

# Space-Grade, 100-krad, Window Comparator Circuit

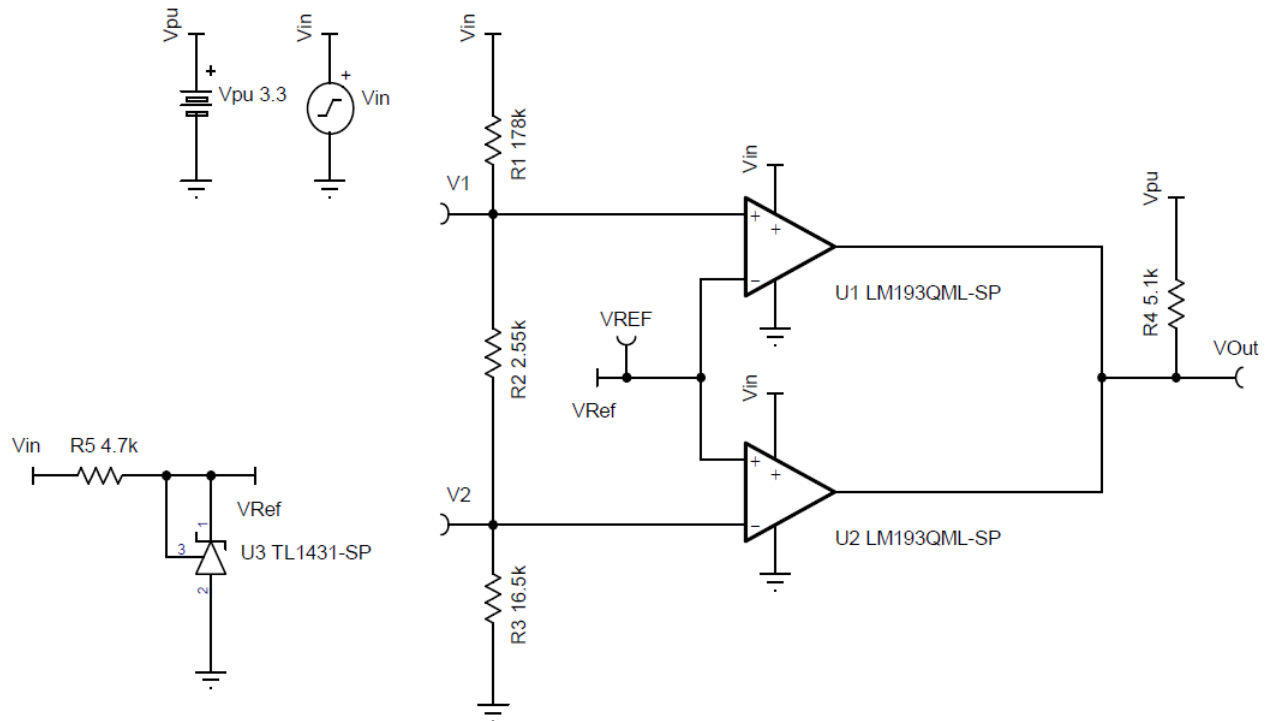


## Design Goals

Input Supply	Comparator Output Status (OUT)		Radiation	
Operating Range	$26V \leq V_{in} \leq 30V$	$V_{in} < 26V$ or $V_{in} > 30V$	Total Ionizing Dose (TID)	SEL Immunity to LET
20 V to 36 V	$V_{out} = V_{pu}$	$V_{out} = GND$	100 krad(Si)	85 MeV·cm <sup>2</sup> /mg

## Design Description

This application brief shows how to implement a voltage window comparator circuit, targeted to monitor a 28-V power rail, a spacecraft bus voltage commonly found in smaller aircraft. This wide single-supply window comparator circuit utilizes a dual open-collector comparator and 3 resistors to set the window voltage. A shunt regulator, TL1431-SP, is used to provide a reference voltage from the input voltage. Therefore, only a single power supply is utilized for the input portion of the circuit. The LM193AQL-SP was used for its open collector output, radiation specifications, and two channel count. Whenever the input voltage,  $V_{in}$ , is within the window of comparison (26 V to 30 V), the output of the circuit,  $V_{OUT}$ , is high. Whenever  $V_{in}$  is outside of the window of comparison, the  $V_{OUT}$  is pulled down to GND.



## Design Notes

1. Select a high-voltage comparator with an open collector output stage.
2. Select a comparator with low input offset voltage to optimize accuracy.
3. Calculate values for the resistor divider so that  $V_{OUT}$  goes high whenever  $V_1$  crosses  $V_{REF}$  and goes low whenever  $V_2$  crosses  $V_{REF}$ .
4. Calculate  $R_5$  such that shunt regulator is within sink current specification for entire operating range.

## Design Steps

1. Select a high-voltage comparator with an open collector output stage that can operate at the highest possible supply voltage. In this design, the highest input/supply voltage is 36 V.
2. Determine an appropriate reference level,  $V_{REF}$ , for the window comparator. The TL1431-SP internal reference voltage, 2.5 V, was used for ease of calculations. If another reference voltage were to be used with the TL1431-SP, a voltage divider would be needed between the cathode and anode of the shunt regulator, with  $V_{REF}$  between the resistors.
3. Calculate the value of  $R_5$ , the resistor across  $V_{IN}$  and  $V_{REF}$ , by relating  $V_{REF}$  to the operating voltage range. Ensure that  $R_5$  is at a level where the shunt regulator is sufficiently biased for the entire operating range. The current needed to bias the TL1431-SP,  $I_{Bias}$ , has to be between 1 mA and 100 mA. A 4.7-k $\Omega$  resistor was chosen as it kept the bias current within this range for the entire voltage operating range.

$$I_{Bias (Min)} = \frac{V_{in (Min)} - V_{Ref}}{R_5} = \frac{20 \text{ V} - 2.5 \text{ V}}{4.7 \text{ k}\Omega} = 3.72 \text{ mA}$$

$$I_{Bias (Max)} = \frac{V_{in (Max)} - V_{Ref}}{R_5} = \frac{36 \text{ V} - 2.5 \text{ V}}{4.7 \text{ k}\Omega} = 7.12 \text{ mA}$$

Values between 350  $\Omega$  and 16 k $\Omega$  could be used in this design. Consideration was made to minimize the bias current, yet give some buffer from the 1 mA minimum specification. If  $V_{REF}$  is seen to be noisy, a decoupling capacitor can be placed between the node and GND to filter out the noise.

4. The positive input to the top comparator,  $V_1$ , and the negative input to the bottom comparator,  $V_2$ , can be related to  $V_{in}$  through voltage division:

$$V_1 = V_{in} \left( \frac{R_2 + R_3}{R_1 + R_2 + R_3} \right), \quad V_2 = V_{in} \left( \frac{R_3}{R_1 + R_2 + R_3} \right)$$

The window comparator trips when  $V_1$  passes  $V_{REF}$  to output high, and again when  $V_2$  passes  $V_{REF}$  to output low. The comparator is low if  $V_1$  is less than  $V_{REF}$ . In this design, the window comparator will trip high when  $V_{in}$  equals 26 V and trip low when  $V_{in}$  equals 30 V; both while  $V_{REF}$  equals 2.5 V.

$$2.5 = 26 \left( \frac{R_2 + R_3}{R_1 + R_2 + R_3} \right) \rightarrow 10.4 = \frac{R_1 + R_2 + R_3}{R_2 + R_3}$$

$$2.5 = 30 \left( \frac{R_3}{R_1 + R_2 + R_3} \right) \rightarrow 12 = \frac{R_1 + R_2 + R_3}{R_3}$$

5. Solve both equations from step 4 for  $(R_1 + R_2 + R_3)$  and substitute one equation for the other.

$$10.4 R_2 + 10.4 R_3 = R_1 + R_2 + R_3$$

$$12 R_3 = R_1 + R_2 + R_3$$

$$12 R_3 = 10.4 R_2 + 10.4 R_3$$

$$10.4 R_2 = 1.6 R_3 \rightarrow 6.5 R_2 = R_3$$

6. Using the relationship obtained in step 5, solve for a relationship between  $R_1$  and  $R_2$ .

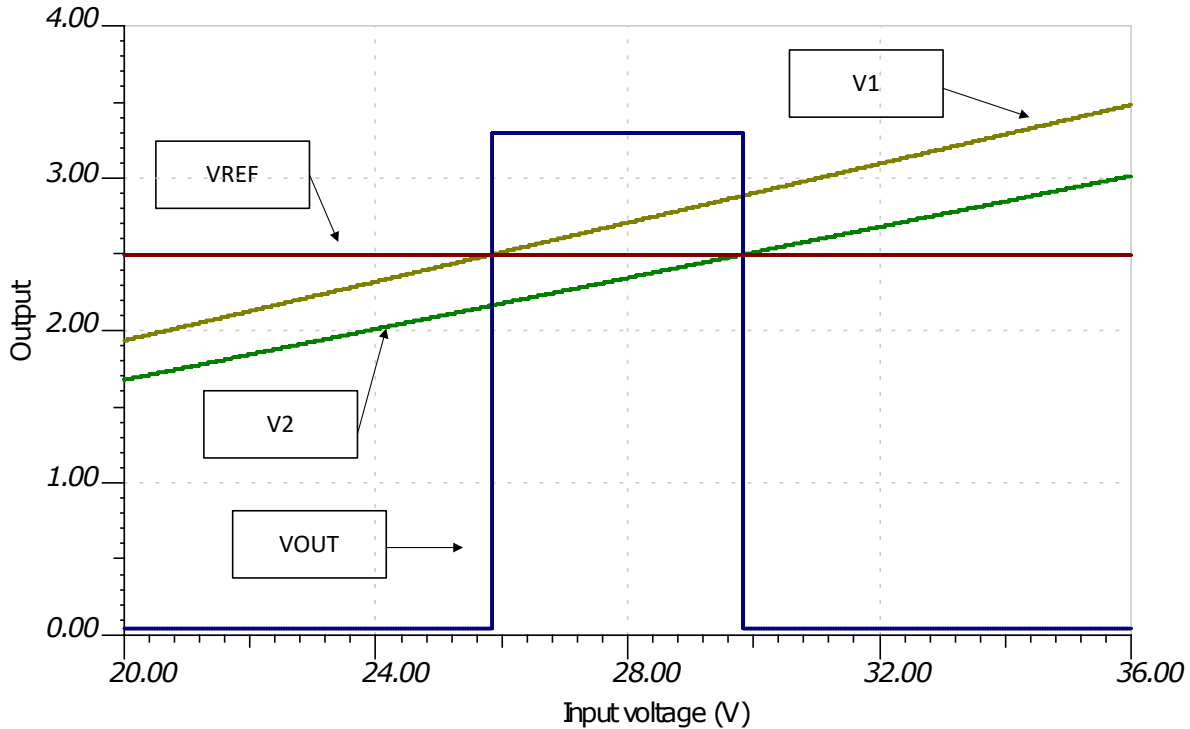
$$12 (6.5 R_2) = R_1 + R_2 + 6.5 R_2$$

$$78 R_2 = R_1 + 7.5 R_2 \rightarrow 70.5 R_2 = R_1$$

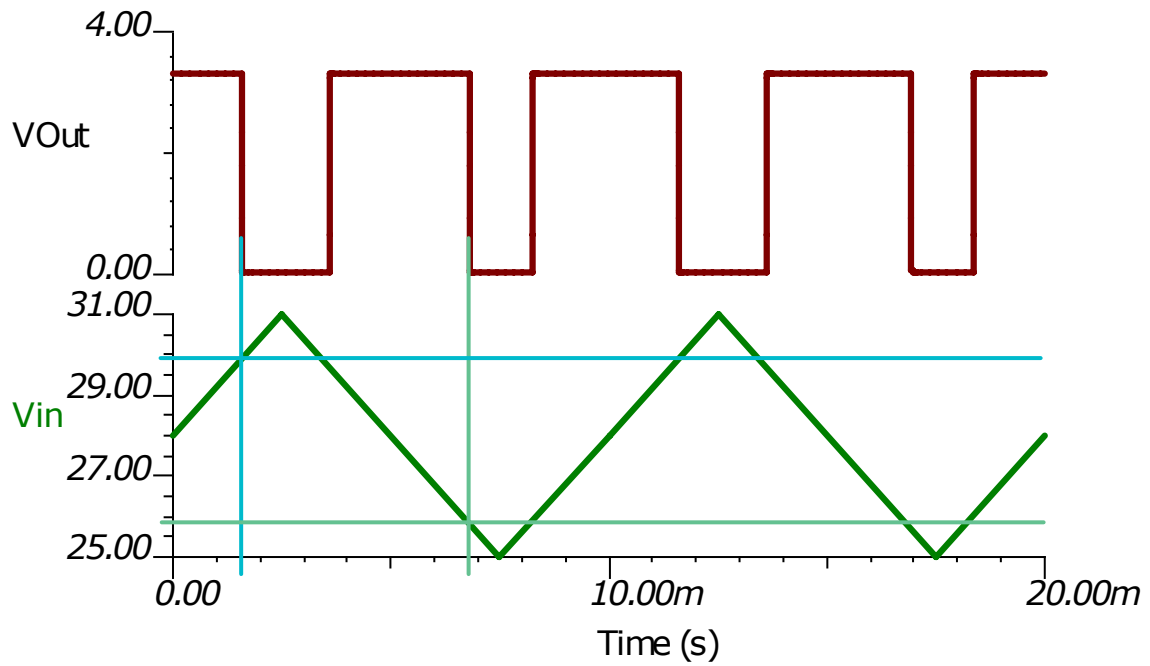
7. Using the equations derived in steps 5 and 6, size resistors  $R_1$ ,  $R_2$ , and  $R_3$  accordingly. For this design,  $R_2$  was set to be 2.55 k $\Omega$ , which meant  $R_1$  and  $R_3$  would be 179.775 k $\Omega$  and 16.575 k $\Omega$ , respectively. The magnitude of these resistors were chosen based off of the current consumption across the voltage divider (around 100 to 180  $\mu$ A across the operating condition).
8. Select a 5% tolerant resistor to act as the pullup resistor,  $R_4$ , from the output of the window comparator to  $V_{PU}$ . Size this component large enough to ensure the current sunk by the comparator is not large, but small enough that the leakage current drawn by the comparator output when high is not causing too large of a voltage drop.
9. The values obtained in step 7 were adjusted for 1% resistor tolerances to be 178 k $\Omega$ , 2.55 k $\Omega$ , and 16.5 k $\Omega$  for  $R_1$ ,  $R_2$ , and  $R_3$ , respectively. Due to these changes, the window of comparison was shifted to trip earlier for overvoltage conditions and later for undervoltage conditions. In the [DC Simulation Results](#), the window of comparison is between 25.8595 V and 29.856 V.

## Design Simulations

### DC Simulation Results



### Transient Simulation Results



**References:**

1. SPICE Simulation File: <http://www.ti.com/lit/zip/snom708>.

**Design Featured Comparator**

LM193QML-SP	
$V_S$	2 V to 36 V
$V_{inCM}$	0 V to 34.5 V
$V_{OUT}$	Open-Collector
$V_{OS}$	5 mV
$I_Q$	200 $\mu$ A/channel
$t_{PD(HL)}$	2.50 $\mu$ s
<b>TID Radiation Lot Acceptance Test (RLAT) / RHA</b>	100 krad(Si)
<b>TID Characterization (ELDRS-Free)</b>	100 krad(Si)
<b>SEL Immune to LET</b>	SEL Immune (Bipolar process)
<a href="http://www.ti.com/product/LM193QML-SP">http://www.ti.com/product/LM193QML-SP</a>	

**Design Featured Shunt Reference**

TL1431-SP	
$V_{KA}$	2.5 V to 36 V
$I_{KA}$	1 mA to 100 mA
$V_{I(ref)}$	2.5 V
<b>Initial Accuracy</b>	0.4%
<b>TID</b>	100 krad(Si)
<b>SEL Immune to LET</b>	SEL Immune (Bipolar process)
<a href="http://www.ti.com/product/TL1431-SP">www.ti.com/product/TL1431-SP</a>	

**Design Alternate Comparator**

	TLV1704-SEP	LM139AQML-SP
$V_S$	2.2 V to 36 V	2 V to 36 V
$V_{inCM}$	Rail-to-rail	0 V to 34 V
$V_{OUT}$	Open-Collector, Rail-to-rail	Open-Collector
$V_{OS}$	500 $\mu$ V	2 mV
$I_Q$	55 $\mu$ A/channel	200 $\mu$ A/channel
$t_{PD(HL)}$	460 ns	2.50 $\mu$ s
<b>TID Characterization (ELDRS-Free)</b>	30 krad(Si)	100 krad(Si)
<b>TID Radiation Lot Acceptance Test (RLAT) / RHA</b>	20 krad(Si)	100 krad(Si)
<b>SEL Immune to LET</b>	43 MeV·cm <sup>2</sup> /mg	SEL Immune (Bipolar process)
	<a href="https://www.ti.com/product/TLV1704-SEP">https://www.ti.com/product/TLV1704-SEP</a>	<a href="https://www.ti.com/product/LM139AQML-SP">https://www.ti.com/product/LM139AQML-SP</a>

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