Analog Engineer's Circuit

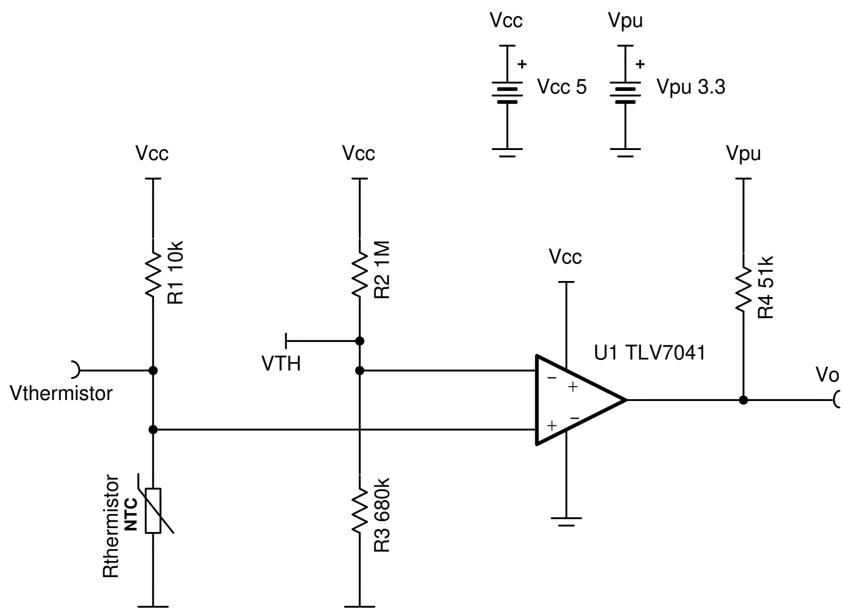
Thermal Switch Circuit

Design Goals

Temperature Switching Point	Output		Supply		
T_{sp}	V_o = HIGH	V_o = LOW	V_{cc}	V_{ee}	V_{pu}
100 °C	$T_A < T_{sp}$	$T_A > T_{sp}$	5 V	0 V	3.3 V

Design Description

This thermal switch solution will signal low (to a GPIO pin) when a certain temperature is exceeded thus alerting when conditions are no longer optimal or device-safe. This circuit incorporates an NTC thermistor with a comparator configured in a non-inverting fashion.



Design Notes

1. The resistance of an NTC thermistor drops as temperature increases.
2. The TLV7041 has an open drain output, so a pull-up resistor is required.
3. Configurations where the thermistor is placed near the high side of the divider can be done; however, the comparator will have to be used in an inverting fashion to still have the output switch low.
4. To exercise good practice, a positive feedback resistor should be placed to add external hysteresis (for simplicity, it is not done in this example).

Design Steps

1. Select an NTC thermistor, preferably one with a high nominal resistance, R_0, (resistance value when ambient temperature, T_A, is 25 °C) since the TLV7041 has a very low input bias current. This will help lower power consumption, thus reducing the likelihood of reading a slightly higher temperature due to thermal dissipation in the thermistor. The thermistor chosen has its R_0 and its material constant, β, listed below.

   $$R_0 = 100k\Omega$$

   $$\beta = 3977K$$

2. Select R_1. For high temperature switching points, R_1 should be 10 times smaller than the nominal resistance of the thermistor. This causes a larger voltage difference per temperature change around the temperature switching point, which helps guarantee the output will switch at the desired temperature value.

   $$R_1 = \frac{R_0}{10}$$

   $$R_1 = \frac{100k\Omega}{10} = 10k\Omega \quad \text{(Standard Value)}$$

3. Select R_2. Again, this can be a high resistance value.

   $$R_2 = 1M\Omega \quad \text{(Standard Value)}$$

4. Solve for the resistance of the thermistor, $R_{thermistor}$, at the desired temperature switching point. Using the β formula is an effective approximation for thermistor resistance across the temperature range of -20 °C to 120 °C. Alternatively, the Steinhart-Hart equation can be used, but several device-specific constants must be provided by the thermistor vendor. Note that temperature values are in Kelvin. Here T_0 = 25 °C = 298.15K.

   $$R_{thermistor}\left(T_{sp}\right) = R_0 \times e^{\beta \times \left(\frac{1}{T_{sp}} - \frac{1}{T_0}\right)}$$

   $$R_{thermistor}\left(100°C\right) = 100k\Omega \times e^{3977K \times \left(\frac{1}{373.15K} - \frac{1}{298.15K}\right)}$$

   $$R_{thermistor}(100°C) = 6.85 \quad k\Omega$$

5. Solve for $V_{thermistor}$ at T_{sp}.

   $$V_{thermistor}\left(T_{sp}\right) = V_{cc} \times \frac{R_{thermistor}\left(T_{sp}\right)}{R_1 + R_{thermistor}\left(T_{sp}\right)}$$

   $$V_{thermistor}\left(100°C\right) = 5V \times \frac{6.85k\Omega}{10k\Omega + 6.85k\Omega} = 2.03V$$

6. Solve for R_3 with the threshold voltage, V_{TH}, equal to $V_{thermistor}$. This ensures that $V_{thermistor}$ will always be larger than V_{TH} until the temperature switching point is exceeded.

   $$R_3 = \frac{R_2 \times V_{TH}}{V_{cc} - V_{TH}}$$

   $$R_3 = \frac{1M\Omega \times 2.03V}{5V - 2.03V} = 685k\Omega$$

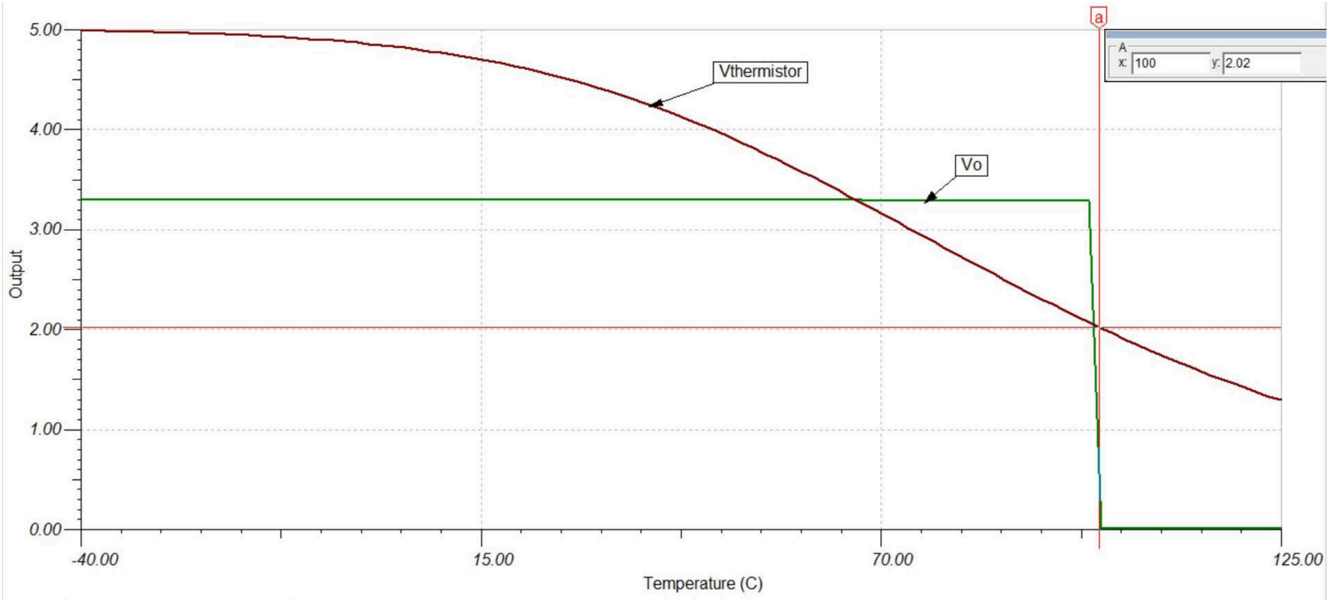
   $$R_3 = 680k\Omega \quad \text{(Standard Value)}$$

7. Select an appropriate pull up resistor, R_4. Here, V_{pu} = 3.3 V (digital high for a microcontroller).

   $$R_4 = 51k\Omega \quad \text{(Standard Value)}$$

Design Simulations

DC Temperature Simulation Results



Design References

See *Analog Engineer's Circuit Cookbooks* for TI's comprehensive circuit library.

See Circuit SPICE Simulation File, SLVMCS1.

Design Featured Comparator

TLV7041	
Output Type	Open-Drain
V_{cc}	1.6 V to 6.5 V
V_{inCM}	Rail-to-rail
V_{os}	±100 µV
V_{HYS}	7 mV
I_q	335 nA/Ch
t_{pd}	3 µs
#Channels	1
TLV7041	

Design Alternate Comparator

TLV1701	
Output Type	Open-Collector
V_{cc}	2.2 V to 36 V
V_{inCM}	Rail-to-rail
V_{os}	±500 µV
V_{HYS}	N/A
I_q	55 µA/Ch
t_{pd}	560 ns
#Channels	1, 2, and 4
	TLV1701
	TLV1701-Q1

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