Peter Semig, Take Sato

TI Designs – Precision: Verified Design
Window Comparator Reference Design

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Design Resources

TIPD178	All Design files
TINA-TI™	SPICE Simulator
TLV1702	Product Folder

Circuit Description

This 5V single-supply window comparator utilizes a dual open-collector comparator and three resistors to set the window voltage. The TLV1702 was used in this design due to its low power consumption and open collector output, which allows the output to be pulled up as high as 36 V.

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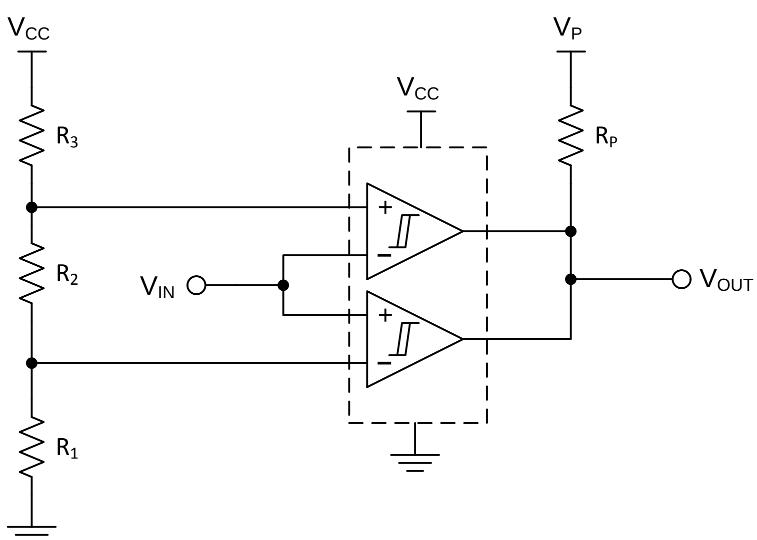

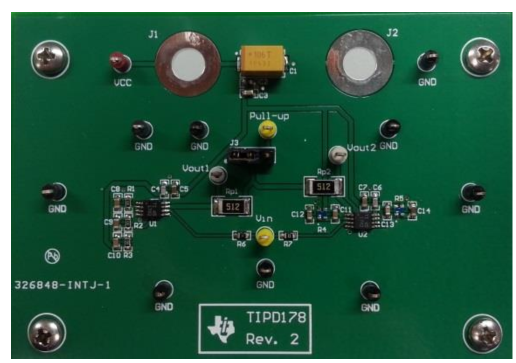

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1 Design Summary

The design requirements are as follows:

- Supply Voltage: 5 V
- Input Range: 0 V – 5 V
- Window Range: 1.66 V – 3.33 V
- Output: 0 V to 10 V (36 V maximum)

The design goals and performance are summarized in Table 1. Figure 1 depicts the measured transfer function of the design.

Table 1. Comparison of Design Goals, Simulation, and Measured Performance

	Goal	Simulated	Measured
VH (Upper Window Voltage)	3.33 V	3.33V ± 819 µV	3.329 V
VL (Lower Window Voltage)	1.66 V	1.66V ± 818 µV	1.659 V

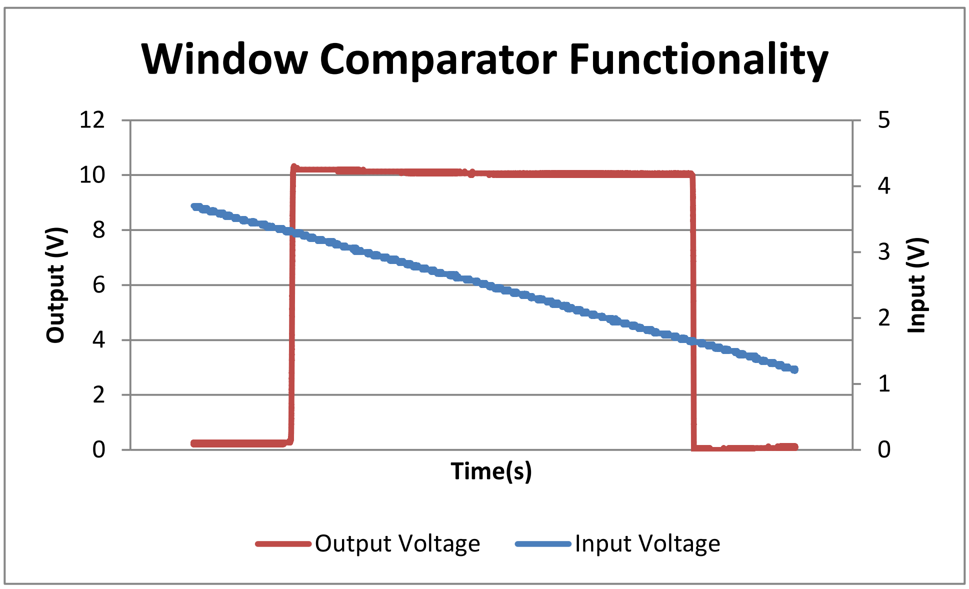

Figure 1: Measured Transfer Function

2 Theory of Operation

Figure 2 depicts a more detailed schematic for this reference design.

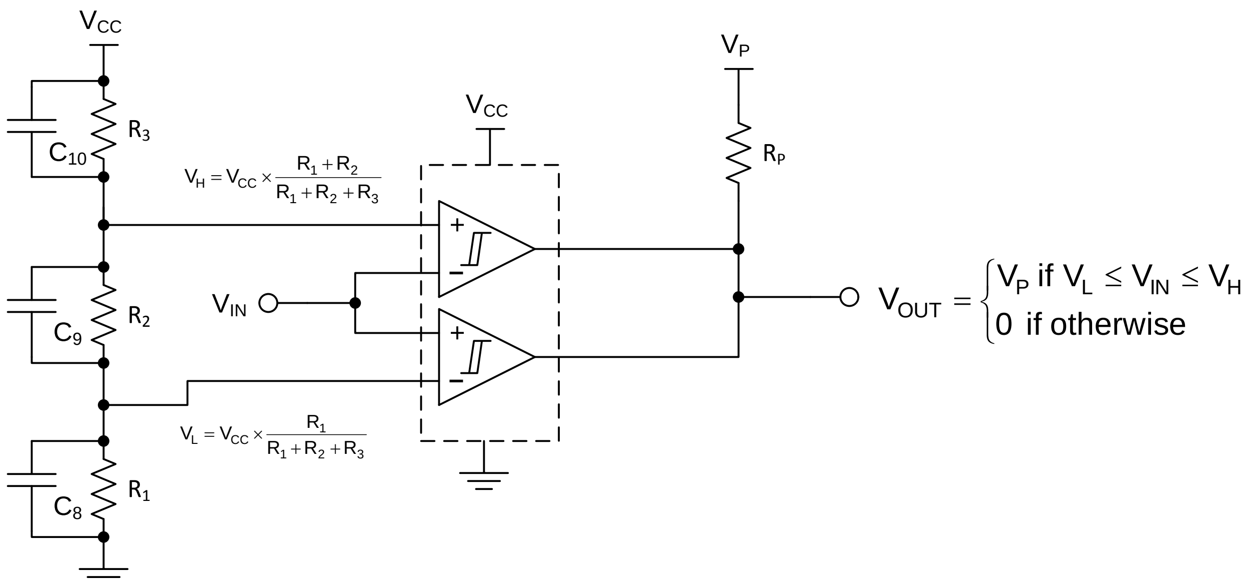

Figure 2: Detailed Window Comparator Schematic

A reference voltage, V_{CC}, is divided down by resistors R_1-R_3. The two node voltages, V_H and V_L, define the upper window voltage and lower window voltage, respectively. When the input voltage is between V_H and V_L, the output is 'high', or V_P. When outside the window voltage, the output is pulled down to 0 V.

Equations (1) and (2) define V_H and V_L, respectively.

$$V_H = V_{CC} \times \frac{R_1 + R_2}{R_1 + R_2 + R_3} \quad (1)$$

$$V_L = V_{CC} \times \frac{R_1}{R_1 + R_2 + R_3} \quad (2)$$

Capacitors C_8-C_{10} are included in order to both reduce noise and improve start up time. If only C_8 were installed to reduce noise, the V_L node would have to charge based on the time constant associated with R_2, R_3, and C_3. Placing equal capacitors across all three resistors allows for equal, cross-charging of the capacitors thereby quickening start up time.

3 Component Selection

3.1 Window Voltage Resistors (R_1-R_3)

Solving Equations (1) and (2) for V_{CC}, setting them equal to each other, then simplifying yields Equation (**3**).

$$V_H\left(\frac{R_1+R_2+R_3}{R_1+R_2}\right)=V_L\left(\frac{R_1+R_2+R_3}{R_1}\right)\rightarrow\frac{V_H}{V_L}=\frac{R_1+R_2}{R_1} \quad (3)$$

Given V_H=3.33 V and V_L=1.66 V, the ratio of R_1 and R_2 is calculated in Equation (4).

$$\frac{V_H}{V_L}=\frac{R_1+R_2}{R_1}\rightarrow\frac{3.33}{1.66}=2=1+\frac{R_2}{R_1}\rightarrow 1=\frac{R_2}{R_1} \quad (4)$$

To limit the current drawn from the reference voltage source, R_1 and R_2 were selected to be 10 kΩ. Please note, however, that the value of the resistors and the amount of noise they generate are directly related. For more information about resistor noise, please refer to TI Precision Labs.

While the values of R_1 and R_2 are related to the ratio of the window voltages, R_3 determines the voltage value. R_3 is calculated in Equation (5).

$$V_L=V_{CC}\times\frac{R_1}{R_1+R_2+R_3}\rightarrow R_3=\frac{R_1\times V_{CC}}{V_L}-(R_1+R_2)=10\text{k}\Omega \quad (5)$$

In summary, R_1=R_2=R_3=10 kΩ. In order to obtain precise window voltages, 0.1% tolerance resistors were selected.

3.2 Comparator

For this design, the TLV1702 was selected because it features a wide supply voltage range, low power consumption, rail-to-rail inputs, and an open-collector output stage. Given a single 5 V supply, the input voltage range is 0 V to 5 V. The open-collector output stage allows for output voltages up to 36 V. The dual device also comes in a small 8 pin VSSOP package.

3.2.1 Pull-up Resistor (R_P)

The output swing of the TLV1702 depends on current, as shown by Figure 3 below (Figure 4 in the TLV1702 data sheet).

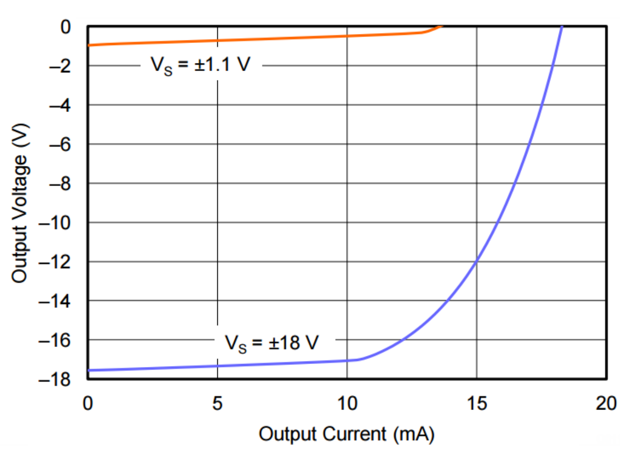

Figure 3: TLV1702 Output Voltage vs. Output Current

In order for the output voltage to swing close to the rail, the current should be limited to less than ~4 mA. Given a pull-up voltage of 10 V, R_P should be 2.5 kΩ or greater. Therefore, R_P was selected to be 5.1 kΩ since this value was used when characterizing the device as shown in the TLV1702 data sheet. If the pull-up voltage is increased, R_P may have to be increased in order to obtain good output swing to the negative rail. The tolerance of this resistor is not critical in this design, so a 5% resistor was selected.

4 Simulation

4.1 Functionality

Figure 4 depicts the TINA-TI™ schematic used to verify the functionality of this design.

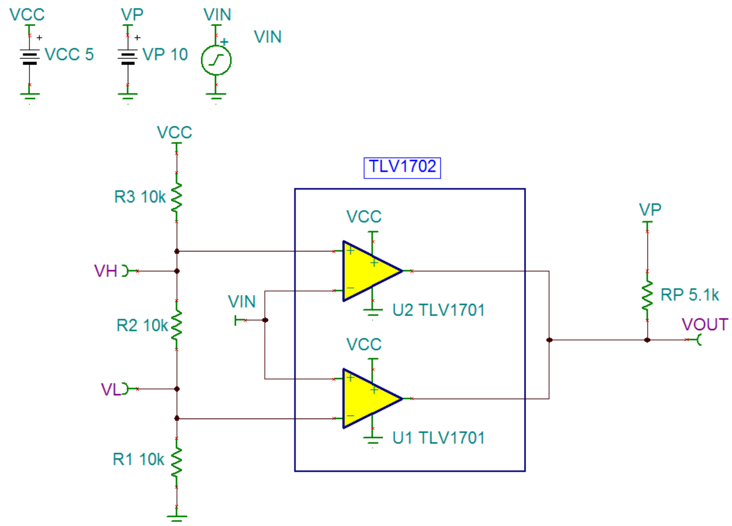

Figure 4: TINA-TI™ Functionality Schematic

Figure 5 depicts the proper operation of the window comparator. Notice that when the input, V_{IN}, is between V_H and V_L, the output goes to the pull-up voltage, V_P.

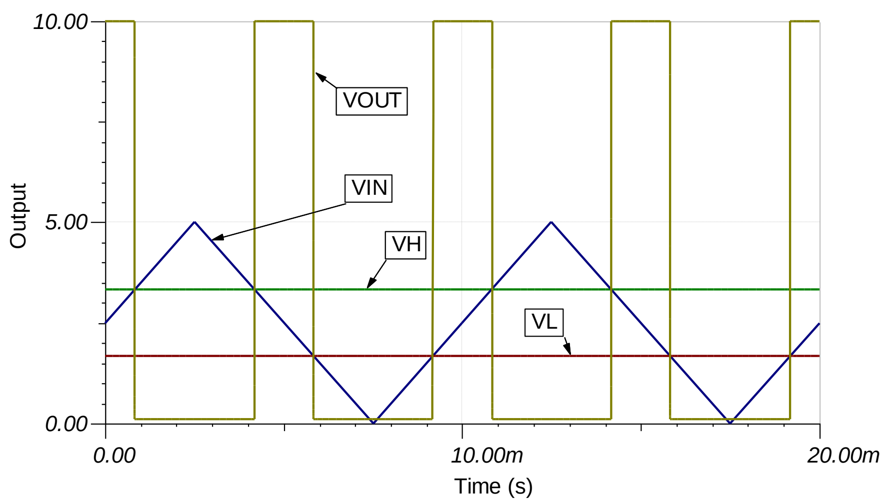

Figure 5: Window Comparator Functionality

4.2 Performance

TINA-TI™ can be used to determine the tolerance of the window comparator voltage thresholds. Performing a worst-case analysis after adjusting each input voltage divider resistor tolerance from 0.1% to 0.033% yields the typical performance. This represents ~67%, or ±1σ, of the distribution. The results for V_H and V_L are shown in Figure 6 and Figure 7 below.

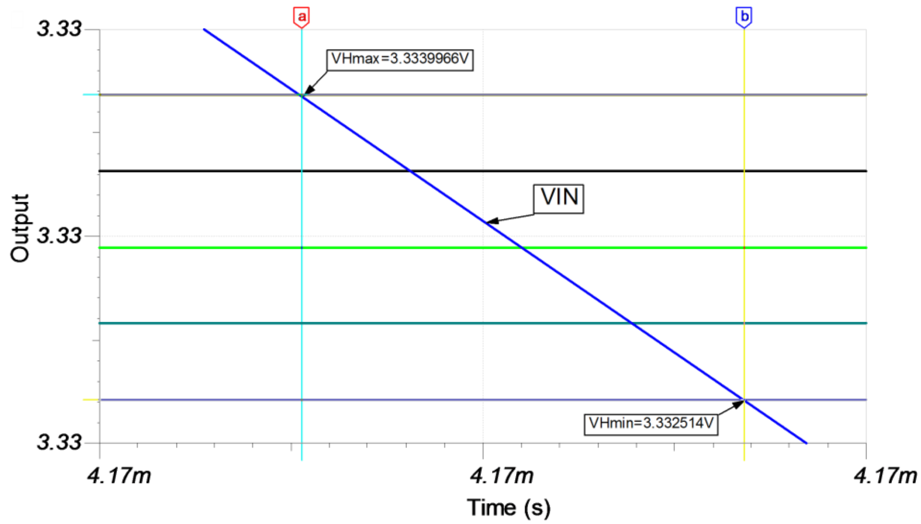

Figure 6: V_H Tolerance (Typical)

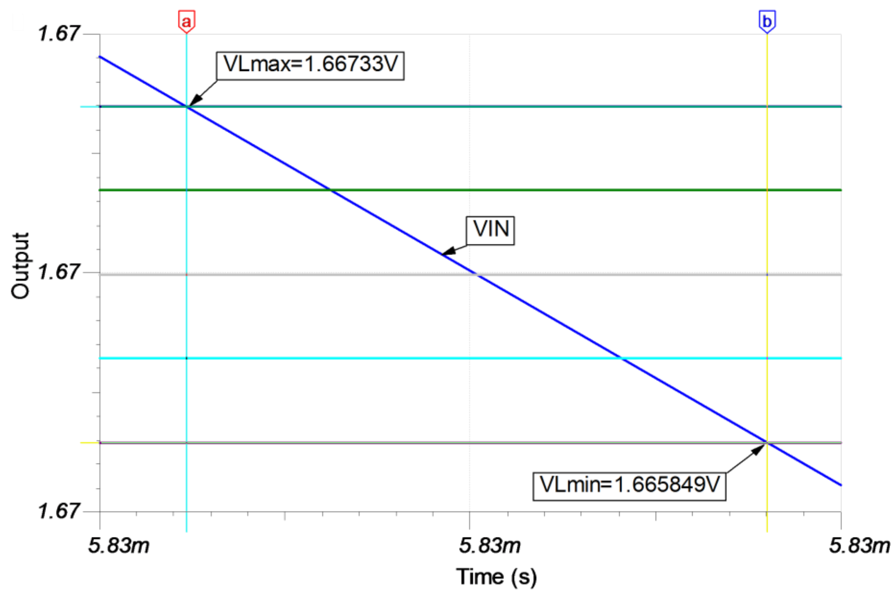

Figure 7: V_L Tolerance (Typical)

5 PCB Design

The PCB schematic and bill of materials can be found in the Appendix.

5.1 PCB Layout

Figure 8 depicts the PCB layout for this design. Note that there are two designs on this board. The design that utilizes U1 corresponds to TIPD178. General PCB layout guidelines were followed, including proper power supply decoupling and the use of short, wide traces when possible. A solid ground plane was poured on the top and bottom of the PCB to minimize return current paths.

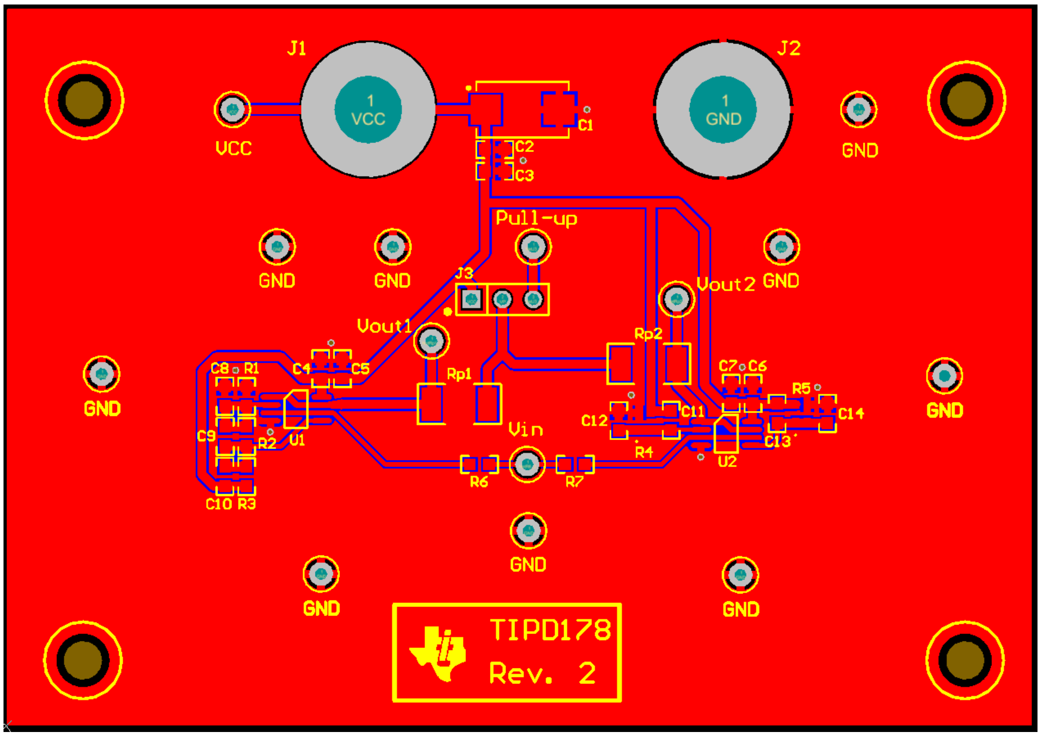

Figure 8: PCB Layout for TIPD178

6 Verification & Measured Performance

6.1 Transfer Function

Figure 9 depicts the functionality of this reference design.

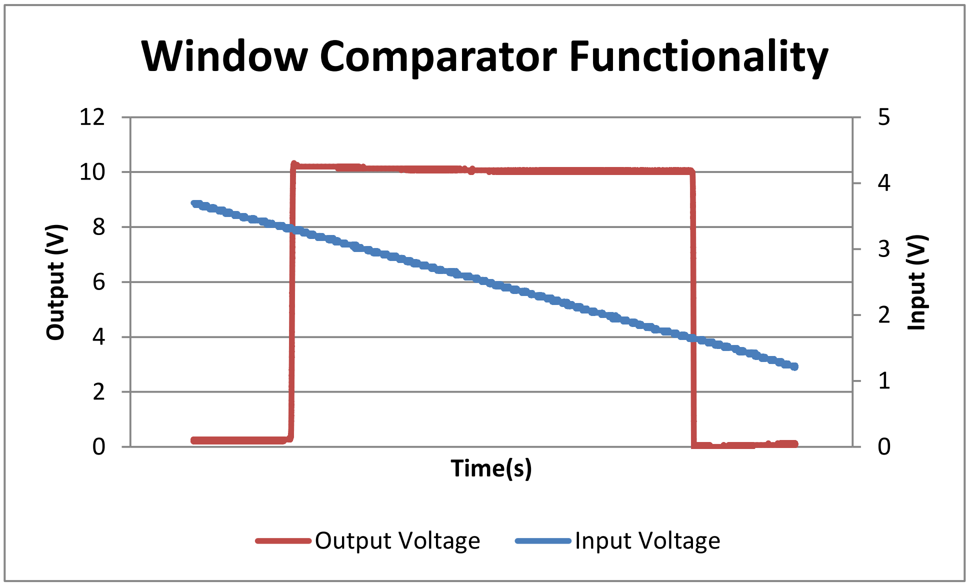

Figure 9: Functionality of Window Comparator

Notice that the output (yellow trace) is 10 Vpp. The input thresholds were measured using a precision sourcemeter. The upper window voltage was measured to be 3.329 V and the upper window voltage was measured to be 1.659 V. These values agree with the simulation results.

7 Modifications

Using resistors with greater precision will yield a better-defined window, but at the expense of component cost. Increasing the resistor values will lower the power consumption, but introduce more noise.

The topology presented in this design can be used for a vast array of comparators with different supply voltages and output topologies.

8 About the Authors

Pete Semig is an Analog Applications Engineer in the Precision Linear group at Texas Instruments. He supports Texas Instruments' difference amplifiers & instrumentation amplifiers. Prior to joining Texas Instruments in 2007, he earned his B.S.E.E. and M.S.E.E. from Michigan State University in 1998 & 2001, respectively. From 2001-2007 he was a faculty member in Michigan State University's Department of Electrical & Computer Engineering where he taught a variety of courses and laboratories.

Take Sato received his Bachelor of Engineering from Niigata University in March 2010, and Master of Science from The University of Tokyo in March 2012. He joined TI Japan as a Field Application Engineer in April 2012. Joined Precision Linear Apps team as global rotation program from July to Dec in 2014 before returning to Japan as a Field Applications Engineer.

9 Acknowledgements

The authors would like to thank Collin Wells & Tim Claycomb for their technical contributions.

Appendix A.

A.1 Electrical Schematic

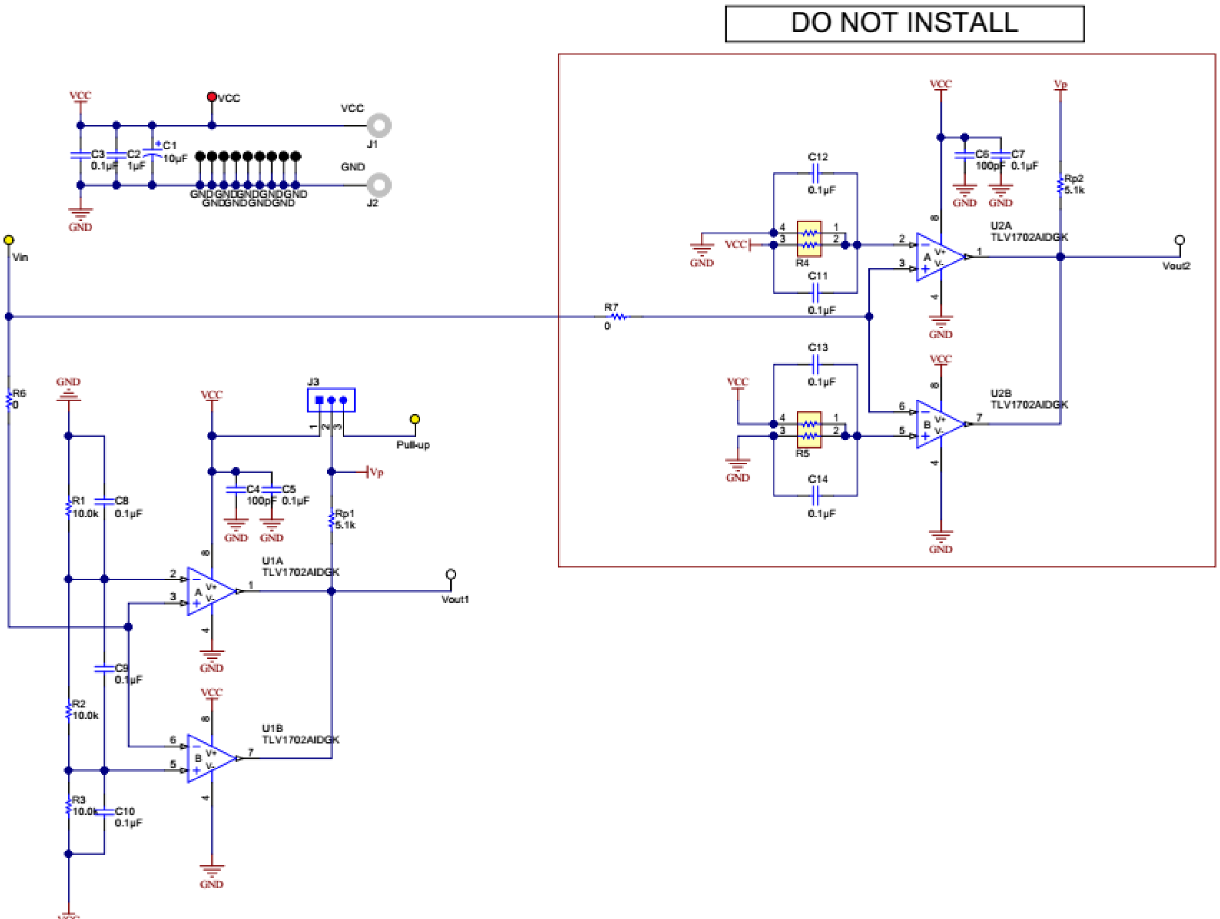

Figure A-1: Electrical Schematic

A.2 Bill of Materials

Quantity	Designator	Value	Description	Manufacturer	Manufacturer Part Number	Supplier	Supplier Part Number
1	C1	10uF	CAP TANT 10UF 50V 10% 2917	AVX	TPSE106K050R0500	Digikey	478-2424-1-ND
1	C2	1uF	CAP CER 1UF 50V X7R 0603	Taiyo Yuden	UMK107AB7105KA-T	Digikey	587-3247-1-ND
5	C3, C5, C8, C9, C10	0.1uF	CAP CER 0.1UF 50V X7R 0603	AVX	06035C104KAT2A	Digikey	478-5052-1-ND
1	C4	100pF	CAP CER 100PF 50V NP0 0603	AVX	06035A101JAT2A	Digikey	478-1175-1-ND
1	VCC	N/A	JACK NON-INSULATED .218"	Keystone	575-4	Digikey	36-575-4-ND
1	GND	N/A	JACK NON-INSULATED .218"	Keystone	575-4	Digikey	36-575-4-ND
1	J3	N/A	CONN HEADER .100 SINGL STR 3POS	Sullins Connector Solutions	PEC03SAAN	Digikey	S1012E-03-ND
3	R1, R2, R3	10.0k	RES SMD 10K OHM 0.1% 1/10W 0603	Susumu Co Ltd	RG1608P-103-B-T5	Digikey	RG16P10.0KBCT-ND
1	R6	0	RES SMD 0.0OHM JUMPER 1/10W 0603	Panasonic	ERJ-3GEY0R00V	Digikey	P0.0GCT-ND
1	Rp1	5.1k	RES SMD 5.1K OHM 5% 1/2W 2010	Rohm	MCR50JZHJ512	Digikey	RHM5.1KBGCT-ND
1	VCC	Red	TEST POINT PC MINI .040"D RED	Keystone	5000	Digikey	36-5000-ND
9	GND	Black	TEST POINT PC MINI .040"D BLACK	Keystone	5001	Digikey	36-5001-ND
1	Pull-up	Yellow	TEST POINT PC MINI .040"D YELLOW	Keystone	5004	Digikey	36-5004-ND
1	Vin	Yellow	TEST POINT PC MINI .040"D YELLOW	Keystone	5004	Digikey	36-5004-ND
1	Vout1	White	TEST POINT PC MINI .040"D WHITE	Keystone	5002	Digikey	36-5002-ND
1	U1	N/A	IC COMPARATOR DUAL 8VSSOP	Texas Instruments	TLV1702AIDGK	Digikey	296-37236-1-ND
4	N/A	N/A	HEX STANDOFF 4-40 ALUMINUM 1"	Keystone	2205	Digikey	36-2205-ND
4	N/A	N/A	MACHINE SCREW PAN PHILLIPS 4-40	B&F Fastener Supply	PMSSS 440 0025 PH	Digikey	H703-ND

Figure A-2: Bill of Materials

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