



24-bit Capacitance to Digital Converter with Temperature Sensor

Preliminary Technical Data

AD7745/AD7746

FEATURES

Capacitance to Digital Converter (CDC)

Standard One Chip Solution

Interfaces to Single or Differential Floating Sensors

Resolution: 20 aF (i.e. 19-bit) at 16.6 Hz

Accuracy: 2 fF

Linearity: 0.01%

Input Range: ± 4 pF

Offset / Common Capacitance Removal: up to 17 pF

Update rate: 5 Hz to 90 Hz

Simultaneous 50 Hz and 60 Hz rejection at 16.6 Hz

Tolerant of ground capacitance and ground leakage current

Temperature sensor on chip

Resolution: 0.1°C, accuracy: $\pm 2^\circ\text{C}$

Voltage input channel

Internal clock oscillator

2-Wire Serial Interface (I²C®-Compatible)

Power

2.7 V to 5.25 V Single-Supply Operation

1 mA Current Consumption

Operating temperature: -40°C to $+125^\circ\text{C}$

Package: 16-lead TSSOP

APPLICATIONS

Automotive, Industrial and Medical Systems for:

Pressure Measurement

Position Sensors

Level Sensors

Flowmeters

Humidity Sensors

Impurity Detection

GENERAL DESCRIPTION

The AD7745/AD7746 is a high-resolution Σ - Δ capacitance to digital converter (CDC). The capacitance to be measured is connected directly to the device inputs. The architecture features inherent high resolution (24-bit no missing codes, 19-bit effective resolution at 16.6 Hz data rate), high linearity ($\pm 0.01\%$) and high accuracy (± 2 fF factory calibrated). The AD7745/AD7746 capacitance input range is ± 4 pF (changing), while it can accept up to 17 pF absolute capacitance (not changing), which is compensated by an on-chip digital to capacitance converter (CAPDAC).

The AD7745 has one capacitance input channel, while the AD7746 has two channels. Each channel can be configured as single ended or differential. The AD7745/AD7746 is designed for floating capacitive sensors. For capacitive sensors with one plate connected to ground, the AD7747 is recommended.

The parts have an on-chip temperature sensor with resolution of 0.1°C and accuracy of $\pm 2^\circ\text{C}$. The on-chip voltage reference and the on-chip clock generator eliminate the need for any external components in most capacitive sensor applications. The parts have a standard voltage input, which together with the differential reference input allows easy interface to an external temperature sensor, such as an RTD, thermistor or diode.

The AD7745/AD7746 has a 2-wire, I²C compatible serial interface. Both parts operate from a single 3 V or 5 V power supply. They are specified over the automotive temperature range of -40°C to $+125^\circ\text{C}$ and are housed in a 16-lead TSSOP package.

FUNCTIONAL BLOCK DIAGRAMS

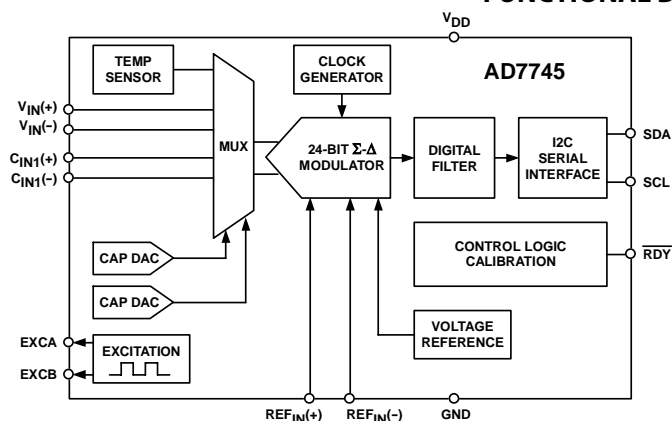


Figure 1.

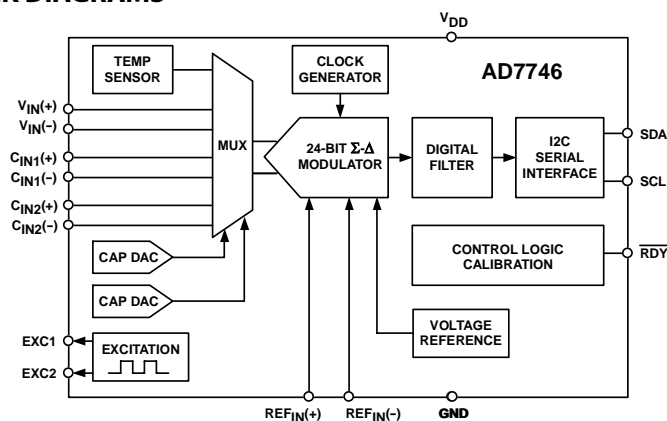


Figure 2.

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AD7745/AD7746—PRELIMINARY SPECIFICATIONS

Table 1. ($V_{DD} = 2.7\text{ V to }3.3\text{ V}$, or $4.75\text{ V to }5.25\text{ V}$, $GND = 0\text{ V}$, $-40^{\circ}\text{C to }+125^{\circ}\text{C}$, unless otherwise noted.)

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
CAPACITIVE INPUT (INPUTS)					
Conversion Input Range		± 4.096		pF	Factory calibrated
Integral Nonlinearity (INL) ¹			± 0.01	% of FSR	
No-missing Codes ¹	24			bit	62ms conversion time
Resolution p-p		16.5		bit	62ms conversion time
Resolution effective		19		bit	62ms conversion time
Output Noise rms		5		aF/ $\sqrt{\text{Hz}}$	62ms conversion time
Absolute Error ²			± 2	fF	25°C, after offset calibration 62ms conversion time
Offset Error		32		aF	After system offset calibration
Offset Drift vs. Temperature		-1		aF/ $^{\circ}\text{C}$	
Gain Error		0.02		% of FS	
Gain Drift vs. Temperature ¹	-29	-27	-25	ppm of FS/ $^{\circ}\text{C}$	
Allowed Capacitance to GND ¹			60	pF	
Power Supply Rejection		500		aF/V	
Conversion Time	11.0		217.3	ms	Configurable via digital interface
CAPDAC					
Full Range	17	21		pF	
Resolution ³		164		fF	7-bit CAPDAC
Drift vs. Temperature ¹		+27		ppm of FS/ $^{\circ}\text{C}$	
EXCITATION					
Frequency		32		kHz	Exc. setup register bit CLKCTRL = 0
Voltage across Capacitance		$\pm V_{DD}/8$		V	Configurable via digital interface
		$\pm V_{DD}/4$		V	
		$\pm V_{DD} \times 3/8$		V	
		$\pm V_{DD}/2$		V	
Average DC Voltage across Capac.		$< \pm 50$		mV	
Allowed Capacitance to GND ¹			100	pF	
TEMPERATURE SENSOR ⁴					
Resolution		0.1		$^{\circ}\text{C}$	
Error ¹		± 0.5	± 2	$^{\circ}\text{C}$	Internal temperature sensor
		± 2	± 4	$^{\circ}\text{C}$	External sensing diode
VOLTAGE INPUT ⁴					
Differential VIN Voltage Range		$\pm V_{REF}$		V	
Absolute VIN Voltage	GND -0.03		$V_{DD} + 0.03$	V	
Integral Nonlinearity (INL) ¹		± 5	± 15	ppm of FSR	
No-missing Codes ¹	24			Bit	62ms conversion time
Resolution p-p		16		bits	62ms conversion time
Output Noise		3		$\mu\text{V rms}$	62ms conversion time
Offset Error		± 3		μV	
Offset Drift vs. Temperature		15		nV/ $^{\circ}\text{C}$	
Full-Scale Error ⁵		TBD		μV	
Full-Scale Drift vs. Temperature		0.5		ppm of FSR/ $^{\circ}\text{C}$	External reference
Average VIN Input Current		400		nA/V	
Analog VIN Input Current Drift		± 50		pA/V/ $^{\circ}\text{C}$	
Power Supply Rejection		90		dB	External reference
Power Supply Rejection		80		dB	Internal reference
Common-Mode Rejection		90		dB	
Conversion Time	20.1		122.1	ms	Configurable via Digital Interface

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
INTERNAL VOLTAGE REFERENCE Voltage Drift vs. Temperature	1.168	1.17 10	1.172	V ppm/°C	At $V_{DD} = 4V$, $T_A = 25^\circ C$
EXTERNAL VOLTAGE REFERENCE INPUT Differential REFIN Voltage ¹ Absolute REFIN Voltage Average REFIN Input Current Average REFIN Input Current Drift	0.1 GND –0.03	2.5 400 ±50	V_{DD} $V_{DD} + 0.03$	V V nA/V pA/V/°C	
SERIAL INTERFACE LOGIC INPUTS (SCL, SDA) V_{IH} Input High Voltage V_{IL} Input Low Voltage Hysteresis	2.1	150	0.8	V V mV	
OPEN-DRAIN OUTPUT (SDA) V_{OL} Output Low Voltage I_{OH} Output High Leakage Current		0.1	0.4 1	V μA	$I_{SINK} = -6.0\text{ mA}$ $V_{OUT} = V_{DD}$
LOGIC OUTPUT (RDY) V_{OL} Output Low Voltage V_{OH} Output High Voltage V_{OL} Output Low Voltage V_{OH} Output High Voltage	4.0 $DV_{DD} - 0.6$		0.4 0.4	V V V V	$I_{SINK} = 1.6\text{ mA}$, $V_{DD} = 5\text{ V}$ $I_{SOURCE} = 200\text{ μA}$, $V_{DD} = 5\text{ V}$ $I_{SINK} = 100\text{ μA}$, $V_{DD} = 3\text{ V}$ $I_{SOURCE} = 100\text{ μA}$, $V_{DD} = 3\text{ V}$
POWER REQUIREMENTS V_{DD} to GND Voltage I_{DD} Current I_{DD} Current Power Down Mode	4.75 2.7	1	5.25 3.3 1	V V mA μA	$V_{DD} = 5\text{ V}$ nominal $V_{DD} = 3\text{ V}$ nominal Digital inputs equal to V_{DD} or GND Digital inputs equal to V_{DD} or GND

¹ Specification is not production tested, but is supported by characterization data at initial product release.

² Factory calibrated The absolute error includes factory gain calibration error, integral nonlinearity error, and offset error after system offset calibration, all at 25°C. At different temperatures, compensation for gain drift over temperature is required.

³ The CAPDAC resolution is 7-bit in the actual CAPDAC full range. Using the on-chip offset calibration or adjusting the capacitive offset calibration register can further reduce the CIN offset or the non-changing CIN component.

⁴ The VTCHOP bit in the VT SETUP register must be set to 1 for the specified temperature sensor and voltage input performance.

⁵ Full-scale error applies to both positive and negative full-scale.

TIMING SPECIFICATIONS

Table 2. ($V_{DD} = 2.7\text{ V}$ to 3.3 V , or 4.75 V to 5.25 V , $GND = 0\text{ V}$; Input Logic 0 = 0 V ; Input Logic 1 = V_{DD} ; -40°C to $+125^{\circ}\text{C}$, unless otherwise noted.)

Parameter	Min	Typ	Max	Unit	Test Conditions/Comments
SERIAL INTERFACE ^{1,2}					See Figure 3
SCL Frequency	0		400	kHz	
SCL High Pulse Width, t_{HIGH}	0.6			μs	
SCL Low Pulse Width, t_{LOW}	1.3			μs	
SCL, SDA Rise Time, t_R		0.3		μs	
SCL, SDA Fall Time, t_F		0.3		μs	
Hold Time (Start Condition), $t_{HD:STA}$	0.6			μs	After this period, the first clock is generated
Setup Time (Start Condition), $t_{SU:STA}$	0.6			μs	Relevant for repeated start condition
Data Setup Time, $t_{SU:DAT}$	0.1			μs	
Setup Time (Stop Condition), $t_{SU:STO}$	0.6			μs	
Data Hold Time, $t_{HD:DAT}$ (Master)	0			μs	
Bus Free Time (Between Stop and Start Condition, t_{BUF})	1.3			μs	

¹ Sample tested during initial release to ensure compliance.

² All input signals are specified with input rise/fall times = 3 ns , measured between the 10% and 90% points. Timing reference points at 50% for inputs and outputs. Output load = 10 pF .

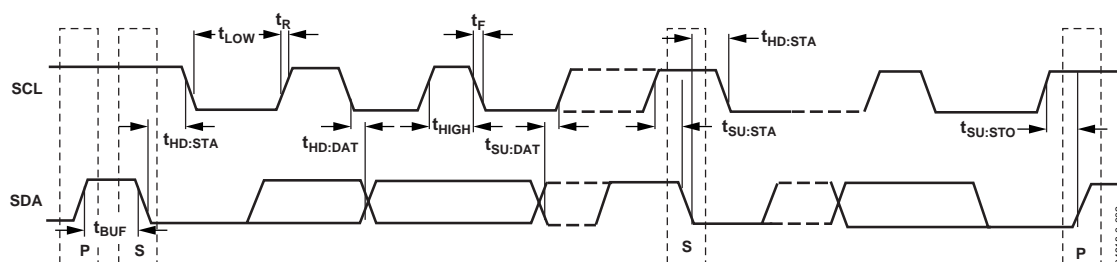


Figure 3. Serial Interface Timing Diagram

ABSOLUTE MAXIMUM RATINGS

Table 3. ($T_A = 25^{\circ}\text{C}$, unless otherwise noted.)

Parameter	Rating
Positive Supply Voltage V_{DD} to GND	-0.3 V to $+6.5\text{ V}$
Voltage on any input or output pin to GND	-0.3 V to $V_{DD} + 0.3\text{ V}$
ESD Rating (ESD Association Human Body Model, S5.1)	TBD V
Operating Temperature Range	-40°C to $+125^{\circ}\text{C}$
Storage Temperature Range	-65°C to $+150^{\circ}\text{C}$
Junction Temperature	150°C
TSSOP Package θ_{JA} Thermal Impedance to Air	128°C/W
TSSOP Package θ_{JC} Thermal Impedance to Case	14°C/W
Lead Temperature, Soldering	
Vapor Phase (60 sec)	215°C
Infrared (15 sec)	220°C

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

OUTPUT NOISE AND RESOLUTION SPECIFICATIONS

The AD7745/46 resolution is limited by noise. The noise performance varies with the selected conversion time.

The Table 4 and Table 5 show typical noise performance and resolution for the capacitive channel. These numbers were generated from 1000 data samples acquired in continuous conversion mode, $V_{DD} = 5.0V$, all CIN and EXC pins open circuit.

RMS noise represents standard deviation, p-p noise represents difference between minimum and maximum result in the data.

Effective resolution is calculated from RMS noise, p-p resolution is calculated from p-p noise.

Table 4. Typical Capacitive Input Noise and Resolution versus Conversion Time, CAP CHOP = 0

Conversion Time (ms)	Output Data Rate (Hz)	RMS Noise (aF)	P-P Noise (aF)	Effective Resolution (Bits)	P-P Resolution (Bits)
11.0	90.9	40.0	212.4	17.6	15.2
11.9	83.8	27.3	137.7	18.2	15.9
20.0	50.0	12.2	82.5	19.4	16.6
38.0	26.3	7.3	50.3	20.1	17.3
62.0	16.1	5.4	33.7	20.5	17.9
77.0	13.0	4.9	28.3	20.7	18.1
92.0	10.9	4.4	27.8	20.8	18.2
109.6	9.1	4.4	27.3	20.8	18.2

Table 5. Typical Capacitive Input Noise and Resolution versus Conversion Time, CAP CHOP = 1

Conversion Time (ms)	Output Data Rate (Hz)	RMS Noise (aF)	P-P Noise (aF)	Effective Resolution (Bits)	P-P Resolution (Bits)
20.1	49.8	31.7	159.2	18.0	15.7
22.0	45.6	24.9	118.2	18.3	16.1
38.1	26.3	9.8	63.0	19.7	17.0
74.1	13.5	4.9	31.7	20.7	18.0
122.1	8.2	3.9	26.4	21.0	18.2
152.1	6.6	3.4	21.5	21.2	18.5
182.1	5.5	2.9	18.6	21.4	18.8
217.3	4.6	2.9	18.6	21.4	18.8

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

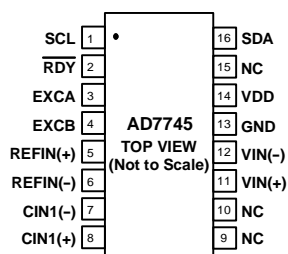


Figure 4. AD7745 Pin Configuration (16-Lead TSSOP)

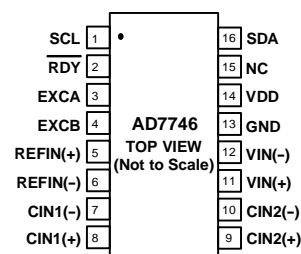


Figure 5. AD7746 Pin Configuration (16-Lead TSSOP)

Table 6. Pin Function Descriptions

Pin No.	Mnemonic	Description
1	SCL	Serial interface clock input. Connects to the master's clock line. (Requires pull-up resistor if not already provided in the system.)
2	$\overline{\text{RDY}}$	Logic output. A falling edge on this output indicates that a conversion on enabled channel(s) has been finished and the new data are available. Alternatively, the status register can be read via the 2-wire serial interface and the relevant bit(s) decoded to query finished conversion. If not used, this pin should be left open circuit.
3, 4	EXCA, EXCB	CDC excitation outputs. The measured capacitance is connected between one of the EXC pins and one of the CIN pins. If not used, these pins should be left open circuit.
5, 6	REFIN(+), REFIN(-)	Differential voltage reference input for the voltage channel (ADC). Alternatively, the on-chip internal reference can be used for the voltage channel. These reference input pins are not used for conversion on capacitive channel(s) (CDC). If not used, these pins can be left open circuit or connected to GND.
7	CIN1(-)	CDC negative capacitive input in differential mode. This pin is internally disconnected in single ended CDC configuration. If not used, this pin can be left open circuit or connected to GND.
8	CIN1(+)	CDC capacitive input (in single ended mode) or positive capacitive input (in differential mode). The measured capacitance is connected between one of the EXC pins and one of the CIN pins. If not used, this pin can be left open circuit or connected to GND.
9	CIN2(+)	AD7746 only. CDC second capacitive input (in single ended mode) or positive capacitive input (in differential mode). If not used, this pin can be left open circuit or connected to GND.
10	CIN2(-)	AD7746 only. CDC negative capacitive input in differential mode. This pin is internally disconnected in single ended CDC configuration. If not used, this pin can be left open circuit or connected to GND.
11, 12	VIN(+), VIN(-)	Differential voltage input for the voltage channel (ADC). These pins are also used to connect an external temp sensing diode. If not used, these pins can be left open circuit or connected to GND.
13	GND	Ground pin.
14	V _{DD}	Power supply voltage. This pin should be decoupled to GND, using a low impedance capacitor, for example combination of 10uF tantalum and 0.1uF multilayer ceramic.
15	NC	Not connected. This pin should be left open circuit.
16	SDA	Serial interface bidirectional data. Connects to the master's data line. Requires pull-up resistor if not provided elsewhere in the system.

SERIAL INTERFACE

The AD7745/AD7746 supports an I2C compatible two wire serial interface. The two wires on the I2C Bus are called SCL, (clock) and SDA, (data). These two wires carry all addressing, control and data information one bit at a time over the bus to all connected peripheral devices. The SDA wire carries the data, while the SCL wire synchronizes the sender and receiver during the data transfer. I2C devices are classified as either a MASTER or SLAVE devices. A device that initiates a data transfer message is called a master, while a device that responds to this message is called a slave.

To control the AD7745/AD7746 device on the bus the following protocol must be followed. First, the master initiates a data transfer by establishing a START CONDITION, defined by a high-to-low transition on SDA while SCL remains high. This indicates that the START BYTE will follow next. This 8 bit, start byte is made up of a 7 bit address plus an R/W bit indicator.

All peripherals connected to the bus respond to the start condition and shift in the next eight bits (7-bit address + R/W bit). The bits arrive MSB first. The peripheral that recognizes the transmitted address responds by pulling the data line low during the ninth clock pulse. This is known as the ACKNOWLEDGE bit. All other devices withdraw from the bus at this point and maintain an IDLE CONDITION. An exception to this is the GENERAL CALL address which is described later in this document. The idle condition is where the device monitors the SDA and SCL lines waiting for the start condition and the correct address byte. The R/W bit determines the direction of the data transfer. A logic '0' LSB in the start byte means that the master will write information to the addressed peripheral. In this case the AD7745/AD7746 becomes a slave receiver. A logic '1' LSB in the start byte means that the master will read information from the addressed peripheral. In this case the AD7745/AD7746 becomes a slave transmitter. In all instances, the AD7745/AD7746 acts as a standard slave device on the I2C bus.

The start byte address for the AD7745/AD7746 is 0x90 for a Write and 0x91 for a Read.

WRITE OPERATION

When a WRITE is selected, the byte following the start byte is always the register ADDRESS POINTER (sub-address) byte, which points to one of the internal registers on the AD7745/AD7746. The address pointer byte is automatically loaded into the address pointer register and acknowledged by the AD7745/AD7746. After the address pointer byte acknowledge, a STOP CONDITION, REPEATED START CONDITION, or another data byte can follow from the master.

A stop condition is defined by a low-to-high transition on SDA while SCL remains high. If a stop condition is ever encountered by the AD7745/AD7746, it will return to its idle condition and the address pointer is reset to address 0x00.

If a data byte is transmitted after the register address pointer byte, the AD7745/AD7746 will load this byte into the register that is currently addressed by the address pointer register, send an acknowledge and the address pointer auto-incrementer will automatically increment the address pointer register to the next internal register address. Thus subsequent transmitted data bytes will be loaded into sequentially incremented addresses.

If a repeated start condition is encountered after the address pointer byte, all peripherals connected to the bus respond exactly as outlined above for a start condition, i.e. a repeated start condition is treated the same as a start condition. (When a master device issues a stop condition, it relinquishes control of the bus, allowing another master device to take control of the bus. Hence, a master wanting to retain control of the bus will issue successive start conditions known as repeated start conditions).

READ OPERATION

When a READ is selected in the start byte, the register that is currently addressed by the address pointer is transmitted on to the SDA line by the AD7745/AD7746. This is then clocked out by the master device and the AD7745/AD7746 will await an acknowledge from the master.

If an acknowledge is received from the master, the address auto-incrementer will automatically increment the address pointer register and output the next addressed registers contents on to the SDA line for transmission to the master. If no acknowledge is received the AD7745/AD7746 returns to its idle state and the address pointer is not incremented.

The address pointers' auto-incrementer allows block data to be written or read from the starting address and subsequent incremental addresses. The user can also access any unique register (address) on a one-to-one basis without having to update all the registers. The address pointer register contents cannot be read.

If an incorrect address pointer location is accessed or, if the user allows the auto incrementer to exceed the required register address, the following applies:

1. In Read Mode, the AD7745/AD7746 will continue to output various internal register contents until the master device issues a not-acknowledge, start or stop condition. The address pointers' auto-incrementer's contents will reset to point to the STATUS REGISTER at address 0x00 when a stop condition is received at the end of a read operation. This allows the status register to be read (polled) continually without having to constantly write to address pointer.
2. In Write Mode, the data for the invalid address will not be loaded into the AD7745/AD7746 registers but an acknowledge will be issued by the AD7745/AD7746.

GENERAL CALL

When a master issues a slave address consisting of seven zeros with the eighth bit (R/W bit) set to zero, this is known as the general call address. The general call address is for addressing every device connected to the I2C bus. The AD7745/AD7746 will acknowledge this address and read in the following data byte.

If the second byte is 0x06, the AD7745/AD7746 will reset completely uploading all default values. The AD7745/AD7746 will not acknowledge any other general call commands.

AD7745/AD7746 RESET

In order that the AD7745/AD7746 can be reset without having to reset the entire I2C bus, an explicit reset command is provided. This uses a particular address pointer word as a command word to reset the part and upload all default settings.

The reset command address word is 0xBF.

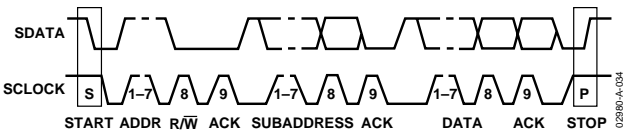


Figure 6. Bus Data Transfer

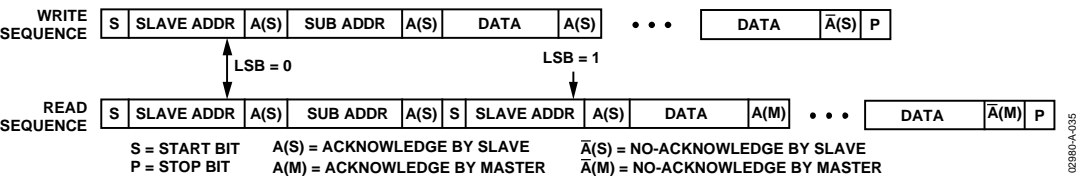


Figure 7. Write and Read Sequences

REGISTER DESCRIPTIONS

The master can write to or read from all of the AD7745/AD7746 registers except the address pointer register, which is a write-only register. The address pointer register determines which register the next read or write operation accesses. All communications with the part through the bus start with an access to the address pointer register.

After the part has been accessed over the bus and a read/write operation is selected, the address pointer register is set up. The address pointer register determines to/from which register the operation takes place. A read/write operation is performed from to the target address, which then increments to the next address until a stop command on the bus is performed.

Table 7. Register Summary

Register	Address Pointer		Dir	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
	(dec)	(hex)		(Default Value)							
Status	0	0x00	R	-	-	-	-	EXCERR	RDY	RDYVT	RDYCAP
				0	0	0	0	0	1	1	1
Cap Data H	1	0x01	R	Capacitive channel data – High byte 0x00							
Cap Data M	2	0x02	R	Capacitive channel data – Middle byte 0x00							
Cap Data L	3	0x03	R	Capacitive channel data – Low byte 0x00							
VT Data H	4	0x04	R	Voltage / Temperature channel data – High byte 0x00							
VT Data M	5	0x05	R	Voltage / Temperature channel data – Middle byte 0x00							
VT Data L	6	0x06	R	Voltage / Temperature channel data – Low byte 0x00							
Cap Setup	7	0x07	R/W	CAPEN	CIN2 ¹	CAPDIFF	-	-	-		CAPCHOP
				0	0	0	0	0	0	0	0
VT Setup	8	0x08	R/W	VTEN	VTMD1	VTMD0	EXTREF	-	-	VTSHORT	VTCHOP
				0	0	0	0	0	0	0	0
Exc Setup	9	0x09	R/W	CLKCTRL	EXCON	EXCB	EXCB	EXCA	EXCA	EXCLVL1	EXCLVL0
				0	0	0	0	0	0	1	1
Configuration	10	0x0A	R/W	VTFS1	VTFS0	CAPFS2	CAPFS1	CAPFS0	MD2	MD1	MD0
				1	0	1	0	0	0	0	0
Cap DAC A	11	0x0B	R/W	DACAENA	DACA – 7-Bit Value						
				0	0x00						
Cap DAC B	12	0x0C	R/W	DACBENB	DACB – 7-Bit Value						
				0	0x00						
Cap Offset H	13	0x0D	R/W	Capacitive offset calibration – High byte 0x80							
Cap Offset L	14	0x0E	R/W	Capacitive offset calibration – Low byte 0x00							
Cap Gain H	15	0x0F	R/W	Capacitive gain calibration – High byte Factory calibrated							
Cap Gain L	16	0x10	R/W	Capacitive gain calibration – Low byte Factory calibrated							
Volt Gain H	17	0x11	R/W	Voltage gain calibration – High byte Factory calibrated							
Volt Gain L	18	0x12	R/W	Voltage gain calibration – Low byte Factory calibrated							

¹ The CIN2 bit is relevant only for AD7746. The CIN2 bit should be always 0 on AD7745.

STATUS REGISTER

Address pointer 0x00, read only, default value 0x07

Indicates status of the converter. Status register can be read via the 2-wire serial interface to query a finished conversion.

The $\overline{\text{RDY}}$ pin reflects status of the RDY bit. Therefore, the $\overline{\text{RDY}}$ pin high to low transition can be used as an alternative indication of the finished conversion.

Bit	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Mnemonic	-	-	-	-	EXCERR	RDY	RDYVT	RDYCAP
Default	0	0	0	0	0	1	1	1

Bit	Mnemonic	Description
7-4	-	Not used, always read 0
3	EXCERR	EXCERR = 1 indicates that the excitation output cannot be driven properly. The possible reason can be short or too high capacitance between the excitation pin and ground.
2	RDY	RDY = 0 indicates that conversion on the enabled channel(s) has been finished and new unread data are available. If both capacitive and voltage / temperature channels are enabled, the RDY bit will be changed to 0 after conversion on both channels is finished. The RDY bit will return to 1 either when data are read or prior finishing the next conversion. If only one channel is enabled, for example capacitive, then the RDY bit will reflect the RDYCAP bit.
1	RDYVT	RDYVT = 0 indicates that a conversion on the voltage / temperature channel has been finished and new unread data are available.
0	RDYCAP	RDYCAP = 0 indicates that a conversion on the capacitive channel has been finished and new unread data are available.

CAP DATA REGISTER

24 bits, address pointer 0x01, 0x02, 0x03, read only, default value 0x000000

Capacitive channel output data. The register is updated after finished conversion on the capacitive channel, with one exception: When the serial interface read operation from the CAP DATA register is in progress, the data register is not updated and the new capacitance conversion result is lost.

Stop condition on the serial interface is considered as the end of the read operation. Therefore, to prevent data corruption, all 3 bytes of the data register should be read subsequently using the register address pointer auto-increment feature of the serial interface.

To prevent losing some of the results, the CAP DATA register should be read before the next conversion on the capacitive channel is finished.

Code 0x000000 represents negative full-scale (-4.096 pF), code 0x800000 represents zero scale (0 pF) and the code 0xFFFFF represents positive full scale (+4.096 pF).

VT DATA REGISTER

24 bits, address pointer 0x04, 0x05, 0x06, read only, default value 0x000000

Voltage / Temperature channel output data. The register is updated after finished conversion on the voltage channel or temperature channel, with one exception: When the serial interface read operation from the VT DATA register is in progress, the data register is not updated and the new voltage / temperature conversion result is lost.

Stop condition on the serial interface is considered as the end of the read operation. Therefore, to prevent data corruption, all 3 bytes of the data register should be read subsequently using the register address pointer auto-increment feature of the serial interface.

For voltage input, code 0 represents negative full scale ($-V_{\text{REF}}$), code 0x800000 represents zero scale (0 V) and the code 0xFFFFF represents positive full scale ($+V_{\text{REF}}$).

To prevent losing some of the results, the VT DATA register should be read before the next conversion on the voltage / temperature channel is finished.

For temperature sensor, the temperature can be calculated from code using equation:

$$\text{Temperature (}^{\circ}\text{C)} = (\text{Code} / 2048) - 4096$$

CAP SETUP REGISTER

Address pointer 0x07, default value 0x00

Capacitive channel setup.

Bit	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Mnemonic	CAPEN	CIN2	DIFF	-	-	-	-	CAPCHOP
Default	0	0	0	0	0	0	0	0

Bit	Mnemonic	Description
7	CAPEN	CAPEN = 1 enables capacitive channel for single conversion, continuous conversion or calibration.
6	CIN2	CIN2 = 1 switches the internal multiplexer to the second capacitive input on the AD7746.
5	DIFF	DIFF = 1 sets differential mode on the selected capacitive input.
4-1	-	These bits must be 0 for proper operation.
0	CAPCHOP	CAPCHOP = 1 enables chopping on the capacitive channel.

VT SETUP REGISTER

Address pointer 0x08, default value 0x00

Voltage / Temperature channel setup.

Bit	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Mnemonic	VTEN	VTMD1	VTMD0	EXTREF	-	-	VTSHORT	VTCHOP
Default	0	0	0	0	0	0	0	0

Bit	Mnemonic	Description															
7	VTEN	VTEN = 1 enables voltage / temperature channel for single conversion, continuous conversion or calibration.															
6 5	VTMD1 VTMD0	Voltage / temperature channel input configuration: <table><tr><th>VTMD1</th><th>VTMD0</th><th>Channel Input</th></tr><tr><td>0</td><td>0</td><td>Internal Temperature Sensor</td></tr><tr><td>0</td><td>1</td><td>External Temperature Sensor Diode</td></tr><tr><td>1</td><td>0</td><td>V_{DD} Monitor</td></tr><tr><td>1</td><td>1</td><td>External Voltage Input (VIN)</td></tr></table>	VTMD1	VTMD0	Channel Input	0	0	Internal Temperature Sensor	0	1	External Temperature Sensor Diode	1	0	V _{DD} Monitor	1	1	External Voltage Input (VIN)
		VTMD1	VTMD0	Channel Input													
		0	0	Internal Temperature Sensor													
		0	1	External Temperature Sensor Diode													
		1	0	V _{DD} Monitor													
1	1	External Voltage Input (VIN)															
4	EXTREF	EXTREF = 1 selects an external reference voltage connected to REFIN(+), REFIN(-) for the voltage input or the V _{DD} Monitor. EXTREF = 0 selects the on-chip internal reference. The internal reference must be used with the internal temperature sensor for proper operation.															
3-2	-	These bits must be 0 for proper operation.															
1	VTSHORT	VTSHORT = 1 internally shorts the voltage / temperature channel input for test purposes.															
0	VTCHOP = 1	VTCHOP = 1 sets internal chopping on the voltage / temperature channel. The VTCHOP bit must be set to 1 for the specified voltage / temperature channel performance.															

EXC SETUP REGISTER

Address pointer 0x09, default value 0x03

Capacitive channel excitation setup.

Bit	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Mnemonic	CLKCTRL	EXCON	EXCB	EXCB	EXCA	EXCA	EXCLVL1	EXCLVL0
Default	0	0	0	0	0	0	0	0

Bit	Mnemonic	Description																									
7	CLKCTRL	CLKCTRL = 1 decreases the excitation signal frequency and the modulator clock frequency by factor of 2. This also increases the conversion time on all channels (capacitive, voltage and temperature) by factor of 2.																									
6	EXCON	When EXCON = 0, the excitation signal is present on the output only during capacitance channel conversion When EXCON = 1, the excitation signal is present on the output during both capacitance and voltage / temperature conversion																									
5	EXCB	EXCB = 1 enables EXCB pin as the excitation output																									
4	$\overline{\text{EXCB}}$	EXCB = 1 enables EXCB pin as the inverted excitation output Only one of the EXCB or the $\overline{\text{EXCB}}$ bits should be set for proper operation.																									
3	EXCA	EXCA = 1 enables EXCA pin as the excitation output																									
2	$\overline{\text{EXCA}}$	$\overline{\text{EXCA}}$ = 1 enables EXCA pin as the inverted excitation output Only one of the EXCA or the $\overline{\text{EXCA}}$ bits should be set for proper operation.																									
1 0	EXCLVL1, EXCLVL0	Excitation Voltage Level:																									
		<table><tr><th>EXCLVL1</th><th>EXCLVL0</th><th>Voltage on Cap.</th><th>EXC pin Low Level</th><th>EXC pin High Level</th></tr><tr><td>0</td><td>0</td><td>$\pm V_{DD}/8$</td><td>$V_{DD} \times 3/8$</td><td>$V_{DD} \times 5/8$</td></tr><tr><td>0</td><td>1</td><td>$\pm V_{DD}/4$</td><td>$V_{DD} \times 1/4$</td><td>$V_{DD} \times 3/4$</td></tr><tr><td>1</td><td>0</td><td>$\pm V_{DD} \times 3/8$</td><td>$V_{DD} \times 1/8$</td><td>$V_{DD} \times 7/8$</td></tr><tr><td>1</td><td>1</td><td>$\pm V_{DD}/2$</td><td>0</td><td>V_{DD}</td></tr></table>	EXCLVL1	EXCLVL0	Voltage on Cap.	EXC pin Low Level	EXC pin High Level	0	0	$\pm V_{DD}/8$	$V_{DD} \times 3/8$	$V_{DD} \times 5/8$	0	1	$\pm V_{DD}/4$	$V_{DD} \times 1/4$	$V_{DD} \times 3/4$	1	0	$\pm V_{DD} \times 3/8$	$V_{DD} \times 1/8$	$V_{DD} \times 7/8$	1	1	$\pm V_{DD}/2$	0	V_{DD}
		EXCLVL1	EXCLVL0	Voltage on Cap.	EXC pin Low Level	EXC pin High Level																					
		0	0	$\pm V_{DD}/8$	$V_{DD} \times 3/8$	$V_{DD} \times 5/8$																					
		0	1	$\pm V_{DD}/4$	$V_{DD} \times 1/4$	$V_{DD} \times 3/4$																					
		1	0	$\pm V_{DD} \times 3/8$	$V_{DD} \times 1/8$	$V_{DD} \times 7/8$																					
1	1	$\pm V_{DD}/2$	0	V_{DD}																							

CONFIGURATION REGISTER

Address pointer 0x0A, default value 0xA0

Converter update rate and mode of operation setup.

Bit	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Mnemonic	VTF1	VTF0	CAPF2	CAPF1	CAPF0	MD2	MD1	MD0
Default	0	0	0	0	0	0	0	0

Bit	Mnemonic	Description																																																																						
7 6	VTF1 VTF0	<p>Voltage / temperature channel digital filter setup - conversion time / update rate setup.</p> <p>The conversion times in this table are valid for the CLKCTRL = 0 in the EXC SETUP register. The conversion times are longer by factor of two for the CLKCTRL = 1.</p> <table><tr><th colspan="2"></th><th colspan="2">VTCHOP = 1</th></tr><tr><th>VTF1</th><th>VTF0</th><th>Conversion Time (ms)</th><th>Update Rate (Hz)</th></tr><tr><td>0</td><td>0</td><td>20.1</td><td>49.8</td></tr><tr><td>0</td><td>1</td><td>32.1</td><td>31.2</td></tr><tr><td>1</td><td>0</td><td>62.1</td><td>16.1</td></tr><tr><td>1</td><td>1</td><td>122.1</td><td>8.2</td></tr></table>			VTCHOP = 1		VTF1	VTF0	Conversion Time (ms)	Update Rate (Hz)	0	0	20.1	49.8	0	1	32.1	31.2	1	0	62.1	16.1	1	1	122.1	8.2																																														
		VTCHOP = 1																																																																						
VTF1	VTF0	Conversion Time (ms)	Update Rate (Hz)																																																																					
0	0	20.1	49.8																																																																					
0	1	32.1	31.2																																																																					
1	0	62.1	16.1																																																																					
1	1	122.1	8.2																																																																					
5 4 3	CAPF2 CAPF1 CAPF0	<p>Capacitive channel digital filter setup - conversion time / update rate setup.</p> <p>The conversion times in this table are valid for the CLKCTRL = 0 in the EXC SETUP register. The conversion times are longer by factor of two for the CLKCTRL = 1.</p> <table><tr><th></th><th></th><th></th><th colspan="2">CAP CHOP = 1</th><th colspan="2">CAP CHOP = 0</th></tr><tr><th>CAPF2</th><th>CAPF1</th><th>CAPF0</th><th>Conversion Time (ms)</th><th>Update Rate (Hz)</th><th>Conversion Time (ms)</th><th>Update Rate (Hz)</th></tr><tr><td>0</td><td>0</td><td>0</td><td>20.1</td><td>49.8</td><td>11.0</td><td>90.9</td></tr><tr><td>0</td><td>0</td><td>1</td><td>22.0</td><td>45.6</td><td>11.9</td><td>83.8</td></tr><tr><td>0</td><td>1</td><td>0</td><td>38.1</td><td>26.3</td><td>20.0</td><td>50.0</td></tr><tr><td>0</td><td>1</td><td>1</td><td>74.1</td><td>13.5</td><td>38.0</td><td>26.3</td></tr><tr><td>1</td><td>0</td><td>0</td><td>122.1</td><td>8.2</td><td>62.0</td><td>16.1</td></tr><tr><td>1</td><td>0</td><td>1</td><td>152.1</td><td>6.6</td><td>77.0</td><td>13.0</td></tr><tr><td>1</td><td>1</td><td>0</td><td>182.1</td><td>5.5</td><td>92.0</td><td>10.9</td></tr><tr><td>1</td><td>1</td><td>1</td><td>217.3</td><td>4.6</td><td>109.6</td><td>9.1</td></tr></table>				CAP CHOP = 1		CAP CHOP = 0		CAPF2	CAPF1	CAPF0	Conversion Time (ms)	Update Rate (Hz)	Conversion Time (ms)	Update Rate (Hz)	0	0	0	20.1	49.8	11.0	90.9	0	0	1	22.0	45.6	11.9	83.8	0	1	0	38.1	26.3	20.0	50.0	0	1	1	74.1	13.5	38.0	26.3	1	0	0	122.1	8.2	62.0	16.1	1	0	1	152.1	6.6	77.0	13.0	1	1	0	182.1	5.5	92.0	10.9	1	1	1	217.3	4.6	109.6	9.1
			CAP CHOP = 1		CAP CHOP = 0																																																																			
CAPF2	CAPF1	CAPF0	Conversion Time (ms)	Update Rate (Hz)	Conversion Time (ms)	Update Rate (Hz)																																																																		
0	0	0	20.1	49.8	11.0	90.9																																																																		
0	0	1	22.0	45.6	11.9	83.8																																																																		
0	1	0	38.1	26.3	20.0	50.0																																																																		
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1	0	0	122.1	8.2	62.0	16.1																																																																		
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1	1	0	182.1	5.5	92.0	10.9																																																																		
1	1	1	217.3	4.6	109.6	9.1																																																																		
2 1 0	MD2 MD1 MD0	<p>Converter mode of operation setup</p> <table><tr><th>MD2</th><th>MD1</th><th>MD0</th><th>Mode</th></tr><tr><td>0</td><td>0</td><td>0</td><td>Idle</td></tr><tr><td>0</td><td>0</td><td>1</td><td>Continuous Conversion</td></tr><tr><td>0</td><td>1</td><td>0</td><td>Single Conversion</td></tr><tr><td>0</td><td>1</td><td>1</td><td>Power-Down</td></tr><tr><td>1</td><td>0</td><td>0</td><td>-</td></tr><tr><td>1</td><td>0</td><td>1</td><td>Capacitance Offset Calibration</td></tr><tr><td>1</td><td>1</td><td>0</td><td>Capacitance or Voltage Gain Calibration</td></tr><tr><td>1</td><td>1</td><td>1</td><td></td></tr></table>	MD2	MD1	MD0	Mode	0	0	0	Idle	0	0	1	Continuous Conversion	0	1	0	Single Conversion	0	1	1	Power-Down	1	0	0	-	1	0	1	Capacitance Offset Calibration	1	1	0	Capacitance or Voltage Gain Calibration	1	1	1																																			
MD2	MD1	MD0	Mode																																																																					
0	0	0	Idle																																																																					
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0	1	0	Single Conversion																																																																					
0	1	1	Power-Down																																																																					
1	0	0	-																																																																					
1	0	1	Capacitance Offset Calibration																																																																					
1	1	0	Capacitance or Voltage Gain Calibration																																																																					
1	1	1																																																																						

CAP DAC A REGISTER

Address pointer 0x0B, default value 0x00

Capacitive DAC setup.

Bit	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Mnemonic	DACAENA	DACA – 7-Bit Value						
Default	0	0x00						

Bit	Mnemonic	Description
7	DACAENA	DACAENA = 1 connects capacitive DAC A to the positive capacitance input.
6-1	DACA	DAC A value, code 0x00 \approx 0pF, code 0x7F \approx Full Range

CAP DAC B REGISTER

Address pointer 0x0C, default value 0x00

Capacitive DAC setup.

Bit	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Mnemonic	DACBENB	DACB – 7-Bit Value						
Default	0	0x00						

Bit	Mnemonic	Description
7	DACBENB	DACBENB = 1 connects capacitive DAC B to the positive capacitance input.
6-1	DACB	DAC B value, code 0x00 \approx 0pF, code 0x7F \approx Full Range

CAP OFFSET REGISTER

16 bits, address pointer 0x0D, 0x0E default value 0x8000

Capacitive offset calibration register. The register holds capacitive channel zero-scale calibration coefficient. The value in this register is used to digitally remove the capacitive channel offset. The value in this register is updated automatically following the execution of a capacitance offset calibration. The capacitive offset calibration resolution (cap offset register LSB) is less than 32 aF, the full range is 1 pF. On the AD7746, the register is shared by the two capacitive channels.

CAP GAIN REGISTER

16 bits, address pointer 0x0F, 0x10, default value 0xFFFF

Capacitive gain calibration register. The register holds capacitive channel full scale factory calibration coefficient.

VOLT GAIN REGISTER

16 bits, address pointer 0x11, 0x12, default value 0xFFFF

Voltage gain calibration register. The register holds voltage channel full scale factory calibration coefficient.

TYPICAL APPLICATION DIAGRAM

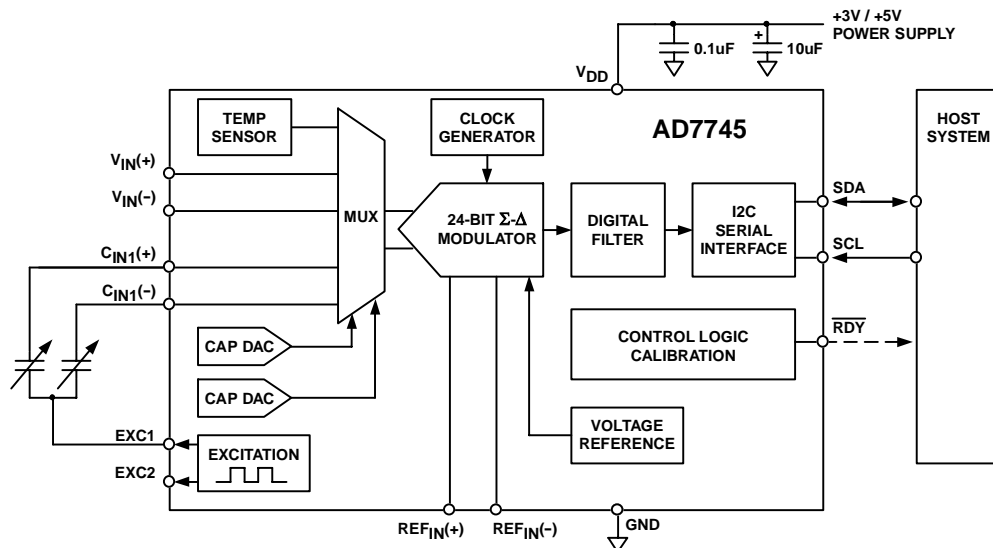


Figure 8. Basic Application Diagram for a Differential Capacitive Sensor

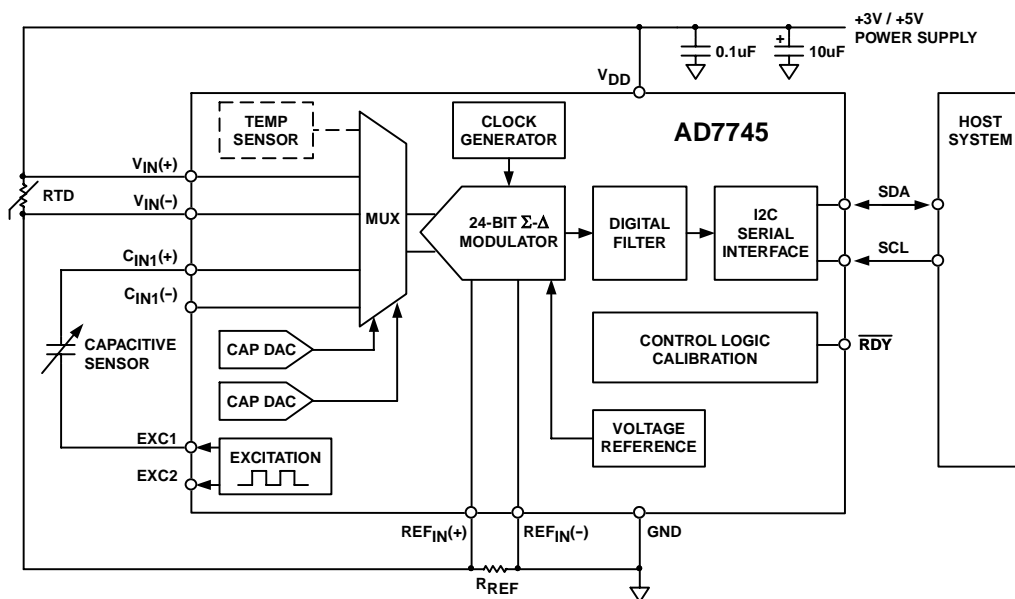


Figure 9. Application Diagram for a Single Capacitive Sensor and an External RTD or PTC Sensor

OUTLINE DIMENSIONS

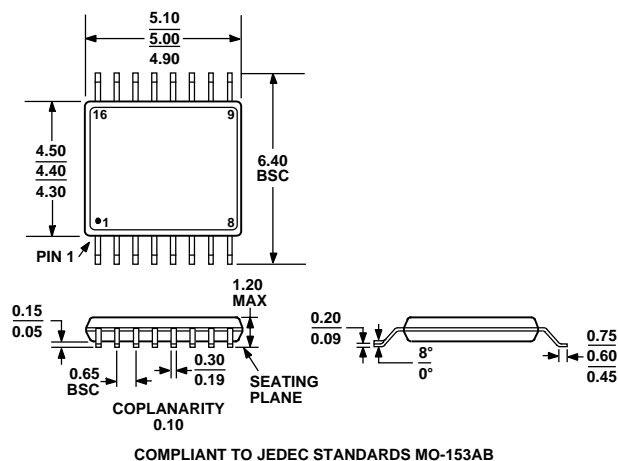


Figure 10. 16-Lead Thin Shrink Small Outline Package [TSSOP] (RU-16)
Dimensions shown in millimeters

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.



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