TC1016

80mA, Tiny CMOS LDO With Shutdown

Features

- Space-Saving 5-Pin SC-70 Package
- Extremely Low Operating Current for Longer Battery Life: 53 µA (typ.)
- Very Low Dropout Voltage
- Rated 80 mA Output Current
- Requires only 1 µF Ceramic Output Capacitance
- High Output Voltage Accuracy: ±0.5% (typ.)
- 10 µsec (typ.) Wake-Up Time from $\overline{\text{SHDN}}$
- Power-Saving Shutdown Mode: 0.05 µA(typ.)
- Over-Current and Over-Temperature Protection
- Pin Compatible Upgrade for Bipolar Regulators

Applications

- Cellular / GSM / PHS Phones
- Battery Operated Systems
- Portable Computers
- Medical Instruments
- Electronic Games
- Pagers

General Description

The TC1016 is a high accuracy (typically ±0.5%) CMOS upgrade for bipolar low dropout regulators. It is offered in an SC-70 package, which represents 50% reduced footprint vs. the popular SOT-23 package.

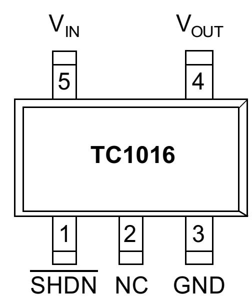
Developed specifically for battery-powered systems, the device's CMOS construction consumes only 53 µA typical supply current over the entire 80 mA operating load range. This can be as much as 60 times less than the quiescent operating current consumed by bipolar LDOs.

With small space requirements and cost in mind, the TC1016 was developed to be stable over the entire input voltage and output current operating range using low value (1 µF ceramic), low equivalent series resistance output capacitors. Additional integrated features such as shutdown, over-current and over-temperature protection further reduce the board space and cost of the entire voltage regulating application.

Key performance parameters for the TC1016 are low drop out voltage (150 mV typical at 80 mA output current), low supply current while shutdown (0.05 µA typical) and fast stable response to sudden input voltage and load changes.

Pin Configurations

SC-70



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1.0 ELECTRICAL CHARACTERISTICS

ABSOLUTE MAXIMUM RATINGS*

Input Voltage 6.5V
Output Voltage .... (–0.3) to (V_{IN} + 0.3)
Power Dissipation .... Internally Limited (Note 7)
Operating Temperature .... –40°C < T_J < 125°C
Storage Temperature .... –65°C to +150°C
Maximum Voltage On Any Pin .... V_{IN} + 0.3V to –0.3V

***Notice:** 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

PIN FUNCTION TABLE

Name	Function
$\overline{SHDN}$	Shutdown control input. The regulator is fully enabled when a logic high is applied to this input. The regulator enters shutdown when a logic low is applied to this input. During shutdown, output voltage falls to zero, and supply current is reduced to 0.5 µA (typ.).
NC	No Connect
GND	Ground Terminal
V_{OUT}	Regulated voltage output.
V_{IN}	Unregulated supply input.

ELECTRICAL CHARACTERISTICS

$V_{IN} = V_R + 1V$, $I_L = 100$ µA, $C_L = 1.0$µF, $\overline{SHDN} > V_{IH}$, $T_A = 25°C$, unless otherwise noted. **Boldface** type specifications apply for junction temperatures of – 40°C to +125°C.

Parameter	Sym	Min	Typ	Max	Units	Test Conditions
Input Operating Voltage	V_{IN}	**2.7**	—	**6.0**	V	**Note 1**
Maximum Output Current	I_{OUTMAX}	**80**	—	—	mA	
Output Voltage	V_{OUT}	**V_R – 2.5%**	V_R ±0.5%	**V_R + 2.5%**	V	**Note 2**
V_{OUT} Temperature Coefficient	TCV_{OUT}	—	**40**	—	ppm/°C	**Note 3**
Line Regulation	$(\Delta V_{OUT}/\Delta V_{IN}) / V_R$	—	0.01	**0.2**	%/V	(V_R + 1V) < V_{IN} < 6V
Load Regulation (**Note 4**)	$\Delta V_{OUT} / V_R$	—	0.23	**1**	%	I_L = 0.1 mA to I_{OUTMAX}
Dropout Voltage (**Note 5**)	$V_{IN} – V_{OUT}$	— — —	2 100 150	— **200** **300**	mV	I_L = 100 µA I_L = 50 mA I_L = 80 mA
Supply Current	I_{IN}	—	53	**90**	µA	$\overline{SHDN} = V_{IH}$, $I_L = 0$
Shutdown Supply Current	I_{INSD}	—	0.05	0.5	µA	$\overline{SHDN}$ = 0V
Power Supply Rejection Ratio	PSRR	—	58	—	dB	f =1 kHz, I_L = 50 mA
Wake-Up Time (from Shutdown Mode)	t_{WK}	—	10	—	µs	V_{IN} = 5V, I_L = 60 mA, C_{IN} = 1 µF, C_{OUT} = 1 µF, f = 100 Hz
Settling Time (from Shutdown Mode)	t_S	—	32	—	µs	V_{IN} = 5V, I_L = 60 mA,C_{IN} = 1 µF, C_{OUT} = 1 µF, f = 100 Hz
Output Short Circuit Current	I_{OUTSC}	—	120	—	mA	V_{OUT} = 0V
Thermal Regulation	V_{OUT}/P_D	—	0.04	—	V/W	**Notes 6, 7**
Thermal Shutdown Die Temperature	T_{SD}	—	160	—	°C	
Thermal Shutdown Hysteresis	ΔT_{SD}	—	10	—	°C	
Output Noise	eN	—	800	—	nV/√Hz	f = 10 kHz
$\overline{SHDN}$ Input High Threshold	V_{IH}	**60**	—	—	$\%V_{IN}$	V_{IN} = 2.7V to 6.0V
$\overline{SHDN}$ Input Low Threshold	V_{IL}	—	—	**15**	$\%V_{IN}$	V_{IN} = 2.7V to 6.0V

Note 1: The minimum V_{IN} has to meet two conditions: $V_{IN} \geq 2.7V$ and $V_{IN} \geq (V_R + 2.5\%)+V_{DROPOUT}$.

2: V_R is the regulator voltage setting. For example: V_R = 1.8V, 2.7V, 2.8V, 3.0V.

3:
$$TCV_{OUT} = \frac{(V_{OUTMAX} - V_{OUTMIN}) \times 10^6}{V_{OUT} \times \Delta T}$$

4: Regulation is measured at a constant junction temperature using low duty cycle pulse testing. Load regulation is tested over a load range from 0.1 mA to the maximum specified output current. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

5: Dropout voltage is defined as the input to output differential at which the output voltage drops 2%below its nominal value at a 1V differential.

6: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a current pulse equal to Ilmax at V_{IN} = 6V for t= 10 msec.

7: The maximum allowable power dissipation is a functionof ambient temperature, the maximum allowable juction temperature and the thermal resistance from junction-to-air (i.e. T_A, T_J, θ_{JA}). Exceeding the maximum allowable power dissipation causes the device to initiate thermal shutdown. Please see “Thermal Considerations” section of this datasheet for more details.

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2.0 DETAILED DESCRIPTION

The TC1016 is a precision fixed output linear voltage regulator. The internal linear pass element is a P-Channel MOSFET. As with all P-Channel CMOS LDOs there is a body drain diode with the cathode connected to Vin and the anode connected to V_{OUT} (Figure 2-1).

As shown in Figure 2-1, the output voltage of the LDO is sensed and divided down internally to reduce external component count. The internal error amplifier has a fixed bandgap reference on the inverting input and the sensed output voltage on the non-inverting input. The error amplifier output will pull the gate voltage down until the inputs of the error amplifier are equal to regulate the output voltage.

By sensing the current in the P-Channel MOSFET, the maximum current delivered to the load is limited to a typical value of 120 mA preventing excessive current from damaging the printed circuit board in the event of a shorted or faulted load.

An internal thermal sensing device is used to monitor the junction temperature of the LDO. When the sensed temperature is over the set threshold of 160°C typical, the P-Channel MOSFET is turned off. When the P-Channel is off, the power dissipation internal to the device is almost zero. The device cools until the junction temperature is approximately 150°C and the P-Channel is turned on. If the internal power dissipation is still high enough for the junction to rise to 160°C it will again shut off and cool. The maximum operating junction temperature of the device is 125°C. Steady state operation at or near the 160°C over temperature point can lead to permanent damage of the device.

The output voltage V_{OUT}, remains stable over the entire input operating voltage range (2.7V to 6.0V) and the entire load range (0 mA to 80 mA). The output voltage is sensed through an internal resistor divider and compared with a precision internal voltage reference. Several fixed output voltages are available by changing the value of the internal resistor divider.

Figure 2-2 shows a typical application circuit. The regulator is enabled any time the shutdown input pin is at or above V_{IH}, and shutdown (disabled) any time the shutdown input pin is below V_{IL}. For applications where the $\overline{SHDN}$ feature is not used, tie the $\overline{SHDN}$ pin directly to the input supply voltage source. While in shutdown, the supply current decreases to 0.05 µA (typical) and the P-Channel MOSFET is turned off.

As shown in Figure 2-2, batteries have internal source impedance. An input capacitor in used to lower the input impedance of the LDO. In some applications, high input impedance can cause the LDO to become unstable. Adding more input capacitance can compensate for this.

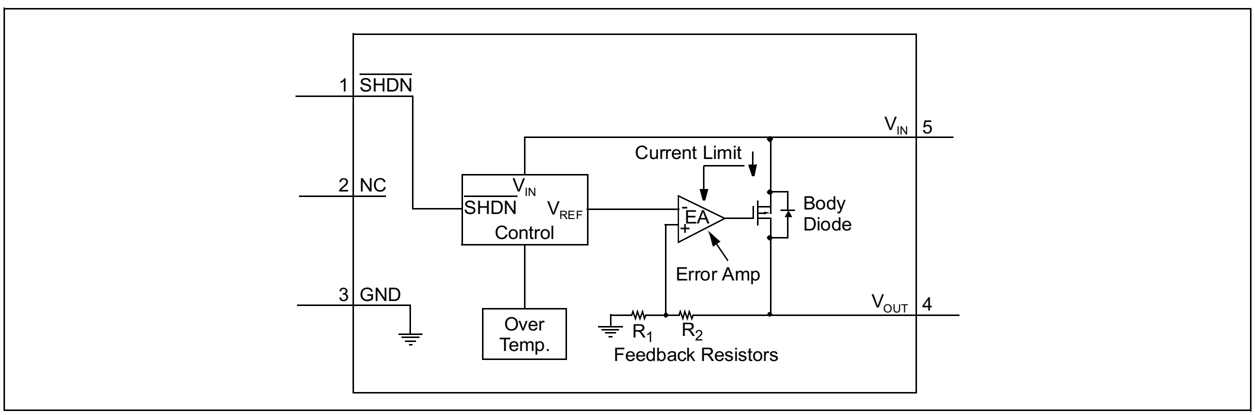

FIGURE 2-1: *TC1016 Block Diagram.*

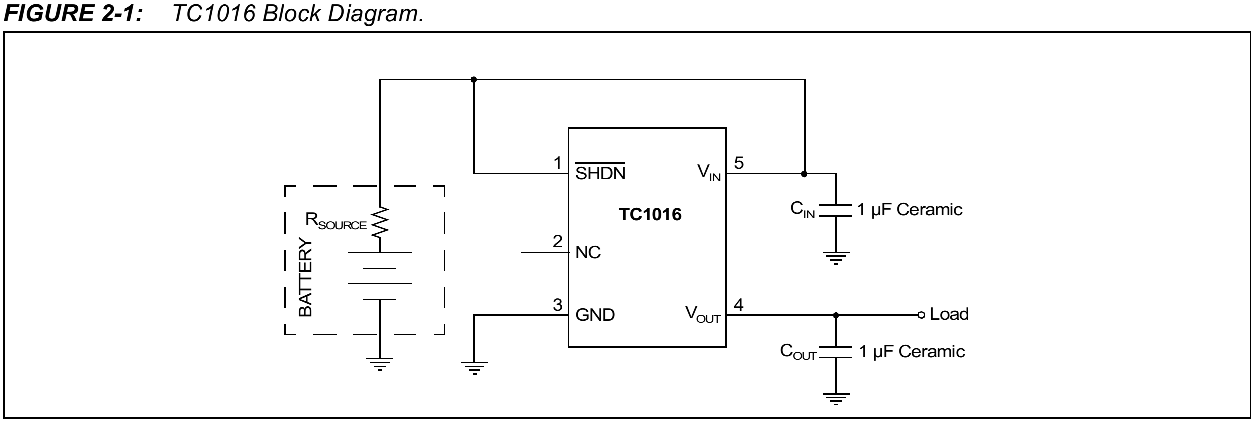

FIGURE 2-2: *Typical Application Circuit.*

2.1 Input Capacitor

Low input source impedance is necessary for the LDO to operate properly. When operating off of batteries or in applications with long lead length (> 10") between the input source and the LDO, some input capacitance is required. A minimum of 0.1 µF is recommended for most applications and the capacitor should be placed as close to the input of the LDO as practical. Larger input capacitors will help reduce the input impedance and further reduce any high frequency noise on the input and output of the LDO.

2.2 Output Capacitor

A minimum output capacitance of 1 µF for the TC1016 is required for stability. The equivalent series resistance (ESR) requirements on the output capacitor are between 0 and 2 ohms. The output capacitor should be located as close to the LDO output as practical. Ceramic materials X7R and X5R have low temperature coefficients and are well within the acceptable ESR range required. A typical 1 µF X5R 0805 capacitor has an ESR of 50 milli-ohms. Larger output capacitors can be used with the TC1016 to improve dynamic behavior and input ripple rejection performance.

Ceramic, aluminum electrolytic or tantalum capacitor types can be used. Since many aluminum electrolytic capacitors freeze at approximately –30°C, ceramic or solid tantalums are recommended for applications operating below –25°C. When operating from sources other than batteries, supply-noise rejection and transient response can be improved by increasing the value of the input and output capacitors and employing passive filtering techniques.

2.3 Turn On Response

The turn on response is defined as two separate response categories, Wake-Up Time (t_{WK}) and Settling Time (t_S).

The TC1016 has a fast Wake-Up Time (10 µsec typical) when released from shutdown. See Figure 2-3 for the Wake-Up Time designated as t_{WK}. The Wake-Up Time is defined as the time it takes for the output to rise to 2% of the V_{OUT} value after being released from shutdown.

The total turn on response is defined as the Settling Time (t_S), see Figure 2-3. Settling Time (inclusive with t_{WK}) is defined as the condition when the output is within 98% of its fully enabled value (42 µsec typical) when released from shutdown. The settling time of the output voltage is dependent on load conditions and output capacitance on V_{OUT} (RC response).

The table below demonstrates the typical turn on response timing for different input voltage power-up frequencies: V_{OUT} = 2.8V, V_{IN} = 5.0V, I_{OUT} = 60 mA and C_{OUT} = 1 µF.

Frequency	Typical (t_{WK})	Typical (t_S)
1000 Hz	5.3 µsec	14 µsec
500 Hz	5.9 µsec	16 µsec
100 Hz	9.8 µsec	32 µsec
50 Hz	14.5 µsec	52 µsec
10 Hz	17.2 µsec	77 µsec

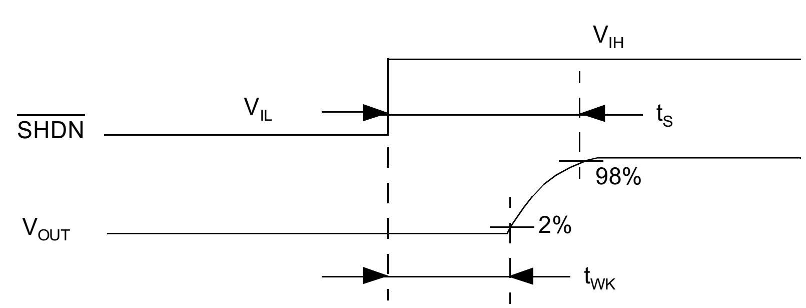

FIGURE 2-3: *Wake-Up Time from Shutdown.*

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3.0 THERMAL CONSIDERATIONS

3.1 Thermal Shutdown

Integrated thermal protection circuitry shuts the regulator off when die temperature exceeds approximately 160°C. The regulator remains off until the die temperature drops to approximately 150°C.

3.2 Power Dissipation

The TC1016 is available in the SC70 package. The thermal resistance for the SC70 package is approximately 450°C/W when the copper area used in the printed circuit board layout is similar to the JEDEC J51-7 high thermal conductivity standard or Semi G42-88 standard. For applications with larger or thicker copper area, the thermal resistance can be lowered. See AN792 for a method to determine the thermal resistance for a particular application.

The TC1016 power dissipation capability is dependant upon several variables, input voltage, output voltage, load current, ambient temperature and maximum junction temperature. The absolute maximum steady state junction temperature is rated at 125°C. The power dissipation within the device is equal to:

$$P_D = (V_{IN} - V_{OUT}) \times I_{LOAD} + V_{IN} \times I_{GND} \quad \textbf{[3-1]}$$

The V_{IN} x I_{GND} term is typically very small when compared to the (V_{IN}-V_{OUT}) x I_{LOAD} term simplifying the power dissipation within the LDO to be:

$$P_D = (V_{IN} - V_{OUT}) \times I_{LOAD} \quad \textbf{[3-2]}$$

To determine the maximum power dissipation capability, the following equation is used:

$$P_{DMAX} = \frac{(T_{J\_MAX} - T_{A\_MAX})}{R\theta_{JA}} \quad \textbf{[3-3]}$$

Where:

T_{J_MAX} = the maximum junction temperature allowed

T_{A_MAX} = the maximum ambient temperature

$R\theta_{JA}$ = the thermal resistance from junction to air

Given the following example:

V_{IN}	=	3.0V to 4.1V
V_{OUT}	=	2.8V ±2.5%
I_{LOAD}	=	60 mA (output current)
T_{AMAX}	=	55°C (max. ambient temp.)

Find:

1. Internal power dissipation:

$$\begin{aligned} P_{DMAX} &= (V_{IN\_MAX} - V_{OUT\_MIN}) \times I_{LOAD} \\ &= (4.1V - 2.8 \times (0.975)) \times 60mA \\ &= 82.2mW \end{aligned}$$

2. Junction temperature:

$$\begin{aligned} T_{J\_MAX} &= P_{DMAX} \times R\theta_{JA} \\ &= 82.2mWatts \times 450°C/W + T_{AMAX} \\ &= 37°C + 55°C \\ &= 92°C \end{aligned}$$

3. Maximum allowable dissipation:

$$\begin{aligned} P_D &= \frac{T_{J\_MAX} - T_{A\_MAX}}{R\theta_{JA}} \\ &= \frac{125°C - 55°C}{450°C/W} \\ &= 155mW \end{aligned}$$

In this example, the TC1016 dissipates approximately 82.2 mWatts and the junction temperature is raised 37°C over the 55°C ambient to 92°C. The absolute maximum power dissipation is 155 mW when given a maximum ambient temperature of 55°C.

Input voltage, output voltage or load current limits can also be determined by substituting known values in equations 3-2 and 3-3.

3.3 Layout Considerations

The primary path for heat conduction out of the SC70 package is through the package leads. Using heavy wide traces at the pads of the device will facilitate the removal of the heat within the package thus lowering the thermal resistance $R\theta_{JA}$. By lowering the thermal resistance, the maximum internal power dissipation capability of the package is increased.

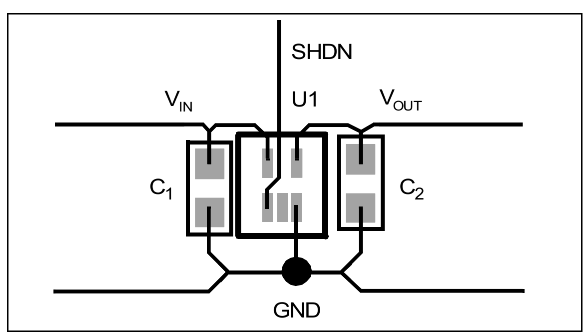

FIGURE 3-1: *Suggested layout*

4.0 TYPICAL PERFORMANCE CHARACTERISTICS

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore outside the warranted range.

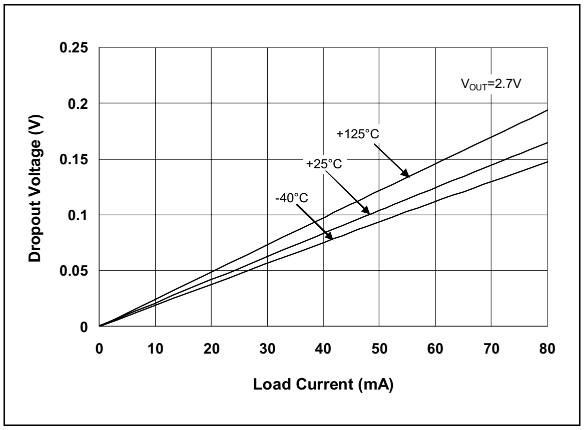

FIGURE 4-1: *Dropout Voltage vs. Output Current.*

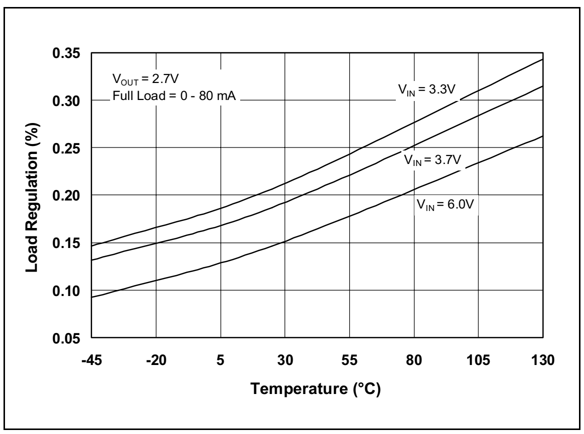

FIGURE 4-2: *Load Regulation vs. Temperature.*

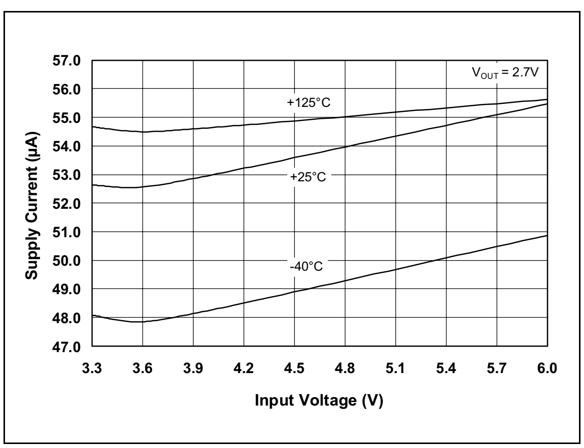

FIGURE 4-3: *Supply Current vs. Input Voltage.*

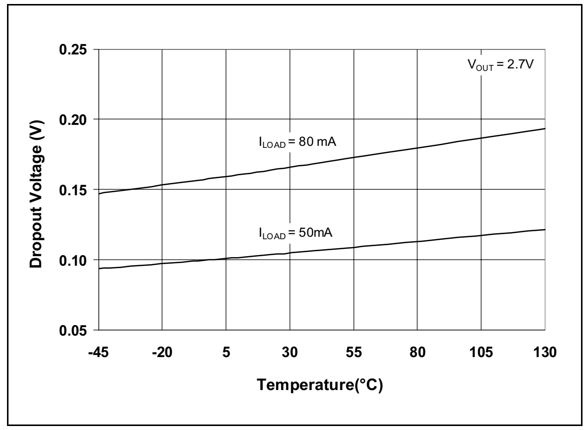

FIGURE 4-4: *Dropout Voltage vs. Temperature.*

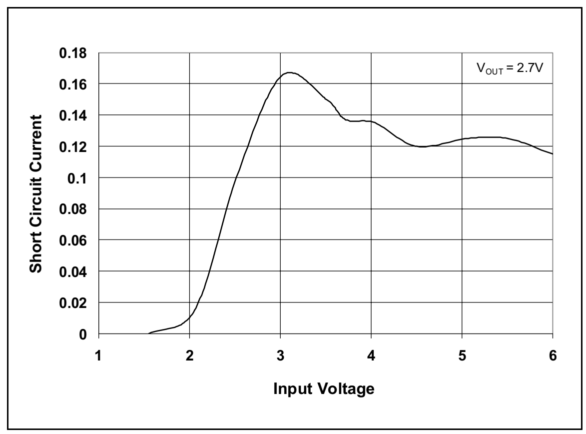

FIGURE 4-5: *Short Circuit Current vs. Input Voltage.*

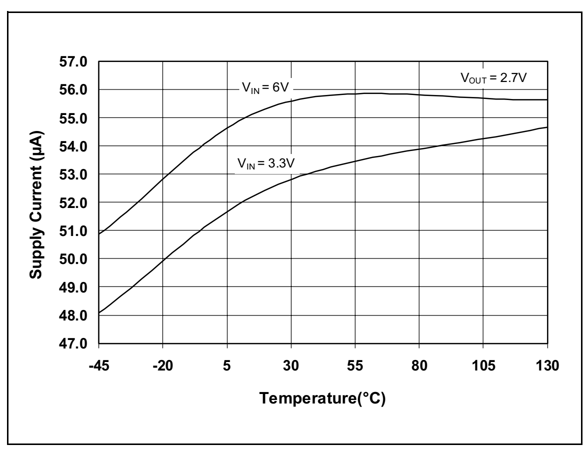

FIGURE 4-6: *Supply Current vs. Temperature.*

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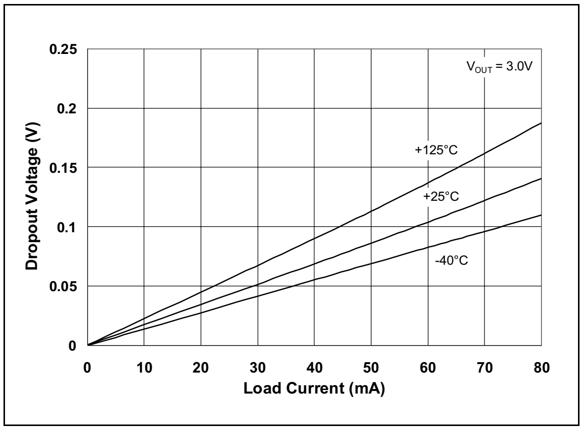

FIGURE 4-7: *Dropout Voltage vs. Output Current.*

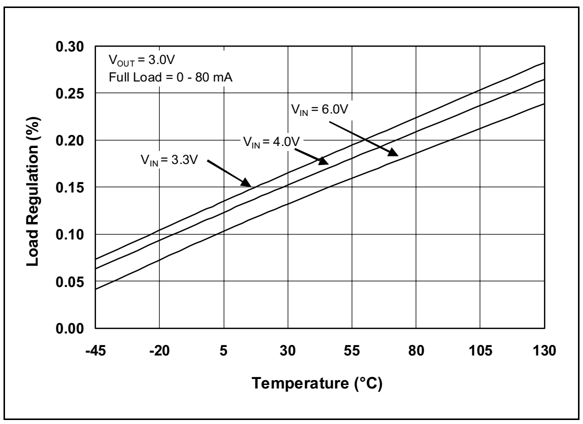

FIGURE 4-8: *Load Regulation vs. Temperature.*

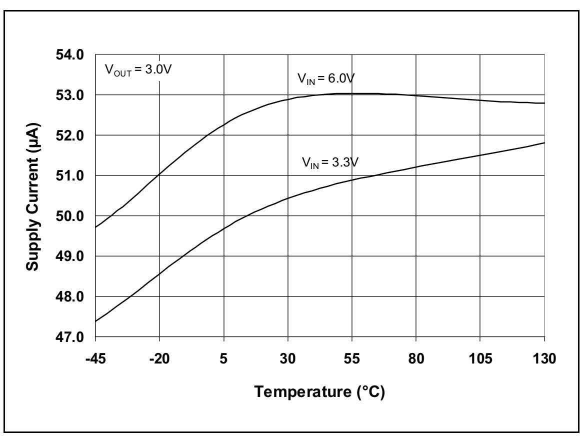

FIGURE 4-9: *Supply Current vs. Temperature.*

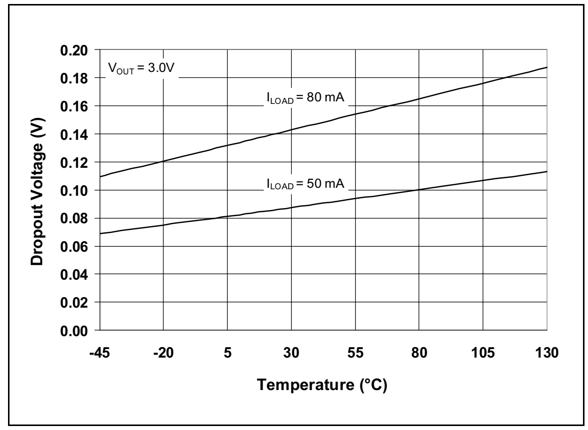

FIGURE 4-10: *Dropout Voltage vs. Temperature.*

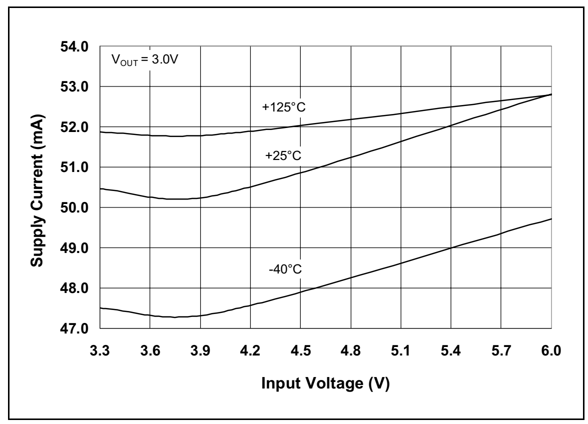

FIGURE 4-11: *Supply Current vs. Input Voltage*

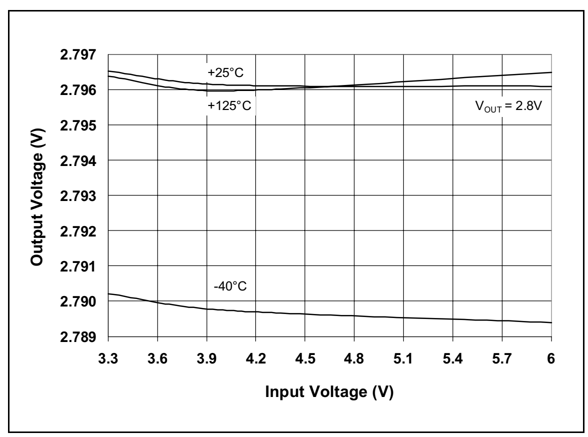

FIGURE 4-12: *Output Voltage vs. Supply Voltage.*

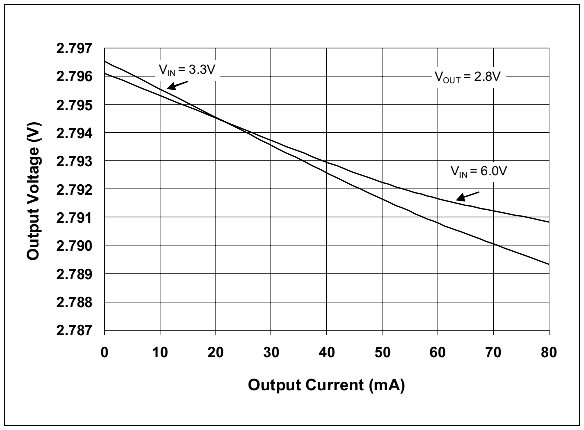

FIGURE 4-13: Output Voltage vs. Output Current.

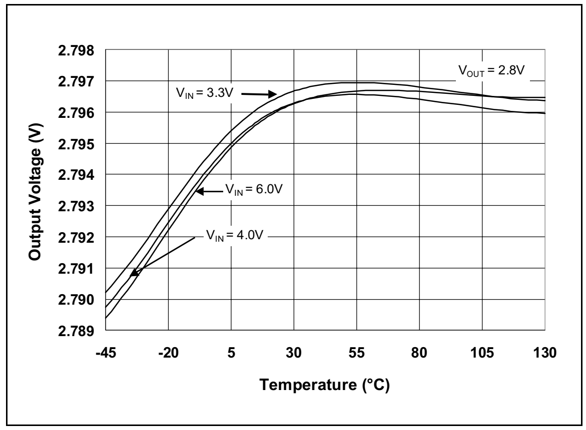

FIGURE 4-16: Output Voltage vs. Temperature.

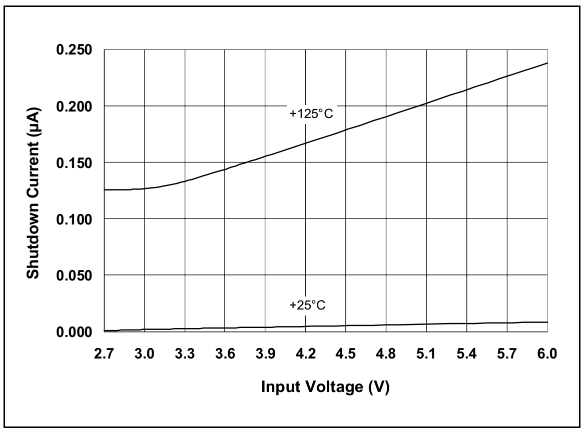

FIGURE 4-14: Shutdown Current vs. Input Voltage.

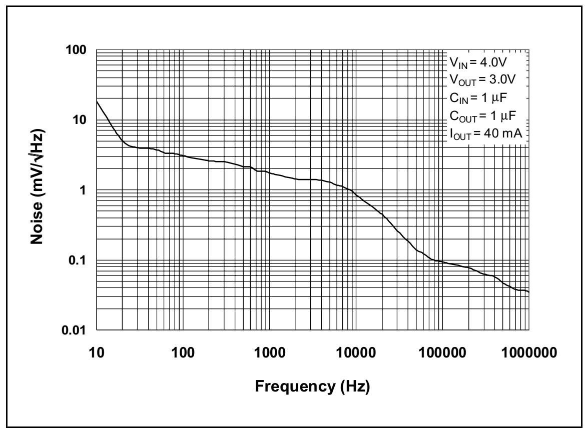

FIGURE 4-17: Output Noise vs. Frequency.

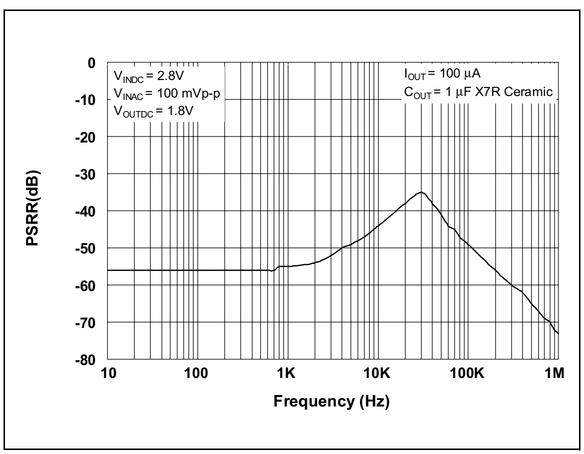

FIGURE 4-15: Power Supply Rejection Ratio vs. Frequency.

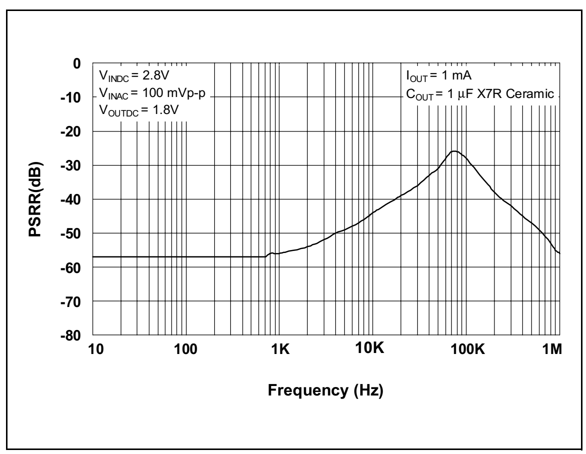

FIGURE 4-18: Power Supply Rejection Ratio vs. Frequency.

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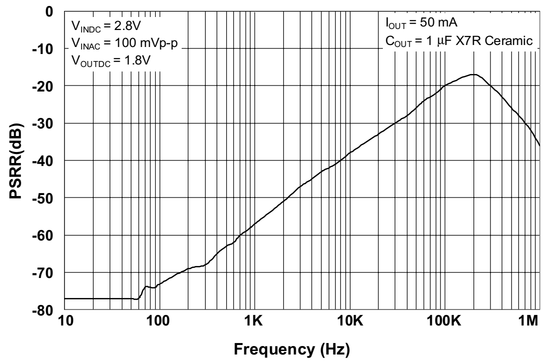

FIGURE 4-19: *Power Supply Rejection Ratio vs. Frequency.*

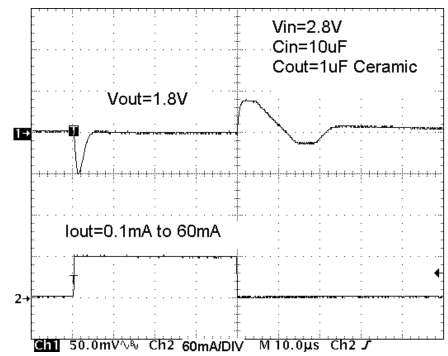

FIGURE 4-22: *Load Transient Response.*

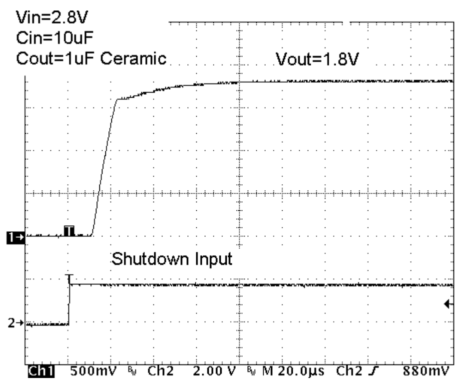

FIGURE 4-20: *Wake-Up Response.*

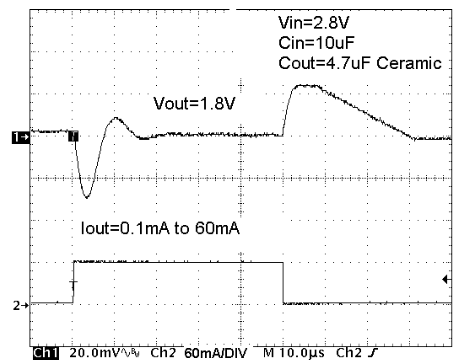

FIGURE 4-23: *Load Transient Response.*

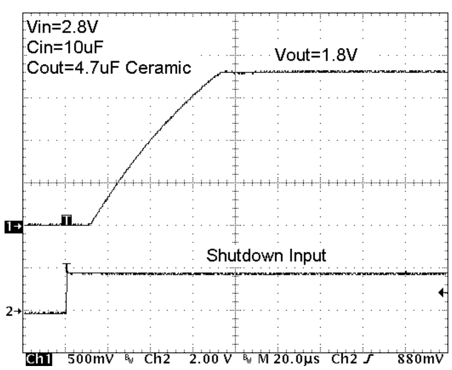

FIGURE 4-21: *Wake-Up Response.*

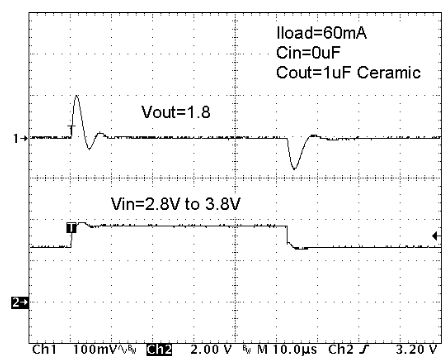

FIGURE 4-24: *Line Transient Response.*

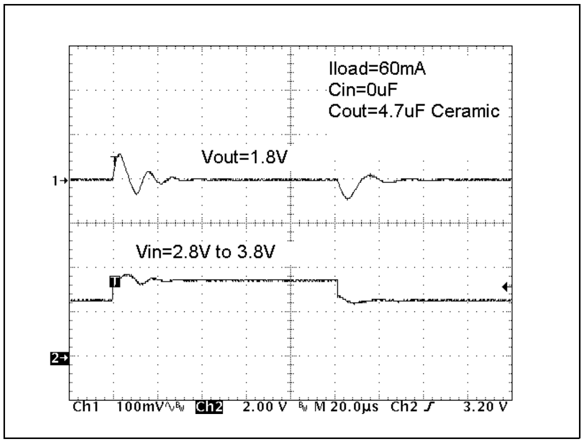

FIGURE 4-25: *Line Transient Response.*

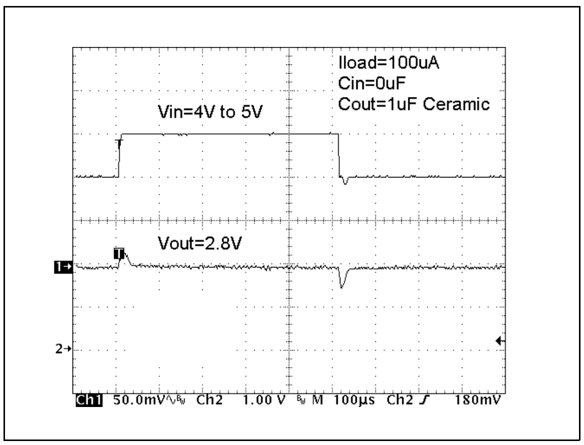

FIGURE 4-26: *Line Transient Response.*

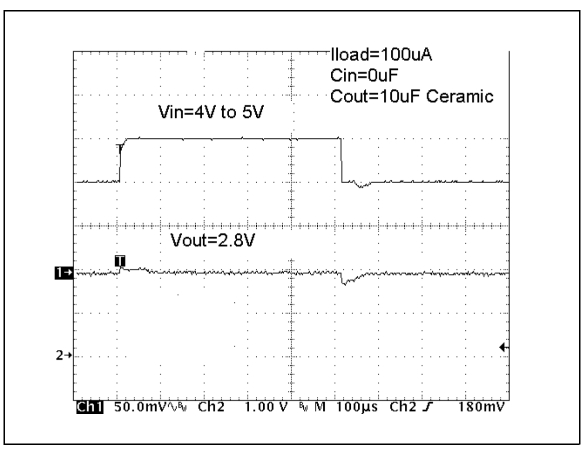

FIGURE 4-27: *Line Transient Response.*

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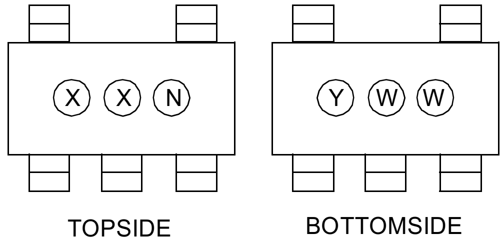
5.0 PACKAGE INFORMATION

5.1 Package Marking Information

5-Pin SC-70



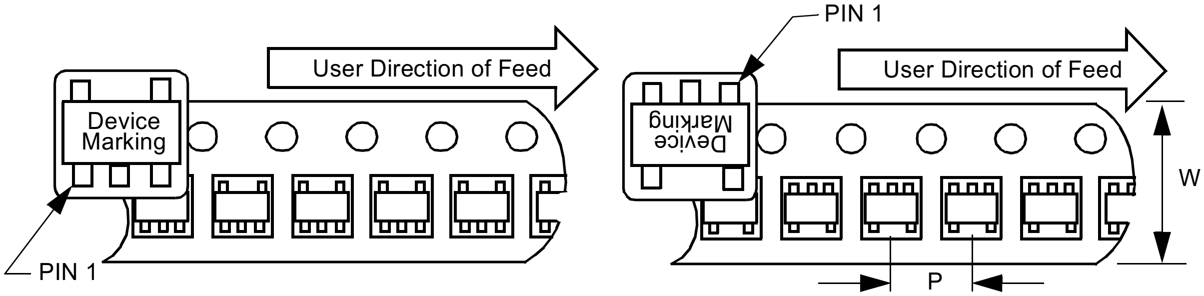
Part Number	Code
TC1016 - 1.8VLT	AA
TC1016 - 2.7VLT	AD
TC1016 - 2.8VLT	AB
TC1016 - 3.0VLT	AC

Legend:
X Part Number + temperature range and voltage
X Part Number + temperature range and voltage
N Traceability code
Y Year
WW Work week

Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line thus limiting the number of available characters for customer specific information.

5.2 Package Dimensions

Component Taping Orientation for 5-Pin SC-70

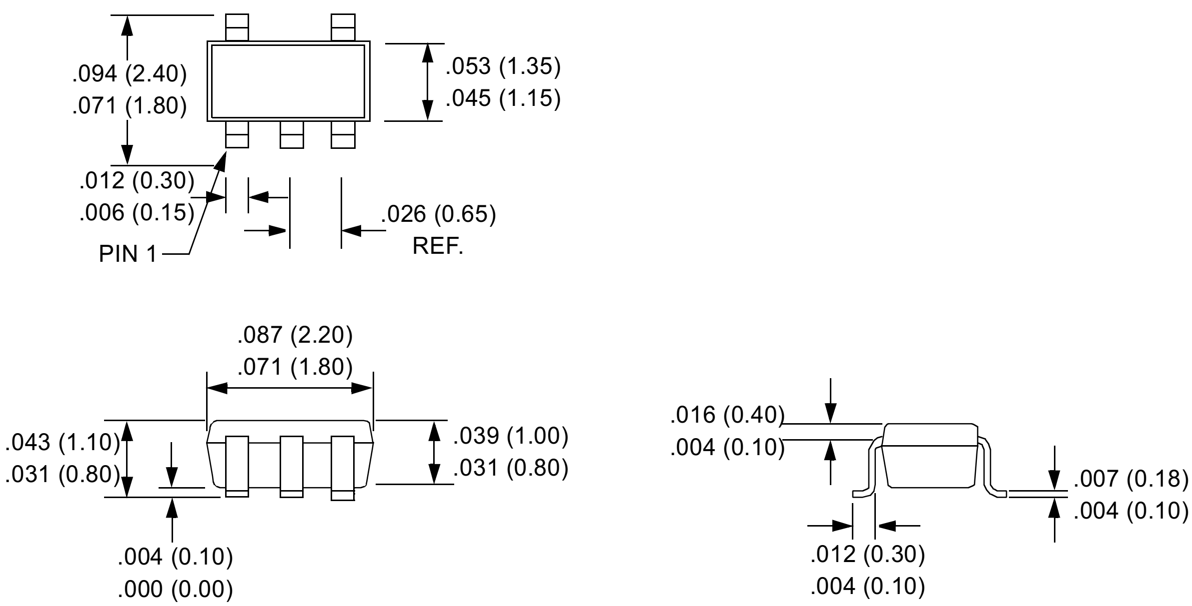


Standard Reel Component Orientation
for TR Suffix Device
(Mark Right Side Up)

Reverse Reel Component Orientation
for RT Suffix Device
(Mark Upside Down)

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

Package	Carrier Width (W)	Pitch (P)	Part Per Full Reel	Reel Size
5-Pin SO-70	8 mm	4 mm	3000	7 in.



Dimensions: inches (mm)

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013001

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Device: **TC1016**   Literature Number: **DS21666A**

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PART NO.	XX	X
Device	Voltage Range	Temperature Range

Device:	TC1016: 80 mA Tiny CMOS LDO with Shutdown
Voltage Range:	AA = 1.8V AD = 2.7V AB = 2.8V AC = 3.0V
Temperature Range:	V = -40°C to +125°C
Package:	5-pin SC-70

Examples:

a) TC1016-1.8VLTTR: 80 mA Tiny CMOS LDO with Shutdown.

b) TC1016-2.7VLTTR: 80 mA Tiny CMOS LDO with Shutdown.

c) TC1016-2.8VLTTR: 80 mA Tiny CMOS LDO with Shutdown.

d) TC1016-3.0VLTTR: 80 mA Tiny CMOS LDO with Shutdown.

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