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

FEATURES

- Nanopower Op Amp, Comparator, and 0.58V Reference in Single 4 mm^2 Package
- Ultra Low Total Supply Current: 1.6µA (max)
- Supply Voltage Operation: 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_{VOL} = 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 Stage with Crowbar-Current Free Switching
- TS12012: Open-drain Output Stage for Wired-OR or Mixed-Voltage System Applications

APPLICATIONS

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

DESCRIPTION

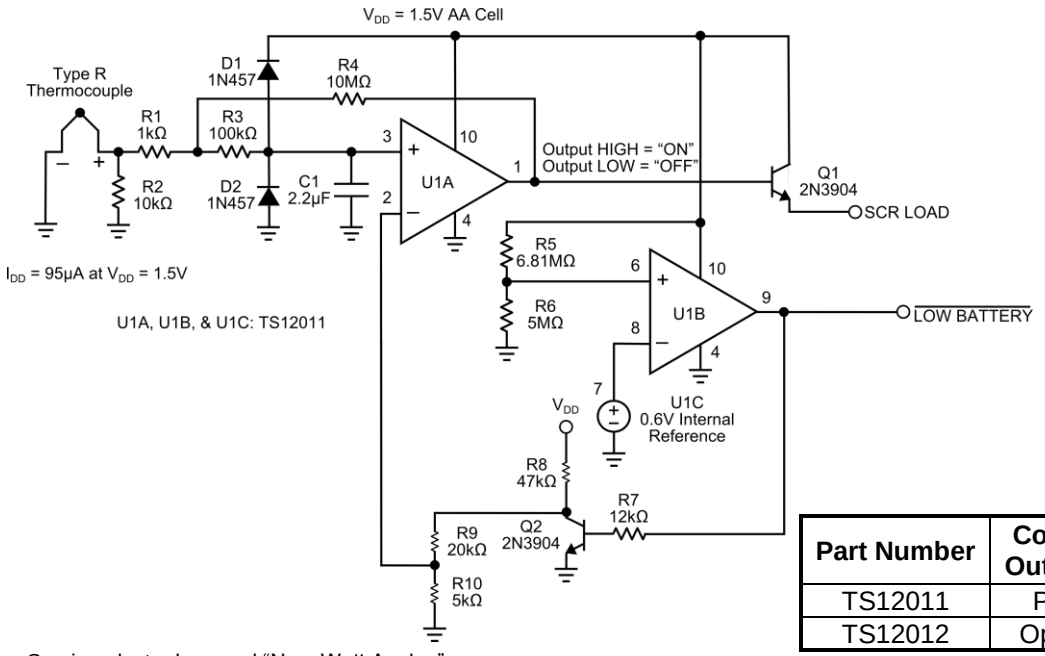
The TS12011/TS12012 combine a 0.58V reference, a 20µs analog comparator, and a unity-gain stable operational amplifier in a single package. All three devices operate from a single 0.8V to 2.5V power supply and consume less than 1.6µA total supply current. Optimized for ultra-long life, single-cell and battery-powered applications, these devices expand Touchstone's growing "NanoWatt Analog™" high-performance analog integrated circuits portfolio.

Both the analog comparator and the op amp feature rail-to-rail input stages. The analog comparator exhibits ±7.5mV of internal hysteresis for clean, chatter-free output switching. The internal reference was designed to sink or source up to 0.1µA load currents. When compared against similar products, the TS12011 and the TS12012 offer a factor-of-20 lower power consumption and at least a 55% reduction in pcb area.

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

Pilot Light Flame Detector with Low-Battery Lockout Circuit



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

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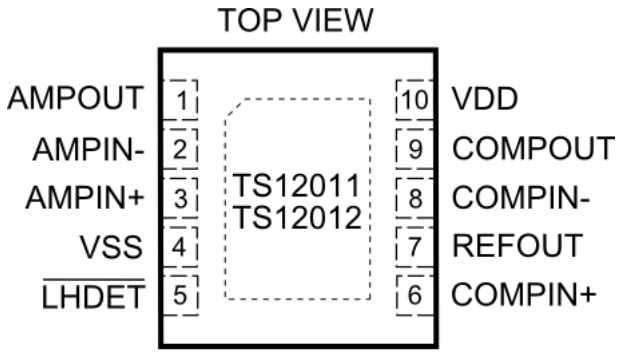
ABSOLUTE MAXIMUM RATINGS

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
$\overline{LHDET}$…….…….. 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)..... ±2.75V

Output Current
AMPOUT, COMPOUT…….....50mA
Short-Circuit Duration
(REFOUT, AMPOUT, COMPOUT)……..…Continuous
Continuous Power Dissipation (T_A = +70°C)
10-Pin TDFN (Derate at 13.48mW/°C above +70°C)..... 1078mW
Operating Temperature Range..... -40°C to +85°C
Junction Temperature…….……+150°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



2mm x 2mm x 0.75mm DFN-EP 10L
TD1022 Package

ORDER NUMBER	PART MARKING	CARRIER	QUANTITY	ORDER NUMBER	PART MARKING	CARRIER	QUANTITY
TS12011ITD1022TP	AAL	Tape & Reel	-----	TS12012ITD1022TP	AAM	Tape & Reel	-----
TS12011ITD1022T		Tape & Reel	3000	TS12012ITD1022T		Tape & Reel	3000

Lead-free Program: Touchstone Semiconductor supplies only lead-free packaging.

Consult Touchstone Semiconductor for products specified with wider operating temperature ranges.

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°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°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°C		1.1	1.6	µA
			-40°C ≤ T_A ≤ 85°C			2	
REFERENCE SECTION							
Reference Output Voltage	V_{REFOUT}		T_A = +25°C	555	577	600	mV
			-40°C ≤ T_A ≤ 85°C	552		602	
Reference Load Regulation		I_{OUT} = ±100nA				0.5	%
AMPLIFIER SECTION							
Input Offset Voltage	V_{OS}	$V_{AMPIN+/-}$ = V_{DD} or $V_{AMPIN+/-}$ = V_{SS}	T_A = +25°C			3.5	mV
			-40°C ≤ T_A ≤ 85°C			7	
Input Bias Current	I_{IN+}, I_{N-}	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 to V_{DD}/2; V_{SS} + 50mV < V_{OUT} < V_{DD} - 50mV		90	104		dB
Gain-Bandwidth Product	GBWP	R_L = 100kΩ//20pF			15		kHz
Phase Margin	φ_M	R_L = 100kΩ//20pF			70		deg
Slew Rate	SR	R_L = 100kΩ//20pF			6		V/ms
Common-Mode Rejection Ratio	CMRR	0V ≤ $V_{IN(CM)}$ ≤ 2.1V; V_{DD} = 2.5V		50	75		dB
Power-Supply Rejection Ratio	PSRR	0.65V ≤ (V_{DD} - V_{SS}) ≤ 2.5V		50	75		dB
Output High Voltage	V_{OH}	R_L = 100kΩ to V_{SS}		V_{DD} – 50mV			V
Output Low Voltage	V_{OL}	R_L = 100kΩ 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
COMPARATOR SECTION							
Input Offset Voltage	V_{OS}	$V_{AMPIN+/-}$ = V_{DD}; $V_{AMPIN+/-}$ = V_{SS}; See Note 2	T_A = +25°C			4.5	mV
			-40°C ≤ T_A ≤ 85°C			8	
Input Hysteresis	V_{HB}	See Note 3			±7.5		mV
Input Bias Current	I_{IN+}, I_{N-}	$V_{COMPIN+}$, $V_{COMPIN-}$ = 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 ≤ $V_{IN(CM)}$ ≤ 2.1V; V_{DD} = 2.5V		50	60		dB
Power-Supply Rejection Ratio	PSRR	0.8V ≤ (V_{DD} - V_{SS}) ≤ 2.5V		50	70		dB
Low-to-High Propagation Delay	t_{PD+}	$V_{OVERDRIVE}$ = 10mV; See Note 4	TS12011		30		µs
		$V_{OVERDRIVE}$ = 100mV; See Note 4	TS12011		20		µs
High-to-Low Propagation Delay	t_{PD-}	$V_{OVERDRIVE}$ = 10mV; See Note 4			30		µs
		$V_{OVERDRIVE}$ = 100mV; See Note 4			20		µs
Output High Voltage	V_{OH}	TS12011; I_{OUT} = -100µA		V_{DD} – 0.1			V
Output Low Voltage	V_{OL}	TS12011 ; I_{OUT} = 100µA				V_{SS} + 0.1	V
Output Low Voltage	V_{OL}	TS12012 ; I_{OUT} = 100µA				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

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°C to +85°C, unless otherwise noted. Typical values are at T_A = +25°C. See note 1.

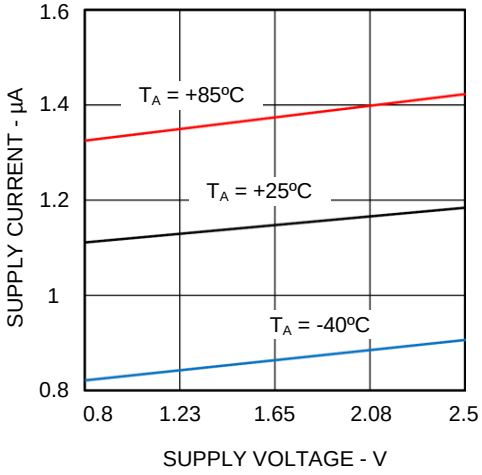
PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
CONTROL PIN SECTION							
$\overline{LHDET}$ Input Low Voltage	V_{IL}	Comparator Latched Output Enabled	0.8V ≤ V_{DD} ≤ 1.1V			0.1	V
			1.1V < V_{DD} ≤ 2.5V			0.2	
$\overline{LHDET}$ Input High Voltage	V_{IH}	Comparator Latched Output Disabled	0.8V ≤ V_{DD}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

Note 1: All devices are 100% production tested at T_A = +25°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 $V_{IN(CM)}$.
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.

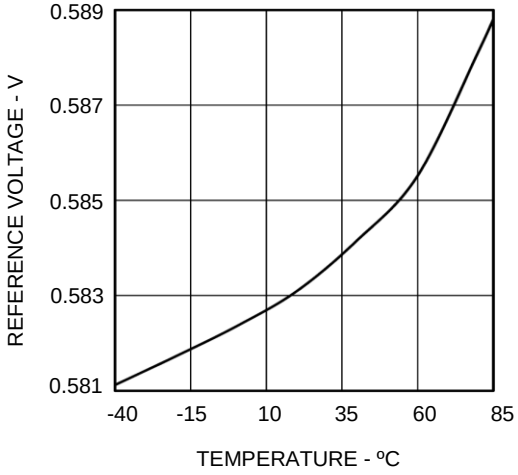
TYPICAL PERFORMANCE CHARACTERISTICS

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

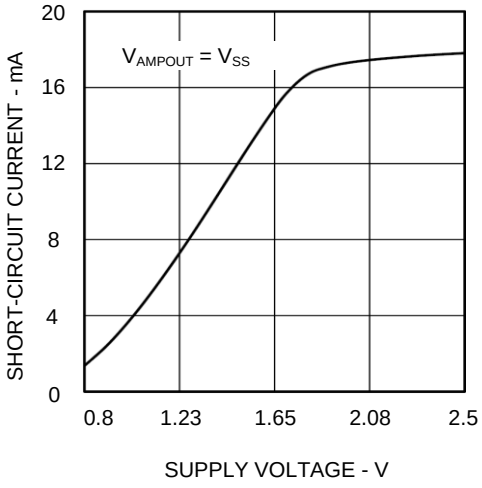
Supply Current vs Supply Voltage and Temperature



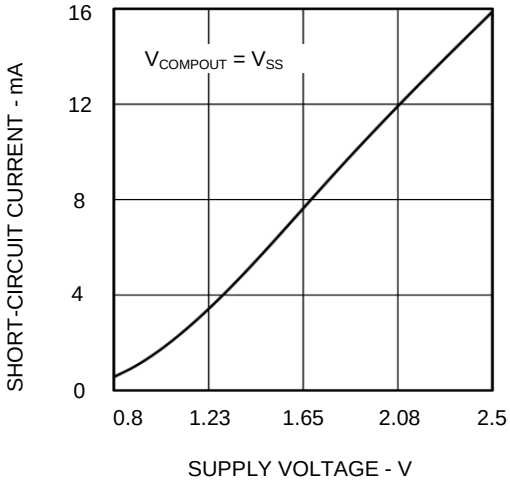
Reference Voltage vs Temperature



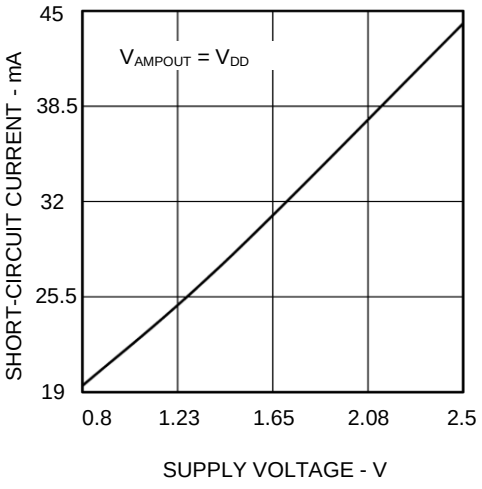
Op Amp Short-Circuit Current vs Supply Voltage



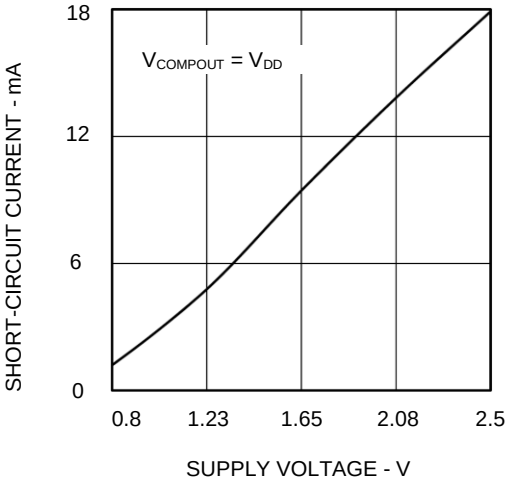
Comparator Short-Circuit Current vs Supply Voltage



Op Amp Short-Circuit Current vs Supply Voltage



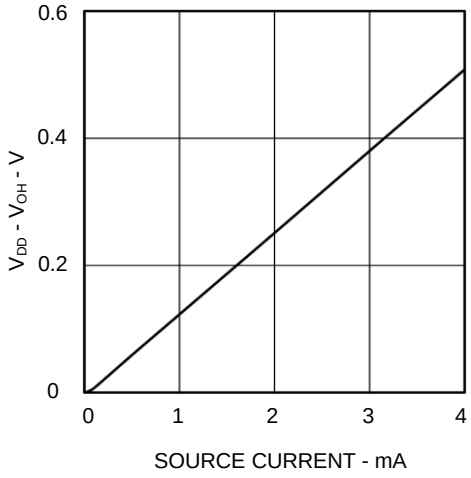
Comparator Short-Circuit Current vs Supply Voltage



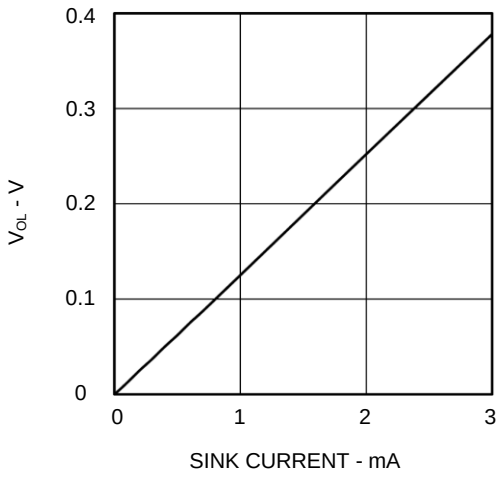
TYPICAL PERFORMANCE CHARACTERISTICS

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

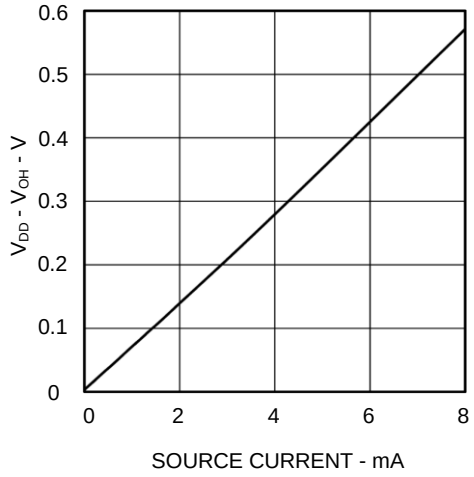
Comparator Output Voltage High vs Source Current



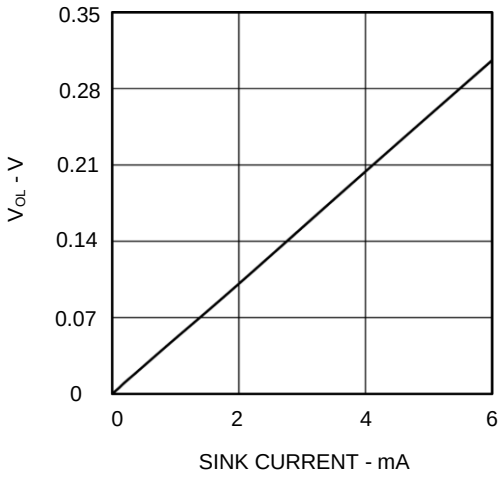
Comparator Output Voltage Low vs Sink Current



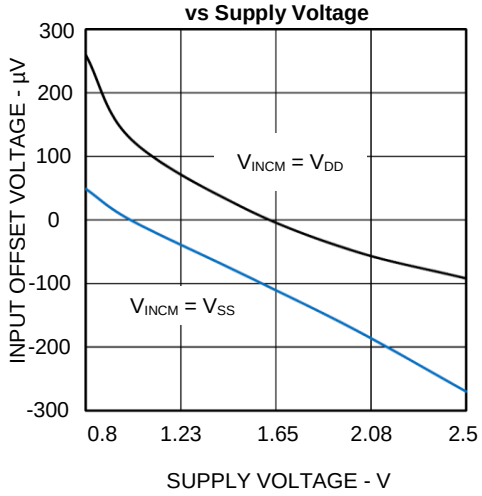
Op Amp Output Voltage High vs Source Current



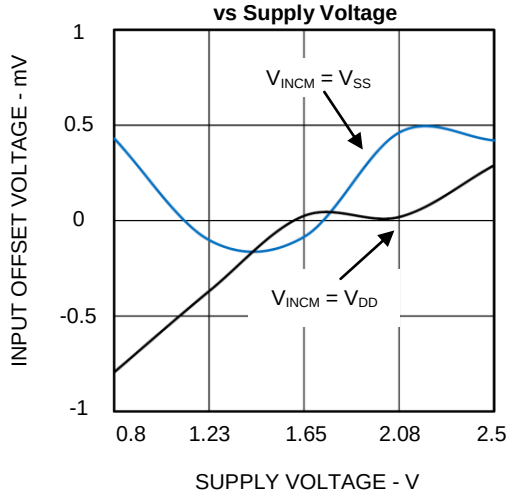
Op Amp Output Voltage Low vs Sink Current



Op Amp Input Offset Voltage vs Supply Voltage



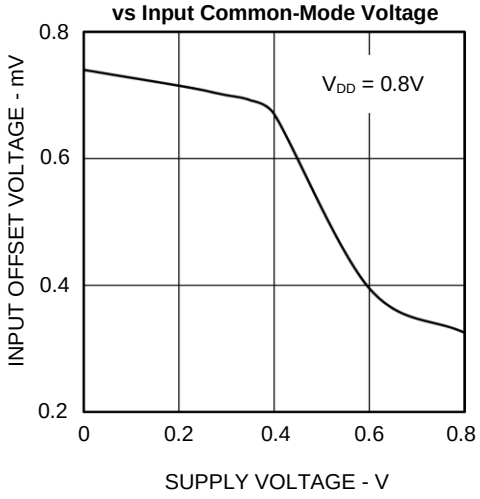
Comparator Input Offset Voltage vs Supply Voltage



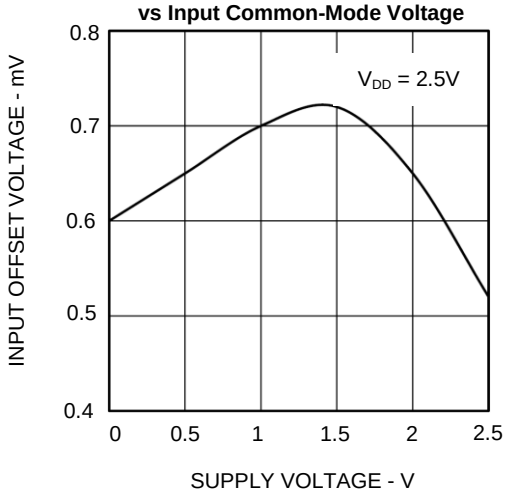
TYPICAL PERFORMANCE CHARACTERISTICS

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

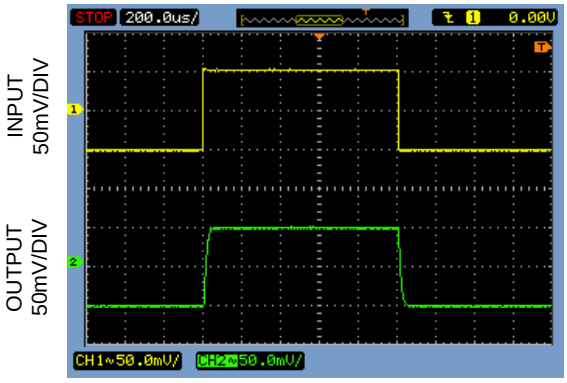
Op Amp Input Offset Voltage vs Input Common-Mode Voltage



Op Amp Input Offset Voltage vs Input Common-Mode Voltage

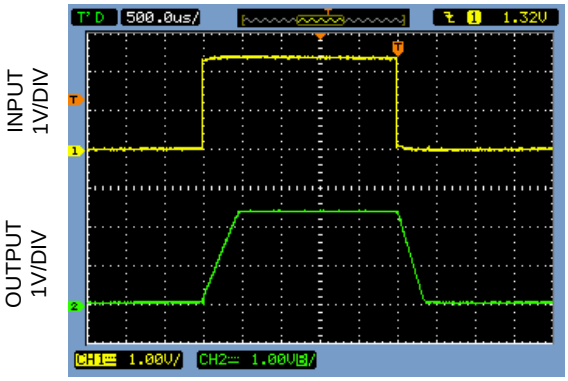


TS12011
Op Amp Small-Signal Transient Response
V_{DD} = 2.5V, R_{LOAD} = 100kΩ, C_{LOAD} = 15pF



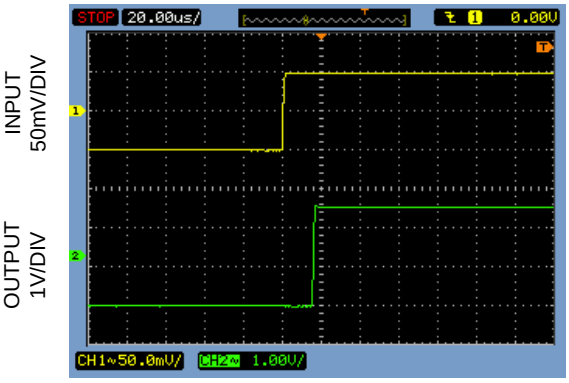
200µs/DIV

TS12011
Op Amp Large Signal Transient Response
V_{DD} = 2.5V, R_{LOAD} = 100kΩ, C_{LOAD} = 15pF



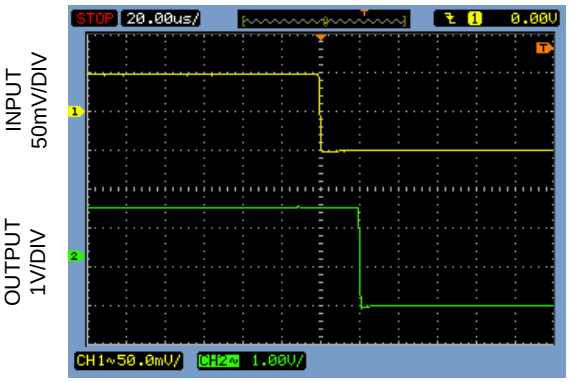
500µs/DIV

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



20µs/DIV

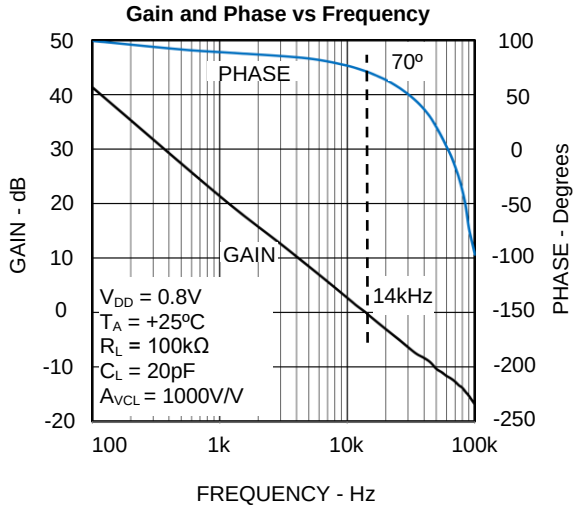
TS12011
Comparator Propagation Delay (T_{PD-})
V_{DD} = 2.5V, $V_{OVERDRIVE}$ = 100mV, C_{LOAD} = 15pF



20µs/DIV

TYPICAL PERFORMANCE CHARACTERISTICS

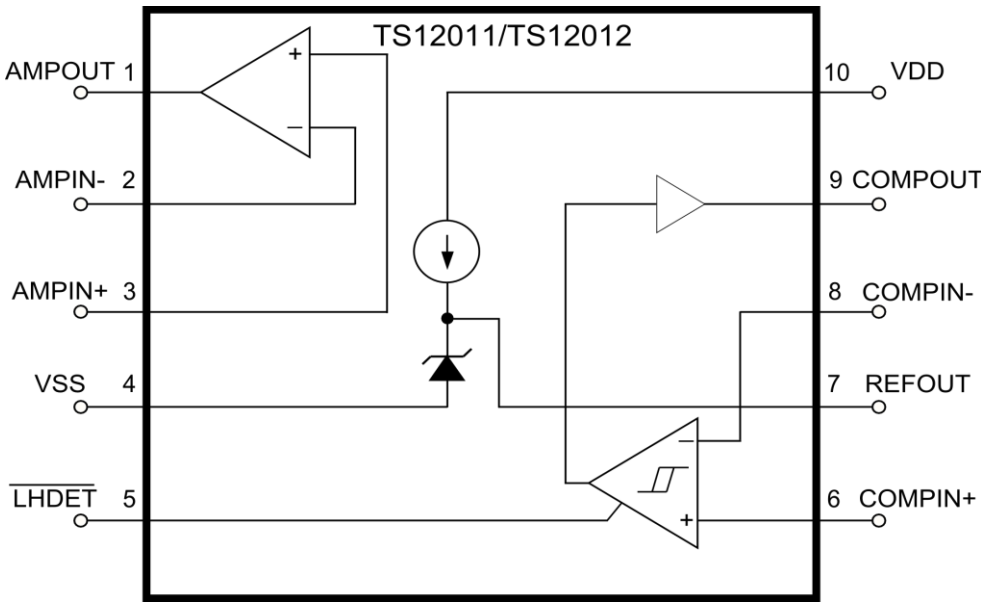
V_{DD} = 2.5V; V_{SS} = 0V; V_{AMPOUT} = HiZ; $V_{COMPOUT}$ = HiZ, unless otherwise noted. Typical values are at T_A = +25°C.



PIN FUNCTIONS

PIN	NAME	FUNCTION
1	AMPOUT	Amplifier Output
2	AMPIN-	Amplifier Inverting Input
3	AMPIN+	Amplifier Non-inverting Input
4	VSS	Negative Supply Voltage.
5	$\overline{\text{LHDET}}$	Latch Enable Pin. When $\overline{\text{LHDET}}$ is set HIGH, the output of the comparator will toggle normally based on the inputs to the comparator. For instance, when $\overline{\text{LHDET}}$ is set LOW and the TS12011 output is HIGH, the output will remain HIGH despite any changes to the input of the comparator. The output will once again respond to changes to the input when $\overline{\text{LHDET}}$ is toggled HIGH. If the output of the comparator is initially LOW and the $\overline{\text{LHDET}}$ is then LOW, the output will stay LOW. If a LOW-to-HIGH transition occurs on the output, the output will switch to HIGH and stay HIGH and not respond to any changes at the input. The $\overline{\text{LHDET}}$ pin must always be set to a known state. The TS12012 output is the inverted version of the TS12011 output. For unlatched comparator operation, set $\overline{\text{LHDET}}$ to HIGH.
6	COMPIN+	Comparator Non-inverting Input
7	REFOUT	0.58V Reference Output
8	COMPIN-	Comparator Inverting Input
9	COMPOUT	Comparator Output.TS12011 has a push-pull output stage. TS12012 has an open-drain output stage.
10	VDD	Positive Supply Voltage. Connect a 0.1µF bypass capacitor from this pin to analog VSS/GND.
EP	----	Exposed paddle is electrically connected to VSS/GND.

BLOCK DIAGRAM



THEORY OF OPERATION

The TS12011 and TS12012 combine a 0.58V ±4.5% reference, a 20µs analog comparator, and a unity-gain stable operational amplifier in a single package. All three devices operate from a single 0.8V to 2.5V power supply and consume less than 1.6µA total supply current. The TS12011 comparator has a push-pull output stage while the TS12012 comparator has an open-drain output stage that allows for easy output voltage level translation as can occur when driving systems powered with a different power supply rail. Both the analog comparator and the op amp feature a common mode input range from V_{SS} to V_{DD}. The analog comparator exhibits ±7.5mV of internal hysteresis for clean, chatter-free output switching. The internal reference was designed to sink or source up to 0.1µA load currents.

The TS12011 and the TS12012 have a latch enable pin ($\overline{LHDET}$) that allows the output of the comparator to latch to either a HIGH or LOW state under certain conditions. If $\overline{LHDET}$ is set HIGH, the COMPOUT output will respond to the applied comparator input. However, when $\overline{LHDET}$ is set LOW and the TS12011 output is HIGH, COMPOUT will remain HIGH until $\overline{LHDET}$ toggles LOW. When COMPOUT is initially LOW instead, COMPOUT will latch HIGH and remain HIGH on a LOW-to-HIGH transition at the input of the comparator until $\overline{LHDET}$ goes HIGH. The TS12012 output is the inverted version of the TS12011 output. The $\overline{LHDET}$ pin must not be left open and should be connected to V_{DD} for normal unlatched operation or to V_{SS} for latched operation.

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 50pF. The common mode input voltage range extends from V_{SS} to V_{DD} and the input bias current and

input offset current are less than 20nA and 2nA, respectively.

Comparator

The TS12011 and TS12012 analog comparator input stage is robust as it can tolerate input voltages 300mV beyond the power supply rails. To insure clean output switching behavior, the analog comparator features ±7.5mV internal hysteresis. The 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 open drain output stage TS12012 can be connected to supply voltages above V_{DD} to an absolute maximum of 5.5V above V_{SS}. Where wired-OR logic connections are needed, the open-drain output stage makes it easy to use this analog comparator. The TS12011 and the TS12012 can sink 0.5mA and 1.4mA of current, respectively. The TS12011 can source 0.1mA of current.

Reference

The TS12011 and TS12012 on-board 0.58V ±4.5% reference voltage can source and sink 0.1µA and 0.1µA of current and can drive a capacitive load less than 50pF and greater than 50nF with a maximum capacitive load of 250nF. 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 250nF capacitive load, the reference voltage will settle to within specifications in approximately 20ms.

Op-Amp Stability

The TS12011 and TS12012 op-amp is able to drive up to 50pF 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 100kΩ//20pF 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 10MΩ resistor coupled with a 1pF 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 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 were reversed, the figure would be the same with an inverted output. To save cost and external pcb area, an internal ±7.5mV hysteresis circuit was added to the TS12011 and TS12012.

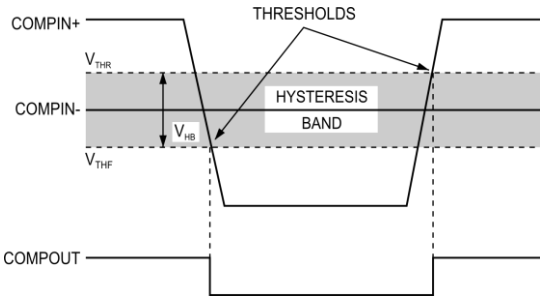


Figure 1. TS12011/TS12012 Threshold Hyesteresis Band

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:

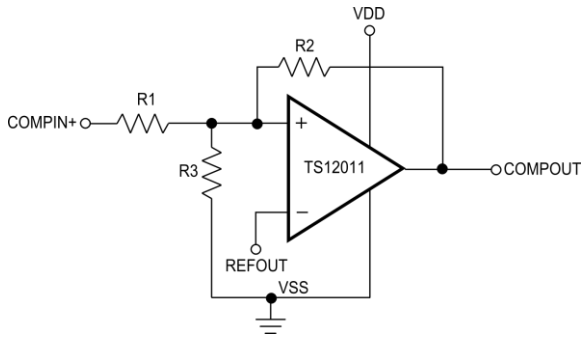


Figure 2. Using Three Resistors Introduces Additional Hysteresis in the TS12011

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: 3.87MΩ and 12.8MΩ - a 4.02MΩ 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 = 4.02MΩ x (100mV/2.5V) = 160.8kΩ.

   The 160kΩ 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 x 160kΩ) - (1/160kΩ) - (1/4.02MΩ)] = 66.43kΩ

   In this example, a 69.8kΩ, 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

   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_{DD} as shown in Figure 3.

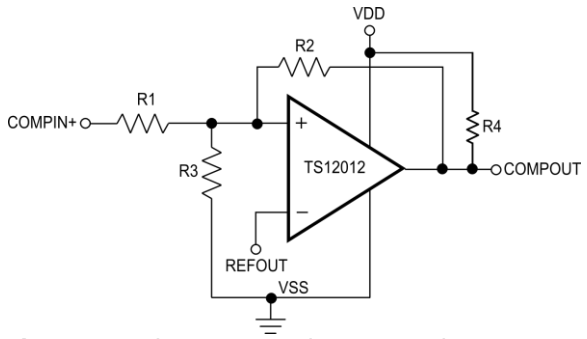


Figure 3. Using Four Resistors Introduces Additional Hysteresis in the TS12012

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 $V_{THR} - V_{THF}$

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 900ºC to 1500ºC, 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.

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.

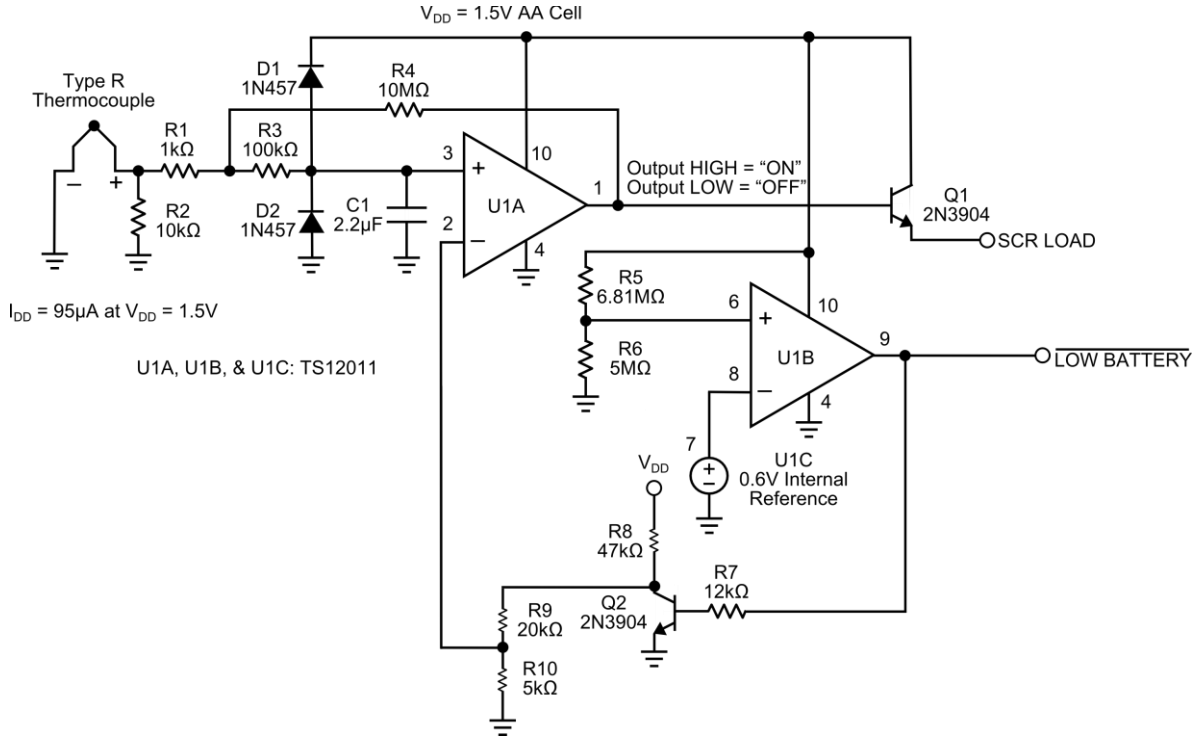
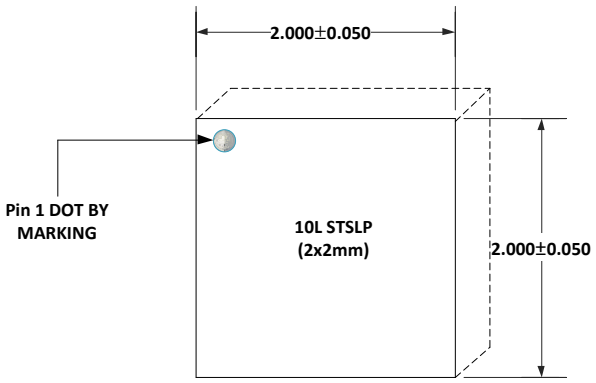


Figure 4. Pilot Light Flame Detector with Low-Battery Lockout Circuit

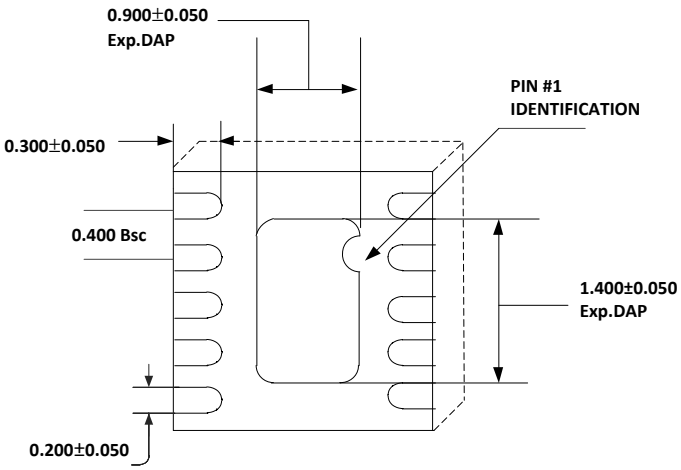
PACKAGE OUTLINE DRAWING

10-Pin TDFN22 Package Outline Drawing

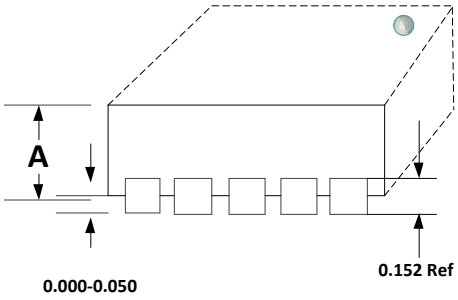
(N.B., Drawings are not to scale)



TOP VIEW



BOTTOM VIEW



SIDE VIEW

NOTE!

- **All dimensions in mm.**
- **This part is compliant with JEDEC MO-229 spec**

A	**MAX.**	**0.600**
	NOM.	**0.550**
	MIN.	**0.500**

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