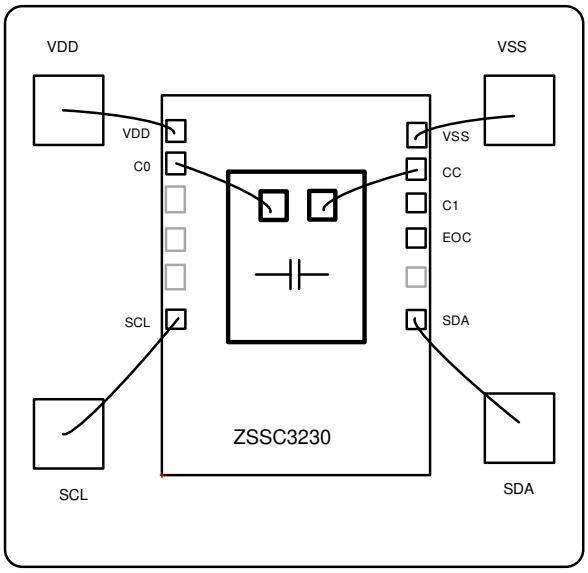
Description

The ZSSC3230 is a CMOS integrated circuit for accurate capacitance-to-digital conversion and sensor-specific correction of capacitive sensor signals. Digital compensation of sensor offset, sensitivity, and temperature drift is accomplished via an internal digital signal processor running a correction algorithm with calibration coefficients stored in a nonvolatile, multiple-time programmable (NVM) memory. Programming the ZSSC3230 is simple via the serial interface. The interface is used for the PC-controlled calibration procedure, which programs the set of calibration coefficients in memory. The ZSSC3230 is configurable for capacitive sensors with capacitances up to 30pF and will provide an output resolution that is scalable up to 18-bit. It is compatible with single-ended capacitive sensors. Measured and corrected sensor values can be output as I2C (≤ 3.4MHz).

The ZSSC3230 provides accelerated signal processing, increased resolution, and improved noise immunity in order to support high-speed control, safety, and real-time sensing applications with the highest requirements for energy efficiency.

Basic Application Diagram



Typical Applications

- Humidity sensors
- Pressure sensors, level sensors
- Smart, digital, capacitive sensors for energy-efficient solutions
- Consumer / white goods (e.g., HVAC)
- Medical applications

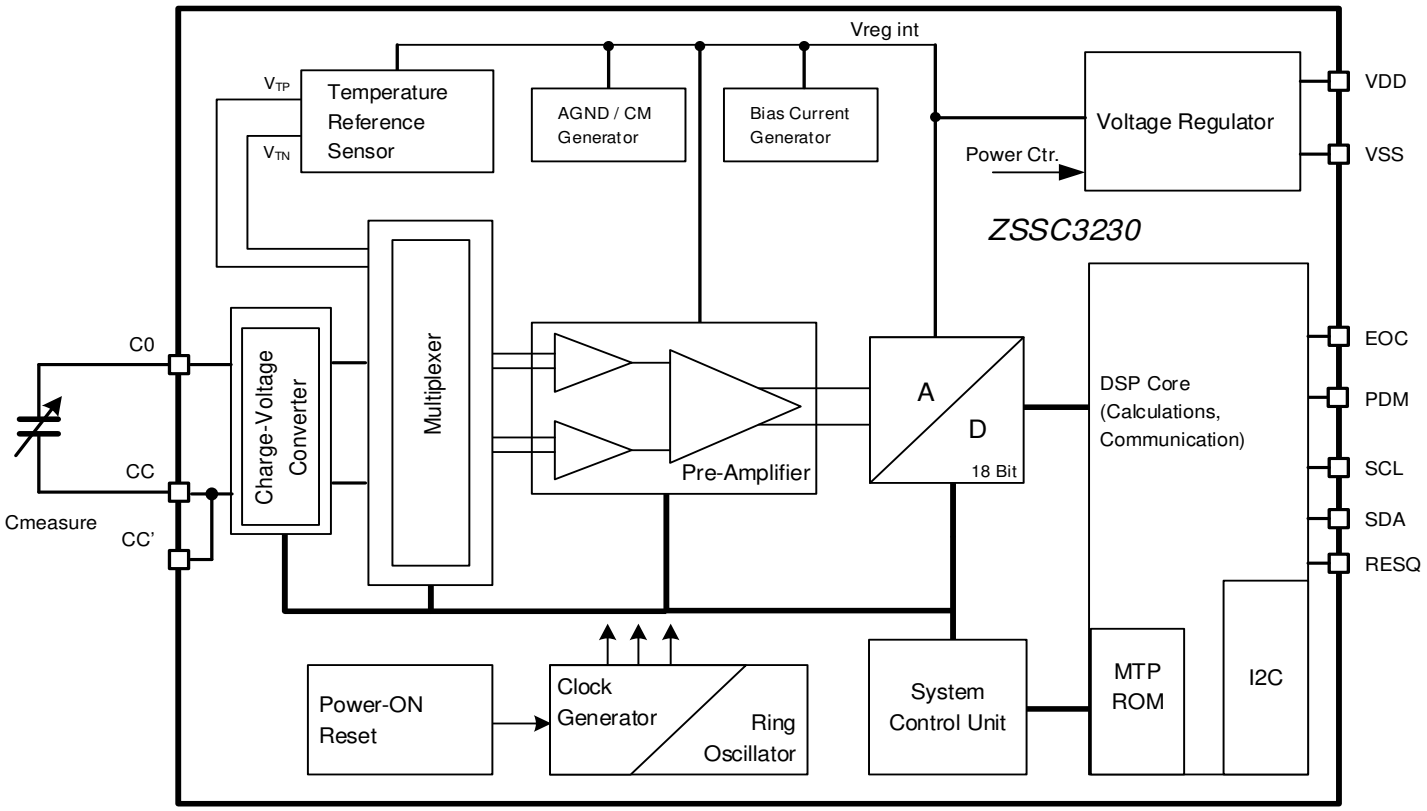
Features

- Low current consumption: 1.3µA at 1 sample per second
- Maximum target input capacitance: 30pF
- Programmable capacitance span and offset
- High sampling rate with 2ms at 14-bit resolution
- ADC resolution: Adjustable in speed and resolution, 18-bit maximum
- Internal auto-compensated temperature sensor; not stress sensitive
- Programmable measurement sequence, single-shot and automatic cycling of measurements with end-of-sequence interrupt output
- Oversampling modes using internal averaging
- Interrupt features
- Integrated NVM for configuration and free space for customer use
- Small die size
- External reset pin (low active)
- No external trimming components required
- Highly integrated CMOS design

Physical Characteristics

- Supply voltage V_{DD}: 1.68V to 3.6V
- Operating temperature: -40°C to 125°C depending on the part code
- I2C Interface compatible, supporting
  - Standard Mode(100kHz)
  - Fast Mode (400kHz)
  - High-Speed Mode (3.4MHz)
- Capacitive input range 0 to 30pF
- Capacitive offset compensation 0 to 15pF
- Available in 4 × 4 mm² 24-PQFN package or as die

Block Diagram



Typical Application Examples

Figure 1. Isolated C Mode

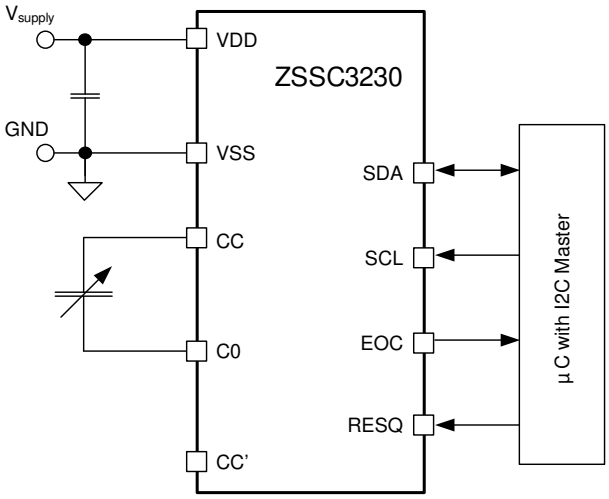
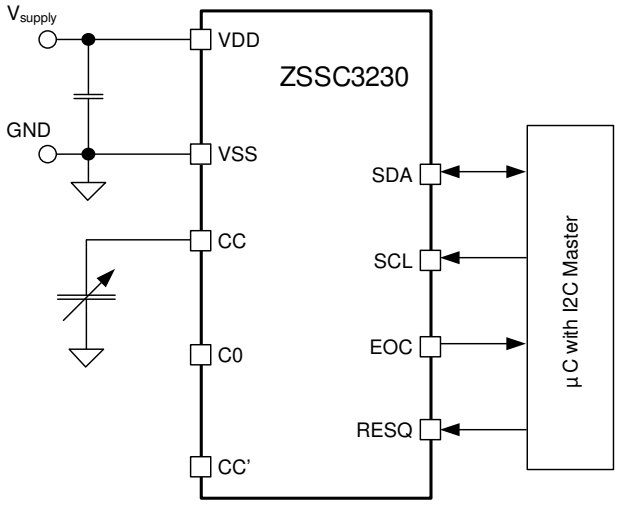


Figure 2. Grounded C Mode



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1. Pin Assignments

The ZSSC3230 is available as 8-inch wafer* and QFN24 package. Details about the package are provided in section 7.

Figure 3. Pin Assignments for 4 × 4 mm 24-PQFN Package – Top View

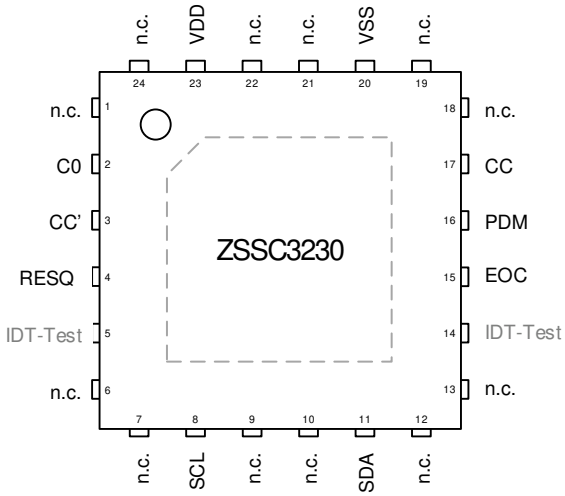
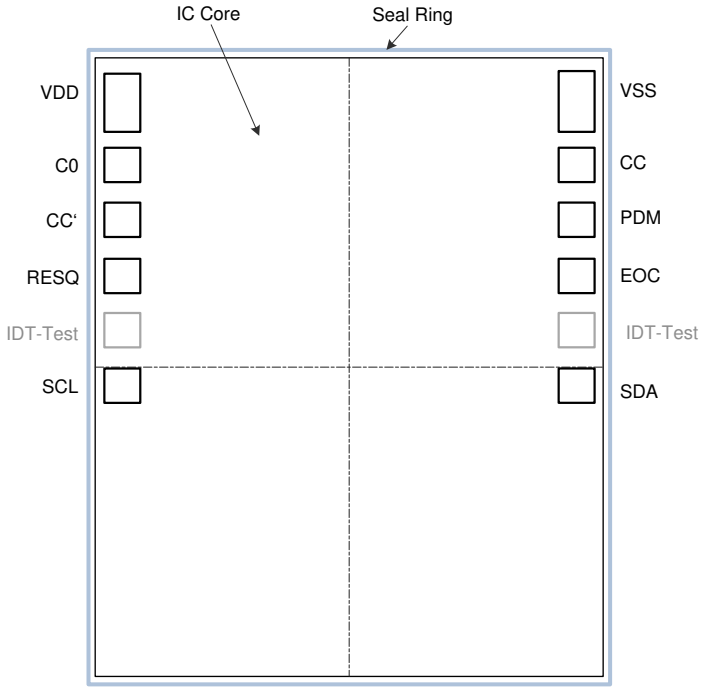


Figure 4. Pin (Pad) Assignments for Bare-Die



* Detailed information about wafer-shipments, etc., is available on request. See last page for contact information.

2. Pin Descriptions

Table 1. Pin Descriptions

Pin Number	Name	Type	Description
1	n.c.	–	No connection. Leave pin floating.
2	C0	Analog Input	Capacitor input signal.
3	CC’	Analog Input	Capacitor input signal, duplicate of CC (pin 17).
4	RESQ	Digital Input	RESET, low active; internal pull-up.
5	IDT-Test	–	Connect to VSS; otherwise no connection; leave pin floating.
6	n.c.	–	No connection. Leave pin floating.
7	n.c.	–	No connection. Leave pin floating.
8	SCL	Digital Input	Clock input for I2C interface.
9	n.c.	–	No connection. Leave pin floating.
10	n.c.	–	No connection. Leave pin floating.
11	SDA	Digital Input/Output	Bi-directional data I/O for I2C. Pull-up to VDD.
12	n.c.	–	No connection. Leave pin floating.
13	n.c.	–	No connection. Leave pin floating.
14	IDT-Test	–	Connect to VSS; otherwise no connection; leave pin floating.
15	EOC	Digital Output	End-of-conversion and output interrupt signal.
16	PDM	Digital Output	Digital output for pulse-density modulated output.
17	CC	Analog Input	Capacitor input signal, duplicate to CC’ (pin 3).
18	n.c.	–	No connection. Leave pin floating.
19	n.c.	–	No connection. Leave pin floating.
20	VSS	Ground	Power supply ground.
21	n.c.	–	No connection. Leave pin floating.
22	n.c.	–	No connection. Leave pin floating.
23	VDD	Supply	Power supply.
24	n.c.	–	No connection. Leave pin floating.

3. Absolute Maximum Ratings

The absolute maximum ratings are stress ratings only. Stresses greater than those listed below can cause permanent damage to the device. Functional operation of the ZSSC3230 at absolute maximum ratings is not implied. Exposure to absolute maximum rating conditions may affect device reliability.

Table 2. Absolute Maximum Ratings

Symbol	Parameter	Conditions	Minimum	Maximum	Units
T_J	Junction temperature		–	135	°C
T_S	Storage temperature		-45	150	°C
	ESD – Human Body Model		–	2000	V
	ESD – Charged Device Model		–	750	V
	Latch-up		-100	+100	mA
VDD_{max}	Voltage supply range	Referenced to VSS	-0.3	3.63	V
V_{IF_max}	Voltage at digital interface pins	I2C pins: SDA, SCL	-0.3	VDD +0.5V or 3.63V max.	V

4. Recommended Operating Conditions

Table 3. Recommended Operating Conditions

Symbol	Parameter	Minimum	Typical	Maximum	Units
V_{DD}	Power supply voltage	1.68	–	3.6	V
T_A	Ambient temperature	-40	–	125	°C
C_{VDD}	External (parasitic) capacitance between VDD and VSS	0	10	–	nF
SR_{VDD_POR}	Recommended V_{DD} rise slew rate for power-on-reset (POR)[a]	10	–	–	V/ms

[a] Per design, there is no (theoretical) minimum V_{DD} slew-rate to trigger a clean POR; however, a reasonable slew rate is recommended.

5. Electrical Characteristics

All parameter values are valid only under specified operating conditions. All voltages are referenced to V_{SS}.

Table 4. Electrical Characteristics

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
IC Supply						
I_{IC}	Current consumption, active ZSSC3230	Excluding connected sensor elements; *noise_mode* = 0; see Table 16	–	750	1100	µA
I_{IDLE}	Idle current consumption, ZSSC3230 in Sleep State		–	0.07	1	µA
I_{AVE}	Average current draw	Mean current consumption for one complete SSC-measurement cycle per second at 14-bit digital-only output, *noise_mode* = 0	–	1.7	3.3	µA
PSRR	Static power supply rejection ratio (PSRR)	VDD = 3V	–	40	–	dB
CDC Characteristics						
C_{RANGE}	Sensor capacitance range		0	–	30	pF
C_{OFFSET}	Absolute sensor capacitance offset		0	–	15	pF
C_{SIGNAL}	Effective sensor capacitance		-15	–	15	pF
f_{clk}	Analog base clock frequency		–	750	–	kHz
ENOB	Effective number of bits, $\pm 3\sigma_{Noise}$	r_{ADC} = 18-bit, no oversampling	–	14.4	–	Bit
Analog-to-Digital Converter (ADC, A2D)						
r_{ADC}	Resolution		12	–	18	Bit
$f_{S,RAW}$	Conversion rate; conversions per second	Single external sensor A2D conversion (including auto-zero measurement AZ); resolution and mode dependent	94	–	1250	Hz
$f_{S,CORR}$	SSC-conversion rate for full SSC cycle; conversions per second	Full SSC-measurements per second: temperature (14-bit) + capacitance (12 to18 bit)	86	–	555	Hz
$f_{S,TEMP}$	SSC-conversion rate for temperature measurement	14-bit resolution	–	960	–	Hz
ADCnoise	ADC-noise sigma	r_{ADC} = 16-bit	–	1	–	LSB
ENOB	Effective number of bits, $\pm 3\sigma_{Noise}$	r_{ADC} = 18-bit, no oversampling	–	16	–	Bit

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
Power-Up Conditions						
t_{stup1}	Start-up time communication	Delay between VDD ramp up and start of first command (proven by design)	–	–	1	ms
t_{stup2}	Start-up time analog operation	Delay between VDD ramp up and analog operation (proven by design)	–	–	2.5	ms
t_{wup1}	Wake-up time communication	Delay between sleep state and start of first command (proven by design)	–	–	0.5	ms
t_{wup2}	Wake-up time analog operation	Delay between sleep state and analog operation (proven by design)	–	–	2	ms
Sensor Signal Conditioning Performance						
f_{SSCout}	Output (update) rate	SSC-corrected digital output rate; capacitance sensor measurement: 16-bit; temperature measurement: 14-bit; *noise_mode* = 0; see Table 16	–	290	–	Hz
$Err_{A,IC}$	ZSSC3230 accuracy error using internal SSC calculation math	Accuracy error for sensor being ideally linear (for temperature and measurand)	–	0.1	–	%FSO
Oscillator						
f_{CLK}	Internal oscillator frequency		–	3.0	–	MHz
Temperature Sensor(s)						
r_{Temp}	Internal temperature sensor resolution		–	55	–	LSB/K
Interface and Memory						
$f_{C,I2C}$	I2C clock frequency		–	–	3.4	MHz
t_{PROG}	NVM program time	Programming time per 16-bit word	–	20	–	ms
n_{NVM}	NVM endurance	Number of reprogramming cycles	1000	10000	–	Numeric
$t_{RET,NVM}$	Data retention		10	–	–	Years

6. Device Description

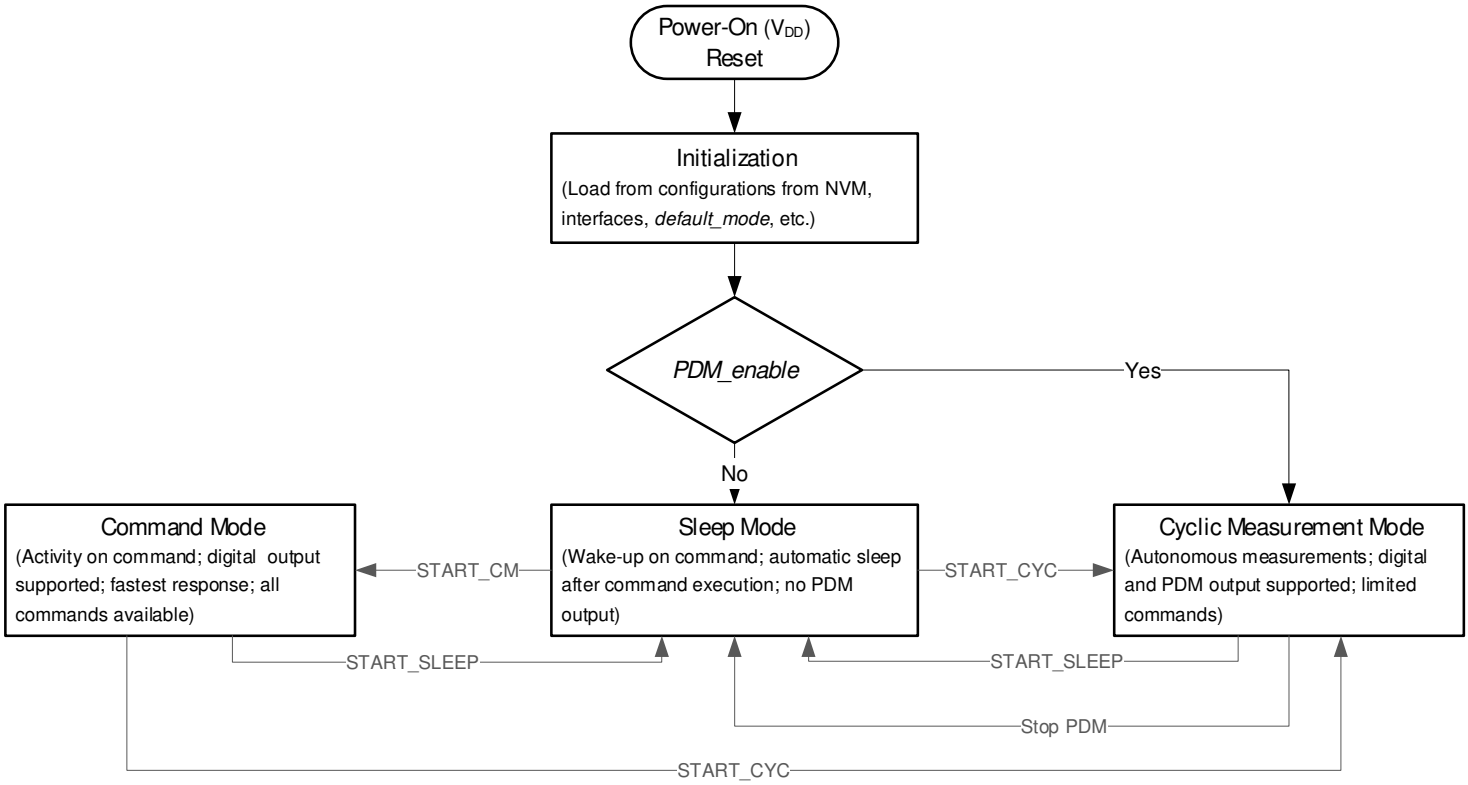
The ZSSC3230 can be set up for one of three main operating modes:

- Sleep Mode – Sleep Mode based operation is recommended for smart sensors for the lowest average power consumption. The ZSSC3230 automatically enters an idle state after command execution for minimum current consumption; however, the interface is still listening and accepts commands. After receiving of a valid command, the ZSSC3230 wakes up, executes the command, and provides the results at the digital interface and then returns to Sleep State.
- Command Mode – Command Mode is most appropriate for evaluation, test, and calibration purposes. In this mode, all commands are available, both digital and analog outputs are supported, and no restrictions for any functionality need to be considered. Command Mode can be used for applications requiring re-occurring (or even continuous) digital interaction and minimum latency. Applications in Command Mode are only active on command request. See Table 15 for definitions of the commands.
- Cyclic Measurement Mode – Cyclic operation means autonomous, cyclically repeated sensor measurements and related digital and output updates.

After power-on, the voltage regulators are switched on, and the ZSSC3230's low-voltage section (LV) is active while the related interface configuration information is read from memory. Then the LV section is switched off, the ZSSC3230 goes into Sleep Mode, and the interface is ready to receive commands. The interface is always powered by V_{DD}, so it is referred to as the high voltage section (HV).

Figure 5 shows the ZSSC3230 main operation modes: Normal Mode (which uses two operation principles: "Sleep" and "Cyclic") and Command Mode. The Normal Mode automatically returns to Sleep Mode after executing the requested measurements, or periodically wakes up and conducts another measurement according to the setting for the sleep duration configured by the *CYC_period* (bits[14:12] in memory register 02_{HEX}; see Table 16). In Command Mode, the ZSSC3230 remains active if a dedicated command (e.g., Start_NOM) is sent, which is helpful during calibration. Command Mode can only be entered if a Start_CM (command $A9_{HEX}$; see Table 15) is the first command received after a POR.

Figure 5. Main Operating Modes of the ZSSC3230



6.1 Signal Flow

See Figure 1 and Figure 2 for the ZSSC3230 block diagram sensors input options. The CC pin is duplicated as CC' depending on the preferred physical sensor connection. Selecting CC or CC' can be done using the signal setup *CC_pin_selection* bits[1:0] in memory register 19_{HEX} (see Table 16).

Two sensor connections are possible:

- Differential Measurement Mode, which is an isolated C mode with C_{MEAS} connected between CC and C0 or CC' and C0 so that both ends of the capacitor are connected to the ZSSC3230.
- Single-Ended Measurement Mode, which is a grounded C mode with C_{MEAS} connected between CC and VSS or CC' and VSS/ground. In this mode, C0 is switched to VSS. In this mode, only one capacitor input pin needs to be directly connected to the ZSSC3230.

The capacitance amplifier (CapAmp), which is also referred to as the charge-voltage converter (CVC), measures an external capacitance value, C_{MEAS} and provides a differential output voltage proportional to the capacitance (change) to the subsequent ADC. Thereby C_{MEAS} is connected with both ends to the IC or with one pin to VSS.

The bias current for the stage (CapAmp) can be programmed (using the setup signal *noise_mode* bit 8 in the *Sensor_config* memory register 12_{HEX}; see Table 16) to allow a trade-off between current consumption and achievable signal to noise ratio (SNR).

The system control unit controls the analog circuitry to perform the measurement types for the external capacitive sensor and internal temperature. The multiplexer selects the signal input to the amplifier, which can be the voltage-converted signals of the external capacitive sensor or the internal temperature reference sensor signal. A full measurement request will trigger an automatic sequence of all measurement types and all input signals.

The gain amplifier (PGA) adjusts the respective signal from the capacitance-to-voltage converter or internal temperature sensor. The ZSSC3230 employs a programmable analog-to-digital converter (ADC) optimized for conversion speed and noise suppression. The programmable resolution from 12 to 18 bits provides flexibility for adapting the conversion characteristics.

The math core accomplishes the auto-zero, span, and 1st and 2nd order temperature compensation of the measured external sensor signal. The correction coefficients are stored in the nonvolatile memory. The ZSSC3230 supports I2C interface communication for controlling the ZSSC3230, configuration, and measurement result output. An adequate PDM signal for the compensated sensor signal can be provided in Cyclic Measurement Mode at the PDM pin.

Table 5 lists the conversion time of a full corrected and compensated measurement. The temperature measurement always has a 14-bit resolution. The conversion time for the sensor channels includes a full ADC conversion plus auto-zero measurement and the corresponding CVC conversion time for this channel and the respective temperature measurement and math calculation. The 2 noise modes (bit[8] in memory register 12_{HEX}) are listed separately.

Table 5. Conversion Time for Full Temperature Compensated Measurement

adc_bits[7:6]		ADC Resolution [Bits]	Conversion Time for Full Temperature Compensated Measurement, Typical [µs]	
bit[7]	bit[6]		*noise_mode* = 0	*noise_mode* = 1
0	0	12	1770	2550
0	1	14	2310	3850
1	0	16	3390	6440
1	1	18	5520	11630

6.2 Capacitive Sensor Front-End

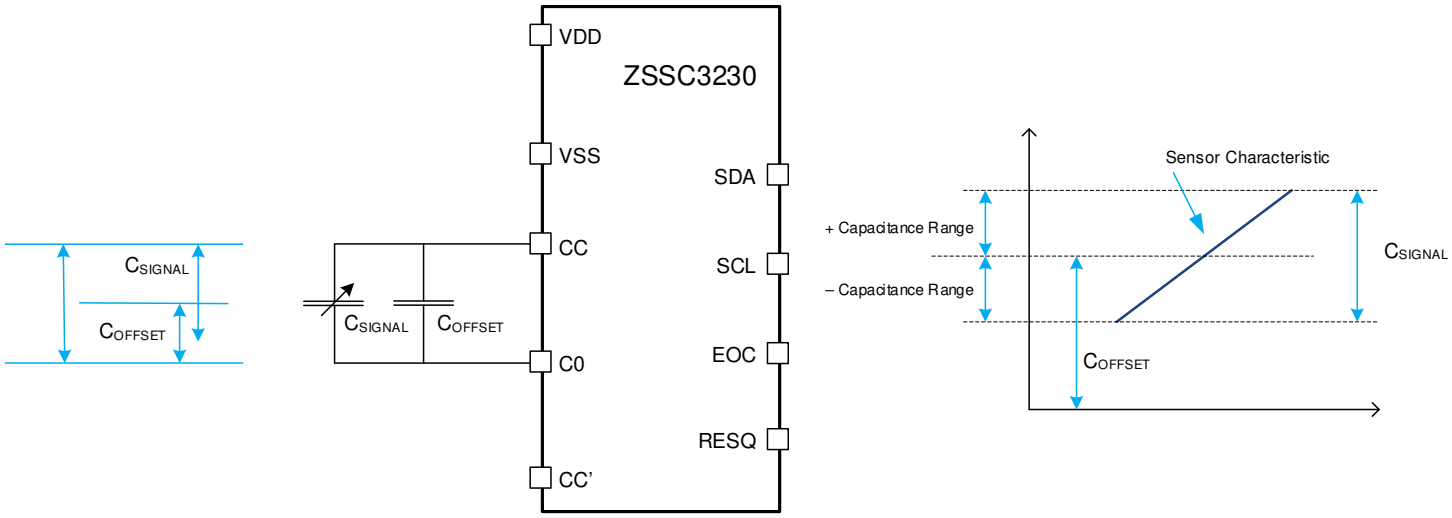
The capacitance amplifier input range (C_{RANGE}) must be adjusted to the external capacitance conditions for signal (C_{SIGNAL}) and offset shift (C_{OFFSET}) as given in Equation 1. See Figure 6 for an illustration of the terms.

$$C_{RANGE} = C_{OFFSET} + C_{SIGNAL} \qquad \text{Equation 1}$$

C_{OFFSET} operates as a zero-shift capacitance to cancel a given offset by the sensor. The offset-shift capacitance must not exceed the selected input capacitance range C_{RANGE}. For C_{OFFSET}, the respective configuration must be set up in the EEPROM for the *shift_cap* parameter (bits[5:0] in memory register 12_{HEX}; see Table 16).

The correlating setup for C_{SIGNAL} must be done in the EEPROM for parameter *cap_range* (bits[13:9] in memory register 12_{HEX}). In Table 16, the respective values are given. These values can be measured in the positive and negative direction, so the effective range of C_{SIGNAL} will be doubled compared to the *cap_range* setting. The principle is shown in Figure 6.

Figure 6. Capacitive Input Signal Conditions

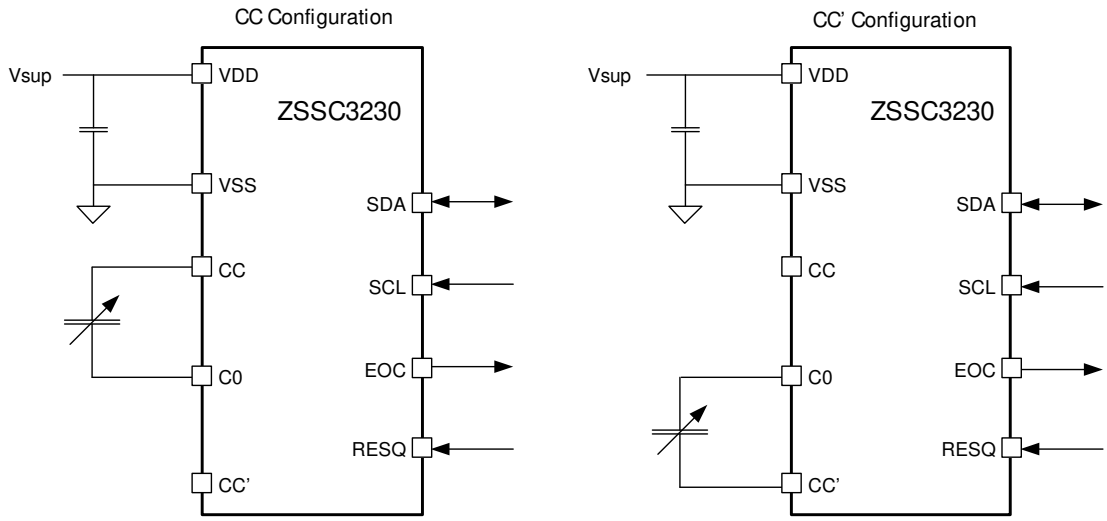


6.2.1 Differential Mode

The most relevant measurement mode is the Differential Measurement Mode, with C_{MEAS} connected between CC and C0 or CC' and C0 so that both ends of the capacitor are connected to the ZSSC3230. For electrical connections, see Figure 7.

For the ZSSC3230 for the Differential Measurement Mode, the configuration must be done in the EEPROM for parameter *sensecap_type* (bit[15] in memory register 12_{HEX}; see Table 16). When the *sensecap_type* is 0, the differential mode is selected, which is the default configuration.

Figure 7. Capacitive Input in Differential Mode



6.2.2 Single-Ended Mode

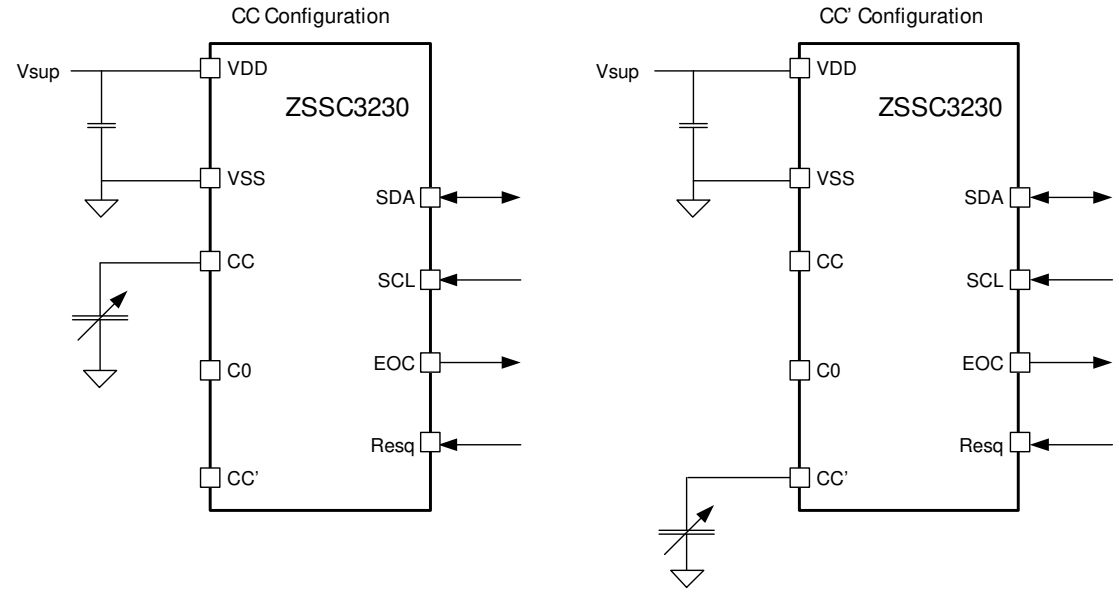
Another measurement mode is the single ended measurement mode, with C_{MEAS} connected between CC and VSS or CC' and VSS/ground. In this mode C0 is switched to VSS. In this mode only 1 Pin needs to be directly connected to the IC.

Configuring the ZSSC3230 for Single-Ended Input Mode must be done in the EEPROM via the parameter *sensecap_type* (bit[15] in memory register 12_{HEX}; see Table 16). Since the respective bit is defined as "0" in the default configuration for Differential Mode, the bit must be programmed to "1."

6.2.3 Sensor Leakage Compensation

Sensor leakage compensation is an additional option for Single-Ended Mode to enable the sensor element's leakage current compensation. The leakage current is caused by the sensor element's parasitic resistance. Enabling this function via the *sensor_leakage* bit[14] in memory register 12_{HEX} leads to loss of dynamic range and a decrease in the SNR. With losing 1-bit effective resolution on leakage compensation, the respective capacitive input range for C_{SIGNAL} will be doubled compared to the description in section 6.2.

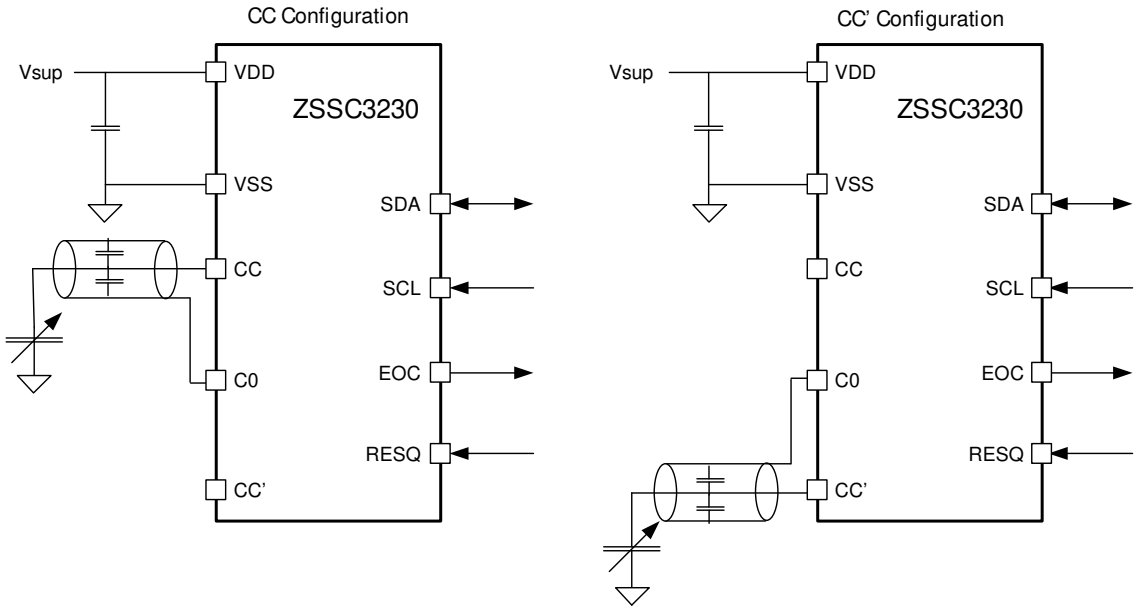
Figure 8. Capacitive Input in Single-Ended Mode



6.2.4 Shield Driver Mode

The Shield Driver Mode is a special sub-mode for Single-Ended Mode. In this mode, the C0 pin will be forced to the same level as the CC/CC' pin. This pin can be used to drive a shield, so the shield parasitic capacitance does not have an effect on the measurement. The Shield Driver Mode can be enabled by setting the EEPROM parameter *En_shlddrv* (bit[4] in memory register 19_{HEX}) to "1" (see Table 16).

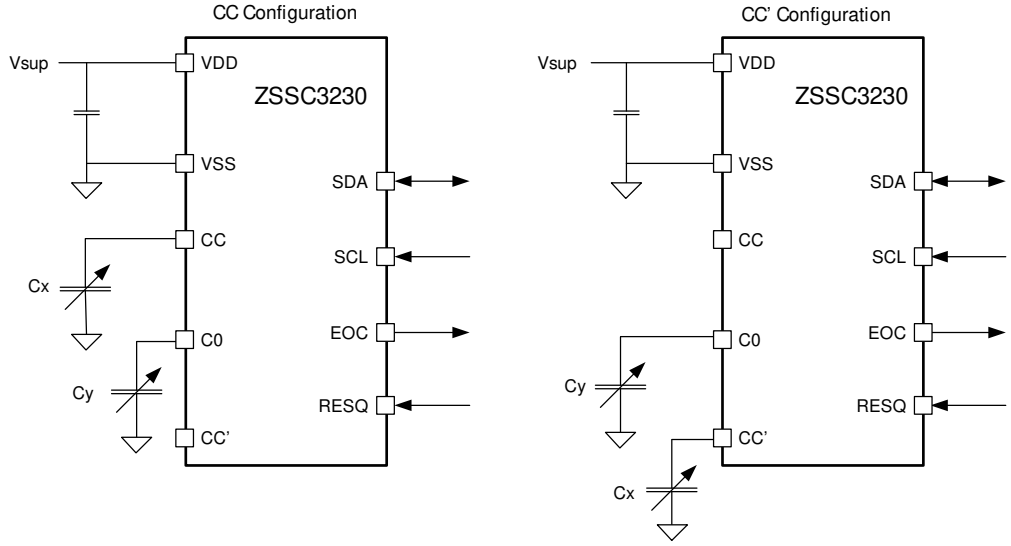
Figure 9. Shield Driver Mode



6.2.5 Subtraction Mode

The Subtraction Mode is a special sub-mode for Single-Ended Mode. It is activated by setting the *En_sh2* bit to "1" (bit[3] in memory register 19_{HEX}; see Table 16). In this mode, C0 is charged to the opposite reference of the CC/CC' node level. In conversion phase the charge of CC/CC' and C0 are integrated. In this mode, the integrated capacitance corresponds to "Cx-Cy"; thus this mode can provide an additional range extension.

Figure 10. Subtraction Mode



6.3 Temperature Sensor

The ZSSC3230 provides a PTAT-based internal temperature sensor measurement to allow compensation for temperature effects. The temperature output signal is a differential voltage that is adapted by the amplifier (PGA) for the ADC input. For IC-internal temperature measurements, the respective settings are defined and programmed in the NVM by IDT. The resolution setting for temperature measurements is defined as 14-bit.

6.4 Analog to Digital Converter (ADC)

An analog-to-digital converter (ADC) is used to digitize the amplifier signal. To allow optimizing the trade-off between conversion time and resolution, the resolution can be programmed from 12-bit to 18-bit by configuring the parameter *adc_bits*, (bits [7:6] in memory register 12_{HEX}; see Table 16). The ADC processes differential input signals provided by the internal amplifier for sensor measurement and temperature measurement. The application default setting is 16-bit. The corresponding conversion times are listed in Table 6. The conversion time for the sensor channels includes a full ADC conversion as well as the corresponding CVC conversion time for this channel. There are 2 noise modes (selected with bit[8] in memory register 12_{HEX}). The listed conversion times are valid for raw measurements including auto-zero compensation.

Table 6. ADC Resolution and Conversion Times for a Single Analog-to-Digital Conversion with Auto-Zero

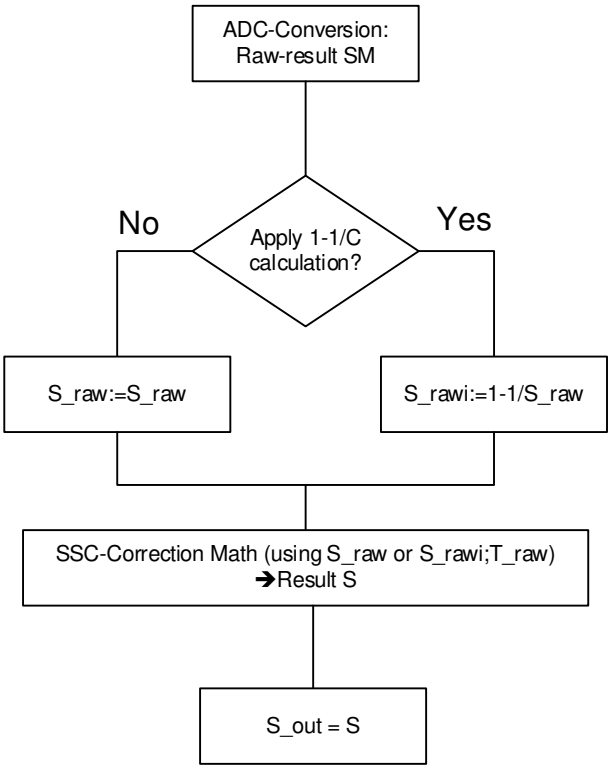
adc_bits[7:6]		ADC Resolution [Bits]	Conversion Time ADC (including CVC), typical [µs]		Conversion Time Temperature, Typical [µs]
bit[7]	bit[6]		*noise_mode* = 0	*noise_mode* = 1	
0	0	12	770	1550	630
0	1	14	1310	2850	1040
1	0	16	2390	5440	1810
1	1	18	4550	10620	3470

6.5 Calibration Math

The data path internally calculates with a 26-bit two's-complement integer representation. The coefficients in the memory are stored as integers in sign-magnitude representation (1-bit sign + 23-bit magnitude). Each multiplication scales the product by 2^{23}. There is an option to preprocess the data by applying a 1/C algorithm. 1/C is typically used to pre-process transfer characteristics for capacitive pressure sensors. A principle flow is shown in Figure 11.

Internal overflows and underflows are detected and the result is automatically saturated. The saturation is reported in the status byte.

Figure 11. Principal Compensation Flow



6.5.1 1/C Pre-compensation

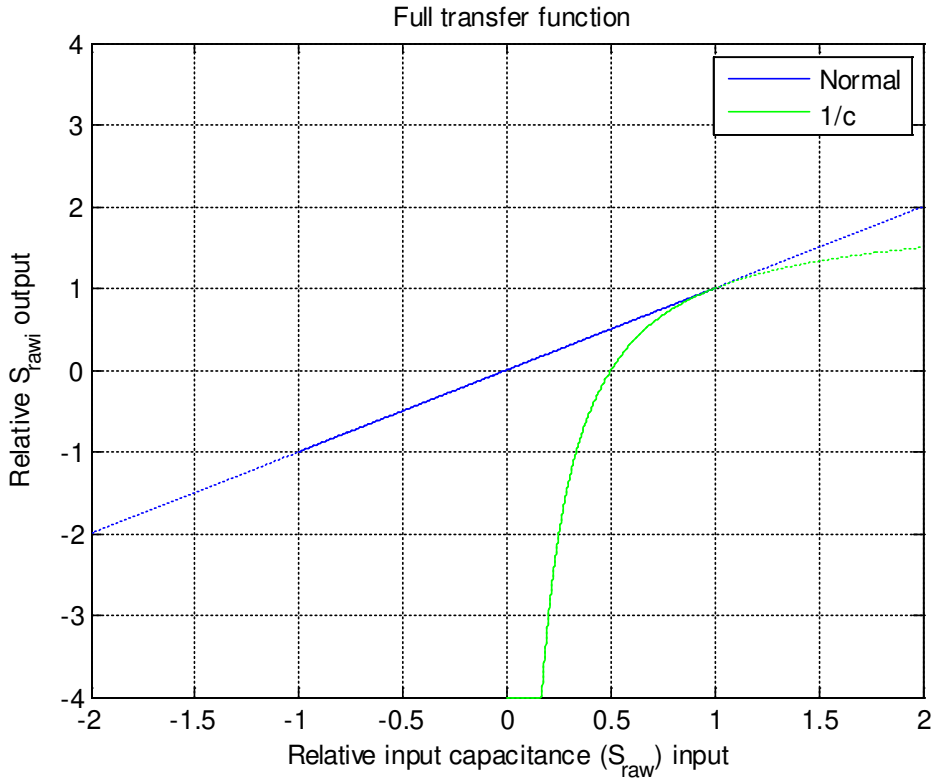
For capacitive pressure sensors, a pre-compensation of the ADC signal might be beneficial. Using this function will help to fit the typical pressure sensor transfer characteristic to matching the second-order compensation input requirements for more accurate compensation results. If the 1/C pre-compensation is activated, it will apply only in Normal Measurement Mode with math compensation, not in RAW measurements using Command Mode. The respective 1/C calculation for determination of calibration coefficients is handled in the respective *calibration.dll*. This feature can be enabled by setting the corresponding bit *siginv* (bit[11] in memory register 02_{HEX}; see Table 16). Before the 1/C math is applied, the ADC value of the respective sensor input signal will be inverted.

This leads to the following transfer function for *S_raw* with the system transfer function that is shown in Figure 12.

$$S_{rawi} = \left[2^{24} - \frac{2^{46}}{S_{raw}}\right]_{-2^{25}}^{2^{25}-1} \qquad \text{Equation 2}$$

Note: For the application, if a "C_{range}/C_{Sens}" inversion will be performed, the shift capacitor must to be set to "0."

Figure 12. System Transfer Function for 1/C



6.5.2 Sensor Signal Compensation Math

The *SOT_curve* (bit [15] in EEPROM word 02_{HEX}; see Table 16) selects whether second-order equations compensate for sensor nonlinearity with a parabolic or S-shaped curve. The parabolic compensation is recommended.

Equations for the Parabolic *SOT_curve* Setting (*SOT_curve* = 0):

The coefficients from the memory (23-bit absolute and 1-bit sign; see Table 7) are read into 26-bit-wide registers in the calculation block. The 24-bit-memory coefficients are shifted by two bits so that the MSB of the 24-bit memory coefficient is placed at the MSB of the 26-bit calculation register coefficient.

Simplified:

$$K_1 = 2^{23} + \frac{T\_Raw}{2^{23}} \cdot \left(\frac{4 \cdot SOT\_tcg}{2^{23}} \cdot T_{\_Raw} + 4 \cdot Tcg \right) \qquad \text{Equation 3}$$

$$K_2 = 4 \cdot Offset\_S + S\_Raw + \frac{T\_Raw}{2^{23}} \cdot \left(\frac{4 \cdot SOT\_tco}{2^{23}} \cdot T_{\_Raw} + 4 \cdot Tco \right) \qquad \text{Equation 4}$$

$$Z_{SP} = \frac{4 \cdot Gain\_S}{2^{23}} \cdot \frac{K_1}{2^{23}} \cdot K_2 + 2^{23} \quad \text{(Bounded to positive number range)} \qquad \text{Equation 5}$$

$$S = \frac{Z_{SP}}{2^{23}} \cdot \left(\frac{4 \cdot SOT\_sensor}{2^{23}} \cdot Z_{SP} + 2^{23} \right) + Sensor\_Shift \quad \text{(Bounded to positive number range)} \qquad \text{Equation 6}$$

Equations for the S-shaped *SOT_curve* Setting (*SOT_curve* = 1):

Simplified:

$$Z_{SS} = \frac{4 \cdot Gain\_S}{2^{23}} \cdot \frac{K_1}{2^{23}} \cdot K_2 \qquad \text{Equation 7}$$

$$S = \frac{Z_{SS}}{2^{23}} \cdot \left(\frac{4 \cdot SOT\_sensor}{2^{23}} \cdot |Z_{SS}| + 2^{23} \right) + 2^{23} + Sensor\_Shift \quad \text{(Bounded to positive number range)} \qquad \text{Equation 8}$$

Complete:

$$Z_{SS} = \left\lfloor \frac{Gain\_S}{2^{21}} \cdot \left\lfloor \frac{K_1}{2^{23}} \cdot K_2 \right\rceil_{-2^{25}}^{2^{25}-1} \right\rceil_{-2^{25}}^{2^{25}-1} \qquad \text{Equation 9}$$

$$S = \left\lfloor \left\lfloor \frac{Z_{SS}}{2^{23}} \cdot \left\lfloor \left\lfloor \frac{SOT\_sensor}{2^{21}} \cdot |Z_{SS}| \right\rceil_{-2^{25}}^{2^{25}-1} + 2^{23} \right\rceil_{-2^{25}}^{2^{25}-1} \right\rceil_{-2^{25}}^{2^{25}-1} + 2^{23} + Sensor\_Shift \right\rceil_{0}^{2^{24}-1} \qquad \text{Equation 10}$$

Where the following representations are valid:

S	Corrected capacitive sensor reading output via I2C; range: [0 to FFFFFF$_{HEX}$]
S_Raw	Raw capacitive sensor reading from ADC (after auto-zero correction); shifted range to: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
Gain_S	Capacitive sensor gain term; range: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
Offset_S	Capacitive sensor offset term; range: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
Tcg	Temperature coefficient gain term; range: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
Tco	Temperature coefficient offset term; range: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
T_Raw	Raw temperature reading (after AZ correction); shifted range to: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
SOT_tcg	Second-order term for Tcg non-linearity; range: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
SOT_tco	Second-order term for Tco non-linearity; range: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
SOT_sensor	Second-order term for sensor non-linearity; range: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
Sensor_shift	Post-calibration, post-assembly offset shift; range: [-7FFFFF$_{HEX}$ to 7FFFFF$_{HEX}$]
$\lvert \ldots \rvert$	Absolute value
$\lfloor \ldots \rceil_{ll}^{ul}$	Bound number range from ll to ul; if needed, apply saturation at the limits ll or ul and report overflow/underflow in the status byte

6.5.3 Temperature Signal Compensation

Temperature is measured internally. Temperature correction contains both linear gain and offset terms as well as a second-order term to correct for any nonlinearities. For temperature, second-order compensation for nonlinearity is always parabolic:

Simplified:

$$Z_T = \frac{4 \cdot Gain\_T}{2^{23}} \cdot (T\_Raw + 4 \cdot Offset\_T) + 2^{23} \quad \text{(Bounded to positive number range)} \qquad \text{Equation 11}$$

$$T = \frac{Z_T}{2^{23}} \cdot \left(\frac{4 \cdot SOT\_T}{2^{23}} \cdot Z_T + 2^{23} \right) + T\_Shift \quad \text{(Bounded to positive number range)} \qquad \text{Equation 12}$$

Where

T	Corrected Temperature reading output via I2C; range [0_{HEX} to $0xFFFFFF_{HEX}$]
Gain_T	Gain coefficient for temperature; range [$-7FFFFF_{HEX}$ to $7FFFFF_{HEX}$]
T_Raw	Raw temperature reading after AZ correction; shifted range to [$-7FFFFF_{HEX}$ to $7FFFFF_{HEX}$]
Offset_T	Offset coefficient for temperature; range [$-7FFFFF_{HEX}$ to $7FFFFF_{HEX}$]
SOT_T	Second-order term for temperature source non-linearity; range [$-7FFFFF_{HEX}$ to $7FFFFF_{HEX}$]
T_Shift	Shift for post-calibration/post-assembly offset compensation [$-7FFFFF_{HEX}$ to $7FFFFF_{HEX}$]

Table 7. Data Format of Calibration Coefficients in Memory

Bit Number:	23	22	21	20	…	2	1	0
Meaning, Weighting:	0 = Positive 1 = Negative	2^1	2^0	2^{-1}	…	2^{-19}	2^{-20}	2^{-21}

6.6 Output Stages

The ZSSC3230 supports signal output via a PDM output pin and I2C output. Measured values are provided at an I2C output interface and at a pulse-density modulation (PDM) output. The digital interface can be used for configuration and the calibration procedure using the user's computer in order to program a set of calibration coefficients into the on-chip memory.

6.6.1 PDM Output Stage

To use the ZSSC3230 in PDM Output Mode, the Cyclic Measurement Mode is required. The ZSSC3230 will not go into Sleep Mode or power-down between measurements. The PDM Output Mode can be enabled via the *PDM_enable* bit (bit[9] in memory register 02_{HEX}; see Table 16). In this case, the PDM output will be started after power-on reset.

Note: If the ZSSC3230 is not used in PDM Output Mode, the PDM pin should not be connected.

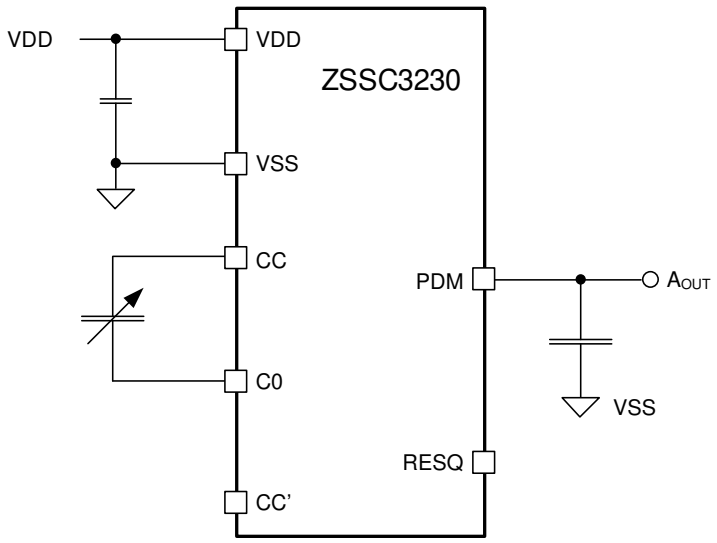
The ZSSC3230 provides a pseudo-analog output of a sigma-delta modulator, i.e. a pulse-density stream, which can be converted into an analog DAC-like output by external low-pass filtering. The PDM signal will be output selectively at the PDM pin. The PDM output is available for the compensated sensor signal. The PDM output is scaled to a 16-bit wide output signal.

When the PDM output is used, an external capacitor must be connected to the PDM output as shown in Figure 13.

Table 8. Analog Output Performance by External Capacitor Value

Filter Capacitance (nF)	Vout Ripple (µV/V)	0 to 90%Settling Time (ms)	Analog Output Resolution (Bit)
100	1000.0	2.3	10
400	250	9.2	12
1600	62	36.8	14
6400	16	147.2	16

Figure 13. PDM Output Configuration



6.6.2 I2C Output

The ZSSC3230 supports an I2C slave interface for digital output operation. The implementation of the interfaces is such that the available commands (see section 6.7.2) and request codes for the ZSSC3230 are the same regardless on the interface type used.

Initially after power-up or reset, the I2C slave address is loaded from the on-chip NVM from the *Slave_Addr* bits [6:0] in register 02_{HEX}; see Table 16). There is a general status byte, which is part of the ZSSC3230's digital response on READ requests. Every response starts with a status byte followed by the data word. The data word depends on the previous command. It is possible to read the same data more than once if the read request is repeated. The next command invalidates any previous data.

Table 9. General Status Byte

Bit-Number:	7	6	5	4	3	2	1	0
Meaning:	0	Powered?	Busy?	Mode		Memory Error?	ADC Overflow	Math Saturation

- Bit 7 is intentionally not assigned in order to allow for a 1 bit-length time.
- Bit 6 indicates power: 1 if device is powered, 0 if not powered.
- Bit 5 indicates whether the ZSSC3230 is busy. The data for the last command is not available yet. No new commands are processed if the device is busy. It is "1" if the device is busy.

- Bit 3 and 4 indicate the actual mode of the ZSSC3230: 00 = Normal Operation Mode; 01 = Command Mode; 10 = Test Mode. See Table 10.
- Bit 2 shows whether there has been a memory integrity/error as indicated by whether the checksum-based integrity check passed or failed: 0 if the integrity test passed; 1 if the test failed.
- Bit 1 shows whether there has been an ADC overflow, which is detected if the raw ADC-output value for capacitive measurement exceeded the nominal, digital ADC-output range, depending on the selected ADC resolution. This check is only for the raw results for the capacitive measurement.
- Bit 0 shows the status Information regarding ALU saturation. If the last executed command was a measurement request, this bit is 0 if any intermediate value and the final SSC result are in a valid range and no SSC-calculation internal saturation occurred. If the last command was a measurement request, this bit is 1 if an SSC-calculation internal saturation occurred. This bit is also 0 for any non-measurement command.

Table 10. Mode Status

Status[4:3]	Mode
00	Normal Operation Mode (sleep and cyclic operations)
01	Command Mode
10	IDT Reserved for Test Mode
11	IDT Reserved

The I2C interface is compliant with the *NXP I2C Bus Specification, Rev. 06* (UM10204, 4 April 2014). All modes up to High Speed Mode are supported. Slave address codes 04_{HEX} to 07_{HEX} must not be programmed to the ZSSC3230 since they are exclusively used for the High Speed Mode. The ZSSC3230 will support 7 bit addressing only.

In I2C Mode, each command is started as shown in Figure 14. Only the number of bytes that are needed for the command must be sent. An exception is the I2C High Speed Mode where 3 bytes must always be sent. After the execution of a command (busy = 0), the expected data can be read as illustrated in Figure 15 or if no data are returned by the command, the next command can be sent. The status can be read at any time as described in Figure 16.

Figure 14. I2C Command Request

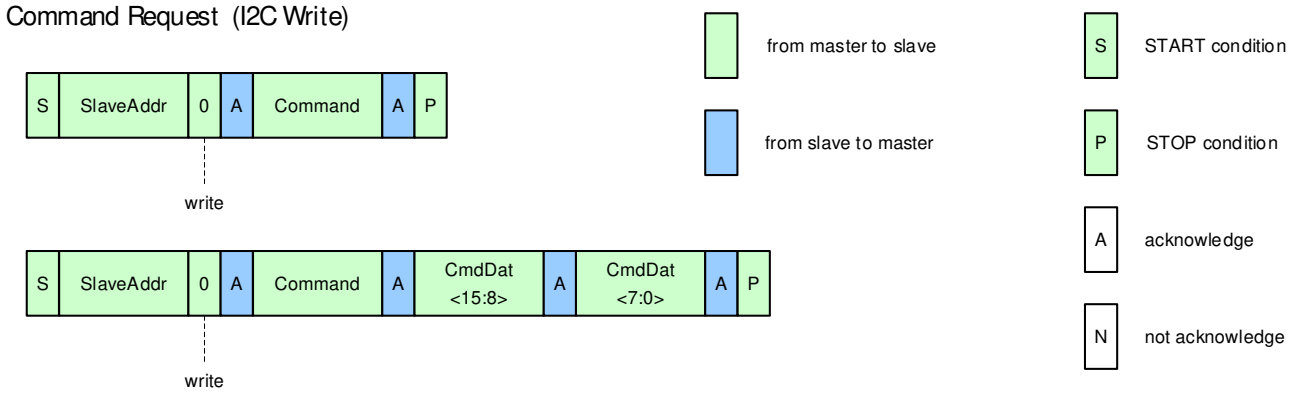
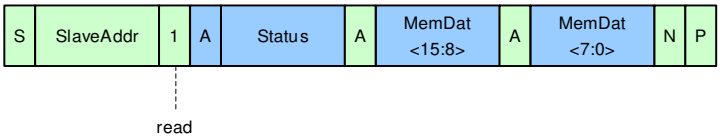


Figure 15. I2C Read Data

Read Data (I2C Read)

(a) Example: after the completion of a Memory Read command



(b) Example: after the completion of a *Measure* command (AA_{HEX})

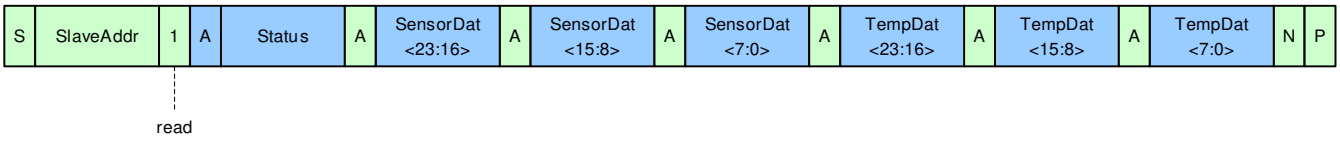


Figure 16. I2C Read Status

Read Status (I2C Read)

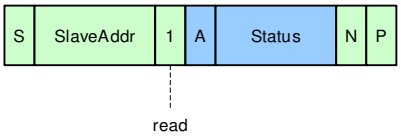


Table 11. I2C Interface Parameters

Symbol	Parameter	Conditions	Minimum	Typical	Maximum	Units
f_{SCL}	Interface clock		0.1	–	3.4	MHz
D_{SPI}	Duty cycle		33	–	50	%
$V_{high,I2C}$	Input HIGH level voltage	Referenced to the external supply voltage V_{DD}	0.7	–	1.0	V_{DD}
$V_{low,I2C}$	Input LOW level voltage		0.0	–	0.3	V_{DD}
C_{SDA}	Capacitive load at input pin, SDA	▪ 100pF ⇔ maximum for Standard and Fast Mode; in High-Speed Mode $f_{SCL,max}$ = 3.4MHz ▪ 400pF ⇔ only in High-Speed Mode, $f_{SCL,max}$ = 1.7MHz	–	100	400	pF
I_{OL}	LOW level output current	V_{SDA}=0.4V, Standard and Fast Mode with 400kHz; 400pF load	3	6	40	mA

Details for timing and protocol of the ZSSC3230-supported I2C communication in Standard Mode, Fast Mode, and High-Speed Mode are given in the *I2C-Bus Specification, Rev.6, UM10204*.

6.6.3 EOC and Output Interrupt Signaling

The EOC pin can be programmed to operate either as a “measurement busy” indicator and end-of-conversion (EOC) transducer, or as a configurable interrupt transducer. The respective basic operation must be programmed into *INT_setup* bits in the memory (bits[8:7] in NVM register 02_{HEX}; see Table 16). One or two 24-bit-quantized thresholds can be programmed (see the *Interrupt Level Setup* memory registers: 13_{HEX}, 14_{HEX} and 15_{HEX}). Depending on the *INT_setup* selection, the EOC pin provides a logic 1 or logic 0 according to the SSC-corrected measurement result. The respective thresholds are programmed left-aligned in the memory, such that they must be programmed with the threshold’s MSB in the memory register’s MSB, etc. The LSBs of the 24-bit threshold in the memory must be ignored according to the number of bits of the selected ADC resolution (according to *adc_bits*).

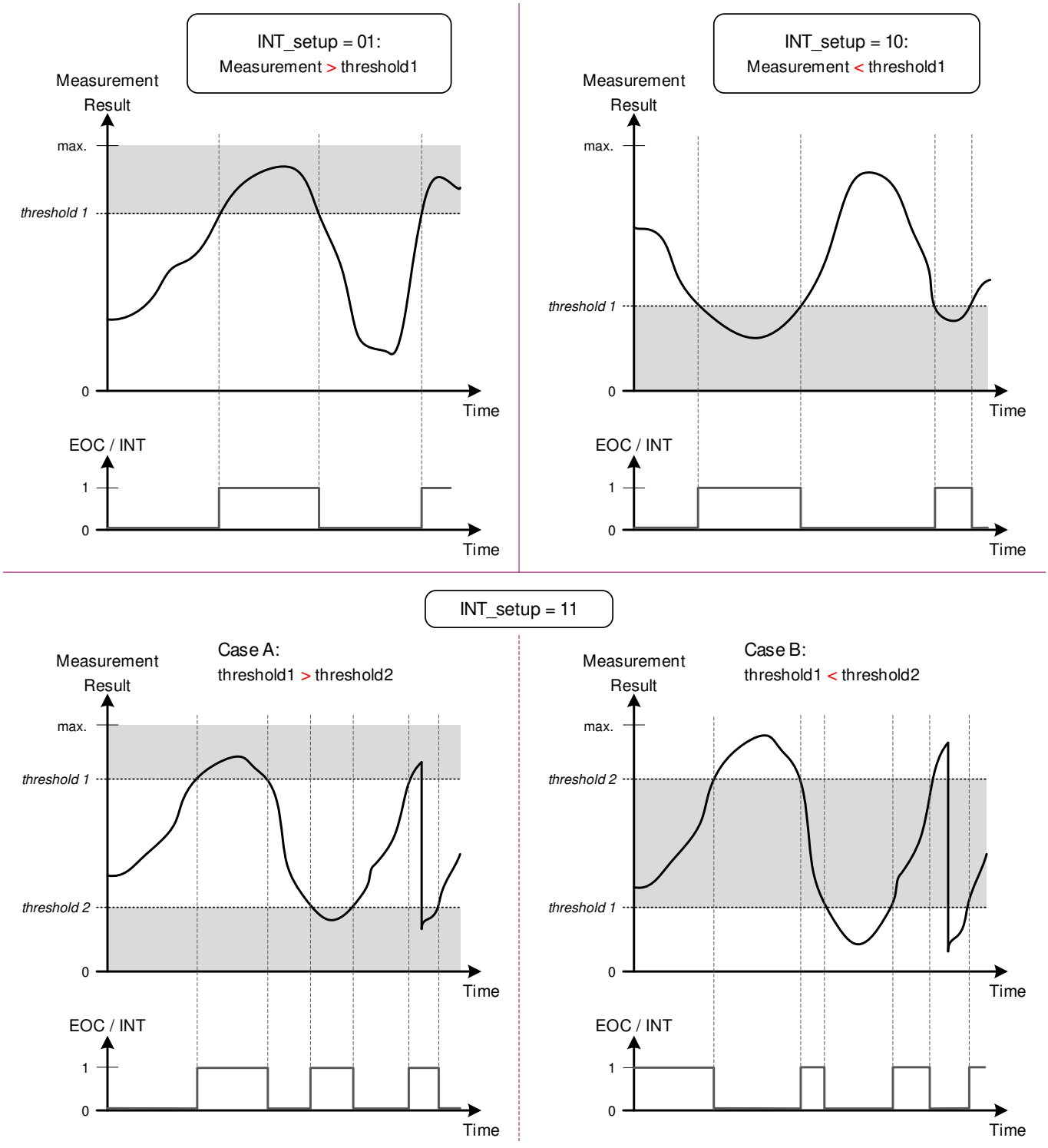
If only the effective end-of-conversion is signalized (*INT_setup* = 00_{BIN}), the EOC signal is pulse of approximately 5µs. The next command will be executed only after this EOC-signaling period.

The interrupt functionality is only available for digital values from the SSC-calculation unit. The interrupt feature cannot monitor any type of raw values. The encoding and data format of the interrupt thresholds is the same as for SSC-corrected measurement results (see Table 12).

Table 12. Data Format of Interrupt Thresholds (TRSH1 and TRSH2)

Bit-Number:	23	22	21	20	…	2	1	0
Meaning, Weighting:	2^{0}	2^{-1}	2^{-2}	2^{-3}	…	2^{-21}	2^{-22}	2^{-23}

Figure 17 EOC and Interrupt Thresholds



6.7 Measurement and Output Options

Sensor measurement results of the ZSSC3230 are provided in digital at the I2C interface. This will be the main active interaction path, and it can combined with the PDM output configuration.

6.7.1 Single Measurements: Digital Raw and SSC Results

The ZSSC3230 generates digital raw values, which are processed by the IC-internal math-core generating the SSC-corrected (linearized, temperature-compensated) output signal; see section 6.5.2 for details about SSC math, etc. In addition to the SSC-corrected digital measurement results, the ZSSC3230 can provide raw values with or without SSC correction for evaluation and/or calibration purposes. The respective results are provided at the digital interface as a 24-bit-wide data word. Raw values are LSB-aligned. SSC results are MSB-aligned.

Table 13. Data Format of Raw ADC Readings

Bit-Number:	23	22	21	20	…	2	1	0
Meaning, Weighting:	-2^{0}	2^{-1}	2^{-2}	2^{-3}	…	2^{-21}	2^{-22}	2^{-23}

Table 14. Data Format of Corrected SSC Results

Bit-Number:	23	22	21	20	…	2	1	0
Meaning, Weighting:	2^{0}	2^{-1}	2^{-2}	2^{-3}	…	2^{-21}	2^{-22}	2^{-23}

The ZSSC3230 can process and digitize the following signals:

- Direct sensor signal inputs; i.e. perform sensor measurements, *SM*
- Auto-zero signals for the sensor channel, referred to as *AZS*
- Direct temperature signal inputs; i.e. perform temperature measurements, *TM*
- Auto-zero signals for the temperature channel, referred to as *AZT*

The utilization of auto-zero measurements allows inherent compensation for long-term drift effects of the ZSSC3230, such that the risk of lifetime signal degradation for the application and smart sensor is minimized. For the auto-zero measurement, the sensor signal remains the input for the auto-zero measurement with the gain and ADC setups the same as for the original signal measurement, but with swapped inputs and offset configurations of the PGA and ADC such that the following holds for the resulting raw value:

- Sensor raw value with auto-zero: $S\_raw = 0.5 * (SM - AZS)$
- Temperature raw value with auto-zero: $T\_raw = 0.5 * (TM - AZT)$

Enabling auto-zero measurements is strongly recommended.

The NVM configuration and measurement request commands can be used to select which effective measurements are conducted, processed, and provided at the digital interface. The possible options for a single measurement request and output are the following:

- SSC-corrected sensor readings (requested by the “Measure” command AA_{HEX}) generating an output of SSC-corrected, 24-bit sensor data followed by SSC-corrected, 24-bit temperature data.
- Raw sensor measurement with auto-zero correction (requested by the “Raw Sensor Measure” command $A2_{HEX}$) generating an output of raw, 24-bit sensor data.
- Raw temperature measurement with auto-zero correction (requested by the “Raw Temperature Measure” command $A6_{HEX}$) generating an output of raw, 24-bit temperature data.

6.7.2 Digital Commands

The availability of commands depends on the active Main Operating Mode: Command, Sleep, or Cyclic Measurement Mode.

Table 15. Command List

Command Code (Byte)	Return	Description	Available in Sleep Mode	Available in Command Mode	Available in Cyclic Measurement Mode
00_{HEX} to $1F_{HEX}$	16-bit data	Memory Read: Read address 00_{HEX} to $1F_{HEX}$.	Yes	Yes	No
20_{HEX} to $3C_{HEX}$ followed by data (0000_{HEX} to $FFFF_{HEX}$)	–	Memory Write: Write data to addresses 00_{HEX} to $1C_{HEX}$ (the NVM-register address is the command minus 20_{HEX}). Note: If the NVM is locked, write requests are not acknowledged or ignored.	Yes	Yes	No
90_{HEX}	–	Calculate NVM Checksum: Calculate the checksum for the NVM and write it to the memory.	Yes	Yes	No
$A2_{HEX}$ followed by data 0000_{HEX}	24-bit raw data	Raw Sensor Measurement:* Conduct a sensor measurement without SSC correction. The configuration is loaded to the controlling shadow registers from the *Sensor_config* register in NVM. Note: The auto-zero sensor measurement is also performed.	Yes	Yes	No
$A3_{HEX}$ followed by data $ssss_{HEX}$	24-bit raw data	Raw Sensor Measurement:† Conduct a sensor measurement without SSC correction. The ssss is the user's configuration setting for the measurement provided via the interface. The format and purpose of the configuration bits must be according to the definitions for *Sensor_config.* Note: The auto-zero sensor measurement is also performed.	Yes	Yes	No
$A6_{HEX}$ followed by data 0000_{HEX}	24-bit raw data	Raw Temperature Measurement:† Conduct a temperature measurement without SSC correction. The configuration is loaded to the controlling shadow registers from the *extTemp_Config1/2* or *T_config1/2* registers in NVM as well as the *SSF1/2* registers. Note: Auto-zero-sensor measurement is performed.	Yes	Yes	No
$A8_{HEX}$	–	START_SLEEP: Exit Command Mode or Cyclic Measurement Mode and transition to Sleep Mode. Note: The response to Start_Sleep is only the status byte.	No	Yes	Yes
$A9_{HEX}$	–	START_CM: Enter Command Mode and enable/allow respective commands. This command must be sent as the first command after power-up.	No	Yes	No
AA_{HEX}	24-bit SSC-corrected sensor data and 24-bit SSC-corrected temperature data	Measure – trigger a full measurement (auto-zero-sensor, sensor, auto-zero-temperature, temperature) and perform the SSC correction.	Yes	Yes	No

* These commands can be used to conduct a measurement without SSC correction; e.g., during smart sensor calibration procedure. No digital correction is performed on the measurement result.

Command Code (Byte)	Return	Description	Available in Sleep Mode	Available in Command Mode	Available in Cyclic Measurement Mode
AB_{HEX}	24-bit SSC-corrected sensor data and 24-bit SSC-corrected temperature data	START_CYC: Enter Cyclic Measurement Mode: continuous measurement cycles, SSC corrections, and automatic, continuous digital output updates.	Yes	Yes	No
AC_{HEX}	24-bit SSC-corrected sensor data and 24-bit SSC-corrected temperature data	Oversample-2 Measure:* Complete multiple measurements for mean-value generation: 2 full measurements are performed (the same as measurements triggered with AA_{HEX}, not cyclic) and the resulting mean value is provided as output.	Yes	Yes	No
AD_{HEX}		Oversample-4 Measure:‡ Complete multiple measurements for mean-value generation: 4 full measurements are performed (the same as AA_{HEX} measurements, not cyclic) and the resulting mean value is provided as output.	Yes	Yes	No
AE_{HEX}		Oversample-8 Measure:‡ Complete multiple measurements for mean-value generation: 8 full measurements are performed (the same as AA_{HEX} measurements, not cyclic) and the resulting mean value is provided as output.	Yes	Yes	No
AF_{HEX}		Oversample-16 Measure:‡ Complete multiple measurements for mean-value generation: 16 full measurements are performed (the same as AA_{HEX} measurements, not cyclic) and the resulting mean value is provided as output.	Yes	Yes	No
$B0_{HEX}$	16-bit data output 0 pass / 1 fail	Broken Chip: Test resistance of corner wire.	Yes	Yes	No
$B4_{HEX}$	-	Stop PDM: This command can be used to stop the PDM in order to change the PDM enable in NVM. This command does not sent an ack.	No	No	Yes
$FX_{HEX\ X}$ followed by data XX_{HEX}	-	Soft-Reset: Full reset of digital part. Note: Any FX_{HEX} command extended by one arbitrary data byte results in the soft reset. This command will not be answered by an acknowledge	Yes	Yes	Yes

6.7.3 Nonvolatile Memory (NVM)

In the ZSSC3230, the memory is organized in 16-bit wide registers and can be programmed multiple times (approximately 10000). There are 28 x 16-bit registers available for customer use. Each register can be re-programmed. Basically, there are two NVM content sectors:

- Customer Use – Accessible by means of regular WRITE operations: 20_{HEX} to $3C_{HEX}$. It contains the customer ID, interface setup data, measurement setup information, calibration coefficients, etc.
- IDT Use – Only accessible for WRITE operations by IDT. This sector contains specific trim information and is programmed during manufacturing test by IDT; e.g., configurations for the internal temperature sensor are stored there.

* Use oversample measurements to obtain noise-minimized measurement results in Sleep or Command Mode. With higher oversampling factors, the command execution time increases proportionally.

6.7.4 Memory Contents

Table 16. Memory (NVM) Content Assignments

NVM Address	Word/Bit Range	Default Setting	Word/Bit Field Name	Description
00_{HEX}	15:0	0000_{HEX}	Cust_ID0	Customer ID byte 0 (combines with memory word 01_{HEX} to form the customer ID).*
01_{HEX}	15:0	0000_{HEX}	Cust_ID1	Customer ID byte 1 (combines with memory word 00_{HEX} to form the customer ID).
Interface Configuration				
02_{HEX}	6:0	$000\ 0000_{BIN}$	Slave_Addr	I2C and OWI slave address; valid range: 00_{HEX} to $7F_{HEX}$ (default: 00_{HEX}). Note: Address codes 04_{HEX} to 07_{HEX} are reserved for entering the I2C High Speed Mode.

	8:7	00_{BIN}	INT_setup	Interrupt configuration, EOC pin functionality:
				00 End-of-conversion signal
				01 0-1 transition if threshold1 (TRSH1) is exceeded and 1-0 transition if threshold1 is underrun again
				10 0-1 transition if threshold1 is underrun and 1-0 transition if threshold1 is exceeded again
				11 EOC is determined by threshold settings (see section 6.6.3):
				If (TRSH1 > TRSH2) then EOC/INT (interrupt level) = 0 if (TRSH1 > MEAS ≥ TRSH2) where MEAS is the conditioned measurement result.
				Otherwise EOC/INT=1.
				If (TRSH1 ≤ TRSH2) then EOC = 1 if (TRSH1 ≤ MEAS < TRSH2).
				Otherwise EOC = 0.

	9	0_{BIN}	PDM_enable	Enables PDM-output: 0 ⇔ PDM output disabled 1 ⇔ PDM output enabled If PDM_enable bit is 1, the ZSSC3230 will start after reset without any further command in Cyclic Measurement Mode
	10	0_{BIN}	Reserved	
	11	0_{BIN}	siginv	Enables input signal inversion (“1-1/C”) in conditioning math: 0 ⇔ “1-1/C” disabled 1 ⇔ “1-1/C” enabled
	14:12	000_{BIN}	CYC_period	Update period (ZSSC3230 sleep time, except oscillator) in cyclic operation: 000 ⇔ 0.0ms (= PDM default) 100 ⇔ 1333ms 001 ⇔ 167ms 101 ⇔ 2667ms 010 ⇔ 333ms 110 ⇔ 5333ms 011 ⇔ 666ms 111 ⇔ Not assigned
	15	0_{BIN}	SOT_curve	Type/shape of second-order curve correction for the sensor signal. 0 ⇔ parabolic curve 1 ⇔ s-shaped curve

* For I^3C operation, this should contain the Legacy Virtual Register “LVR” info: 0x1X … Index 0; Fast Mode supported.

NVM Address	Word/Bit Range	Default Setting	Word/Bit Field Name	Description
Signal Conditioning Parameters				
03_{HEX}	15:0	0000_{HEX}	Offset_S[15:0]	Bits [15:0] of the 24-bit-wide sensor offset correction coefficient *Offset_S*. (MSBs of this coefficient including sign are *Offset_S*[23:16], which are bits [15:8] in $0D_{HEX}$.)
04_{HEX}	15:0	0000_{HEX}	Gain_S[15:0]	Bits [15:0] of the 24-bit-wide value of the sensor gain coefficient *Gain_S*. (MSBs of this coefficient including sign are *Gain_S*[23:16], which are bits [7:0] in $0D_{HEX}$.)
05_{HEX}	15:0	0000_{HEX}	Tcg[15:0]	Bits [15:0] of the 24-bit-wide coefficient *Tcg* for the temperature correction of the sensor gain. (The MSBs of this coefficient including sign are *Tcg*[23:16], which are bits [15:8] in $0E_{HEX}$.)
06_{HEX}	15:0	0000_{HEX}	Tco[15:0]	Bits [15:0] of the 24-bit-wide coefficient *Tco* for temperature correction of the sensor offset. (The MSBs of this coefficient including sign are *Tco*[23:16], which are bits [7:0] in $0E_{HEX}$.)
07_{HEX}	15:0	0000_{HEX}	SOT_tco[15:0]	Bits [15:0] of the 24-bit-wide 2nd order term *SOT_tco* applied to Tco. (The MSBs of this term including sign are *SOT_tco*[23:16], which are bits[15:8] in $0F_{HEX}$.)
08_{HEX}	15:0	0000_{HEX}	SOT_tcg[15:0]	Bits [15:0] of the 24-bit-wide 2nd order term *SOT_tcg* applied to Tcg. (The MSBs of this term including sign are *SOT_tcg*[23:16], which are bits[7:0] in $0F_{HEX}$.)
09_{HEX}	15:0	0000_{HEX}	SOT_sens[15:0]	Bits [15:0] of the 24-bit-wide 2nd order term *SOT_sens* applied to the sensor read-out. (The MSBs of this term including sign are *SOT_sens*[23:16], which are bits[15:8] in 10_{HEX}.)
$0A_{HEX}$	15:0	0000_{HEX}	Offset_T[15:0]	Bits [15:0] of the 24-bit-wide temperature offset correction coefficient *Offset_T*. (MSBs of this coefficient including sign are *Offset_T*[23:16]; i.e., bits[7:0] in 10_{HEX}.)
$0B_{HEX}$	15:0	0000_{HEX}	Gain_T[15:0]	Bits [15:0] of the 24-bit-wide absolute value of the temperature gain coefficient *Gain_T*. (The MSBs of this coefficient including sign are *Gain_T*[23:16], which are bits[15:8] in 11_{HEX}.)
$0C_{HEX}$	15:0	0000_{HEX}	SOT_T[15:0]	Bits [15:0] of the 24-bit-wide 2nd-order term *SOT_T* applied to the temperature reading. (The MSBs of this coefficient including sign are *SOT_T*[23:16], which are bit[7:0] in 11_{HEX}.)
$0D_{HEX}$	7:0	00_{HEX}	Gain_S[23:16]	Bits [23:16] including sign for the 24-bit-wide sensor gain correction coefficient *Gain_S*. (The LSBs of this coefficient are *Gain_S*[15:0] in register 03_{HEX}.)
	15:8	00_{HEX}	Offset_S[23:16]	Bits [23:16] including sign for the 24-bit-wide sensor offset correction coefficient *Offset_S*. (The LSBs are *Offset_S*[15:0] in register 04_{HEX}.)
$0E_{HEX}$	7:0	00_{HEX}	Tco[23:16]	Bits [23:16] including sign for the 24-bit-wide coefficient *Tco* for temperature correction for the sensor offset. (The LSBs are *Tco*[15:0] in register 05_{HEX}.)
	15:8	00_{HEX}	Tcg[23:16]	Bits [23:16] including sign for the 24-bit-wide coefficient *Tcg* for the temperature correction of the sensor gain. (The LSBs are *Tcg*[15:0] in register 06_{HEX}.)
$0F_{HEX}$	7:0	00_{HEX}	SOT_tcg[23:16]	Bits [23:16] including sign for the 24-bit-wide 2nd order term *SOT_tcg* applied to Tcg. (The LSBs are *SOT_tcg*[15:0] in register 07_{HEX}.)
	15:8	00_{HEX}	SOT_tco[23:16]	Bits [23:16] including sign for the 24-bit-wide 2nd order term *SOT_tco* applied to Tco. (The LSBs are *SOT_tco*[15:0] in register 08_{HEX}.)
10_{HEX}	7:0	00_{HEX}	Offset_T[23:16]	Bits [23:16] including sign for the 24-bit-wide temperature offset correction coefficient *Offset_T*. (The LSBs are *Offset_T*[15:0] in register 09_{HEX}.)
	15:8	00_{HEX}	SOT_sens[23:16]	Bits [23:16] including sign for the 24-bit-wide 2nd order term *SOT_sens* applied to the sensor readout. (The LSBs are *SOT_sens*[15:0] in register $0A_{HEX}$.)

NVM Address	Word/Bit Range	Default Setting	Word/Bit Field Name	Description
11_{HEX}	7:0	00_{HEX}	SOT_T[23:16]	Bits [23:16] including sign for the 24-bit-wide 2nd-order term *SOT_T* applied to the temperature reading. (The LSBs are *SOT_T*[15:0] in register $0B_{HEX}$.)
	15:8	00_{HEX}	Gain_T[23:16]	Bits [23:16] including sign for the 24-bit-wide absolute value of the temperature gain coefficient *Gain_T*. (The LSBs are *Gain_T*[15:0] in register $0C_{HEX}$.)
Measurement Configuration (Sensor_config) Register				
12_{HEX}	5:0	$00\ 0000_{BIN}$	shift_cap	Defines the zero shift capacitance⇔ input offset shift to cancel the static input capacitance of the sensor: 00 0000 ⇔ no offset shift 00 0001 ⇔ 0.25pF 00 0010 ⇔0.50pF 00 0011 ⇔0.75pF 00 0100 ⇔1.00pF 00 0101 ⇔1.25pF 00 0110 ⇔1.50pF 00 0111 ⇔1.75pF 00 1000 ⇔2.00pF 00 1001 ⇔2.25pF … 11 1101 ⇔15.00pF 11 1110 ⇔15.50pF 11 1111 ⇔15.75pF Note: the offset shift capacitance must not exceed the selected input capacitance's range (see *cap_range*).
	7:6	00_{BIN}	adc_bits	Defines the absolute number of bits for the A2D conversion: 00 ⇔12-bit 01 ⇔14-bit (default) 10 ⇔16-bit 11 ⇔18-bit
	8	0_{BIN}	noise_mode	Select between control sequences for noise-quality vs. energy consumption optimization: 0 ⇔ Low Current Mode 1 ⇔ Low Noise Mode
	13:9	$0\ 0000_{BIN}$	cap_range	Selection maximum possible external signal capacitance; i.e. the capacitance sensor range (without any offset): 00000 ⇔ 0.5pF 00001 ⇔ 1.0pF 00010 ⇔ 1.5pF 00011 ⇔ 2.0pF 00100 ⇔ 2.5pF 00101 ⇔ 3.0pF 00110 ⇔ 3.5pF 00111 ⇔ 4.0pF 01000 ⇔ 4.5pF 01001 ⇔ 5.0pF 01010 ⇔ 5.5pF 01011 ⇔ 6.0pF 01100 ⇔ 6.5pF 01101 ⇔ 7.0pF 01110 ⇔ 7.5pF 01111 ⇔ 8.0pF 10000 ⇔ 8.5pF 10001 ⇔ 9.0pF 10010 ⇔ 9.5pF 10011 ⇔ 10.0pF 10100 ⇔ 10.5pF 10101 ⇔ 11.0pF 10110 ⇔ 11.5pF 10111 ⇔ 12.0pF 11000 ⇔ 12.5pF 11001 ⇔ 13.0pF 11010 ⇔ 13.5pF 11011 ⇔ 14.0pF 11100 ⇔ 14.5pF 11101 ⇔ 15.0pF 11110 ⇔ 15.5pF 11111 ⇔ 16.0pF

NVM Address	Word/Bit Range	Default Setting	Word/Bit Field Name	Description
12_{HEX} (Continued)	14	0_{BIN}	sensor_leakage	Option to enable sensor element's leakage current compensation (due to sensor element's parasitic resistance) ⇔ leakage cancellation leads to loss of dynamic range and decrease of SNR (loss of 1 bit of effective resolution). The following setups are possible: 0 ⇔ no sensor leakage cancellation; full internal dynamic range; full Vref applied to external sensor 1 ⇔ sensor leakage cancellation enabled; applied voltage at external sensor of 0.5 ∗ Vref (loss of 1 bit of effective resolution)
	15	0_{BIN}	sensecap_type	Selection of applied (external) sensor capacitance: 0 ⇔ "differential" sensor capacitance between C0 and CC (CC') pads 1 ⇔ single ended sensor capacitance between VSS and CC (CC') pad; applied voltage at external sensor of 0.5 × Vref (loss of 1 bit of effective resolution)
Interrupt Level Setup and Post-Calibration (Digital) Offset Calibration				
13_{HEX}	15:0	0000_{HEX}	TRSH1[15:0]	Bits [15:0] of the 24-bit-wide interrupt threshold1, *TRSH1*. (The MSBs for this threshold are *TRSH1*[23:16], which are bits [7:0] of register 15_{HEX}.)
14_{HEX}	15:0	0000_{HEX}	TRSH2[15:0]	Bits [15:0] of the 24-bit-wide interrupt threshold2, *TRSH2*. (The MSBs for this threshold are *TRSH2*[23:16], which are bits[15:8] of register 15_{HEX}.)
15_{HEX}	7:0	00_{HEX}	TRSH1[23:16]	Bits [23:16] of the 24-bit-wide interrupt threshold1, *TRSH1*. (The LSBs for this threshold are *TRSH1*[15:0], which are bits[15:0] of register 13_{HEX}.)
	15:8	00_{HEX}	TRSH2[23:16]	Bits [23:16] of the 24-bit-wide interrupt threshold2, *TRSH2*. (The LSBs for this threshold are *TRSH2*[15:0], which are bits[15:0] of register 14_{HEX}.)
16_{HEX}	15:0	0000_{HEX}	SENS_Shift[15:0]	Bits [15:0] of the post-calibration sensor offset shift coefficient *SENS_Shift*. (The MSBs of *SENS_Shift* are bits [7:0] of register 18_{HEX}.)
17_{HEX}	15:0	0000_{HEX}	T_Shift[15:0]	Bits [15:0] of the post-calibration temperature offset shift coefficient *T_Shift*. (The MSBs of *T_Shift* are bits [15:8] of register 18_{HEX}.)
18_{HEX}	7:0	00_{HEX}	SENS_Shift[23:16]	Bits [23:16] of the post-calibration sensor offset shift coefficient *SENS_Shift*. (The LSBs of *SENS_Shift* are in register 16_{HEX}.)
	15:8	00_{HEX}	T_Shift[23:16]	Bits [23:16] of the post-calibration temperature offset shift coefficient *T_Shift*. (The LSBs of *T_Shift* are in register 17_{HEX}.)

NVM Address	Word/Bit Range	Default Setting	Word/Bit Field Name	Description
Configuration Register				
19_{HEX}	1:0	00_{BIN}	CC_pin_selection	Defines which pin is used for measurement (CC and/or CC'): 00 ⇔ no input 01 ⇔ CC 10 ⇔ CC' 11 ⇔ CC and CC'
	2	0_{BIN}	Dither	Enable/disable digital dithering to improve EMI performance: 0 ⇔ No dithering 1 ⇔ Dithering enabled
	3	0_{BIN}	En_sh2	Enable Subtraction Mode in grounded mode (see section 6.2.5): 0 ⇔ Disabled 1 ⇔ Enabled
	4	0_{BIN}	En_shlddrv	Enable active shield drive at the C0 pin (see section 6.2.4): 0 ⇔ Disabled 1 ⇔ Enabled
	5	0_{BIN}	Dyn_imp	Enables higher drive current in analog front end, which will be needed if the sensor range is much smaller than the shift capacitor: 0 ⇔ Disabled 1 ⇔ Enabled
	6	0_{BIN}	Test_cap	Enables an internal reference sensor capacitor of approx. 2pF in parallel to sensor input: 0 ⇔ Disabled 1 ⇔ Enabled
	15:7		Reserved	IDT lot tracking information; can be overwritten and used as free space for customer use.
$1A_{HEX}$	15:0	0000_{HEX}	Reserved	IDT lot tracking information; can be overwritten and used as free space for customer use.
$1B_{HEX}$	15:0	0000_{HEX}	Reserved	IDT lot tracking information; can be overwritten and used as free space for customer use.
$1C_{HEX}$	15:0	0000_{HEX}	CRC	Generated checksum (CRC) for whole memory through a linear feedback shift register (LFSR); Signature is checked upon power-up to ensure memory content integrity

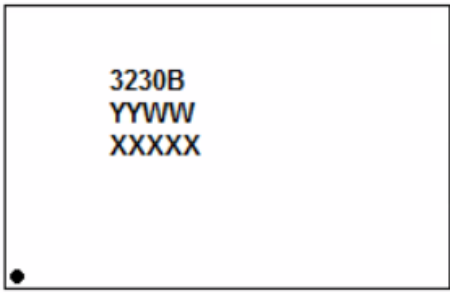
The NVM-consistency checksum is calculated (IC-internally for the whole NVM) using the polynomial: $x^{16} + x^{15} + x^2 + 1$. The checksum verification is only realized directly after V_{DD} power-on. If the checksum is successfully verified, then the "Memory Error" status bit is set to 0_{BIN}.

7. Package Outline Drawings

The package outline drawings VFQFPN package are appended at the end of this document and are accessible from the link below. The package information is the most current data available.

24-VFQFPN Package Outline Drawing

8. Marking Diagram



1. Line 1 is the truncated part number.
2. Line 2 – “YYWW” are the last two digit of the year and week that the part was assembled.
3. Line 3 – “XXXXX” denotes assembly lot number.

9. Ordering Information

Orderable Part Number	Description and Package	MSL Rating	Carrier Type	Temperature
ZSSC3230BC1B	Dice on 304µm wafer no inking	Not applicable	Wafer Box	-40 to 85°C
ZSSC3230BC2B	Dice on 725µm wafer no inking	Not applicable	Wafer Box	-40 to 85°C
ZSSC3230BI1B	Dice on 304µm wafer no inking	Not applicable	Wafer Box	-40 to 125°C
ZSSC3230BI2B	Dice on 725µm wafer no inking	Not applicable	Wafer Box	-40 to 125°C
ZSSC3230BC5B	Dice on 304µm wafer with inking	Not applicable	Wafer Box	-40 to 85°C
ZSSC3230BC6B	Dice on 725µm wafer with inking	Not applicable	Wafer Box	-40 to 85°C
ZSSC3230BI5B	Dice on 304µm wafer with inking	Not applicable	Wafer Box	-40 to 125°C
ZSSC3230BI6B	Dice on 725µm wafer with inking	Not applicable	Wafer Box	-40 to 125°C
ZSSC3230BC3R	4 × 4 mm^2 PQFN	MSL1	13” Reel	-40 to 85°C
ZSSC3230BI3R	4 × 4 mm^2 PQFN	MSL1	13” Reel	-40 to 125°C
ZSSC3230BI3W	4 × 4 mm^2 PQFN	MSL1	7” Reel	-40 to 125°C
ZSSC3230KIT	ZSSC3230 Evaluation Board with USB Cable and 5 Samples			

10. Glossary

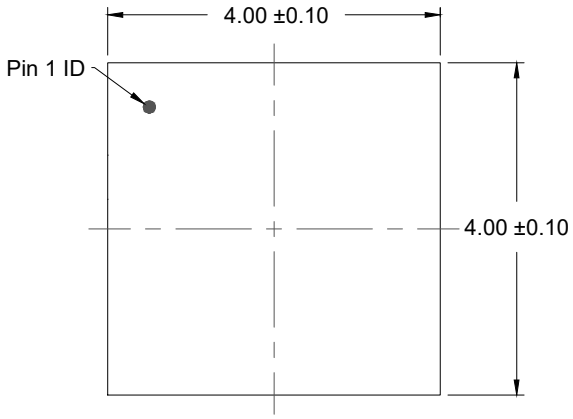
Term	Description
A2D	Analog-to-Digital
ACK	Acknowledge (interface's protocol indicator for successful data/command transfer)
ADC	Analog-to-Digital Converter or Conversion
AGND	Analog Ground
AZ	Auto-Zero (unspecific)
AZS	Auto-Zero Measurement for (External) Sensor Path
AZT	Auto-Zero Measurement for (External or Internal) Temperature Path
CLK	Clock
CVC	Charge-Voltage Converter
DAC	Digital-to-Analog Converter or Conversion
EOC	End of Conversion
FSO	Full Scale Output (value in percent relative to the ADC maximum output code; resolution dependent)
HVAC	Heating, Ventilation, and Air Conditioning
LFSR	Linear Feedback Shift Register
LSB	Least Significant Bit
MSB	Most Significant Bit
MSL	Moisture Sensitivity Level
NACK	Not Acknowledge (interface's protocol indicator for unsuccessful data/command transfer)
NVM	Nonvolatile Memory
OpAmp	Operating Amplifier
PGA	Programmable Gain Amplifier
POR	Power-On Reset
PSRR	Power Supply (Disturbance) Rejection Ratio
PTAT	Proportional to Absolute Temperature
S	SSC-Corrected Sensor Readout / Result
SM	Sensor Measurement
SNR	Signal to Noise Ratio
SOT	Second-Order Term
SSF	Smart-Sensor Function (specific NVM registers)
T	SSC-Corrected (additional) Temperature Readout / Result
TC	Temperature Coefficient

11. Revision History

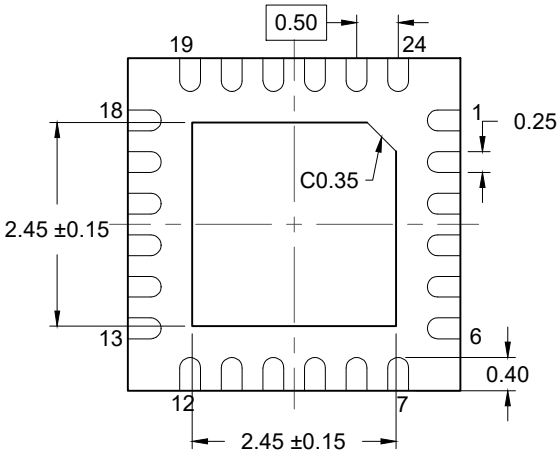
Revision Date	Description of Change
December 1, 2022	Updated POD links in Package Outline Drawings.
October 15, 2019	▪ Values updated for Power-up conditions ▪ Conditions updated for equations for the S-shaped SOT_curve setting
September 10, 2019	Initial release.

Package Outline Drawing

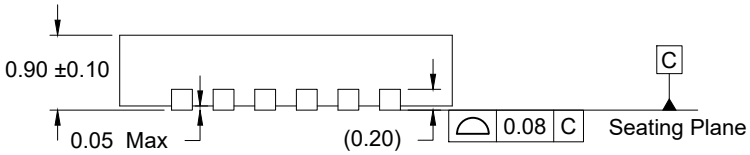
Package Code:NLG24P1
24-VFQFPN 4.0 x 4.0 x 0.9 mm Body, 0.5mm Pitch
PSC-4192-01, Revision: 05, Date Created: Aug 1, 2022



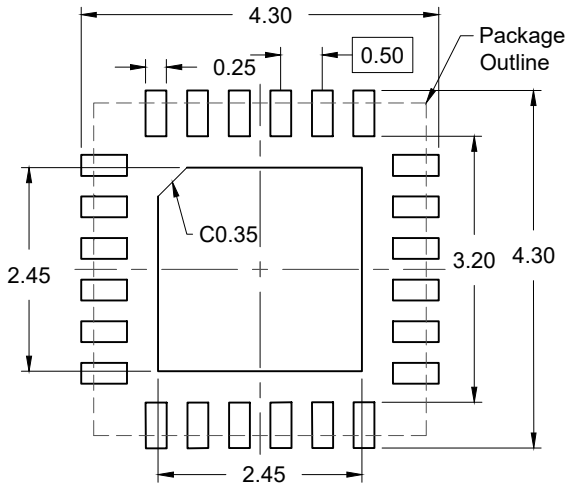
TOP VIEW



BOTTOM VIEW



SIDE VIEW



RECOMMENDED LAND PATTERN
(PCB Top View, NSMD Design)

NOTES:

1. JEDEC compatible.
2. All dimensions are in mm and angles are in degrees.
3. Use ±0.05 mm for the non-toleranced dimensions.
4. Numbers in ( ) are for references only.

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