TC3401

16-Bit Low Cost, Low Power Sigma-Delta 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 300µA; Sleep: 50µA
- microPort™ Serial Bus Requires only two Interface Lines
- Uses Internal or External Reference
- Automatically Enters Sleep Mode when not in use
- True Differential Inputs with Built-In Multiplexer Provide Ratiometric Conversions
- Early Warning Power Fail Detector, also suitable as Wake-Up Timer Operational in Shutdown Mode
- V_{DD} Monitor and Reset Generator Operational in Shutdown Mode

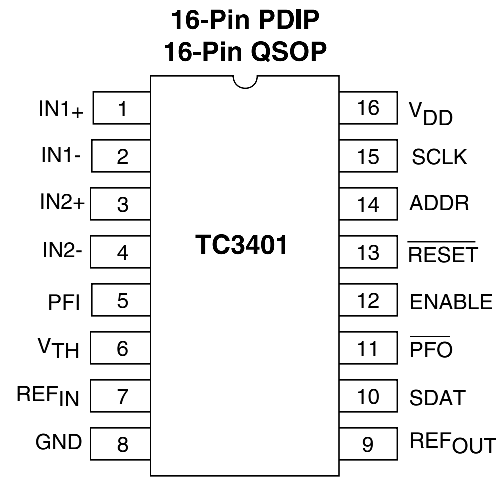
Applications

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

Device Selection Table

Part Number	Package	Temperature Range
TC3401VPE	16-Pin PDIP (Narrow)	0°C to +85°C
TC3401VQR	16-Pin QSOP Narrow)	0°C to +85°C

Package Type



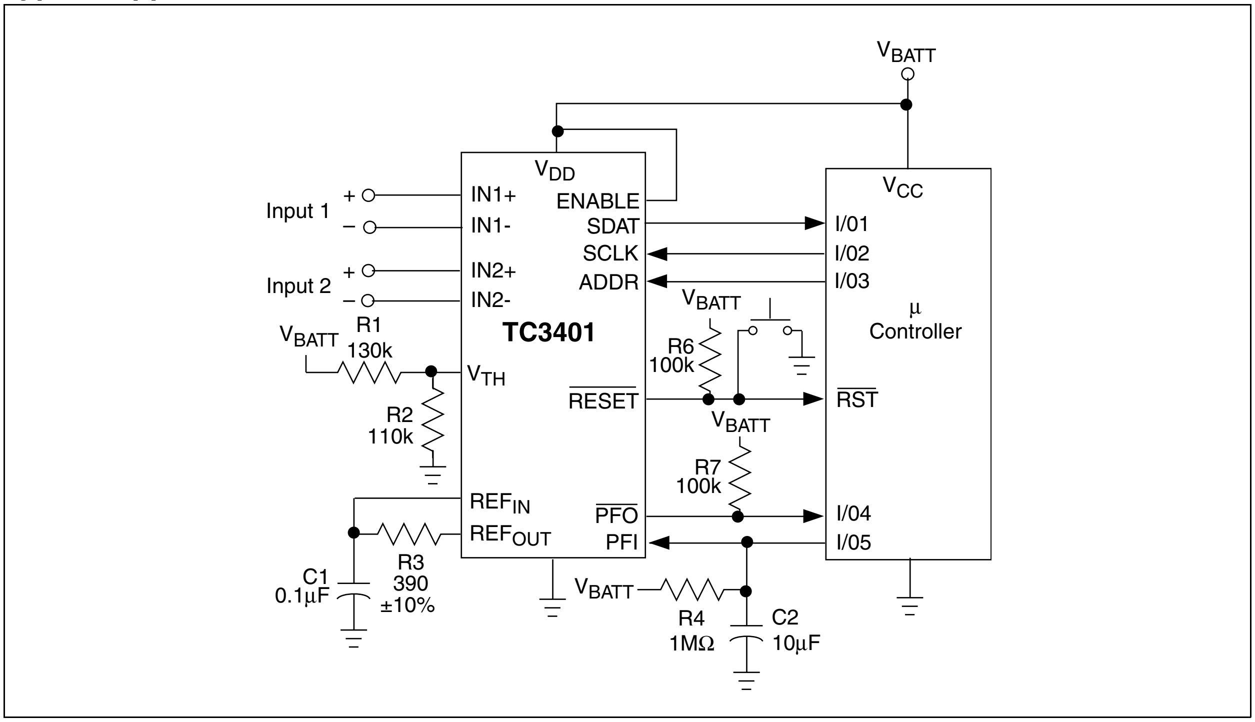
General Description

The TC3401 is a low cost, low power analog-to-digital converter based on Microchip's Sigma-Delta technology. It will perform 16-bit conversions (15-bit plus sign) at up to eight per second. The TC3401 is optimized for use as a microcontroller peripheral in low cost, battery operated systems. A voltage reference is included, or an external reference can be used. A V_{DD} monitor with a reset generator provides Power-on Reset and Brown-out protection while an extra threshold detector is suitable for use as an early warning Power Fail detector, or as a Wake-up Timer.

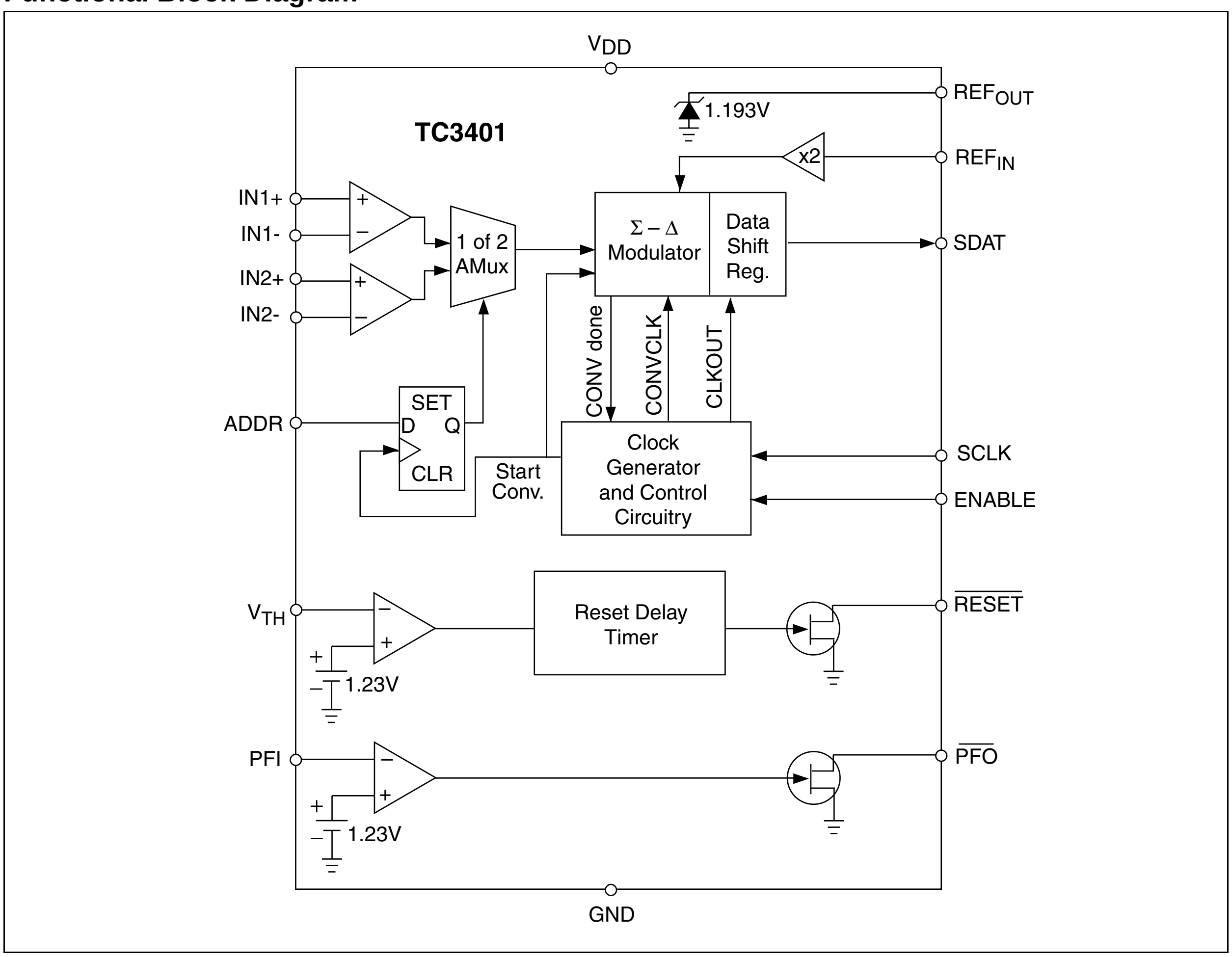
The TC3401's 2-wire microPort™ digital interface is used for starting conversions and for reading out the data. Driving the SCLK line low starts a conversion. After the conversion starts, each additional falling edge (up to six) detected on SCLK for t_4 seconds reduces the A/D resolution by one bit and 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 part automatically sleeps when not performing a data conversion.

The TC3401 is available in a 16-Pin PDIP and a 16-Pin QSOP package.

Typical Application



Functional Block Diagram



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings*

Supply Voltage 6.0V
Voltage on Pins:
PFO, RESET .... (GND – 0.3V) to 5.5V
Input Voltage (All Other Pins):
.... (GND – 0.3V) to (V_{DD} + 0.3V)
Operating Temperature Range .... 0°C to 85°C
Storage Temperature .... -65°C to +150°C

*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 operation sections of the specifications is not implied. Exposure to Absolute Maximum Rating conditions for extended periods may affect device reliability.

TC3401 DC ELECTRICAL SPECIFICATIONS

Electrical Characteristics: T_A = 25°C and V_{DD} = 2.7V, unless otherwise specified. **Boldface** type specifications apply for temperatures of 0°C to 85°C. V_{REF} = 1.25V, Internal Clock Frequency = 520kHz.

Symbol	Parameter	Min	Typ	Max	Unit	Test Conditions
Power Supply						
V_{DD}	Supply Voltage	1.8	—	5.5	V	
I_{DD}	Supply Current, During Data Conversion	—	300	—	µA	
$I_{DDSLEEP}$	Supply Current, Sleep Mode	—	50	80	µA	T_A = +25°C
		—	**50**	130	µA	
Accuracy (Differential Inputs)						
RES	Resolution	—	16	—	Bits	
INL	Integral Non-Linearity	—	.0038	—	%FSR	V_{DD} = 2.7V
V_{OS}	Offset Error	—	—	**±0.9**	%FSR	IN+, IN- = 0V
V_{NOISE}	Referred to input	—	60	—	µVrms	
CMR	Common Mode Rejection	—	75	—	dB	At DC
FSE	Full Scale Error	—	0.4%	—	%FS	
PSRR	Power Supply Rejection Ratio	—	75	—	dB	V_{DD} = 2.5V to 3.5V
IN+, IN-						
V_{IN}±	Differential Input Voltage	—	—	V_{DD}	V	**Note 1**
	Absolute Voltage Range on IN+, IN-	GND	—	V_{DD}	V	
	Input Bias Current	—	1	100	nA	
C_{IN}	Input Sampling Capacitance	—	2	—	pF	
R_{IN}	Differential Input Resistance	—	2.0	—	MΩ	**Note 2**
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	

Note 1: Differential input voltage defined as (V_{IN}+ – V_{IN}-).
2: Resistance from INn+ to INn- or INn to GND.
3: @ V_{DD} = 1.8V, $I_{SOURCE} \leq 200\mu A$.

TC3401 DC ELECTRICAL SPECIFICATIONS (CONTINUED)

Symbol	Parameter	Min	Typ	Max	Unit	Test Conditions
Electrical Characteristics: T_A = 25°C and V_{DD} = 2.7V, unless otherwise specified. **Boldface** type specifications apply for temperatures of 0°C to 85°C. V_{REF} = 1.25V, Internal Clock Frequency = 520kHz.						
SCLK, ADDR, 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, $\overline{\text{RESET}}$, $\overline{\text{PFO}}$						
V_{OL}	Output Low Voltage	—	—	0.4	V	I_{OL} = 1.5mA
V_{OH}	Output High Voltage (SDAT)	0.9 x V_{DD}	—	—	V	I_{SOURCE} = 400µA **(Note 3)**
V_{DDMIN}	Minimum V_{DD} for $\overline{\text{PFO}}$, $\overline{\text{RESET}}$ Valid	—	1.1	1.3	µA	
V_{TH}, PFI						
V_{CCPFI}	PFI Input Voltage Range	0	—	V_{DD}	V	
	V_{TH}, PFI Input Current	-0.1	.01	0.1	µA	
V_{THR}	Threshold (V_{TH}, PFI)	—	1.23	—	V	
	Threshold Hysteresis	—	30	—	mV	
	Threshold Tempco	—	30	—	ppm/°C	

Note 1: Differential input voltage defined as (V_{IN}+ – V_{IN}-).
2: Resistance from INn+ to INn- or INn to GND.
3: @ V_{DD} = 1.8V, I_{SOURCE} ≤ 200µA.

TC3401 AC ELECTRICAL SPECIFICATIONS

Symbol	Parameter	Min	Typ	Max	Unit	Test Conditions
Electrical Characteristics: T_A = 25°C and V_{DD} = 2.7V, unless otherwise specified. **Boldface** type specifications apply for temperatures of 0°C to 85°C. V_{REF} = 1.25V, Internal Clock Frequency = 520kHz.						
t_1	Resolution Reduction Clock Width	1	—	—	µsec	Width of SCLK (Negative)
t_2	Resolution Reduction Clock Width	1	—	—	µsec	Width of SCLK (Positive)
t_3	Conversion Time (15-bit Plus Sign)	—	125	—	msec	16-bit Conversion, T_A = 25°C **(Note 1)**
	Conversion Time (14-bit Plus Sign)	—	t_3/2.0	—	msec	15-bit Conversion
	Conversion Time (13-bit Plus Sign)	—	t_3/4.0	—	msec	14-bit Conversion
	Conversion Time (12-bit Plus Sign)	—	t_3/7.8	—	msec	13-bit Conversion
	Conversion Time (11-bit Plus Sign)	—	t_3/15.1	—	msec	12-bit Conversion
	Conversion Time (10-bit Plus Sign)	—	t_3/28.6	—	msec	11-bit Conversion
	Conversion Time (9-bit Plus Sign)	—	t_3/51.4	—	msec	10-bit Conversion
t_4	Resolution Reduction Window	—	t_3/85.7	—	msec	Width of SCLK
t_5	SCLK to Data Valid	**1000**	—	—	nsec	SCLK Falling Edge to SDAT Valid
t_6	Address Setup	**0**	—	—	nsec	Address Valid to SCLK
t_7	Address Hold	**1000**	—	—	nsec	SCLK to Address Valid Hold
t_8	Acknowledge Delay	—	—	**1000**	nsec	SCLK to SDAT Delay
t_9	$\overline{\text{RESET}}$ Active Time-out Period	—	t_3*2	—	msec	Delay from POR or Brown-out Recovery to $\overline{\text{RESET}}$ = V_{OH}
t_{10}	$\overline{\text{PFO}}$ Delay	—	25	—	µsec	PFI to $\overline{\text{PFO}}$ Delay
t_{11}	$\overline{\text{RESET}}$ Delay	5	—	**64**	µsec	Delay V_{TH} Falling at 10V/msec to $\overline{\text{RESET}}$ Low

Note 1: Nominal temperature drift is -2830ppm/C° for temperature less than 25°C and -1340ppm/°C for temperatures greater than 25°C.

2.0 PIN DESCRIPTIONS

The descriptions of the pins are listed in Table 2-1.

TABLE 2-1: PIN FUNCTION TABLE

Pin No. (16-Pin PDIP) (16-Pin QSOP)	Symbol	Description
1	IN1+	Analog Input. This is the positive terminal of a true differential input consisting of IN1+ and IN1-. V_{IN1} = (IN1+ – IN-). See Section 1.0, Electrical Characteristics.
2	IN1-	Analog Input. This is the negative terminal of a true differential input consisting of IN1+ and IN1-. V_{IN1} = (IN+ – IN-) IN1- can swing to, but not below, ground. See Section 1.0, Electrical Characteristics.
3	IN2+	Analog Input. This is the positive terminal of a true differential input consisting of IN2+ and IN2-. V_{IN2} = (IN2+ – IN-). See Section 1.0, Electrical Characteristics.
4	IN2-	Analog Input. This is the negative terminal of a true differential input consisting of IN2+ and IN2-. V_{IN2} = (IN+ – IN-) IN2- can swing to, but not below, ground. See Section 1.0, Electrical Characteristics.
5	PFI	Analog Input. This is the positive input to an internal comparator used as a threshold detector The negative input is tied to an internal reference.
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. See Section 1.0, Electrical Characteristics.
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 less than 1.25 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 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 Sleep mode.
10	SDAT	Digital Output (push-pull). This is the microPort™ serial data output. SDAT is driven low while the TC3401 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	$\overline{PFO}$	Digital Output (open drain). This is the output of the internal threshold detector. When PFI is less than the internal reference, $\overline{PFO}$ is driven low.
12	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.
13	$\overline{RESET}$	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 Section 1.0, AC Electrical Characteristics.
14	ADDR	Digital Input. This input controls the analog input multiplexer to select one of two input channels. This address is latched at the falling edge of the SCLK, which starts an A/Dconversion. (0 = Input 1, 1 = Input 2).
15	SCLK	Digital Input. This is the microPort™ serial clock input. The TC3401 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 t_4 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.

3.0 DETAILED DESCRIPTION

The TC3401 has a 16-bit sigma-delta A/D converter. It has two differential inputs, an analog multiplexer, a V_{DD} monitor with reset generator and an early warning Power Fail detector. See the Typical Application circuit and the Functional Block diagram. The key components of the TC3401 are described below.

Also refer to Figure 3-5, A/D Operational Flowchart and the Timing Diagrams, Figure 3-1, Figure 3-2 and Figure 3-3.

3.1 A/D Converter Operation

When the TC3401 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 TC3401 is started and the address value (ADDR) 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) during the time interval t_4, will decrement the conversion resolution by one bit and reduce the conversion time by one half. The time interval t_4 is referred to as the resolution reduction window. The minimum conversion resolution is 10-bits so any more than 6 SCLK transitions during t_4 will be ignored.

After each high to low transition of SCLK, in the t_4 interval, the SDAT output is driven high by the TC3401 to acknowledge that the resolution has been decremented. When the SCLK returns high or the t_4 interval ends, the SDAT line returns low (see Figure 3-2). When the conversion is complete SDAT is driven high. The TC3401 now enters Sleep mode and the conversion value can be read as a serial data word on the SDAT line.

3.2 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 followed by 15 magnitude bits, Table 3-1 shows the data word versus input voltage for a 16-bit conversion. Note that the full scale input voltage range is ±(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 3-4 shows typical SCLK and SDAT waveforms for 16, 12 and 10-bit conversions. Note that any complete convert and read cycle requires 17 negative edge clock pulses. The first is the convert command. Then, up to six of these can occur in the resolution reduction window, t_4, to decrement resolution. The remaining pulses clock out the conversion data word.

TABLE 3-1: DATA CONVERSION WORD VS. VOLTAGE INPUT (REF_{IN} = 1.193V)

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 of width less than 50nsec to reduce noise. The rejection width of this pulse can vary between 50nsec and 750nsec depending on processing parameters and supply voltage.

Figure 3-1 and Table 3-2 show information for determining the mode of operation for the TC3401 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 TC3401 is in the conversion and data readout sequence. The microcontroller can simply transition SCLK until it "finds" a Start Conversion condition.

FIGURE 3-1: SCLK, SDAT LOGIC STATE DIAGRAM

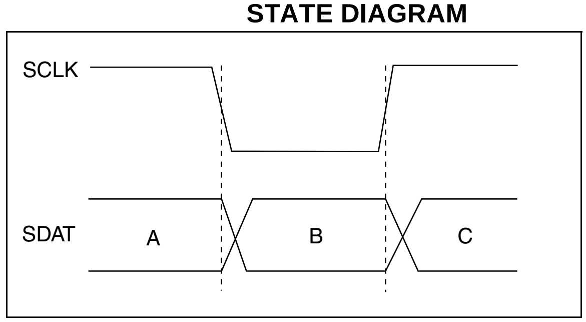


TABLE 3-2: SCLK, SDAT LOGIC STATE

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*

***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 is complete before clocking SCLK again to read out data bits.

FIGURE 3-2: CONVERSION AND DATA OUTPUT TIMING

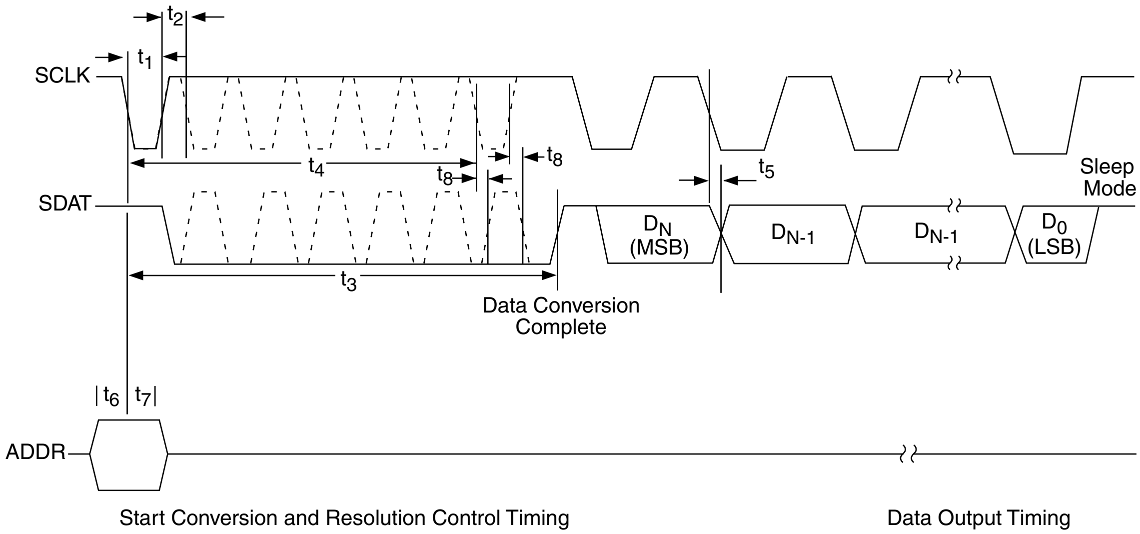
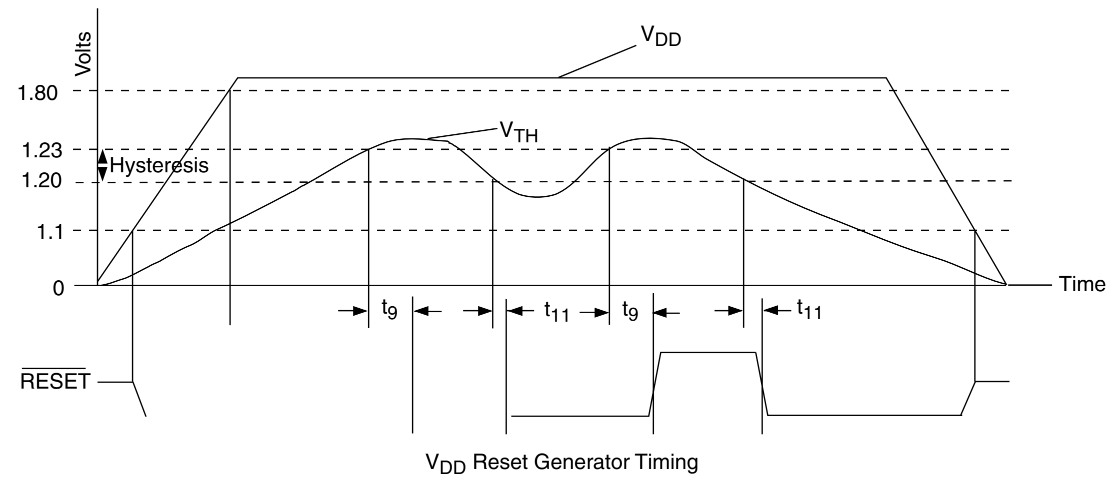


FIGURE 3-3: RESET AND POWER FAIL TIMING



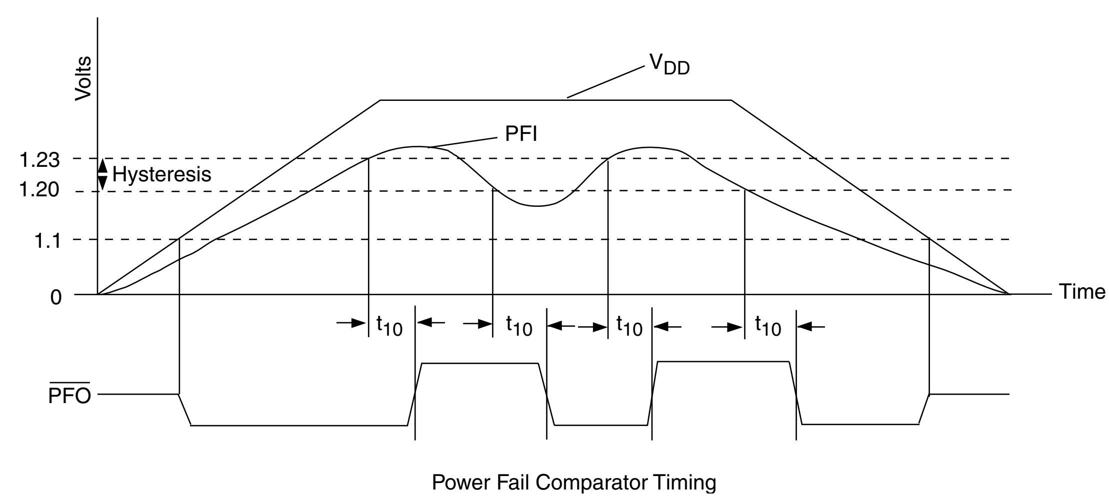


FIGURE 3-4: SCLK AND SDAT WAVEFORMS FOR 16, 12 AND 10-BIT CONVERSIONS

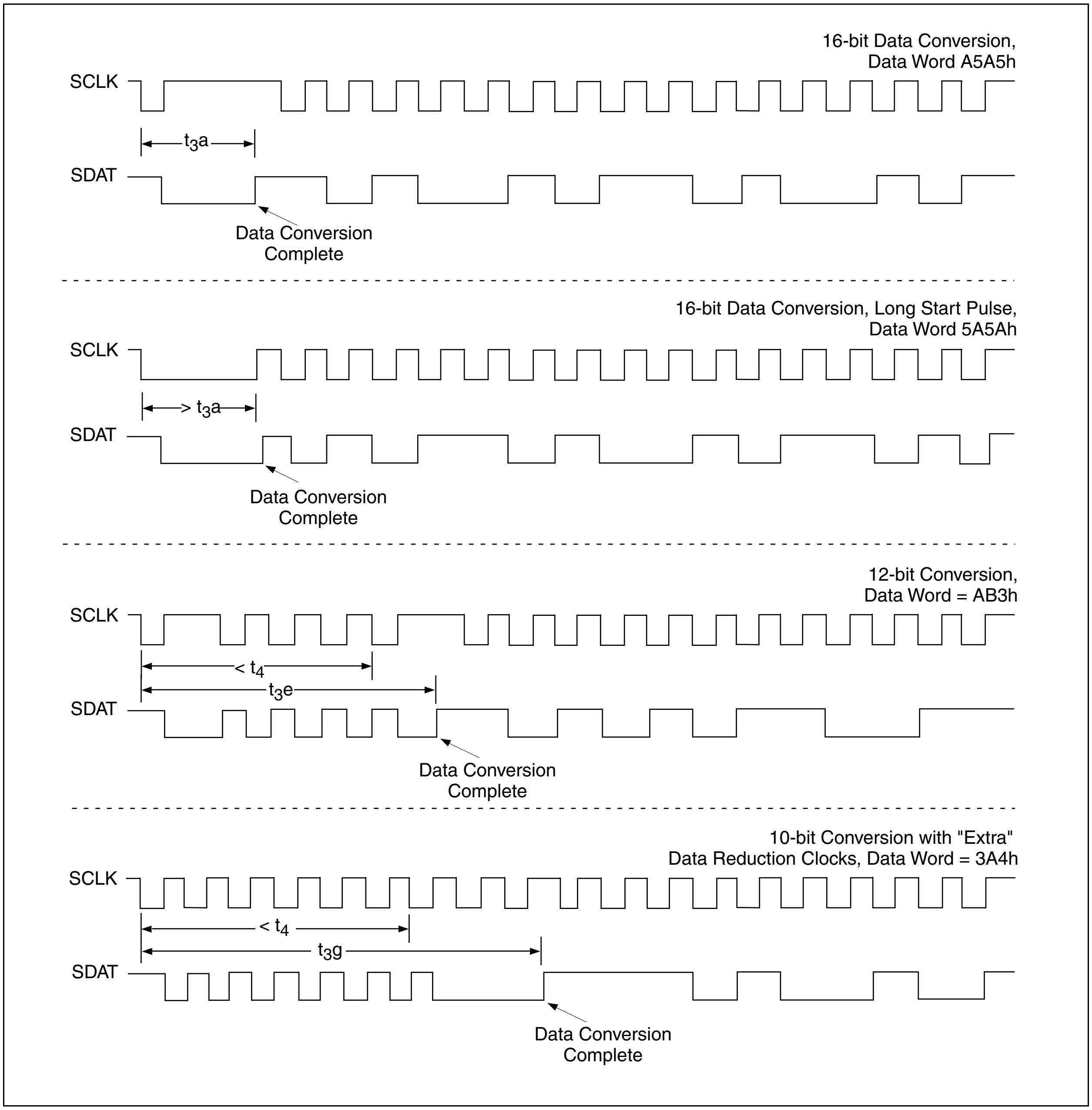
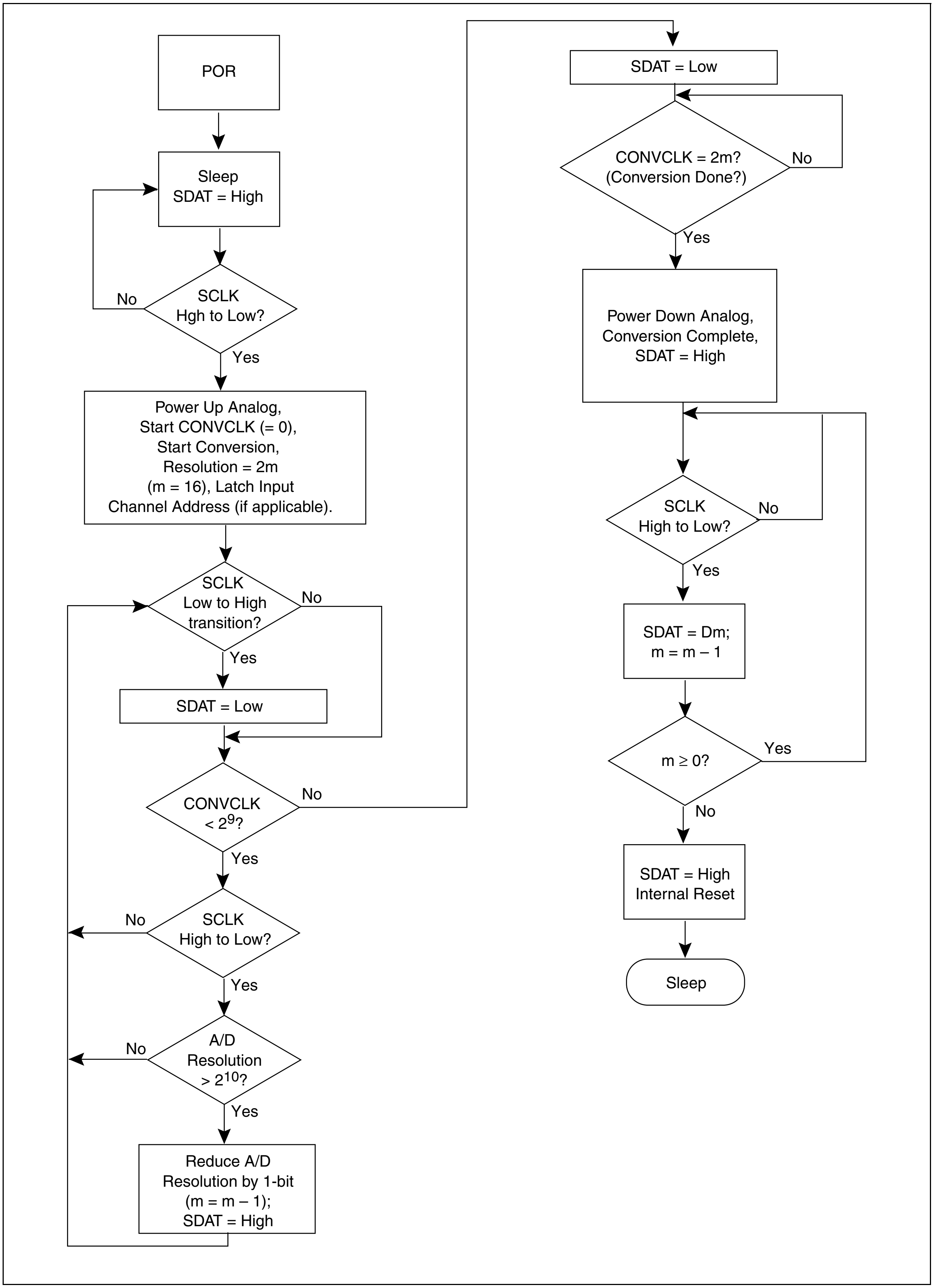


FIGURE 3-5: A/D OPERATIONAL FLOWCHART



3.3 V_{DD} Monitor

The TC3401 $\overline{\text{RESET}}$ output is in high impedance provided the voltage at V_{TH} is greater than the internal voltage reference. This reference is approximately the same value as the voltage appearing at REF_{OUT}. When V_{TH} is less than the internal reference, $\overline{\text{RESET}}$ is pulled low. When V_{TH} rises above the internal reference voltage again, $\overline{\text{RESET}}$ is held low for the reset active time-out period, t_9, before being released. The $\overline{\text{RESET}}$ output is ensured 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 the Typical Application circuit). For example, to generate a POR for a V_{DD} at 3V -10%, the values of R1 and R2 should be 137kΩ and 115kΩ respectively.

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

3.4 Power Fail Detector

The Power Fail detector is a comparator in which the inverting input is connected to the internal voltage reference. The non-inverting input is the PFI pin of the TC3401 and the $\overline{\text{PFO}}$ pin is the active low, open drain output. This comparator is suitable as an early warning fail or low battery indicator. In a typical application, where a voltage regulator is being used to supply power to a system, the Power Fail comparator would monitor the input voltage to the regulator while the V_{DD} monitor would measure the output voltage of the regulator. Both $\overline{\text{PFO}}$ and $\overline{\text{RESET}}$ would drive interrupt pins of a microcontroller.

The Power Fail detector may be used as a Wake-up or Watchdog Timer. The Typical Application circuit shows an RC network on PFI with the capacitor tied to a tristated µC I/O pin. If R4 is 1 MΩ and C2 is 10µF, the time constant is roughly ten seconds. The µC resets the RC network by driving the I/O tied to PFI low and then tristating it. The RC network will ramp to 1.23V in roughly 9 seconds, assuming a V_{BATT} of 3.0V. With $\overline{\text{PFO}}$ tied to a µC input or interrupt, the µC will see a low to high transition on $\overline{\text{PFO}}$ when the voltage on PFI exceeds 1.23V. The $\overline{\text{PFO}}$ output is specified to be valid for V_{DD} = 1.3 to 5.5V.

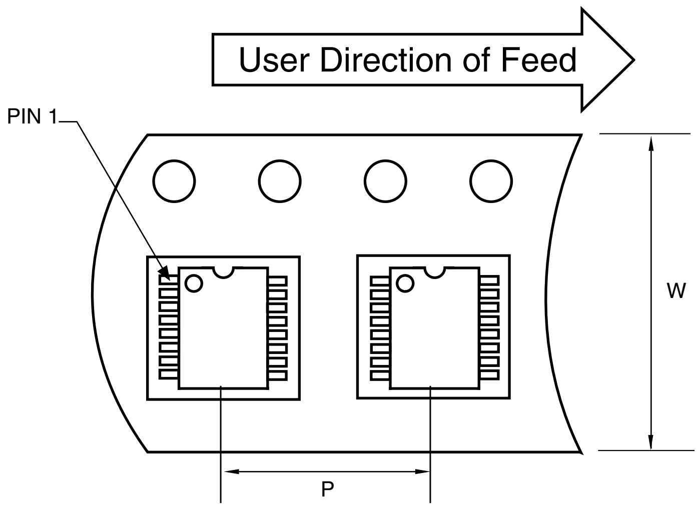
4.0 PACKAGING INFORMATION

4.1 Package Marking Information

Package marking data not available at this time.

4.2 Taping Forms

Component Taping Orientation for 16-Pin QSOP (Narrow) Devices



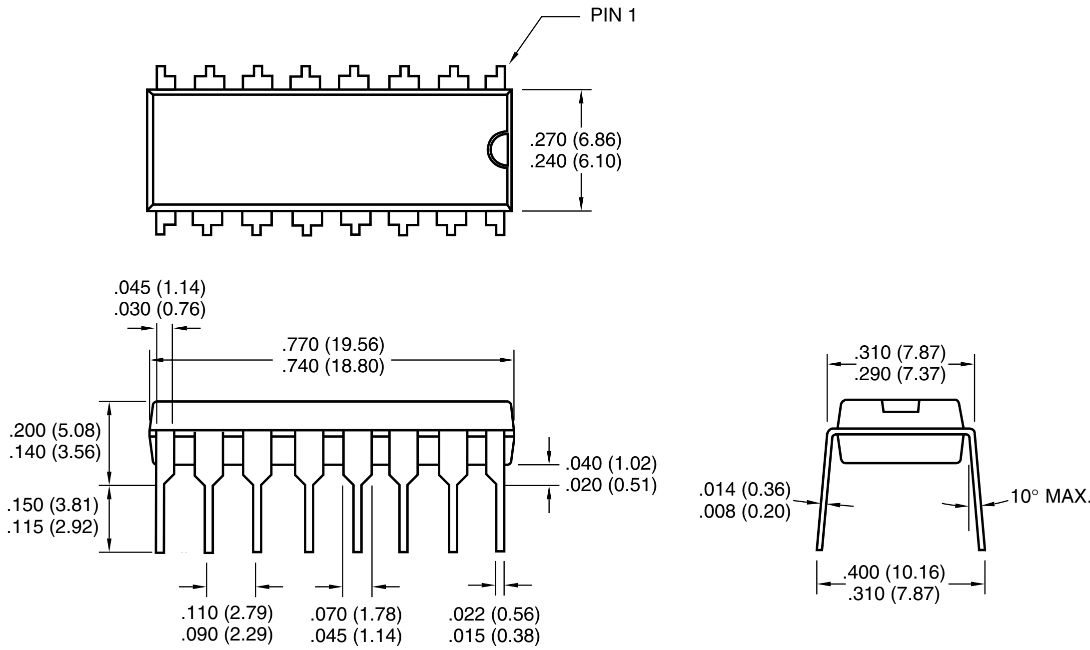
Standard Reel Component Orientation
for TR Suffix Device

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

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

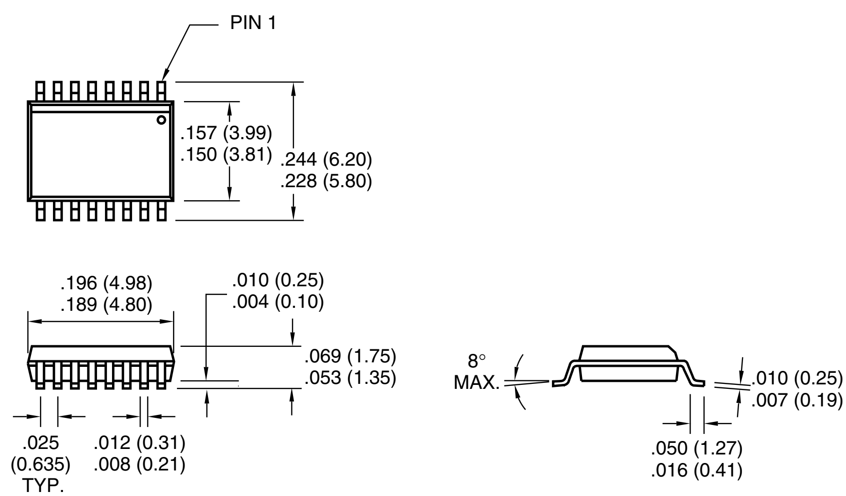
4.3 Package Dimensions

16-Pin PDIP (Narrow)



Dimensions: inches (mm)

16-Pin QSOP (Narrow)



Dimensions: inches (mm)

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05/01/02