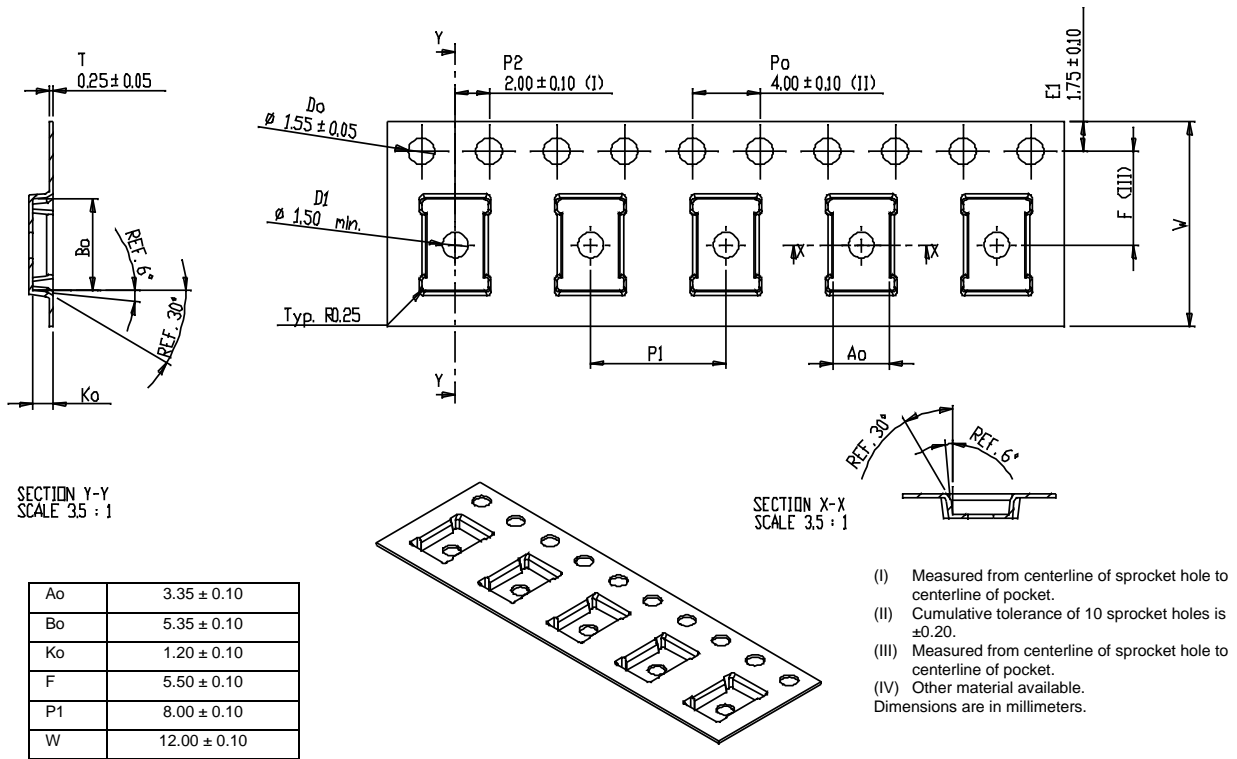


Figure 8. LGA (3 by 5) Embossed Carrier Tape Dimensions

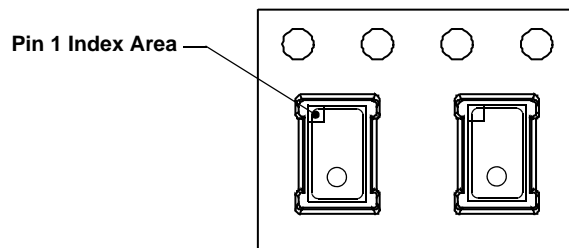
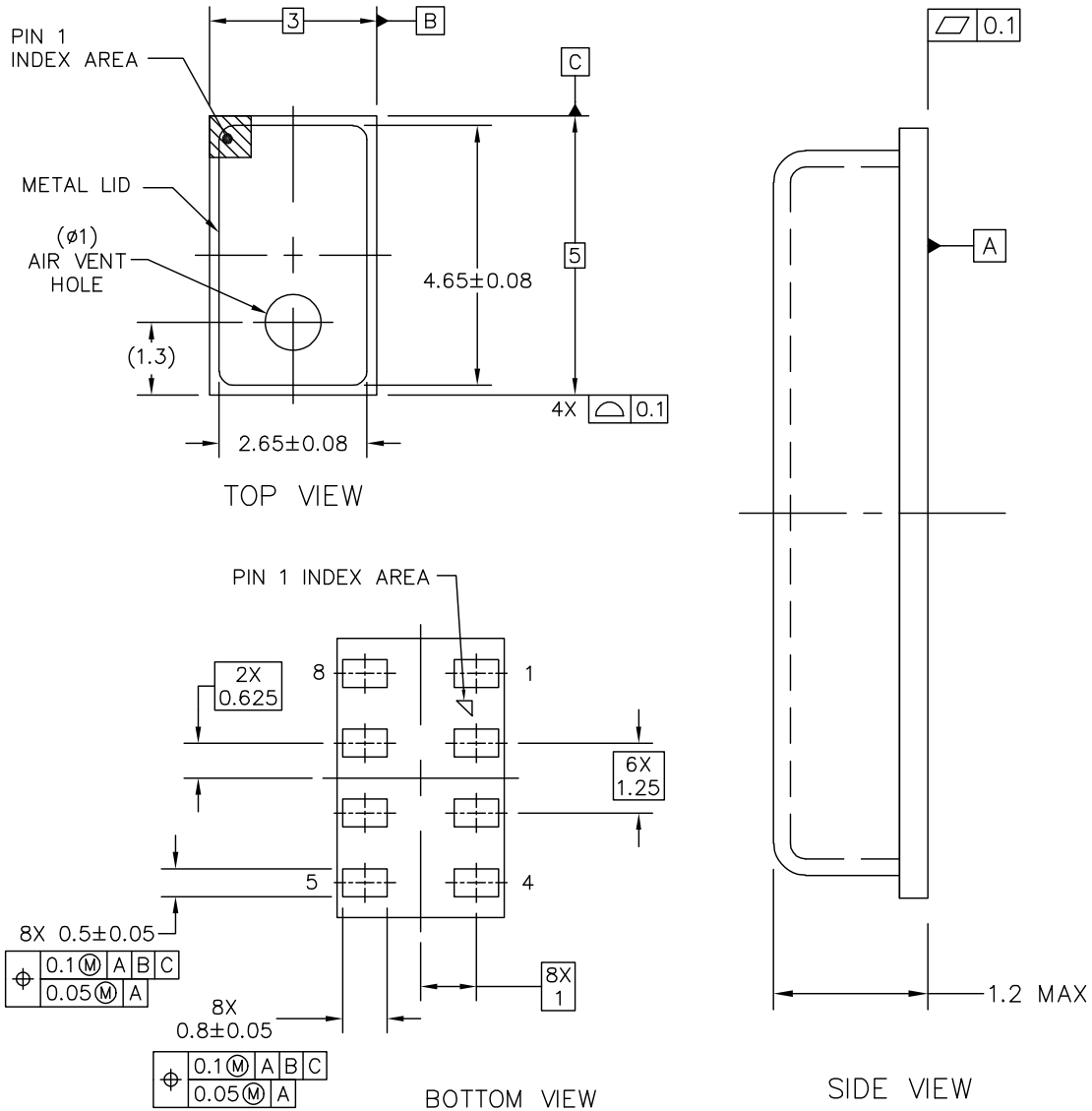


Figure 9. Device Orientation in Chip Carrier

## PACKAGE DIMENSIONS



**NOTES:**

1. ALL DIMENSIONS IN MILLIMETERS.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994

© FREESCALE SEMICONDUCTOR, INC. ALL RIGHTS RESERVED.	<b>MECHANICAL OUTLINE</b>	PRINT VERSION NOT TO SCALE
<b>TITLE:</b> LGA 8 I/O, 3 X 5 X 1.25 PITCH, SENSOR 1.2MAX MM PKG	DOCUMENT NO: 98ASA10829D	REV: A
	CASE NUMBER: 2015-02	10 MAR 2010
	STANDARD: NON-JEDEC	

**CASE 2015-02  
ISSUE A  
LGA PACKAGE**

**Table 4. Revision History**

Revision number	Revision date	Description of changes
7	02/2013	<ul style="list-style-type: none"><li>• Changed Example Binary format definitions b1 signed from 7 to 13, added <math>F_{11}</math> to Coeff b1, b2 and c12 on page 6.</li><li>• Removed MPL115A1T2 from ordering table.</li></ul>

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