

## A 0.8V/1.5µA Nanopower Op Amp, Comparator, and Reference

### FEATURES

- ◆ NanoWatt Analog™ Op Amp, Comparator, and 0.58V Reference in Single 4 mm<sup>2</sup> Package
- ◆ Ultra Low Total Supply Current: 1.6µA (max)
- ◆ Supply Voltage Range: 0.8V to 2.5V
- ◆ Internal 0.58V Reference
- ◆ Op Amp and Comparator Input Ranges are Rail-to-Rail
- ◆ Unity-gain Stable Op Amp with A<sub>voL</sub> = 104dB
- ◆ Op Amp Output: Rail-to-Rail and Phase-Reversal-Free
- ◆ Internal ±7.5mV Comparator Hysteresis
- ◆ 20µs Comparator Propagation Delay
- ◆ Resettable Latched Comparator
- ◆ TS12011: Push-pull Rail-to-Rail Output  
TS12012: Open-drain Output

### APPLICATIONS

Battery-powered Systems  
 Single-Cell and +1.8V, +2.5V Powered Systems  
 Low-Frequency, Local-Area Alarms/Detectors  
 Smoke Detectors and Safety Sensors  
 Infrared Receivers for Remote Controls  
 Instruments, Terminals, and Bar-Code Readers  
 Smart-Card Readers

### DESCRIPTION

The TS12011/TS12012 combine a 0.58V reference, a 20µs comparator, and a unity-gain stable op amp in a single IC. All three devices operate from a single 0.8V to 2.5V power supply and consume less than 1.6µA total supply current. Supply current for all three functions over 0.8V to 2.5V supply range is guaranteed 1.6µA max.

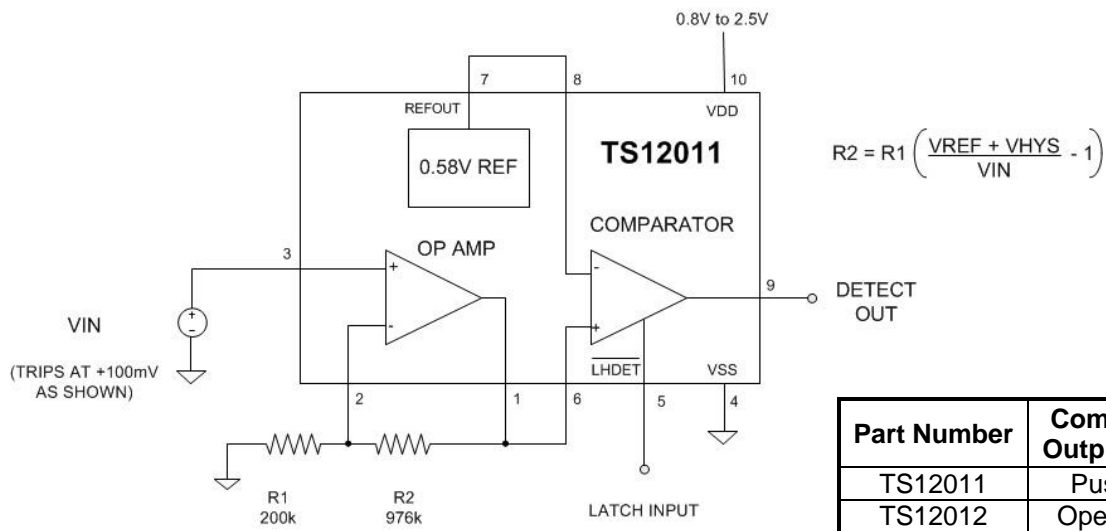
Super-flexible for crafting voltage detectors, timers, and wake-up circuits, these bundled functions exhibit low shoot-through currents and graceful power-down modes. Both the comparator and the op amp feature rail-to-rail input stages. The latching comparator exhibits ±7.5mV of internal hysteresis for clean, chatter-free output switching. When compared against similar products, the TS12011/TS12012 offer a factor-of-20 lower power consumption and at least a 55% reduction in pcb area.

The TS12011's comparator has a push-pull output stage with break-before-make switches for low shoot-through currents. The TS12012's comparator has an open-drain output having no parasitic diode to VDD, for interfacing to wired-OR or mixed-voltage logic.

The TS12011 and the TS12012 are fully specified over the -40°C to +85°C temperature range and each is available in a low-profile, 10-pin 2x2mm TDFN package with an exposed back-side paddle.

### TYPICAL APPLICATION CIRCUIT

LATCHING THRESHOLD DETECTOR WITH GAIN



Part Number	Comparator Output Stage
TS12011	Push-pull
TS12012	Open-Drain

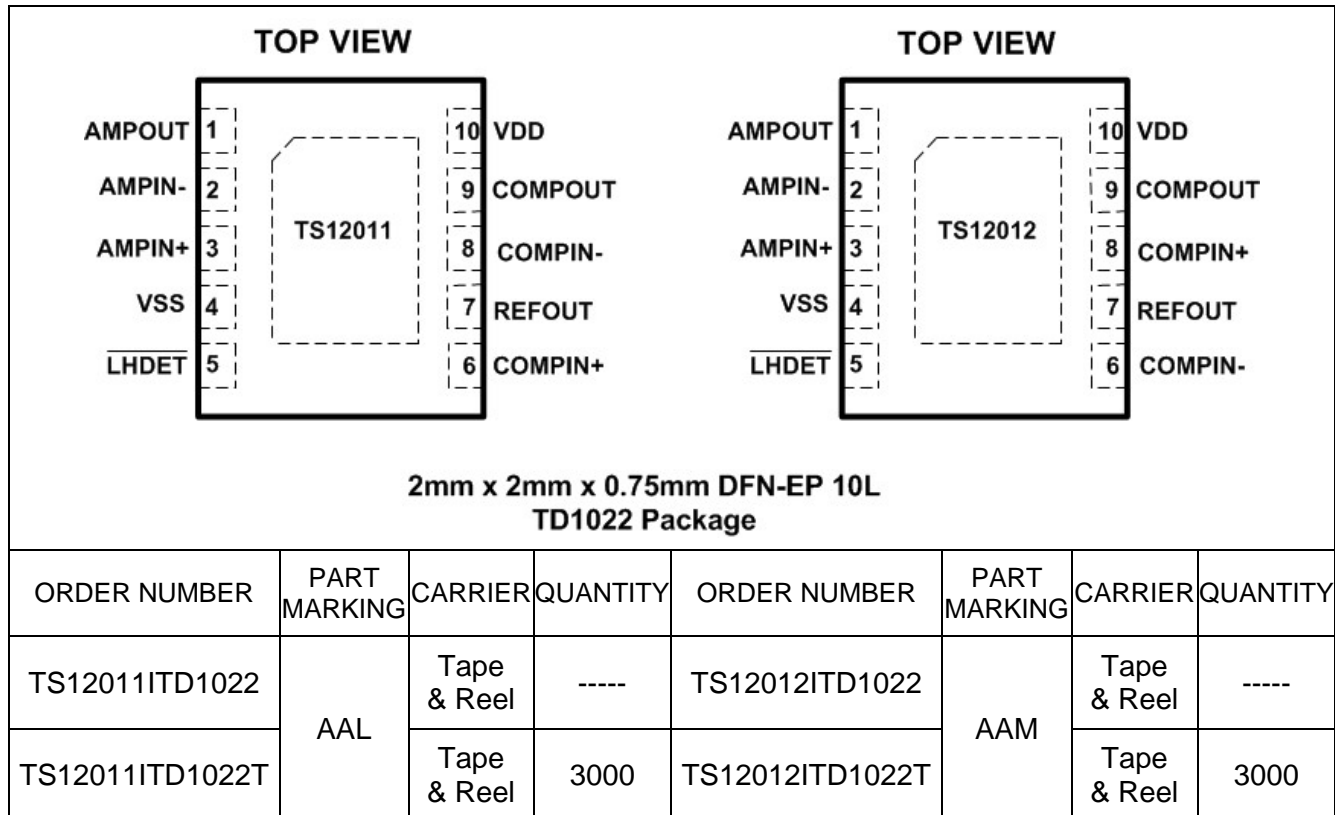
## ABSOLUTE MAXIMUM RATINGS

Supply Voltage ( $V_{DD}$  to  $V_{SS}$ ) ..... +2.75 V  
 Input Voltage  
 AMPIN+, AMPIN-..... $V_{SS} - 0.3V$  to  $V_{DD} + 0.3V$   
 COMPIN+, COMPIN-..... $V_{SS} - 0.3V$  to  $V_{DD} + 0.3V$   
 LHDET.....  $V_{SS} - 0.3V$  to +5.5V  
 Output Voltage  
 AMPOUT, REFOUT..... $V_{SS} - 0.3V$  to  $V_{DD} + 0.3V$   
 COMPOUT (TS12011)..... $V_{SS} - 0.3V$  to  $V_{DD} + 0.3V$   
 COMPOUT (TS12012)..... $V_{SS} - 0.3V$  to +5.5V  
 Differential Input Voltage (AMPIN, COMPIN).....  $\pm 2.75V$

Output Current  
 AMPOUT, COMPOUT.....50mA  
 Short-Circuit Duration  
 (REFOUT, AMPOUT, COMPOUT).....Continuous  
 Continuous Power Dissipation ( $T_A = +70^\circ C$ )  
 10-Pin TDFN (Derate at 13.48mW/ $^\circ C$  above  $+70^\circ C$ ) ..... 1078mW  
 Operating Temperature Range.....  $-40^\circ C$  to  $+85^\circ C$   
 Junction Temperature..... $+150^\circ C$   
 Storage Temperature Range.....  $-65^\circ C$  to  $+150^\circ C$   
 Lead Temperature (Soldering, 10s).....  $+300^\circ C$

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



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

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



SILICON LABS

# TS12011/TS12012

## ELECTRICAL CHARACTERISTICS

$V_{DD} = 0.8V$ ;  $V_{SS} = 0V$ ;  $V_{COMPIN+/-} = 0V$ ;  $V_{AMPIN+/-} = 0V$ ;  $V_{AMPOUT} = (V_{DD} + V_{SS})/2$ ;  $V_{COMPOUT} = HiZ$ ;  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted. Typical values are at  $T_A = +25^{\circ}C$ . See note 1.

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS	
Supply Voltage	$V_{DD}$		0.8		2.5	V	
Supply Current	$I_{DD}$	REFOUT = open	$T_A = +25^{\circ}C$	1.1	1.6	$\mu A$	
			$-40^{\circ}C \leq T_A \leq 85^{\circ}C$		2		
<b>REFERENCE SECTION</b>							
Reference Output Voltage	$V_{REFOUT}$	$V_{DD} = 0.8V$ or $2.5V$	$T_A = +25^{\circ}C$	555	577	600	mV
			$-40^{\circ}C \leq T_A \leq 85^{\circ}C$	552		602	
Reference Load Regulation		$I_{OUT} = \pm 100nA$			0.5	%	
<b>AMPLIFIER SECTION</b>							
Input Offset Voltage	$V_{OS}$	$V_{AMPIN+/-} = V_{DD}$ or $V_{AMPIN+/-} = V_{SS}$	$T_A = +25^{\circ}C$			3.5	mV
			$-40^{\circ}C \leq T_A \leq 85^{\circ}C$			7	
Input Bias Current	$I_{IN+}, I_{IN-}$	$V_{AMPIN+}, V_{AMPIN-} = (V_{DD} - V_{SS})/2$			20	nA	
Input Offset Current	$I_{OS}$	$V_{AMPIN+}, V_{AMPIN-} = (V_{DD} - V_{SS})/2$		0.01	5	nA	
Input Common-Mode Range	IVR	Guaranteed by Input Offset Voltage Test	$V_{SS}$		$V_{DD}$	V	
Large-Signal Voltage Gain	$A_{VOL}$	$R_L = 100k\Omega$ to $V_{DD}/2$ ; $V_{SS} + 50mV < V_{OUT} < V_{DD} - 50mV$	90	104		dB	
Gain-Bandwidth Product	GBWP	$R_L = 100k\Omega//20pF$		15		kHz	
Phase Margin	$\phi_M$	$R_L = 100k\Omega//20pF$		70		deg	
Slew Rate	SR	$R_L = 100k\Omega//20pF$		6		V/ms	
Common-Mode Rejection Ratio	CMRR	$0V \leq V_{IN(CM)} \leq 2.1V$ ; $V_{DD} = 2.5V$	50	75		dB	
Power-Supply Rejection Ratio	PSRR	$0.65V \leq (V_{DD} - V_{SS}) \leq 2.5V$	50	75		dB	
Output High Voltage	$V_{OH}$	$R_L = 100k\Omega$ to $V_{SS}$	$V_{DD} - 50mV$			V	
Output Low Voltage	$V_{OL}$	$R_L = 100k\Omega$ to $V_{DD}$			$V_{SS} + 50mV$	V	
Output Source Current	$I_{SC+}$	$V_{AMPOUT} = V_{SS}$	0.28			mA	
Output Sink Current	$I_{SC-}$	$V_{AMPOUT} = V_{DD}$	4.5			mA	
Output Load Capacitive Drive	$C_{OUT}$			50		pF	
<b>COMPARATOR SECTION</b>							
Input Offset Voltage	$V_{OS}$	$V_{AMPIN+/-} = V_{DD}$ ; $V_{AMPIN+/-} = V_{SS}$ ; See Note 2	$T_A = +25^{\circ}C$			4.5	mV
			$-40^{\circ}C \leq T_A \leq 85^{\circ}C$			8	
Input Hysteresis	$V_{HB}$	See Note 3		$\pm 7.5$		mV	
Input Bias Current	$I_{IN+}, I_{IN-}$	$V_{COMPIN+}, V_{COMPIN-} = V_{DD}$ or $V_{SS}$			20	nA	
Input Offset Current	$I_{OS}$	$V_{COMPIN+}, V_{COMPIN-} = V_{DD}$ or $V_{SS}$		0.2	5	nA	
Input Voltage Range	IVR	Guaranteed by Input Offset Voltage Test	$V_{SS}$		$V_{DD}$	V	
Common-Mode Rejection Ratio	CMRR	$0V \leq V_{IN(CM)} \leq 2.1V$ ; $V_{DD} = 2.5V$	50	60		dB	
Power-Supply Rejection Ratio	PSRR	$0.8V \leq (V_{DD} - V_{SS}) \leq 2.5V$	50	70		dB	
Low-to-High Propagation Delay	$t_{PD+}$	$V_{OVERDRIVE} = 10mV$ ; See Note 4	TS12011		30	$\mu s$	
		$V_{OVERDRIVE} = 100mV$ ; See Note 4			20	$\mu s$	
High-to-Low Propagation Delay	$t_{PD-}$	$V_{OVERDRIVE} = 10mV$ ; See Note 4			30	$\mu s$	
		$V_{OVERDRIVE} = 100mV$ ; See Note 4			20	$\mu s$	
Output High Voltage	$V_{OH}$	TS12011; $I_{OUT} = -100\mu A$	$V_{DD} - 0.1$			V	
Output Low Voltage	$V_{OL}$	TS12011; $I_{OUT} = 100\mu A$			$V_{SS} + 0.1$	V	
Output Low Voltage	$V_{OL}$	TS12012; $I_{OUT} = 100\mu A$			$V_{SS} + 0.11$	V	
Output Short-Circuit Current	$I_{SC}$	Sourcing; $V_{COMPOUT} = V_{SS}$	0.1			mA	
		TS12011; Sinking; $V_{COMPOUT} = V_{DD}$	0.5			mA	
		TS12012; Sinking; $V_{COMPOUT} = V_{DD}$		1.4			mA
Open Drain Leakage		TS12012; $V_{COMPOUT} = 5V$			20	nA	

# TS12011/TS12012



$V_{DD} = 0.8V$ ,  $V_{SS} = 0V$ ,  $V_{COMPIN+/-} = 0V$ ,  $V_{AMPIN+/-} = 0V$ ,  $V_{AMP\ OUT} = (V_{DD} + V_{SS})/2$ ,  $V_{COMP\ OUT} = HiZ$ .  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ , unless otherwise noted. Typical values are at  $T_A = +25^{\circ}C$ . See note 1.

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
<b>CONTROL PIN SECTION</b>						
LHDET Input Low Voltage	$V_{IL}$	Comparator Latched Output Enabled	$0.8V \leq V_{DD} \leq 1.1V$			0.1
			$1.1V < V_{DD} \leq 2.5V$			0.2
LHDET Input High Voltage	$V_{IH}$	Comparator Latched Output Disabled	$0.8V \leq V_{DD} \leq 1.1V$	$V_{DD} - 0.1$		
			$1.1V < V_{DD} \leq 2.5V$	1		
LHDET Input Leakage		$V_{LHDET} = V_{SS}$ ; $V_{LHDET} = 5.5V$			100	nA

**Note 1:** All devices are 100% production tested at  $T_A = +25^{\circ}C$  and are guaranteed by characterization for  $T_A = T_{MIN}$  to  $T_{MAX}$ , as specified.

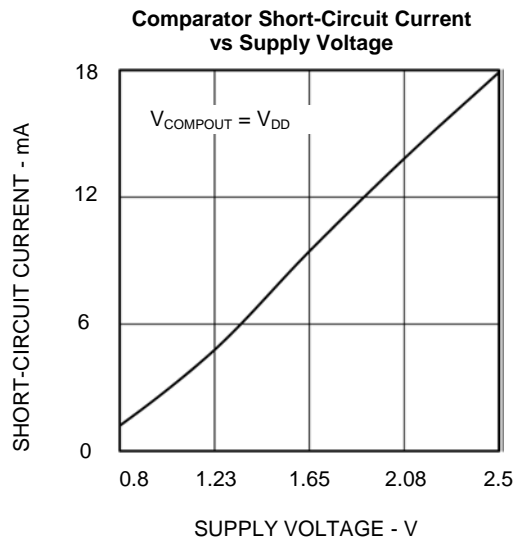
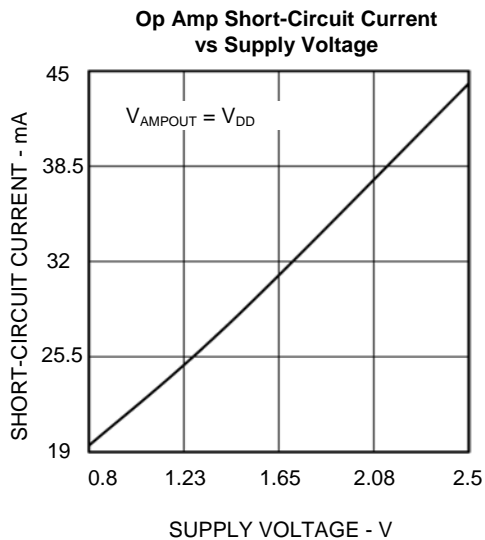
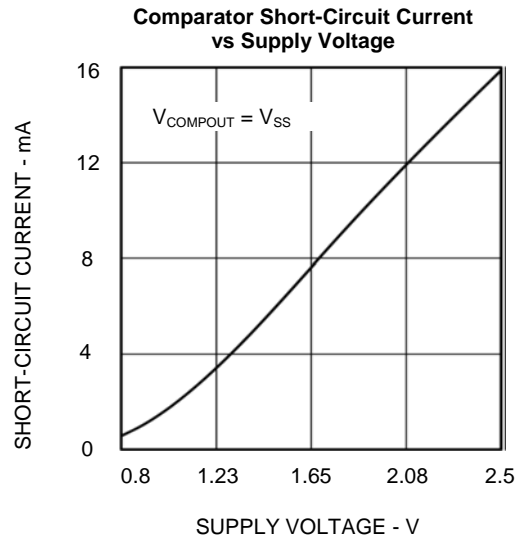
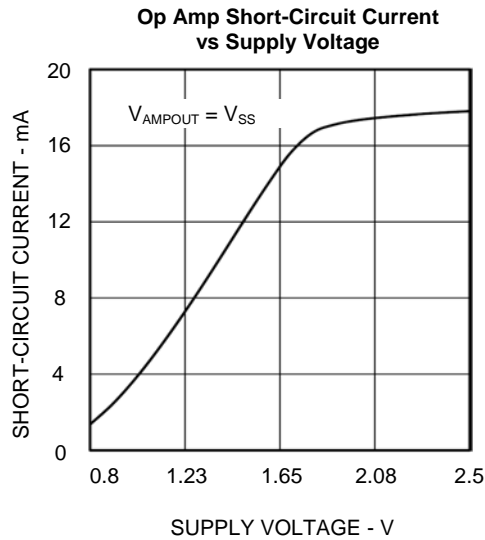
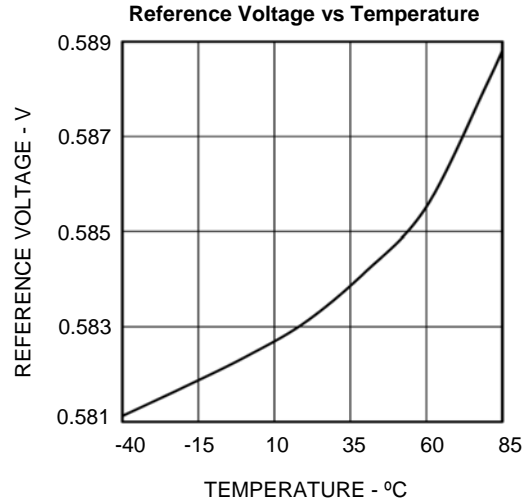
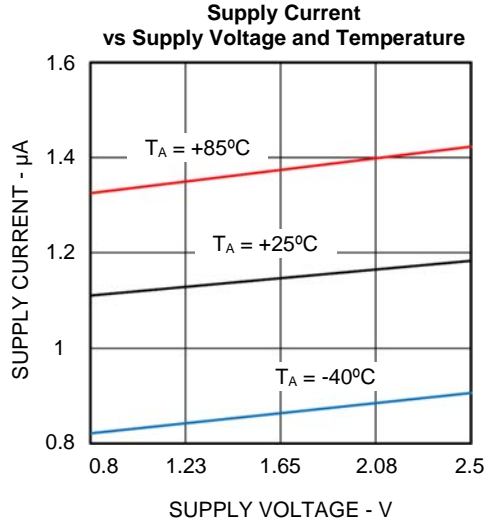
**Note 2:**  $V_{OS}$  is defined as the center of the hysteresis band at the input minus  $V_{IN(ICM)}$ .

**Note 3:** The hysteresis-related trip points are defined by the edges of the hysteresis band and measured with respect to the center of the hysteresis band.

**Note 4:** The propagation delays are specified with an output load capacitance of  $C_L = 15pF$ .  $V_{OVERDRIVE}$  is defined above and is beyond the offset voltage and hysteresis of the comparator input.

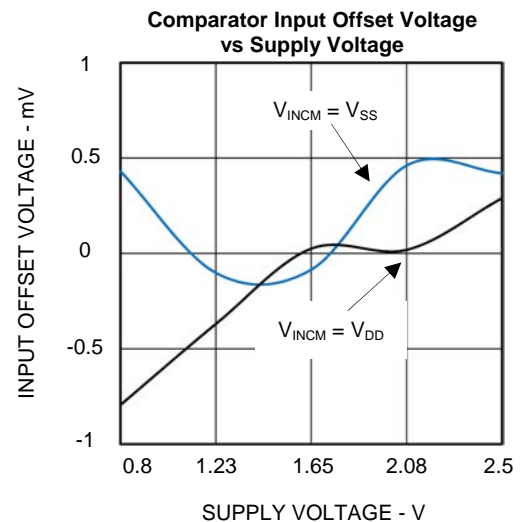
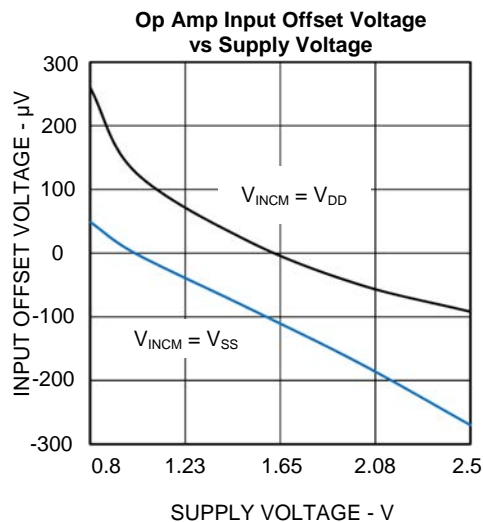
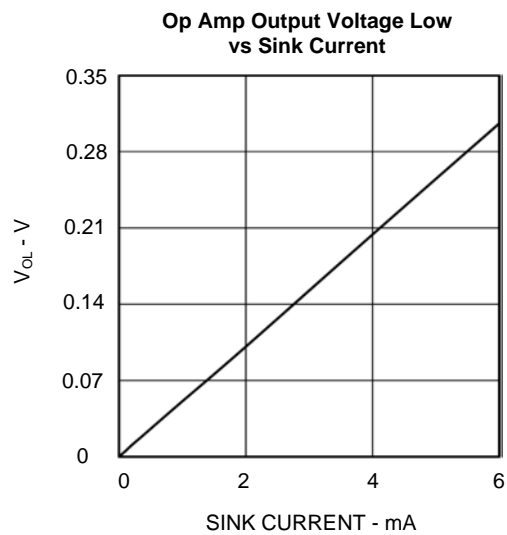
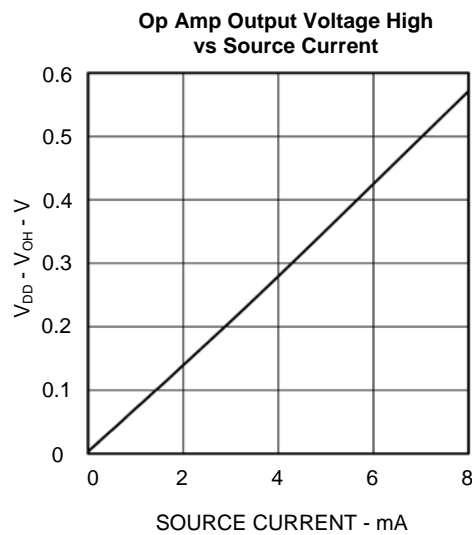
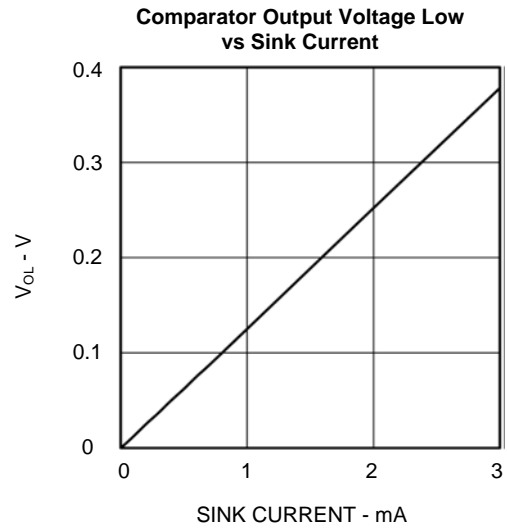
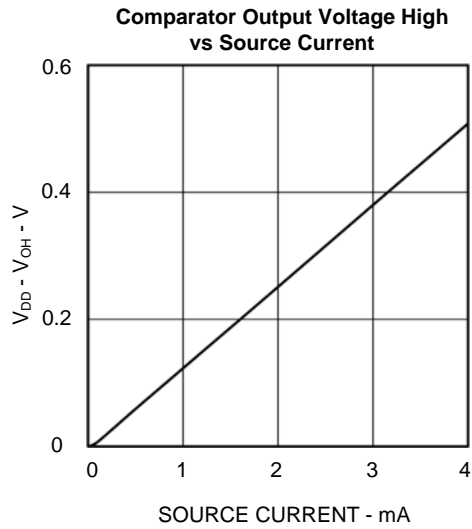
## TYPICAL PERFORMANCE CHARACTERISTICS

$V_{DD} = 2.5V$ ;  $V_{SS} = 0V$ ;  $V_{AMPOUT} = HiZ$ ;  $V_{COMPOUT} = HiZ$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ .



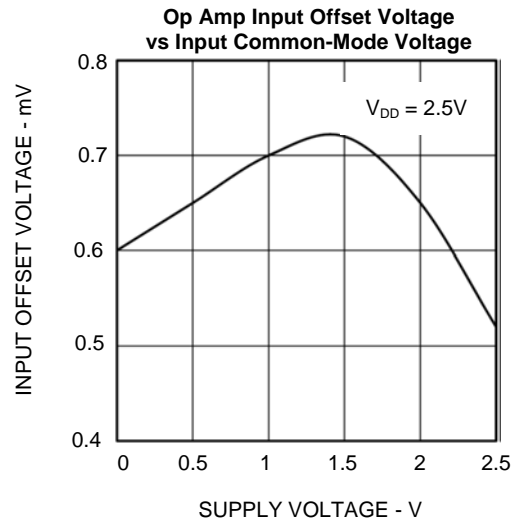
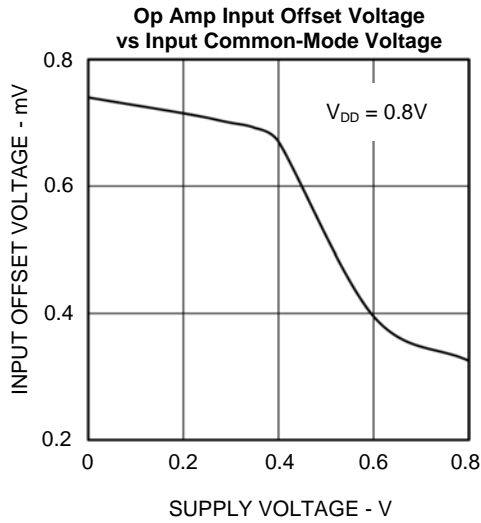
## TYPICAL PERFORMANCE CHARACTERISTICS

$V_{DD} = 2.5V$ ;  $V_{SS} = 0V$ ;  $V_{AMP\,OUT} = HiZ$ ;  $V_{COMP\,OUT} = HiZ$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ .

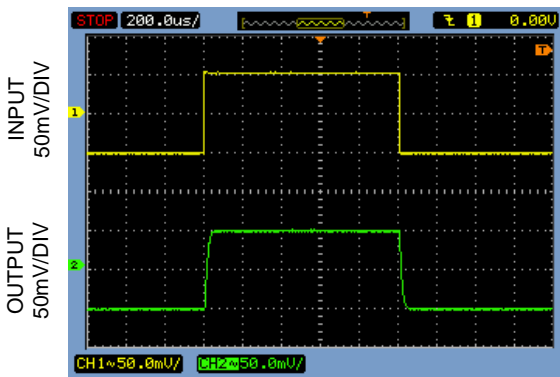


## TYPICAL PERFORMANCE CHARACTERISTICS

$V_{DD} = 2.5V$ ;  $V_{SS} = 0V$ ;  $V_{AMP\ OUT} = HiZ$ ;  $V_{COMP\ OUT} = HiZ$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ .

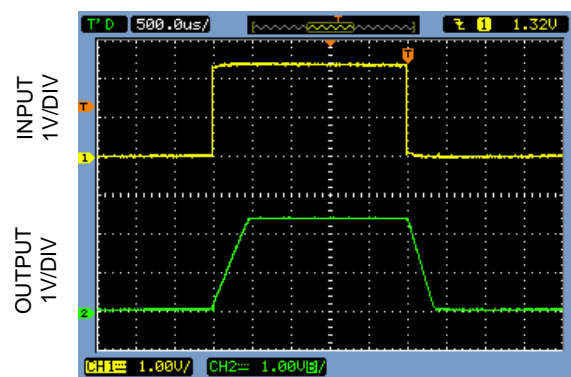


**TS12011**  
**Op Amp Small-Signal Transient Response**  
 $V_{DD} = 2.5V$ ,  $R_{LOAD} = 100k\Omega$ ,  $C_{LOAD} = 15pF$



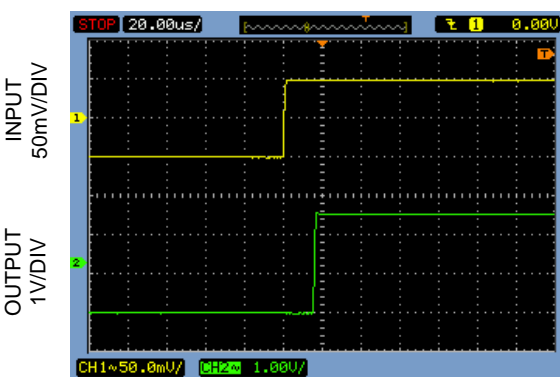
200µs/DIV

**TS12011**  
**Op Amp Large Signal Transient Response**  
 $V_{DD} = 2.5V$ ,  $R_{LOAD} = 100k\Omega$ ,  $C_{LOAD} = 15pF$



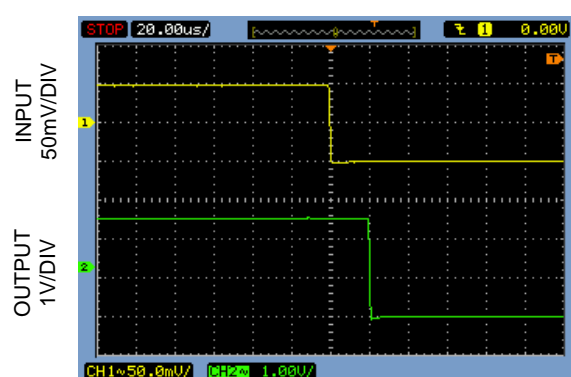
500µs/DIV

**TS12011**  
**Comparator Propagation Delay ( $T_{PD+}$ )**  
 $V_{DD} = 2.5V$ ,  $V_{OVERDRIVE} = 100mV$ ,  $C_{LOAD} = 15pF$



20µs/DIV

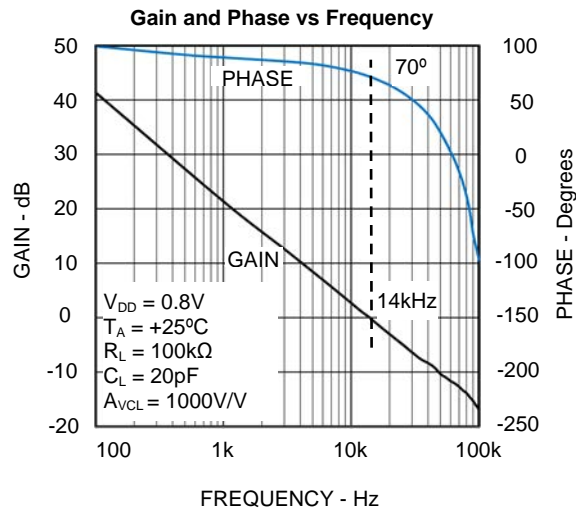
**TS12011**  
**Comparator Propagation Delay ( $T_{PD-}$ )**  
 $V_{DD} = 2.5V$ ,  $V_{OVERDRIVE} = 100mV$ ,  $C_{LOAD} = 15pF$



20µs/DIV

## TYPICAL PERFORMANCE CHARACTERISTICS

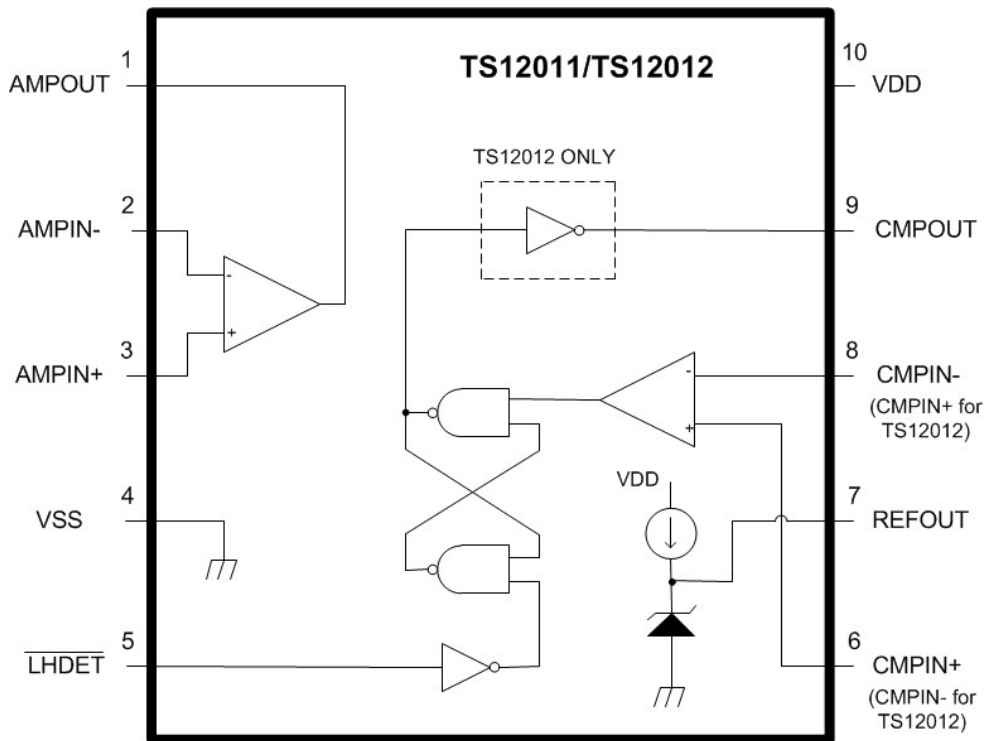
$V_{DD} = 2.5V$ ;  $V_{SS} = 0V$ ;  $V_{AMP\ OUT} = HiZ$ ;  $V_{COMP\ OUT} = HiZ$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ .



## PIN FUNCTIONS

PIN TS12011	PIN TS12012	NAME	FUNCTION
1	1	AMPOUT	Amplifier Output
2	2	AMPIN-	Amplifier Inverting Input
3	3	AMPIN+	Amplifier Non-inverting Input
4	4	VSS	Negative Supply Voltage.
5	5	LHDET	Latch Enable Pin, active low. Tie to VDD for normal operation. Do not leave floating. See Latch Truth Tables below.
6	8	COMPIN+	Comparator Non-inverting Input
7	7	REFOUT	0.58V Reference Output
8	6	COMPIN-	Comparator Inverting Input
9	9	COMPOUT	Comparator Output. TS12011: push-pull TS12012: open-drain
10	10	VDD	Positive Supply Voltage. Connect a 0.1 $\mu F$ bypass capacitor from this pin to analog VSS/GND.
EP	EP	----	Exposed paddle is electrically connected to VSS/GND.





## THEORY OF OPERATION

The TS12011 and TS12012 are multi-purpose CMOS building blocks intended for creating analog glue functions around battery-powered uC systems. There is an op amp for signal conditioning, a comparator for detection, and a reference to establish detection threshold levels. It's possible to build a wide variety of timers, event detectors, regulators, and voltage monitors using these flexible uncommitted blocks.

Optimized for low-voltage operation, these devices draw less than 1.6uA total from a 0.8V to 2.5V supply. The op amp and comparator blocks typically continue to function down to less than 0.5V (REFOUT will go into dropout, however).

### Comparator

The comparator block is designed for high gain and chatter-free output switching in noisy environments. The comparator inputs have rail-to-rail VIN range,

and exhibit +/-7.5mV of hysteresis. The only difference between the two device types is in the output stage of the comparator. The TS12011 has a push-pull output and latches in the high state. The TS12012 has an open-drain output, latches in the low state, and can tolerate pull-up voltages higher than the supply (up to 5.5V absolute max above VSS/GND).

TS12011 push-pull output driver was designed to minimize supply-current surges while driving ±100µA loads with an output swing to within 100mV of the supply rails. The TS12011 and the TS12012 can sink 0.5mA and 1.4mA of current, respectively. The TS12011 can source 0.1mA of current.

The non-traditional latch function works to detect and latch changes in the input state. If the LHDET control input is enabled, the output will latch high (low for the TS12012) whenever the differential input voltage is high enough to force a change in that direction. If the differential voltage is in the wrong direction to force a

change, the comparator stays active and waits for the crossing, at which point it will latch in its final state.

An internal POR circuit ensures that the latch powers up in the “comparator active” state if  $\overline{\text{LHDET}}$  is low when VDD is first applied.

**Latch Truth Table – TS12011**

$\overline{\text{LHDET}}$	CMPOUT initial state	CMPIN+ to CMPIN- difference voltage	CMPOUT
HIGH	X	N/A	Normal operation
LOW	HIGH	X	HIGH (latched)
LOW	LOW	negative	LOW (comparator active)
LOW	LOW	positive	HIGH (latched)

X = Don't Care

**Latch Truth Table – TS12012**

$\overline{\text{LHDET}}$	CMPOUT initial state	CMPIN+ to CMPIN- difference voltage	CMPOUT
HIGH	X	N/A	Normal operation
LOW	LOW	X	LOW (latched)
LOW	HIGH	positive	HIGH (comparator active)
LOW	HIGH	negative	LOW (latched)

X = Don't Care

## Reference

The TS12011 and TS12012 on-board  $0.58\text{V} \pm 4.5\%$  reference voltage can source and sink  $0.1\mu\text{A}$  and  $0.1\mu\text{A}$  of current and can drive a capacitive load less than  $50\text{pF}$  and greater than  $50\text{nF}$  with a maximum capacitive load of  $250\text{nF}$ . The higher the capacitive load, the lower the noise on the reference voltage and the longer the time needed for the reference voltage to respond and become available on the REFOUT pin. With a  $250\text{nF}$  capacitive load, the reference voltage will settle to within specifications in approximately 20ms.

## Op Amp

The TS12011 and TS12012 have a unity-gain stable op-amp with a GBWP of 15kHz, a slew rate of 6V/ms, and can drive a capacitive load up to  $50\text{pF}$ . The common mode input voltage range extends from  $V_{\text{SS}}$  to  $V_{\text{DD}}$  and the input bias current and offset current are less than  $20\text{nA}$  and  $2\text{nA}$ , respectively.

## Op-Amp Stability

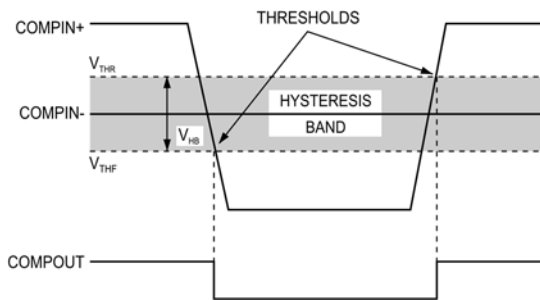
The TS12011 and TS12012 op-amp is able to drive up to  $50\text{pF}$  of capacitive load and still maintain stability in a unity-gain configuration with a 15kHz GBWP and a phase margin of 70 degrees with a  $100\text{k}\Omega//20\text{pF}$  output load.

Though the TS12011 and TS12012 address low frequency applications, it is essential to perform good layout techniques in order to minimize board leakage and stray capacitance, which is of a concern in low power, high impedance circuits. For instance, a  $10\text{M}\Omega$  resistor coupled with a  $1\text{pF}$  stray capacitance can lead to a pole at approximately 15kHz, which is the GBWP of the device. If stray capacitance is unavoidable, a feedback capacitor can be placed in parallel with the feedback resistor.

# APPLICATIONS INFORMATION

## Comparator Hysteresis

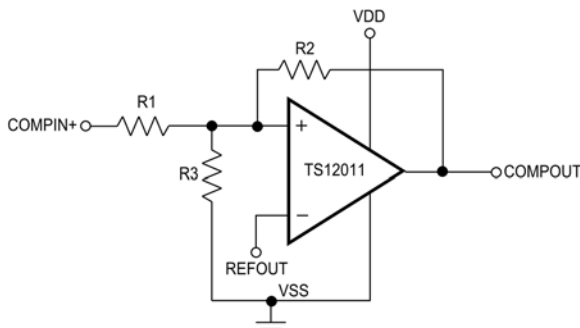
As a result of circuit noise or unintended parasitic feedback, many analog comparators often break into oscillation within their linear region of operation especially when the applied differential input voltage approaches 0V (zero volt). Externally-introduced hysteresis is a well-established technique for stabilizing analog comparator behavior and requires external components. As shown in Figure 1, adding comparator hysteresis creates two trip points:  $V_{\text{THR}}$  (for the rising input voltage) and  $V_{\text{THF}}$  (for the falling input voltage). The hysteresis band ( $V_{\text{HB}}$ ) 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  $\text{IN-}$  input is a fixed voltage and an  $\text{IN+}$  is varied. If the input signals were reversed, the figure would be the same with an inverted output. To save cost and external pcb area, an internal  $\pm 7.5\text{mV}$  hysteresis circuit was added to the TS12011 and TS12012.



**Figure 1.** TS12011/TS12012 Threshold Hysteresis Band

### Adding Hysteresis to the TS12011 Push-pull Output Option

Additional hysteresis can be generated with three external resistors using positive feedback as shown in Figure 2. Unfortunately, this method also reduces the hysteresis response time. The procedure to calculate the resistor values for the TS12011 is as follows:



**Figure 2.** Using Three Resistors Introduces Additional Hysteresis in the TS12011

- 1) Setting R2. As the leakage current at the IN pin is less than 20nA, the current through R2 should be at least 150nA to minimize offset voltage errors caused by the input leakage current. The current through R2 at the trip point is  $(V_{REFOUT} - V_{COMPOUT})/R2$ .

In solving for R2, there are two formulas – one each for the two possible output states:

$$R2 = V_{REFOUT}/I_{R2}$$

or

$$R2 = (V_{DD} - V_{REFOUT})/I_{R2}$$

From the results of the two formulae, the smaller of the two resulting resistor values is chosen. For example, when using the TS12011 ( $V_{REFOUT} = 0.58V$ ) at a  $V_{DD} = 2.5V$

and if  $I_{R2} = 150nA$  is chosen, then the formulae above produce two resistor values:  $3.87M\Omega$  and  $12.8M\Omega$  - a  $4.02M\Omega$  standard value for R2 is selected.

- 2) Next, the desired hysteresis band ( $V_{HYSB}$ ) is set. In this example,  $V_{HYSB}$  is set to 100mV.
- 3) Resistor R1 is calculated according to the following equation:

$$R1 = R2 \times (V_{HYSB}/V_{DD})$$

and substituting the values selected in 1) and 2) above yields:

$$R1 = 4.02M\Omega \times (100mV/2.5V) = 160.8k\Omega.$$

The 160k $\Omega$  standard value for R1 is chosen.

- 4) The trip point for COMPIN+ rising ( $V_{THR}$ ) is chosen such that  $V_{THR} > V_{REFOUT} \times (R1 + R2)/R2$  ( $V_{THF}$  is the trip point for  $V_{COMPIN+}$  falling). This is the threshold voltage at which the comparator switches its output from low to high as  $V_{COMPIN+}$  rises above the trip point. In this example,  $V_{THR}$  is set to 2.
- 5) With the  $V_{THR}$  from Step 4 above, resistor R3 is then computed as follows:

$$R3 = 1/[V_{THR}/(V_{REFOUT} \times R1) - (1/R1) - (1/R2)]$$

$$R3 = 1/[2V/(0.58V \times 160k\Omega) - (1/160k\Omega) - (1/4.02M\Omega)] = 66.43k\Omega$$

In this example, a 69.8k $\Omega$ , 1% standard value resistor is selected for R3.

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

For  $V_{COMPIN+}$  rising:

$$V_{THR} = V_{REFOUT} \times R1 [(1/R1) + (1/R2) + (1/R3)] = 1.93V$$

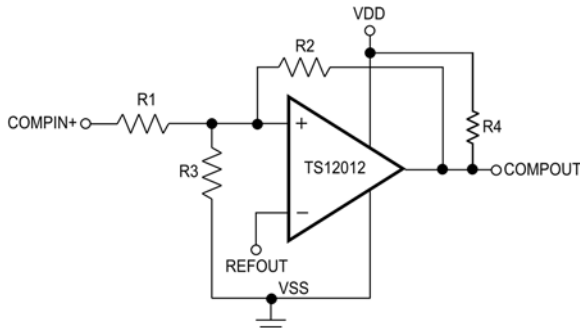
For  $V_{COMPIN+}$  falling:

$$V_{THF} = V_{THR} - (R1 \times V_{DD}/R2) = 1.83V$$

$$\text{and Hysteresis Band} = V_{THR} - V_{THF} = 100mV$$

## Adding Hysteresis to the TS12012 Open-Drain Option

The TS12012 has open-drain output and requires an external pull-up resistor to V<sub>DD</sub> as shown in Figure 3.



**Figure 3.** Using Four Resistors Introduces Additional Hysteresis in the TS12012

Additional hysteresis can be generated using positive feedback; however, the formulae differ slightly from those of the push-pull option TS12011. The procedure to calculate the resistor values for the TS12012 is as follows:

- 1) As in the previous section, resistor R2 is chosen according to the formulae:

$$R2 = V_{REFOUT}/150nA$$

or

$$R2 = (V_{DD} - V_{REFOUT})/150nA - R4$$

where the smaller of the two resulting resistor values is the best starting value.

- 2) As before, the desired hysteresis band ( $V_{HYSB}$ ) is set to 100mV.
- 3) Next, resistor R1 is then computed according to the following equation:

$$R1 = (R2 + R4) \times (V_{HYSB}/V_{DD})$$

- 4) The trip point for  $V_{COMPIN+}$  rising ( $V_{THR}$ ) is chosen (again, remember that  $V_{THF}$  is the trip point for  $V_{COMPIN+}$  falling). This is the threshold voltage at which the comparator switches its output from low to high as  $V_{COMPIN+}$  rises above the trip point.
- 5) With the  $V_{THR}$  from Step 4 above, resistor R3 is computed as follows:

$$R3 = 1/[V_{THR}/(V_{REFOUT} \times R1) - (1/R1) - (1/R2)]$$

- 6) As before, the last step is to verify the trip voltages and hysteresis band with the standard resistor values used in the circuit:

For  $V_{COMPIN+}$  rising:

$$V_{THR} = V_{REFOUT} \times R1 \times (1/R1 + 1/R2 + 1/R3)$$

For  $V_{COMPIN+}$  falling:

$$V_{THF} = V_{REFOUT} \times R1 \times (1/R1 + 1/R3 + 1/(R2 + R4)) - (R1/(R2 + R4)) \times V_{DD}$$

and Hysteresis Band is given by  $V_{THR} - V_{THF}$

## PC Board Layout and Power-Supply Bypassing

While power-supply bypass capacitors are not typically required, it is good engineering practice to use 0.1uF 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.

## Input Noise

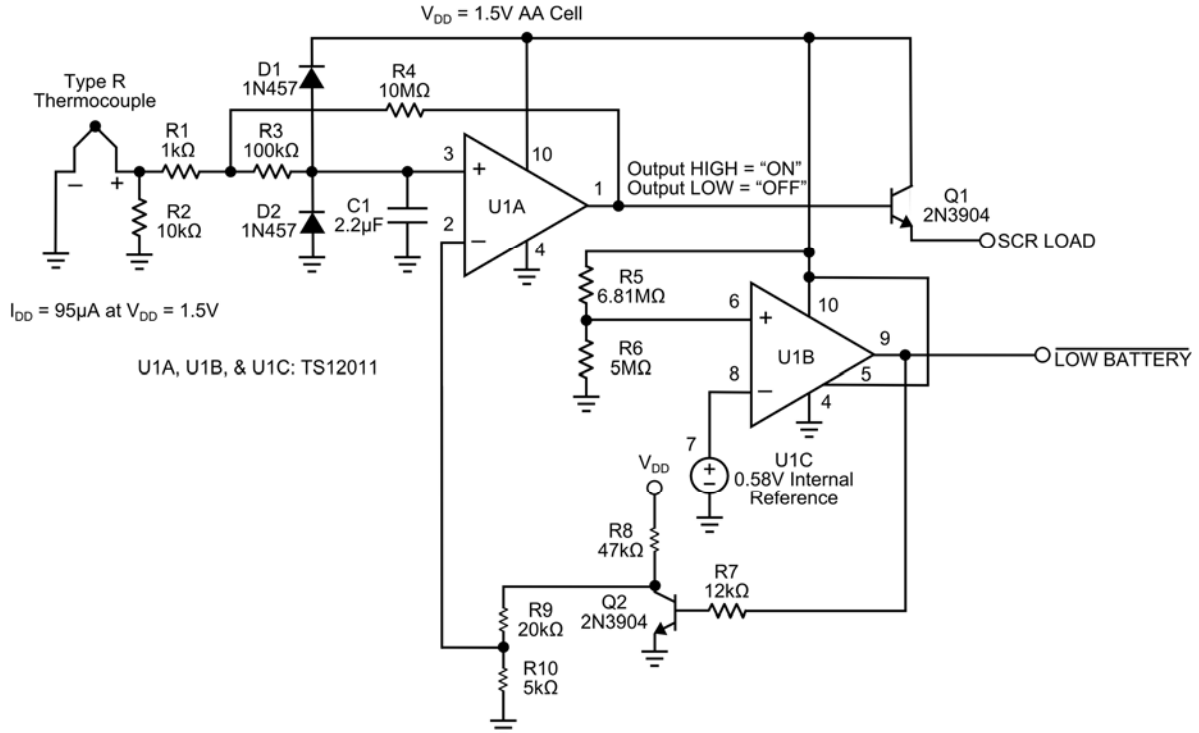
Radiated noise is common in low power circuits that require high impedance circuits. To minimize this effect, all traces between the inputs of the comparator or op-amp and passive component networks should be made as short as possible.

## Pilot Light Flame Detector with Low-Battery Lockout Circuit

The TS12011 can be used to create a pilot flame detector with low-battery lockout circuit as shown in Figure 4. The circuit is able to detect when the thermocouple does not detect the pilot flame and when the battery in the circuit drops to 1.39V. This circuit makes use of the op-amp, comparator, and 0.58V reference in the TS12011. In this example, a type R thermocouple is used. It generates a voltage range from 9mV to 17mV that corresponds to a temperature range of 900°C to 1500°C, which is typical of a methane pilot flame. If the pilot flame is removed, the temperature drops; hence, the output voltage generated by the thermocouple is drops to a minimum voltage of 0.1mV that is applied to the non-

inverting input of the op-amp. This switches the output voltage of the op-amp to a LOW state and in turn, switches Q1 off. If, however, the battery voltage drops from 1.5V to 1.39V, the comparator output will switch from an output HIGH to a LOW. This will turn

off Q2 and the output of the op-amp will turn Q1 off. The complete circuit consumes approximately 95µA of supply current at  $V_{DD} = 1.5V$ .



**Figure 4.** Pilot Light Flame Detector with Low-Battery Lockout Circuit

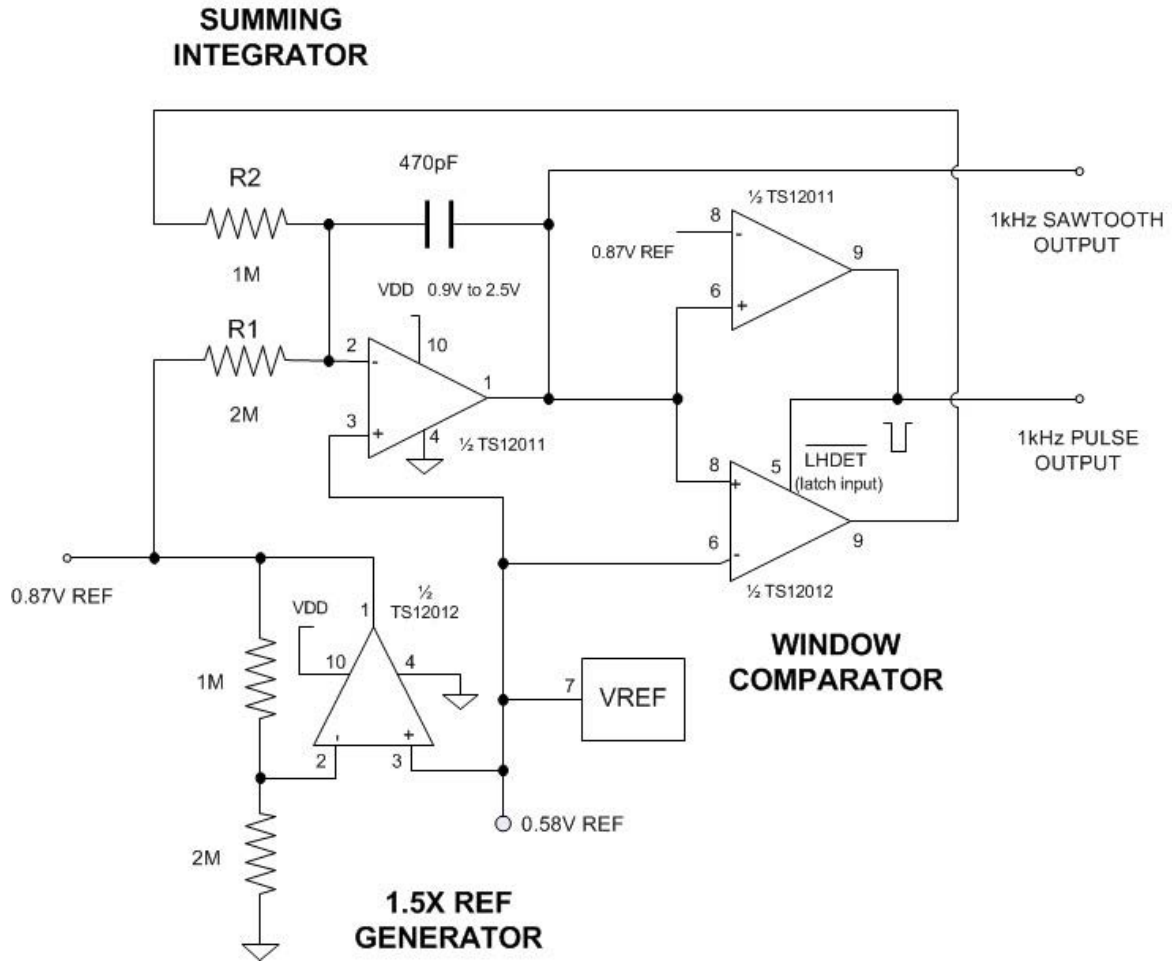
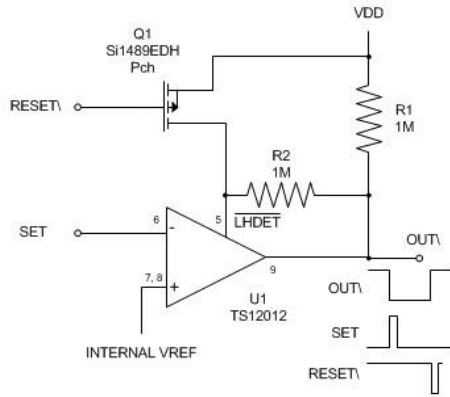
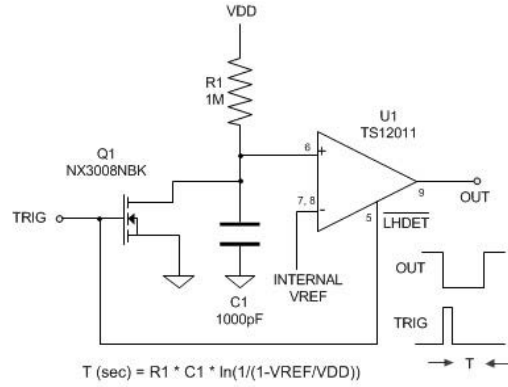


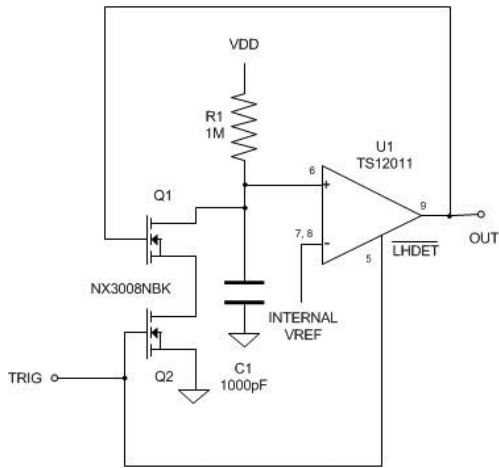
Figure 5. Sawtooth/Triangle Generator with Stable Frequency and Amplitude



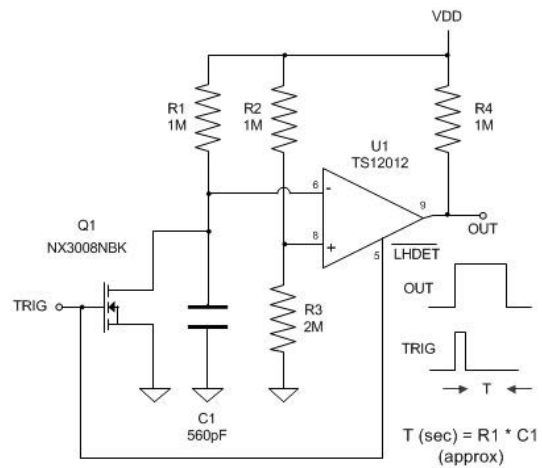
A. SR Latch with accurate threshold



B. Simple one-shot (inverting)

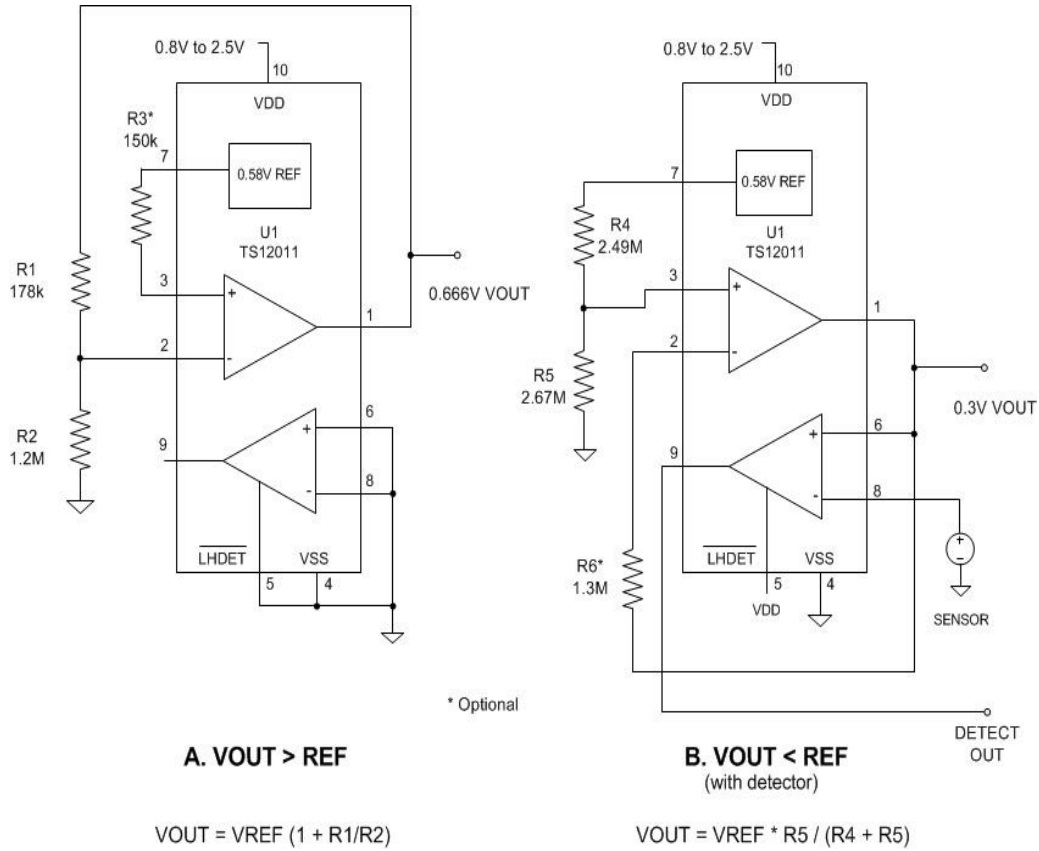


C. Non-retriggerable one-shot (inverting)



D. Ratiometric one-shot (non-inverting)

Figure 6. Low-power One-shot and Latch Circuits



**Figure 7.** Adjustable Buffered Reference Generators





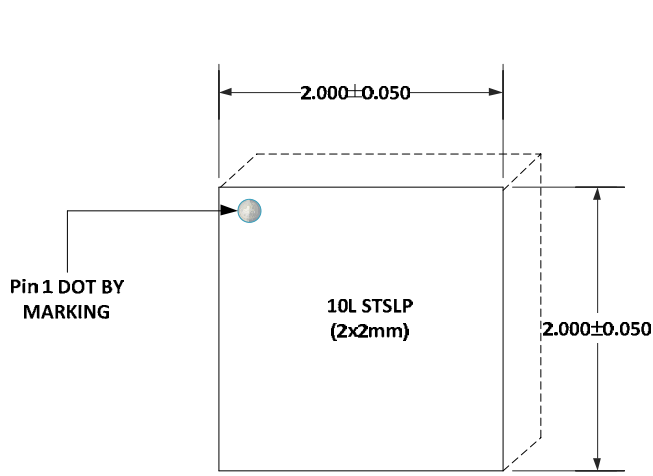
SILICON LABS

TS12011/TS12012

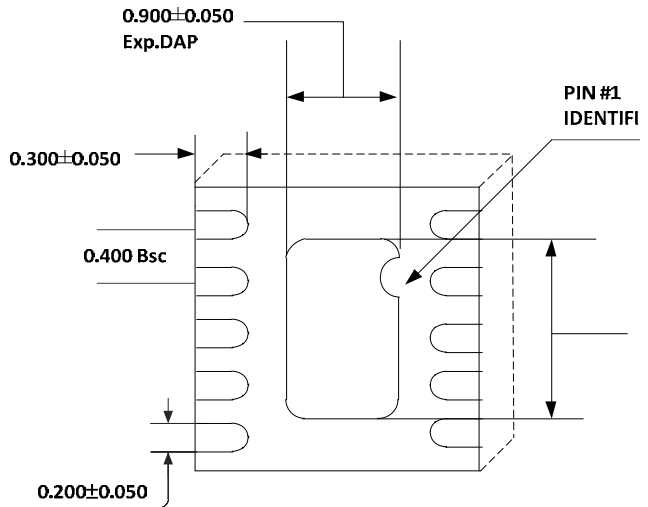
PACKAGE OUTLINE DRAWING

10-Pin TDFN22 Package Outline Drawing

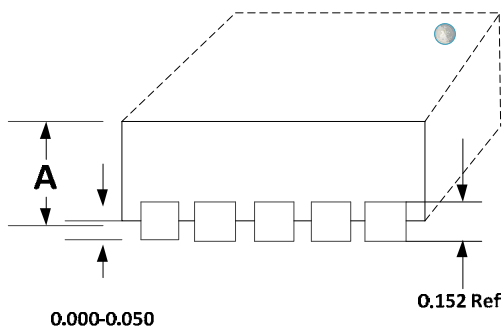
(N.B., Drawings are not to scale)



TOP VIEW



BOTTOM VIEW



SIDE VIEW

NOTE!

- All dimensions in mm.
This part is compliant with JEDEC MO-22

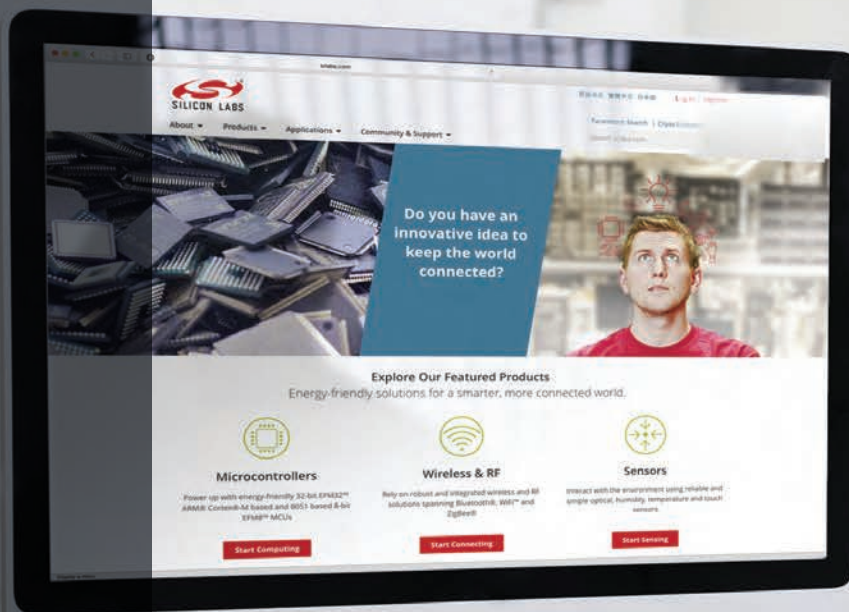
Table with dimensions for parameter A: MAX. 0.600, NOM. 0.550, MIN. 0.500

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