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

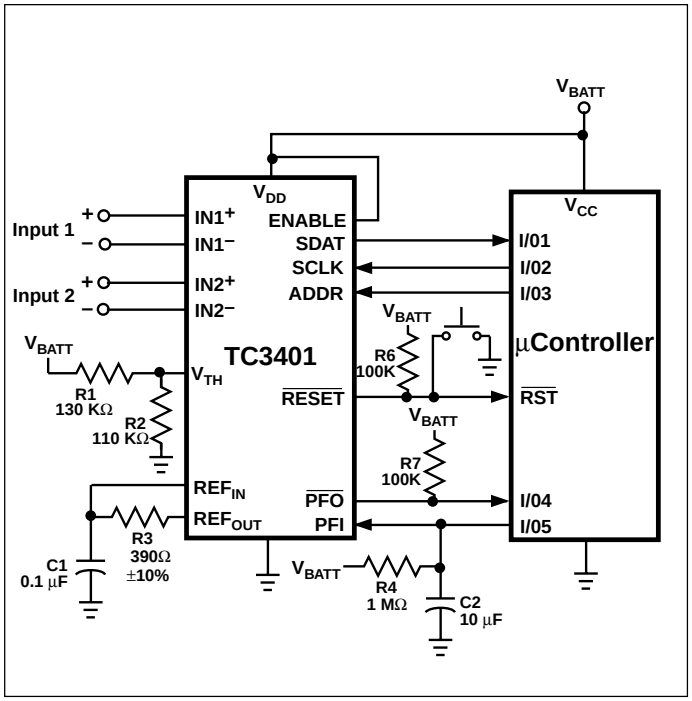
FEATURES

- **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 .... 300μA Sleep: 50μA**
- **True Differential Inputs with Built-In Multiplexer Provide Ratiometric Conversions**
- **MicroPort™ Serial Bus Requires Only Two Interface Lines**
- **Uses Internal or External Reference**
- **V_{DD} Monitor and Reset Generator Operational in Shutdown Mode**
- **Early Warning Power Fail Detector, Also Suitable as Wake-Up Timer 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**

TYPICAL APPLICATION



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 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.

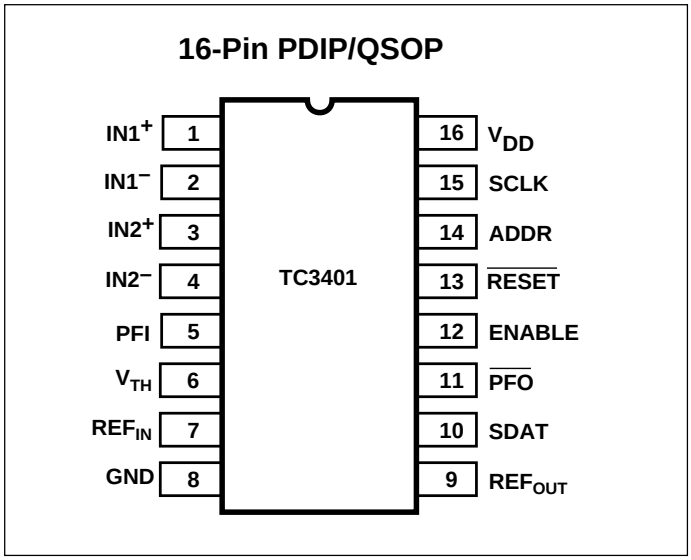
The TC3401's 2-wire MicroPort™digital interface is used for starting conversions and for reading out the data. Driving the SCLK line low starts a conversion. After the conversion starts, each additional falling edge (up to six) detected on SCLK for t4 seconds reduces the A/D resolution by one bit and 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 part automatically sleeps when not performing a data conversion.

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

ORDERING INFORMATION

Part No.	Package	Temp. Range
TC3401VPE	16-Pin PDIP (Narrow)	0°C to +85°C
TC3401VQR	16-Pin QSOP (Narrow)	0°C to +85°C

PIN CONFIGURATIONS



TC3401

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 ..... 0°C to 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		—	300	—	µA
$I_{DD(SLEEP)}$	Supply Current, Sleep Mode	T_A = +25°C	—	50	80	µA
$I_{DD(SLEEP)}$			—	**50**	**130**	µA
ACCURACY (Differential Inputs)						
RES	Resolution		—	16	—	Bits
INL	Integral Non-Linearity	V_{DD} = 2.7V	—	.0038	—	%FSR
V_{OS}	Offset Error	**$IN^+ = IN^-$** = 0V	—	—	**±0.9**	%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						
V_{IN}±	Differential Input Voltage	(Note 1)	—	—	V_{DD}	V
	Absolute Voltage Range on **INn^+, INn^-, INn**		GND	—	V_{DD}	V
	Input Bias Current		—	1	100	nA
C_{IN}	Input Sampling Capacitance		—	2	—	pF
R_{IN}	Differential Input Resistance	(Note 2)	—	2.0	—	MΩ
REF_{IN}, REF_{OUT}, ENABLE						
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
SCLK, ADDR						
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

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

DC ELECTRICAL CHARACTERISTICS (CONT.): 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.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Unit
SDAT, $\overline{\text{RESET}}$						
V_{OL}	Output Low Voltage	I_{OL} = 1.5mA	—	—	0.4	V
V_{OH}	Output High Voltage (SDAT)	I_{SOURCE} = 400µa (Note 2)	0.9 x V_{DD}	—	—	V
$V_{DD(MIN)}$	Minimum V_{DD} for $\overline{\text{PFO}}$, $\overline{\text{RESET}}$ Valid		—	1.1	1.3	V
V_{TH}						
V_{CCPFI}	PFI Input Voltage Range		0	—	V_{DD}	V
	V_{TH}, PFI Input Current		–0.1	.01	0.1	µa
V_{THR}	Threshold		—	1.23	—	V
	Threshold Hysteresis		—	30	—	mV

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° (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_{10}	$\overline{\text{PFO}}$ Delay	PFI to $\overline{\text{PFO}}$ delay	—	25	—	µsec
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 temperatures greater than 25°C.
2. @V_{DD} =1.8V, $I_{SOURCE} \leq$ 200µa

TC3401

PIN DESCRIPTION

TC3401 Pin No.	Symbol	Description
1, 3	INn^+	Analog Input. This is the positive terminal of a true differential input consisting of INn^+ and INn^-. $V_{IN(n)} = (INn^+ – INn^-)$.
2, 4	INn^-	Analog Input. This is the negative terminal of a true differential input consisting of INn^+ and INn^-. $V_{IN(n)} = (INn^+ – INn^-)$ INn^- can swing to, but not below, ground.
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 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 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 (fromMSB 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	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*.)
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/D conversion. 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 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 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. The detailed description of the key components of the TC3401 is outlined below. (Also refer to the *A/D Operational Flowchart* on page 10 and the Timing Diagrams in Figures 2 through 5).

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) 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, in the t4 interval, the SDAT output is driven high by the TC3401 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 3401 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 a16 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 convertion, 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 netgative edge clock pulses. The first is the convert command. Then, up to six of these can occur in the resolution reduction window, t4, to decrement accuracy. The remaining pulses clock out the conversion data word.

Table 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 shows a truth table 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 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

The TC3401 $\overline{RESET}$ output is high provided the voltage at V_{TH} is greater than the internal voltage refererence. This reference is approximately 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 wired-OR'ed with another open drain or external switch if desired.

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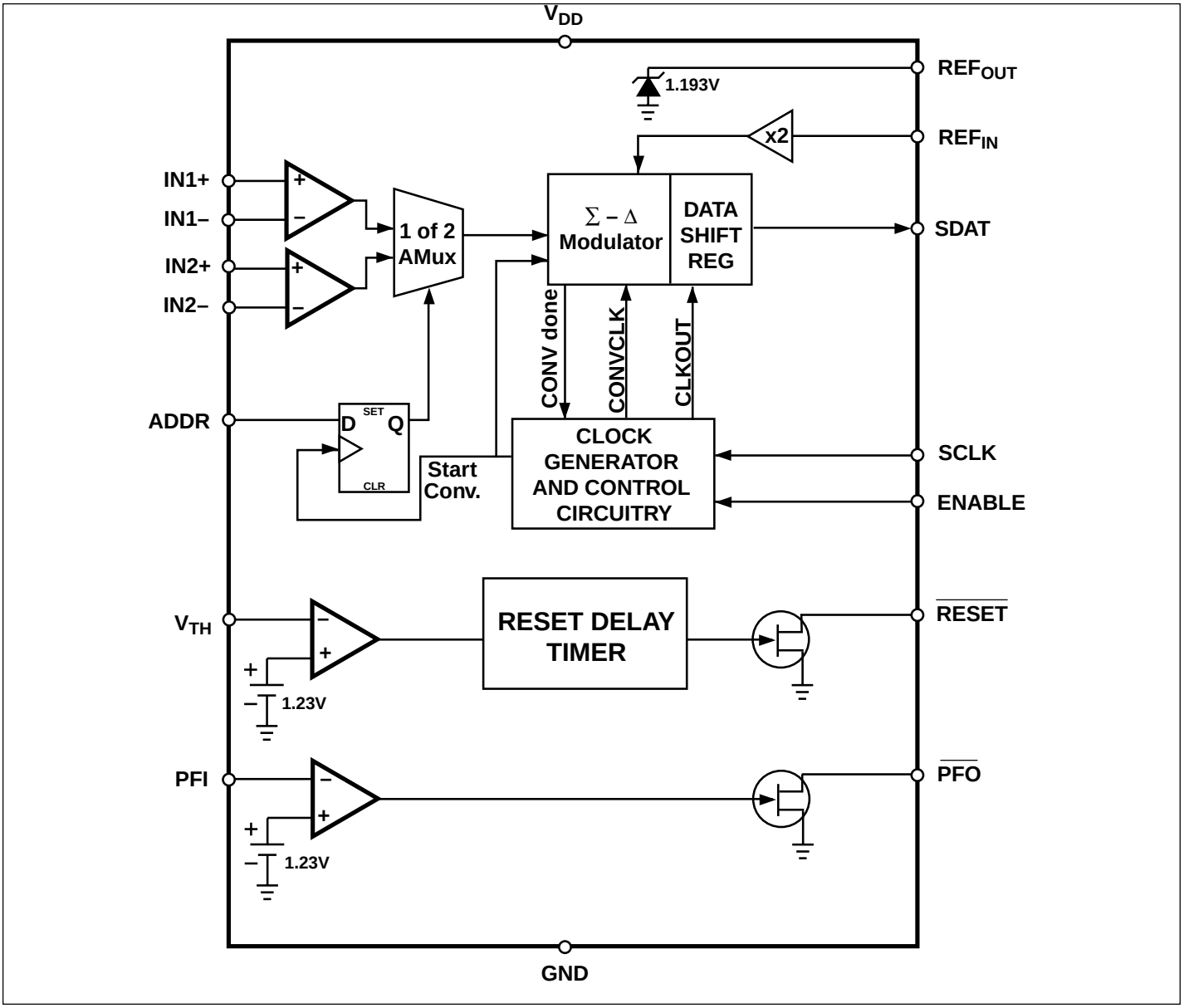
Power Fail Detector

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 PFO pin is the active low, open collector 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 PFO and $\overline{RESET}$ would drive interrupt pins of a microcontroller.

The Power Fail detector, may be used as a Wake-up or Watch-dog Timer. The *Typical Application Circuit* on Page 1 shows an RC network on PFI with the capacitor tied to a tri-stated 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 tri-stating it. The RC network will ramp to 1.23V in roughly 9 seconds, assuming a V_{BATT} of 3.0V. With $\overline{PFO}$ tied to a µC input or interrupt, the µC will see a low-to-high transition on $\overline{PFO}$ when voltage on PFI exceeds 1.23V. The $\overline{PFO}$ output is guaranteed to be valid for V_{DD} = 1.3 to 5.5V.

FUNCTIONAL BLOCK DIAGRAM



TIMING DIAGRAMS

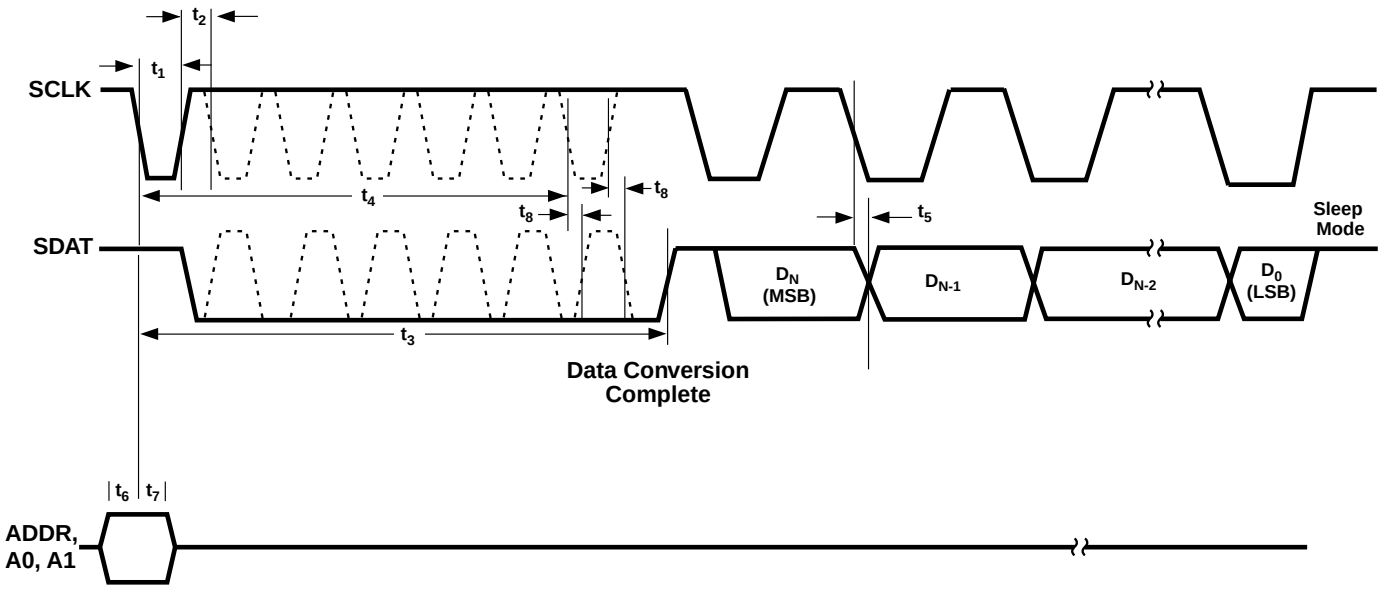
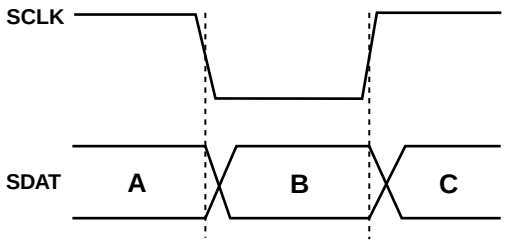


Figure 2. Conversion and Data Output Timing



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

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TIMING DIAGRAMS (CONT.)

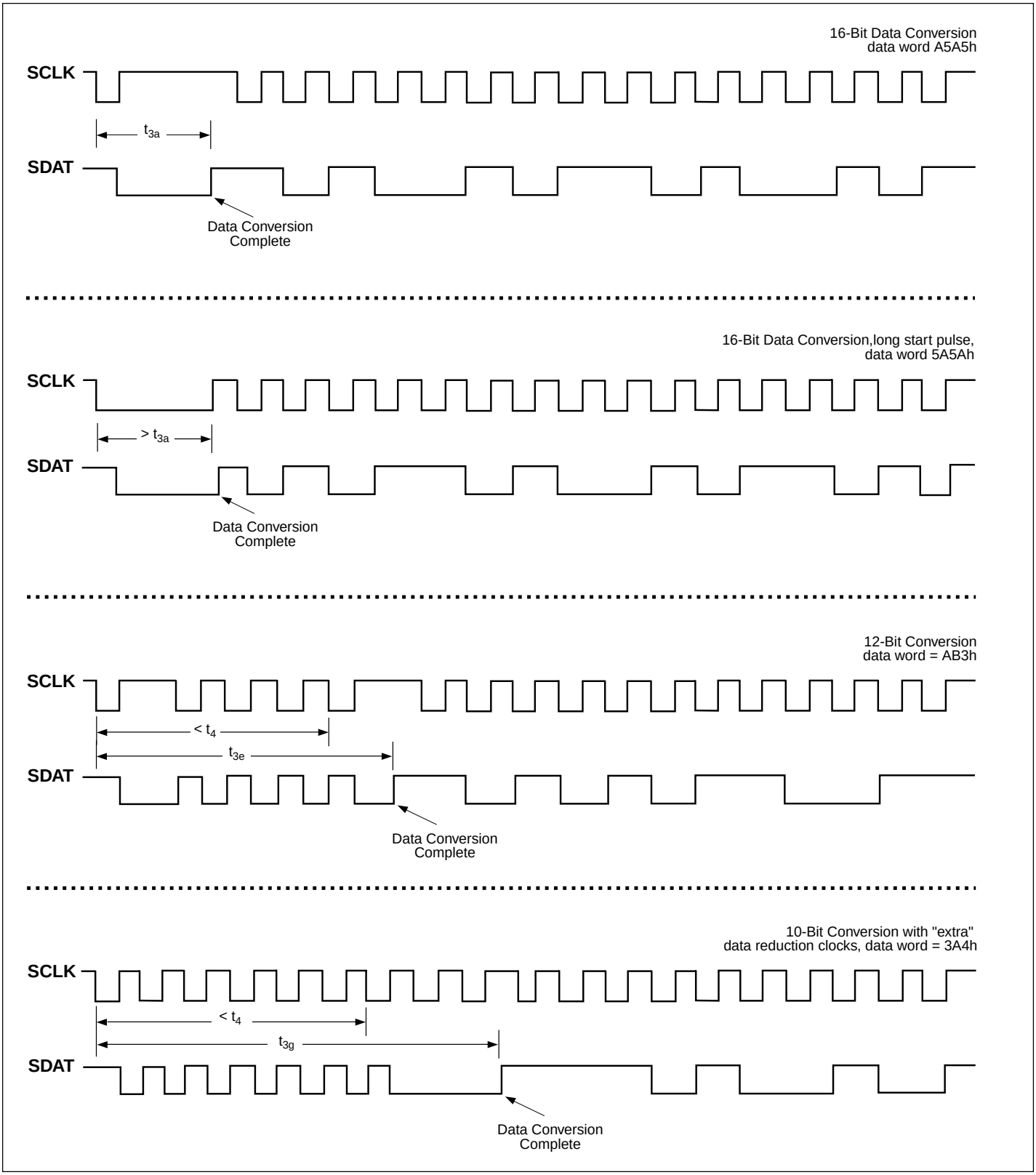
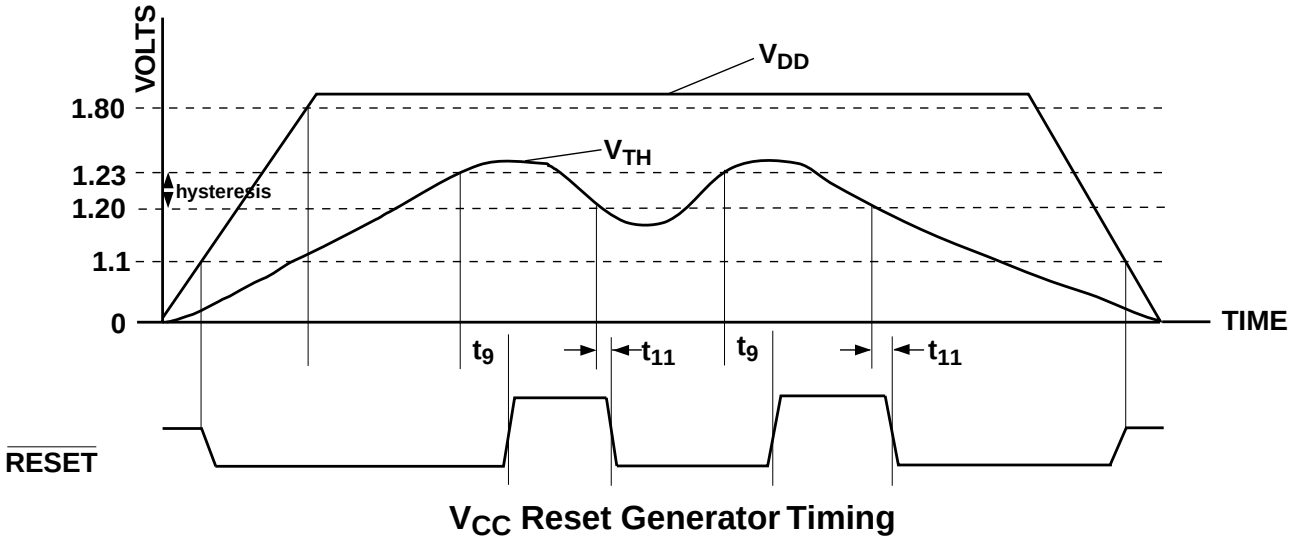
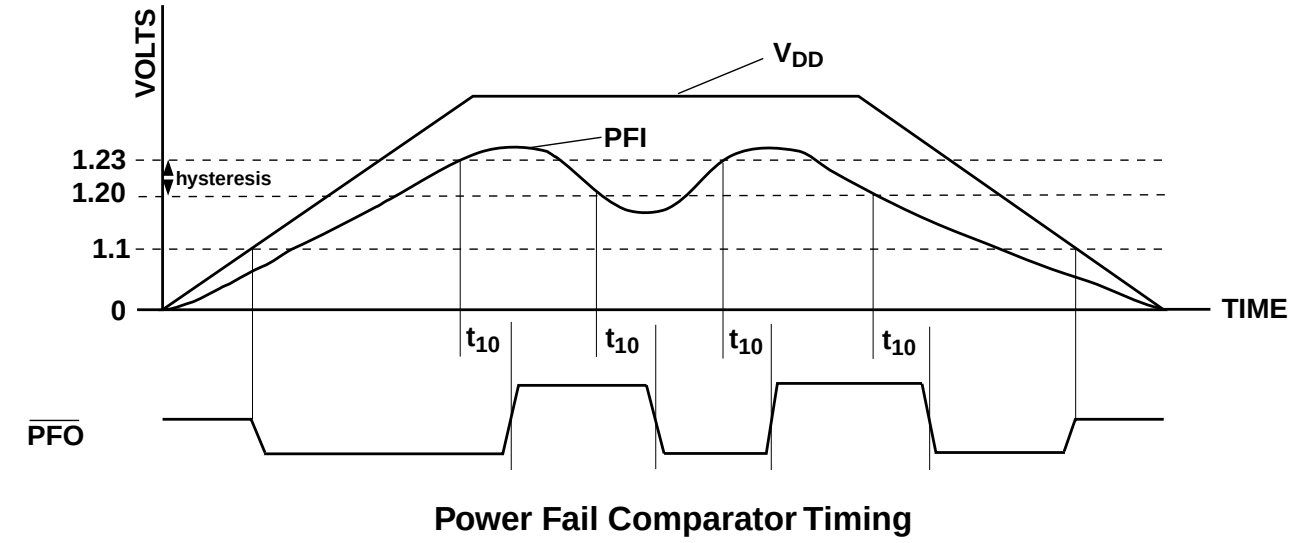


Figure 4. Example Timing Diagrams

TIMING DIAGRAMS (CONT.)



V_{CC} Reset Generator Timing

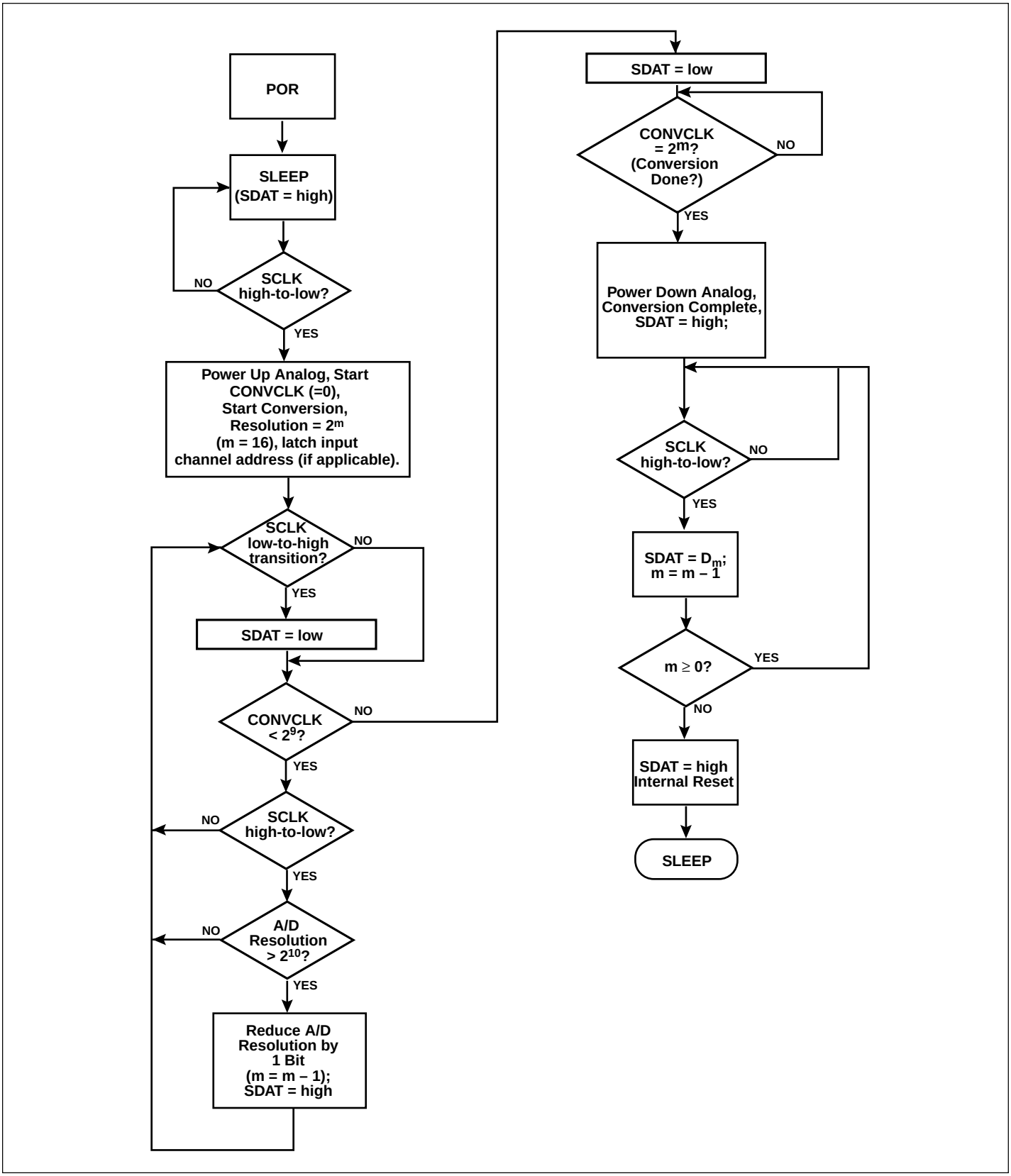


Power Fail Comparator Timing

Figure 5. Reset and Power Fail Timing

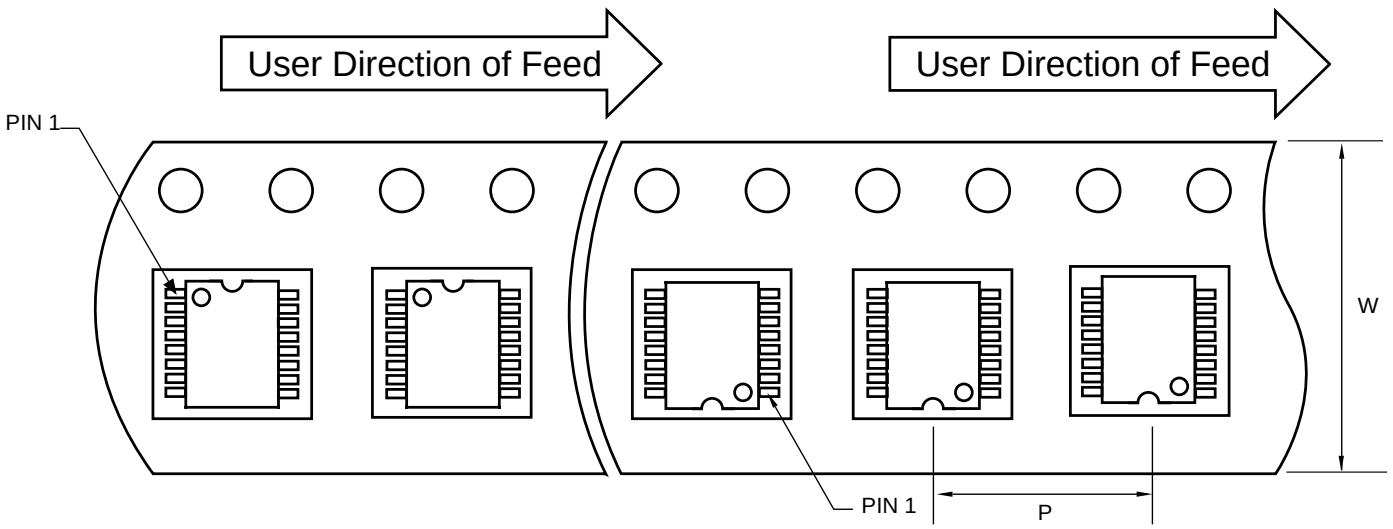
TC3401

A/D OPERATIONAL FLOWCHART



TAPING FORM

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



Standard Reel Component Orientation
for TR Suffix Device

Reverse Reel Component Orientation
for RT Suffix Device

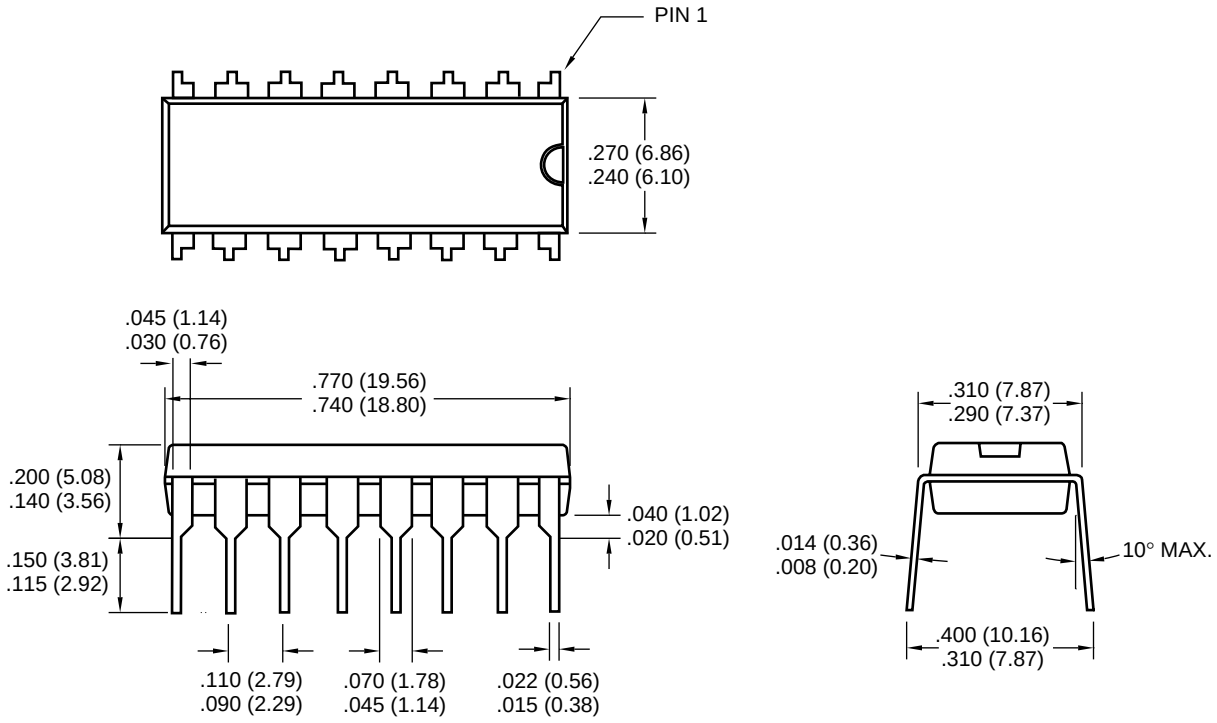
Carrier Tape, Reel Size, Number of Components Per Reel and Reel Size

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

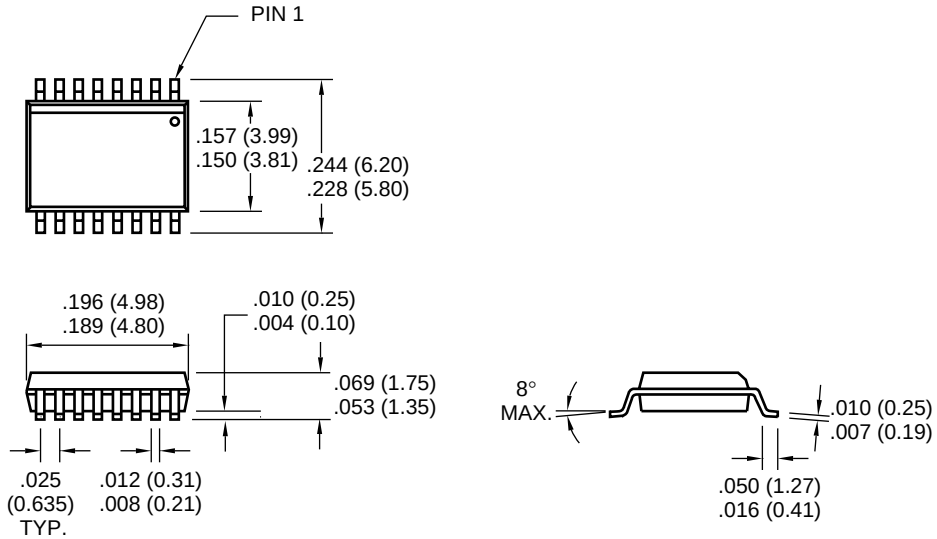
TC3401

PACKAGE DIMENSIONS

16-Pin PDIP (Narrow)



16-Pin QSOP (Narrow)



DImensions: inches(mm)

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AMERICAS

Corporate Office
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7200 Fax: 480-792-7277
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Web Address: http://www.microchip.com

Rocky Mountain
2355 West Chandler Blvd.
Chandler, AZ 85224-6199
Tel: 480-792-7966 Fax: 480-792-7456

Atlanta
500 Sugar Mill Road, Suite 200B
Atlanta, GA 30350
Tel: 770-640-0034 Fax: 770-640-0307

Austin
Analog Product Sales
8303 MoPac Expressway North
Suite A-201
Austin, TX 78759
Tel: 512-345-2030 Fax: 512-345-6085

Boston
2 Lan Drive, Suite 120
Westford, MA 01886
Tel: 978-692-3848 Fax: 978-692-3821

Boston
Analog Product Sales
Unit A-8-1 Millbrook Tarry Condominium
97 Lowell Road
Concord, MA 01742
Tel: 978-371-6400 Fax: 978-371-0050

Chicago
333 Pierce Road, Suite 180
Itasca, IL 60143
Tel: 630-285-0071 Fax: 630-285-0075

Dallas
4570 Westgrove Drive, Suite 160
Addison, TX 75001
Tel: 972-818-7423 Fax: 972-818-2924

Dayton
Two Prestige Place, Suite 130
Miamisburg, OH 45342
Tel: 937-291-1654 Fax: 937-291-9175

Detroit
Tri-Atria Office Building
32255 Northwestern Highway, Suite 190
Farmington Hills, MI 48334
Tel: 248-538-2250 Fax: 248-538-2260

Los Angeles
18201 Von Karman, Suite 1090
Irvine, CA 92612
Tel: 949-263-1888 Fax: 949-263-1338

Mountain View
Analog Product Sales
1300 Terra Bella Avenue
Mountain View, CA 94043-1836
Tel: 650-968-9241 Fax: 650-967-1590

New York
150 Motor Parkway, Suite 202
Hauppauge, NY 11788
Tel: 631-273-5305 Fax: 631-273-5335

San Jose
Microchip Technology Inc.
2107 North First Street, Suite 590
San Jose, CA 95131
Tel: 408-436-7950 Fax: 408-436-7955

Toronto
6285 Northam Drive, Suite 108
Mississauga, Ontario L4V 1X5, Canada
Tel: 905-673-0699 Fax: 905-673-6509

ASIA/PACIFIC

China - Beijing
Microchip Technology Beijing Office
Unit 915
New China Hong Kong Manhattan Bldg.
No. 6 Chaoyangmen Beidajie
Beijing, 100027, No. China
Tel: 86-10-85282100 Fax: 86-10-85282104

China - Shanghai
Microchip Technology Shanghai Office
Room 701, Bldg. B
Far East International Plaza
No. 317 Xian Xia Road
Shanghai, 200051
Tel: 86-21-6275-5700 Fax: 86-21-6275-5060

Hong Kong
Microchip Asia Pacific
RM 2101, Tower 2, Metroplaza
223 Hing Fong Road
Kwai Fong, N.T., Hong Kong
Tel: 852-2401-1200 Fax: 852-2401-3431

India
Microchip Technology Inc.
India Liaison Office
Divyasree Chambers
1 Floor, Wing A (A3/A4)
No. 11, OíShaugnessey Road
Bangalore, 560 025, India
Tel: 91-80-2290061 Fax: 91-80-2290062

Japan
Microchip Technology Intl. Inc.
Benex S-1 6F
3-18-20, Shinyokohama
Kohoku-Ku, Yokohama-shi
Kanagawa, 222-0033, Japan
Tel: 81-45-471- 6166 Fax: 81-45-471-6122

Korea
Microchip Technology Korea
168-1, Youngbo Bldg. 3 Floor
Samsung-Dong, Kangnam-Ku
Seoul, Korea
Tel: 82-2-554-7200 Fax: 82-2-558-5934

ASIA/PACIFIC (continued)

Singapore
Microchip Technology Singapore Pte Ltd.
200 Middle Road
#07-02 Prime Centre
Singapore, 188980
Tel: 65-334-8870 Fax: 65-334-8850

Taiwan
Microchip Technology Taiwan
11F-3, No. 207
Tung Hua North Road
Taipei, 105, Taiwan
Tel: 886-2-2717-7175 Fax: 886-2-2545-0139

EUROPE

Australia
Microchip Technology Australia Pty Ltd
Suite 22, 41 Rawson Street
Epping 2121, NSW
Australia
Tel: 61-2-9868-6733 Fax: 61-2-9868-6755

Denmark
Microchip Technology Denmark ApS
Regus Business Centre
Lautrup hoj 1-3
Ballerup DK-2750 Denmark
Tel: 45 4420 9895 Fax: 45 4420 9910

France
Arizona Microchip Technology SARL
Parc díActivite du Moulin de Massy
43 Rue du Saule Trapu
Batiment A - ler Etage
91300 Massy, France
Tel: 33-1-69-53-63-20 Fax: 33-1-69-30-90-79

Germany
Arizona Microchip Technology GmbH
Gustav-Heinemann Ring 125
D-81739 Munich, Germany
Tel: 49-89-627-144 0 Fax: 49-89-627-144-44

Germany
Analog Product Sales
Lochhamer Strasse 13
D-82152 Martinsried, Germany
Tel: 49-89-895650-0 Fax: 49-89-895650-22

Italy
Arizona Microchip Technology SRL
Centro Direzionale Colleoni
Palazzo Taurus 1 V. Le Colleoni 1
20041 Agrate Brianza
Milan, Italy
Tel: 39-039-65791-1 Fax: 39-039-6899883

United Kingdom
Arizona Microchip Technology Ltd.
505 Eskdale Road
Winnersh Triangle
Wokingham
Berkshire, England RG41 5TU
Tel: 44 118 921 5869 Fax: 44-118 921-5820