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FEATURES

- Programmable capacitance-to-digital converter (CDC)
 - Femtofarad resolution
 - 13 capacitance sensor inputs
 - 9 ms update rate, all 13 sensor inputs
 - No external RC components required
 - Automatic conversion sequencer
- On-chip automatic calibration logic
 - Automatic compensation for environmental changes
 - Automatic adaptive threshold and sensitivity levels
- Register map is compatible with the [AD7142](#)
- On-chip RAM to store calibration data
- SPI-compatible (serial-peripheral-interface-compatible) serial interface ([AD7147](#))
- I²C-compatible serial interface ([AD7147-1](#))
- Separate V_{DRIVE} level for serial interface
- Interrupt output and general-purpose input/output (GPIO)
- 24-lead, 4 mm × 4 mm LFCSP
- 2.6 V to 3.3 V supply voltage
- Low operating current
 - Full power mode: 1 mA
 - Low power mode: 21.5 μA
- Qualified for automotive applications

APPLICATIONS

- Cell phones
- Personal music and multimedia players
- Smart handheld devices
- Television, A/V, and remote controls
- Gaming consoles
- Digital still cameras

GENERAL DESCRIPTION

The [AD7147](#) CapTouch™ controller is designed for use with capacitance sensors implementing functions such as buttons, scroll bars, and wheels. The sensors need only one PCB layer, enabling ultrathin applications.

The [AD7147](#) is an integrated CDC with on-chip environmental calibration. The CDC has 13 inputs channeled through a switch matrix to a 16-bit, 250 kHz sigma-delta (Σ - Δ) converter. The CDC is capable of sensing changes in the capacitance of the external sensors and uses this information to register a sensor activation. By programming the registers, the user has full control over the CDC setup.

High resolution sensors require minor software to run on the host processor.

Rev. E

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FUNCTIONAL BLOCK DIAGRAM

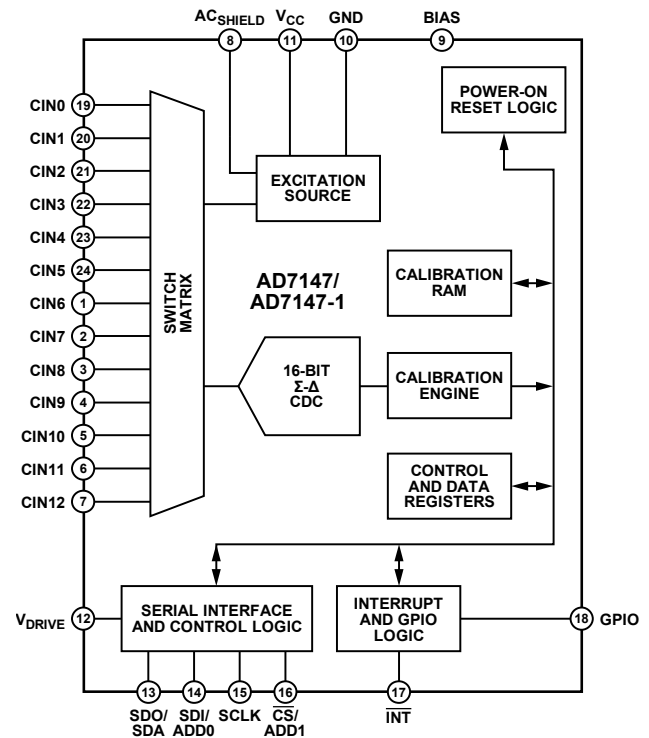


Figure 1.

The [AD7147](#) is designed for single electrode capacitance sensors (grounded sensors). There is an active shield output to minimize noise pickup in the sensor.

The [AD7147](#) has on-chip calibration logic to compensate for changes in the ambient environment. The calibration sequence is performed automatically and at continuous intervals as long as the sensors are not touched. This ensures that there are no false or nonregistering touches on the external sensors due to a changing environment.

The [AD7147](#) has an SPI-compatible serial interface, and the [AD7147-1](#) has an I²C®-compatible serial interface. Both parts have an interrupt output, as well as a GPIO. There is a V_{DRIVE} pin to set the voltage level for the serial interface independent of V_{CC}.

The [AD7147](#) is available in a 24-lead, 4 mm × 4 mm LFCSP and operates from a 2.6 V to 3.6 V supply. The operating current consumption in low power mode is typically 26 μA for 13 sensors.

AD7147* PRODUCT PAGE QUICK LINKS

Last Content Update: 02/23/2017

COMPARABLE PARTS

View a parametric search of comparable parts.

EVALUATION KITS

- EVAL-AD7147 & EVAL-AD7147-1 Evaluation Boards

DOCUMENTATION

Application Notes

- AN-925: Sensors for the AD7147 and AD7148 CapTouch® Controllers
- AN-929: Tuning the AD714x for CapTouch® Applications
- AN-957: Layout Guidelines for the AD7147 and AD7148 CapTouch® Controllers

Data Sheet

- AD7147: CapTouch Programmable Controller for Single-Electrode Capacitance Sensors Data Sheet

Product Highlight

- Leading Inside Advertorials: Providing an Edge in Capacitive Sensor Applications

SOFTWARE AND SYSTEMS REQUIREMENTS

- AD714X Input CapTouch® Programmable Controller Linux Driver

REFERENCE MATERIALS

Technical Articles

- MS-2210: Designing Power Supplies for High Speed ADC

DESIGN RESOURCES

- AD7147 Material Declaration
- PCN-PDN Information
- Quality And Reliability
- Symbols and Footprints

DISCUSSIONS

View all AD7147 EngineerZone Discussions.

SAMPLE AND BUY

Visit the product page to see pricing options.

TECHNICAL SUPPORT

Submit a technical question or find your regional support number.

DOCUMENT FEEDBACK

Submit feedback for this data sheet.

TABLE OF CONTENTS

Features	1	Capacitance Sensor Behavior Without Calibration.....	24
Applications.....	1	Threshold Equations.....	25
General Description	1	Capacitance Sensor Behavior with Calibration.....	25
Functional Block Diagram	1	Slow FIFO.....	25
Revision History	3	SLOW_FILTER_UPDATE_LVL.....	26
Specifications.....	4	Adaptive Threshold and Sensitivity	27
Average Current Specifications	5	Interrupt Output.....	29
SPI Timing Specifications (AD7147)	6	CDC Conversion-Complete Interrupt	29
I ² C Timing Specifications (AD7147-1).....	7	Sensor-Touch Interrupt.....	29
Absolute Maximum Ratings.....	8	GPIO $\overline{\text{INT}}$ Output Control	31
ESD Caution.....	8	Outputs	33
Pin Configurations and Function Descriptions	9	AC _{SHIELD} Output	33
Typical Performance Characteristics	10	General-Purpose Input/Output (GPIO)	33
Theory of Operation	12	Using the GPIO to Turn On/Off an LED.....	33
Capacitance Sensing Theory.....	12	Serial Interface	34
BIAS Pin.....	13	SPI Interface	34
Operating Modes.....	13	I ² C-Compatible Interface	36
Capacitance-to-Digital Converter.....	15	V _{DRIVE} Input	38
Oversampling the CDC Output	15	PCB Design Guidelines	39
Capacitance Sensor Offset Control.....	15	Capacitive Sensor Board Mechanical Specifications	39
Conversion Sequencer	15	Chip Scale Packages	39
CDC Conversion Sequence Time	17	Power-Up Sequence	40
CDC Conversion Results.....	17	Typical Application Circuits	41
Capacitance Sensor Input Configuration.....	18	Register Map	42
CINx Input Multiplexer Setup.....	18	Detailed Register Descriptions	43
Single-Ended Connections to the CDC	18	Bank 1 Registers	43
Noncontact Proximity Detection	19	Bank 2 Registers	53
Recalibration	19	Bank 3 Registers	58
Proximity Sensitivity	19	Outline Dimensions	70
FF_SKIP_CNT.....	22	Ordering Guide	70
Environmental Calibration	24	Automotive Products.....	70

REVISION HISTORY

1/15—Rev. D to Rev. E

Updated Outline Dimensions.....70
 Changes to Ordering Guide.....70

9/11—Rev. C to Rev. D

Changes to Ordering Guide.....70

5/11—Rev. B to Rev. C

Changes to Features Section1
 Changes to Ordering Guide.....70
 Added Automotive Products Section70

7/09—Rev. A to Rev. B

Changes to BIAS Pin Description.....8
 Changes to BIAS Pin Section.....12

8/08—Rev. 0 to Rev. A

Changes to Table 34
 Added Figure 3, Renumbered Sequentially6
 Changes to Low Power Mode Section.....13
 Added Latency from Touch to Response Section.....13
 Added Low Latency from Touch to Response Section13
 Changes to Figure 60 and Figure 6140
 Changes to Figure 6241
 Added Exposed Pad Notation to Outline Dimensions68

9/07—Revision 0: Initial Version

SPECIFICATIONS

$V_{CC} = 2.6\text{ V to }3.6\text{ V}$, $T_A = -40^\circ\text{C to }+85^\circ\text{C}$, unless otherwise noted.

Table 1.

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
CAPACITANCE-TO-DIGITAL CONVERTER					
Update Rate	8.73	9	9.27	ms	12 conversion stages, decimation = 64
	17.46	18	18.54	ms	12 conversion stages, decimation = 128
	34.9	36	37.1	ms	12 conversion stages, decimation = 256
Resolution		16		Bits	
CINx Input Range		± 8		pF	
No Missing Codes	16			Bits	Guaranteed by design, but not production tested
CINx Input Leakage		25		nA	
Maximum Output Load			20	pF	Capacitance load on CINx to ground
Total Unadjusted Error			± 20	%	
Output Noise (Peak-to-Peak)		12		Codes	Decimation rate = 64
		7		Codes	Decimation rate = 128
		3		Codes	Decimation rate = 256
Output Noise (RMS)		1.1		Codes	Decimation rate = 64
		0.8		Codes	Decimation rate = 128
		0.5		Codes	Decimation rate = 256
C_{STRAY} Offset Range		20		pF	
C_{STRAY} Offset Resolution		0.32		pF	
Low Power Mode Delay Accuracy			4	%	Percentage of 200 ms, 400 ms, 600 ms, or 800 ms
AC_{SHIELD}					
Frequency		250		kHz	
Output Voltage	0		V_{CC}	V	Oscillating
Short-Circuit Source Current		10		mA	
Short-Circuit Sink Current		10		mA	
Maximum Output Load			150	pF	Capacitance load on AC _{SHIELD} to ground
LOGIC INPUTS (SDI, SCLK, \overline{CS}, SDA, GPIO)					
V_{IH} Input High Voltage	$0.7 \times V_{DRIVE}$			V	
V_{IL} Input Low Voltage			0.4	V	
I_{IH} Input High Current	-1			μA	$V_{IN} = V_{DRIVE}$
I_{IL} Input Low Current			1	μA	$V_{IN} = \text{GND}$
Hysteresis		150		mV	
OPEN-DRAIN OUTPUTS (SCLK, SDA, \overline{INT})					
V_{OL} Output Low Voltage			0.4	V	$I_{SINK} = -1\text{ mA}$
I_{OH} Output High Leakage Current		± 0.1	± 1	μA	$V_{OUT} = V_{DRIVE}$
LOGIC OUTPUTS (SDO, GPIO)					
V_{OL} Output Low Voltage			0.4	V	$I_{SINK} = 1\text{ mA}$, $V_{DRIVE} = 1.65\text{ V to }3.6\text{ V}$
V_{OH} Output High Voltage	$V_{DRIVE} - 0.6$			V	$I_{SOURCE} = 1\text{ mA}$, $V_{DRIVE} = 1.65\text{ V to }3.6\text{ V}$
GPIO, SDO Floating State Leakage Current			± 1	μA	Pin three-state, leakage measured to GND and V_{CC}
POWER					
V_{CC}	2.6	3.3	3.6	V	
V_{DRIVE}	1.65		3.6	V	Serial interface operating voltage
I_{CC}		0.9	1	mA	In full power mode, $V_{CC} + V_{DRIVE}$
		15.5	21.5	μA	Low power mode, converter idle, $V_{CC} + V_{DRIVE}$, decimation = 256
		2.3	7.5	μA	Full shutdown, $V_{CC} + V_{DRIVE}$

AVERAGE CURRENT SPECIFICATIONS

Table 2. Typical Average Current in Low Power Mode¹

Low Power Mode Delay	Decimation Rate	Current Values of Conversion Stages (µA)											
		1	2	3	4	5	6	7	8	9	10	11	12
200 ms	64	20.83	24.18	27.52	30.82	34.11	37.37	40.6	43.81	46.99	50.16	53.3	56.41
	128	25.3	31.92	38.45	44.87	51.21	57.45	63.6	69.66	75.63	81.52	87.33	93.05
	256	34.11	46.99	59.51	71.66	83.47	94.94	106.1	116.96	127.52	137.81	147.82	157.58
400 ms	64	18.17	19.86	21.55	23.23	24.9	26.57	28.23	29.88	31.53	33.17	34.81	36.44
	128	20.43	23.79	27.12	30.43	33.72	36.98	40.22	43.43	46.62	49.78	52.93	56.05
	256	24.9	31.53	38.06	44.5	50.83	57.08	63.23	69.3	75.28	81.17	86.98	92.71
600 ms	64	17.28	18.41	19.54	20.67	21.79	22.91	24.03	25.14	26.25	27.36	28.47	29.57
	128	18.79	21.04	23.28	25.51	27.73	29.94	32.13	34.32	36.49	38.65	40.81	42.95
	256	21.79	26.25	30.67	35.04	39.37	43.66	47.9	52.11	56.27	60.39	64.47	68.51
800 ms	64	16.84	17.69	18.53	19.38	20.23	21.07	21.91	22.75	23.59	24.43	25.26	26.09
	128	17.97	19.66	21.35	23.03	24.7	26.37	28.03	29.69	31.34	32.98	34.62	36.25
	256	20.23	23.59	26.93	30.24	33.53	36.79	40.03	43.24	46.43	49.6	52.74	55.86

¹ V_{CC} = 3.3 V, T_A = 25°C, load = 50 pF.Table 3. Maximum Average Current in Low Power Mode¹

Low Power Mode Delay	Decimation Rate	Current Values of Conversion Stages (µA)											
		1	2	3	4	5	6	7	8	9	10	11	12
200 ms	64	27.96	32.06	36.12	40.15	44.16	48.12	52.06	55.97	59.85	63.69	67.51	71.29
	128	33.41	41.49	49.44	57.26	64.97	72.55	80.02	87.37	94.61	101.74	108.77	115.69
	256	44.16	59.85	75.05	89.79	104.09	117.97	131.45	144.53	157.25	169.61	181.63	193.33
400 ms	64	24.74	26.8	28.86	30.91	32.95	34.99	37.01	39.03	41.04	43.04	45.03	47.02
	128	27.49	31.59	35.66	39.7	43.71	47.68	51.62	55.53	59.41	63.26	67.08	70.87
	256	32.95	41.04	49	56.83	64.54	72.12	79.6	86.96	94.2	101.34	108.37	115.3
600 ms	64	23.66	25.04	26.42	27.79	29.17	30.53	31.89	33.25	34.61	35.96	37.31	38.66
	128	25.5	28.25	30.99	33.71	36.41	39.1	41.78	44.44	47.09	49.72	52.34	54.95
	256	29.17	34.61	40	45.33	50.6	55.82	60.98	66.09	71.15	76.15	81.1	86.01
800 ms	64	23.12	24.16	25.19	26.23	27.26	28.29	29.32	30.34	31.36	32.38	33.4	34.42
	128	24.5	26.57	28.63	30.68	32.72	34.76	36.79	38.8	40.81	42.81	44.81	46.79
	256	27.26	31.36	35.44	39.47	43.48	47.46	51.4	55.31	59.19	63.04	66.86	70.66

¹ V_{CC} = 3.6 V, T_A = -40°C to +85°C, load = 50 pF.

SPI TIMING SPECIFICATIONS (AD7147)

$T_A = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$, sample tested at 25°C to ensure compliance. $V_{\text{DRIVE}} = 1.65\text{ V}$ to 3.6 V , and $V_{\text{CC}} = 2.6\text{ V}$ to 3.6 V , unless otherwise noted. All input signals are specified with $t_R = t_F = 5\text{ ns}$ (10% to 90% of V_{CC}) and timed from a voltage level of 1.6 V .

Table 4. SPI Timing Specifications

Parameter	Limit	Unit	Description
f_{SCLK}	5	MHz max	SCLK frequency
t_1	5	ns min	$\overline{\text{CS}}$ falling edge to first SCLK falling edge
t_2	20	ns min	SCLK high pulse width
t_3	20	ns min	SCLK low pulse width
t_4	15	ns min	SDI setup time
t_5	15	ns min	SDI hold time
t_6	20	ns max	SDO access time after SCLK falling edge
t_7	16	ns max	$\overline{\text{CS}}$ rising edge to SDO high impedance
t_8	15	ns min	SCLK rising edge to $\overline{\text{CS}}$ high

SPI Timing Diagram

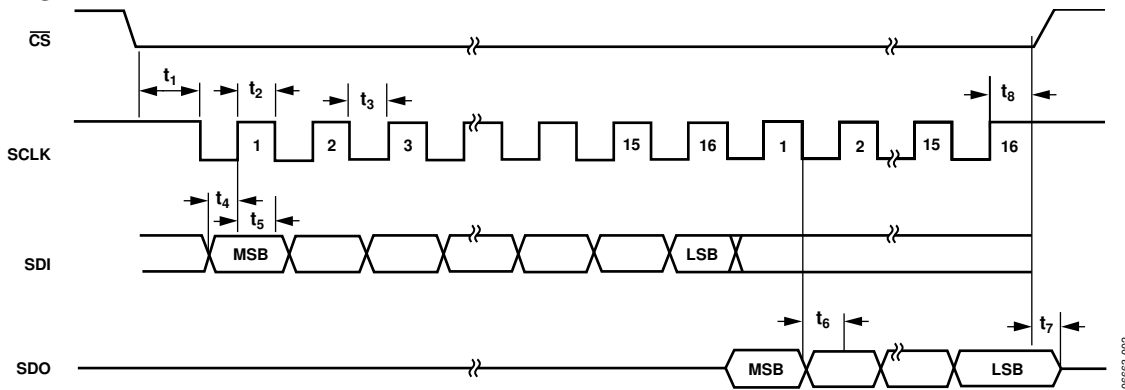


Figure 2. SPI Detailed Timing Diagram

06963-002

I²C TIMING SPECIFICATIONS (AD7147-1)

T_A = -40°C to +85°C, sample tested at 25°C to ensure compliance. V_{DRIVE} = 1.65 V to 3.6 V, and V_{CC} = 2.6 V to 3.6 V, unless otherwise noted. All input signals timed from a voltage level of 1.6 V.

Table 5. I²C Timing Specifications¹

Parameter	Limit	Unit	Description
f _{SCLK}	400	kHz max	
t ₁	0.6	μs min	Start condition hold time, t _{HD;STA}
t ₂	1.3	μs min	Clock low period, t _{LOW}
t ₃	0.6	μs min	Clock high period, t _{HIGH}
t ₄	100	ns min	Data setup time, t _{SU;DAT}
t ₅	300	ns min	Data hold time, t _{HD;DAT}
t ₆	0.6	μs min	Stop condition setup time, t _{SU;STO}
t ₇	0.6	μs min	Start condition setup time, t _{SU;STA}
t ₈	1.3	μs min	Bus-free time between stop and start conditions, t _{BUF}
t _R	300	ns max	Clock/data rise time
t _F	300	ns max	Clock/data fall time

¹ Guaranteed by design, not production tested.

I²C Timing Diagram

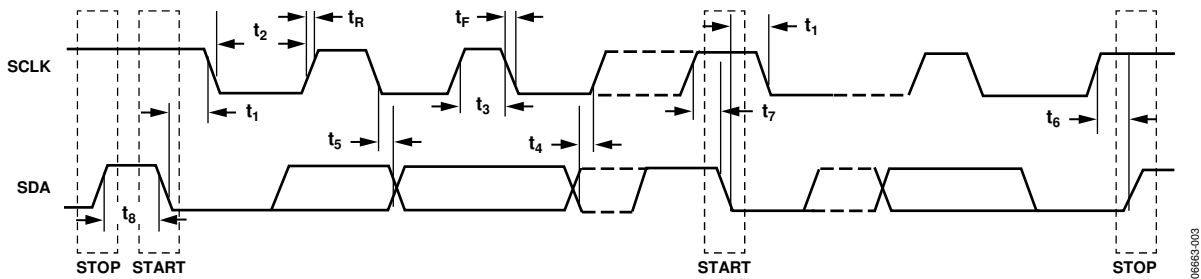


Figure 3. I²C Detailed Timing Diagram

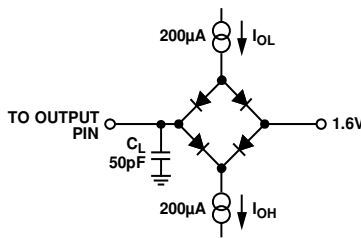


Figure 4. Load Circuit for Digital Output Timing Specifications

ABSOLUTE MAXIMUM RATINGS

Table 6.

Parameter	Rating
V _{CC} to GND	−0.3 V to +3.6 V
Analog Input Voltage to GND	−0.3 V to V _{CC} + 0.3 V
Digital Input Voltage to GND	−0.3 V to V _{DRIVE} + 0.3 V
Digital Output Voltage to GND	−0.3 V to V _{DRIVE} + 0.3 V
Input Current to Any Pin Except Supplies ¹	10 mA
ESD Rating (Human Body Model)	2.5 kV
Operating Temperature Range	−40°C to +105°C
Storage Temperature Range	−65°C to +150°C
Junction Temperature	150°C
LFCSP	
Power Dissipation	450 mW
θ _{JA} Thermal Impedance	135.7°C/W
IR Reflow Peak Temperature	260°C (±0.5°C)
Lead Temperature (Soldering 10 sec)	300°C

¹ Transient currents of up to 100 mA do not cause SCR latch-up.

Stresses at or above those listed under Absolute Maximum Ratings may cause permanent damage to the product. This is a stress rating only; functional operation of the product at these or any other conditions above those indicated in the operational section of this specification is not implied. Operation beyond the maximum operating conditions for extended periods may affect product reliability.

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATIONS AND FUNCTION DESCRIPTIONS

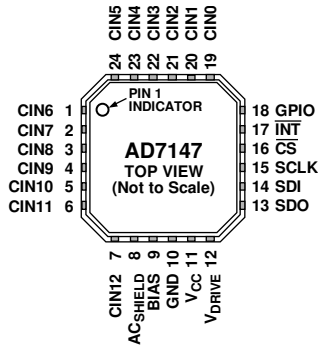


Figure 5. AD7147 Pin Configuration

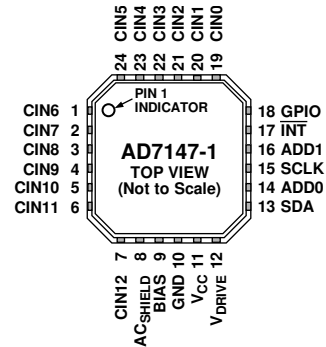


Figure 6. AD7147-1 Pin Configuration

NOTES
 1. THE EXPOSED PAD IS NOT CONNECTED INTERNALLY. FOR INCREASED RELIABILITY OF THE SOLDER JOINTS AND MAXIMUM THERMAL CAPABILITY IT IS RECOMMENDED THAT THE PAD BE SOLDERED TO THE GROUND PLANE.

NOTES
 1. THE EXPOSED PAD IS NOT CONNECTED INTERNALLY. FOR INCREASED RELIABILITY OF THE SOLDER JOINTS AND MAXIMUM THERMAL CAPABILITY IT IS RECOMMENDED THAT THE PAD BE SOLDERED TO THE GROUND PLANE.

Table 7. Pin Function Descriptions

Pin No.		Mnemonic	Description
AD7147	AD7147-1		
1	1	CIN6	Capacitance Sensor Input.
2	2	CIN7	Capacitance Sensor Input.
3	3	CIN8	Capacitance Sensor Input.
4	4	CIN9	Capacitance Sensor Input.
5	5	CIN10	Capacitance Sensor Input.
6	6	CIN11	Capacitance Sensor Input.
7	7	CIN12	Capacitance Sensor Input.
8	8	AC _{SHIELD}	CDC Active Shield Output. Connect to external shield or plane.
9	9	BIAS	Bias Node for Internal Circuitry. Requires 100 nF capacitor to ground.
10	10	GND	Ground Reference Point for All Circuitry.
11	11	V _{CC}	Supply Voltage.
12	12	V _{DRIVE}	Serial Interface Operating Voltage Supply.
13	N/A	SDO	SPI Serial Data Output.
N/A	13	SDA	I ² C Serial Data Input/Output. SDA requires pull-up resistor.
14	N/A	SDI	SPI Serial Data Input.
N/A	14	ADD0	I ² C Address Bit 0.
15	15	SCLK	Clock Input for Serial Interface.
16	N/A	CS	SPI Chip Select Signal.
N/A	16	ADD1	I ² C Address Bit 1.
17	17	INT	General-Purpose Open-Drain Interrupt Output. Programmable polarity; requires pull-up resistor.
18	18	GPIO	Programmable GPIO.
19	19	CIN0	Capacitance Sensor Input.
20	20	CIN1	Capacitance Sensor Input.
21	21	CIN2	Capacitance Sensor Input.
22	22	CIN3	Capacitance Sensor Input.
23	23	CIN4	Capacitance Sensor Input.
24	24	CIN5	Capacitance Sensor Input.

TYPICAL PERFORMANCE CHARACTERISTICS

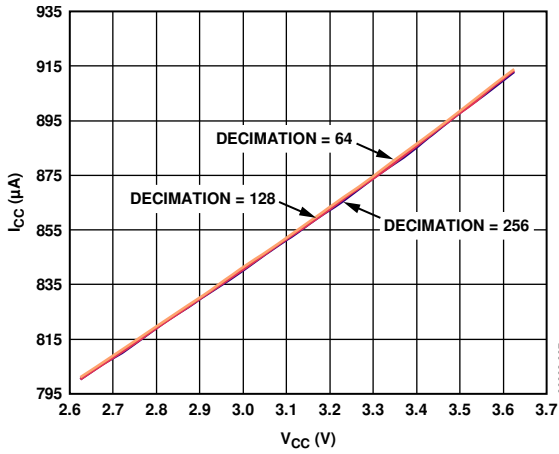


Figure 7. Supply Current vs. Supply Voltage

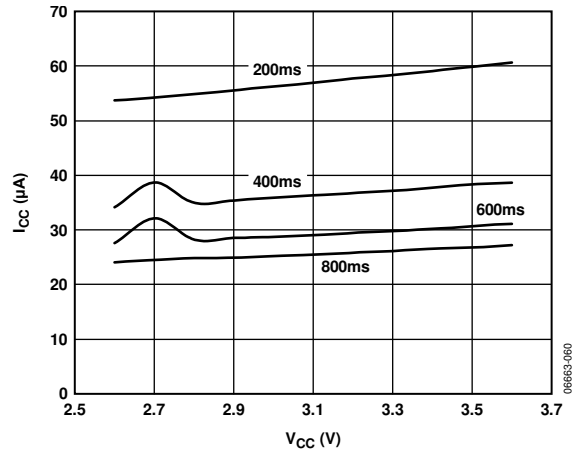


Figure 10. Low Power Supply Current vs. Supply Voltage, Decimation Rate = 64

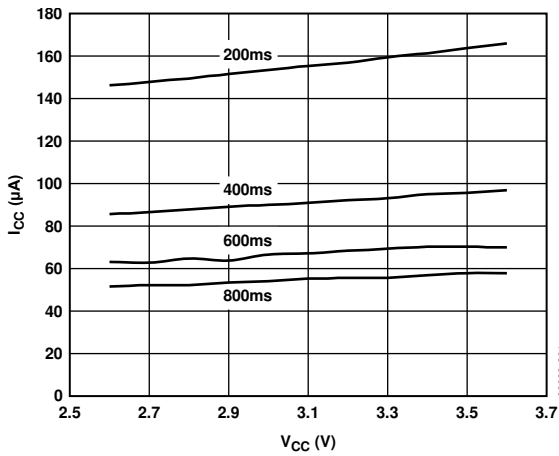


Figure 8. Low Power Supply Current vs. Supply Voltage, Decimation Rate = 256

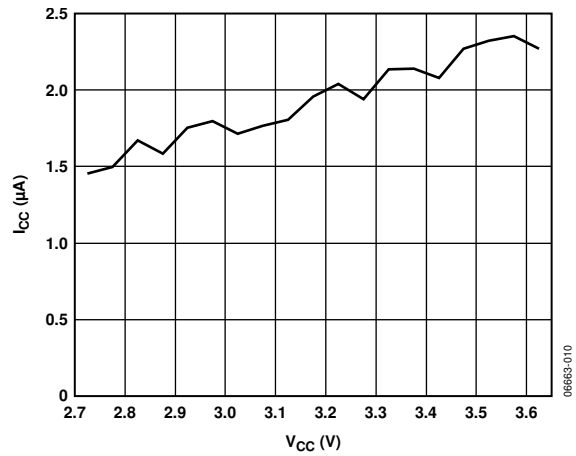


Figure 11. Shutdown Supply Current vs. Supply Voltage

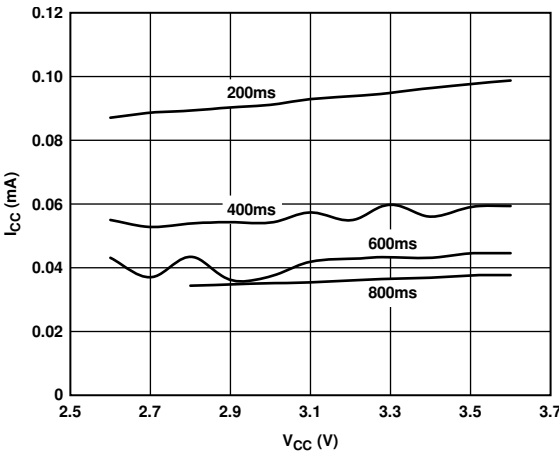


Figure 9. Low Power Supply Current vs. Supply Voltage, Decimation Rate = 128

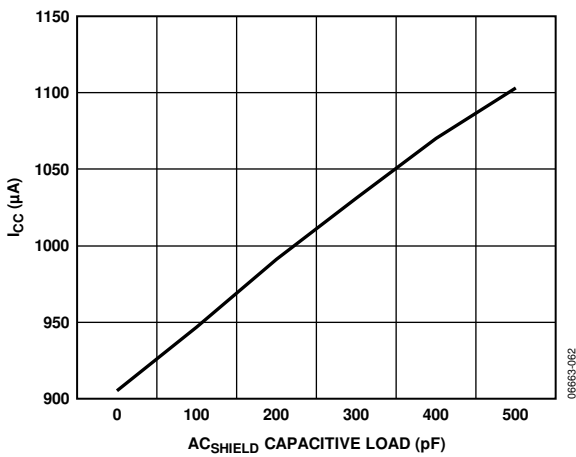


Figure 12. Supply Current vs. Capacitive Load on AC_{SHIELD}

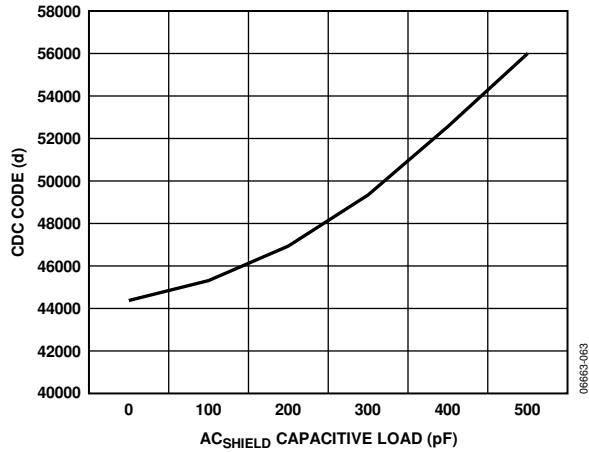


Figure 13. Output Code vs. Capacitive Load on AC_{SHIELD}

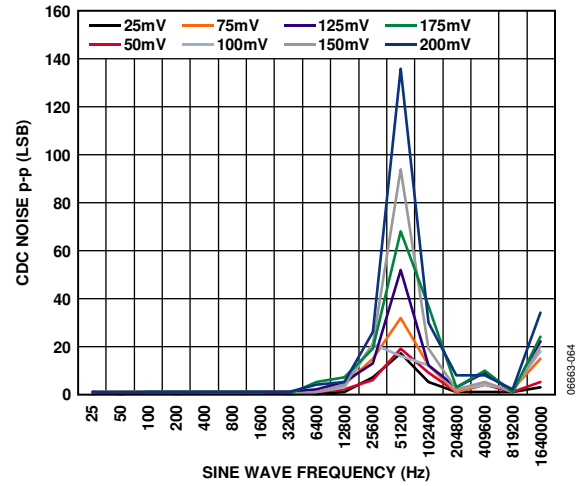


Figure 16. Power Supply Sine Wave Rejection, V_{CC} = 3.6 V

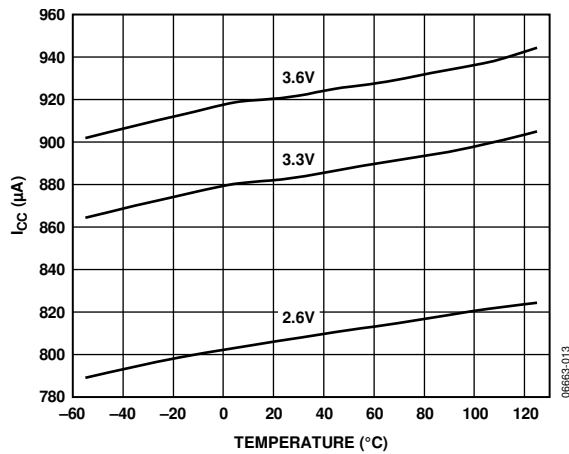


Figure 14. Supply Current vs. Temperature

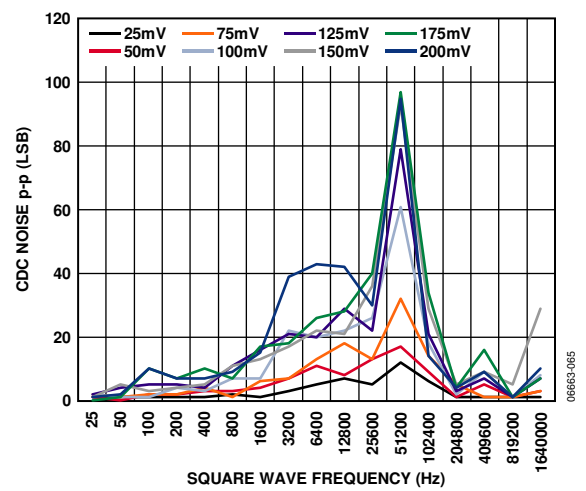


Figure 17. Power Supply Square Wave Rejection, V_{CC} = 3.6 V

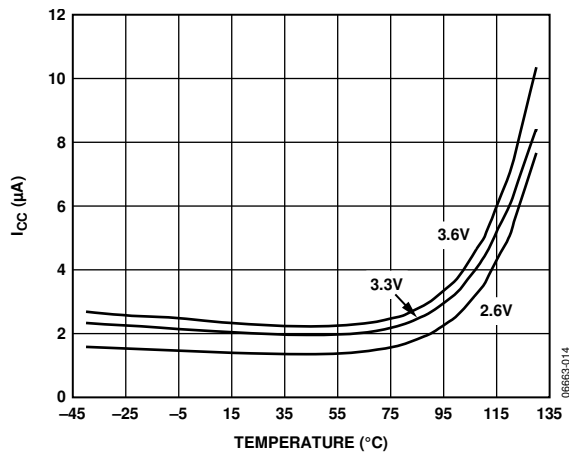


Figure 15. Shutdown Supply Current vs. Temperature

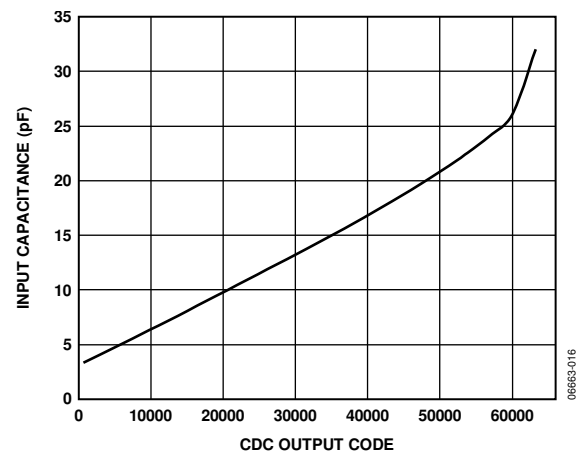


Figure 18. CDC Linearity, V_{CC} = 3.3 V

THEORY OF OPERATION

The [AD7147](#) and [AD7147-1](#) are CDCs with on-chip environmental compensation. They are intended for use in portable systems requiring high resolution user input. The internal circuitry consists of a 16-bit, Σ - Δ converter that can change a capacitive input signal into a digital value. There are 13 input pins, CIN0 to CIN12, on the [AD7147](#) or [AD7147-1](#). A switch matrix routes the input signals to the CDC. The result of each capacitance-to-digital conversion is stored in on-chip registers. The host subsequently reads the results over the serial interface. The [AD7147](#) has an SPI interface, and the [AD7147-1](#) has an I²C interface, ensuring that the parts are compatible with a wide range of host processors. [AD7147](#) refers to both the [AD7147](#) and [AD7147-1](#), unless otherwise noted, from this point forward in this data sheet.

The [AD7147](#) interfaces with up to 13 external capacitance sensors. These sensors can be arranged as buttons, scroll bars, or wheels, or as a combination of sensor types. The external sensors consist of an electrode on a single- or multiple-layer PCB that interfaces directly to the [AD7147](#).

The [AD7147](#) can be set up to implement any set of input sensors by programming the on-chip registers. The registers can also be programmed to control features such as averaging, offsets, and gains for each of the external sensors. There is an on-chip sequencer that controls how each of the capacitance inputs is polled.

The [AD7147](#) has on-chip digital logic and 528 words of RAM that are used for environmental compensation. The effects of humidity, temperature, and other environmental factors can affect the operation of capacitance sensors. Transparent to the user, the [AD7147](#) performs continuous calibration to compensate for these effects, allowing the [AD7147](#) to consistently provide error-free results.

The [AD7147](#) requires a companion algorithm that runs on the host or another microcontroller to implement high resolution sensor functions, such as scroll bars or wheels. However, no companion algorithm is required to implement buttons. Button sensors are implemented on chip, entirely in digital logic.

The [AD7147](#) can be programmed to operate in either full power mode or low power automatic wake-up mode. The automatic wake-up mode is particularly suited for portable devices that

require low power operation to provide the user with significant power savings and full functionality.

The [AD7147](#) has an interrupt output, $\overline{\text{INT}}$, to indicate when new data has been placed into the registers. $\overline{\text{INT}}$ is used to interrupt the host on sensor activation. The [AD7147](#) operates from a 2.6 V to 3.6 V supply and is available in a 24-lead, 4 mm × 4 mm LFCSP.

CAPACITANCE SENSING THEORY

The [AD7147](#) measures capacitance changes from single electrode sensors. The sensor electrode on the PCB comprises one plate of a virtual capacitor. The other plate of the capacitor is the user's finger, which is grounded with respect to the sensor input.

The [AD7147](#) first outputs an excitation signal to charge the plate of the capacitor. When the user comes close to the sensor, the virtual capacitor is formed, with the user acting as the second capacitor plate.

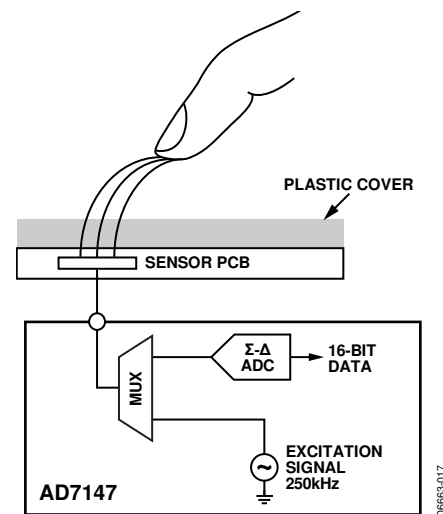


Figure 19. Capacitance-Sensing Method

A square wave excitation signal is applied to CIN_x during the conversion, and the modulator continuously samples the charge going through CIN_x. The output of the modulator is processed via a digital filter, and the resulting digital data is stored in the CDC_RESULT_S_x registers for each conversion stage, at Address 0x00B to Address 0x016.

Registering a Sensor Activation

When a user approaches a sensor, the total capacitance associated with that sensor changes and is measured by the AD7147. If the change causes a set threshold to be exceeded, the AD7147 interprets this as a sensor activation.

On-chip threshold limits are used to determine when a sensor activation occurs. Figure 20 shows the change in CDC_RESULT_Sx when a user activates a sensor. The sensor is deemed to be active only when the value of CDC_RESULT_Sx is either greater than the value of STAGEx_HIGH_THRESHOLD or less than the value of STAGEx_LOW_THRESHOLD.

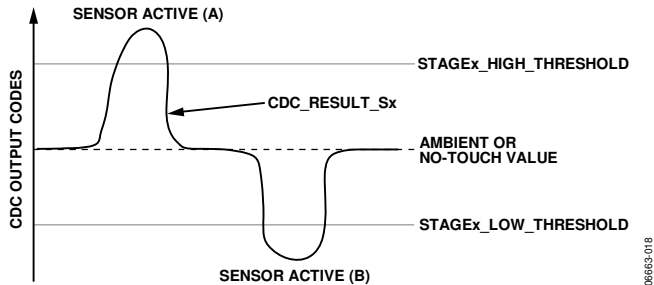


Figure 20. Sensor Activation Thresholds

In Figure 20, two sensor activations are shown. Sensor Active A occurs when a sensor is connected to the positive input of the converter. In this case, when a user activates the sensor, there is an increase in CDC code, and the value of CDC_RESULT_Sx exceeds that of STAGEx_HIGH_THRESHOLD. Sensor Active B occurs when the sensor is connected to the negative input of the converter. In this case, when a user activates the sensor, there is a decrease in CDC code, and the value of CDC_RESULT_Sx becomes less than the value of STAGEx_LOW_THRESHOLD.

For each conversion stage, the STAGEx_HIGH_THRESHOLD and STAGEx_LOW_THRESHOLD registers are in Register Bank 3. The values in these registers are updated automatically by the AD7147 due to its environmental calibration and adaptive threshold logic.

At power-up, the values in the STAGEx_HIGH_THRESHOLD and STAGEx_LOW_THRESHOLD registers are the same as those in the STAGEx_OFFSET_HIGH and STAGEx_OFFSET_LOW registers in Bank 2. The user must program the STAGEx_OFFSET_HIGH and STAGEx_OFFSET_LOW registers on device power-up. See the Environmental Calibration section of the data sheet for more information.

Complete Solution for Capacitance Sensing

Analog Devices, Inc., provides a complete solution for capacitance sensing. The two main elements to the solution are the sensor PCB and the AD7147.

If the application requires high resolution sensors such as scroll bars or wheels, software is required that runs on the host processor. The memory requirements for the host depend on the sensor and are typically 10 kB of code and 600 bytes of data memory, depending on the sensor type.

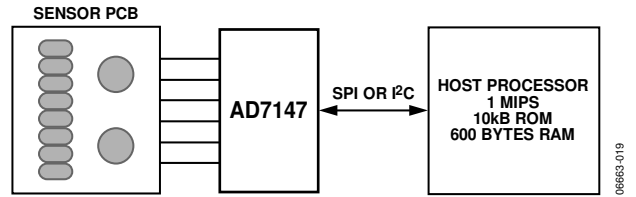


Figure 21. Three-Part Capacitance Sensing Solution

Analog Devices supplies the sensor PCB footprint design libraries to the customer and supplies any necessary software on an open source basis.

BIAS PIN

This pin is connected internally to a bias node of the AD7147. To ensure correct operation of the AD7147, connect a 100 nF capacitor between the BIAS pin and ground. The voltage seen at the BIAS pin is $V_{CC}/2$.

OPERATING MODES

The AD7147 has three operating modes. Full power mode, where the device is always fully powered, is suited for applications where power is not a concern (for example, game consoles that have an ac power supply). Low power mode, where the part automatically powers down when no sensor is active, is tailored to provide significant power savings compared with full power mode and is suited for mobile applications, where power must be conserved. In shutdown mode, the part shuts down completely.

The POWER_MODE bits (Bit 0 and Bit 1) of the control register set the operating mode on the AD7147. The control register is at Address 0x000. Table 8 shows the POWER_MODE settings for each operating mode. To put the AD7147 into shutdown mode, set the POWER_MODE bits to either 01 or 11.

Table 8. POWER_MODE Settings

POWER_MODE Bits	Operating Mode
00	Full power mode
01	Shutdown mode
10	Low power mode
11	Shutdown mode

The power-on default setting of the POWER_MODE bits is 00, full power mode.

Full Power Mode

In full power mode, all sections of the AD7147 remain fully powered and converting at all times. While a sensor is being touched, the AD7147 processes the sensor data. If no sensor is touched, the AD7147 measures the ambient capacitance level and uses this data for the on-chip compensation routines. In full power mode, the AD7147 converts at a constant rate. See the CDC Conversion Sequence Time section for more information.

Low Power Mode

When AD7147 is in low power mode, the POWER_MODE bits are set to 10 upon device initialization. If the external sensors are not touched, the AD7147 reduces its conversion frequency, thereby greatly reducing its power consumption. The part remains in a reduced power state while the sensors are not touched. The AD7147 performs a conversion after a delay defined by the LP_CONV_DELAY bits, and it uses this data to update the compensation logic and check if the sensors are active. The LP_CONV_DELAY bits set the delay between conversions to 200 ms, 400 ms, 600 ms, or 800 ms.

In low power mode, the total current consumption of the AD7147 is an average of the current used during a conversion and the current used while the AD7147 is waiting for the next conversion to begin. For example, when LP_CONV_DELAY is 400 ms, the AD7147 typically uses 0.85 mA of current for 36 ms and 14 μ A of current for 400 ms during the conversion interval. (Note that these conversion timings can be altered through the register

settings. See the CDC Conversion Sequence Time section for more information.)

The time for the AD7147 to transition from a full power state to a reduced power state after the user stops touching the external sensors is configurable. The PWR_DOWN_TIMEOUT bits (in the Ambient Compensation Control 0 (AMB_COMP_CTRL0) Register at Address 0x002) control the time delay before the AD7147 transitions to the reduced power state after the user stops touching the sensors.

Latency from Touch to Response

In low power mode, the AD7147 remains in a low power state until any one of the external sensors are touched. When a sensor is touched, the AD7147 begins a conversion sequence every 36 ms to read back data from the sensors. This means that the latency between the user touching the sensor, and the AD7147 responding, is a maximum of LP_CONV_DELAY ms.

Low Latency from Touch to Response

In low power mode, the AD7147P model remains in a low power state until proximity is detected on any one of the external sensors. When proximity is detected, the AD7147P begins a conversion sequence every 36 ms, or 18 ms, or 9 ms to read back data from the sensors. The latency between first touch and the AD7147P responding is much reduced, compared to the AD7147, because the part is already in a full power state by the time the user has touched the sensor.

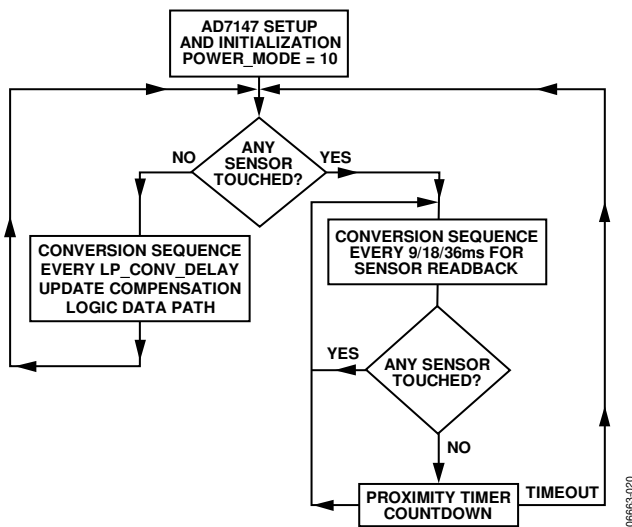


Figure 22. Low Power Mode Operation, AD7147

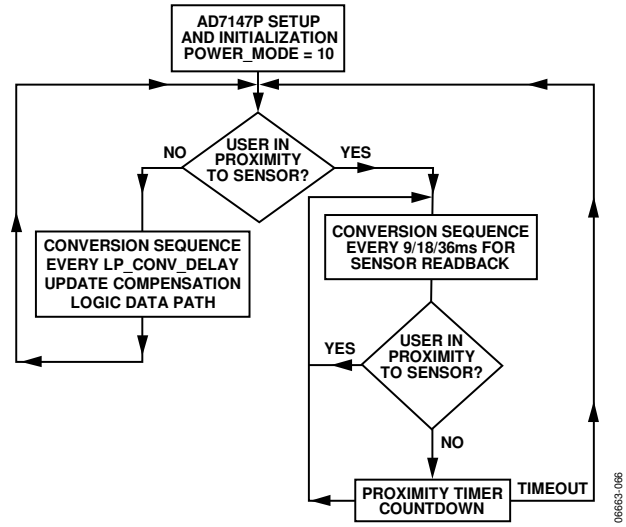


Figure 23. Low Power Mode Operation, AD7147P

CAPACITANCE-TO-DIGITAL CONVERTER

The capacitance-to-digital converter on the AD7147 has a Σ - Δ architecture with 16-bit resolution. There are 13 possible inputs to the CDC that are connected to the input of the converter through a switch matrix. The sampling frequency of the CDC is 250 kHz.

OVERSAMPLING THE CDC OUTPUT

The decimation rate, or oversampling ratio, is determined by Bits[9:8] of the power control (PWR_CONTROL) register (Address 0x000), as listed in Table 9.

Table 9. CDC Decimation Rate

Decimation Bits	Decimation Rate	CDC Output Rate Per Stage (ms)
00	256	3.072
01	128	1.536
10	64	0.768
11	64	0.768

The decimation process on the AD7147 is an averaging process, where a number of samples are taken and the averaged result is output. Due to the architecture of the digital filter employed, the number of samples taken (per stage) is equal to $3 \times$ the decimation rate. So 3×256 or 3×128 samples are averaged to obtain each stage result.

The decimation process reduces the amount of noise present in the final CDC result. However, the higher the decimation rate, the lower the output rate per stage; therefore, there is a trade-off possible between the amount of noise in the signal and the speed of sampling.

CAPACITANCE SENSOR OFFSET CONTROL

There are two programmable DACs on board the AD7147 to null the effect of any stray capacitances on the CDC measurement. These offsets are due to stray capacitance to ground.

A simplified block diagram in Figure 24 shows how to apply the STAGEx_AFE_OFFSET registers to null the offsets. The 6-bit POS_AFE_OFFSET and NEG_AFE_OFFSET bits program the offset DAC to provide 0.32 pF resolution offset adjustment over a range of 20 pF.

The best practice is to ensure that the CDC output for any stage is approximately equal to midscale ($\sim 32,700$) when all sensors are inactive. To correctly offset the stray capacitance to ground for each stage, use the following procedure:

1. Read back the CDC value from the CDC_RESULT_Sx register.
2. If this value is not close to midscale, increase the value of POS_AFE_OFFSET or NEG_AFE_OFFSET (depending on if the CINx input is connected to the positive or negative input of the converter) by 1. The CINx connections are determined by the STAGEx_CONNECTION registers.
3. If the CDC value in CDC_RESULT_Sx is now closer to midscale, repeat Step 2. If the CDC value is further

from midscale, decrease the POS_AFE_OFFSET or NEG_AFE_OFFSET value by 1.

The goal is to ensure that the CDC_RESULT_Sx is as close to midscale as possible. This process is only required once during the initial capacitance sensor characterization.

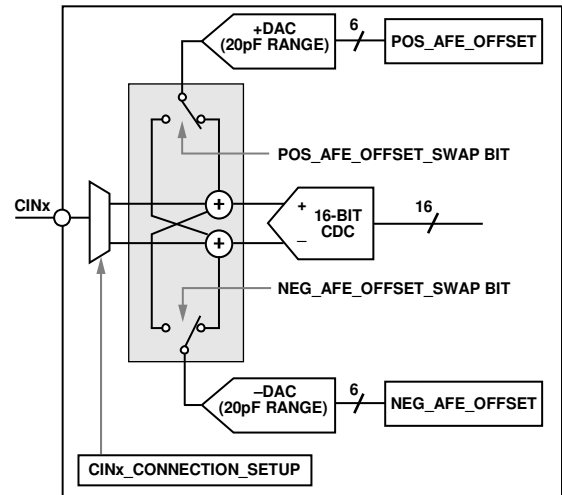


Figure 24. Analog Front-End Offset Control

CONVERSION SEQUENCER

The AD7147 has an on-chip sequencer to implement conversion control for the input channels. Up to 12 conversion stages can be performed in one sequence. Each of the 12 conversions stages can measure the input from a different sensor. By using the Bank 2 registers, each stage can be uniquely configured to support multiple capacitance sensor interface requirements. For example, a slider sensor can be assigned to STAGE1 through STAGE8, with a button sensor assigned to STAGE0. For each conversion stage, the input mux that connects the CINx inputs to the converter can have a unique setting.

The AD7147 on-chip sequence controller provides conversion control, beginning with STAGE0. Figure 25 shows a block diagram of the CDC conversion stages and CINx inputs. A conversion sequence is defined as a sequence of CDC conversions starting at STAGE0 and ending at the stage determined by the value programmed in the SEQUENCE_STAGE_NUM bits. Depending on the number and type of capacitance sensors that are used, not all conversion stages are required. Use the SEQUENCE_STAGE_NUM bits to set the number of conversions in one sequence. This number depends on the sensor interface requirements. For example, the register should be set to 5 if the CINx inputs are mapped to only six conversion stages. In addition, the STAGE_CAL_EN register should be set according to the number of stages that are used.

The number of required conversion stages depends solely on the number of sensors attached to the AD7147. Figure 26 shows how many conversion stages are required for each sensor and how many inputs to the AD7147 each sensor requires.

A button sensor generally requires one sequencer stage; this is shown in Figure 26 as B1. However, it is possible to configure two button sensors to operate differentially for one conversion stage. Only one button can be activated at a time; pressing both buttons simultaneously results in neither button being activated. The configuration with two button sensors operating differentially requires one conversion stage and is shown in Figure 26, with B2 and B3 representing the differentially configured button sensors.

A wheel sensor requires eight stages, whereas a slider requires two stages. The result from each stage is used by the host software to determine the user's position on the slider or wheel. The algorithms that perform this process are available from Analog Devices and are free of charge, but require signing a software license.

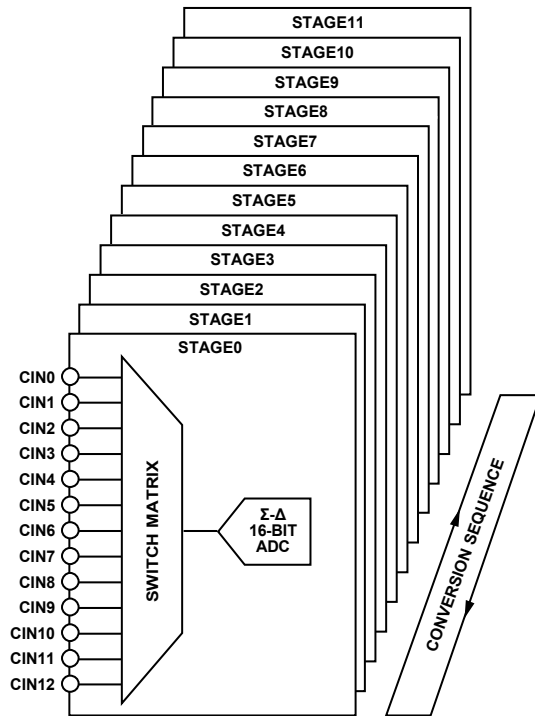


Figure 25. CDC Conversion Stages

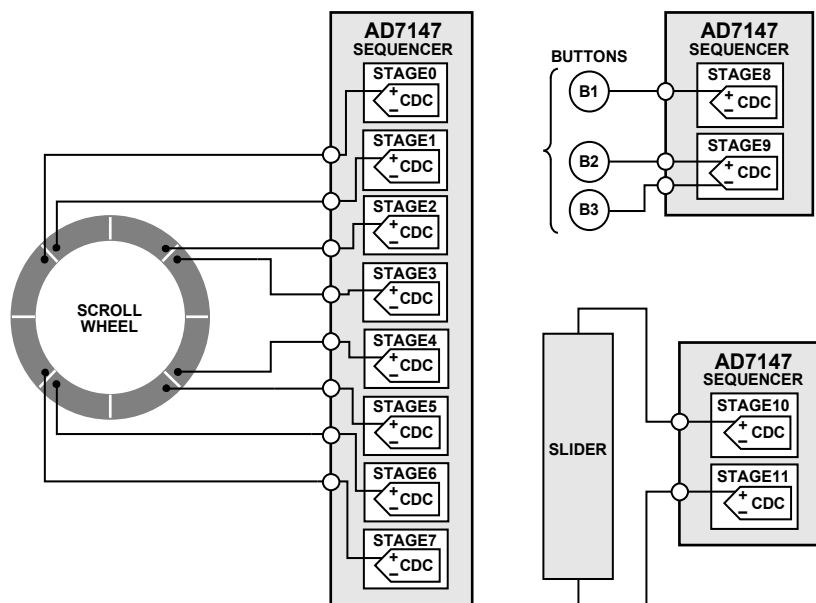


Figure 26. Sequencer Setup for Sensors

CDC CONVERSION SEQUENCE TIME

Table 10. CDC Conversion Times for Full Power Mode

SEQUENCE_STAGE_NUM	Conversion Time (ms)		
	Decimation = 64	Decimation = 128	Decimation = 256
0	0.768	1.536	3.072
1	1.536	3.072	6.144
2	2.304	4.608	9.216
3	3.072	6.144	12.288
4	3.84	7.68	15.36
5	4.608	9.216	18.432
6	5.376	10.752	21.504
7	6.144	12.288	24.576
8	6.912	13.824	27.648
9	7.68	15.36	30.72
10	8.448	16.896	33.792
11	9.216	18.432	36.864

The time required for the CDC to complete the measurement of all 12 stages is defined as the CDC conversion sequence time. The SEQUENCE_STAGE_NUM and DECIMATION bits determine the conversion time, as listed in Table 10.

For example, if the device is operated with a decimation rate of 128 and the SEQUENCE_STAGE_NUM bit is set to 5 for the conversion of six stages in a sequence, the conversion sequence time is 9.216 ms.

Full Power Mode CDC Conversion Sequence Time

The full power mode CDC conversion sequence time for all 12 stages is set by configuring the SEQUENCE_STAGE_NUM and DECIMATION bits as outlined in Table 10.

Figure 27 shows a simplified timing diagram of the full power mode CDC conversion time. The full power mode CDC conversion time (t_{CONV_FP}) is set using the values shown in Table 10.

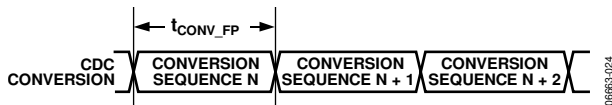


Figure 27. Full Power Mode CDC Conversion Sequence Time

Low Power Mode CDC Conversion Sequence Time with Delay

The frequency of each CDC conversion while operating in the low power automatic wake-up mode is controlled by using the LP_CONV_DELAY bits located at Address 0x000[3:2] in addition to the registers listed in Table 10. This feature provides some flexibility for optimizing the tradeoff between the conversion time needed to meet system requirements and the power consumption of the AD7147.

For example, maximum power savings is achieved when the LP_CONV_DELAY bits are set to 11. With a setting of 11,

the AD7147 automatically wakes up, performing a conversion every 800 ms.

Table 11. LP_CONV_DELAY Settings

LP_CONV_DELAY Bits	Delay Between Conversions (ms)
00	200
01	400
10	600
11	800

Figure 28 shows a simplified timing example of the low power mode CDC conversion time. As shown, the low power mode CDC conversion time is set by t_{CONV_FP} and the LP_CONV_DELAY bits.

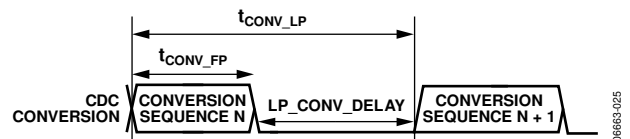


Figure 28. Low Power Mode CDC Conversion Sequence Time

CDC CONVERSION RESULTS

Certain high resolution sensors require the host to read back the CDC conversion results for processing. The registers required for host processing are located in the Bank 3 registers. The host processes the data read back from these registers using a software algorithm in order to determine position information.

In addition to the results registers in the Bank 3 registers, the AD7147 provides the 16-bit CDC output data directly, starting at Address 0x00B of Bank 1. Reading back the CDC 16-bit conversion data register allows for customer-specific application data processing.

CAPACITANCE SENSOR INPUT CONFIGURATION

Each input connection from the external capacitance sensors to the converter of the AD7147 can be uniquely configured by using the registers in Bank 2 (see Table 38). These registers are used to configure the input pin connection setups, sensor offsets, sensor sensitivities, and sensor limits for each stage. Each sensor can be individually optimized. For example, a button sensor connected to STAGE0 can have different sensitivity and offset values than a button with another function that is connected to a different stage.

CIN_x INPUT MULTIPLEXER SETUP

Table 34 and Table 35 list the available options for the CIN_x_CONNECTION_SETUP bits when the sensor input pins are connected to the CDC.

The AD7147 has an on-chip multiplexer that routes the input signals from each CIN_x pin to the input of the converter. Each input pin can be tied to either the negative or positive input of the CDC, or it can be left floating. Each input can also be internally connected to the BIAS signal to help prevent cross coupling. If an input is not used, always connect it to the BIAS.

Connecting a CIN_x input pin to the positive CDC input results in an increase in CDC output code when the corresponding sensor is activated. Connecting a CIN_x input pin to the negative CDC input results in a decrease in CDC output code when the corresponding sensor is activated.

The AD7147 performs a sequence of 12 conversions. The multiplexer can have different settings for each of the 12 conversions. For example, CIN₀ is connected to the negative CDC input for conversion STAGE1, left floating for conversion STAGE1, and so on, for all 12 conversion stages.

For each CIN_x input for each conversion stage, two bits control how the input is connected to the converter, as shown in Figure 29.

Examples

To connect CIN₃ to the positive CDC input on Stage 0 use the following setting:

```
STAGE0_CONNECTION[6:0] = 0xFFBF
STAGE0_CONNECTION[12:7] = 0x2FFF
```

To connect CIN₀ to the positive CDC input and CIN₁₂ to the negative CIN input on Stage 5 use the following settings:

```
STAGE5_CONNECTION[6:0] = 0xFFFE
STAGE5_CONNECTION[12:7] = 0x37FF
```

SINGLE-ENDED CONNECTIONS TO THE CDC

A single-ended connection to the CDC is defined as one CIN_x input connected to either the positive or negative CDC input for one conversion stage. A differential connection to the CDC is defined as one CIN_x input connected to the positive CDC input and a second CIN_x input connected to the negative input of the CDC for one conversion stage.

For any stage, if a single-ended connection to the CDC is made in that stage, the SE_CONNECTION_SETUP bits (Bits[13:12] in the STAGEx_CONNECTION[12:7] register) should be applied as follows:

- SE_CONNECTION_SETUP = 00: do not use.
- SE_CONNECTION_SETUP = 01: single-ended connection. For this stage, there is one CIN_x connected to the positive CDC input.
- SE_CONNECTION_SETUP = 10: single-ended connection. For this stage, there is one CIN_x connected to the negative CDC input.
- SE_CONNECTION_SETUP = 11: differential connection. For this stage, there is one CIN_x connected to the negative CDC input and one CIN_x connected to the positive CDC input.

These bits ensure that during a single-ended connection to the CDC, the input paths to both CDC terminals are matched, which in turn improves the power-supply rejection of the converter measurement.

These bits should be applied in addition to setting the other bits in the STAGEx_CONNECTION registers, as outlined in the CIN_x Input Multiplexer Setup section.

If more than one CIN_x input is connected to either the positive or negative input of the converter for the same conversion, set SE_CONNECTION_SETUP to 11. For example, if CIN₀ and CIN₃ are connected to the positive input of the CDC, set SE_CONNECTION_SETUP to 11.

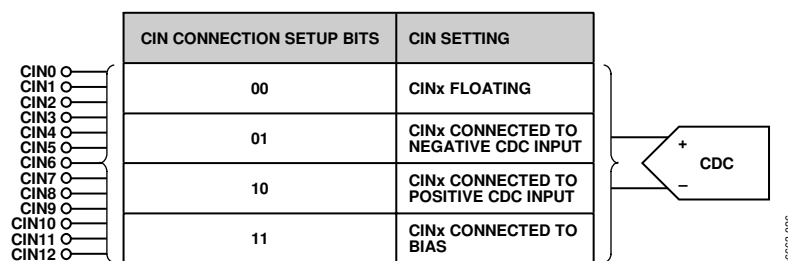


Figure 29. Input Mux Configuration Options

NONCONTACT PROXIMITY DETECTION

The AD7147 internal signal processing continuously monitors all capacitance sensors for noncontact proximity detection. This feature provides the ability to detect when a user is approaching a sensor, at which time all internal calibration is immediately disabled while the AD7147 is automatically configured to detect a valid contact.

The proximity control register bits are described in Table 12. The FP_PROXIMITY_CNT and LP_PROXIMITY_CNT register bits control the length of the calibration disable period after the user stops touching the sensor and is not in close proximity to the sensor during full or low power mode. The calibration is disabled during this period and then enabled again. Figure 30 and Figure 31 show examples of how these registers are used to set the calibration disable periods for the full and low power modes.

The calibration disable period in full power mode is the value of the FP_PROXIMITY_CNT multiplied by 16 multiplied by the time for one conversion sequence in full power mode. The calibration disable period in low power mode is the value of the LP_PROXIMITY_CNT multiplied by 4 multiplied by the time for one conversion sequence in low power mode.

RECALIBRATION

In certain situations (for example, when a user hovers over a sensor for a long time), the proximity flag can be set for a long period. The environmental calibration on the AD7147 is suspended while proximity is detected, but changes may occur to the ambient capacitance level during the proximity event. This means that the ambient value stored on the AD7147 no longer represents the actual ambient value. In this case, even when the user is not in close proximity to the sensor, the proximity flag may still be set. This situation can occur if the user interaction creates some moisture on the sensor, causing the new sensor ambient value to be different from the expected value. In this situation, the AD7147 automatically forces a recalibration internally. This ensures that the ambient values are recalibrated, regardless of how long the user hovers over the sensor. A recalibration ensures maximum AD7147 sensor performance.

The AD7147 recalibrates automatically when the measured CDC value exceeds the stored ambient value by an amount determined

by the PROXIMITY_RECAL_LVL bits for a set period of time known as the recalibration timeout. In full power mode, the recalibration timeout is controlled by FP_PROXIMITY_RECAL; in low power mode, by LP_PROXIMTY_RECAL.

The recalibration timeout in full power mode is the value of the FP_PROXIMITY_RECAL multiplied by the time for one conversion sequence in full power mode. The recalibration timeout in low power mode is the value of the LP_PROXIMITY_RECAL multiplied by the time for one conversion sequence in low power mode.

Figure 32 and Figure 33 show examples of how the FP_PROXIMITY_RECAL and LP_PROXIMITY_RECAL register bits control the timeout period before a recalibration while operating in the full and low power modes. In these examples, a user approaches a sensor and then leaves, but the proximity detection remains active. The measured CDC value exceeds the stored ambient value by the amount set in the PROXIMITY_RECAL_LVL bits for the entire timeout period. The sensor is automatically recalibrated at the end of the timeout period.

PROXIMITY SENSITIVITY

The fast filter in Figure 34 is used to detect when someone is close to the sensor (proximity). Two conditions, detected by Comparator 1 and Comparator 2, set the internal proximity detection signal: Comparator 1 detects when a user is approaching or leaving a sensor, and Comparator 2 detects when a user hovers over a sensor or approaches a sensor very slowly.

The sensitivity of Comparator 1 is controlled by the PROXIMITY_DETECTION_RATE bits. For example, if PROXIMITY_DETECTION_RATE is set to 4, the Proximity 1 signal is set when the absolute difference between WORD1 and WORD3 exceeds (4×16) LSB codes.

The PROXIMITY_RECAL_LVL bits (Address 0x003) control the sensitivity of Comparator 2. For example, if PROXIMITY_RECAL_LVL is set to 75, the Proximity 2 signal is set when the absolute difference between the fast filter average value and the ambient value exceeds (75×16) LSB codes.

Table 12. Proximity Control Registers (See Figure 34)

Bit Name	Length (Bits)	Register Address	Description
FP_PROXIMITY_CNT	4	0x002[7:4]	Calibration disable time in full power mode.
LP_PROXIMITY_CNT	4	0x002[11:8]	Calibration disable time in low power mode.
FP_PROXIMITY_RECAL	8	0x004[9:0]	Full power mode proximity recalibration time.
LP_PROXIMITY_RECAL	6	0x004[15:10]	Low power mode proximity recalibration time.
PROXIMITY_RECAL_LVL	8	0x003[7:0]	Proximity recalibration level. This value multiplied by 16 controls the sensitivity of Comparator 2 (see Figure 34).
PROXIMITY_DETECTION_RATE	6	0x003[13:8]	Proximity detection rate. This value multiplied by 16 controls the sensitivity of Comparator 1 (see Figure 34).

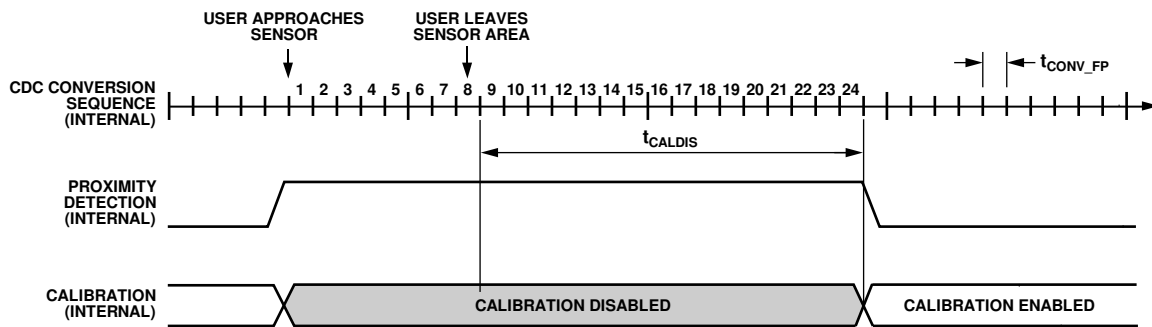
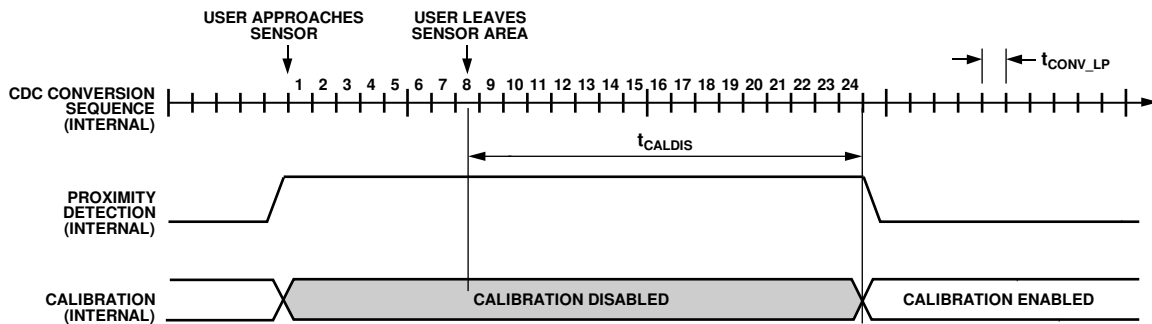


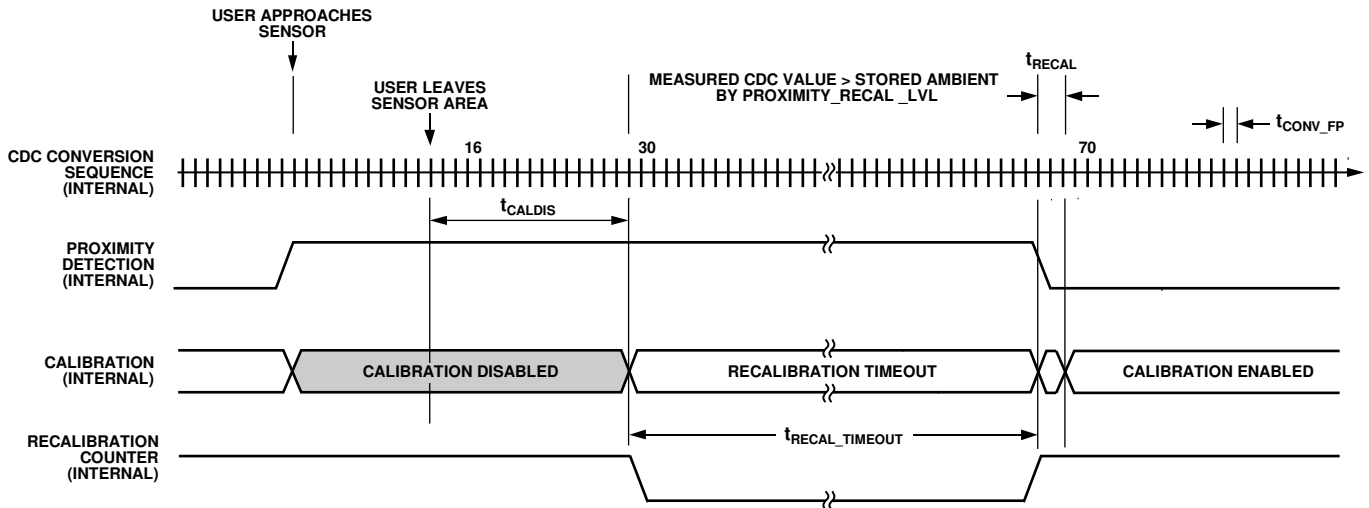
Figure 30. Example of Full Power Mode Proximity Detection (FP_PROXIMITY_CNT = 1)



NOTES

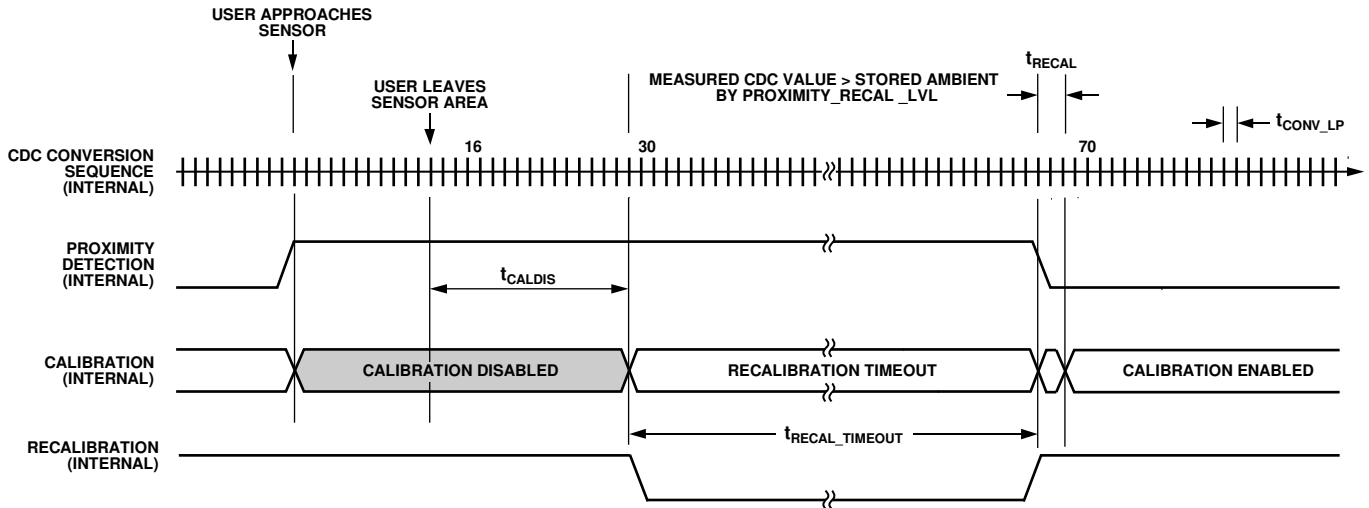
1. SEQUENCE CONVERSION TIME $t_{CONV_LP} = t_{CONV_FP} + LP_CONV_DELAY$.
2. PROXIMITY IS SET WHEN USER APPROACHES THE SENSOR, AT WHICH TIME THE INTERNAL CALIBRATION IS DISABLED.
3. $t_{CALDIS} = (t_{CONV_LP} \times LP_PROXIMITY_CNT \times 4)$.

Figure 31. Example of Low Power Mode Proximity Detection (LP_PROXIMITY_CNT = 4)



- NOTES
1. SEQUENCE CONVERSION TIME t_{CONV_FP} (SEE TABLE 10).
 2. $t_{CALDIS} = t_{CONV_FP} \times FP_PROXIMITY_CNT \times 16$.
 3. $t_{RECAL_TIMEOUT} = t_{CONV_FP} \times FP_PROXIMITY_RECAL$.
 4. $t_{RECAL} = 2 \times t_{CONV_FP}$.

Figure 32. Example of Full Power Mode Proximity Detection with Forced Recalibration ($FP_PROXIMITY_CNT = 1$ and $FP_PROXIMITY_RECAL = 40$)



- NOTES
1. SEQUENCE CONVERSION TIME $t_{CONV_LP} = t_{CONV_FP} + LP_CONV_DELAY$.
 2. $t_{CALDIS} = t_{CONV_LP} \times LP_PROXIMITY_CNT \times 4$.
 3. $t_{RECAL_TIMEOUT} = t_{CONV_LP} \times LP_PROXIMITY_RECAL$.
 4. $t_{RECAL} = 2 \times t_{CONV_LP}$.

Figure 33. Example of Low Power Mode Proximity Detection with Forced Recalibration ($LP_PROXIMITY_CNT = 4$ and $LP_PROXIMITY_RECAL = 40$)

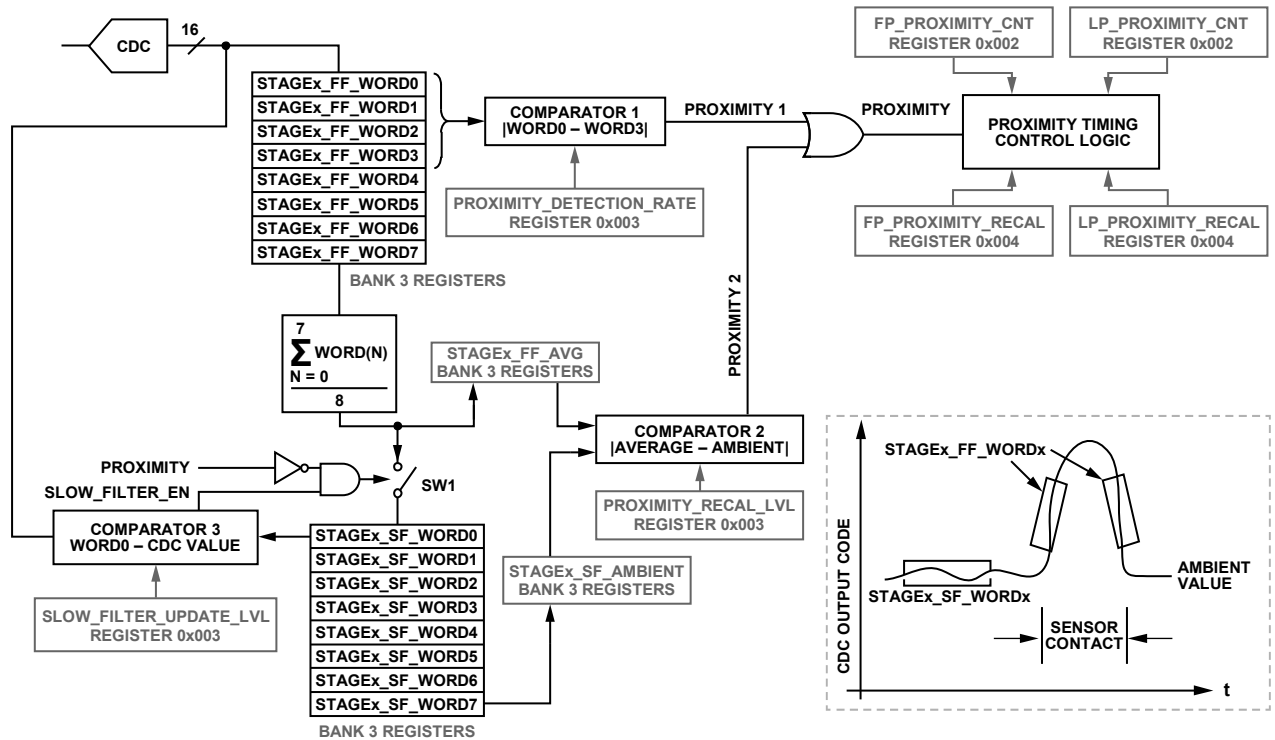
FF_SKIP_CNT

The proximity detection fast FIFO is used by the on-chip logic to determine if proximity is detected. The fast FIFO expects to receive samples from the converter at a set rate. FF_SKIP_CNT is used to normalize the frequency of the samples going into the FIFO, regardless of how many conversion stages are in a sequence. In Register 0x002, Bits[3:0] are the fast filter skip control, FF_SKIP_CNT. This value determines which CDC samples are not used (skipped) by the proximity detection fast FIFO.

Determining the FF_SKIP_CNT value is required only once during the initial setup of the capacitance sensor interface. Table 13 shows how FF_SKIP_CNT controls the update rate of the fast FIFO. The recommended value for the setting when using all 12 conversion stages on the AD7147 is 0000, or no samples skipped.

Table 13. FF_SKIP_CNT Settings

FF_SKIP_CNT	FAST FIFO Update Rate		
	Decimation = 64	Decimation = 128	Decimation = 256
0	$0.768 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$1.536 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$3.072 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
1	$1.536 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$3.072 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$6.144 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
2	$2.3 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$4.608 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$9.216 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
3	$3.072 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$6.144 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$12.288 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
4	$3.84 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$7.68 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$15.36 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
5	$4.6 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$9.216 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$18.432 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
6	$5.376 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$10.752 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$21.504 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
7	$6.144 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$12.288 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$24.576 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
8	$6.912 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$13.824 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$27.648 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
9	$7.68 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$15.36 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$30.72 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
10	$8.448 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$16.896 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$33.792 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
11	$9.216 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$18.432 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$36.864 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
12	$9.984 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$19.968 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$39.936 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
13	$10.752 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$21.504 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$43.008 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
14	$11.52 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$23.04 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$46.08 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms
15	$12.288 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$24.576 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms	$49.152 \times (\text{SEQUENCE_STAGE_NUM} + 1)$ ms



NOTES

1. SLOW_FILTER_EN, WHICH IS THE NAME OF THE OUTPUT OF COMPARATOR 3, IS SET AND SW1 IS CLOSED WHEN |STAGEx_SF_WORD0 – CDC VALUE| EXCEEDS THE VALUE PROGRAMMED IN THE SLOW_FILTER_UPDATE_LVL REGISTER PROVIDING PROXIMITY IS NOT SET.
2. PROXIMITY 1 IS SET WHEN |STAGEx_FF_WORD0 – STAGEx_FF_WORD3| EXCEEDS THE VALUE PROGRAMMED IN THE PROXIMITY_DETECTION_RATE REGISTER.
3. PROXIMITY 2 IS SET WHEN |AVERAGE – AMBIENT| EXCEEDS THE VALUE PROGRAMMED IN THE PROXIMITY_RECAL_LVL REGISTER.
4. DESCRIPTION OF COMPARATOR FUNCTIONS:
 COMPARATOR 1: USED TO DETECT WHEN A USER IS APPROACHING OR LEAVING A SENSOR.
 COMPARATOR 2: USED TO DETECT WHEN A USER IS HOVERING OVER A SENSOR OR APPROACHING A SENSOR VERY SLOWLY. ALSO USED TO DETECT IF THE SENSOR AMBIENT LEVEL HAS CHANGED AS A RESULT OF THE USER INTERACTION. FOR EXAMPLE, HUMIDITY OR DIRT LEFT BEHIND ON SENSOR.
 COMPARATOR 3: USED TO ENABLE THE SLOW FILTER UPDATE RATE. THE SLOW FILTER IS UPDATED WHEN SLOW_FILTER_EN IS SET AND PROXIMITY IS NOT SET.

Figure 34. AD7147 Proximity-Detection Logic

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ENVIRONMENTAL CALIBRATION

The AD7147 provides on-chip capacitance sensor calibration to automatically adjust for environmental conditions that have an effect on the ambient levels of the capacitance sensor. The output levels of the capacitance sensor are sensitive to temperature, humidity, and, in some cases, dirt.

The AD7147 achieves optimal and reliable sensor performance by continuously monitoring the CDC ambient levels and compensating for any environmental changes by adjusting the values of the STAGEx_HIGH_THRESHOLD register and the STAGEx_LOW_THRESHOLD registers as described in the Threshold Equations section. The CDC ambient level is defined as the output level of the capacitance sensor during periods when the user is not approaching or in contact with the sensor.

After the AD7147 is configured, the compensation logic runs automatically with each conversion when the AD7147 is not being touched. This allows the AD7147 to compensate for rapidly changing environmental conditions.

The ambient compensation control registers provide the host with access to general setup and controls for the compensation algorithm. On-chip RAM stores the compensation data for each conversion stage, as well as setup information specific for each stage.

Figure 35 shows an example of the ideal behavior of a capacitance sensor, where the CDC ambient level remains constant regardless of the environmental conditions. The CDC output shown is for a pair of differential button sensors, where one sensor caused an increase and the other caused a decrease in measured capacitance when activated. The positive and negative sensor threshold levels are calculated as a percentage of the STAGEx_OFFSET_HIGH and STAGEx_OFFSET_LOW values and are based on the threshold sensitivity settings and the ambient value. These values are sufficient to detect a sensor contact and result in the AD7147 asserting the $\overline{\text{INT}}$ output when the threshold levels are exceeded.

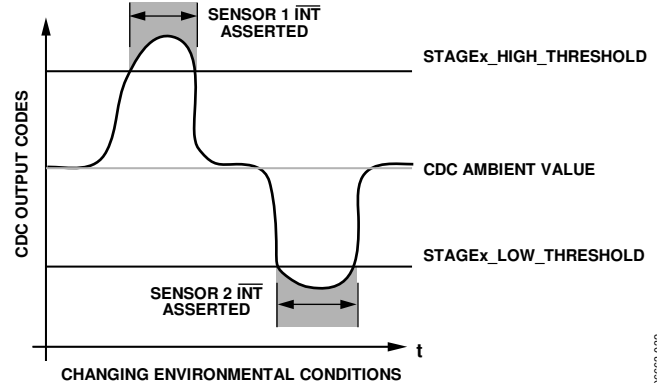


Figure 35. Ideal Sensor Behavior with a Constant Ambient Level

CAPACITANCE SENSOR BEHAVIOR WITHOUT CALIBRATION

Figure 36 shows the typical behavior of a capacitance sensor when calibration is not applied. This figure shows ambient levels drifting over time as environmental conditions change. As a result of the initial threshold levels remaining constant while the ambient levels drift upward, Sensor 2 fails to detect a user contact in this example.

The Capacitance Sensor Behavior with Calibration section describes how the AD7147 adaptive calibration algorithm prevents such errors from occurring.

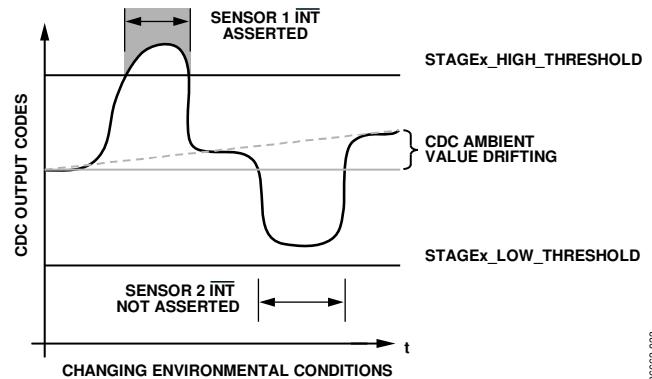


Figure 36. Typical Sensor Behavior Without Calibration