

General Description

The MAX965-MAX970 single/dual/quad micropower comparators feature rail-to-rail inputs and outputs, and fully specified single-supply operation down to +1.6V. These devices draw less than 5µA per comparator and have open-drain outputs that can be pulled beyond VCC to 6V (max) above ground. In addition, their rail-to-rail input common-mode voltage range makes these comparators suitable for ultra-low-voltage operation.

A +1.6V to +5.5V single-supply operating voltage range makes the MAX965 family of comparators ideal for 2-cell battery-powered applications. The MAX965/MAX967/ MAX968/MAX969 offer programmable hysteresis and an internal 1.235V ±1.5% reference. All devices are available in either space-saving 8-pin µMAX® or 16-pin QSOP packages.

Applications

2-Cell Battery-Powered/Portable Systems Window Comparators Threshold Detectors/Discriminators Mobile Communications Voltage-Level Translation Ground/Supply-Sensing Applications

Selector Guide

PART	INTERNAL REFERENCE	COMPARATORS PER PACKAGE	PROGRAMMABLE HYSTERESIS
MAX965	Yes	1	Yes
MAX966	No	2	No
MAX967	Yes	2	Yes
MAX968	Yes	2	Yes
MAX969	Yes	4	Yes
MAX970	No	4	No

Features

- ♦ Ultra-Low Single-Supply Operation down to +1.6V
- ♦ Rail-to-Rail Common-Mode Input Voltage Range
- ♦ 3µA Quiescent Supply Current per Comparator
- ♦ Open-Drain Outputs Swing Beyond Vcc
- ♦ 1.235V ±1.5% Precision Internal Reference (MAX965/967/968/969)
- ♦ 10µs Propagation Delay (50mV overdrive)
- ♦ Available in Space-Saving Packages: 8-Pin µMAX (MAX965-MAX968) 16-Pin QSOP (MAX969/MAX970)

Ordering Information

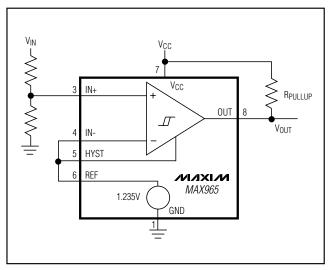
PART	TEMP RANGE	PIN- PACKAGE	PKG CODE
MAX965ESA	-40°C to +85°C	8 SO	S8-2
MAX965EUA-T	-40°C to +85°C	8 μMAX-8	U8-1
MAX966ESA	-40°C to +85°C	8 SO	S8-2
MAX966EUA-T	-40°C to +85°C	8 μMAX-8	U8-1
MAX967ESA	-40°C to +85°C	8 SO	S8-2
MAX967EUA-T	-40°C to +85°C	8 μMAX-8	U8-1

Ordering Information continued on last page.

Pin Configurations appear at end of data sheet.

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Typical Operating Circuit



MIXIM

Maxim Integrated Products 1

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V _{CC})+6V Voltages	8-Pin µMAX (derate 4. 14-Pin SO (derate 8.3)
IN, IN_+, REF, HYST0.3V to (V _{CC} + 0.3V)	16-Pin SO (derate 8.70
OUT0.3V to +6.0V	16-Pin QSOP (derate s
Current into Input Pins±20mA	Operating Temperature F
Duration of OUT_ Short Circuit to GND or V _{CC} Continuous	Storage Temperature Rar
Continuous Power Dissipation	Lead Temperature (solde
8-Pin SO (derate 5.88mW/°C above +70°C) 471mW	•

8-Pin µMAX (derate 4.10mW/°C abo	ove +70°C)330mW
14-Pin SO (derate 8.33mW/°C abov	/e +70°C)667mW
16-Pin SO (derate 8.70mW/°C abov	ve +70°C)696mW
16-Pin QSOP (derate 5.70mW/°C a	bove +70°C)457mW
Operating Temperature Range	40°C to +85°C
Storage Temperature Range	65°C to +150°C
_ead Temperature (soldering, 10s)	+300°C

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 conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

 $(V_{CC} = +1.6 \text{V to } +5.5 \text{V}, T_A = T_{MIN} \text{ to } T_{MAX}, \text{ unless otherwise noted. Typical values are at } V_{CC} = 3 \text{V} \text{ and } T_A = +25 ^{\circ} \text{C.})$

PARAMETER	SYMBOL	C	MIN	TYP	MAX	UNITS		
POWER SUPPLIES	1			1				
		All packages, T _A = 0°C to +85°C			1.6		5.5	
Supply Voltage Range	Vcc	SO/QSOP packag	ges, T _A = -4	0°C to +85°C	1.7		5.5	V
		μMAX package,	$T_A = -40^{\circ}C t$	o +85°C	1.8		5.5	
Comparator Minimum Operating Voltage				1.0		V		
		MAX965				7.0	12	
		MAX966				6.0	10	
Supply Current	Icc	MAX967/MAX968	3			10	16	μΑ
		MAX969				14	22	
		MAX970				11	18	
Power-Up Time (V _{CC} to output valid)		V _{CC} stepped 0V		20		μs		
COMPARATOR		1		I.				
Power-Supply Rejection Ratio	PSRR	1.7V ≤ V _{CC} ≤ 5.5°	V			0.1	1.0	mV/V
Common-Mode Voltage Range	V _{CMR}	T _A = +25°C		-0.25		Vcc	V	
Common-wode voltage hange	VCMR	$T_A = -40^{\circ}C \text{ to } +8$	5°C		-0.25	V	CC - 0.25	V
		Common-mode	SO package				3.0	
		range = -0.25V	QSOP pad	QSOP package			4.0	
		to 1.3V,	μMAX	0°C to +85°C			4.0	
Input Offset Voltage	Vos	V _{CC} > 1.8V	package	-40°C to +85°C			6.0	mV
input Onset Voltage	VUS		SO package				7.0	1111
		Full common-	QSOP package				10.0	
		mode range	μMAX	0°C to +85°C			10.0	
			package	-40°C to +85°C			15.0	
Input Hysteresis	V _{HYST}	HYST = REF				±1		mV
Input Bias Current	IB	Common-mode range = -0.25V to (V _{CC} - 0.25V)			0.001	±5	nA	
input bias Guitetit		Full common-mode range, T _A = +25°C				0.001	±50	11/ \
Input Offset Current	los					0.2		рА
Input Capacitance	CIN					7.0		pF

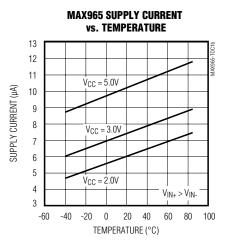
ELECTRICAL CHARACTERISTICS (continued)

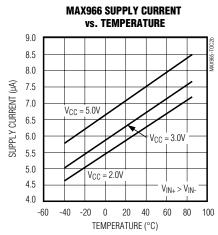
 $(V_{CC} = +1.6V \text{ to } +5.5V, T_A = T_{MIN} \text{ to } T_{MAX}, \text{ unless otherwise noted.}$ Typical values are at $V_{CC} = 3V \text{ and } T_A = +25^{\circ}C.)$

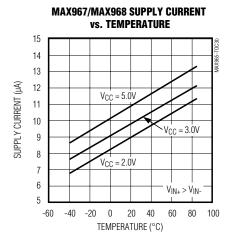
PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS	
Common-Mode Rejection Ratio	CMRR			1.5	4.0	mV/V		
HYST Input Voltage Range			V _{REF} - 0.05		VREF	V		
HYST Input Leakage	I _{HYST}					±10	nA	
Hysteresis Gain					1.0		V/V	
Input Voltage Noise	en	$f = 100Hz$ to $100kHz$, $C_{REF} =$	= 1000pF		10		μVRMS	
OUT Output Voltage Low	Voi	I _{OUT} = 100μA, 1.6V < V _{CC} <			0.2	V		
Oo'i Output Voltage Low	V _{OL}	I _{OUT} = 500μA, 2.7V < V _{CC} <			0.4	\ \ \		
OUT Output Leakage Current	li = Air	V _{CC} = 5.5V, V _{OUT} = 5.5V			1	100	nA	
OUT Output Leakage Current	ILEAK	V _{CC} = 1.6V, V _{OUT} = 1.6V						
Propagation Dolov	ton	$R_{PULLUP} = 1M\Omega,$	10mV overdrive		20		110	
Propagation Delay	t _{PD} -	$C_{LOAD} = 15pF$, high to low	50mV overdrive		10		- µs	
REFERENCE								
		SO package		1.125	1.235	1.255		
Reference Voltage	VREF	QSOP package	1.205	1.235	1.265	5 V		
Reference voltage	VREF	μMAX package, T _A = 0°C to +85°C		1.205	1.235		1.265	
		μMAX package, T _A = -40°C	1.185	1.235	1.285			
Source Current	I _{REF+}	HYST = REF	15	50		μΑ		
Sink Current	I _{REF-}		200	400		nA		
Output Voltage Noise		$f = 100Hz$ to $100kHz$, $C_{REF} =$		10		μVRMS		

Typical Operating Characteristics

 $(V_{CC} = +3.0V, R_{PULLUP} = 100k\Omega, V_{CM} = 0V, T_A = +25^{\circ}C, unless otherwise noted.)$

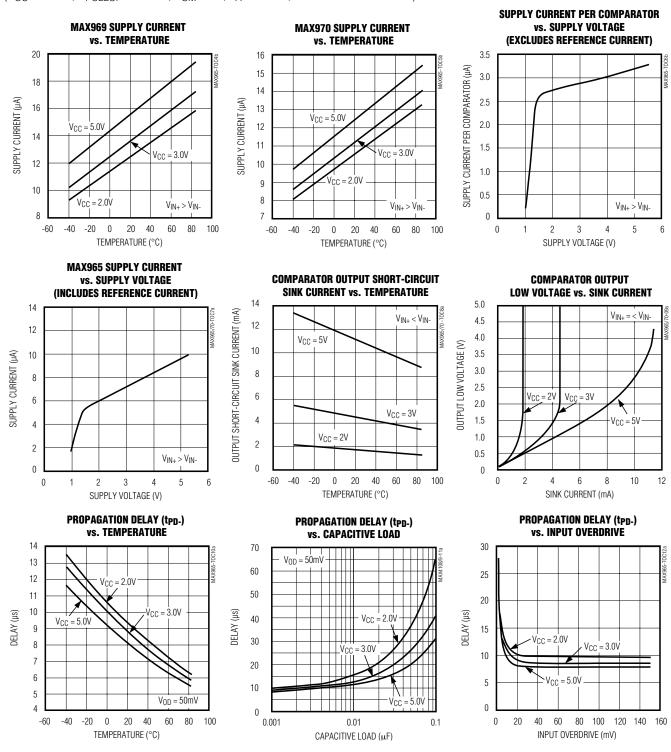






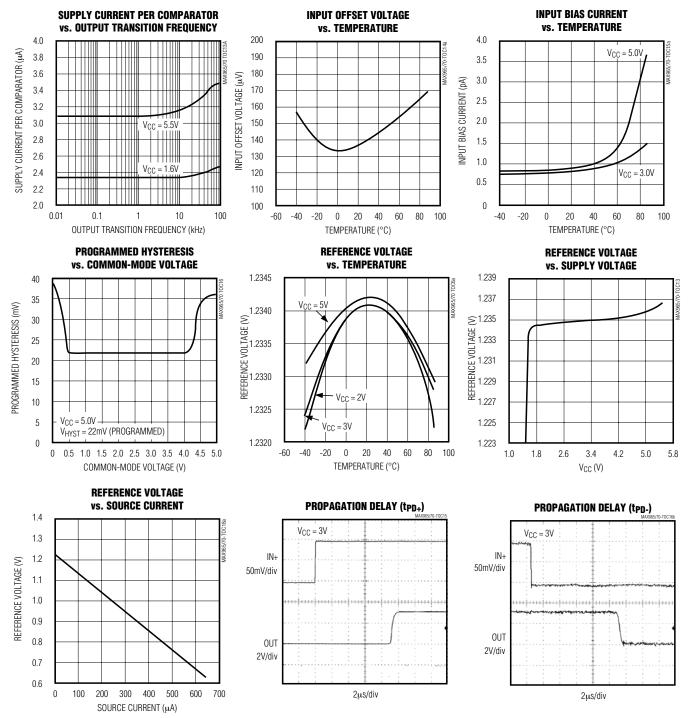
Typical Operating Characteristics (continued)

 $(V_{CC} = +3.0V, R_{PULLUP} = 100k\Omega, V_{CM} = 0V, T_A = +25^{\circ}C, unless otherwise noted.)$



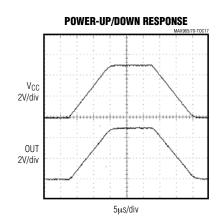
Typical Operating Characteristics (continued)

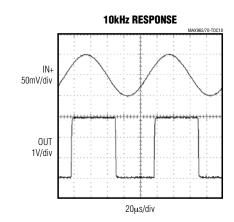
 $(V_{CC} = +3.0V, R_{PULLUP} = 100k\Omega, V_{CM} = 0V, T_A = +25^{\circ}C, unless otherwise noted.)$



_Typical Operating Characteristics (continued)

 $(VCC = +3.0V, RPULLUP = 100k\Omega, VCM = 0V, TA = +25°C, unless otherwise noted.)$





Pin Descriptions

MAX965-MAX968

, 1,1000	MANGOO					
	PIN		PIN		NAME	FUNCTION
MAX965	MAX966	MAX967	MAX968	NAME	FUNCTION	
_	1	1	1	OUTA	Comparator A Open-Drain Output	
1	2	2	2	GND	Ground	
2	_	_	_	N.C.	No Connection. Not internally connected.	
3	_	_	_	IN+	Comparator Noninverting Input	
_	3	3	3	INA+	Comparator A Noninverting Input	
4	_	_	_	IN-	Comparator Inverting Input	
_	4	_	_	INA-	Comparator A Inverting Input	
_	5	_	4	INB-	Comparator B Inverting Input	
_	6	4	_	INB+	Comparator B Noninverting Input	
5	_	5	5	HYST	Hysteresis Input. Connect HYST to REF if not used. Input voltage range is from V_{REF} to $(V_{REF}$ - 50mV).	
6	_	6	6	REF	Internal Reference Output. Typically 1.235V with respect to GND.	
7	7	7	7	Vcc	Positive Supply Voltage, +1.6V to +5.5V	
8	_	_	_	OUT	Comparator Open-Drain Output	
_	8	8	8	OUTB	Comparator B Open-Drain Output	

Pin Descriptions (continued)

MAX969/MAX970

	PIN				
MAYOO	MAX970		NAME	FUNCTION	
MAX969	so	QSOP			
1	1	1	OUTB	Comparator B Open-Drain Output	
2	2	2	OUTA	Comparator A Open-Drain Output	
3	3	3	VCC	Positive Supply Voltage, +1.6V to +5.5V	
4	4	4	INA-	Comparator A Inverting Input	
5	5	5	INA+	Comparator A Noninverting Input	
6	6	6	INB-	Comparator B Inverting Input	
7	7	7	INB+	Comparator B Noninverting Input	
_	_	8, 9	N.C.	No Connection. Not internally connected.	
8	_	_	REF	Internal Reference Output. Typically 1.235V with respect to GND.	
9	_	_	HYST	Hysteresis Input. Connect to REF if not used. Input voltage range is from (V _{REF} - 50mV) to V _{REF} .	
10	8	10	INC-	Comparator C Inverting Input	
11	9	11	INC+	Comparator C Noninverting Input	
12	10	12	IND-	Comparator D Inverting Input	
13	11	13	IND+	Comparator D Noninverting Input	
14	12	14	GND	Ground	
15	13	15	OUTD	Comparator D Open-Drain Output	
16	14	16	OUTC	Comparator C Open-Drain Output	

Detailed Description

The MAX965–MAX970 single/dual/quad, micropower, ultra-low-voltage comparators feature rail-to-rail inputs and outputs and an internal 1.235V $\pm 1.5\%$ bandgap reference. These devices operate from a single +1.6V to +5.5V supply voltage range, and consume less than 5µA supply current per comparator over the extended temperature range. Internal hysteresis is programmable up to $\pm 50 \text{mV}$ using two external resistors and the device's internal reference. The rail-to-rail input common-mode voltage range and the open-drain outputs allow easy voltage-level conversion for multivoltage systems. All inputs and outputs can tolerate a continuous short-circuit fault condition to either rail.

The MAX965 is a single comparator with adjustable hysteresis and a reference output pin. The MAX966 is a dual comparator without the reference and without adjustable hysteresis. The MAX967 is a dual compara-

tor configured as a dual voltage monitor with common hysteresis adjustment and a reference output. The dual MAX968 is similar to the MAX967, but is configured as a window comparator. The MAX969 is a quad comparator with a common hysteresis adjustment and a reference output pin. The MAX970 is a quad comparator without a reference and without hysteresis adjustment. (See Functional Diagrams and Selector Guide.)

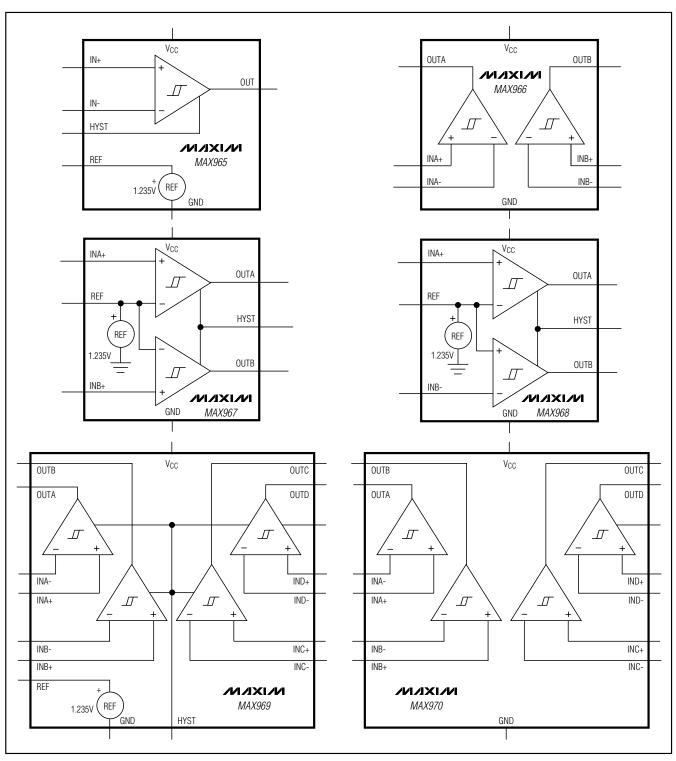
Comparator Input

The MAX965–MAX970 have a -0.25V to VCC input common-mode range. Both comparator inputs may operate at any differential voltage within the common-mode voltage range, and the comparator displays the correct output logic state.

Low-Voltage Operation: Vcc Down to 1V

The minimum operating voltage is 1.6V. As the supply voltage falls below 1.6V, performance degrades and supply current falls. The reference does not





8 ______ **/\| X\| /**

function below about 1.5V, although the comparators typically continue to operate with a supply voltage as low as 1V. At low supply voltages (<1.6V), the input common-mode range remains rail-to-rail, but the comparator's output sink capability is reduced and propagation delay increases (see *Typical Operating Characteristics*).

Figure 1 shows a typical comparator application that monitors V_{CC} at 1.6V. Resistor divider R1/R2 sets the voltage trip point (V_{TRIP}) at 1.6V. As V_{CC} drops below 1.6V and approaches 1V, the reference voltage typically falls below the divider voltage (V+). This causes the comparator output to change state. If OUT's state must be maintained under these conditions, a latching circuit is required.

Comparator Output

The MAX965–MAX970 contain a unique slew-rate-controlled output stage capable of rail-to-rail operation with an external pull-up resistor. Typical comparators consume orders of magnitude more current during switching than during steady-state operation. With the MAX965 family of comparators, during an output transition from high to low, the output slew rate is limited to minimize switching current.

Voltage Reference

With VCC greater than 1.6V but less than 5.5V, the internal 1.235V bandgap reference is $\pm 1.5\%$ accurate over the commercial temperature range and $\pm 2.5\%$ accurate over the extended temperature range. The REF output is typically capable of sourcing 50µA. To reduce reference noise or to provide noise immunity, bypass REF with a capacitor (0.1nF to 0.1µF).

V_{CC} 1.6V V_{REF} V_{+} V_{+} V_{REF} V_{+} V_{+

Figure 1. Operation below 1.6V

Noise Considerations

The comparator has an effective wideband peak-to-peak noise of around $10\mu V$. The voltage reference has peak-to-peak noise approaching 1.0mV with a $0.1\mu F$ bypass capacitor. Thus, when a comparator is used with the reference, the combined peak-to-peak noise is about 1.0mV. This, of course, is much higher than the individual components' RMS noise. Avoid capacitive coupling from any output to the reference pin. Crosstalk can significantly increase the references' actual noise.

_Applications Information

Hysteresis

Many comparators oscillate in the linear region of operation because of noise or undesired parasitic feedback. This tends to occur when the voltage on one input is equal or very close to the voltage on the other input. The MAX965–MAX970 have internal hysteresis to counter parasitic effects and noise. In addition, with the use of external resistor, the MAX965/MAX967/MAX968/MAX969's hysteresis can be programmed to as much as ±50mV (see the section *Adding Hysteresis to the MAX965/MAX967/MAX968/MAX969*).

The hysteresis in a comparator creates two trip points: one for the rising input voltage and one for the falling input voltage (Figure 2). The difference between the trip points is the hysteresis. When the comparator's input voltages are equal, the hysteresis effectively causes one comparator input voltage to move quickly past the other, thus taking the input out of the region where oscillation occurs.

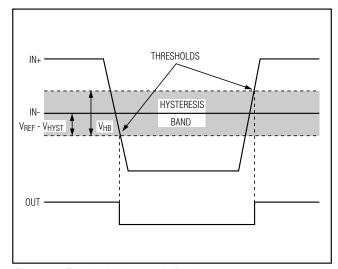


Figure 2. Threshold Hysteresis Band

Figure 2 illustrates the case in which IN- has a fixed voltage applied, and IN+ is varied. If the inputs were reversed, the figure would be the same, except with an inverted output.

Adding Hysteresis to the MAX965/MAX967/MAX968/MAX969

To add hysteresis to the MAX965/MAX967/MAX968/MAX969, connect resistor R1 between REF and HYST, and connect resistor R2 between HYST and GND (Figure 3). If additional hysteresis is not required, connect HYST to REF. When hysteresis is added, the upper and lower trip points change by the same amount in opposite directions. The hysteresis band (the difference between the upper and lower trip points, VHB) is approximately twice the voltage between HYST and REF. The HYST input voltage range is from REF down to (REF - 50mV). This yields a hysteresis band from ±1mV to a maximum of ±50mV. Calculate the values of R1 and R2 for the desired hysteresis band with the following formulas:

 $R1 = V_{HB} / I_{REF}$ $R2 = (V_{REF} - V_{HB}) / I_{REF}$

where IREF (the current sourced by the reference) does not exceed the REF source capability (12 μ A typical), and is significantly larger than the HYST leakage current (5nA typical). IREF values between 0.1 μ A and 4 μ A are good choices. If 2.4M Ω is chosen for R2 (IREF = 0.5 μ A), the equation for R1 and VHB can be approximated as:

$$R1(k\Omega) = 2 \times V_{HB} (mV)$$

In the MAX967/MAX968/MAX969, the HYST pin programs the same hysteresis for all comparators in the package.

+1.6V TO +5.5V

REF VCC

MAX965

MAX967

MAX968

MAX969

HYST

GND

Figure 3. Programming the HYST Pin

Due to the internal structure of the input developed for ultra-low-voltage operation, the hysteresis band varies with common-mode voltage. The graph Programmed Hysteresis vs. Common-Mode Voltage in the Typical Operating Characteristics shows this variation. Notice that the hysteresis band increases to almost twice the calculated value toward the ends of the common-mode range. This is apparent only when programming additional hysteresis using the HYST pin. The hysteresis band is constant when HYST is connected to REF.

Adding Hysteresis to the MAX966/MAX970

The MAX966/MAX970 do not have a HYST pin for programming hysteresis. Hysteresis can be generated with three resistors using positive feedback (Figure 4). This method generally draws more current than the method using the HYST pin on the MAX965/MAX967/MAX968/MAX969. Also, the positive feedback method slows hysteresis response time. Use the following procedure to calculate the resistor values:

 Select R3. The leakage current of IN+ is under 5nA, so the current through R3 should be at least 500nA to minimize errors caused by leakage current. The current through R3 at the trip point is (VREF - VOUT) / R3. Taking into consideration the two possible output states and solving for R3 yields two formulas:

$$R3 = V_{REF} / 500nA$$

and

$$R3 = (V_{REF} - V_{CC}) / 500nA$$

Use the smaller of the two resulting resistor values. For example, if $V_{REF}=1.2V$ and $V_{CC}=5.0V$, then the two resistor values are $2.4M\Omega$ and $7.6m\Omega$. For R3, choose the $2.2M\Omega$ standard value.

2) Choose the hysteresis band required (V_{HB}). For this example, choose 50mV.

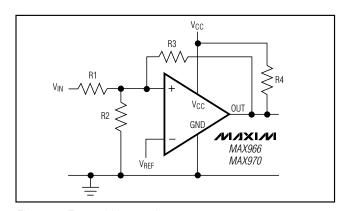


Figure 4. External Hysteresis

- 3) Calculate R1: R1 = (R3 + R4) x (V_{HB} / V_{CC}). Putting in the values for this example, R1 = $(2.2M\Omega + 10k\Omega)$ x (50mV / 5.0V) = $22.1k\Omega$.
- 4) Choose the trip point for V_{IN} rising. This is the threshold voltage where the comparator output transitions from low to high as V_{IN} rises above the trip point. For this example, choose 3.0V.
- 5) Calculate R2 as follows:

$$R2 = \frac{1}{\left(\frac{V_{THR}}{V_{REF} \times R1}\right) - \frac{1}{R1} - \frac{1}{R3 + R4}}$$

$$R2 = \frac{1}{\left(\frac{3.0V}{1.2 \times 22k\Omega}\right) - \frac{1}{22k\Omega} - \frac{1}{2.2M\Omega + 10k\Omega}} = 14.76k\Omega$$

where V_{THR} is the rising-voltage trip threshold. Choose a standard value of 15k Ω .

6) Verify trip voltages and hysteresis as follows:

V_{IN} rising:

$$V_{THR} = V_{REF} \times R1 \times \left(\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3 + R4}\right)$$

V_{IN} falling:

$$V_{THF} = V_{THR} - \left(\frac{R1 \times V_{CC}}{R3 + R4}\right)$$

Hysteresis = $V_{THR} - V_{THF}$

where V_{THR} is the rising-voltage trip point, and V_{THF} is the falling-voltage trip point.

Circuit Layout and Bypassing

Power-supply bypass capacitors are not needed if supply impedance is low, but 100nF bypass capacitors should be used when supply impedance is high or when supply leads are long. Minimize signal lead lengths to reduce stray capacitance between the input and output that might cause instability.

IR Receiver

Figure 5 shows an application using the MAX965 as an infrared receiver. The infrared photodiode creates a current relative to the amount of infrared light present. This current creates a voltage across R1. When this voltage level crosses the reference voltage applied to the inverting input, the output transitions. Optional R3 provides additional hysteresis for noise immunity.

2-Cell to TTL Logic-Level Shifter

Figure 6 shows an application using the MAX965 to convert a 2-cell voltage-level signal into a TTL-compatible signal. The supply voltage for the comparator comes from the 2-cell supply. The output is pulled up to a 5V supply.

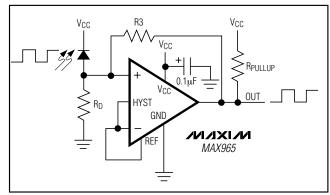


Figure 5. IR Receiver

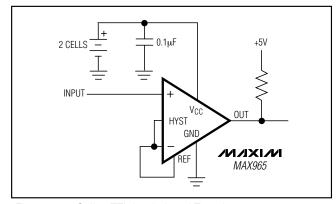
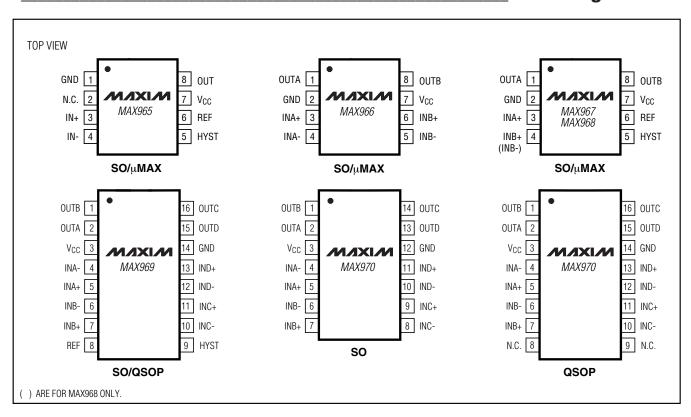


Figure 6. 2-Cell to TTL Logic-Level Translator

_Pin Configurations



_Ordering Information (continued)

PART	TEMP RANGE	PIN- PACKAGE	PKG CODE	
MAX968ESA	-40°C to +85°C	8 SO	S8-2	
MAX968EUA-T	-40°C to +85°C	8 μMAX-8	U8-1	
MAX969ESE	-40°C to +85°C	16 Narrow SO	S16-1	
MAX969EEE	-40°C to +85°C	16 QSOP	E16-1	
MAX970ESD	-40°C to +85°C	14 SO	S14-4	
MAX970EEE	-40°C to +85°C	16 QSOP	E16-1	

Chip Information

TRANSISTOR COUNTS:

MAX965 = 216

MAX966 = 190

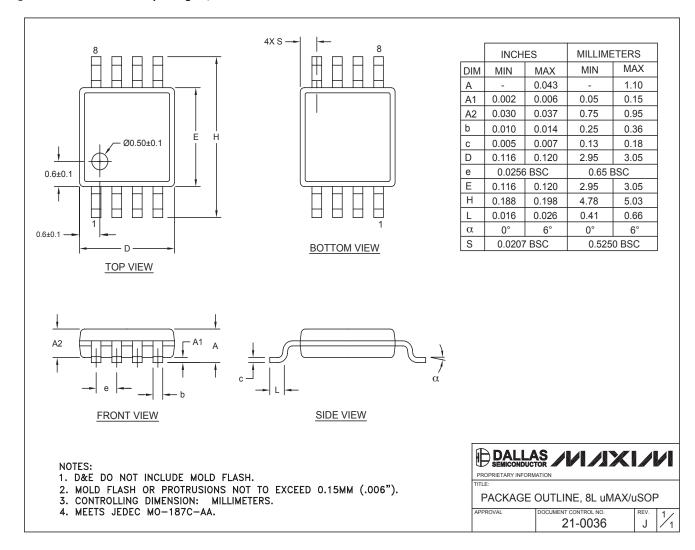
MAX967/MAX968 = 299

MAX969 = 465

MAX970 = 380

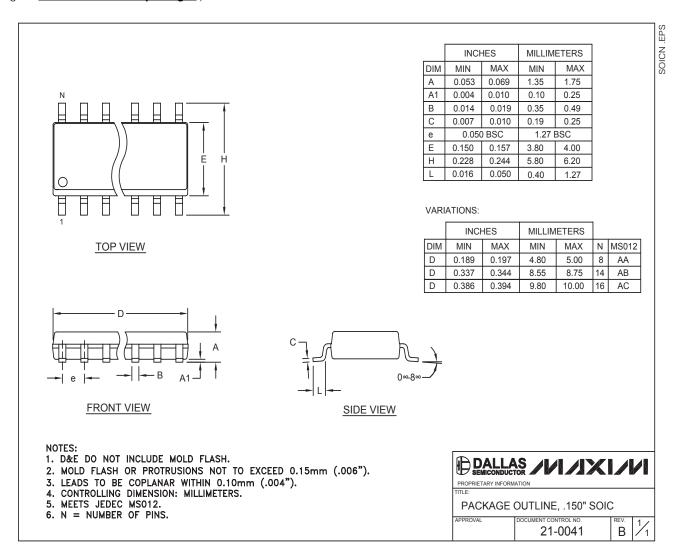
Package Information

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information go to www.maxim-ic.com/packages.)



Package Information (continued)

(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information go to www.maxim-ic.com/packages.)



_Revision History

Pages changed at Rev 3: 1-7, 9, 11, 12, 14

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