

High Accuracy, Low Power, Waterproof Barometric Pressure and Temperature Sensor IC

GENERAL INFORMATION

The ICP-101xx pressure sensor family is based on MEMS capacitive technology which provides ultra-low noise at the lowest power, enabling industry leading relative accuracy, sensor throughput, and temperature stability. The pressure sensor can measure pressure differences with an accuracy of ± 1 Pa, an accuracy enabling altitude measurement differentials as small as 8.5 cm, less than the height of a single stair step.

Consuming only 1.3 μ A @1 Hz, available in a small footprint 2 mm x 2 mm x 0.72 mm waterproof to 1.5m depth 10-pin LGA package (ICP-10100), the ICP-101xx is ideally suited for mobile phones, wearable fitness monitoring, drones, and battery powered IoT.

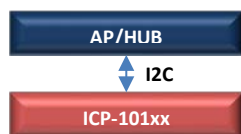
The ICP-101xx offers an industry leading temperature coefficient offset of ± 0.5 Pa/ $^{\circ}$ C. The combination of high accuracy, low power, temperature stability, waterproofing in a small footprint enables higher performance barometric pressure sensing for sports activity identification, mobile indoor/outdoor navigation, and altitude-hold in drones.

DEVICE INFORMATION

PART NUMBER	PACKAGE	LID OPENING
ICP-10100	2x2x0.72mm LGA-10L	3-Hole, IPx8: 1.5m Waterproof
ICP-10101	2x2x0.72mm LGA-10L	1-Hole
ICP-10110	2x2.5x0.92mm LGA-8L	3-Hole, IPx8: 1.5m Waterproof
ICP-10111	2x2.5x0.92mm LGA-8L	1-Hole

Denotes RoHS and Green-Compliant Package

BLOCK DIAGRAMS

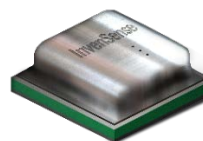


APPLICATIONS

- Altitude Control of Drones and Flying Toys
- Mobile Phones
- Virtual Reality and Gaming Equipment
- Indoor/Outdoor Navigation (dead-reckoning, floor/elevator/step detection)
- Vertical velocity monitoring
- Leisure, Sports, and Fitness Activity Identification
- Weather Forecasting

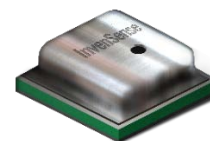
FEATURES

- Pressure operating range: 30 to 110 kPa
- Noise and current consumption
 - 0.4 Pa @ 10.4 μ A (ULN mode)
 - 0.8 Pa @ 5.2 μ A (LN mode)
 - 3.2 Pa @ 1.3 μ A (LP mode)
- Pressure Sensor Relative Accuracy: ± 1 Pa for any 10 hPa change over 950 hPa-1050 hPa at 25 $^{\circ}$ C
- Pressure Sensor Absolute Accuracy: ± 1 hPa over 950 hPa-1050 hPa, 0 $^{\circ}$ C to 65 $^{\circ}$ C
- Pressure Sensor Temperature Coefficient Offset: ± 0.5 Pa/ $^{\circ}$ C over 25 $^{\circ}$ C to 45 $^{\circ}$ C at 100 kPa
- Temperature Sensor Absolute Accuracy: $\pm 0.4^{\circ}$ C
- IPx8: Waterproof to 1.5m depth (ICP-10100 & ICP-10110)
- Temperature operating range: -40 $^{\circ}$ C to 85 $^{\circ}$ C
- Host Interface: I 2 C at up to 400 kHz
- Single Supply voltage: 1.8V $\pm 5\%$
- RoHS and Green compliant



3-Hole IPx8 Lid Opening

ICP-10100 & ICP-10110



1-Hole Lid Opening

ICP-10101 & ICP-10111

TYPICAL OPERATING CIRCUIT

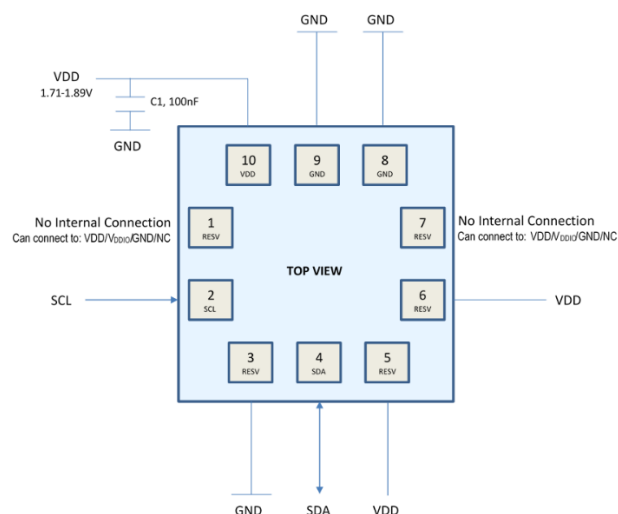


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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This document is a preliminary product specification, providing a description, specifications, and design related information for the ICP-101xx Pressure Sensor.

Specifications are subject to change without notice. Final specifications will be updated based upon characterization of production silicon.

1.2 PRODUCT OVERVIEW

The ICP-101xx is an ultra-low power, low noise, digital output barometric pressure and temperature sensor IC. It is based on an innovative MEMS capacitive pressure sensor technology that can measure pressure differences with an accuracy of ± 1 Pa at the industry's lowest power. The high accuracy MEMS capacitive pressure sensor is capable of measuring altitude differentials down to 8.5 cm without the penalty of increased power consumption or reduced sensor throughput.

The capacitive pressure sensor has a ± 1 hPa absolute accuracy over its full range of 300 hPa -1100 hPa. The pressure sensor has an embedded temperature sensor and 400 kHz I²C bus for communication. For power-critical applications, the ICP-101xx features a low power mode of 1.3 μ A at a noise of 3.2 Pa or for high performance applications, it features a low noise mode of 0.8 Pa while only consuming 5.2 μ A.

The ICP-10100 and ICP-10110 has three 0.025 mm package openings, making waterproof to 1.5m for 30 minutes providing many mobile applications improved water resistance with no additional waterproofing costs.

The ICP-101xx also offers industry leading temperature stability of the pressure sensor with a temperature coefficient offset of ± 0.5 Pa/ $^{\circ}$ C. The high accuracy, temperature stability, and market leading low power consumption of 1.3 μ A @1 Hz offered by ICP-101xx makes it ideally suited for applications such as mobile phones, drone flight control and stabilization, indoor/outdoor navigation (elevator, floor, and stair step detection), sports and fitness activity monitoring, and battery-powered IoT.

2 PRESSURE AND TEMPERATURE SENSOR SPECIFICATIONS

2.1 OPERATION RANGES

The sensor shows best performance when operated within the recommended temperature and pressure range (hereafter called normal conditions) of 0°C – 45°C and 95 kPa – 105 kPa, respectively. The following ranges are defined for the device:

OPERATION RANGE	PRESSURE (KPA)	TEMPERATURE (°C)
Normal	95 to 105	0 to 45
Extended	30 to 110	-20 to 65
Maximum	25 to 115	-40 to 85

Table 1. Operation Ranges

2.2 OPERATION MODES

The sensor can be operated in up to four different measurement modes to satisfy different requirements for power consumption vs. noise, accuracy and measurement frequency. An overview of the operation modes is given in Table 2.

PARAMETER	CONDITIONS	SENSOR MODE	TYP	MAX	UNITS	NOTES
Conversion Time	Time between sending last bit of measurement command, and sensor data ready for measurement	Low Power (LP)	1.6	1.8	ms	1
		Normal (N)	5.6	6.3		1
		Low Noise (LN)	20.8	23.8		1
		Ultra Low Noise (ULN)	83.2	94.5		1
Current Consumption	1 Hz ODR	Low Power (LP)	1.3		μA	
		Normal (N)	2.6			
		Low Noise (LN)	5.2			
		Ultra Low Noise (ULN)	10.4			
Pressure RMS Noise	Valid for P = 100 kPa, T = 25°C, and U = 1.8V	Low Power (LP)	3.2		Pa	
		Normal	1.6			
		Low Noise (LN)	0.8			
		Ultra Low Noise (ULN)	0.4			

Table 2. Operation Modes

Notes:

1. Guaranteed by design.

Low Power modes supports ODR greater than 500 Hz while the Low Noise mode provides industry leading RMS noise at a fast 40 Hz ODR. Further decrease in noise may be achieved by software oversampling and filtering through customer's software implementation or custom TDK-InvenSense operation modes available upon request.

2.3 PRESSURE SENSOR SPECIFICATIONS

Pressure sensor specifications are given in Table 3. Default conditions of 25 °C and 1.8V supply voltage apply, unless otherwise stated.

PARAMETER	CONDITIONS	TYP	UNITS	NOTES
Absolute Accuracy	Normal range	±1	hPa	1
	Extended range	±1.5		
Relative Accuracy	Any step ≤ 1 kPa, 25 °C	±1	Pa	
	Any step ≤ 10 kPa, 25 °C	±3		
Long-term drift During 1 year	Extended range	±1	hPa/y	
Solder drift		1.5	hPa	1, 2
Temperature coefficient offset	P = 100 kPa 25°C ... 45°C	±0.5	Pa/°C	
Resolution	Maximum range	0.01	Pa	

Table 3. Pressure Sensor Specifications

Notes:

1. Absolute accuracy may be improved through One Point Calibration
2. Sensor accuracy post Solder reflow may be improved through One Point Calibration

2.4 TEMPERATURE SENSOR SPECIFICATIONS

Specifications of the temperature sensor are shown in Table 4.

PARAMETER	CONDITIONS	TYP	UNITS
Absolute Accuracy	Extended range	±0.4	°C
Repeatability	Extended range	±0.1	°C
Resolution	Maximum range	0.01	°C
Long-term drift	Normal range	<0.04	°C/y

Table 4. Temperature Sensor Specifications

2.5 RECOMMENDED OPERATION CONDITIONS

The pressure sensor exhibits best performance when operated within the normal pressure and temperature range 0°C < T < 45°C and 95 kPa < P < 105 kPa.

Injected photo current due to strong light sources can influence the sensor performance and should be avoided to guarantee best operation.

The sensor should not be exposed to high mechanical stress, the resulting deformation of the package can alter internal dimensions and therefore falsify the sensor signal. Solder reflow may affect device performance. One point calibration can improve the sensor accuracy post solder reflow.

3 ELECTRICAL SPECIFICATIONS

3.1 ELECTRICAL CHARACTERISTICS

Default conditions of 25 °C and 1.8V supply voltage apply to values in Table 5, unless otherwise stated.

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS	COMMENTS
Supply voltage	V_{DD}		1.71	1.8	1.89	V	
Power-up/down level	V_{POR}	Static power supply	1.0	1.25	1.5	V	
Supply Ramp Time	T_{RAMP}	Monotonic ramp. Ramp rate is 10% to 90% of the final value	0.01		100	ms	
Supply current	I_{DD}	Idle state	-	1.0	2.5	μA	
		Measurement	-	210	300	μA	Current consumption while sensor is measuring.
		Average	-	1.3	-	μA	Current consumption in continuous operation @ 1 Hz ODR in LP Mode
			-	5.2	-	μA	Current consumption in continuous operation @1 Hz ODR in LN Mode
Low level input voltage	V_{IL}		0	-	$0.3 V_{DD}$	V	
High level input voltage	V_{IH}		$0.7 V_{DD}$	-	V_{DD}	V	
Low level output voltage	V_{OL}	$0 < I_{OL} < 3 \text{ mA}$	-	-	$0.2 V_{DD}$	V	
Output Sink Current	I_{OL}	$V_{OL} = 0.4V$	3.1	4.1	-	mA	
		$V_{OL} = 0.6V$	3.5	4.5	-	mA	

Table 5. Electrical Specifications

3.2 ABSOLUTE MAXIMUM RATINGS

Stress levels beyond those listed in Table 6 may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these conditions cannot be guaranteed. Exposure to the absolute maximum rating conditions for extended periods may affect the reliability of the device.

PARAMETER	RATING
Supply voltage, VDD	-0.3V to +2.16V
Supply Voltage, SCL & SDA	-0.3V to VDD +0.3V
Operating temperature range	-40°C to +85°C
Storage temperature range	-40°C to +125°C
ESD HBM	2.0 kV
ESD CDM	250V
Latch up, JEDEC Class II, 85°C	100 mA
Overpressure	>600kPa

Table 6. Absolute Maximum Ratings

3.3 SENSOR SYSTEM TIMING

Default conditions of 25°C and 1.8V supply voltage apply to typ. values listed in Table 7, unless otherwise stated. Max. values apply over the specified operating range of VDD and over the operating temperature range.

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS	COMMENTS
Power-up time	t_{PU}	After hard reset, $V_{DD} \geq V_{POR}$	-	170	-	μs	Time between V_{DD} reaching V_{PU} and sensor entering idle state
Soft reset time	t_{SR}	After soft reset	-	170	-	μs	Time between ACK of soft reset command and sensor entering idle state
Measurement duration	t_{MEAS}	LN Mode	-	20.8	23.8	ms	Duration for a pressure and temperature measurement

Table 7. System Timing Specifications

3.4 I²C TIMING CHARACTERIZATION

Default conditions of 25°C and 1.8V supply voltage apply to values in Table 8, unless otherwise stated.

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
SCL clock frequency	f_{SCL}		0	-	400	kHz
Hold time (repeated) START condition	$t_{HD;STA}$	After this period, the first clock pulse is generated	0.6	-	-	μs
LOW period of the SCL clock	t_{LOW}		1.3	-	-	μs
HIGH period of the SCL clock	t_{HIGH}		0.6	-	-	μs
Set-up time for a repeated START condition	$t_{SU;STA}$		0.6	-	-	μs
SDA hold time	$t_{HD;DAT}$		0	-	-	μs
SDA set-up time	$t_{SU;DAT}$		100	-	-	ns
SCL/SDA rise time	t_R		20	-	300	ns
SCL/SDA fall time	t_F		-	-	300	ns
SDA valid time	$t_{VD;DAT}$		-	-	0.9	μs
Set-up time for STOP condition	$t_{SU;STO}$		0.6	-	-	μs
Capacitive load on bus line	C_B		-	-	400	pF

Table 8. I²C Parameters Specification

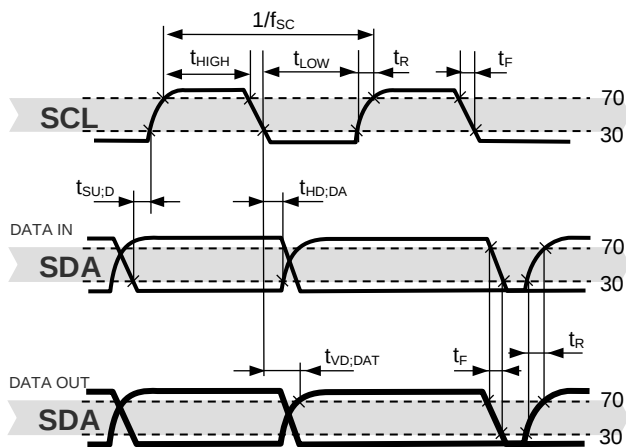


Figure 1. Digital I/O Pads Timing

4 APPLICATIONS INFORMATION

4.1 INTERFACE SPECIFICATIONS

The ICP-101xx supports I²C fast mode, SCL clock frequency from 0 to 400 kHz.

4.2 PIN OUT DIAGRAM AND SIGNAL DESCRIPTION

ICP-10100 and ICP-10101: 2x2x0.72mm 10-pin LGA

PIN NUMBER	PIN NAME	DESCRIPTION
1	RESV	No Internal Connection: Can connect to VDD/V _{DDIO} /GND/NC
2	SCL	I ² C Serial Clock
3	RESV	Connect to Ground
4	SDA	I ² C Serial Data
5	RESV	Connect to VDD
6	RESV	Connect to VDD
7	RESV	No Internal Connection: Can connect to VDD/V _{DDIO} /GND/NC
8	GND	Connect to Ground
9	GND	Connect to Ground
10	VDD	Power Supply VDD

Table 9. Signal Descriptions

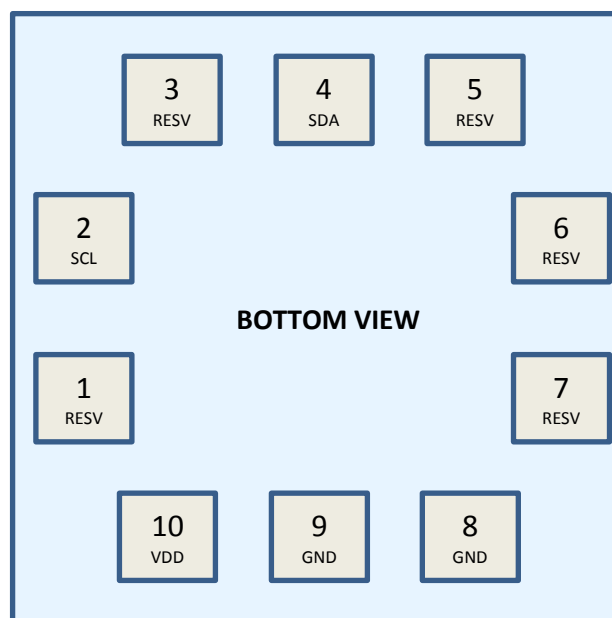


Figure 2. Pin Out Diagram for ICP-10100 & ICP10101, 2 mm x 2 mm x 0.72 mm LGA

ICP-10110 and ICP-10111: 2x2.5x0.92 mm 8-pin LGA

PIN NUMBER	PIN NAME	DESCRIPTION
1	GND	Connect to Ground
2	RESV	No Internal Connection: Can connect to VDD/V _{DDIO} /GND/NC
3	SDA	I ² C Serial Data
4	SCL	I ² C Serial Clock
5	RESV	Connect to Ground
6	RESV	No Internal Connection: Can connect to VDD/V _{DDIO} /GND/NC
7	GND	Connect to Ground
8	VDD	Power Supply VDD

Table 10. Signal Descriptions

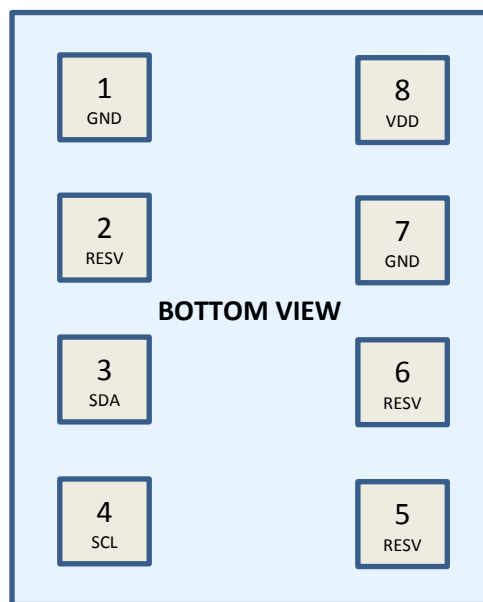


Figure 3. Pin Out Diagram for ICP-10110 & ICP-10111 2 mm x 2.5 mm x 0.92 mm LGA

4.3 TYPICAL OPERATING CIRCUIT

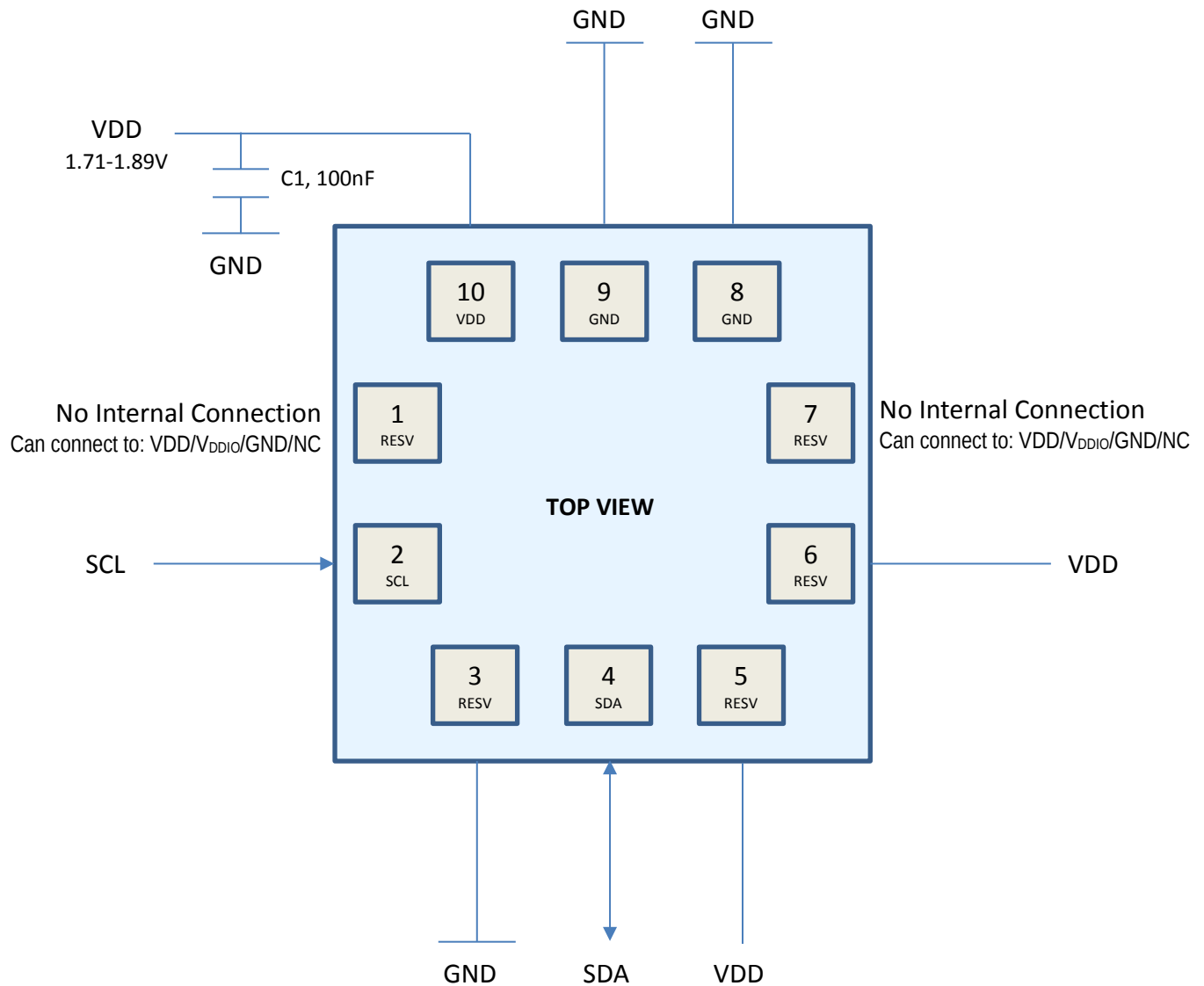


Figure 4. ICP-10100 & ICP-10101 Application Schematic

Power supply pins supply voltage(Vdd) and ground (Vss) must be decoupled with a 100 nF capacitor that shall be placed as close to the sensor as possible (see Figure 5).

Power supply pins supply voltage(Vdd) and ground (Vss) must be decoupled with a 100 nF capacitor that shall be placed as close to the sensor as possible (see Figure 7).

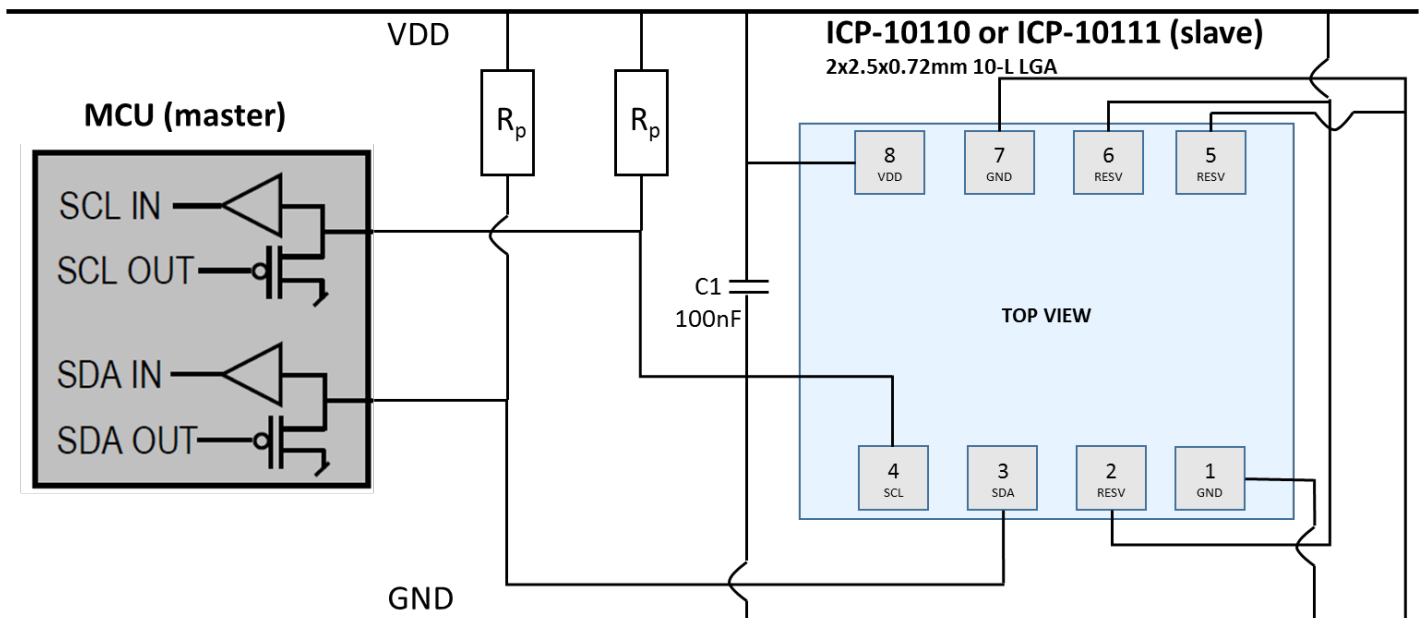


Figure 7. Example: Typical application circuit, including pull-up resistor R_p and decoupling of VDD and VSS by capacitor (2 x 2.5 mm package)

4.4 BILL OF MATERIALS FOR EXTERNAL COMPONENTS

COMPONENT	LABEL	SPECIFICATION	QUANTITY
VDD Bypass Capacitor	C1	Ceramic, X7R, 100 nF $\pm 10\%$	1

Table 11. Bill of Materials

5 OPERATION AND COMMUNICATION

All commands and memory locations of the ICP-101xx are mapped to a 16-bit address space which can be accessed via the I²C protocol.

ICP-101XX	BINARY	DECIMAL	HEXADECIMAL
I ² C address	110'0011	99	0x63

Table 12. ICP-101xx I²C Device Address

5.1 POWER-UP AND COMMUNICATION START

Upon VDD reaching the power-up voltage level V_{POR} , the ICP-101xx enters idle state after a duration of t_{PU} . In idle state, the ICP-101xx is ready to receive commands from the master (microcontroller).

Each transmission sequence begins with START condition (S) and ends with an (optional) STOP condition (P) as described in the I²C-bus specification. Whenever the sensor is powered up, but not performing a measurement or communicating, it automatically enters idle state for energy saving.

5.2 MEASUREMENT COMMANDS

The ICP-101xx provides the possibility to define the sensor behavior during measurement as well as the transmission sequence of measurement results. These characteristics are defined by the appropriate measurement command (see Figure 13). Each measurement command triggers both a temperature *and* a pressure measurement.

OPERATION MODE	TRANSMIT T FIRST	TRANSMIT P FIRST
Low Power (LP)	0x609C	0x401A
Normal (N)	0x6825	0x48A3
Low Noise (LN)	0x70DF	0x5059
Ultra-Low Noise (ULN)	0x7866	0x58E0

Table 13. Measurement Commands

5.3 STARTING A MEASUREMENT

A measurement communication sequence consists of a START condition followed by the I²C header with the 7-bit I²C device address and a write bit (write W: '0', 8-bit word including I²C header: 0xC6). The sensor indicates the proper reception of a byte by pulling the SDA pin low (ACK bit) after the falling edge of the 8th SCL clock. Then the sensor is ready to receive a 16-bit measurement command. Again, the ICP-101xx acknowledges the proper reception of each byte with ACK condition. A complete measurement cycle is presented in Figure 3.

With the acknowledgement of the measurement command, the ICP-101xx starts measuring pressure and temperature.

5.4 SENSOR BEHAVIOR DURING MEASUREMENT

In general, the sensor does not respond to any I²C activity during measurement, i.e. I²C read and write headers are not acknowledged (NACK).

5.5 READOUT OF MEASUREMENT RESULTS

After a measurement command has been issued and the sensor has completed the measurement, the master can read the measurement results by sending a START condition followed by an I²C read header (8-bit word including I²C header: 0xC7). The sensor will acknowledge the reception of the read header and send the measured data in the specified order to the master. The MSB of the corresponding data is always transmitted first. Temperature data is transmitted in two 8-bit words and pressure data is transmitted in four 8-bit words. Regarding the pressure data, only the first three words MMSB, MLSB and LMSB contain information about the ADC pressure value p_{dout} (see Figure for a full data sequence). Therefore, for retrieving the ADC pressure value, LLSB must be disregarded:

$$p_{dout} = \text{MMSB} \ll 16 \mid \text{MLSB} \ll 8 \mid \text{LMSB}.$$

Two bytes of data are always followed by one byte CRC checksum, for calculation see section 5.8. Each byte must be acknowledged by the microcontroller with an ACK condition for the sensor to continue sending data. If the ICP-101xx does not receive an ACK from the master after any byte of data, it will not continue sending data.

Whether the sensor sends out pressure or temperature data first depends on the measurement command that was sent to the sensor to initiate the measurement (see Table 12).

The I²C master can abort the read transfer with a NACK condition after any data byte if it is not interested in subsequent data, e.g. the CRC byte or the second measurement result, to save time.

5.6 SOFT RESET

The ICP-101xx provides a soft reset mechanism that forces the system into a well-defined state without removing the power supply. If the system is in idle state (i.e. if no measurement is in progress) the soft reset command will be accepted by ICP-101xx. This triggers the sensor to reset all internal state machines and reload calibration data from the memory.

COMMAND	HEXADECIMAL CODE	BINARY CODE
Soft reset	0x805D	1000'0000'0101'1101

Table 14. Soft Reset Command

5.7 READ-OUT OF ID REGISTER

The ICP-101xx has an ID register which contains a specific product code. The read-out of the ID register can be used to verify the presence of the sensor and proper communication. The command to read the ID register is shown in Table 14.

COMMAND	HEXADECIMAL CODE	BINARY CODE
Read ID register	0xEFC8	1110'1111'1100'1000

Table 15. Read-Out Command of ID Register

It needs to be sent to the ICP-101xx after an I²C write header. After the ICP-101xx has acknowledged the proper reception of the command, the master can send an I²C read header and the ICP-101xx will submit the 16-bit ID followed by 8 bits of CRC. The structure of the ID is described in Table 15. Bits 15:6 of the ID contain unspecified information (marked as "x"), which may vary from sensor to sensor, while bits 5:0 contain the ICP-101xx specific product code.

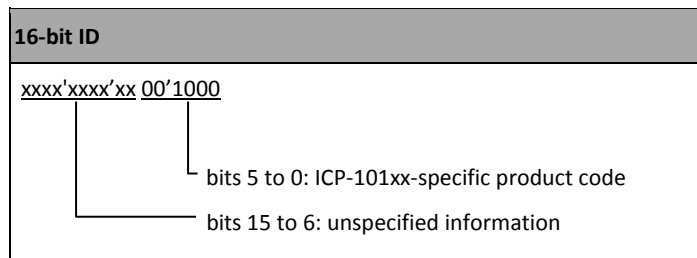


Table 16. 16-bit ID Structure

5.8 CHECKSUM CALCULATION

The 8-bit CRC checksum transmitted after each data word is generated by a CRC algorithm with the properties displayed in Table 16. The CRC covers the contents of the two previously transmitted data bytes.

PROPERTY	VALUE
Name	CRC-8
Width	8 bits
Polynomial	0x31 ($x^8 + x^5 + x^4 + 1$)
Initialization	0xFF
Reflect input	false
Reflect output	false
Final XOR	0x00
Examples	CRC(0x00) = 0xAC CRC(0xBEEF) = 0x92

Table 17. ICP-101xx I²C CRC Properties

5.9 CONVERSION OF SIGNAL OUTPUT

Pressure measurement data is always transferred as 4 8-bit words; temperature measurement data is always transferred as two 8-bit words. Please see section 5.5 for more details.

Temperature measurement values t_dout are linearized by the ICP-101xx and must be calculated to °C by the user via the following formula:

$$T = -45^{\circ}\text{C} + \frac{175^{\circ}\text{C}}{2^{16}} \times t_dout.$$

For retrieving physical pressure values in Pa the following conversion formula has to be used:

$$P = A + \frac{B}{C + p_dout},$$

where p_dout is the sensor's raw pressure output. The converted output is compensated for temperature effects via the temperature dependent functions A , B and C . Besides the raw temperature output t_dout , the calculation of A , B and C requires to access calibration parameters OTP0, OTP1, OTP2, OTP3 stored in the OTP of the sensor. Read-out of OTP parameters is described in section 5.10.

Full sample code for calculating physical pressure values is given in section 5.11. The general workflow of the conversion is done by:

- 1) Import class `Invensense_pressure_conversion`
- 2) Read out values OTP0, ..., OTP3 and save to $c1$, ..., $c4$
- 3) Create object *name* for an individual sensor with parameter values $c1$, ..., $c4$

```
name = Invensense_pressure_conversion
      ([c1,c2,c3,c4])
```
- 4) Get raw pressure p_dout and temperature t_dout data from the sensor as described in chapter 5.5.
- 5) Call function `get_pressure`:

```
name.get_pressure(p_dout, t_dout)
```

The sample code from section 5.12 gives an example of this workflow.

5.10 READ-OUT OF CALIBRATION PARAMETERS

For converting raw pressure data to physical values, four calibration parameters have to be retrieved from the OTP of the sensor.

Set up of OTP read:

- 1) Send I²C write header 0xC6
- 2) Send command 0xC595 (move pointer in address register)
- 3) Send address parameter together with its CRC 0x00669C

Steps 1) – 3) can be executed on many platforms by a single I²C write of the value 0xC59500669C.

Read out parameters:

Repeat the following procedure 4 times:

- a) Send I²C write header 0xC6
- b) Send command 0xC7F7 (incremental read-out of OTP)
- c) Send I²C read header 0xC7
- d) Read 3B (2B of data and 1B of CRC)
- e) Decode data as 16bit big endian signed integer and store result into n-th calibration parameter cn.

Steps a) to d) can be executed on many platforms by a single write 0xC7F7 to the chip address followed by a single read of 3 B from the chip address.

5.11 SAMPLE CODE: EXAMPLE C SYNTAX

```
/* data structure to hold pressure sensor related parameters */
typedef struct inv_invpres
{
    struct inv_invpres_serif serif;
    uint32_t min_delay_us;
    uint8_t pressure_en;
    uint8_t temperature_en;
    float sensor_constants[4]; // OTP values
    float p_Pa_calib[3];
    float LUT_lower;
    float LUT_upper;
    float quadr_factor;
    float offst_factor;
} inv_invpres_t;

int inv_invpres_init(struct inv_invpres * s)
{
    short otp[4];

    read_otp_from_i2c(s, otp);

    init_base(s, otp);

    return 0;
}

int read_otp_from_i2c(struct inv_invpres * s, short *out)
{
    unsigned char data_write[10];
    unsigned char data_read[10] = {0};
    int status;
    int i;

    // OTP Read mode
    data_write[0] = 0xC5;
    data_write[1] = 0x95;
    data_write[2] = 0x00;
}
```

```

data_write[3] = 0x66;
data_write[4] = 0x9C;
status = inv_invpres_serif_write_reg(&s->serif, ICC_ADDR_PRS, data_write, 5);
if (status)
    return status;

// Read OTP values
for (i = 0; i < 4; i++) {
    data_write[0] = 0xC7;
    data_write[1] = 0xF7;
    status = inv_invpres_serif_write_reg(&s->serif, ICC_ADDR_PRS, data_write, 2);
    if (status)
        return status;

    status = inv_invpres_serif_read_reg(&s->serif, ICC_ADDR_PRS, data_read, 3);
    if (status)
        return status;

    out[i] = data_read[0]<<8 | data_read[1];
}

return 0;
}

void init_base(struct inv_invpres * s, short *otp)
{
    int i;

    for(i = 0; i < 4; i++)
        s->sensor_constants[i] = (float)otp[i];

    s->p_Pa_calib[0] = 45000.0;
    s->p_Pa_calib[1] = 80000.0;
    s->p_Pa_calib[2] = 105000.0;
    s->LUT_lower = 3.5 * (1<<20);
    s->LUT_upper = 11.5 * (1<<20);
    s->quadr_factor = 1 / 16777216.0;
    s->offst_factor = 2048.0;
}

// p_LSB -- Raw pressure data from sensor
// T_LSB -- Raw temperature data from sensor
int inv_invpres_process_data(struct inv_invpres * s, int p_LSB, int T_LSB,
                             float * pressure, float * temperature)
{
    float t;
    float s1,s2,s3;
    float in[3];
    float out[3];
    float A,B,C;

    t = (float)(T_LSB - 32768);
    s1 = s->LUT_lower + (float)(s->sensor_constants[0] * t * t) * s->quadr_factor;
    s2 = s->offst_factor * s->sensor_constants[3] + (float)(s->sensor_constants[1] * t * t) * s->quadr_factor;
    s3 = s->LUT_upper + (float)(s->sensor_constants[2] * t * t) * s->quadr_factor;
    in[0] = s1;
    in[1] = s2;
    in[2] = s3;

    calculate_conversion_constants(s, s->p_Pa_calib, in, out);
    A = out[0];
    B = out[1];
    C = out[2];

    *pressure = A + B / (C + p_LSB);
    *temperature = -45.f + 175.f/65536.f * T_LSB;

    return 0;
}

// p_Pa -- List of 3 values corresponding to applied pressure in Pa
// p_LUT -- List of 3 values corresponding to the measured p_LUT values at the applied pressures.
void calculate_conversion_constants(struct inv_invpres * s, float *p_Pa,
                                   float *p_LUT, float *out)
{
    float A,B,C;

    C = (p_LUT[0] * p_LUT[1] * (p_Pa[0] - p_Pa[1]) +

```

```

        p_LUT[1] * p_LUT[2] * (p_Pa[1] - p_Pa[2]) +
        p_LUT[2] * p_LUT[0] * (p_Pa[2] - p_Pa[0])) /
        (p_LUT[2] * (p_Pa[0] - p_Pa[1]) +
        p_LUT[0] * (p_Pa[1] - p_Pa[2]) +
        p_LUT[1] * (p_Pa[2] - p_Pa[0]));
    A = (p_Pa[0] * p_LUT[0] - p_Pa[1] * p_LUT[1] - (p_Pa[1] - p_Pa[0]) * C) / (p_LUT[0] - p_LUT[1]);
    B = (p_Pa[0] - A) * (p_LUT[0] + C);

    out[0] = A;
    out[1] = B;
    out[2] = C;
}

```

5.12 SAMPLE CODE: CONVERSION FORMULA (EXAMPLE PYTHON SYNTAX)

```

class InvensensePressureConversion:

    """ Class for conversion of the pressure and temperature output of the Invensense sensor"""

    def __init__(self, sensor_constants):

        """ Initialize customer formula

        Arguments:
        sensor_constants -- list of 4 integers: [c1, c2, c3, c4]
        """

        self.sensor_constants = sensor_constants

        # configuration for ICP-101xx Samples
        self.p_Pa_calib = [45000.0, 80000.0, 105000.0]
        self.LUT_lower = 3.5 * (2**20)
        self.LUT_upper = 11.5 * (2**20)
        self.quadr_factor = 1 / 16777216.0
        self.offst_factor = 2048.0

    def calculate_conversion_constants(self, p_Pa, p_LUT):

        """ calculate temperature dependent constants

        Arguments:
        p_Pa -- List of 3 values corresponding to applied pressure in Pa
        p_LUT -- List of 3 values corresponding to the measured p_LUT values at the applied pressures.
        """

        C = (p_LUT[0] * p_LUT[1] * (p_Pa[0] - p_Pa[1]) +
            p_LUT[1] * p_LUT[2] * (p_Pa[1] - p_Pa[2]) +
            p_LUT[2] * p_LUT[0] * (p_Pa[2] - p_Pa[0])) / \
            (p_LUT[2] * (p_Pa[0] - p_Pa[1]) +
            p_LUT[0] * (p_Pa[1] - p_Pa[2]) +
            p_LUT[1] * (p_Pa[2] - p_Pa[0]))
        A = (p_Pa[0] * p_LUT[0] - p_Pa[1] * p_LUT[1] - (p_Pa[1] - p_Pa[0]) * C) / (p_LUT[0] - p_LUT[1])
        B = (p_Pa[0] - A) * (p_LUT[0] + C)

        return [A, B, C]

```

```
def get_pressure(self, p_LSB, T_LSB):
    """ Convert an output from a calibrated sensor to a pressure in Pa.

    Arguments:
    p_LSB -- Raw pressure data from sensor
    T_LSB -- Raw temperature data from sensor
    """
    t = T_LSB - 32768.0
    s1 = self.LUT_lower + float(self.sensor_constants[0] * t * t) * self.quadr_factor
    s2 = self.offst_factor * self.sensor_constants[3] + float(self.sensor_constants[1] * t * t) * self.quadr_factor
    s3 = self.LUT_upper + float(self.sensor_constants[2] * t * t) * self.quadr_factor
    A, B, C = self.calculate_conversion_constants(self.p_Pa_calib, [s1, s2, s3])
    return A + B / (C + p_LSB)
```

[end of the pseudocode]

5.13 SAMPLE CODE: USING CONVERSION FORMULA (EXAMPLE PYTHON SYNTAX)

```
def read_otp_from_i2c():
    # TODO: implement read from I2C
    # refer to data sheet for I2C commands to read OTP
    return 1000, 2000, 3000, 4000

def read_raw_pressure_temp_from_i2c():
    # TODO: implement read from I2C
    # refer to data sheet for I2C commands to read pressure and temperature
    return 8000000, 32000

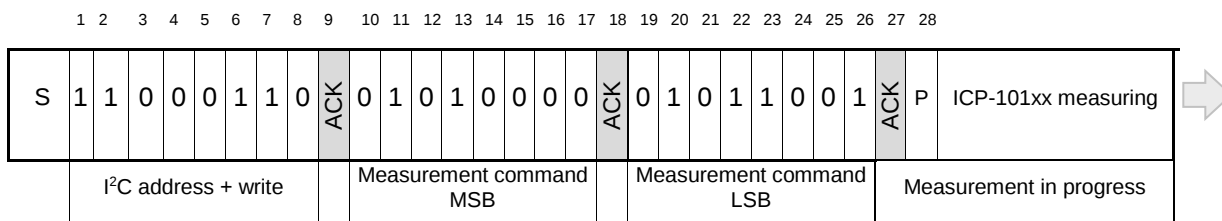
# Sample code to read
from Invensense_pressure_conversion import Invensense_pressure_conversion

# -- initialization
c1, c2, c3, c4 = read_otp_from_i2c()
conversion = Invensense_pressure_conversion([c1, c2, c3, c4])

# -- read raw pressure and temp data, calculate pressure
p, T = read_raw_pressure_temp_from_i2c()
pressure = conversion.get_pressure(p, T)
print 'Pressure: %f' % pressure
```

[end of the pseudocode]

5.14 COMMUNICATION DATA SEQUENCES



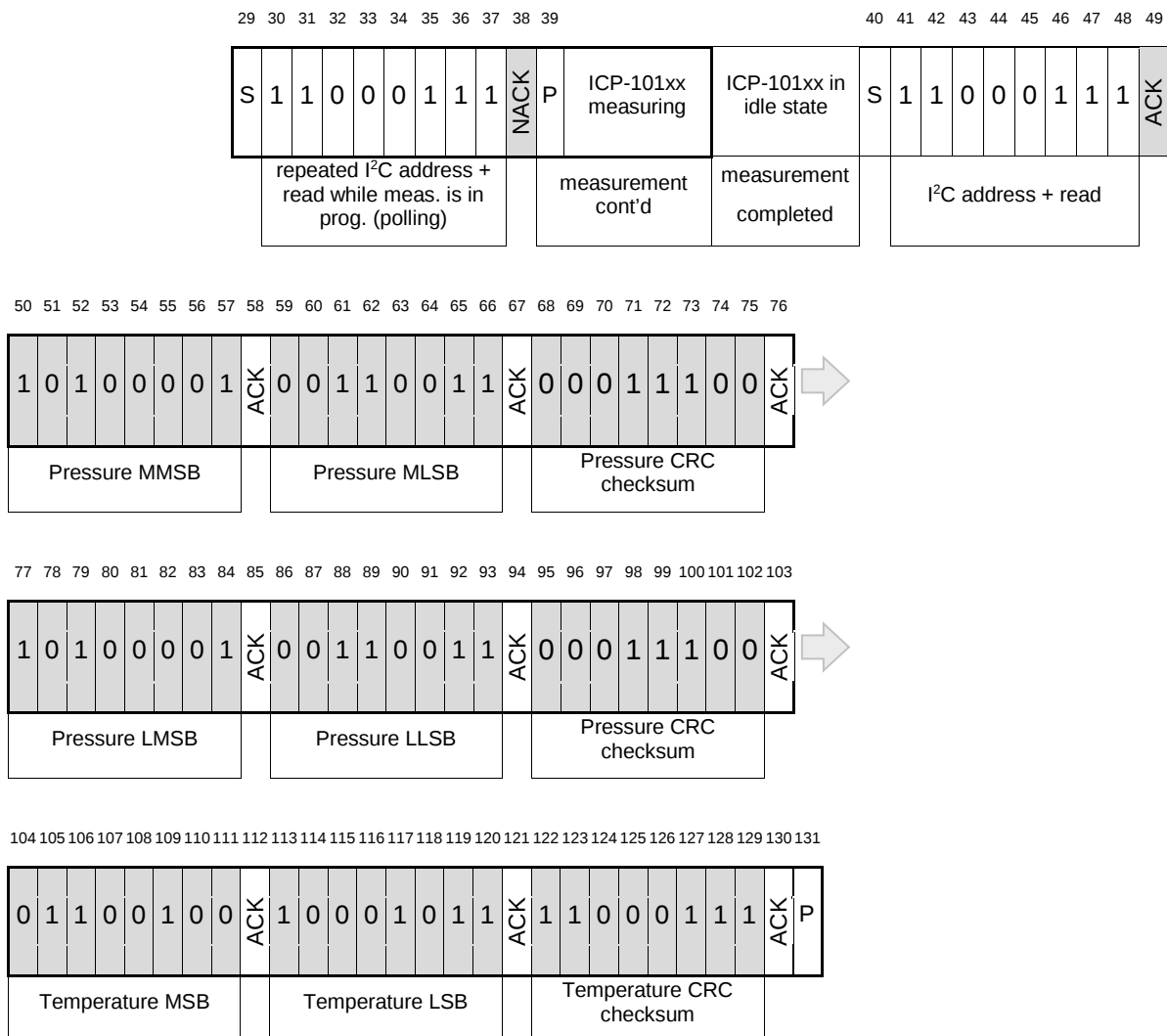


Figure 8. Communication Data Sequences

6 ASSEMBLY

This section provides general guidelines for assembling TDK-InvenSense Micro Electro-Mechanical Systems (MEMS) pressure sensors.

6.1 IMPLEMENTATION AND USAGE RECOMMENDATIONS

Soldering

When soldering, use the standard soldering profile IPC/JEDEC J-STD-020 with peak temperatures of 260°C. ICP-101xx may exhibit a pressure offset after soldering, some settling time may be required depending on soldering properties, PCB properties, and ambient conditions.

The ICP-101xx is an open cavity package, it is mandatory to use no-clean solder paste and no board wash should be applied. The ICP-101xx should be limited to a single reflow and no rework is recommended.

Chemical Exposure and Sensor Protection

The ICP-101xx is an open cavity package, the ICP-101x0 is waterproof to 1.5m for 30 minutes (IPx8), however the ICP-101x1 should not be exposed to particulates or liquids. If any type of protective coating must be applied to the circuit board, the sensor must be protected during the coating process.

SYMBOLS	DIMENSIONS IN MILLIMETERS		
	MIN.	NOM.	MAX.
A	0.64	0.72	0.800
A3	---	0.595 REF.	---
b	---	0.25	---
c	---	0.125 REF.	---
D	1.90	2.00	2.10
D1	---	1.85	---
E	1.90	2.00	2.10
E1	---	1.85	---
e	---	0.50	---
L	0.275	0.375	0.400
L1	0.025	0.075	0.100
L3	0.250	0.300	0.325

Table 18. ICP-10100 & ICP-10101 Package Dimensions

Recommended PCB land pattern for the ICP-10100 & ICP-10101:

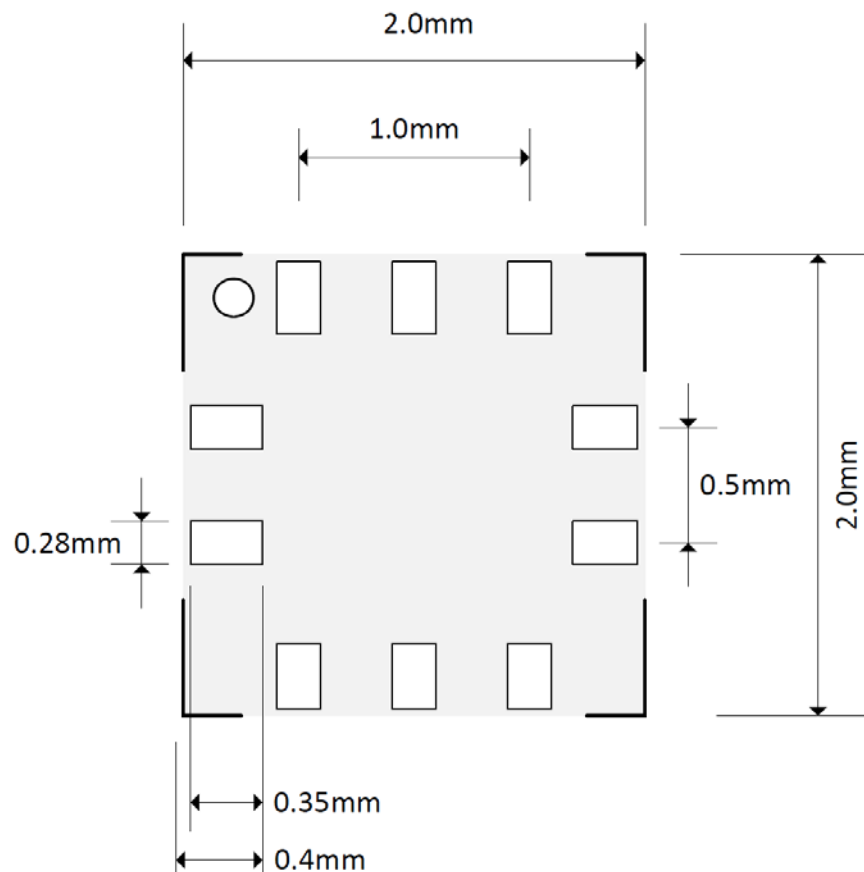


Figure 10. ICP-10100 & ICP-10101 recommended PCB land pattern

Technical drawing of a square plate with a central hole and chamfered corners. The drawing includes the following dimensions and features:

- Overall Dimensions:** The plate is square with side length E . The inner square, defined by the hole and chamfers, has a side length $E1$.
- Central Hole:** A circular hole with diameter $\phi 0.28$ is centered on the plate. It is shown with a center crosshair and a dashed circle representing the hole's boundary.
- Chamfers:** The corners of the inner square are chamfered. The chamfer angle is 30° . The chamfer width is dimensioned as $3 - \phi 0.025$, indicating a transition from the outer edge to the hole.
- Offset Dimensions:** The distance from the center of the hole to the corner of the inner square is 0.825 . This dimension is shown for both the horizontal and vertical offsets.
- Inner Square Dimensions:** The side length of the inner square is $D1$. The overall side length of the plate is D .

Technical drawing of a square plate with the following dimensions and features:

- Overall width: D
- Overall height: E
- Inner width: $D1$
- Inner height: $E1$
- Distance from top edge to hole center: 0.825
- Distance from right edge to hole center: 0.825
- Hole diameter: $\varnothing 0.3$

Technical drawing of a rectangular plate. The left view shows a semi-circular end with a radius of $A/2$ and a total width of A . The right view shows a rectangular plate with a width of 0.75 and a height of 0.3 . The plate is divided into a grid of 8 numbered squares (1-8) arranged in two columns of four. A diagonal line labeled $RW 1$ and $\phi 0.2$ indicates a hole or feature. Dimensions $L1$, $L3$, and L are shown at the bottom.

Figure 11. ICP-10110 & ICP-10111 Package Diagrams

SYMBOLS	DIMENSIONS IN MILLIMETERS		
	MIN.	NOM.	MAX.
A	0.84	0.92	1.00
A3	---	0.79 REF.	---
b	---	0.35	---
c	---	0.13 REF.	---
D	1.90	2.00	2.10
D1	---	1.85	---
E	2.40	2.50	2.60
E1	---	2.35	---
e	---	0.65	---
L	0.35	0.45	0.55
L1	0.05	0.10	0.15
L3	0.30	0.35	0.40
S	---	0.10	---

Table 19. ICP-10110 & ICP-10111 Package Dimensions

Recommended PCB land pattern for the ICP-10110 & ICP-10111:

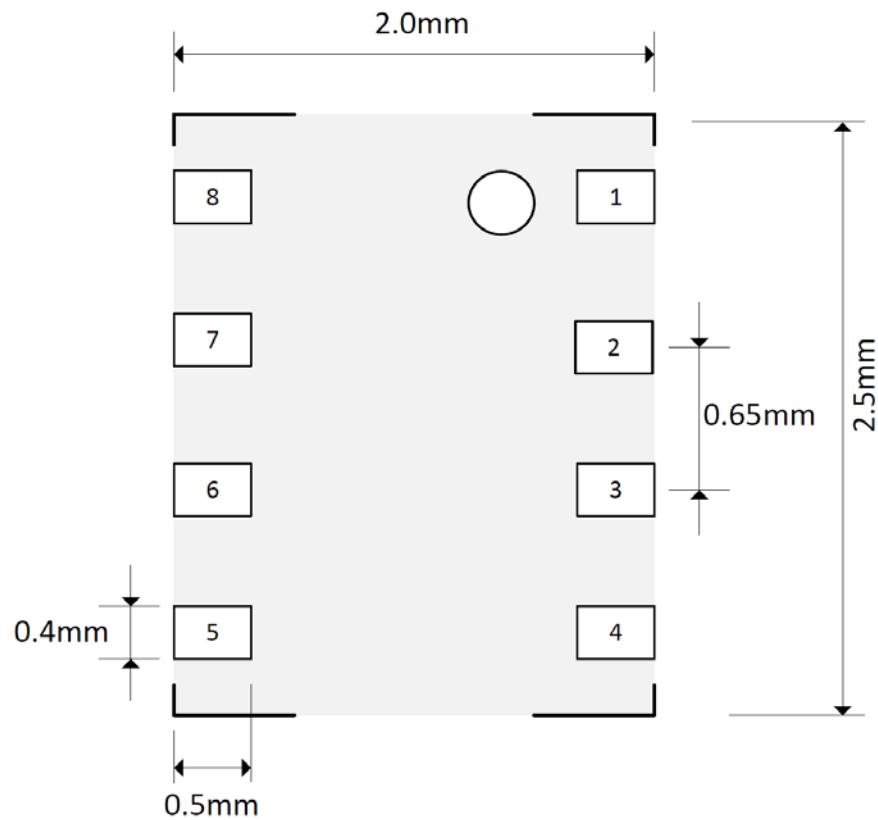


Figure 12. ICP-10110 & ICP-10111 recommended PCB land pattern

8 PART NUMBER PART MARKINGS

The part number part markings for ICP-101xx devices are summarized below:

PART NUMBER	PART MARKING
ICP-10100	P1
ICP-10101	P2
ICP-10110	P5
ICP-10111	P6

Table 20. Part Number Part Markings

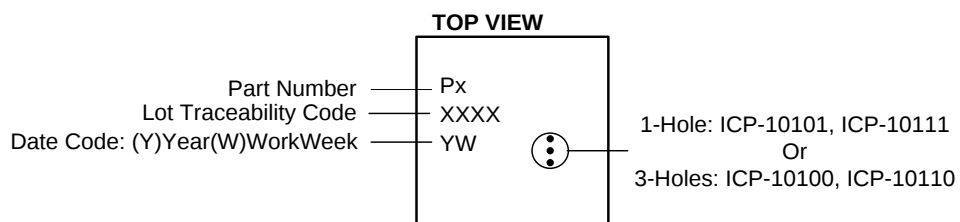


Figure 13. Part Number Part Markings

9 ORDERING GUIDE

PART	TEMP RANGE	PACKAGE BODY	PACKAGE LID	QUANTITY	PACKAGING
ICP-10100†	–40°C to +85°C	2x2x0.72mm LGA-10L	3-Hole: 1.5m Waterproof	10,000	13" Tape and Reel
ICP-10101†	–40°C to +85°C	2x2x0.72mm LGA-10L	1-Hole	10,000	13" Tape and Reel
ICP-10110†	–40°C to +85°C	2x2.5x0.92mm LGA-8L	3-Hole: 1.5m Waterproof	10,000	13" Tape and Reel
ICP-10111†	–40°C to +85°C	2x2.5x0.92mm LGA-8L	1-Hole	10,000	13" Tape and Reel

†Denotes RoHS and Green-Compliant Package

10 REFERENCES

Please refer to “InvenSense MEMS Handling Application Note (AN-IVS-0002A-00)” for the following information:

- Manufacturing Recommendations
 - o Assembly Guidelines and Recommendations
 - o PCB Design Guidelines and Recommendations
 - o MEMS Handling Instructions
 - o ESD Considerations
 - o Reflow Specification
 - o Storage Specifications
 - o Package Marking Specification
 - o Tape & Reel Specification
 - o Reel & Pizza Box Label
 - o Packaging
 - o Representative Shipping Carton Label
- Compliance
 - o Environmental Compliance
 - o DRC Compliance
 - o Compliance Declaration Disclaimer

11 REVISION HISTORY

Revision Date	Revision	Description
01/02/2017	1.0	Initial Release

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