Design Goals

<table>
<thead>
<tr>
<th>Temperature Switching Point</th>
<th>Output</th>
<th>Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{sp}$</td>
<td>$V_o = \text{HIGH}$</td>
<td>$V_{cc}$</td>
</tr>
<tr>
<td>$V_o = \text{LOW}$</td>
<td>$V_{cc}$</td>
<td>$V_{ee}$</td>
</tr>
<tr>
<td>$T_A &lt; T_{sp}$</td>
<td>$T_A &gt; T_{sp}$</td>
<td>$V_{pu}$</td>
</tr>
<tr>
<td>100 °C</td>
<td>5V</td>
<td>0V</td>
</tr>
<tr>
<td></td>
<td>3.3V</td>
<td></td>
</tr>
</tbody>
</table>

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, \( \beta \), listed below.
   \[
   R_0 = 100\text{k}\Omega \\
   \beta = 3977\text{K}
   \]

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.
   \[
   R_1 = \frac{R_0}{10} \\
   R_1 = \frac{100\text{k}\Omega}{10} = 10\text{k}\Omega \quad \text{(Standard Value)}
   \]

3. Select \( R_2 \). Again, this can be a high resistance value.
   \[
   R_2 = 1\text{M}\Omega \quad \text{(Standard Value)}
   \]

4. Solve for the resistance of the thermistor, \( R_{\text{thermistor}} \), at the desired temperature switching point. Using the \( \beta \) 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 \( T_0 = 25 \text{ °C} = 298.15\text{K} \).
   \[
   R_{\text{thermistor}}(T_{sp}) = R_0 \times e^{\beta \left( \frac{1}{T_{sp}} - \frac{1}{T_0} \right)}
   \]
   \[
   R_{\text{thermistor}}(100\text{°C}) = 100\text{k}\Omega \times e^{3977\text{K} \times \left( \frac{1}{373.15\text{K}} - \frac{1}{298.15\text{K}} \right)}
   \]
   \[
   R_{\text{thermistor}}(100\text{°C}) = 6.85 \text{ k}\Omega
   \]

5. Solve for \( V_{\text{thermistor}} \) at \( T_{sp} \).
   \[
   V_{\text{thermistor}}(T_{sp}) = V_{cc} \times \frac{R_{\text{thermistor}}(T_{sp})}{R_1 + R_{\text{thermistor}}(T_{sp})}
   \]
   \[
   V_{\text{thermistor}}(100\text{°C}) = 5V \times \frac{6.85\text{K}}{10\text{k}\Omega + 6.85\text{K}} = 2.03\text{V}
   \]

6. Solve for \( R_3 \) with the threshold voltage, \( V_{TH} \), equal to \( V_{\text{thermistor}} \). This ensures that \( V_{\text{thermistor}} \) will always be larger than \( V_{TH} \) until the temperature switching point is exceeded.
   \[
   R_3 = \frac{R_2 \times V_{TH}}{V_{cc} - V_{TH}}
   \]
   \[
   R_3 = \frac{1\text{M}\Omega \times 2.03\text{V}}{5V - 2.03\text{V}} = 685\text{k}\Omega
   \]
   \[
   R_3 = 680\text{k}\Omega \quad \text{(Standard Value)}
   \]

7. Select an appropriate pull up resistor, \( R_4 \). Here, \( V_{pu} = 3.3\text{V} \) (digital high for a microcontroller).
   \[
   R_4 = 51\text{k}\Omega \quad \text{(Standard Value)}
   \]
Design Simulations

DC Temperature Simulation Results
Design References

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


Design Featured Comparator

<table>
<thead>
<tr>
<th>TLV7041</th>
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</thead>
<tbody>
<tr>
<td>Output Type</td>
</tr>
<tr>
<td>$V_{cc}$</td>
</tr>
<tr>
<td>$V_{inCM}$</td>
</tr>
<tr>
<td>$V_{os}$</td>
</tr>
<tr>
<td>$V_{HYS}$</td>
</tr>
<tr>
<td>$I_{q}$</td>
</tr>
<tr>
<td>$t_{pd}$</td>
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<tr>
<td>#Channels</td>
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www.ti.com/product/tlv7041

Design Alternate Comparator

<table>
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<th>TLV1701</th>
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<tbody>
<tr>
<td>Output Type</td>
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<tr>
<td>$V_{HYS}$</td>
</tr>
<tr>
<td>$I_{q}$</td>
</tr>
<tr>
<td>$t_{pd}$</td>
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<tr>
<td>#Channels</td>
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