Keywords: comparators, comparaters, hysteresis, histeresis, rail to rail, beyond the rails

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APPLICATION NOTE 886

Selecting the Right Comparator

Abstract: This application note describes comparator features and specifications as well as the differences between comparators and op amps. It also includes circuits that combine comparators and an internal reference, dual comparators used in window applications, and a quad comparator used to resolve a voltage or current measurement into one of four ranges.

The comparator often stands in the shadow of its big brother, the operational amplifier (op amp). Its humble status is offset by the features which distinguish modern comparators and make them ideal for their basic task: comparing two voltages. This article explains comparator features and describes the parameters that should be considered when selecting comparators.

The Function of a Comparator

A comparator accepts two analog signals and produces a binary signal at the output, a function of which input voltage is higher. The output signal remains constant as the differential input voltage changes. When described that way, the comparator resembles a 1-bit ADC.

Comparing Comparators and Op Amps

An op amp running without negative feedback can serve as a comparator, because its high voltage gain enables it to resolve very small differences in input voltage. Op amps used this way are generally slower than comparators and lack other special features, such as hysteresis and internal references.

Comparators cannot generally be used as op amps. They are trimmed to provide excellent switching times at the expense of the frequency-response correction that makes op amps so versatile. The internal hysteresis employed in many comparators, which prevents oscillation at the output, also prevents their use as op amps.

Supply Voltage

Comparators operate with the same supply voltages used by op amps. Many older comparators require bipolar (e.g., ±15V) or unipolar supply voltages as high as 36V. These supply voltages are still used in industrial applications.

For most new applications, however, the comparator operates within the range of low unipolar voltages typically found in battery-operated devices. Modern applications for comparators require low current consumption, small packages, and (in some cases) a shutdown function. The MAX919, MAX9119, and MAX9019 comparators, for example, work with voltages from 1.6V or 1.8V to 5.5V, draw a maximum of 1.2µA/1.5µA over the entire temperature range, and are available in a SOT23 and SC70 packages. The MAX965 and MAX9100 families of comparators operate with supply voltages as low as 1.6V and 1.0V, respectively. See **Table 1**.

Table 1. MAX9015-MAX9020 Selection Guide

Part	Comparator(s)	Int. Reference (V)	Output	Supply Current (µA)
MAX9015A	1	1.236, ±1%	Push-pull	1
MAX9016A	1	1.236, ±1%	Open drain	1
MAX9017A	2	1.236, ±1%	Push-pull	1.2
MAX9017B	2	1.24, ±1.75%	Push-pull	1.2
MAX9018A	2	1.236, ±1%	Open drain	1.2
MAX9018B	2	1.24, ±1.75%	Open drain	1.2
MAX9019	2	-	Push-pull	0.85
MAX90120	2	-	Open drain	0.85

Comparators in Tiny Packages

Nano-powered comparators in space-saving chip-scale packages (UCSP) with a low 1µA supply current, such as the MAX9025-MAX9098 families, are ideal for ultra-low-power system applications. Available in small 5-pin SC70 packages, the MAX9117-MAX9120 single-comparator families feature an ultra-low 600nA supply current with two outputs from which to select, push-pull or open-drain. See **Table 2**. These comparators are ideal for all 2-cell battery-monitoring/management applications.

Table 2. Tiny Space-Saving Comparators

Package	Part	Comparator(s)	Int. Reference	Output	Supply Current (µA)
6-UCSP	MAX9025	1	√	Push-pull	1.0
6-UCSP	MAX9026	1	√	Open drain	1.0
6-UCSP	MAX9027	1		Push-pull	0.6
6-UCSP	MAX9028	1		Open drain	0.6
5-SC70	MAX9117	1	√	Push-pull	0.6
5-SC70	MAX9118	1	√	Open drain	0.6
5-SC70	MAX9119	1		Push-pull	0.35
5-SC70	MAX9120	1		Open drain	0.35

Basic Comparator Features

A comparator normally changes its output state when the voltage between its inputs crosses through approximately zero volts. Small voltage fluctuations, always present on the inputs, produce very small voltage differences. When the voltage difference is near zero volts, it can cause undesirable changes in the comparator's output state . To prevent this output oscillation, a small hysteresis of a few millivolts is integrated into many modern comparators. In place of one switching point, hysteresis introduces two: one for rising voltages, and one for falling voltages (**Figure 1**). The difference between the higher-level trip value (V_{TRIP+}) and the lower-level trip value (V_{TRIP-}) equals the hysteresis voltage (V_{HYST}). For comparators with hysteresis, the offset voltage (V_{OS}) is simply the mean value of V_{TRIP+} and V_{TRIP-}.

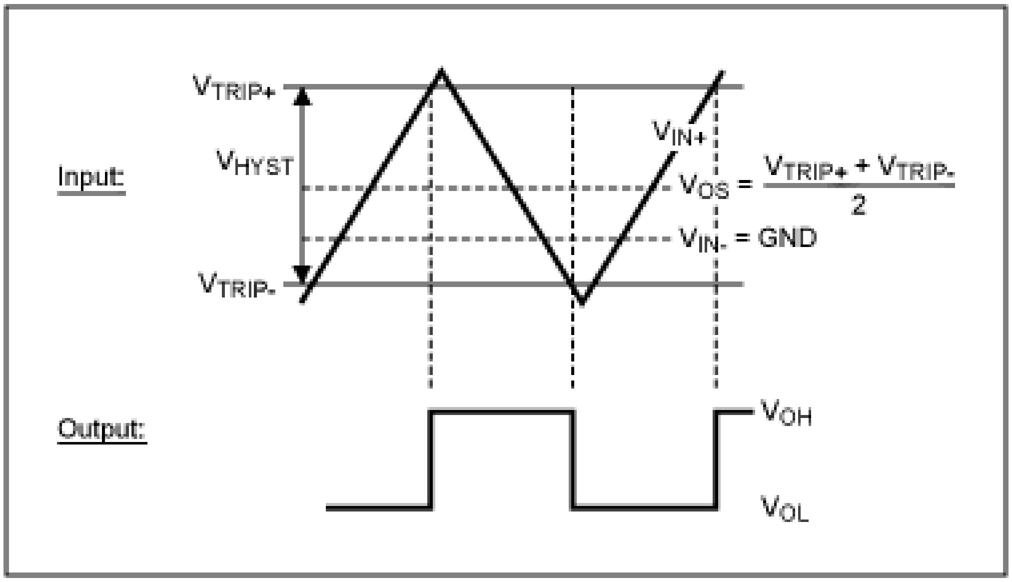

Figure 1. Switch thresholds, hysteresis, and offset voltage.

For comparators without hysteresis, the voltage difference between the inputs needed to switch the comparator is the offset voltage, rather than the zero voltage required by an ideal comparator. However, the offset voltage (and, consequently, the switching voltage) changes with temperature and supply voltage. One measurement of that dependence is the power-supply rejection ratio (PSRR), which shows the relationship between a change in the nominal supply voltage and the resulting change in offset voltage.

The inputs of an ideal comparator exhibit infinitely high input resistance, and thus no current flows into its inputs. For actual comparators, however, the currents that flow into their inputs also flow through the internal resistance of any voltage source that is attached to them, thus generating an error voltage. Bias current (I_{BIAS}) is defined as the median value of the two comparator-input currents. For the MAX917 and MAX9117 comparator families, for example, the maximum I_{BIAS} current is 2nA over the entire temperature range, and less than 1nA at room temperatures, TA = +25°C. See **Table 3**.

Table 3. Low I_{BIAS}

Part	I_{BIAS}
MAX9025—MAX9028	1nA (max) @ TA = +25°C 2nA (max) @ TA = T_{MIN} to T_{MAX}
MAX9117—MAX9120	1nA (max) @ TA = +25°C 2nA (max) @ TA = T_{MIN} to T_{MAX}
MAX917	1nA (max) @ TA = +25°C 2nA (max) @ TA = T_{MIN} to T_{MAX}

As lower supply voltages become common, Maxim expanded the input-voltage range of comparators beyond the supply voltages. Some Maxim comparators employ the parallel switching of two npn/pnp input stages, which has allowed input voltages as high as 250mV beyond each supply rail. Such devices are called Beyond-the-Rail comparators. The range of input common-mode voltages available can be found in the comparator's data sheet.

Comparator Outputs

Because comparators have only two output states, their outputs are near zero or near the supply voltage. Bipolar rail-to-rail comparators have a common-emitter output that produces a small voltage drop between the output and each rail. That drop is equal to the collector-to-emitter voltage of a saturated transistor. When output currents are light, output voltages of CMOS rail-to-rail comparators, which rely on a saturated MOSFET, range closer to the rails than their bipolar counterparts.

One criterion for selecting a comparator is the time its output takes to alter its state after a signal has been applied at its input. This propagation time must account for propagation delay through the component and rise/fall times in the output driver as well. A very fast comparator like the MAX961, and MAX9010-MAX9013, for example, has a typical propagation delay of only 4.5ns or 5ns, and a rise time of 2.3ns and 3ns, respectively. (Remember that the propagation delay measurement includes a portion of the rise time). One should note the different influences that affect propagation time (**Figure 2**). These factors include temperature, load capacitance, and voltage drive in excess of the switching threshold (input overdrive). Propagation time is called t_{PD-} for the inverting input, and t_{PD+} for the noninverting input. The difference between t_{PD+} and t_{PD-} is called skew. Supply voltage also has a strong effect on propagation time.

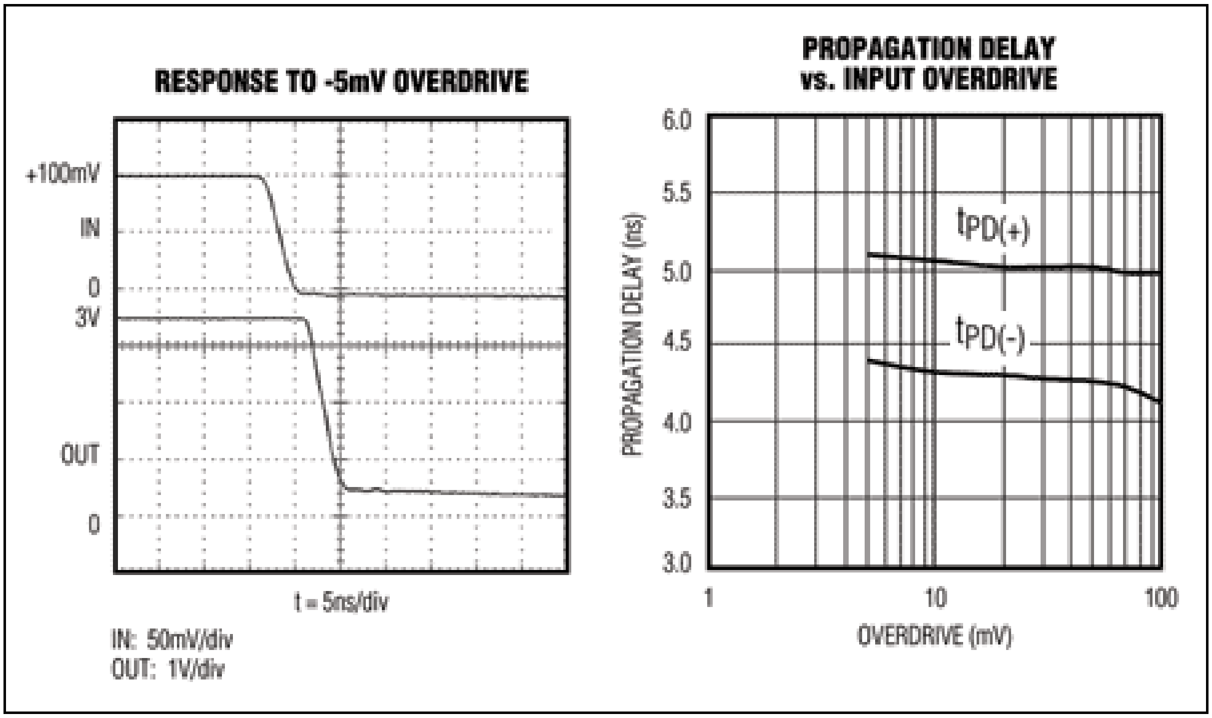

Figure 2. The effect of external influences on propagation time.

For a given application, select either a comparator with high speed or one that saves power. Maxim offers a range of performance for this purpose: from the MAX919 (800nA, 30µs) to the MAX9075 (6µA, 540ns); from the MAX998 (600µA, 20ns) to the MAX961 (11mA, 4.5ns); and from the MAX9107 (350µA, 25ns) to the MAX9010 (900µA, 5ns). The recent MAX9010 (in a SC70 package) represents a useful compromise in these parameters, with a 5ns propagation time and 900µA supply current.

For ultra-high-speed ECL and PECL outputs with 500ps propagation delay, refer to the MAX9600/MAX9601/MAX9602 part families.

Comments about Particular Comparators

The most frequent application for comparators is the comparison between a voltage and a stable reference. Maxim offers various comparators in which a reference voltage is integrated on the chip. Combining the reference and comparator in one chip not only saves space, but also draws less supply current than a comparator with an external reference. The MAX9117 device family, for example, requires only 1.3µA maximum (including reference) over the entire temperature range. The precision of an integrated reference typically ranges from 1% to 4%. For high accuracy, however, references in the MAX9040 family of comparators offer 0.4% initial accuracy and a maximum 30ppm/°C temperature drift.

The MAX9017/MAX9018, MAX923, and MAX933 dual comparators and the open-drain-output MAX973 and MAX983 dual comparators are ideally suited for window-comparator applications. Because the integrated reference within all four of these devices can connect to the comparator's inverting or noninverting input, overvoltage and undervoltage thresholds can be implemented with just three external resistors. These components also provide a hysteresis pin. By adding two additional external resistors, this pin allows the addition of a hysteresis threshold, as shown in Figure 1. Some comparators such as the MAX912/913 offer complementary outputs - i.e., two outputs that transition in the opposite direction of each other for a change of relative input polarity.

Fast propagation delay (1ms typically at 5mV overdrive) makes the MAX9201/MAX9203 ideal for fast ADCs and sampling circuits like receivers, V/F converters, and many other data-discriminating applications.

Other high-speed, low-power comparators like the MAX9107/MAX9108/MAX9109 are low-cost upgrades to the industry-standard comparators, MAX907/MAX908/MAX909. The dual comparator, MAX9107, is offered in a space-saving 8-pin SOT23 package. The single comparator, MAX9109, is available in a tiny 6-pin SC70, while the quad comparator, MAX9108, is offered in a 14-pin TSSOP. See **Table 4** and **Figure 3**.

Table 4. Ultra-Fast Comparators

Speed (ns)	Part	Comparator(s)	Supply Current (A)	Package
4.5	MAX999	1	5m	5-SOT23
4.5	MAX962	2	5m	8-µMAX
5	MAX9010	1	0.9m	6-SC70
5	MAX9011	1	0.9m	6-SOT23
5	MAX9012	2	0.9m	8-µMAX
5	MAX9013	1	0.9m	8-µMAX
7	MAX9201	4	4.7m	16-TSSOP
7	MAX9202	2	2.5m	14-TSSOP
7	MAX9203	1	1.3m	8-SOT23
8	MAX900	4	2.5m	20-SO
8	MAX901	4	2.5m	16-SO
8	MAX902	2	2.5m	14-SO
8	MAX903	1	2.5m	8-SO
10	MAX912	2	6m	16-SO
10	MAX913	1	6m	8-µMAX
25	MAX9107	2	350µ	8-SOT23
25	MAX9108	4	350µ	14-TSSOP
25	MAX9109	1	350µ	6-SC70
40	MAX9140	1	150µ	5-SC70
40	MAX9141	1	165µ	8-SOT23
40	MAX9142	2	150µ	8-SOT23
40	MAX9144	4	150µ	14-TSSOP
40	MAX907	2	700µ	8-SO
40	MAX908	4	700µ	14-SO

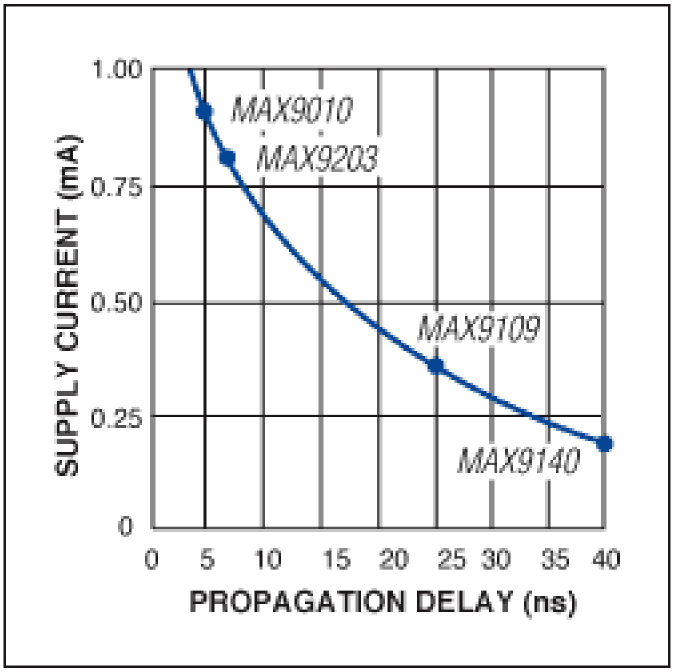

Figure 3. Illustration of the best speed/power choices for a comparator in an SC70 package.

Applications

This section introduces three applications that require comparators.

The first example application is a level shifter from 3V logic to 5V logic. As shown in **Figure 4**, this circuit requires only a single comparator with an open-drain output as in the MAX986. The circuit provides great flexibility in choosing the voltages to be translated. It also allows the translation of bipolar ±5V logic to unipolar 3V logic by using the MAX972. In that application, take care that no voltage exceeds the maximum voltage allowed on any pin and that the current into the output is limited by a sufficiently large-valued pull-up resistor (refer to the MAX986's Absolute Maximum Ratings in its data sheet).

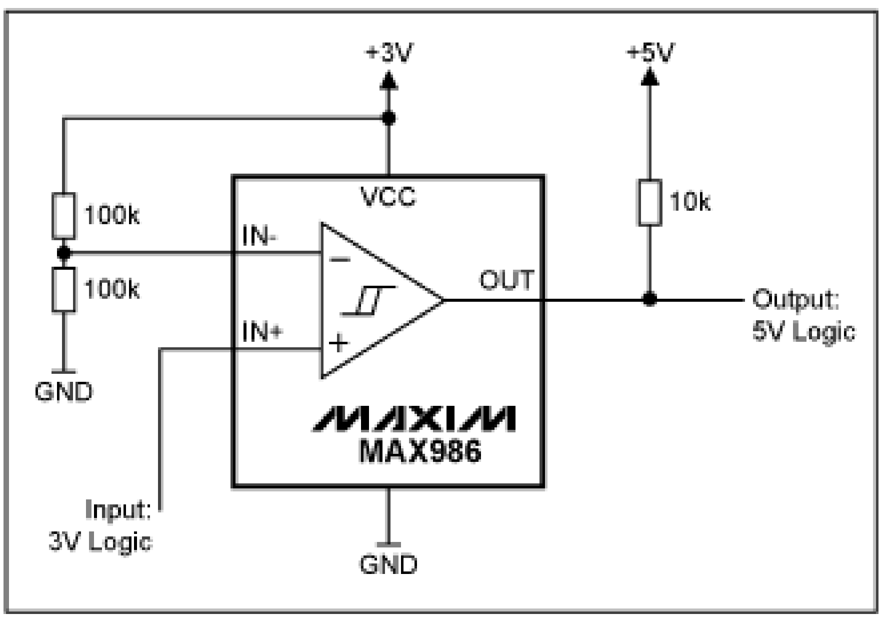

Figure 4. Level translation from 3V to 5V logic.

The circuit of **Figure 5** solves another frequently encountered problem. Configured as shown, a single unipolar comparator converts a bipolar input signal (a sine wave in this case) to a unipolar digital output signal. The required offset voltage is calculated as:

$$V_{OS} = \frac{V_{CC}R_1R_2 + V_2R_1R_3}{R_1R_2 + R_1R_3 + R_2R_3}$$

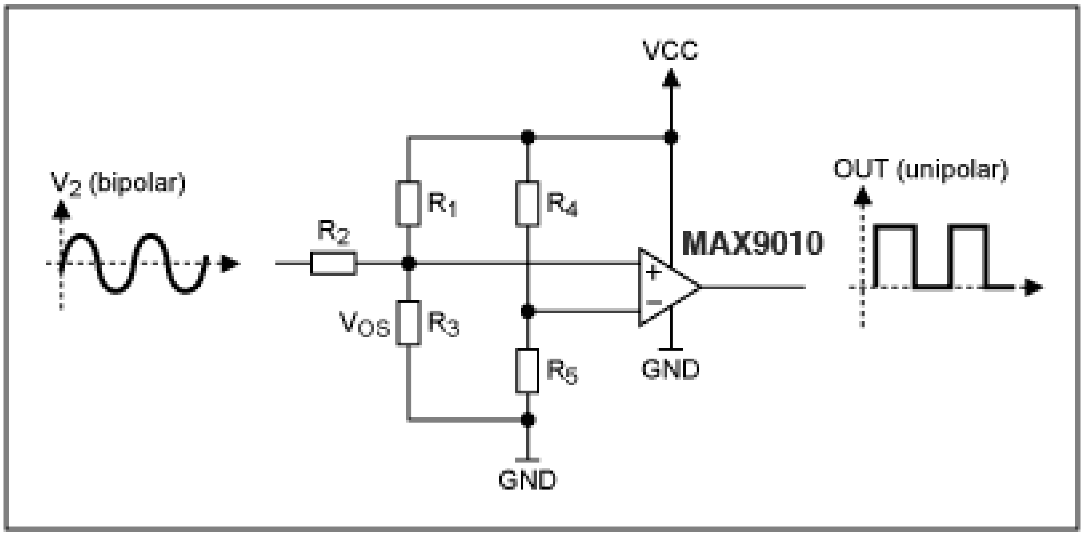

Figure 5. Unipolar comparator with bipolar input signal.

As shown above in Figure 5, two equal-valued resistors (labeled R4) establish the comparator's trip threshold at half the supply voltage. In the circuit of **Figure 6**, four comparator outputs form a thermometer gauge indicating one of four ranges for the input-current level. The shunt resistor converts the input current to a voltage, and resistors R1 and R2 set the op-amp gain as required for the desired level of reference voltage. Resistors R4 to R7 denote thresholds for the desired digital outputs.

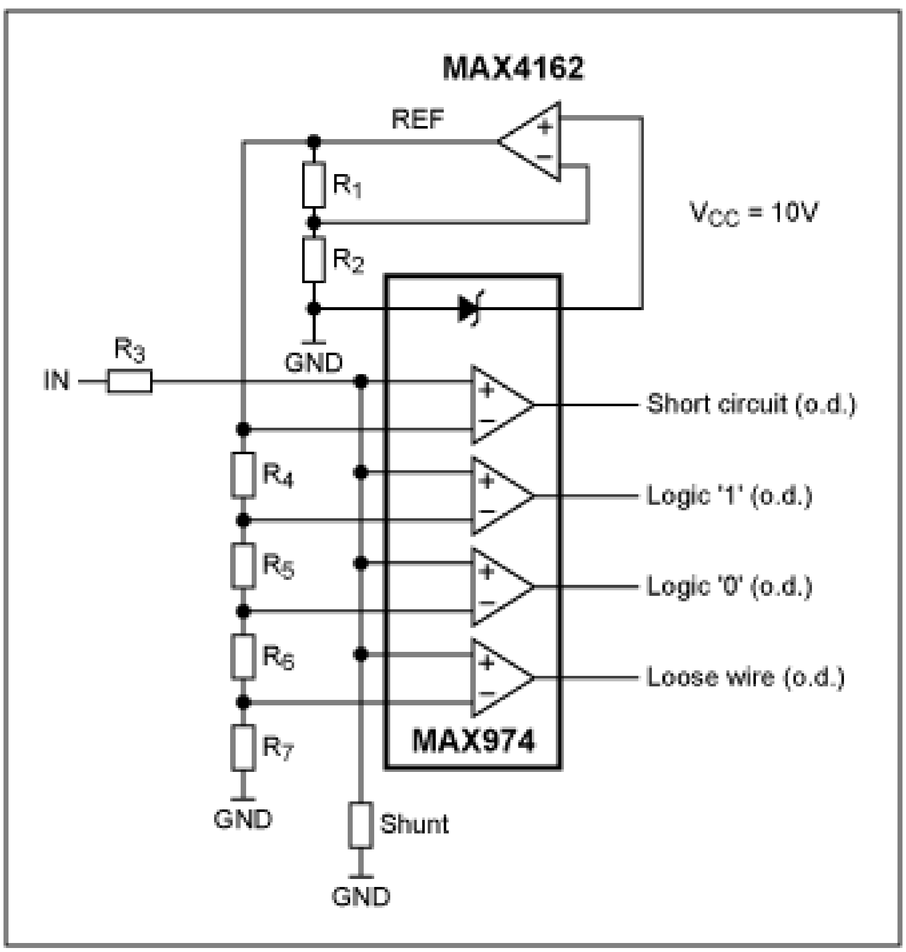

Figure 6. Resolving a current measurement into one of four ranges.

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Application Note 886: http://www.maxim-ic.com/an886

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MAX919: QuickView -- Full (PDF) Data Sheet -- Free Samples

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