AF-3x68 Datasheet

Ultra-Low Power Analog Front-End

FEATURES

- Analog Front-End for MEMS Force Sensors
- Integrated Instrumentation Amplifier with Programmable Gain
- Sensor Duty-Cycle Control
- Auto Preload Adjustment
- Ultra-Low Power
- Low Latency
- Software- and Hardware-Programmable Interrupt Threshold
- Industry-Standard I²C Interface
- Ultra-Small 9-pin WLCSP

Description

The AF-3x68 is an ultra-low power and high SNR single-channel Analog Front-End (AFE). The AFE is designed to work with a broad range of industry sensors, including all Semtech analog sensors, to enable industry-leading sensing solutions.

The integrated digital output provides seamless connection to host processors via a standard I²C interface, simplifying system integration while reducing external component count and PCB area requirements.

The AFE is designed for Always-On applications, off-loading the host by taking care of the sensing and event detection. This architecture minimizes host processor wake events, enabling ultra-low system power consumption by maintaining the host in low-power states until a predefined force threshold is exceeded.

In active mode, the AFE incorporates automatic preload adjustment for offset correction to compensate for large preload changes caused by assembly processes and ambient temperature variations.

The AFE is compatible with standard surface-mount assembly processes, including pick-and-place equipment and reflow soldering profiles, facilitating high-volume manufacturing on both rigid PCB and flexible FPCB substrates.

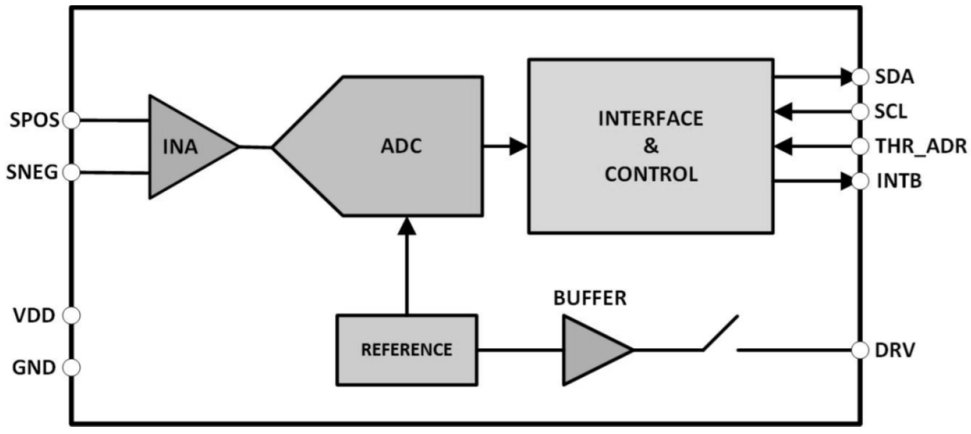
Applications

- Automotive
- Consumer: Smartphones, Tablets, Wearables
- IoT: Smart Home Devices
- Input Devices: Stylus, Touchpads
- Gaming and AR/VR: Force-Sensing Controls

Characteristics

- 3.3 V and 1.8 V Supply Voltage
- 5 µA @ 100 Hz (Sensor + AFE)
- Package Size: 1.16 x 1.16 x 0.475 mm³
- Minimum Latency: 1 ms

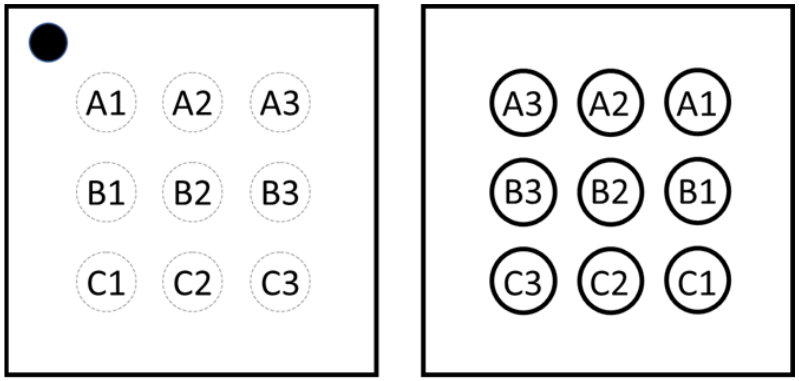
Functional Block Diagram



Ordering Information

PART NUMBER	OPERATING TEMPERATURE	GRADE	DESCRIPTION
AF-3068A00	-20°C to +70°C	Consumer	5000pc 7-inch reel
AF-3068A00SR	-20°C to +70°C	Consumer	300pc sample reel
AF-3568B00	-40°C to +85°C	Automotive Grade 3	5000pc 7-inch reel
AF-3568B00SR	-40°C to +85°C	Automotive Grade 3	300pc sample reel
AF-3568C00	-40°C to +105°C	Automotive Grade 2	5000pc 7-inch reel
AF-3568C00SR	-40°C to +105°C	Automotive Grade 2	300pc sample reel
FT-4100DK	N/A	N/A	Full Design Kit (FT-4100 + AF-3068)
FT-4100PCK	N/A	N/A	Design Kit, Sensor Module only (FT-4100 + AF-3068)

Pin Configuration



Top View
Laser Mark

Bottom View
Bump Side

Pin Description

SOLDER BUMP	PIN NAME	PIN DESCRIPTION
A1	DRV	Driver Voltage Output. Designed to bias analog force sensor.
A2	SNEG	Differential Input. Negative input from analog force sensor.
A3	SPOS	Differential Input. Positive input from analog force sensor.
B1	INTB	Interrupt Output. Alert the host when programmed force is exceeded.
B2	THR_ADR	Threshold/Address Pin. Dual function: I^2C address selection and hardware-programmed force threshold setting at power-up.
B3	GND	Ground. Common ground reference for all signals.
C1	SCL	Serial Clock Input. I^2C clock input.
C2	SDA	Serial Data I/O. Bidirectional I^2C data line.
C3	VDD	Power Supply.

Absolute Maximum Ratings

Stresses beyond those listed may cause permanent damage to the device. These are stress ratings only; functional operation of the device under these or any other conditions beyond those indicated in the operational sections is not implied. Prolonged exposure to absolute maximum rating conditions may degrade device reliability.

PARAMETER	VALUE
VDD to GND	-0.3 V to +4.0 V
SPOS, SNEG to GND	-0.3 V to +4.0 V
DRV to GND	-0.3 V to VDD + 0.3 V
THR_ADR, SCL, SDA, INTB to GND	-0.3 V to +4.0 V
Operating Temperature Range	See Ordering Information
Storage Temperature	-65 °C to +150 °C
Lead Temperature (Soldering 10 s)	+260 °C
Electrostatic Discharge Protection (ESD)	2000 V (HBM), 500 V (CDM)

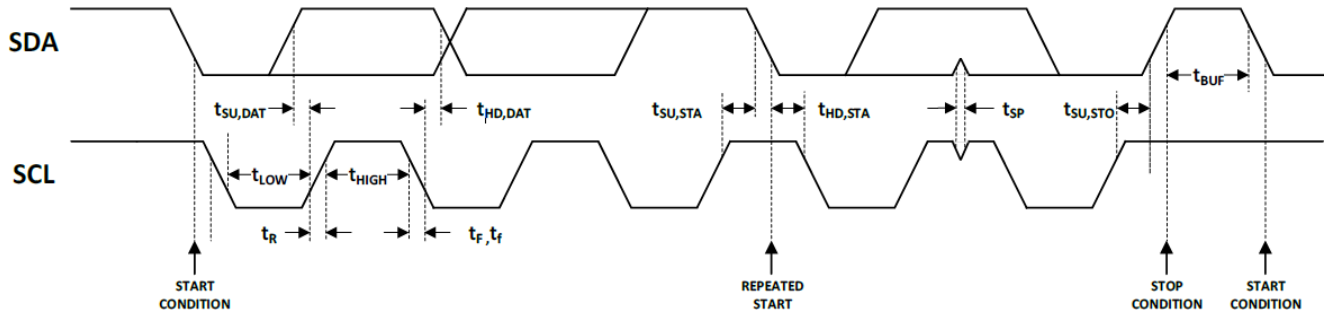
Electrical Characteristics

VDD = 1.80 V ± 10% or 3.30 V ± 10%, T_A = -40 °C to +85 °C, typical values are at T_A = +25 °C unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	MIN.	TYP.	MAX.	UNITS
ANALOG INPUT						
Common-Mode Input Voltage Range[1]	V_{CM}		V_{DRV}/2-0.1		V_{DRV}/2+0.1	V
DRIVER BUFFER OUTPUT						
DRV Pin Voltage	V_{DRV}			1.62		V
ANALOG-TO-DIGITAL CONVERTER						
Resolution				12		Bits
Maximum Data Rate[3]	F_S	WAIT=000 (0 ms)			1000	Sample/s
Dynamic Range		INAGAIN=101 (x115)		60		dB
		INAGAIN=000 (x1)		73.4		
POWER SUPPLY REQUIREMENTS						
Power Supply[1]	VDD		1.62		3.63	V
Supply Current	I_{CC}	AFE + FS, WAIT=000 (1 KHz)		50		µA
		AFE + FS, WAIT=011 (100 Hz)		5		
		AFE + FS, WAIT=110 (10 Hz)		1.5		
Shutdown Current[1,2]	I_{SHDN}	EN=0, VDD=1.8V		0.4	1.5	µA
		EN=0, VDD=3.3V		1.0	3.0	
DIGITAL INTERFACE						
Output Low Voltage[1,2]	V_{OL}	I_{SINK}=2 mA			0.36	V
		I_{SINK}=6 mA, VDD=3.3 V			0.4	
I²C Input Voltage, High[1,2]	V_{IH}	SDA, SCL, THR_ADR	0.7*VDD			V
I²C Input Voltage, Low[1,2]	V_{IL}	SDA, SCL, THR_ADR			0.3*VDD	V
Input Hysteresis	V_{HYS}			270		mV
Input Capacitance	C_{IN}			0.5		pF

PARAMETER	SYMBOL	CONDITIONS	MIN.	TYP.	MAX.	UNITS
Input Leakage Current[1,2]	I_{IN}	VDD = 0V & VDD = 3.63 V			1	µA
I²C TIMING CHARACTERISTICS[3]						
Serial Clock Frequency	f_{SCL}		100	400		kHz
Bus Free Time Between STOP and START	t_{BUF}		0.5			µs
Hold Time (Repeated) START Condition	$t_{HD,STA}$		0.26			µs
Low Period of the SCL Clock	t_{LOW}		0.5			µs
High Period of the SCL Clock	t_{HIGH}		0.26			µs
Setup Time for a Repeated START	$t_{SU,STA}$		0.26			µs
Setup Time for STOP Condition	$t_{SU,STO}$		0.26			µs
Data Hold Time	$t_{HD,DAT}$		0			µs
Data Setup Time	$t_{SU,DAT}$		50			ns
Bus Capacitance	C_B	f_{SCL}=400 kHz			400	pF
		f_{SCL}=1000 kHz			100	
SDA and SCL Rx Rise Time	t_R				120	ns
SDA and SCL Rx Fall Time	t_F		20*VDD/5.5		120	ns
SDA Tx Fall Time	t_f	C_B = 400 pF	20*VDD/5.5		250	ns
		C_B = 100 pF			120	
Pulse Width of Suppressed Spike	t_{SP}		0		50	ns
I²C Timeout	t_{TO}			51		ms

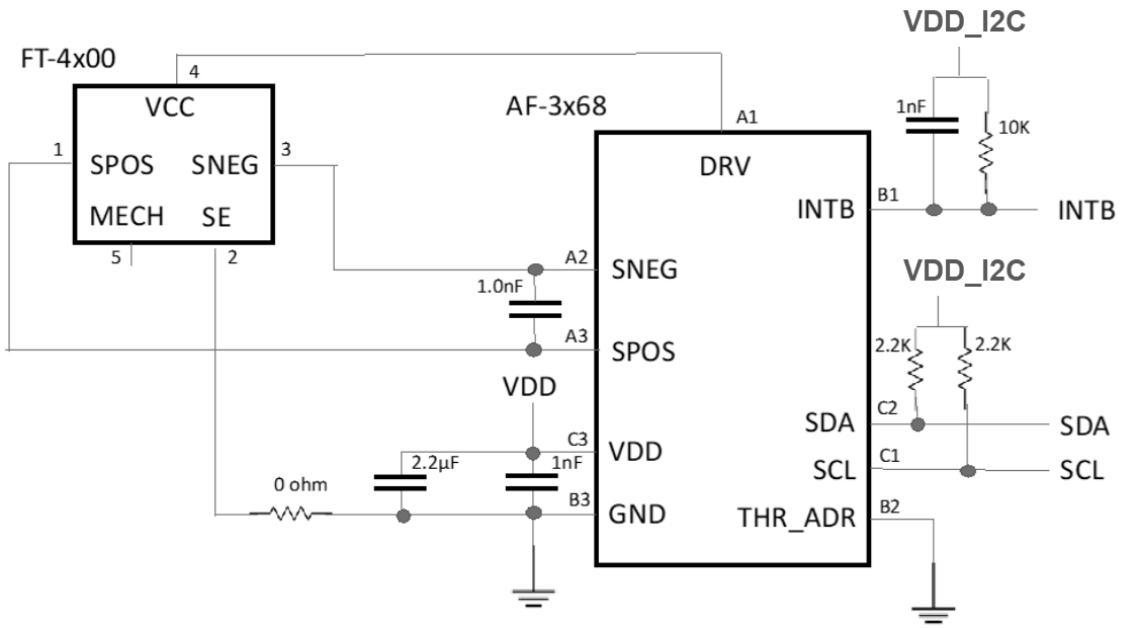
[1] Values based on final test and performed on all parts at room temperature.
[2] Values based on characterization over temperature.
[3] Value guaranteed by design.



I²C Communications Timing Diagram

Typical Application Circuit

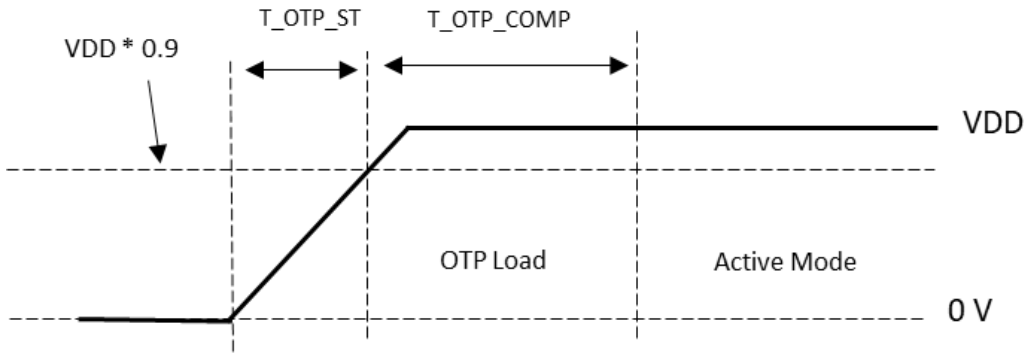
Figure below shows a typical circuit for a button application utilizing Semtech AFE. The AFE generates an interrupt when the programmed threshold is exceeded. The host processor can change the threshold by writing to the AFE registers using the I²C interface.



Power-up Sequence

The AFE will enter active mode by default and be fully operational 10 ms after power is initially applied to the chip. VDD must meet 90% of nominal value within 2 ms after power-up for correct operation, then followed by OTP load in the next 8 ms.

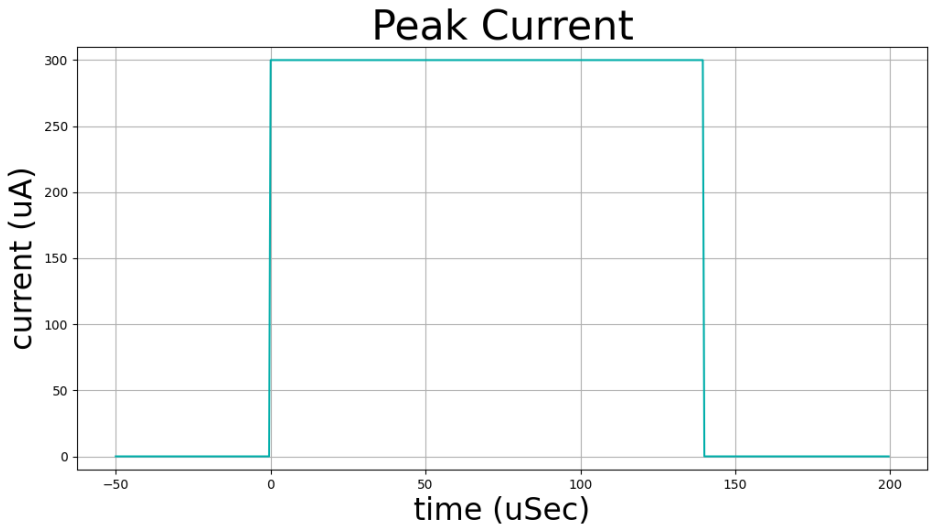
REQUIREMENT	DESCRIPTION	MIN.	TYP.	MAX.	UNITS
T_OTP_ST	Time from power on to OTP load start			2	ms
T_OTP_COMP	Time from OTP load start to complete		8		ms



Power-up Ramp and Full Operation

Peak Current

Peak current pulses repeat at the WAIT interval, draws 300 µA (typ.) for ~140 µs (measurement based on AFE + FT-4100 sensor). These pulses do not occur simultaneously and exclude I²C current. Contact Semtech sales for a detailed application note.



Bidirectional Digital Communication Interface

The AFE implements a standard I²C peripheral interface supporting standard-mode (100 kHz), fast-mode (400 kHz) or higher (≤ 1 MHz)). The 7-bit I²C address is configured at power-up via the THR_ADR pin, allowing up to 4 AFEs on a single bus. Four unique addresses are selectable based on THR_ADR pin connection; see the table below for details.

THR_ADR CONNECTION	AFE I²C ADDRESS[1]
THR_ADR = 5 kΩ - 25 kΩ Resistor[2] to GND	0x44
THR_ADR = 5 kΩ - 25 kΩ Resistor[2] to VDD	0x45
THR_ADR = GND	0x46
THR_ADR = VDD	0x47

[1] 10-bit I²C peripheral addressing and General-Call (broadcast) addressing are not supported.

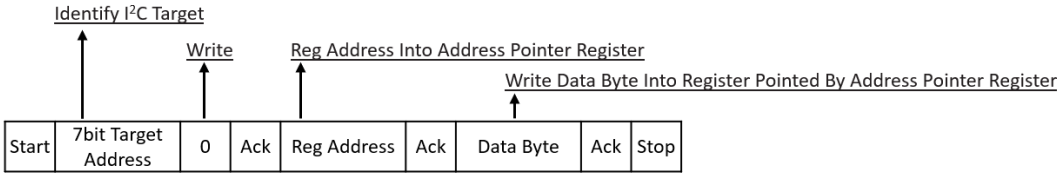
[2] Use a 10 kΩ resistor if used for address assignment only.

I²C Address Selection using THR_ADR

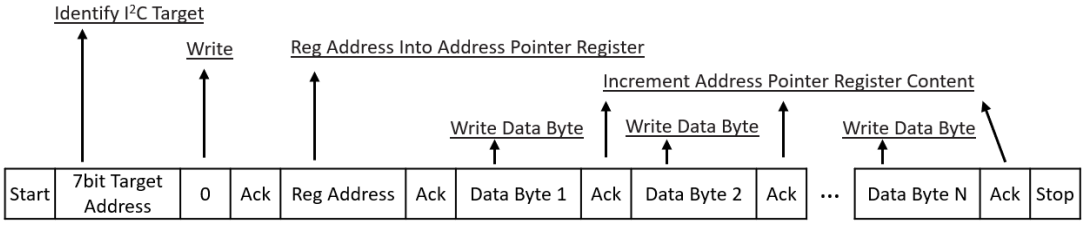
The AFE has an optional I²C timeout, which resets the bus if either the SCL or SDA signal line is low for ≥ 51 ms. It is recommended that the I²C interface is operated at speeds exceeding 100 kHz to ensure timely reading of the data for low latency AFE output processing. Latency is calculated as INTRSAMPLES x (WAIT+1) ms.

I²C bus signals (SDA and SCL) are open-drain and require external pull-up resistors per I²C specification. This is typically done with a 2 kΩ pull-up resistor (or greater for lower power operation). Series resistors in the signal path are optional to protect the AFE input architecture from high-voltage spikes on the bus lines, minimize crosstalk, and undershoot events of the bus signals. The supply voltage to the AFE should be less than or equal to the pull-up voltage for the I²C and INTB.

The I²C controller initiates all data transfer and generates the SCL clock signal. The AFE responds as a target device, supporting bidirectional communication on the SDA line. The AFE also supports single-byte and multi-byte burst transfers. Figure below shows the frame format for single-byte and multi-byte write and read transfers to and from the AFE.



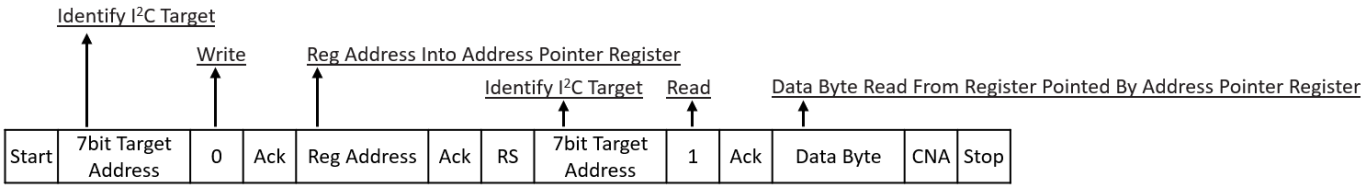
1 Byte Write



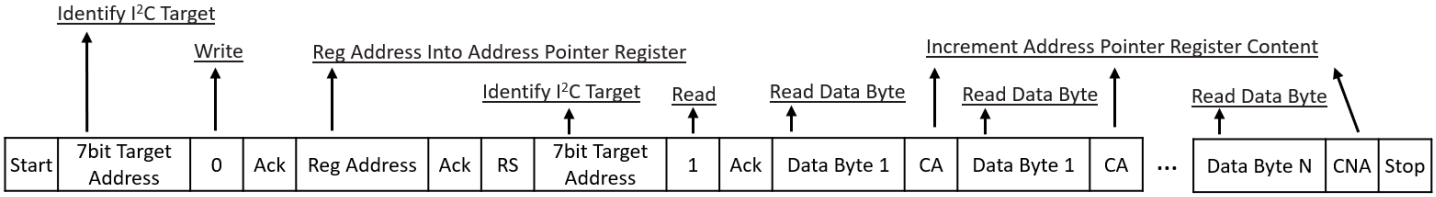
N Byte Write

Start	Start Condition From Controller
Ack	Acknowledgement Bit
Stop	Stop Condition From Controller

I²C Write



1 Byte Read



N Byte Read

RS	Repeated Start Condition From Controller
CA	Controller Acknowledgement
CNA	Controller Not Acknowledgement

I²C Read

Interrupt System

The INTB output enables autonomous AFE operation with minimal host intervention. The interrupt system supports flexible triggering conditions, debounce filtering, and configurable signal polarity to accommodate various interrupt controller architectures.

Interrupt Signal and Operation

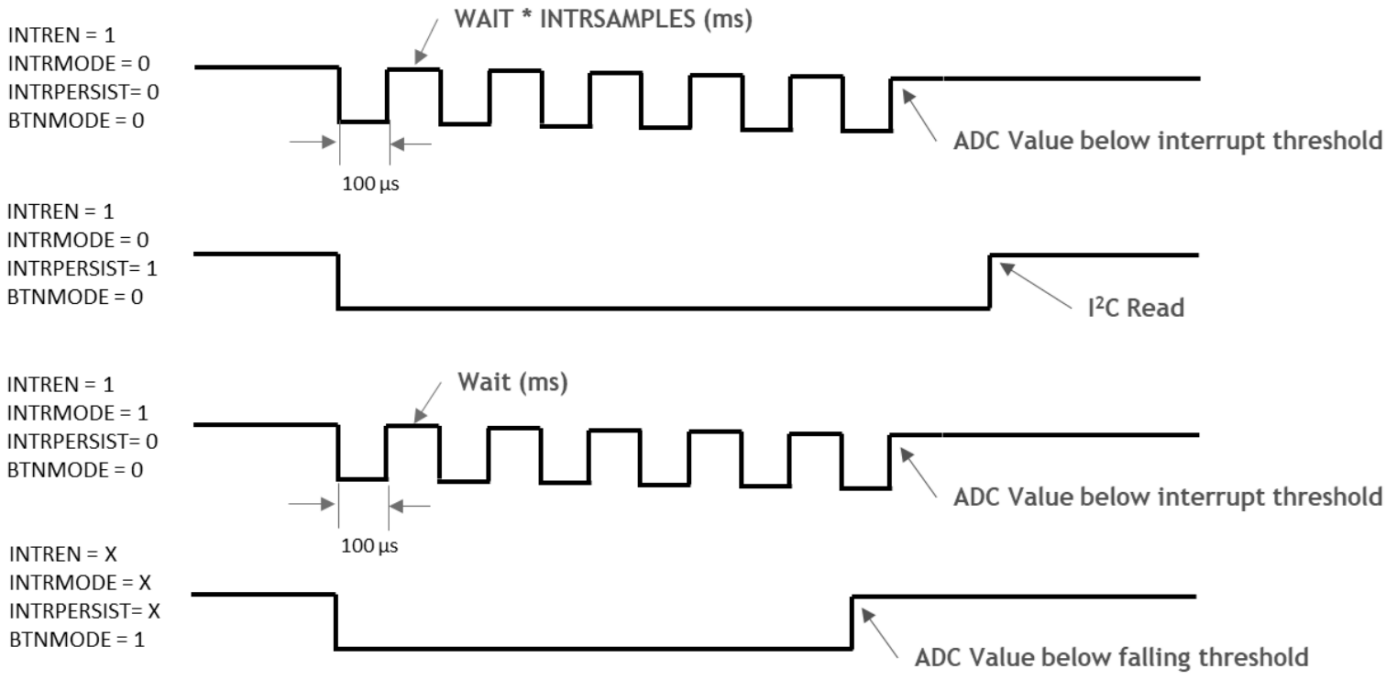
Interrupt output is open-drain and requires external pull-up resistor (10 kΩ or greater for low-power operation) to VDD. Interrupt polarity is configurable via INTRPOL register (0x09[3]). Default is active-low.

Interrupt Modes

The AFE has configurable interrupt modes (register addresses 0x0C-0x0E and 0x16-0x17), allowing different trigger conditions.
Interrupt is generated when the AFE measurement exceeds the programmed threshold set by INTRTHR registers (0x0C-0x0D) for a specified number of consecutive samples set by INTRSAMPLE (INTRMODE selects qualification mode).

Standard Mode (BTNMODE = 0):
INTB can be configured to either output 100 µs pulses (INTRPERSIST=0) for as long as the signal is above the threshold level or a constant level (INTRPERSIST=1) until the interrupt status register (0x02) is read by controller.

Button Mode (BTNMODE = 1):
Implements press-and-release detection with separate rising set by INTRTHR registers (0x0C-0x0D) and falling thresholds set by FALLTHR registers (0x16-0x17), providing hysteresis for stable button emulation.



Interrupt Modes

Hardware Programmable Interrupt Threshold

The AFE implements autonomous interrupt threshold configuration through an external resistor between THR_ADR pin and VDD or GND. This dual-function pin configures both the AFE I²C address and the AFE interrupt threshold (0x0C-0x0D) during power-on reset. The interrupt threshold can be overwritten by the controller if required.

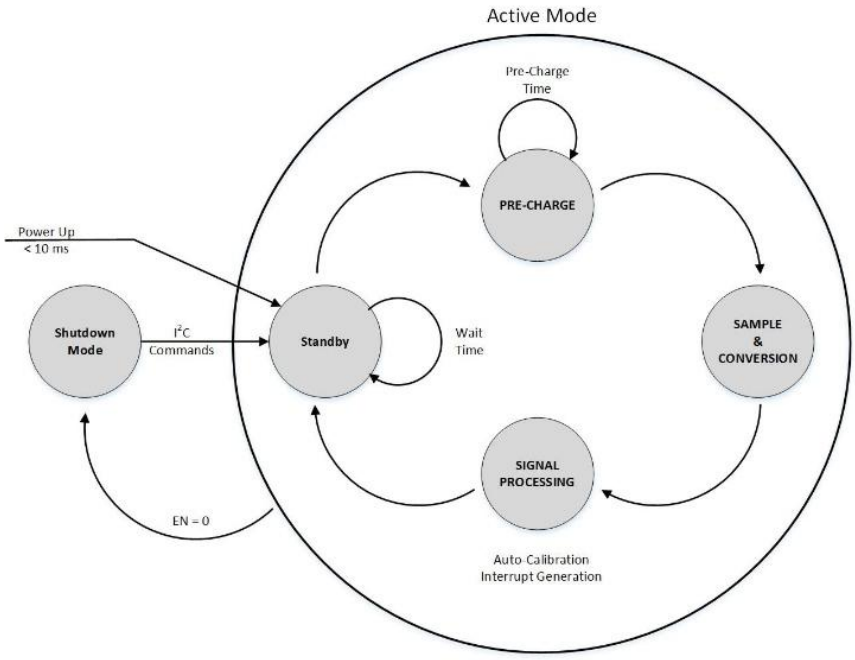
The relationship between external resistor value and programmed threshold follows the empirically derived transfer function:

External R [in KΩ] = 900/ INT threshold [in counts] – 0.7

1% E96 STANDARD RESISTOR VALUE (KΩ)	CALCULATED INT THRESHOLD (COUNTS)
5	158
10	84
24.9	35

States and Modes of Operation

The AFE implements a state machine architecture with two primary operating modes—Active Mode and Shutdown Mode—optimized for ultra-low-power operation in battery-powered and Always-On applications.



Shutdown Mode

Shutdown mode provides maximum power savings by completely disabling the analog front-end while retaining digital register contents (except PRELDADJ register) and I²C interface responsiveness, allowing the host to read configuration or initiate return to Active Mode via register write.

In this mode, PRELDADJ changes back to POR value when AUTOPRELDADJ is on. If AUTOPRELDADJ is off the value of PRELDADJ will be the last manually-written-in value or the POR, if it is never manually written.

To enter shutdown mode from active mode, disable AFE by writing a “0” to EN register.
When exiting shutdown mode (setting EN from 0 to 1), clear the INTREN and BTNMODE bits. Set both bits to zero before enabling the AFE. If

needed, re-enable these bits no earlier than Δt = 3 * (WAIT + PRECHARGE + 1) after setting EN to 1.

Active Mode

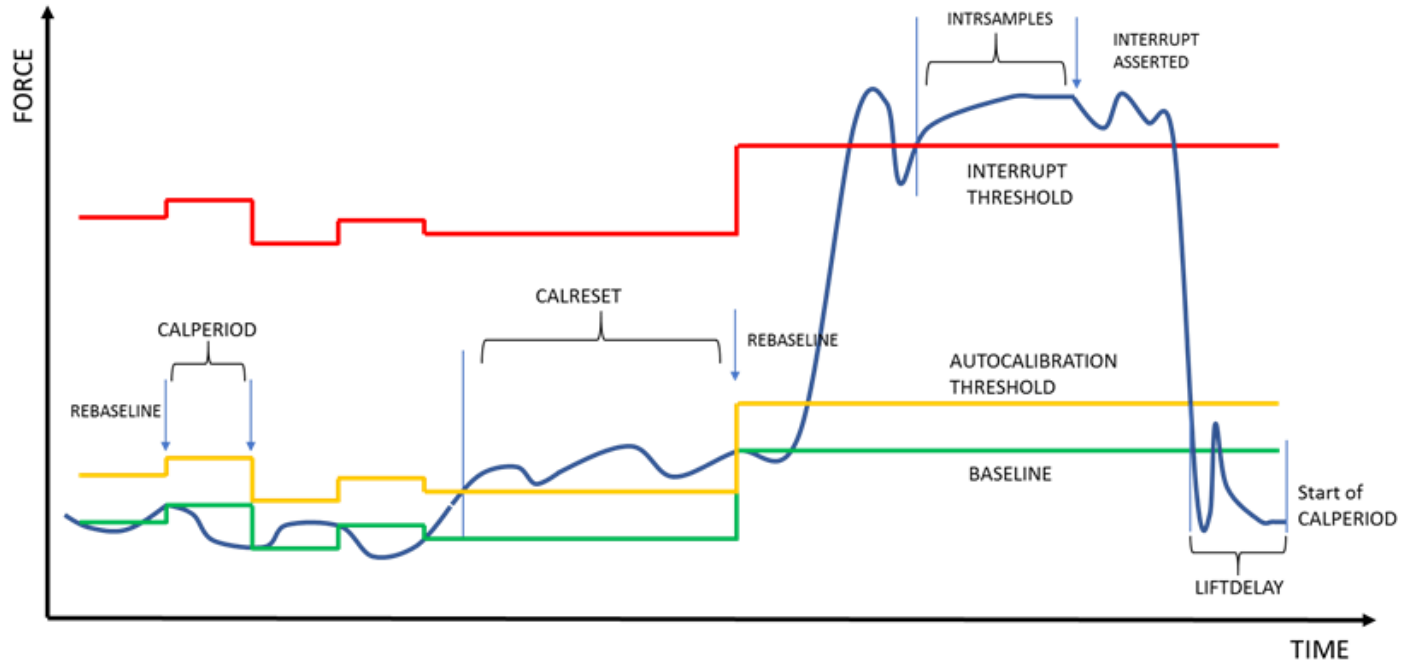
In active mode, the AFE performs periodic ADC conversions at specified intervals: WAIT+1 ms. Between conversions, the AFE enters a standby state where all analog circuitry powers down while retaining digital register contents and I²C interface responsiveness.

Baselined Data Output (ADCRAW=0, Default)
This mode implements automatic baseline tracking with continuous offset correction, suitable for applications requiring long-term stability, autonomous interrupt generation, and minimal host intervention.

In this mode, the output represents instantaneous force magnitude relative to a dynamically updated zero-force reference point (baseline): ADCOUT = Raw_ADC – BASELINE (in two's complement).
AUTOCAL and INTRTHR thresholds are referenced to current BASELINE value. Interrupt and auto-calibration threshold values shall be positive and interrupt threshold shall be higher than auto-calibration threshold value.

When the sensor signal is less than the AUTOCAL threshold, the baseline is updated at a rate specified by CALPERIOD and weight specified by RISEBLWGT and FALLBLWGT.
When the sensor signal exceeds the auto-calibration threshold, the baseline is updated at a rate specified by CALRESET and weight specified by RISEBLWGT. The auto-calibration and interrupt levels are referenced to the baseline value; therefore, baseline updates automatically change the stated thresholds. When the interrupt threshold is exceeded for the number of samples set by the INTRSAMPLE register (0x0E), an interrupt is asserted.

When the sensor signal is higher than the interrupt threshold, no auto-calibration is performed unless ENCALMODE is enabled. Once sensor signal drops below the auto-calibration threshold, the auto-calibration routine is re-enabled after a one-time delay defined by the LIFTDELAY register (0x0A).



Baselining, Auto-calibration & Interrupt Generation

Raw Data Output (ADCRAW=1)
Raw mode disables automatic baseline tracking and automatic offset correction, providing unprocessed ADC data for applications requiring custom signal processing algorithms or where baseline subtraction is performed in host software. This mode is essential for advanced filtering techniques.

In this mode, BASELINE = 0 and ADCOUT = Raw ADC Value (in two's complement). Output reflects absolute sensor capacitance with electrical offset and mechanical preload included. AUTOCAL and INTRTHR thresholds become absolute thresholds (not baseline-referenced). To make preload adjustments manually, AUTOPRELDADJ should be disabled (set to 0) and then adjustments made through PRELDADJ register.

Register map

REGISTER	BIT7	BIT6	BIT5	BIT4	BIT3	BIT2	BIT1	BIT0	ADDRESS	POR	R/W
CONFIGURATION & STATUS											
Main Configuration	TOEN	WAIT[2:0]			ADCRAW			EN	0x00	0XB5	R/W
Analog Configuration		INAGAIN[2:0]				PRECHARGE[2:0]			0x01	0x50	R/W
Status Register	BUSY				OVRINTRTH	OVRACALTH	SNSERR[1]	INTR[1]	0x02	0x00	R/RCLR
ADC READING											
ADC Sensor High Byte	ADCOUT[11:4]								0x03	0x00	R
ADC Sensor Low Byte & Sample Counter-12bit	ADCOUT[3:0]				SCOUNT[3:0]				0x04	0x00	R
AUTOCAL DEFINITION											
Autocal Threshold High Byte	AUTOCAL[11:4]								0x07	0x02	R/W
Autocal Threshold Low Byte	AUTOCAL[3:0]						AUTOPRELDADJ		0x08	0x02	R/W
Autocal Config-1 & Interrupt	ENCALMODE	CALRESET[2:0]			INTRPOL	CALPERIOD[2:0]			0x09	0X30	R/W
Autocal Config-2		RISEBLWGT[2:0]				LIFTDELAY[2:0]			0x0A	0x30	R/W
Autocal Config-3	PRELDADJ[4:0]					FALLBLWGT[2:0]			0x0B	0x03	R/W
INTERRUPT DEFINITION											
Interrupt Threshold High Byte	INTRTHR[11:4]								0x0C	0xXX	R/W
Interrupt Threshold Low Byte	INTRTHR[3:0]					FALLTHRSEL[2:0]			0x0D	0xX0	R/W
Interrupt Configuration	INTREN	INTRMODE	INTRPERSIST	BTNMODE		INTRSAMPLE[2:0]			0x0E	0x03	R/W
MISCELLANEOUS											
Baseline Control								FORCEBL	0x0F	0x00	R/W
Sensor Baseline High Byte	BASELINE[11:4]								0x12	0x00	R
Sensor Baseline Low Byte	BASELINE[3:0]								0x13	0x00	R
Falling Threshold High Byte	FALLTHR[11:4]								0x16	0x0C	R/W
Falling Threshold Low Byte	FALLTHR[3:0]								0x17	0x80	R/W
Device and Revision ID	DEVID[4:0]					REV[2:0]			0x80	0x11	R

[1]The SNSERR & INTR bit is cleared immediately after I²C read of the STATUS register.

Register Definitions

REGISTER ADDRESS	DATA BITS	BIT FIELD NAME	DEFAULT	DESCRIPTION	READ/ WRITE
0x00	Reg00[7]	TOEN	1b1	0: I²C time out disabled 1: I²C time out enabled. Time out=51.2 ms typ, resets the bus if there is no activity.	R/W
0x00	Reg00[6:4]	WAIT[2:0]	3b011	Wait period between successive force sensor samples. 000: 0 ms 001: 1 ms 010: 4 ms 011: 8 ms 100: 16 ms 101: 32 ms 110: 64 ms 111: 256 ms	R/W
0x00	Reg00[3]	ADCRAW	1b0	Indicates baselined or raw sensor ADC conversion. 0: Baselined ADC sensor measurement. In this mode, the baseline is subtracted from the raw sensor measurement in 2's complement. 1: Raw ADC sensor measurement in 2's complement.	R/W
0x00	Reg00[0]	EN	1b1	0: Disable sensor conversion, shutdown mode 1: Enable sensor conversion	R/W
0x01	Reg01[6:4]	INAGAIN[2:0]	3b101	Instrumentation amplifier gain selection. 000: x1 001: x8 010: x16 011: x31 100: x61 101: x115 110: x208 (recommend to set PRECHARGE ≥ 200 µs at this gain) 111: x416 (recommend to set PRECHARGE ≥ 400 µs at this gain)	R/W
0x01	Reg01[2:0]	PRECHARGE[2:0]	3b000	Sensor bridge settling time selection. The ADC will wait for this much time before conversion starts. 000: 50 µs 001: 100 µs 010: 200 µs 011: 400 µs 100: 800 µs 101: 1.6 ms 110: 3.2 ms 111: 6.4 ms	R/W
0x02	Reg02[7]	BUSY	1b0	Device boot in progress. ADC conversion is not accurate until boot is complete. 0: Boot done 1: Boot in progress	R
0x02	Reg02[3]	OVRINTRTH	1b0	The last ADC reading from sensor was above the interrupt threshold. 0: ADC reading under interrupt threshold 1: ADC reading over interrupt threshold	R
0x02	Reg02[2]	OVRACALTH	1b0	The last ADC reading from sensor was above the auto-calibration threshold. 0: ADC reading under auto-calibration threshold 1: ADC reading over auto-calibration threshold	R

REGISTER ADDRESS	DATA BITS	BIT FIELD NAME	DEFAULT	DESCRIPTION	READ/ WRITE
0x02	Reg02[1]	SNSERR	1b0	Status bit indicating an input fault condition, such as SPOS or SNEG shorted or un-shorted to VDD or GND. It generates an interrupt which is non-maskable. A read of the STATUS register clears this bit but does not clear the sensor error state. 0: No sensor error. 1: Sensor error. This bit needs to be cleared once before use. The bit is set after 1 ADC conversion cycle (WAIT)	RCLR
0x02	Reg02[0]	INTR	1b0	Status bit to indicate new sensor interrupt. A read of the STATUS register clears this bit and the hardware interrupt (if BTNMODE=0 and INTRPERSIST=1). This bit is set and cleared even if the INTREN bit is low. 0: No interrupt 1: Interrupt generated	RCLR
0x03	Reg03[7:0]	ADCOUT[11:4]	8b00000000	Digitized 2's complement sensor ADC out, -2048 to +2047	R
0x04	Reg04[7:4]	ADCOUT[3:0]	4b0000		
0x04	Reg04[3:0]	SCOUNT[3:0]	4b0000	ADC sample counter. Wraparound sample counter increments by 1 after each sample. Used to assist data timestamping & algorithm post-processing. Associated with ADC data reading.	R
0x07	Reg07[7:0]	AUTOCAL[11:4]	8b00000010	Auto-calibration threshold setting for sensor in 2's complement. Always use positive values (MSB first) and it shall be lower than Interrupt threshold value.	R/W
0x08	Reg08[7:4]	AUTOCAL[3:0]	4b0000		
0x08	Reg08[1]	AUTOPRELDADJ	1b1	Automatic offset adjustments. When enabled, the PRELDADJ[4:0] is automatically set to minimize offset. Whenever the baseline is above 1280 ADC counts then it is reduced to below it and if the baseline is below -1793 ADC counts then it is increased to above it, using PRELDADJ. 0: Disabled 1: Enabled	R/W
0x09	Reg09[7]	ENCALMODE	1b0	CALRESET trigger zone and weight selection. ENCALMODE = 0 is recommended for cases with very long press and ENCALMODE = 1 is recommended for button applications as it helps to recover a stuck condition. 0: CALRESET timeout triggers auto-calibration when sensor readings are between AUTOCAL threshold and INTRTHR threshold. Uses RISEBLWGT at intervals of CALRESET to recover. 1: CALRESET timeout triggers auto-calibration when sensor readings are above AUTOCAL threshold. Uses RISEBLWGT at intervals of CALRESET to recover.	R/W
0x09	Reg09[6:4]	CALRESET[2:0]	3b011	Defines timeout before triggering baseline recalibration when sensor measurement remain above auto-calibration threshold. Upon expiry of this timer, the new baseline value is calculated based on ENCALMODE and RISEBLWGT. 000: 0.5 s 001: 1 s 010: 2 s 011: 4 s 100: 8 s 101: 16 s 110: 32 s 111: Infinite (no reset, unless forced)	R/W
0x09	Reg09[3]	INTRPOL	1b0	Interrupt polarity. 0: INTB pin active low (recommended) 1: INTB pin active high	R/W

REGISTER ADDRESS	DATA BITS	BIT FIELD NAME	DEFAULT	DESCRIPTION	READ/ WRITE
0x09	Reg09[2:0]	CALPERIOD [2:0]	3b000	Auto-calibration timeout. Defines the time interval for auto-calibration operation when the sensor measurement is below auto-calibration threshold. 000: 100 ms 001: 200 ms 010: 400 ms 011: 800 ms 100: 1600 ms 101: 3200 ms 110: 6400 ms 111: Infinite (no recalibration, unless forced)	R/W
0x0A	Reg0A[6:4]	RISEBLWGT[2:0]	3b011	Defines the weight of the current baseline to compute the new baseline on CALPERIOD expiry, when the sensor measurement is higher than current baseline. Higher values make the baseline change slower. ((current baseline)(RISEBLWGT) + current ADC reading)/(RISEBLWGT +1) 000: 0 001: 1 010: 3 011: 7 100: 15 101: 31 110: 63 111: 127	R/W
0x0A	Reg0A[2:0]	LIFTDELAY[2:0]	3b000	Defines the wait period before resuming baselining after the sensor value falls below the auto-calibration threshold following an interrupt threshold exceedance. 000: 0 ms 001: 20 ms 010: 40 ms 011: 80 ms 100: 160 ms 101: 320 ms 110: 640 ms 111: 460 ms	R/W
0x0B	Reg0B[7:3]	PRELDADJ[4:0]	5b00000	5-bit sensor offset adjustment; MSB is sign bit. It is read-only when AUTOPRELDADJ = 1. 3.1mV/LSB for FT-4x00 & 3.3mV/LSB for FT-7600	R/W
0x0B	Reg0B[2:0]	FALLBLWGT[2:0]	3b011	Defines the weight of the current baseline to compute the new baseline on CALPERIOD expiry, when the sensor measurement is lower than current baseline. Higher values make the baseline change slower. ((current baseline)(FALLBLWGT) + current ADC reading)/(FALLBLWGT +1) 000: 0 001: 1 010: 3 011: 7 100: 15 101: 31 110: 63 111: 127	R/W
0x0C	Reg0C[7:0]	INTRTHR[11:4]	8bXXXXXXXX	Interrupt threshold setting for sensor in 2's complement when signal is rising. Default value corresponds to the resistance on the THR_ADR pin. Always use positive values (MSB first). Do not set INTRTHR lower than AUTOCAL.	R/W
0x0D	Reg0D[7:4]	INTRTHR[3:0]	4bXXXX		

REGISTER ADDRESS	DATA BITS	BIT FIELD NAME	DEFAULT	DESCRIPTION	READ/ WRITE
0x0D	Reg0D[2:0]	FALLTHRSEL[2:0]	3b000	Falling threshold when BTNMODE=1. Defined as fraction of falling threshold value (FALLTHR[11:0] register 0x16/0x17), when: 000: FALLTHR[11:0] X 1 Defined as fraction of interrupt threshold value (INTRTHR[11:0] register 0x0C/0x0D), when: 001: INTRTHR[11:0] X 0.25 010: INTRTHR[11:0] X 0.375 011: INTRTHR[11:0] X 0.5 100: INTRTHR[11:0] X 0.625 101: INTRTHR[11:0] X 0.75 110: INTRTHR[11:0] X 0.875 111: INTRTHR[11:0] X 1	R/W
0x0E	Reg0E [7]	INTREN	1b0	Determines if the INTB pin is driven with the sensor measurements. Does not mask the INTR status bit. Clear this bit (set to 0) before exiting shutdown (EN set to 1). If needed, re-enable no earlier than Δt = 3 * (WAIT + PRECHARGE + 1) after setting EN to 1. 0: INTB pin not driven upon interrupt, unless BTNMODE = 1 1: INTB pin driven upon interrupt	R/W
0x0E	Reg0E[6]	INTRMODE	1b0	Interrupt mode. Controls if interrupt is generated by each sensor ADC conversion or after meeting the INTRSAMPLE requirement. 0: Uses INTRSAMPLE to qualify interrupt 1: Interrupt generated after each sensor ADC conversion if the sample value is above interrupt threshold	R/W
0x0E	Reg0E[5]	INTRPERSIST	1b0	Sets how long interrupt is pulled low. 0: 100 µs interrupt pulse 1: Infinite, until the Status register is read	R/W
0x0E	Reg0E[4]	BTNMODE	1b0	Enable button mode. Clear this bit (set to 0) before exiting shutdown (EN set to 1). If needed, re-enable no earlier than Δt = 3 * (WAIT + PRECHARGE + 1) after setting EN to 1. 0: Disable button mode, see “Interrupt Modes” section for detail. 1: Enable button mode, falling threshold to de-assert interrupt.	R/W
0x0E	Reg0E[2:0]	INTRSAMPLE[2:0]	3b011	Number of samples above interrupt threshold after which an interrupt is asserted (and de-asserted when BTNMODE=1). 000: 1 001: 1 010: 2 011: 3 100: 4 101: 5 110: 6 111: 7	R/W
0x0F	Reg0F[0]	FORCEBL	1b0	Force baseline (ADC reading transferred to Baseline). 0: Auto-Baseline enabled 1: Forces baseline to the next sensor ADC reading. This bit is automatically reset after the baseline is updated.	R/W
0x12	Reg12[7:0]	BASELINE[11:4]	8b00000000	Digitized 2’s complement sensor baseline data, -2048 to +2047	R
0x13	Reg13[7:4]	BASELINE[3:0]	4b0000		
0x16	Reg16[7:0]	FALLTHR[11:4]	8b00001100	Interrupt threshold setting to de-assert INTB for sensor in 2’s complement when signal is falling, BTNMODE=1, and FALLTHRSEL[2:0]=000. Only writable when FALLTHRSEL[2:0]=000, read-only otherwise.	R/W
0x17	Reg17[7:4]	FALLTHR[3:0]	4b1000		
0x80	Reg80[7:3]	DEVID[4:0]	5b00010	Identifier for sensor	R
0x80	Reg80[2:0]	REV[2:0]	3b001	Revision identifier	R

Sample Code

I²C WRITE

```
u8 ni_i2c_write(struct ni_sensor_t s, u8 reg, u8 length, u8 *data)
{
u8 error = NI_OK;

//ATTENTION: FOLLOWING CODE SNIPPET IS AN EXAMPLE
//FOR ATMEL STUDIO, USER SHOULD CHANGE IT TO
//WORK ON THEIR PLATFORM.

u8 i;
u8 status;
u8 buffer[length+2];

buffer[0] = s.addr << 1;
buffer[1] = reg;

for(i=0; i<length; i++) {
 buffer[i+2] = data[i];
}

status = USI_TWI_Start_Transceiver_With_Data(buffer, length+2);
USI_TWI_Master_Stop();

if (status == 0) {
 error = NI_ERROR_COM;
}

//END CODE SNIPPET

return error;
}
```

I²C READ

```
u8 ni_i2c_read(struct ni_sensor_t s, u8 reg, u8 length, u8 *data)
{
u8 error = NI_OK;

//ATTENTION: FOLLOWING CODE SNIPPET IS AN
//EXAMPLE FOR ATMEL STUDIO, USER SHOULD
//CHANGE IT TO WORK ON THEIR PLATFORM.

u8 i;
u8 status;
u8 buffer[length+1];

buffer[0] = s.addr << 1;
buffer[1] = reg;

//USI_TWI_Start_Transceiver returns 0 if unsuccessful
status = USI_TWI_Start_Transceiver_With_Data(buffer, 2);

if (status == 0) {
 error = NI_ERROR_COM;
 return error;
}

//Read from registers
buffer[0] = (s.addr << 1) | 1;
status = USI_TWI_Start_Transceiver_With_Data(buffer, length+1);
USI_TWI_Master_Stop();

if (status == 0) {
 error = NI_ERROR_COM;
 return error;
}

//Copy read values from buffer into data
for(i=0; i<length; i++) {
 data[i] = buffer[i+1];
}

//END CODE SNIPPET

return error;
}
```

Electrical Design, Layout, Placement, Handling and Package Information

Electrical Design Considerations

The AFE is a sensitive mixed-signal device. All routing, bypassing, and component placement practices described in this section are intended to preserve signal integrity, minimize noise coupling, and ensure reliable AFE operation across the operating temperature and supply-voltage range.

- Power all analog circuitry from a low-noise supply source, preferably a dedicated on-board LDO.
- Match the SPOS and SNEG trace lengths and minimize parasitic asymmetry between the sensor and the AFE differential inputs.
- Add a 1 nF differential filter capacitor (highlighted in the table below) between SPOS and SNEG and place the differential capacitor close to the differential inputs of the AFE.

The differential capacitor value affects both sensor power-on settling time and the analog noise-filter cut-off frequency. After DRV from AFE is applied to the sensor, the AFE must wait (PRECHARGE register should be programmed to accommodate this external RC time constant) for the sensor to settle before sampling. Sensor power-on settling time and noise-filter cut-off frequency as a function of capacitor value are tabulated in the table below for the FT-4x00 sensor.

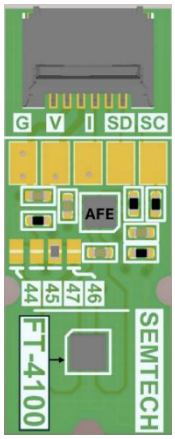
DIFFERENTIAL CAPACITOR	SENSOR POWER-ON TIME (2.3 * R * C)	NOISE FILTER CUT-OFF FREQUENCY $(2\pi*R*C)^{-1}$
0.1 nF	1.73 µs	212 kHz
1 nF	**17.3 µs**	**21.2 kHz**
33 nF	569 µs	643 Hz
0.1 µF	1.73 ms	212 Hz
0.33 µF	5.69 ms	64.3 Hz

Power-On Time & Noise Filter Cut-Off Frequencies for FT-4x00

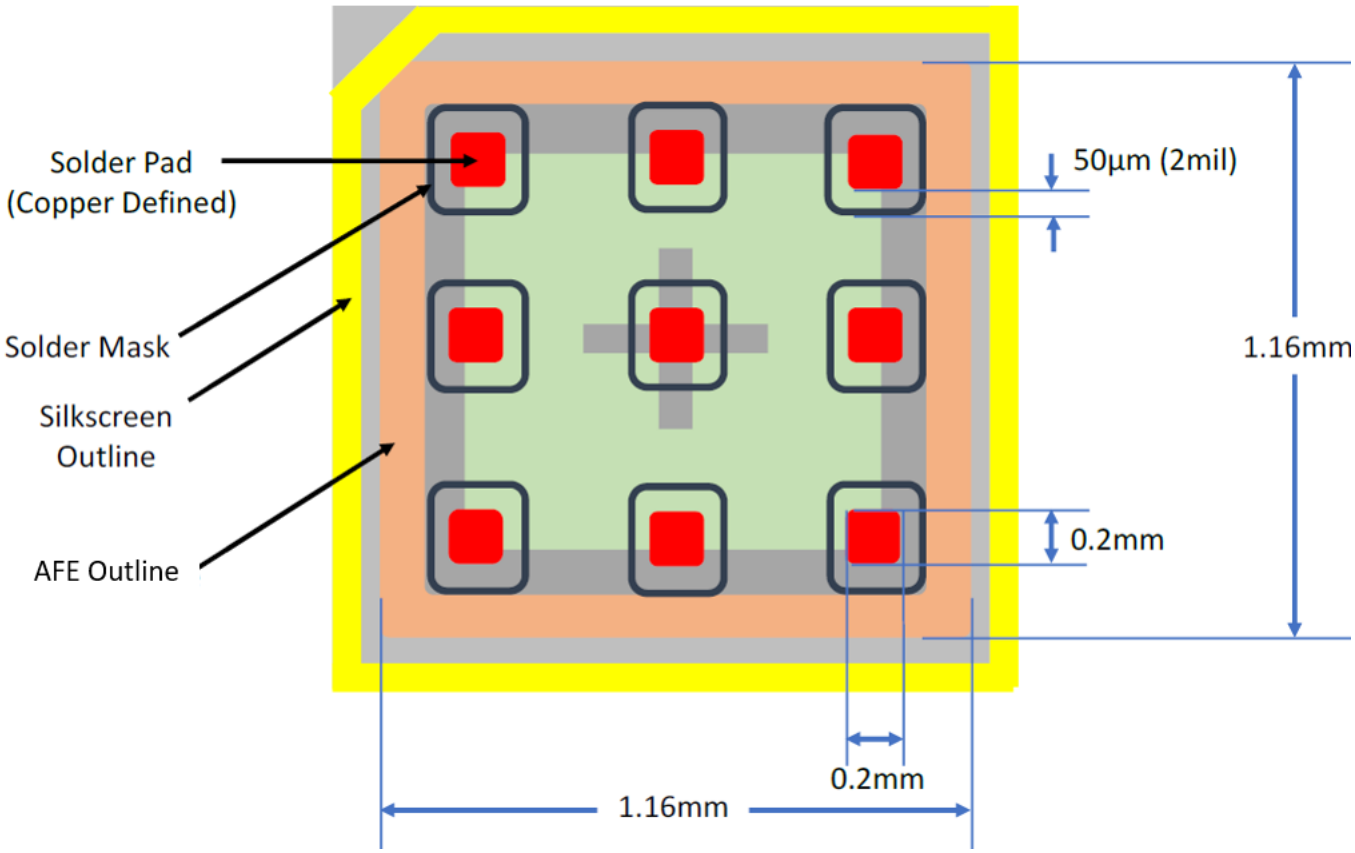
For offset and temperature coefficient of offset (TCO) tuning using R_{PV}, R_{PS}, R_{NS} and R_{NV} resistor network, contact Semtech for details.

PCB Layout Best Practices

- Two bypass capacitors are required, 2.2 µF & 1 nF, to reduce noise on the power supply. Use higher value bypass capacitors for noisy power supplies. Ensure that both capacitors are placed close to the AFE VDD pin – ***REQUIRED***.
- Do not use vias directly under the sensor solder balls.
- Keep signal lines short and free of 90° turns (steep angles/corners can cause undesired acid traps during the manufacturing process). Use 45° turns or rounded-edge-turns for all signal/power lines.
- For additional stability consider implementing “teardrop” routing into vias, pin pads and T-junctions; this increases the copper area and avoids steep angles in areas where multiple traces meet in a common point.
- Power the AFE from a dedicated on-board low-noise LDO regulator to minimize supply-induced noise coupling.
- Route sensitive signal and power lines away from high-speed digital clock and digital interface lines.
- Recommend greater than (or equal) 6 mil traces for all signals.
- For applications using Semtech FT-4x00 analog force sensors in combination with Semtech AFE, keep clearance between all adjacent components and sensor rubber.



Footprint and SMT Details



Recommended Footprint

The figure above shows the recommended footprint for the AFE. The parameters below are recommended for SMT.

- Pad dimensions and type
  - Rounded rectangle with dimensions **7.874 mil x 7.874 mil (0.2 mm x 0.2 mm)**
  - Radius of the rounded square pad: **Corner radius of 0.05 mm (not a circular pad)**
  - Copper defined, ***not*** **solder-mask defined**
- Solder mask: **2 mil (50 µm) wider on all sides of the pad**.
- Solder paste stencil thickness: **3 mil (76 µm)**
- Solder paste stencil aperture: **1:1 with the copper pad (0.2 mm x 0.2 mm)**
- Solder Paste: **SAC305 or SAC405**

Device Handling – Best Practices

- Do not pick up the device with metal tweezers. Use a vacuum pickup tool.
- Do not “snap” panelized, assembled PCBs.
- Follow ESD-safe handling recommendations:
  - Store sensors in ESD containers (e.g. T&R, moisture-sealed)
  - Handle devices only in ESD-safe work areas
  - People /machines handling the sensor must be grounded to avoid potential ESD damage

SMT Pick and Place Guidelines

Nozzle Considerations

SMT assembly machines typically employ a vacuum nozzle for Pick & Place (P&P) operations. Not all equipment is the same, but there are some general guidelines to follow, for optimal performance/yield.

- Select a vacuum nozzle only.
  - DO NOT use mechanical grippers or collets that contact the edges/sides of a WLCSP.
  - DO NOT handle WLCSP parts with metal tweezers.
- Select softer nozzle materials where possible.
  - Nozzle materials can vary (metal, ceramic, plastic, rubber), and certain equipment requires certain nozzle materials. Select softer material to avoid potential damage from mechanical shocks.
- Select an appropriate nozzle tip shape.
  - Nozzle tip shape can affect the amount of pressure applied to a single point on a WLCSP part.
  - Nozzle tips should be circular, square/rectangular, and preferably with a vertical separator.
  - The nozzle tip surface should be a single plane; do not use a nozzle with a protruded edge.

Acceptable Vs NOT acceptable Tip Shapes

- Select an appropriate nozzle tip size, for the part being placed.
  - The largest tip dimension should be smaller than the size of the WLCSP part.
  - The tip should account for the tolerance of the pick accuracy, so that it's not possible for the nozzle tip to contact the edge or the corner of a part.
  - The tip size should be as large as possible, while satisfying the above 2 points.

Pick and Place Operation

The P&P operation consists of two key steps: picking a part out of the carrier tape pocket, and placement of that part onto a circuit board. Both operations are performed with some alignment tolerance: nozzle-to-part tolerance during the pick, and part-to-board alignment during the placement. Additionally, the placement should occur with as little force as possible, to press the die into place on the board.

WLCSP parts are shipped to customers in standard carrier tape & reel packaging. Parts sit in a pocket that is slightly larger than the size of the part. A part can move laterally inside the pocket, typically by less than 0.1 mm, but this varies by product.

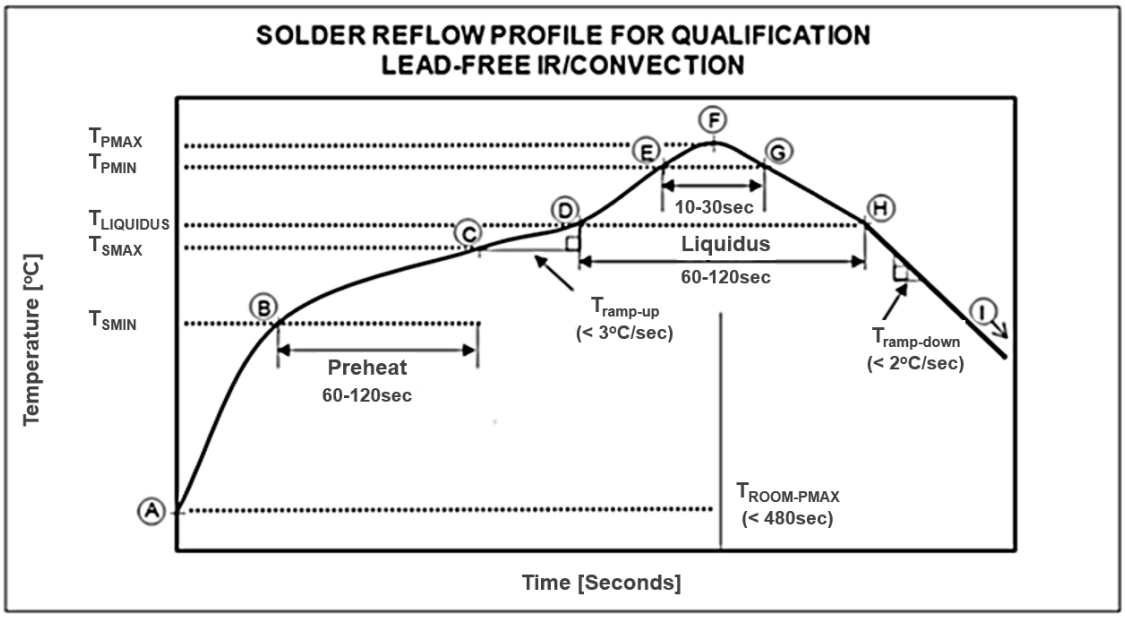
- If available, the P&P equipment should use a vision detection system to align the P&P nozzle to the center of the die, for every part picked.
- If a vision alignment system isn't available, the nozzle size selection should account for the positional tolerance of the WLCSP part in the carrier tape pocket.

The die placement operation shall be performed with a placement accuracy of ≤0.1 mm; placement accuracy of ≤0.05 mm is typical with modern P&P equipment. The placement force shall be the minimum required to bring the WLCSP solder bumps into contact with the solder paste on the board.
A contactless vacuum pickup is strongly preferred; the vacuum force alone should lift the part with only incidental surface contact to the die top.

- Use air-ejection placement in preference to contact placement. A typical air-ejection pressure is 150 mbar.
- If air placement isn't available, use a contact mode for the part placement. Ensure that both the pick and placement force is not larger than 2 N (~200 gf). Placement forces should be verified periodically using a calibrated load cell, to ensure parts aren't placed with a force over this specification.

Assembly Instructions

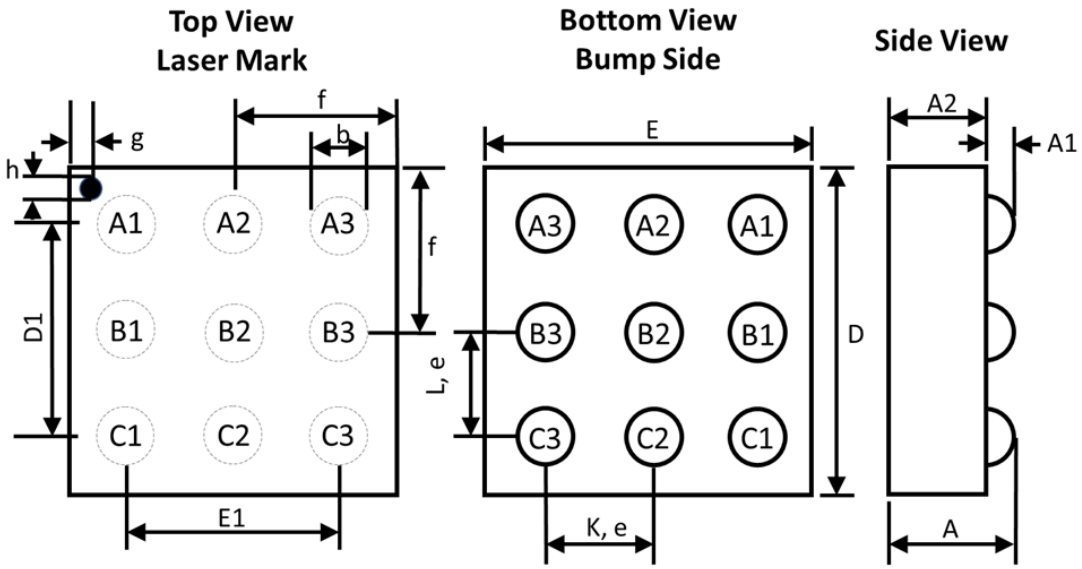
The chip is designed to be reflow-soldered using direct-chip attachment (DCA) techniques to the circuit substrate (e.g. FR-4 or FPC) and reflow profile that is designed for RoHS and Pb-free compliance (see the profile below). Assembly houses should follow this profile closely but can choose more conservative ramp-up/down rates. To avoid damage to the chip do not exceed the maximum ratings of the qualification profile (e.g. TPMAX = 260 °C, measured at the top side of the WLCSP). Customers must verify with their assembly house for the appropriate reflow profile.



Soldering Profile for Reflow Assembly

STEP	PARAMETER	TEMPERATURE [°C]	TIME [S]	MAXIMUM RATE [°C/S]
A	T_{ROOM}	25		
B	T_{SMIN}	150		
C	T_{SMAX}	200	60 < t_BC < 120	
D	$T_{LIQUIDUS}$	217		r (T_{PMAX} - $T_{LIQUIDUS}$) < 3
E	T_{PMIN} [255 °C, 260 °C]	255		r (T_{PMAX} - $T_{LIQUIDUS}$) < 3
F	T_{PMAX} [260 °C, 265 °C]	260	t_AF < 480	r (T_{PMAX} - $T_{LIQUIDUS}$) < 3
G	T_{PMIN} [255 °C, 260 °C]	255	10 < t_EG < 30	r (T_{PMAX} - $T_{LIQUIDUS}$) < 2
H	$T_{LIQUIDUS}$	217	60 < t_DH < 120	
I	T_{ROOM}	25		

Mechanical Information

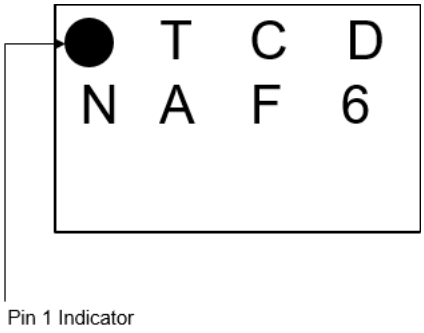


SYMBOL	MIN.	NOM.	MAX.	NOTES
A	0.435	0.475	0.515	Overall height
A1	0.137	0.157	0.177	Solder ball height
A2	0.298	0.318	0.338	Body thickness
D	1.12	1.16	1.20	Body size
D1	0.79	0.80	0.81	Solder ball footprint
E	1.12	1.16	1.20	Body size
E1	0.79	0.80	0.81	Solder ball footprint
-		9		Number of solder balls
b	0.18	0.21	0.24	Solder ball diameter; measured at the maximum solder ball diameter
e	0.395	0.400	0.405	Solder ball pitch
f	0.56	0.58	0.60	Package edge to center solder ball
g	0.10	0.15	0.20	Pin 1 ID to package edge
h	0.05	0.10	0.15	Pin 1 ID diameter
K	0.395	0.400	0.405	Center solder ball to corner solder ball (center), X
L	0.395	0.400	0.405	Center solder ball to corner solder ball (Center), Y

Note: All dimensions are in mm unless otherwise specified; dimensions and tolerances conform to ANSI Y14.5M-1982.

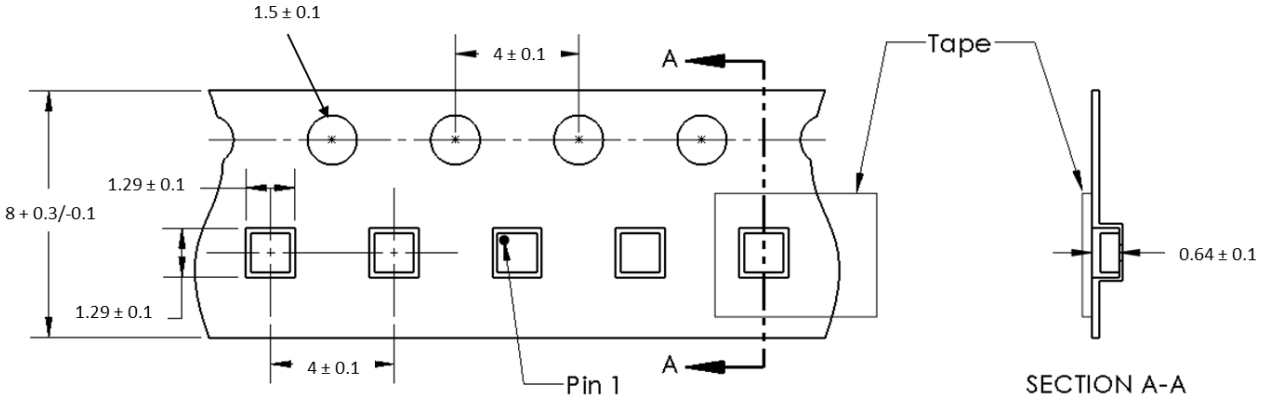
Product Marking

The product marking consists of 3 rows of letters and numbers printed on the top of WLCSP package.



Product Marking - Line1: Trace Code, Line2: Product ID

Tape and Reel Information



All dimensions and tolerances in this tape and reel diagram are in mm.

The image below depicts a tape reel sealed in an ESD-protective bag. The diameter of the sensor reel measures 7 inches (Radius = 3.5 inches) with reel thickness of 0.25 inches to comfortably host the tape. Each reel is stamped with the company logo, part number, lot number, and date code.

Reliability and Environmental Information

The Semtech sensor meets Level 1 (unlimited) Moisture Sensitivity Level (MSL) specifications.

Reliability and Environmental reports are furnished upon request.

GLOSSARY (Alphabetical Order)

Analog-To-Digital Converter (ADC) – Circuit that converts an analog input to a digital output, with the data either transmitted serially or parallel. An ADC's resolution (in bits) usually determines the smallest step size an application can resolve an incoming signal to.

Analog Front End (AFE) – The AFE is a set of analog signal conditioning circuits that uses an input mux, sensitive instrumentation amplifiers and a high-resolution differential ADC allowing Semtech's analog force sensors to interface directly with a microcontroller.

CDM (Charge Device Model) – CDM is a model for characterizing the susceptibility of an electronic device to damage from electrostatic discharge (ESD). CDM is commonly used for semiconductor devices and has been standardized in JEDEC with JEDEC JS-002.

HBM (Human Body Model) – HBM is the most used model for characterizing the susceptibility of an electronic device to damage from electrostatic discharge (ESD). The model simulates an ESD discharge that may occur when a human contacts an electronic device.

I^2C Timeout – This is the maximum time period during which the I^2C bus can remain idle before it automatically resets.

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION/CHANGES	PAGES CHANGED
1	04/08/2026	New Release	NA

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