TS9004

Low-Power Single/Dual-Supply Quad Comparator with Reference

FEATURES

- Ultra-Low Quiescent Current:
  5.1µA (max), All comparators plus Reference
- Single or Dual Power Supplies:
  Single: +2.5V to +11V
  Dual: ±1.25V to ±5.5V
- Input Voltage Range Includes Negative Supply
- 7µs Propagation Delay
- Push-pull TTL/CMOS-Compatible Outputs
- Separate Output GND Pin
- Crowbar-Current-Free Switching
- Continuous Source Current Capability: 40mA
- Internal 1.182V ±1% Reference
- 16-pin Narrow SOIC Package

APPLICATIONS

Threshold Detectors
Window Comparator
Level Translators
Oscillator Circuits
Battery-Powered Systems

DESCRIPTION

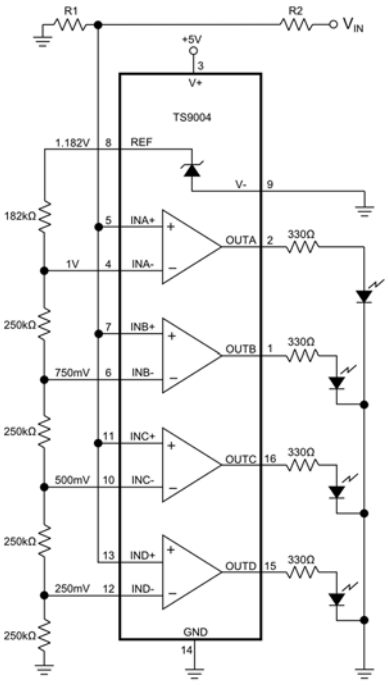
The TS9004 low-voltage, micropower quad analog comparator is form-factor identical to the MAX934 analog comparator with improved electrical specifications. Ideal for 3V or 5V single-supply applications, the TS9004 draws 22% lower supply current with a 50%-better initial accuracy reference voltage. The TS9004 joins the TS9001-1/2 and TS9002 analog comparators in the "NanoWatt Analog™" high performance analog integrated circuits portfolio. This quad comparator can operate from single +2.5V to +11V supplies or from ±1.25V to ±5.5V dual supplies.

The TS9004 exhibits an input voltage range from the negative supply rail to within 1.3V of the positive supply. In addition, its push-pull output stage is TTL/CMOS compatible and capable of sinking and sourcing current. It also incorporates an internal 1.182V ±1% voltage reference. A GND connection available at the TS9004's output stage enables TTL compatibility and bipolar-to-single ended conversion.

The TS9004 is fully specified over the -40ºC to +85ºC temperature range and is available in a 16-pin narrow SOIC package.

TYPICAL APPLICATION CIRCUIT

Using a TS9004 in a 5V Bar-Graph Level Gauge Application



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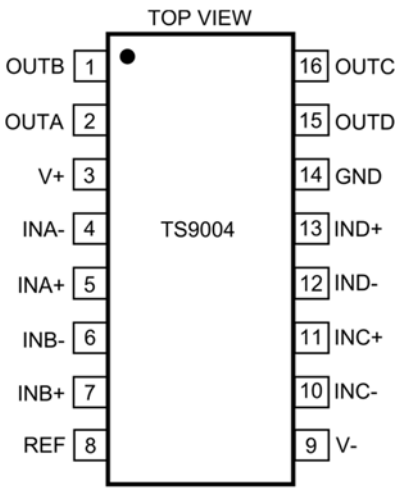
ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V+ to V-, V+ to GND, GND to V-).....-0.3V, +12V
Voltage Inputs
  (IN+, IN-).....(V+ + 0.3V) to (V- - 0.3V)
Output Voltage
  REF..... (V+ + 0.3V) to (V- - 0.3V)
  OUT .....(V+ + 0.3V) to (GND - 0.3V)
Input Current (IN+, IN-).....20mA
Output Current
  REF……20mA
  OUT……..…40mA
Output Short-Circuit Duration (V+ ≤ 5.5V) .....Continuous

Continuous Power Dissipation (T_A = +70°C)
  16-Pin SOIC (derate 8.7mW/°C above +70°C) 696mW
Operating Temperature Ranges.....-40°C to +85°C
Storage Temperature Range .....-65°C to +150°C
Lead Temperature (soldering, 10s) .....+300°C

Electrical and thermal stresses beyond 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 condition beyond those indicated in the operational sections of the specifications is not implied. Exposure to any absolute maximum rating conditions for extended periods may affect device reliability and lifetime.

PACKAGE/ORDERING INFORMATION



ORDER NUMBER	PART MARKING	CARRIER	QUANTITY
TS9004ISN16	TS9004I	Tube	48
TS9004ISN16T		Tape & Reel	2500

Lead-free Program: Silicon Labs supplies only lead-free packaging.

Consult Silicon Labs for products specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS – 5V OPERATION

V+ = 5V, V- = GND = 0V; T_A = -40ºC to +85ºC, unless otherwise noted. Typical values are at T_A = +25ºC. See Note 1.

PARAMETER	CONDITIONS			MIN	TYP	MAX	UNITS
POWER REQUIREMENTS							
Supply Voltage Range	See Note 2			2.5		11	V
Supply Current	IN+ = IN- + 100mV		T_A = +25°C		4.1	5.1	µA
			-40°C to +85°C			8	
COMPARATOR							
Input Offset Voltage	V_{CM} = 2.5V		T_A = +25°C			±4.5	mV
			-40°C to +85°C			±10	
Input Leakage Current (IN-, IN+)	IN+ = IN- = 2.5V		T_A = +25°C		±0.01	±2	nA
			-40°C to +85°C		±0.01	±5	
Input Common-Mode Voltage Range				V-		V+ – 1.3V	V
Common-Mode Rejection Ratio	V- to (V+ – 1.3V)				0.1	1	mV/V
Power-Supply Rejection Ratio	V+ = 2.5V to 11V				0.1	1	mV/V
Output Voltage Noise	100Hz to 100kHz				20		μV_{RMS}
Response Time (High-to-Low Transition)	T_A = +25°C, 100pF Load		Overdrive = 10 mV		17		µs
			Overdrive = 100 mV		7		
Response Time (Low-to-High Transition)	T_A = +25°C, 100pF Load		Overdrive = 10 mV		17		µs
			Overdrive = 100 mV		7		
Output High Voltage		-40°C to +85°C; I_{OUT} = 17mA		V+ – 0.4			V
Output Low Voltage		-40°C to +85°C; I_{OUT} = 1.8mA				GND + 0.4	V
	Dual Supply	-40°C to +85°C; I_{OUT} = 1.8mA				V- + 0.4	V
REFERENCE							
Reference Voltage			T_A = +25°C	1.170	1.182	1.194	V
			-40°C to +85°C	1.158		1.206	
Reference Line Regulation	2.5V ≤ (V+ - V-) ≤ 5V		T_A = +25°C		0.25		mV/V
Source Current	ΔVREF = 1%		T_A = +25°C	20	25		µA
			-40°C to +85°C	6			
Sink Current	ΔVREF = 1%		T_A = +25°C	10	15		µA
			-40°C to +85°C	4			
Output Voltage Noise	100Hz to 100kHz				100		μV_{RMS}

ELECTRICAL CHARACTERISTICS – 3V OPERATION

V+ = 3V, V- = GND = 0V; T_A = -40ºC to +85ºC, unless otherwise noted. Typical values are at T_A = +25ºC. See Note 1.

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
POWER REQUIREMENTS						
Supply Current	IN+ = IN- + 100mV	T_A = +25°C		3.8	4.8	µA
		-40°C to +85°C			6.5	
COMPARATOR						
Input Offset Voltage	V_{CM} = 1.5V	T_A = +25°C			±4.5	mV
		-40°C to +85°C			±10	
Input Leakage Current (IN-, IN+)	IN+ = IN- = 1.5V	T_A = +25°C		±0.01	±1	nA
		-40°C to +85°C		±0.01	±2.5	
Input Common-Mode Voltage Range			V-		V+ – 1.3V	V
Common-Mode Rejection Ratio	V- to (V+ – 1.3V)			0.2	1	mV/V
Power-Supply Rejection Ratio	V+ = 2.5V to 11V			0.1	1	mV/V
Output Voltage Noise	100Hz to 100kHz			20		μV_{RMS}
Response Time (High-to-Low Transition)	T_A = +25°C, 100pF Load	Overdrive = 10 mV		17		µs
		Overdrive = 100 mV		7		
Response Time (Low-to-High Transition)	T_A = +25°C, 100pF Load	Overdrive = 10 mV		17		µs
		Overdrive = 100 mV		7		
Output High Voltage	-40°C to +85°C; I_{OUT} = 10mA		V+ – 0.4			V
Output Low Voltage	-40°C to +85°C; I_{OUT} = 0.8mA				GND + 0.4	V
	Dual Supply	-40°C to +85°C; I_{OUT} = 0.8mA			V- + 0.4	V
REFERENCE						
Reference Voltage		T_A = +25°C	1.170	1.182	1.194	V
		-40°C to +85°C	1.158		1.206	
Reference Line Regulation	2.5V ≤ (V+ - V-) ≤ 3V	T_A = +25°C		0.25		mV/V
Source Current	ΔVREF = 1%	T_A = +25°C	20	25		µA
		-40°C to +85°C	6			
Sink Current	ΔVREF = 1%	T_A = +25°C	10	15		µA
		-40°C to +85°C	4			
Output Voltage Noise	100Hz to 100kHz			100		μV_{RMS}

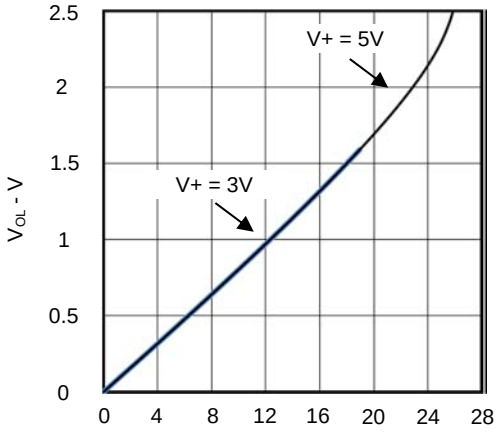
Note 1: All specifications are 100% tested at T_A = +25°C. Specification limits over temperature (T_A = T_{MIN} to T_{MAX}) are guaranteed by device characterization, not production tested.

Note 2: The TS9004 comparator operates below 2.5V. Refer to the “Low-Voltage Operation: V+ = 1.5V” section.

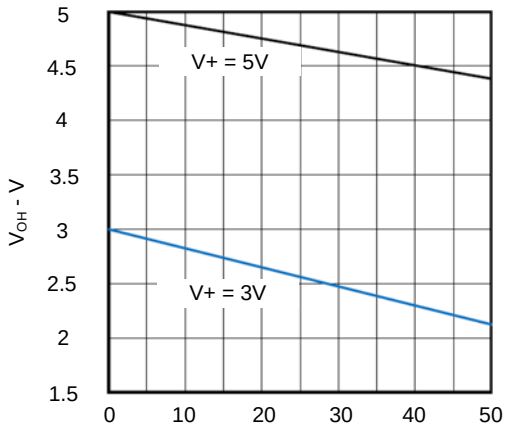
TYPICAL PERFORMANCE CHARACTERISTICS

V_+ = 5V; V_- = GND; T_A = +25°C, unless otherwise noted.

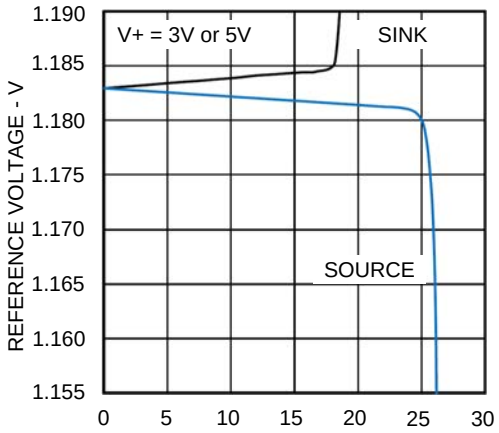
Output Voltage Low vs Load Current



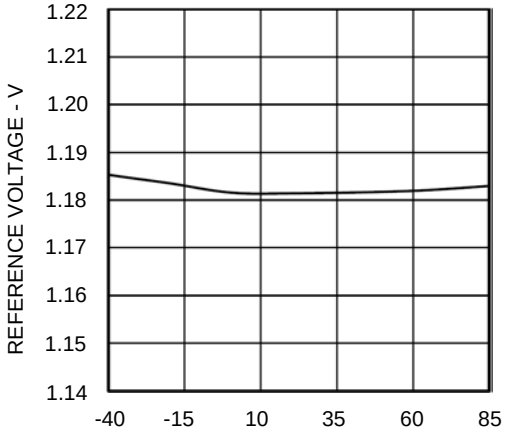
Output Voltage High vs Load Current



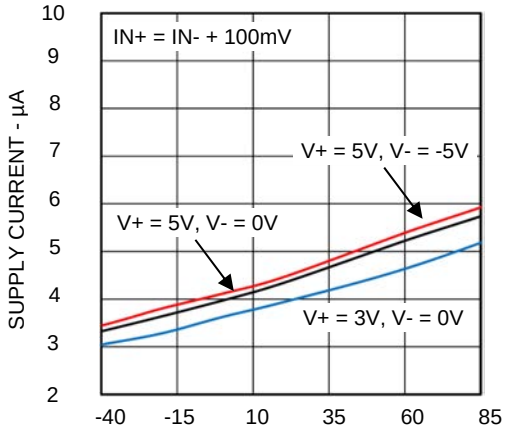
Reference Output Voltage vs Output Load Current



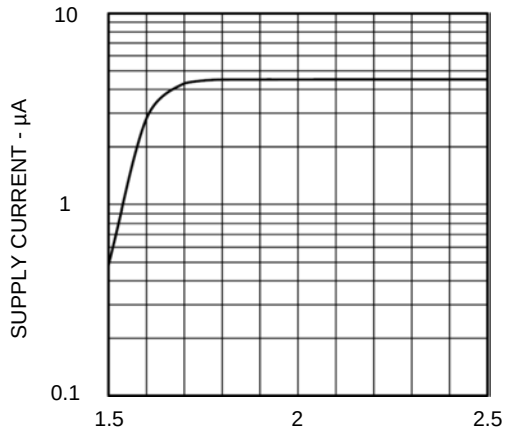
Reference Voltage vs Temperature



Supply Current vs Temperature



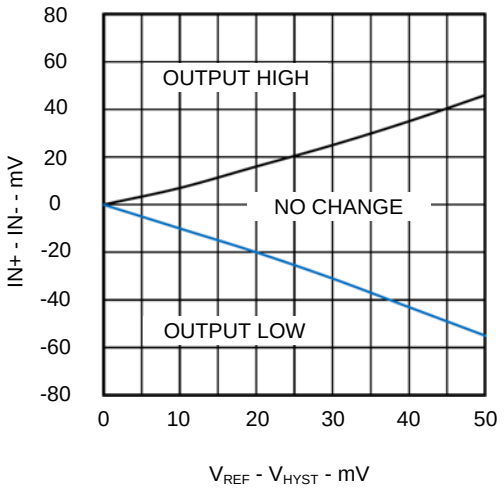
Supply Current vs Low Supply Voltages



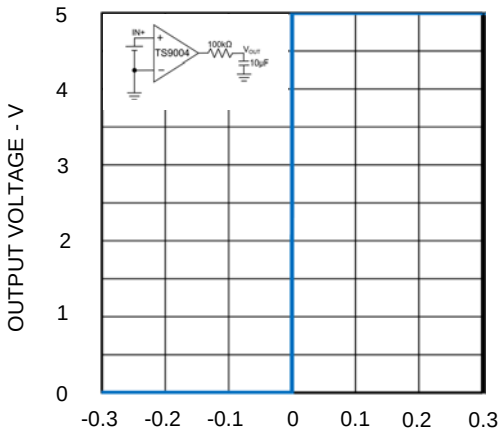
TYPICAL PERFORMANCE CHARACTERISTICS

V_+ = 5V; V_- = GND; T_A = +25°C, unless otherwise noted.

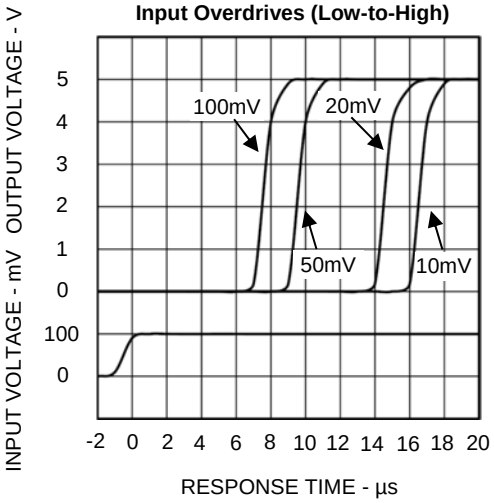
Hysteresis Control



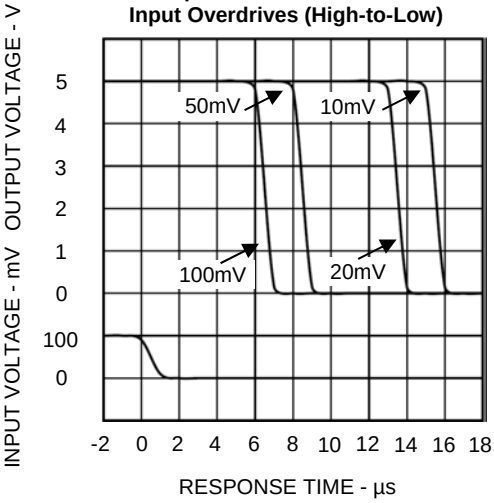
Transfer Function



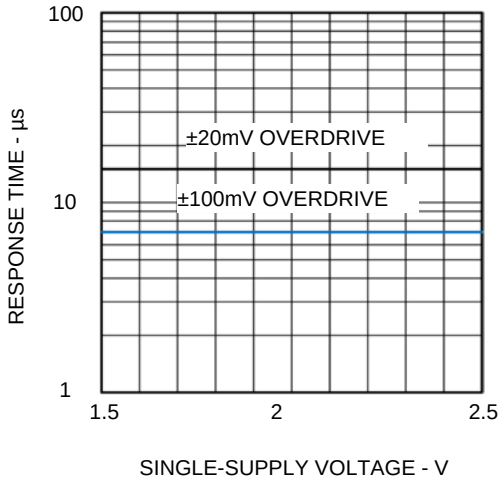
Response Time For Various Input Overdrives (Low-to-High)



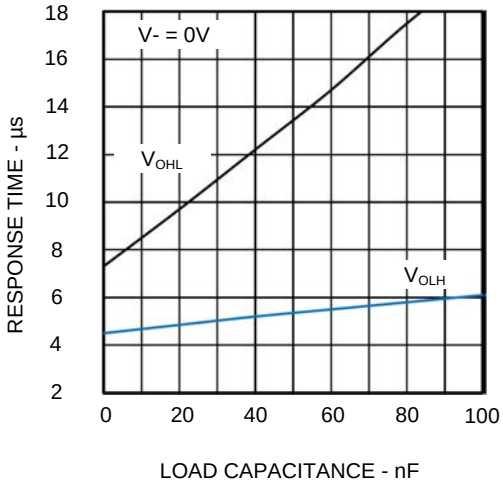
Response Time For Various Input Overdrives (High-to-Low)



Response Time at Low Supply Voltages (Low-to-High)



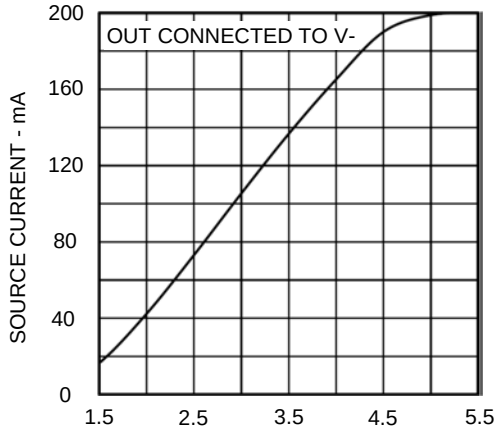
Response Time vs Load Capacitance



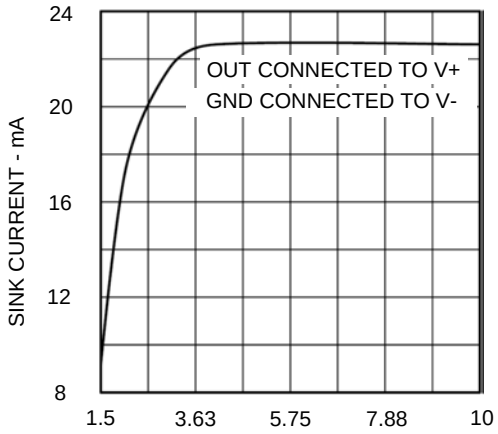
TYPICAL PERFORMANCE CHARACTERISTICS

V_+ = 5V; V_- = GND; T_A = +25°C, unless otherwise noted.

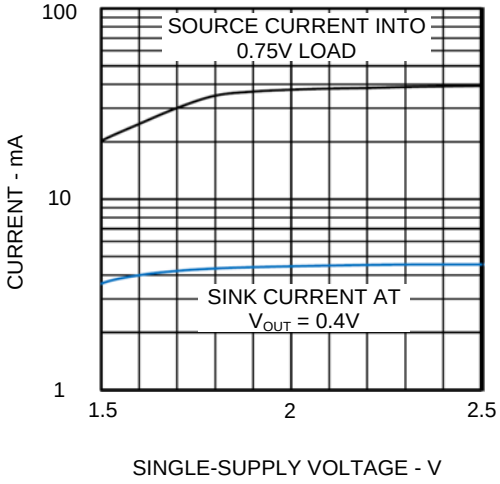
Short-Circuit Source Current vs Supply Voltage



Short-Circuit Sink Current vs Supply Voltage



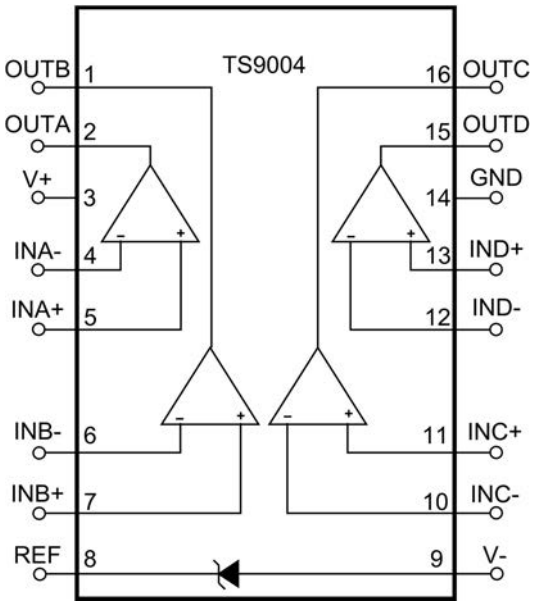
Source and Sink Current at Low Supply Voltages



PIN FUNCTIONS

TS9004 SO-16	NAME	FUNCTION
1	OUTB	Comparator B Output. Sinks and sources current. Swings from V+ to GND.
2	OUTA	Comparator A Output. Sinks and sources current. Swings from V+ to GND.
3	V+	Positive Supply Voltage
4	INA-	Comparator A Inverting Input
5	INA+	Comparator A Noninverting Input
6	INB-	Comparator B Inverting Input
7	INB+	Comparator B Noninverting Input
8	REF	1.182V Reference Output with respect to V-.
9	V-	Negative Supply Voltage. Connect to ground for single-supply operation.
10	INC-	Comparator C Inverting Input
11	INC+	Comparator C Noninverting Input
12	IND-	Comparator D Inverting Input
13	IND+	Comparator D Noninverting Input
14	GND	Ground. Connect to V- for single-supply operation.
15	OUTD	Comparator D Output. Sinks and sources current. Swings from V+ to GND.
16	OUTC	Comparator C Output. Sinks and sources current. Swings from V+ to GND.

BLOCK DIAGRAM



THEORY OF OPERATION

The TS9004 quad, low-voltage, micropower analog comparator provides excellent flexibility and performance while sourcing continuously up to 40mA of current. The TS9004 draws 8µA (max) for all 4 comparators, including the reference. It exhibits an input offset voltage of ±4.5mV, and has an on-board +1.182V ±0.75% voltage reference. To minimize glitches that can occur with parasitic feedback or a less than optimal board layout, the design of the TS9004 output stage is optimized to eliminate crowbar glitches as the output switches.

Power-Supply and Input Signal Ranges

The TS9004 can operate from a single supply voltage range of +2.5V to +11V, provides a wide common mode input voltage range of V- to V+ - 1.3V, and accept input signals ranging from V- to V+ - 1V. The inputs can accept an input as much as 300mV above and below the power supply rails without damage to the part. While the TS9004 is able to operate from a single supply voltage range, a GND pin is available that allows for a dual supply operation with a range of ±1.25V to ±5.5V. If a single supply operation is desired, the GND pin needs to be tied to V-. In a dual supply mode, the TS9004 is compatible with TTL/CMOS with a ±5V voltage.

Low-Voltage Operation: V+ = 1.5V

The TS9004 can operate down to a supply voltage of 2V; however, as the supply voltage reduces, the TS9004 supply current drops and the performance is degraded. When the supply voltage drops to 2.2V, the reference voltage will no longer function; however, the comparators will function down to a 1V supply voltage. Furthermore, the input voltage range is extended to just below 1V the positive supply rail. For applications with a sub-2.5V power supply, it is recommended to evaluate the circuit over the entire power supply range and temperature.

Comparator Output

The TS9004 has a GND pin that allows the output to swing from V+ to GND while the V- pin can be set to a voltage below GND as long as the voltage difference between V+ and V- is within 11V. Having a different voltage on V- will not affect the output swing. For TTL applications, V+ can be set to +5V±10% and V- can be set anywhere between 0V and -5V±10%. Furthermore, the output design of the TS9004 can source and sink more than 40mA and 5mA, respectively, while simultaneously maintaining a quiescent current in the microampere range. If the power dissipation of the package is maintained within the max limit, the output can source pulses of 100mA of current with V+ set to +5V. In an effort to minimize external components needed to address power supply feedback, the TS9004 output does not produce crowbar switching current as the output switches. With a 10mV input overdrive, the propagation delay of the TS9004 is 17µs.

Voltage Reference

The TS9004 has an on-board 1.182V reference voltage with an accuracy of ±0.75%. The REF pin is able to source and sink 20µA and 10µA of current, respectively. The REF pin is referenced to V- and it should not be bypassed.

Noise Considerations

Noise can play a role in the overall performance of the TS9004. Despite having a large gain, if the input voltage is near or equal to the input offset voltage, the output will randomly switch HIGH and LOW. As a result, the TS9004 produces a peak-to-peak noise of about 0.3mV$_{PP}$ while the reference voltage produces a peak-to-peak noise of about 1mV$_{PP}$. Furthermore, it is important to design a layout that minimizes capacitive coupling from a given output to the reference pin as crosstalk can add noise and as a result, degrade performance.

APPLICATIONS INFORMATION

Hysteresis

As a result of circuit noise or unintended parasitic feedback, many analog comparators often break into oscillation within their linear region of operation especially when the applied differential input voltage approaches 0V (zero volt). Externally-introduced hysteresis is a well-established technique to stabilizing analog comparator behavior and requires external components. As shown in Figure 1, adding comparator hysteresis creates two trip points: V_{THR} (for the rising input voltage) and V_{THF} (for the falling input voltage). The hysteresis band (V_{HB}) is defined as the voltage difference between the two trip points. When a comparator's input voltages are equal, hysteresis effectively forces one comparator input to move quickly past the other input, moving the input

out of the region where oscillation occurs. Figure 1 illustrates the case in which an IN- input is a fixed voltage and an IN+ is varied. If the input signals

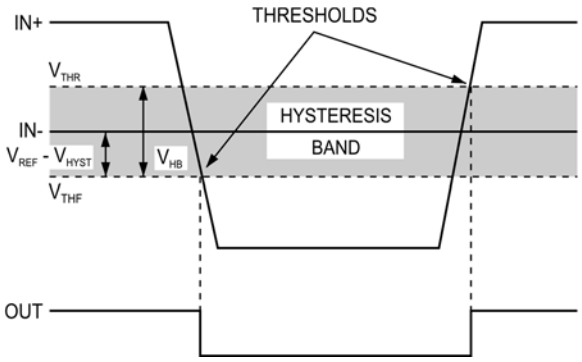


Figure 1. Threshold Hysteresis Band

were reversed, the figure would be the same with an inverted output. To add hysteresis to the TS9004, the circuit in Figure 2 is implemented and uses positive feedback along with two external resistors to set the desired hysteresis. The circuit consumes more current and it slows down the hysteresis effect

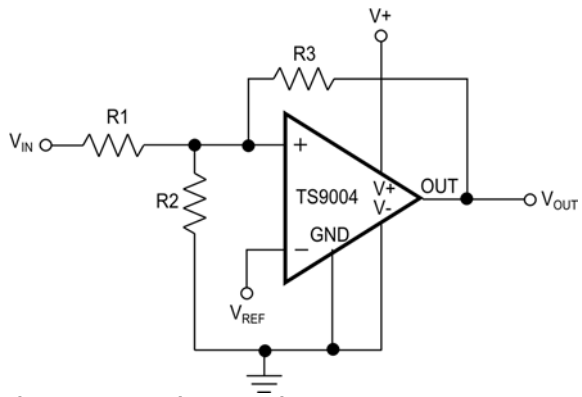


Figure 2. External Hysteresis

due to the high impedance on the feedback. The following procedure explains the steps to design the circuit for a desired hysteresis:

1. Choosing R3. As the leakage current at the IN+ pin is less than 1nA, the current through R3 should be at least 100nA to minimize offset voltage errors caused by the input leakage current. For R3 = 11.8MΩ, the current through R3 is V_{REF}/R3 at the trip point. In this case, a 10MΩ resistor is a good standard value for R3.

2. Next, the desired hysteresis band (V_{HB}) is set. In this example, V_{HB} is set to 50mV.

3. Calculating R1.

$$R1 = R3 \times \frac{V_{HB}}{V+}$$

$$= 10M\Omega \times \frac{50mV}{5V}$$

$$= 100k\Omega$$

In this example, a 100kΩ, 1% standard value resistor is selected for R1.

4. Choose the trip point for V_{IN} rising (V_{THR}), which is the threshold voltage at which the comparator switches its output from low to high as V_{IN} rises above the trip point. In this example, choose V_{THR} = 3V.

5. Calculating R2.

$$R2 = \frac{1}{\left[\left(\frac{V_{THR}}{V_{REF} \times R1}\right) - \frac{1}{R1} - \frac{1}{R3}\right]}$$

$$= \frac{1}{\left[\left(\frac{3}{1.182V \times 100k\Omega}\right) - \frac{1}{100k\Omega} - \frac{1}{10M\Omega}\right]}$$

$$= 65.44k\Omega$$

In this example, a 64.9kΩ, 1% standard value resistor is selected for R2.

6. The last step is to verify the trip voltages and hysteresis band using the standard resistance values:

$$V_{THR} = V_{REF} \times R1 \times \left(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}\right)$$

$$V_{THF} = V_{THR} - \frac{(R1 \times V+)}{R3}$$

Board Layout and Bypassing

While power-supply bypass capacitors are not typically required, it is good engineering practice to use 0.1µF bypass capacitors close to the device's power supply pins when the power supply impedance is high, the power supply leads are long, or there is excessive noise on the power supply traces. To reduce stray capacitance, it is also good engineering practice to make signal trace lengths as short as possible. Also recommended are a ground plane and surface mount resistors and capacitors.

Bar-Graph Level Gauge

A simple four-stage level detector is shown in Figure 3 using the TS9004. Due to its high output source capability, the TS9004 is perfect for driving LEDs. When all of the LEDs are on, the threshold voltage is given as V_{IN} = (R1 + R2)/R1 volts. All other threshold voltages are scaled down accordingly by ¾, ½, and ¼ the threshold voltage. The current through the LEDs is limited by the output resistors.

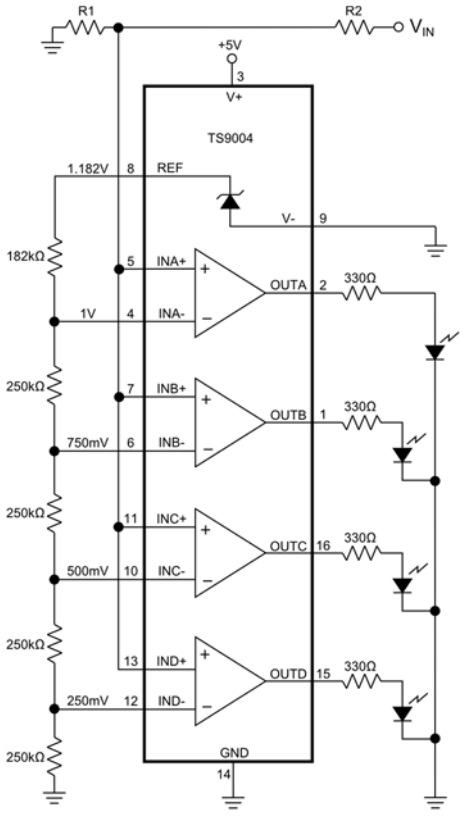


Figure 3. Bar-Graph Level Gauge

Level Shifter

Figure 4 provides a simple way to shift from bipolar ±5V inputs to TTL signals by using the TS9004. To protect the comparator inputs, 10kΩ resistors are placed in series and do not have an effect on the performance of the circuit.

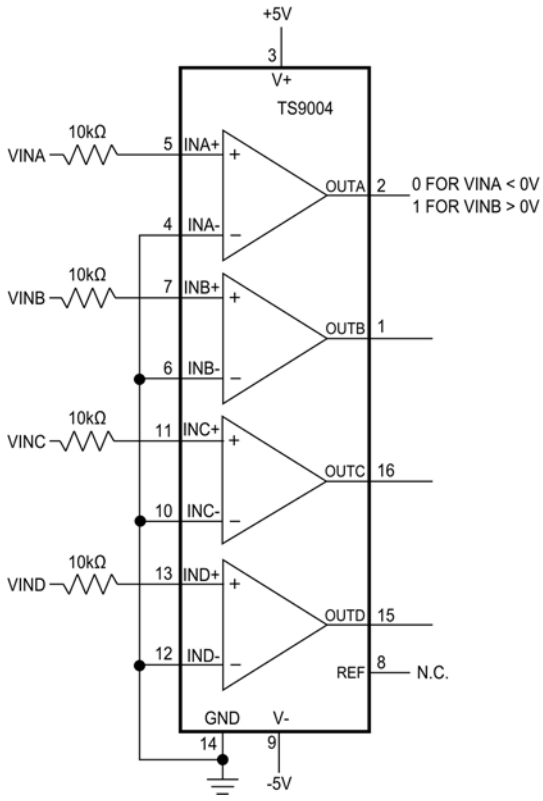
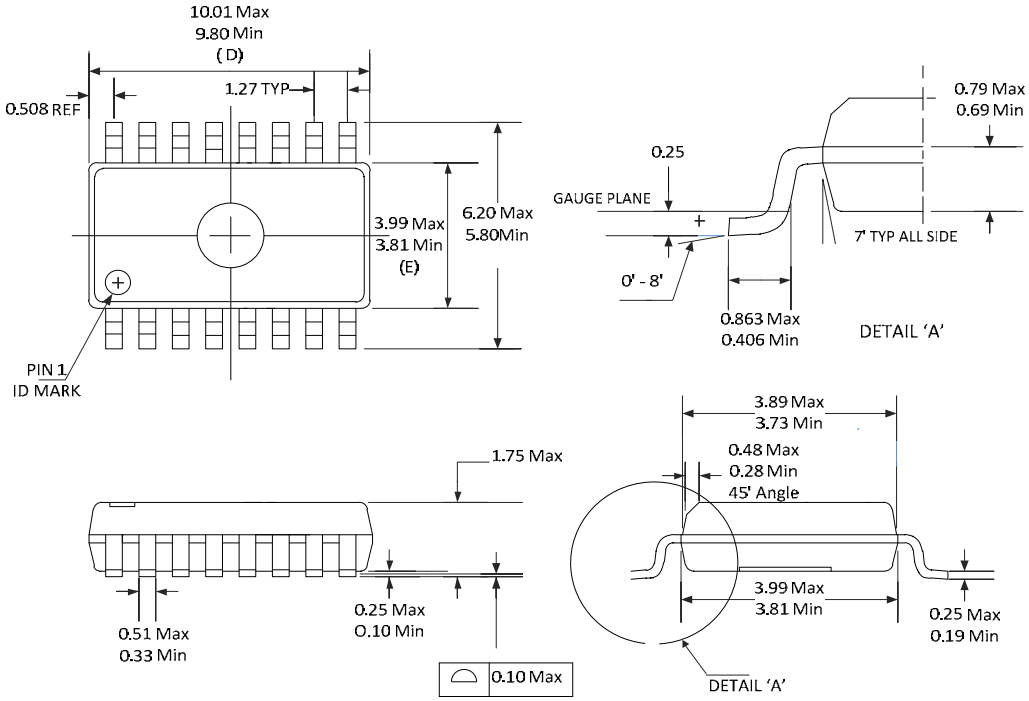


Figure 4. Level Shifter: ±5V Input into CMOS output

PACKAGE OUTLINE DRAWING

16-Pin SOIC Package Outline Drawing

(N.B., Drawings are not to scale)



NOTE:

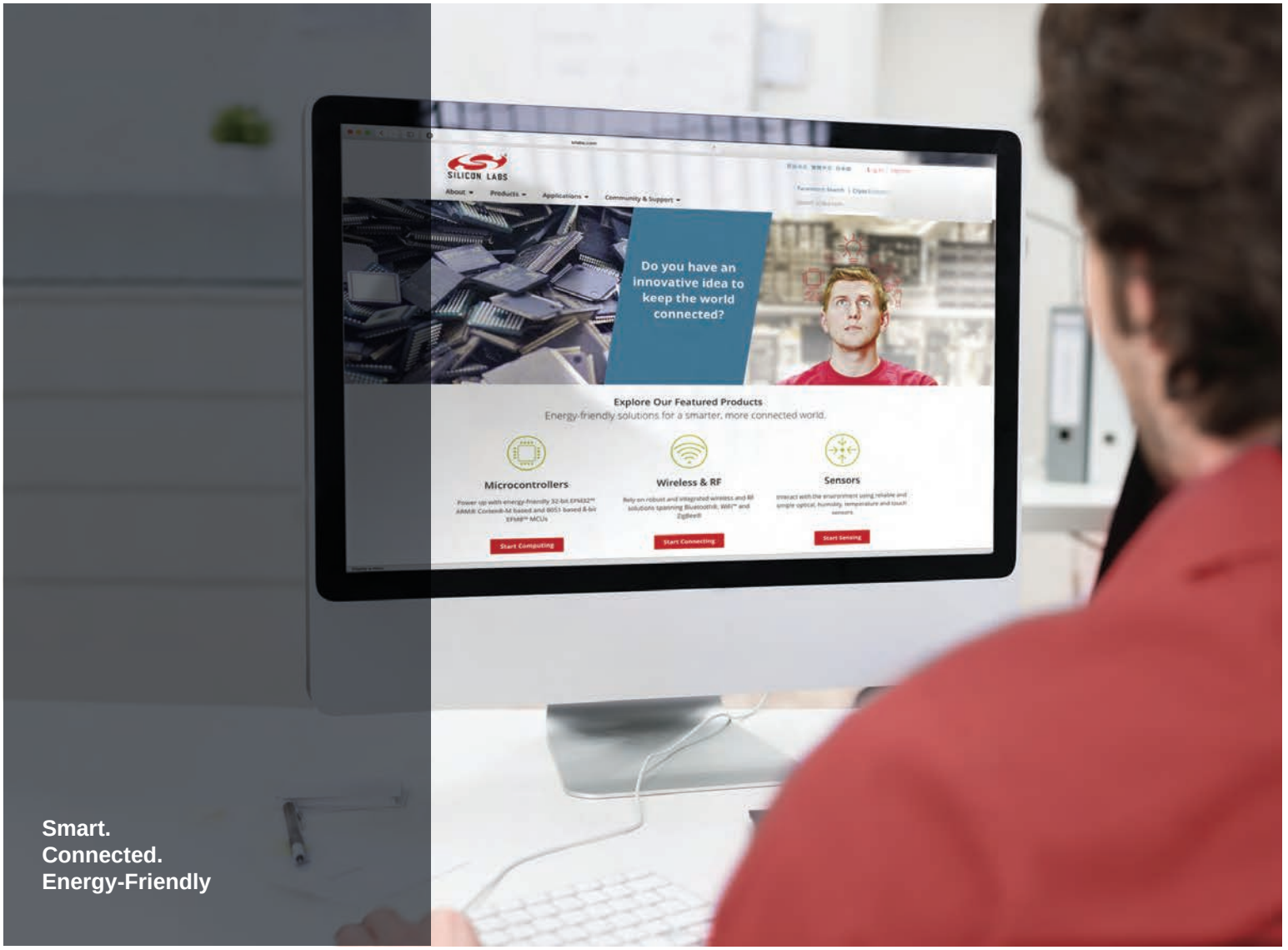
1. "D" DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
   MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.15 mm PER SIDE.
2. "E" DOES NOT INCLUDE INTER-LEAD FLASH OR PROTRUSIONS.
   INTER-LEAD FLASH AND PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.25 mm PER SIDE.
3. CONTROLLING DIMENSIONS IN MILIMETERS AND ANGLES IN DEGREES.
4. THIS PART IS COMPLIANT WITH JEDEC SPECIFICATION MS-012 AB
5. LEAD SPAN/STAND OFF HEIGHT/COPLANARITY ARE CONSIDERED AS SPECIAL CHARACTERISTIC.

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