

# LTC1998

## ABSOLUTE MAXIMUM RATINGS

(Note 1)

Total Supply Voltage (BATT or  $V_{\text{LOGIC}}$  to GND).....6V  
Voltage

$V_{\text{TH.A}}, V_{\text{H.A}}$  ..... BATT + 0.3V to GND – 0.3V

BATTLO .....  $V_{\text{LOGIC}}$  + 0.3V to GND – 0.3V

Operating Temperature Range (Note 3).... –40°C to 85°C

Specified Temperature Range (Note 4)

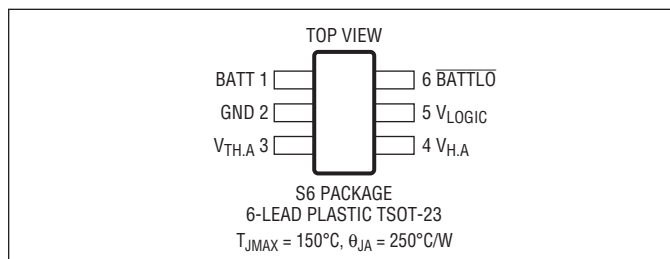
LTC1998C ..... –40°C to 85°C

LTC1998I ..... –40°C to 85°C

Storage Temperature Range..... –65°C to 150°C

Lead Temperature (Soldering, 10 sec) ..... 300°C

## PIN CONFIGURATION



## ORDER INFORMATION

LEAD FREE FINISH	TAPE AND REEL	PART MARKING	PACKAGE DESCRIPTION	SPECIFIED TEMPERATURE RANGE
LTC1998CS6#PBF	LTC1998CS6#TRPBF	LTTY	6-Lead Plastic TSOT-23	–40°C to 85°C
LTC1998IS6#PBF	LTC1998IS6#TRPBF	LTTY	6-Lead Plastic TSOT-23	–40°C to 85°C
LEAD BASED FINISH	TAPE AND REEL	PART MARKING	PACKAGE DESCRIPTION	SPECIFIED TEMPERATURE RANGE
LTC1998CS6	LTC1998CS6#TR	LTTY	6-Lead Plastic TSOT-23	–40°C to 85°C
LTC1998IS6	LTC1998IS6#TR	LTTY	6-Lead Plastic TSOT-23	–40°C to 85°C

Consult LTC Marketing for parts specified with wider operating temperature ranges. \*The temperature grade is identified by a label on the shipping container.

For more information on lead free part marking, go to: <http://www.linear.com/leadfree/>

For more information on tape and reel specifications, go to: <http://www.linear.com/tapeandreel/>

# ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at  $T_A = 25^\circ\text{C}$ .  $V_{\text{GND}} = 0\text{V}$ , unless otherwise noted.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Power Supply						
Supply Voltage Range-BATT		●	1.5		5.5	V
Supply Voltage Range-V <sub>LOGIC</sub>		●	1		V <sub>BATT</sub>	V
Supply Current, V <sub>BATT</sub> = 3V, V <sub>TH,A</sub> = 1.5V	T <sub>A</sub> = 25°C LTC1998CS6 LTC1998IS6	● ● ●		2.5	3.5 4.2 4.5	μA μA μA
Supply Current, V <sub>BATT</sub> = 5.5V, V <sub>TH,A</sub> = 1.5V	T <sub>A</sub> = 25°C LTC1998CS6 LTC1998IS6	● ● ●		3	4.3 5.2 5.5	μA μA μA
Monitor						
Threshold Accuracy	V <sub>BATT,TH</sub> = 2.5V, Pin 3 Shorted to Ground	●		0.6 0.8	0.85 1	% %
	V <sub>BATT,TH</sub> = 3V, Pin 3 Driven by Precision Voltage Source to 1V LTC1998C LTC1998I	● ●		0.5 0.6	0.61 0.71	% %
	V <sub>BATT,TH</sub> = 3V, V <sub>TH,A</sub> = 1V (Note 5) Programmed with 1% Max External Resistors LTC1998C LTC1998I	● ●		0.8 0.9	1 1.1	% %
	V <sub>BATT,TH</sub> = 3.25V, Pin 3 Driven by Precision Voltage Source to 1.5V LTC1998C LTC1998I	● ●		0.6 0.7	0.65 0.85	% %
	V <sub>BATT,TH</sub> = 3.25V, V <sub>TH,A</sub> = 1.5V (Note 5) Programmed with 1% Max External Resistors LTC1998C LTC1998I	● ●		0.9 1	1.1 1.3	% %
Hysteresis Accuracy	V <sub>HYST</sub> ≤ 250mV 250mV ≤ V <sub>HYST</sub> ≤ 750mV	● ●	-5	±5	5	mV mV
Allowable Hysteresis Range (Note 2)		●	10		750	mV
Propagation Delay	C <sub>OUT</sub> = 100pF Overdrive = 10mV Overdrive = 100mV			350 150		μs μs
Threshold Adjust Pin Leakage, I <sub>TH,A</sub>	V <sub>TH,A</sub> ≤ 1.5V	●		0.01	1	nA
Hysteresis Adjust Pin Leakage, I <sub>H,A</sub>	V <sub>H,A</sub> ≤ 1.5V	●		0.01	1	nA
Output						
BATTLO High Voltage	I <sub>OUT</sub> = -1mA, V <sub>LOGIC</sub> ≥ 1.5V	●	V <sub>LOGIC</sub> - 0.3			V
BATTLO Low Voltage	I <sub>OUT</sub> = 1mA, V <sub>BATT</sub> ≥ 2V	●			0.2	V
BATTLO Low Voltage	I <sub>OUT</sub> = 0.25mA, V <sub>BATT</sub> = 1V	●	0.3			V

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** Maximum allowable hysteresis depends on desired trip voltages. See application notes for details.

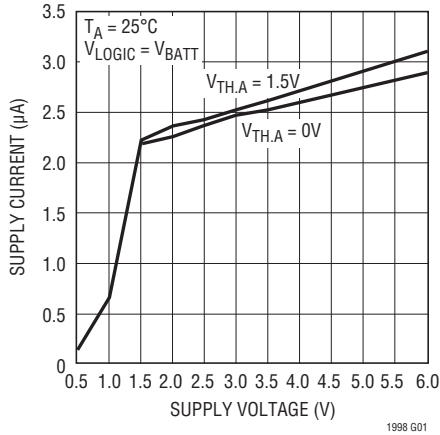
**Note 3:** LTC1998C and LTC1998I are guaranteed functional over the operating temperature range of -40°C to 85°C.

**Note 4:** The LTC1998C is guaranteed to meet specified performance from 0°C to 70°C. The LTC1998C is designed, characterized and expected to meet specified performance from -40°C to 85°C but is not tested or QA sampled at these temperatures. The LTC1998I is guaranteed to meet specified performance from -40°C to 85°C.

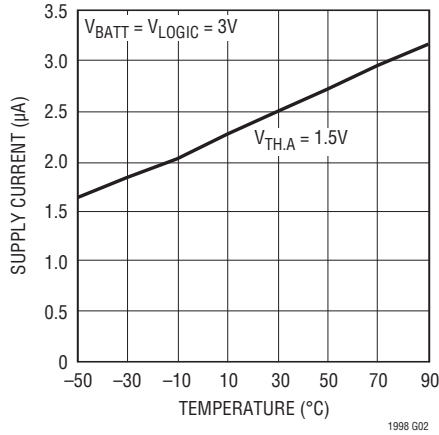
**Note 5:** This parameter is not 100% tested.

# TYPICAL PERFORMANCE CHARACTERISTICS

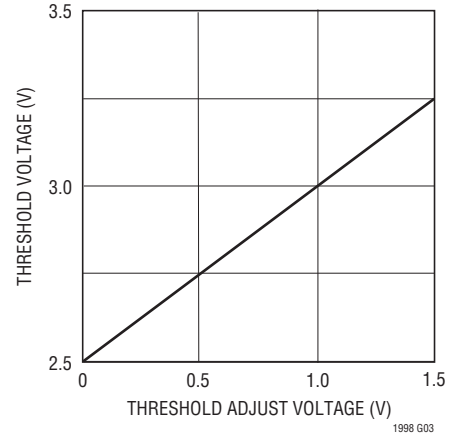
**Quiescent Supply Current vs Supply Voltage**



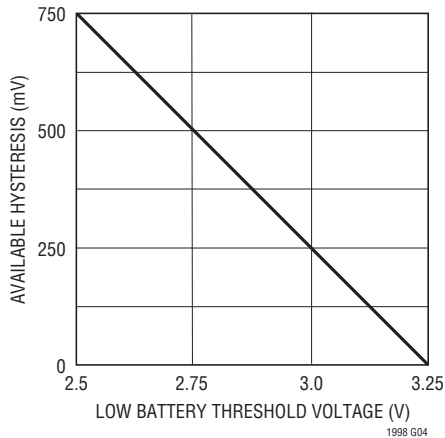
**Quiescent Supply Current vs Temperature**



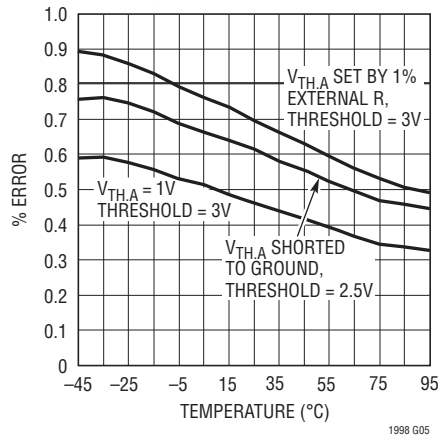
**Threshold Voltage vs Threshold Adjust Voltage**



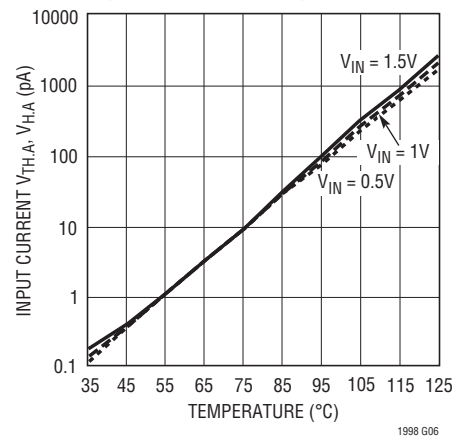
**Available Hysteresis vs Threshold Voltage**



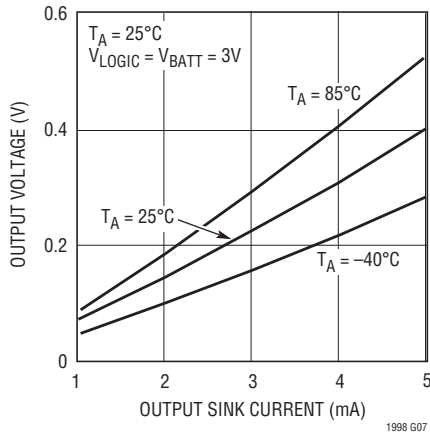
**Threshold Voltage Error vs Temperature**



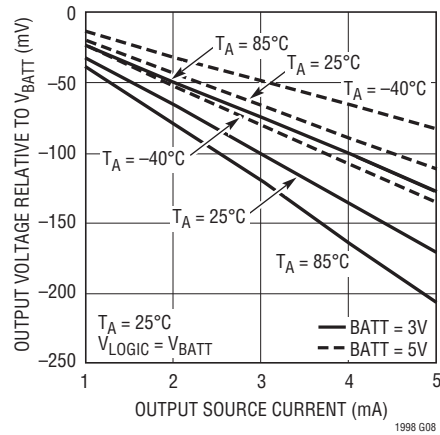
**Input Current vs Temperature**



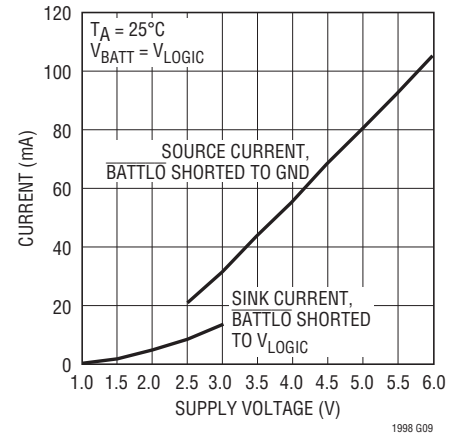
## TYPICAL PERFORMANCE CHARACTERISTICS

Output Low Voltage  
vs Load Current

1998 G07

Output High Voltage  
vs Load Current

1998 G08

Output Short-Circuit Current  
vs Supply Voltage

1998 G09

## PIN FUNCTIONS

**BATT (Pin 1):** Battery Voltage to be monitored. Supply current is also drawn from this pin. Board layout should connect this pin to the battery(+) terminal, through a trace that does not conduct load current.

**GND (Pin 2):** Ground should be connected to the battery (–) terminal through a trace that does not conduct load return current.

**V<sub>TH.A</sub> (Pin 3):** Threshold Adjust Pin. Adjusts the low battery threshold voltage,  $V_{BATT.Th} = 2.5V + (V_{TH.A}/2)$ .  $V_{TH.A}$  can be supplied by a voltage source or a resistor divider.

**V<sub>H.A</sub> (Pin 4):** Hysteresis Adjust. Hysteresis threshold voltage  $V_{TH2} = 2.5V + (V_{H.A}/2)$ .  $V_{H.A}$  can be supplied by a voltage source or resistor divider.  $V_{H.A}$  must always be programmed to a higher potential than  $V_{TH.A}$ . Hysteresis voltage,  $V_{HYST} = V_{TH2} - V_{BATT.Th}$ .

**V<sub>LOGIC</sub> (Pin 5):** Positive Supply Voltage for Output Driver. This voltage can be driven from an external logic supply or tied to BATT.

**BATTLO (Pin 6):** Output of Comparator. Low for  $BATT < V_{BATT.Th}$  (low battery threshold voltage). Output state guaranteed for  $V_{BATT} \geq 1.5V$ .

## QUICK DESIGN GUIDE

### How to Calculate the External Resistor Values

The LTC1998 is a low battery warning indicator and is especially designed for monitoring the voltage of single-cell Lithium-Ion batteries. The LTC1998 compares its supply pin (BATT) to an accurate internal reference; if the battery voltage falls below the programmed low battery threshold voltage of the LTC1998, the battery low pin (BATTLO) will change state, from high to low, to indicate a low battery condition. The low battery threshold voltage is programmed via the voltage threshold adjust pin ( $V_{TH,A}$ ). A hysteresis adjust pin ( $V_{H,A}$ ) will add hysteresis to the programmed value of the low battery threshold voltage.

### Typical Application

Table 1: Design Equations for R1, R2, R3, Figure 1

Choose desired values for:

- $V_{BATT.Th}$ : Low Battery Threshold Voltage
- $V_{HYST}$ : Hysteresis Voltage
- $I_R$ : Max Allowable Resistor Current

Solve:

$$R_{TOTAL} = R1 + R2 + R3 = \frac{4.2V}{I_R}$$

$$R1 = R_{TOTAL} \cdot \left( \frac{5V}{V_{BATT.Th} + V_{HYST}} - 1 \right)$$

$$R2 = R_{TOTAL} \cdot \left( \frac{5V}{V_{BATT.Th}} - 1 \right) - R1$$

$$R3 = R_{TOTAL} - R1 - R2$$

Example 1: A system using a 4.2V (fully charged) Lithium-Ion battery requires a low battery threshold of 2.7V, 100mV hysteresis and can allow up to 4.2μA maximum resistor current.

$$R_{TOTAL} = 1M\Omega, R1 = 786k, R2 = 66k \text{ and } R3 = 148k$$

Choose standard 1% values.

$$R1 = 787k, R2 = 66.5k, R3 = 147k$$

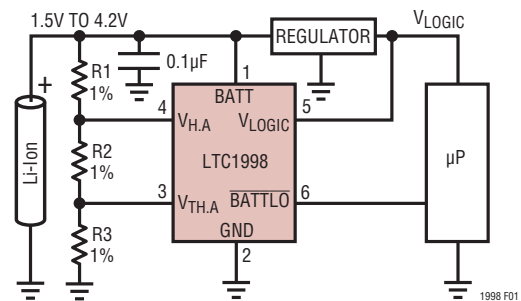


Figure 1. Low Battery Threshold Detector with Hysteresis

## APPLICATIONS INFORMATION

### LOW BATTERY THRESHOLD VOLTAGE AND HYSTERESIS ADJUST

#### Low Battery Threshold Voltage Adjustment, Pin 3

The low battery threshold voltage is the battery voltage which will trip the (BATTLO) pin high to low. It should be adjusted via the threshold adjust pin ( $V_{TH.A}$ ). This is a high input impedance pin that senses an externally applied voltage and programs the low battery threshold voltage ( $V_{BATT.Th}$ ). The  $V_{TH.A}$  pin is designed to accommodate voltages from 0V to 1.5V with respect to ground. This allows the low battery threshold voltage to be set to any voltage between 2.5V and 3.25V, that is:

$$V_{BATT.Th} = 2.5V + \frac{(V_{TH.A})}{2}$$

For instance, if the applied voltage at pin 3,  $V_{TH.A}$ , is 1V the LTC1998 will indicate a low battery condition when the battery voltage pin (BATT) falls below 3V.

The voltage at the threshold adjust pin ( $V_{TH.A}$ ) can be set with any voltage source. This pin allows a continuous time adjustment, that is, the low battery threshold voltage may be changed at any time. The high input impedance of the  $V_{TH.A}$  pin allows the use of a high valued resistive divider (to minimize current drain) from the battery to set the battery low threshold voltage, Figure 2.

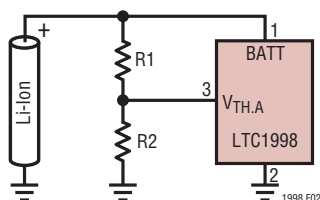


Figure 2. Resistor Divider Sets Threshold

The simple calculations of resistor values R1 and R2 are illustrated below. Set a value for  $R1 + R2$ . This value will affect the max amount of current drawn from the battery when fully charged. For instance if  $R1 + R2 = 1M$  the resistive divider will draw 4.1 $\mu$ A when the battery voltage is 4.1V. Set the desired value of  $V_{BATT.Th}$  (this value should be between 2.5V and 3.25V) that is the value of the battery voltage that will trip the internal circuitry of the LTC1998 and change the state of the battery low pin (BATTLO).

$$\text{Solve for } R1 = (R1 + R2) \left( \frac{5V}{V_{BATT.Th}} - 1 \right)$$

Example: A Lithium-Ion battery is monitored and a battery low signal should be issued when it discharges to 2.85V, that is,  $V_{BATT.Th} = 2.85V$ ; if  $(R1 + R2) = 1M$ , then  $R1 = 754.38k$  and  $R2 = 245.62k$ . Choose the closest 1% value of  $R1 = 750k$  and  $R2 = 243k$ . Calculate the practical value for  $V_{BATT.Th}$  as it will be slightly different from 2.85V, due to the use of standard 1% resistor values.

$$V_{BATT.Th} = 5V \frac{R1 + R2}{R1 + (R1 + R2)} = 2.849V$$

The above low battery threshold of 2.849V is guaranteed to within 1% even though 1% resistors are used to program the  $V_{TH.A}$  voltage applied to Pin 3.

For sake of completeness, the voltage at Pin 3 ( $V_{TH.A}$ ) can be easily calculated by  $V_{TH.A} = V_{BATT.Th} (R2 / (R1 + R2)) = 0.6972V$  (when  $V_{BATTERY} = V_{BATT.Th}$ ).

## APPLICATIONS INFORMATION

### Hysteresis Adjustment, Pin 4.

The LTC1998 has an adjustable hysteresis ranging from 10mV to 0.75V. A large hysteresis is useful in the event that a low battery signal at the LTC1998's  $\overline{\text{BATTLO}}$  pin causes the system to shed some battery load, thus inducing system confusion as the partially loaded battery recovers and changes the status of Pin 6 ( $\overline{\text{BATTLO}}$ ). The 2.5V to 3.25V programming window of low battery threshold voltage includes the hysteresis. If, for instance, the low battery threshold voltage is set to 2.5V, 750mV hysteresis can be added on top of the 2.5V. If the low battery threshold voltage is set to 3.15V, only 100mV hysteresis can be applied.

The programming of the hysteresis threshold adjust pin ( $V_{H.A}$ ) is similar to the programming of the voltage threshold adjust pin ( $V_{TH.A}$ ) already described in the previous paragraph. Pin 4 effectively adjusts the threshold voltage at which the low battery pin ( $\overline{\text{BATTLO}}$ ) changes state from low to high. This threshold ( $V_{TH2}$ ) is defined as:

$$V_{TH2} = 2.5V + \frac{(V_{H.A})}{2}$$

The actual hysteresis voltage is:

$$V_{HYST} = V_{TH2} - V_{BATT.Th}$$

It is imperative that the hysteresis threshold adjust voltage at Pin 4 be set to a higher voltage than the low battery threshold adjust voltage at Pin 3, at all times, to avoid oscillation at the  $\overline{\text{BATTLO}}$  output pin. The hysteresis threshold adjust pin may be set with a voltage source or with a resistor divider, just as with the low battery threshold adjust pin.

### Combined Control of Threshold and Hysteresis

If a resistor divider is desired, then both threshold adjust dividers can be combined in order to save current. This simple technique also guarantees that the hysteresis threshold adjust voltage at Pin 4 is higher than the voltage at the  $V_{TH.A}$  pin, Figure 3.

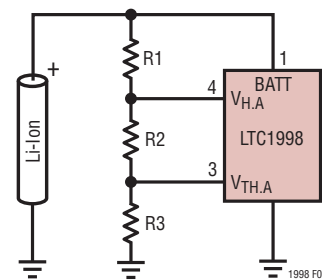


Figure 3. Combined Resistor Divider



## APPLICATIONS INFORMATION

The calculation of the resistor values R1, R2 and R3 is quite straightforward and similar to the procedure outlined in the previous paragraph.

Choose a value for the sum of R1 + R2 + R3 as well as the values for low battery threshold and hysteresis.

Solve for resistor R1:

$$R1 = (R1 + R2 + R3) \left( \frac{5V}{V_{TH2}} - 1 \right)$$

Solve for the sum of

$$(R1 + R2) = (R1 + R2 + R3) \left( \frac{5V}{V_{BATT.Th}} - 1 \right)$$

then solve for R2 and R3.

Example: A system needs to detect a low battery voltage of 3V ( $V_{BATT.Th} = 3V$ ) with 250mV hysteresis ( $V_{TH2} = 3.25V$ ). Set the value of the resistor divider ( $R1 + R2 + R3$ ) = 1M.

R1 = 539k, R1 + R2 = 667k, R2 = 128k, R3 = 333k. Choose the closest 1% values, that is 536k, 332k, 127k. Figure 4 graphically shows the function of the LTC1998 as described above.

## VERSATILE OUTPUT DRIVER

### $V_{LOGIC}$ , $\overline{BATTLO}$ (Pins 5,6)

The LTC1998 uses a CMOS push-pull output stage to drive the low battery output signal. This output pin ( $\overline{BATTLO}$ ) has a separate supply pin, ( $V_{LOGIC}$ ) that can be used to provide an output voltage rail matching the  $V_{DD}$  logic of microprocessors. The  $V_{LOGIC}$  pin may be tied to a voltage lower than the voltage at the BATT pin. The  $V_{LOGIC}$  pin may also be tied to a voltage higher than  $V_{BATT}$  via a series resistor greater than 10k. The output will then act as an open-drain device.

In a given application, if it is possible for  $\overline{BATTLO}$  to be shorted to GND or a supply, a series resistor should be added to limit the short-circuit current to 5mA.

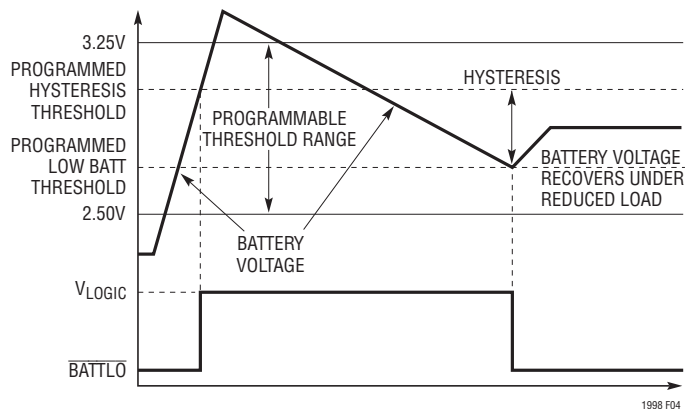
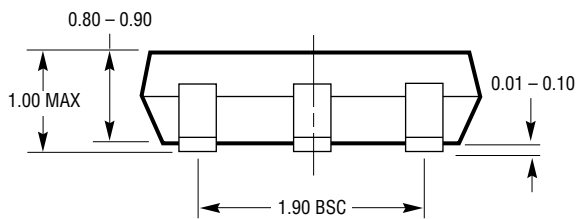
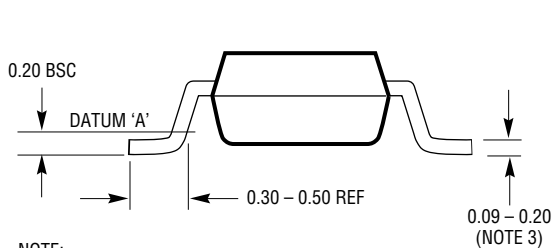
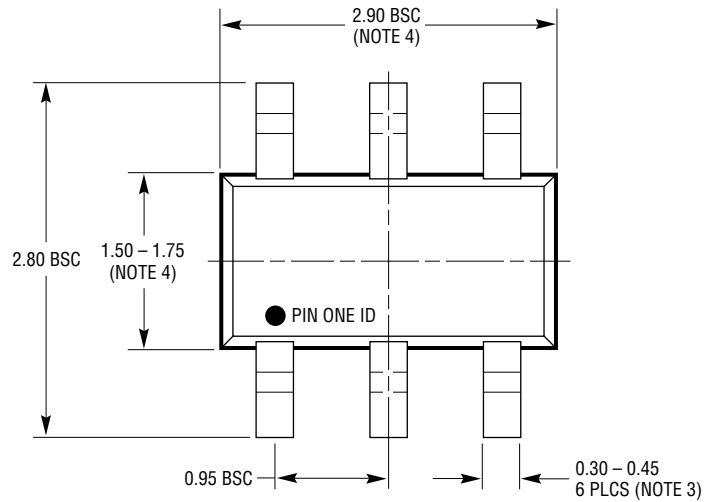
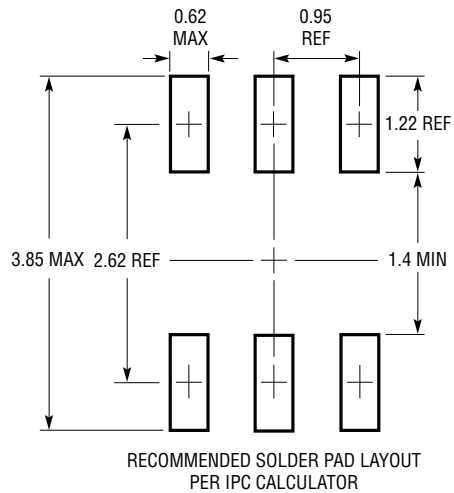


Figure 4. LTC1998 Function Plot

## PACKAGE DESCRIPTION

**S6 Package**  
**6-Lead Plastic TSOT-23**  
 (Reference LTC DWG # 05-08-1636)



S6 TSOT-23 0302 REV B

**NOTE:**

1. DIMENSIONS ARE IN MILLIMETERS
2. DRAWING NOT TO SCALE
3. DIMENSIONS ARE INCLUSIVE OF PLATING
4. DIMENSIONS ARE EXCLUSIVE OF MOLD FLASH AND METAL BURR
5. MOLD FLASH SHALL NOT EXCEED 0.254mm
6. JEDEC PACKAGE REFERENCE IS MO-193

## TYPICAL APPLICATIONS

[illegible]

1998 TAD4

The diagram shows two LTC1998 comparators configured as a window comparator. The top comparator's non-inverting input (pin 3,  $V_{TH.A}$ ) is connected to  $V_{IN}$  through a 383k resistor ( $R_3$ ). Its inverting input (pin 4,  $V_{H.A}$ ) is connected to  $V_{IN}$  through a 619k resistor ( $R_1$ ) and to ground through a 6.04k resistor ( $R_2$ ). The output (pin 5,  $V_{LOGIC}$ ) is connected to  $V_{IN}$ . The bottom comparator's non-inverting input (pin 3,  $V_{TH.A}$ ) is connected to  $V_{IN}$  through a 76.8k resistor ( $R_6$ ). Its inverting input (pin 4,  $V_{H.A}$ ) is connected to  $V_{IN}$  through a 909k resistor ( $R_4$ ) and to ground through a 6.98k resistor ( $R_5$ ). The output (pin 5,  $V_{LOGIC}$ ) is connected to  $V_{IN}$ . The output of the top comparator (pin 5) is connected to the gate of a 2N7002 transistor, which is also connected to  $V_{IN}$  through a 1M resistor ( $R_7$ ). The transistor's source is connected to ground, and its drain is connected to  $V_{OUT}$ . The output of the bottom comparator (pin 5) is connected to  $V_{OUT}$ . The output of the top comparator is high when  $V_{IN}$  is between 2.6V and 3.1V. The output of the bottom comparator is high when  $V_{IN}$  is between 2.6V and 3.1V. The output of the transistor is high when  $V_{IN}$  is between 2.6V and 3.1V.

WINDOW LOW THRESHOLD = 2.6V  
 HYSTERESIS = 10mV  
 WINDOW HIGH THRESHOLD = 3.1V  
 HYSTERESIS = 10mV

1998 TA05

LOW THRESHOLD = 2.7V  
HYSTERESIS = 100mV

998 TA05

PART NUMBER	DESCRIPTION	COMMENTS
LTC1440/LTC1540	Micropower Comparator with 1% Reference	1.182V $\pm$ 1% Reference, $\pm$ 10mV (Max) Input Offset
LTC1441/LTC1442	Micropower Dual Comparator with 1% Reference	1.182V $\pm$ 1% Reference (LTC1442)
LTC1443/LTC1444/LTC1445	Micropower Quad Comparator with 1% Reference	LTC1443 has 1.182V Reference, LTC1444/LTC1445 have 1.221V Reference and Adjustable Hysteresis