TelCom Semiconductor, Inc.

TC3405

16-Bit Low Cost, Low Power ∑ – Δ A/D Converter

FEATURES

- **16-Bit Resolution at Eight Conversions Per Second, Adjustable Down to 10-Bit Resolution at 512 Conversions Per Second**
- **1.8V – 5.5V Operation, Low Power ..... Operating: 250 μA; Sleep: 35 μA**
- **One Differential and Three Single Ended Inputs with Built-In Multiplexer**
- **MicroPort™ Serial Bus Requires Only Two Interface Lines**
- **Uses Internal or External Reference**
- **V_{DD} Monitor and Reset Generator Operational in Shutdown Mode**
- **Automatically Enters Sleep Mode When Not In Use**
- **16-Pin QSOP and PDIP Packages**

TYPICAL APPLICATIONS

- **Consumer Electronics, Thermostats, CO Monitors, Humidity Meters, Security Sensors**
- **Embedded Systems, Data Loggers, Portable Equipment**
- **Medical Instruments**

GENERAL DESCRIPTION

The TC3405 is a low cost, low power analog-to-digital converter based on TelCom's Sigma-Delta technology. It performs 16-bit conversions (15-bit plus sign) at up to eight per second. The device is optimized for use as microcontroller peripherals in low cost, battery operated systems. A voltage reference is included, or an external reference can be used. A V_{DD} monitor with reset generator provides Power-On Reset and Brown-out protection.

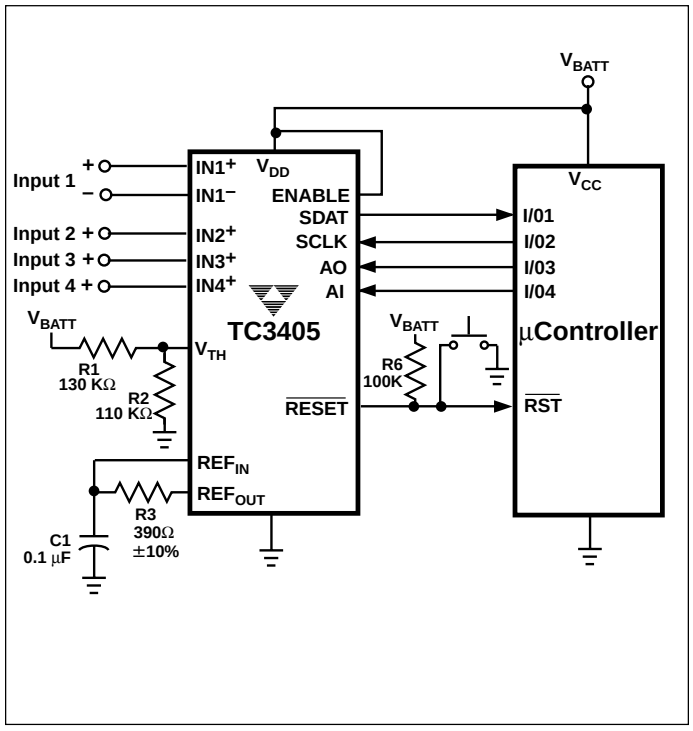
The TC3405's 2-wire MicroPort™ digital interface is used for starting conversions and for reading out the data. Driving the SCLK line low starts a conversion. After the conversion starts, each additional falling edge (up to six) detected on SCLK for t4 seconds reduces the A/D resolution by one bit and cuts conversion time in half. After a conversion is completed, clocking the SCLK line puts the MSB through LSB of the resulting data word onto the SDAT line, much like a shift register. The parts automatically sleep when not performing a data conversion.

The TC3405 is available in PDIP and QSOP packages.

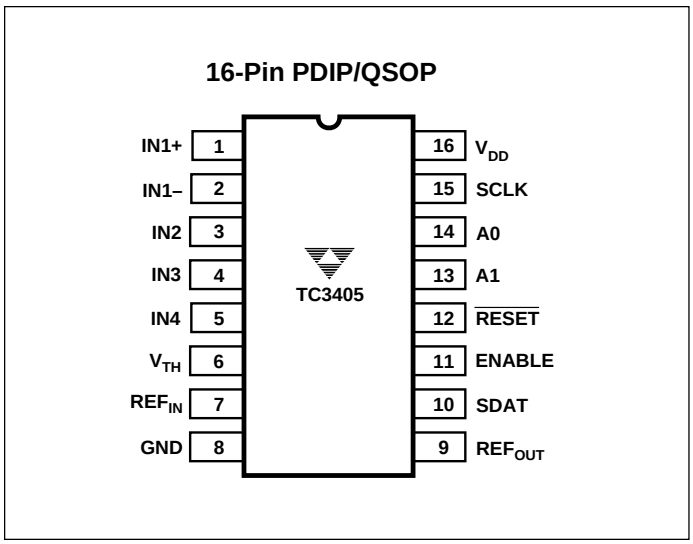
ORDERING INFORMATION

Part No.	Package	Temp. Range
TC3405VPE	16-Pin PDIP (Narrow)	0°C to +85°C
TC3405VQR	16-Pin QSOP (Narrow)	0°C to +85°C

TYPICAL APPLICATION



PIN CONFIGURATIONS



ABSOLUTE MAXIMUM RATINGS*

Supply Voltage 6.0V
Voltage on Pins:
RESET ..... (GND – 0.3V) to 5.5V
Input Voltage (All Other Pins) .....
..... (GND – 0.3V) to (V_{DD} + 0.3V)
Operating Temperature ..... 0°C ≤ 85°C
Maximum Chip Temperature ..... +150°C
Storage Temperature Range ..... – 65°C to +150°C
Lead Temperature (Soldering, 10 sec) ..... +300°C

*Static-sensitive device. Unused devices must be stored in conductive material. Protect devices from static discharge and static fields. Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specifications is not implied. Exposure to Absolute Maximum Rating Conditions for extended periods may affect device reliability.

DC ELECTRICAL CHARACTERISTICS: T_A = 25°C and V_{DD} = 2.7V, unless otherwise specified. Specifications in Bold type apply over a temperature range of 0°C to 85°C. V_{REF} = 1.25V, Internal Clock Freq.= 520kHz

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
POWER SUPPLY						
V_{DD}	Supply Voltage		1.8	—	5.5	V
I_{DD}	Supply Current, During Data Conversion		—	250	—	µA
$I_{DD(SLEEP)}$	Supply Current, Sleep Mode		—	35	—	µA
$I_{DD(SLEEP)}$	Supply Current, Sleep Mode		—	**38**	**50**	µ**a**
ACCURACY (Differential Inputs)						
RES	Resolution		—	16	—	Bits
INL	Integral Non-Linearity		—	±.0038	—	%FSR
V_{OS}	Offset Error	$IN^+ = IN^- = 0V$	—	—	±**1**	%FSR
V_{NOISE}	Refered to input		—	60	—	µVrms
CMR	Common Mode Rejection	at DC	—	75	—	dB
FSE	Full Scale Error		—	0.4	—	%FS
PSRR	Power Supply Rejection Ratio	V_{DD} = 2.5V to 3.5V	—	75	—	dB
INn^+, INn^- , INn						
V_{IN}±	Differential Input Voltage	(Note 1)	—	—	V_{DD}	V
	Absolute Voltage Range on **INn^+, INn^-, INn**		GND	—	V_{DD}	V
IB	Input Bias Current		—	1	100	nA
C_{IN}	Input Sampling Capacitance		—	2	—	pF
R_{IN}	Differential Input Resistance	(Note 2)	—	2	—	MΩ
REF_{IN}, REF_{OUT}						
V_{REF}	**REF_{IN}** Voltage Range		0	—	1.25	V
I_{REF}	**REF_{IN}** Input Current		—	1	—	µA
V_{REFOUT}	**REF_{OUT}** Voltage		—	1.193	—	V
REF_{SINK}	**REF_{OUT}** Current Sink Capability		—	10	—	µA
REF_{SRC}	**REF_{OUT}** Current Source Capability		300	—	—	µA

Notes: 1. Differential input voltage defined as (V_{IN}+ – V_{IN}–)
2. Resistance from INn+ to INn– or INn to GND.

DC ELECTRICAL CHARACTERISTICS: T_A = 25°C and V_{DD} = 2.7V, unless otherwise specified.Specifications in Bold type apply over a temperature range of 0°C to 85°C. V_{REF} = 1.25V, Internal Clock Freq.= 520kHz

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
SCLK, A0, A1, ENABLE						
V_{IL}	Input Low Voltage		—	—	**0.3 x V_{DD}**	V
V_{IH}	Input High Voltage		**0.7 x V_{DD}**	—	—	V
I_{LEAK}	Leakage Current		—	1	—	µA
SDAT, $\overline{\text{RESET}}$						
V_{OL}	Output Low Voltage	I_{OL} = 1.5 mA	—	—	0.4	V
V_{OH}	Output High Voltage(SDAT Only)	I_{SOURCE} = 400µA(Note 2)	0.9 x V_{DD}	—	—	V
$V_{DD(MIN)}$	Minimum V_{DD} for $\overline{\text{RESET}}$ Valid		—	1.1	1.3	V
V_{TH}						
V_{THR}	Threshold		—	1.23	—	V
	Threshold Hysteresis		—	30	—	mV
	Threshold Tempco		—	30	—	ppm/°C
	Input Current		-0.1	.01	0.1	µA

AC ELECTRICAL CHARACTERISTICS: T_A = 25°C and V_{DD} = 2.7V, unless otherwise specified. Specifications in Bold type apply over a temperature range of 0°C to 85°C. V_{REF} = 1.25V, Internal Clock Freq.= 520kHz

Symbol	Parameter	Description	Min	Typ	Max	Unit
t_1		Width of SCLK (Negative)	1	—	—	µsec
t_2	Resolution Reduction Clock Width	Width of SCLK (Positive)	1	—	—	µsec
t_3	Conversion Time (15-Bit Plus Sign)	16-bit conversion, T_A = 25°C(Note 1)	—	125	—	msec
	Conversion Time (14-Bit Plus Sign)	15-bit conversion	—	t3/2.0	—	msec
	Conversion Time (13-Bit Plus Sign)	14-bit conversion	—	t3/4.0	—	msec
	Conversion Time (12-Bit Plus Sign)	13-bit conversion	—	t3/7.8	—	msec
	Conversion Time (11-Bit Plus Sign)	12-bit conversion	—	t3/15.1	—	msec
	Conversion Time (10-Bit Plus Sign)	11-bit conversion	—	t3/28.6	—	msec
	Conversion Time (9-Bit Plus Sign)	10-Bit conversion	—	t3/51.4	—	msec
t_4	Resolution Reduction Window	Width of SCLK	—	t3/85.7	—	msec
t_5	SCLK to Data Valid	SCLK falling edge to SDAT valid	**1000**	—	—	nsec
t_6	Address Setup	Address valid to SCLK	**0**	—	—	nsec
t_7	Address Hold	SCLK to address valid hold	**1000**	—	—	nsec
t_8	Acknowledge Delay	SCLK to SDAT delay	—	—	**1000**	nsec
t_9	$\overline{\text{RESET}}$ Active Timeout Period	Delay from POR or brown-out recovery to $\overline{\text{RESET}}$ = V_{OH}	—	t3*2	—	msec
t_{11}	$\overline{\text{RESET}}$ Delay	Delay for V_{TH} falling at 10 V/msec to $\overline{\text{RESET}}$ low	**5**	—	**64**	µsec

Notes: 1. Nominal temperature drift is -2830 ppm/°C for temperature less than 25°C and -1340 ppm/°C for temperature greater than 25°C.
2. At V_{DD}= 1.8V, $I_{SOURCE} \leq$ 200µa

TC3405

PIN DESCRIPTION

TC3405 Pin No.	Name	Description
1	$IN1^+$	Analog Input. This is the positive terminal of a true differential input consisting of $IN1^+$ and $IN1^-$. $V_{IN(1)} = (IN1^+ – IN1^-)$. (See *Electrical Characteristics*.)
2	$IN1^-$	Analog Input. This is the negative terminal of a true differential input consisting of $IN1^+$ and $IN1^-$. $V_{IN(1)} = (IN1^+ – IN1^-)$ $IN1^-$ can swing to, but not below, ground. (See *Electrical Characteristics*.)
3,4,5	INn	Analog Input. This is the positive terminal of a true differential input with the negative input tied internally to GND. *(See Electrical Characteristics.)*
6	V_{TH}	Analog Input. This is the positive input to the internal comparator used to monitor the voltage supply. The negative input is tied to an internal reference. When V_{TH} falls below the internal reference, the reset generator drives $\overline{RESET}$ low as specified in the *Electrical Characteristics* section.
7	REF_{IN}	Analog Input. The converter's reference voltage is the differential between this pin and ground times two. It may be tied directly to REF_{OUT} or scaled using a resistor divider. Any user supplied reference voltage or the power supply rail may be used in place of REF_{OUT}.
8	GND	Ground Terminal.
9	REF_{OUT}	Analog Output. The internal reference connects to this pin. It may be scaled externally, if desired, and tied to the REF_{IN} input to provide the converter's reference voltage. Care must be taken in connecting external circuitry to this pin. This pin is in a high impedance state during the sleep mode. R_3 in the Typical Application must be 390Ω ±10%.(See *Electrical Characteristics*.)
10	SDAT	Digital Output (push-pull). This is the MicroPort™ serial data output. SDAT is driven low while the TC3405 is converting data, effectively providing a "busy" signal. After the conversion is complete, every high-to-low transition on the SCLK pin puts a bit from the resulting data word on the SDAT pin (from MSB to LSB).
11	ENABLE	Digital Input. When this input control is pulled low, the part is internally restarted. That is, any data conversion or data read sequence is cleared and the part goes into sleep mode. When ENABLE returns high, the part resumes normal operation.
12	$\overline{RESET}$	Digital Output (open drain). This is the output of the V_{DD} monitor reset generator. $\overline{RESET}$ is driven low when a power-on reset or brown-out condition is detected. (See *AC Electrical Characteristics*.)
13	A1	Digital Input. Controls analog multiplexer in conjunction with A0 to select one of four Input channels. This address is latched at the falling edge of the SCLK, which starts an A/D conversion. A1,A0 = 00 = Input 1; 01 = Input 2; 10 = Input 3; 11 = Input 4.
14	A0	Digital Input. Controls analog multiplexer in conjunction with A1 to select one of four Input channels. This address is latched at the falling edge of the SCLK, which starts an A/D conversion. A1,A0 = 00 = Input 1; 01 = Input 2; 10 = Input 3; 11 = Input 4.
15	SCLK	Digital Input. This is the MicroPort™ serial clock input.The TC3405 comes out of sleep mode and a conversion cycle begins when this pin is driven low. After the conversion starts, each additional falling edge (up to six) detected on SCLK for t4 seconds reduces the A/D resolution by one bit. When the conversion is complete, the data word can be shifted out on the SDAT pin by clocking the SCLK pin.
16	V_{DD}	Power Supply Input.

GENERAL THEORY OF OPERATION

The TC3405 is a 16-bit sigma-delta A/D converter. It has one differential input, three single ended inputs, an analog multiplexer and a V_{DD} monitor with reset generator. The following is a detailed description of the device's key components. Refer to the A/D Operational Flowchart and Figures 2 through 5.

A/D Converter Operation

When the TC3405 is not converting, it is in sleep mode with both the SCLK and SDAT lines high. An A/D conversion is initiated by a high to low transition on the SCLK line at which time the internal clock of the TC3405 is started and the address value (A0 and A1) is internally latched. The address value steers the analog multiplexer to select the input channel to be converted. Each additional high to low transition of SCLK (following the initial SCLK falling edge) and during the time interval t4 will decrement the conversion accuracy by one bit and reduce the conversion time by one half. The time interval t4 is referred to as the resolution reduction window. The minimum conversion resolution is 10 bits so any more than 6 SCLK transitions during t4 will be ignored.

After each high to low transition of SCLK the SDAT output is driven high by the TC3405 to acknowledge that the conversion has been decremented. When the SCLK returns high or the t4 interval ends, the SDAT line returns low (see Figure 2). When the conversion is complete SDAT is driven high. The 3405 now enters sleep mode and the conversion value can be read as a serial data word on the SDAT line.

Reading the Data Word

After the conversion is complete and SDAT goes high, the conversion value can be clocked serially onto the SDAT line by high to low transitions of the SCLK. The data word is in two's compliment format with the sign bit clocked onto the SDAT line first followed by the MSB and ending in the LSB. For a 16 bit conversion the data word would consist of a sign bit follwed by 15 magnitude bits, Table 1 shows the data word versus input voltage for a 16 bit conversion. Note that the full scale input voltage range is $\pm(2\,REF_{IN} - 1LSB)$. When REF_{OUT} is fed back directly to REF_{IN}, an LSB is 73µV for a 16 bit conversion, as REF_{OUT} is typically 1.193V.

Figure 4 shows typical SCLK and SDAT waveforms for 16, 12 and 10 bit conversions. Note that any complete convert and read cycle requires 17 clock pulses. Up to six of these can occur in the resolution reduction window, t4, to decrement accuracy while the remaining pulses clock out the conversion data word.

Table 1. Data Conversion Word vs. Voltage Input (REF_{IN} = 1.205V)

Data Word	$INn^+ - INn^-$ (Volts)
0111 1111 1111 1111	2.38596 (Positive Full Scale)
0000 0000 0000 0001	72.8 E – 6
0000 0000 0000 0000	0
1111 1111 1111 1111	–72.8 E – 6
1000 0000 0000 0001	–2.38596 (Negative Full Scale)
1000 0000 0000 0000	Reserved Code

The SCLK input has a filter which rejects any positive or negative pulse width less than 50ns to reduce noise. The rejection width of this pulse can vary between 50ns and 750ns depending on processing parameters and supply voltage.

Figure 3 shows a truth table for determining the mode of operation for the TC3405 part by recording the value of SDAT for SCLK in a high, then low, then high state. For example, if SCLK goes through a 1-0-1 transition and the corresponding values of SDAT are 1-1-0, then the SCLK falling edge started a new data conversion. A 0-1-0 for SDAT would have indicated a resolution reduction had occurred. This is useful if the microcontroller has a watchdog reset or otherwise loses track of where the TC3405 part is in the conversion and data readout sequence. The microcontroller can simply transition SCLK until it "finds" a Start Conversion condition.

V_{DD} Monitor

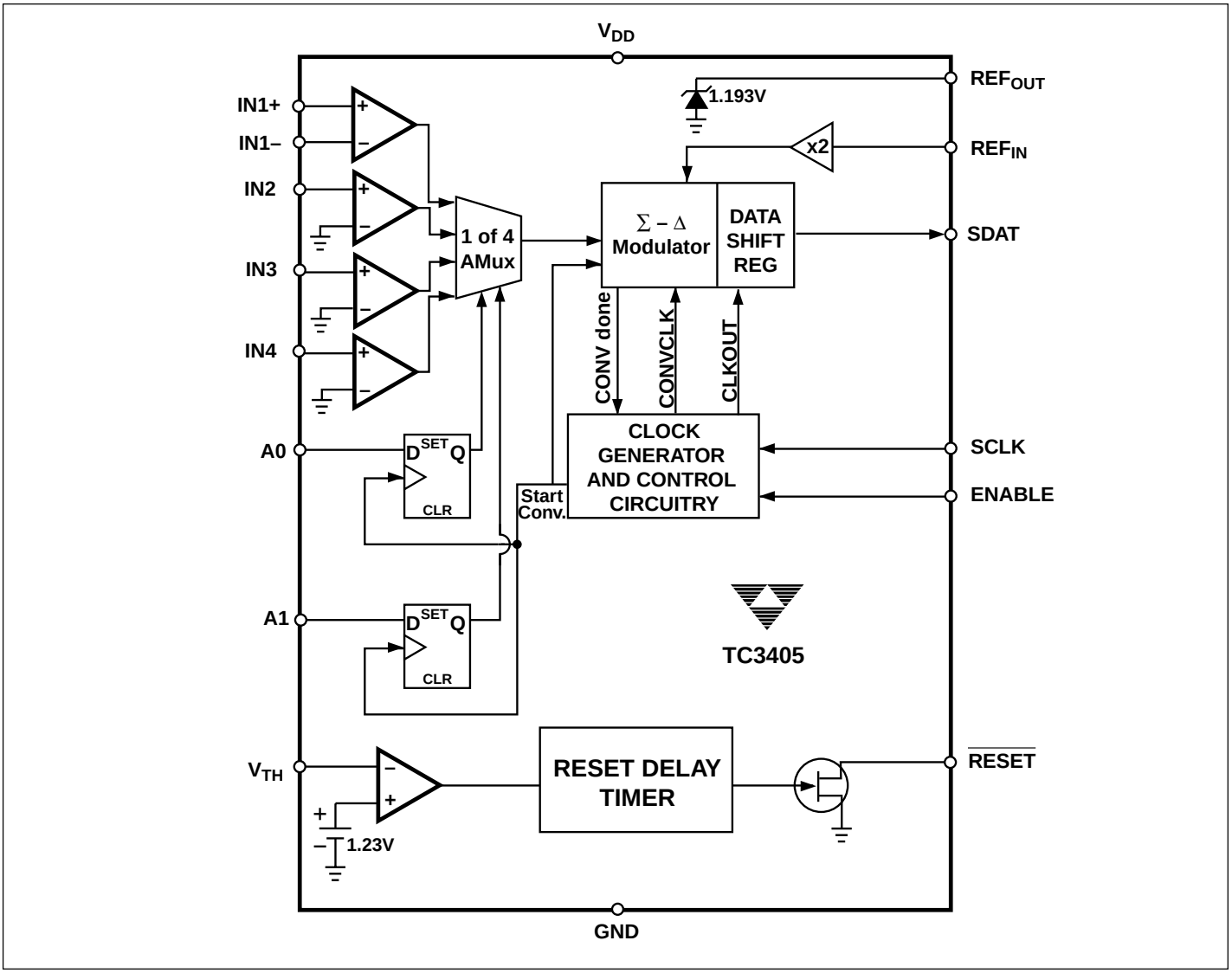
On the TC3405 the $\overline{RESET}$ output is high provided the voltage at V_{TH} is greater than the internal voltage refererence. This reference is the same value as the voltage appearing at REF_{OUT}. When V_{TH} is less than the internal reference, $\overline{RESET}$ is pulled low. When V_{TH} rises above the internal reference voltage again $\overline{RESET}$ is held low for the reset active timeout period, t9, before being released high. The $\overline{RESET}$ output is guaranteed to be valid for V_{DD} = 1.3V to 5.5V.

When used to generate a power-on or brown-out reset an external resistor network is required to divide the appropriate V_{DD} threshold down to 1.23V at the V_{TH} input (see Figure 1). For example, to generate a POR for a V_{DD} at 3V-10%, then the values of R1 and R2 should be 137kΩ and 115kΩ respectively.

Since $\overline{RESET}$ is an open drain it can be wire-OR'ed with another open drain or external switch if desired.

TC3405

FUNCTIONAL BLOCK DIAGRAMS



TIMING DIAGRAMS

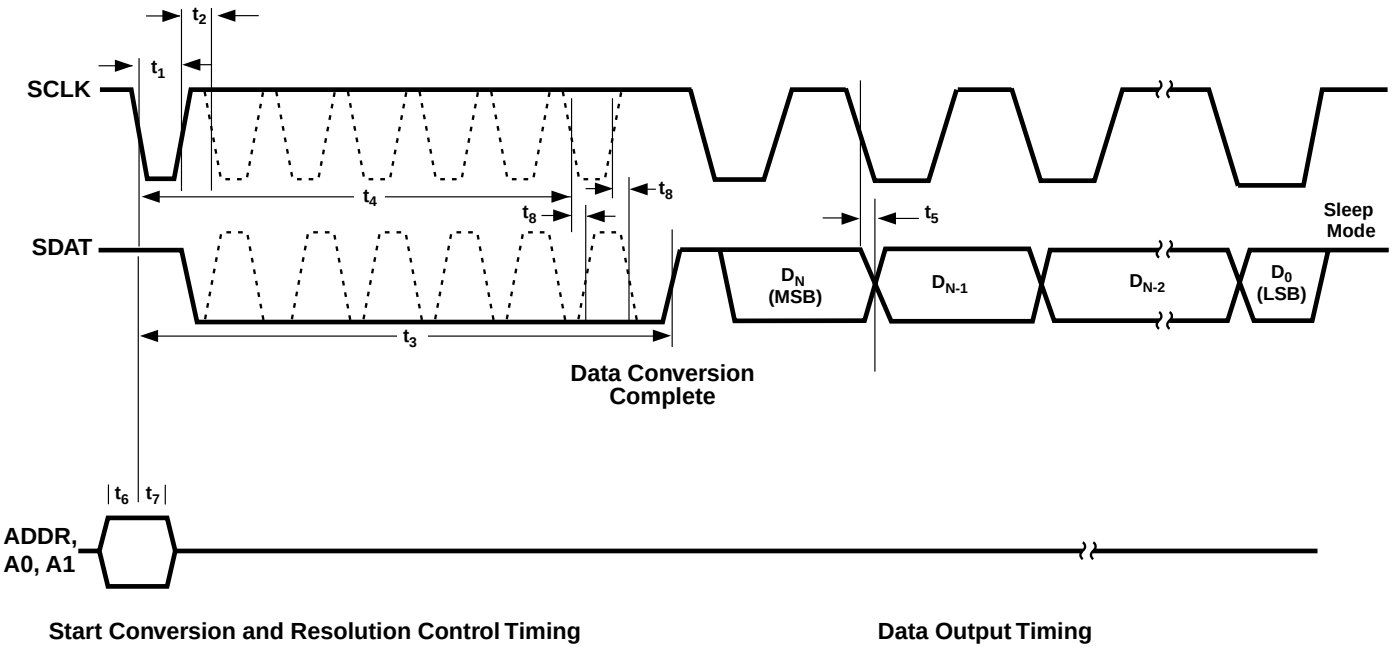
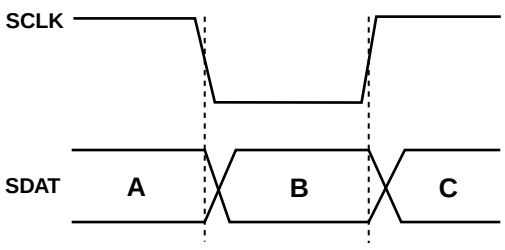


Figure 2. Conversion and Data Output Timing



A	B	C	Status
1	1	0	Start Conversion
0	1	0	Resolution Reduction
x	1	1	Data Transfer
x	0	0	Data Transfer or Busy*
x	0	1	Data Transfer of LSB

*Note: The code x00 has a dual meaning: Data Transfer or Busy Converting.To avoid confusion, the user should send only the required number of pulses for the desired resolution, then wait for SDAT to rise to 1, indicating conversion complete before clocking SCLK again to read out data bits.

Figure 3. SCLK, SDAT Logic State Table

TIMING DIAGRAMS (CONT.)

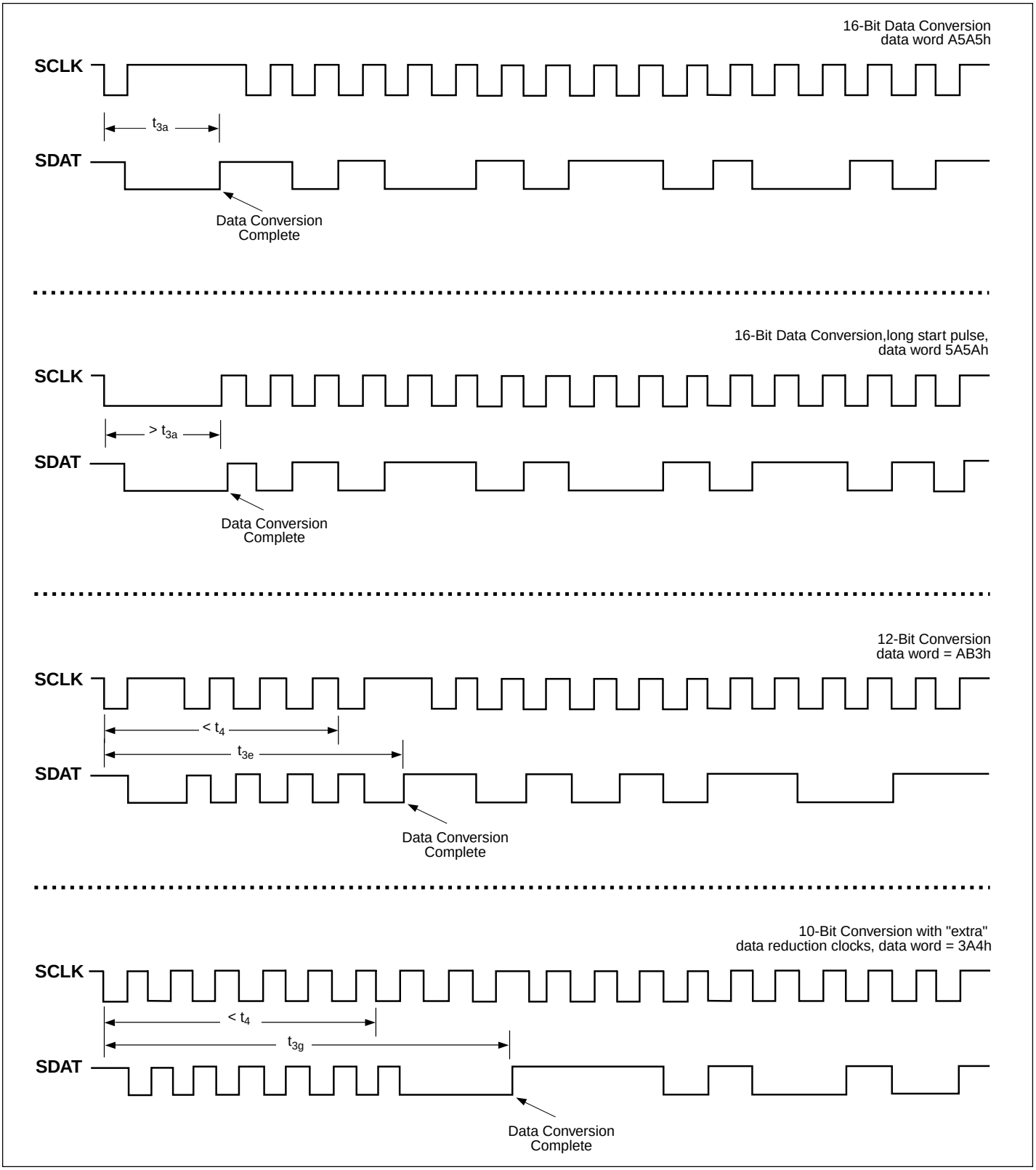


Figure 4. Example Timing Diagrams

TIMING DIAGRAMS (CONT.)

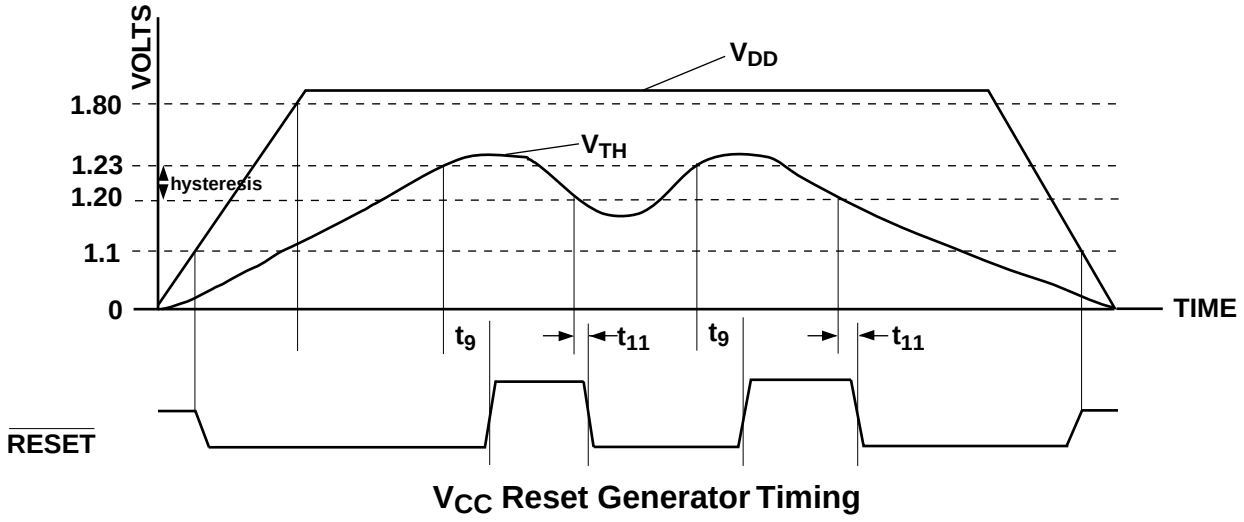
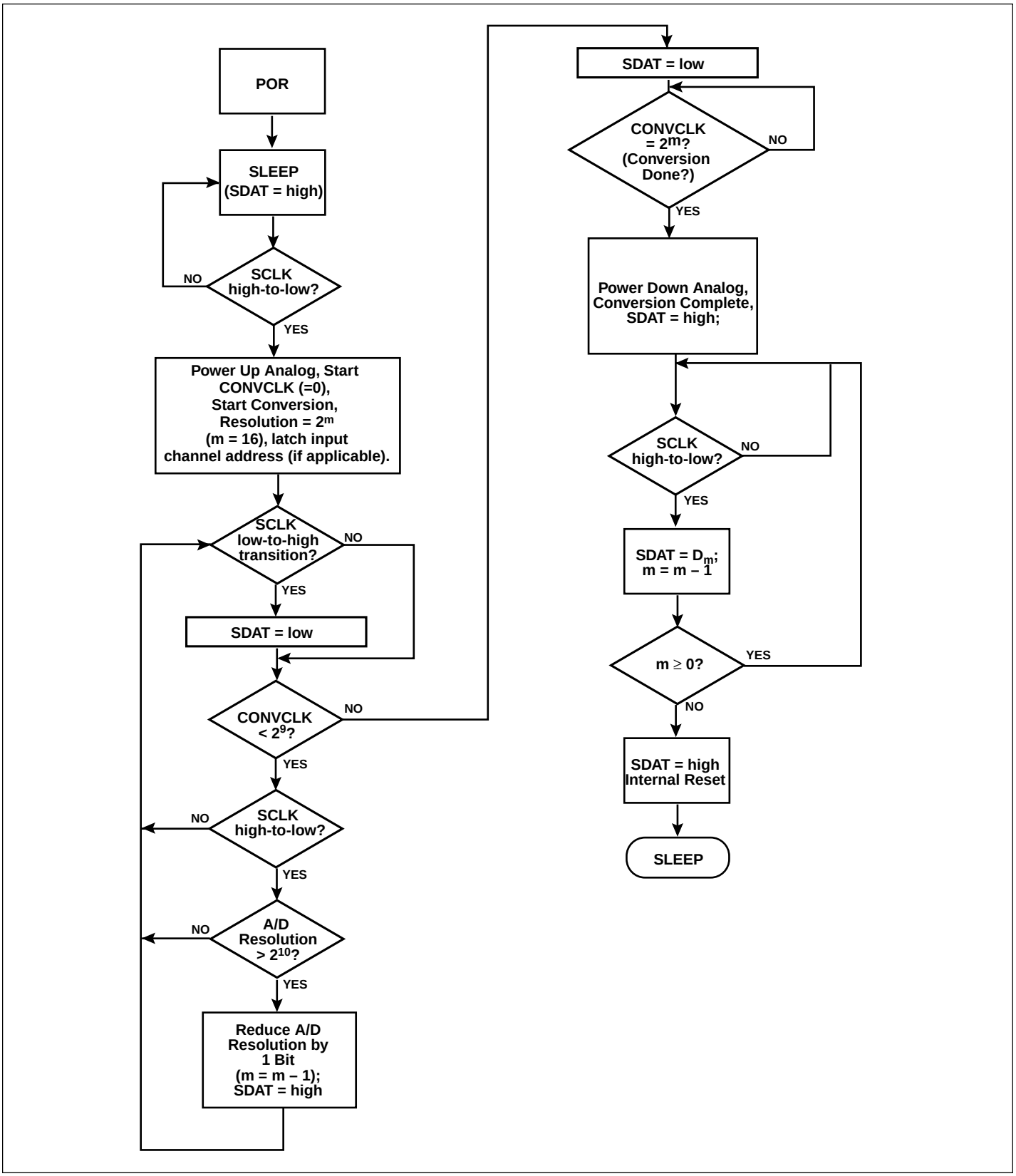


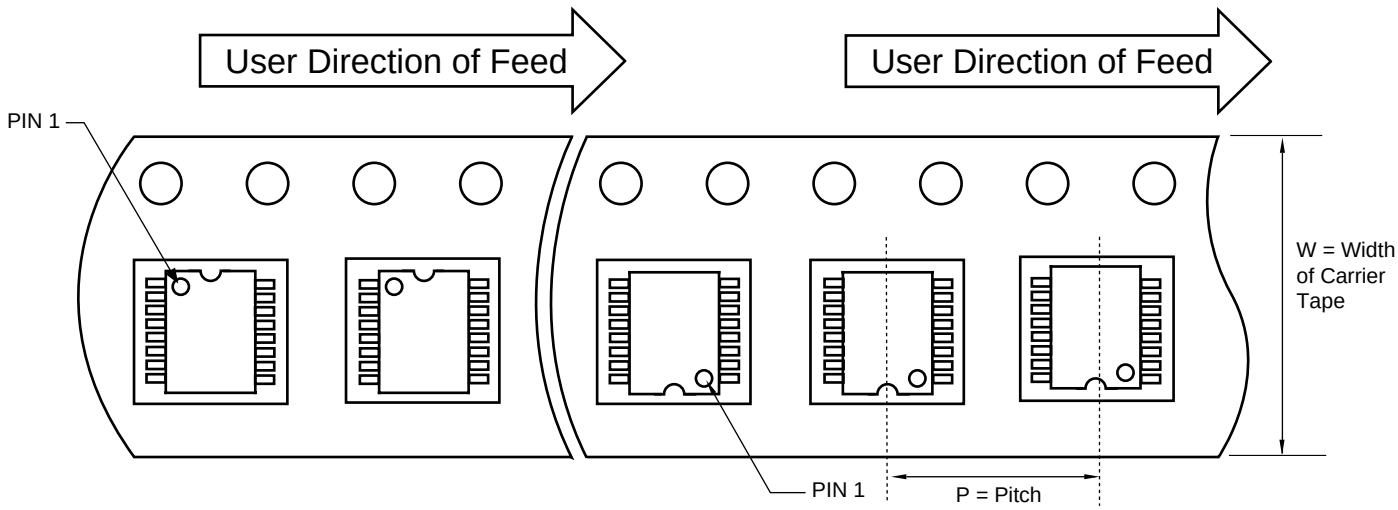
Figure 5. Reset and Power Fail Timing

A/D OPERATIONAL FLOWCHART



TAPING FORM

Component Taping Orientation for 16-Pin QSOP (Narrow)



Standard Reel Component Orientation for TR Suffix Device

Reverse Reel Component Orientation for RT Suffix Device

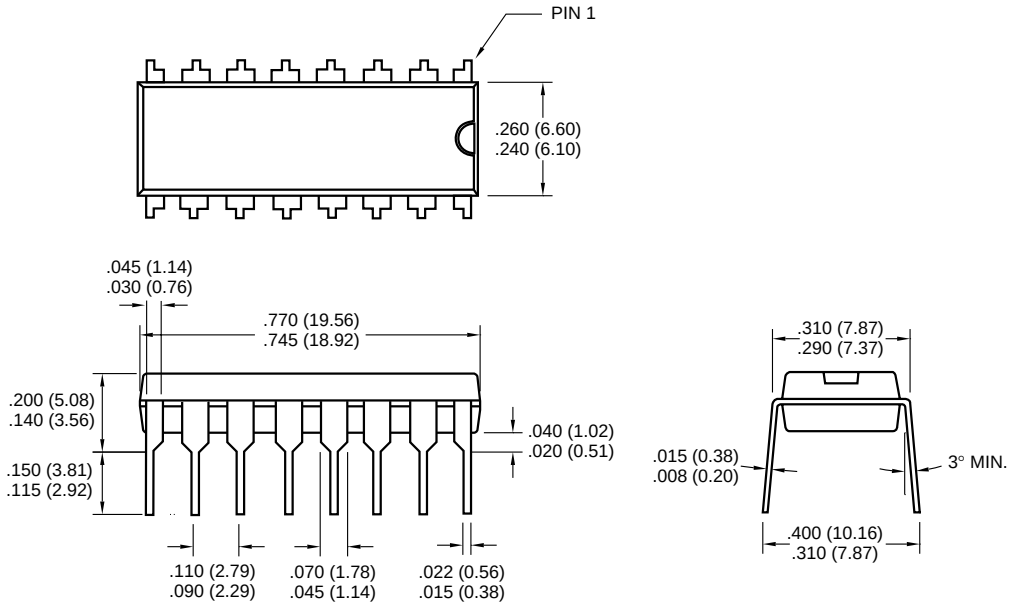
Carrier Tape, Reel Size, and Number of Components Per Reel

Package	Carrier Width (W)	Pitch (P)	Part Per Full Reel	Reel Size
16-Pin QSOP	12 mm	8 mm	2500	13 in

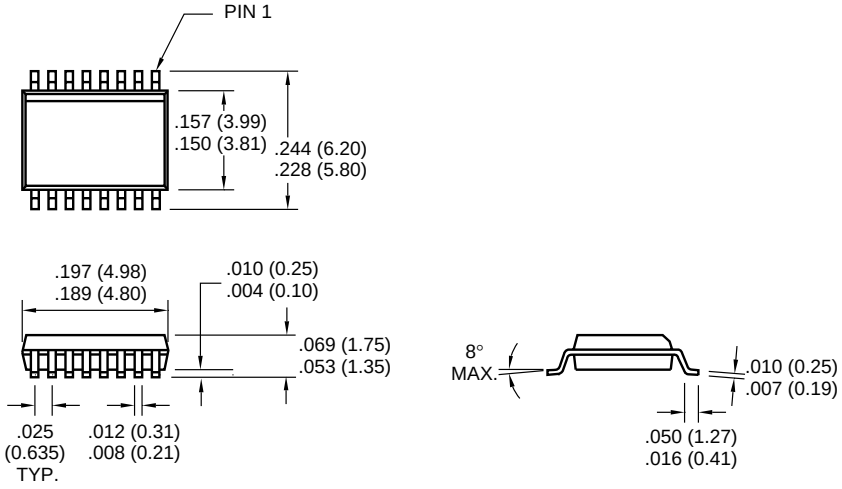
TC3405

PACKAGE DIMENSIONS

16-Pin PDIP (Narrow)



16-Pin QSOP (Narrow)



Dimensions: inches(mm)

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