

Circuit Implementation

The temperature sensor chosen for this design is an industry-standard LM35 temperature sensor, available from many sources. This temperature sensor generates an output voltage proportional to the ambient temperature in degree Celsius and exhibits a scale factor of +10mV/°C. This particular temperature sensor provides a linear output response with a maximum output voltage of 1500mV corresponding to a 150°C ambient temperature. However, given that the hottest temperature achieved on earth is approximately 60°C, this design will focus on temperatures up to this ambient level. The transfer curve for the sensor is shown in Figure 2. In addition, a Si9942DY N-channel MOSFET was used to switch an AP121P 5V/200mA fan ON and OFF.

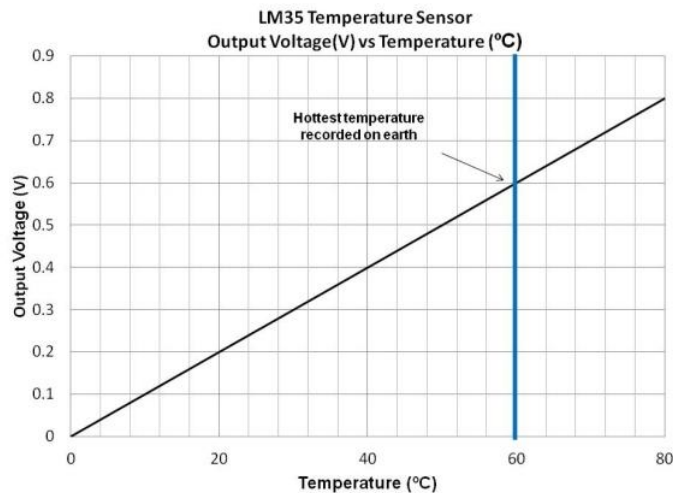


Figure 2: An LM35 temperature sensor transfer curve

The TS6001 voltage reference provides a 2.5V power supply for the TS1001 op-amp. The TS9001-1 comparator, TS6001 voltage reference, LM35 temperature sensor, and the fan are powered with a common 5V power supply, supplied by the USB connector. In this particular design, the TS1001 op-amp is configured in a non-inverting scheme where the output of the temperature sensor is connected to the non-inverting input of the op-amp. When the temperature rises to 26.4°C, the LM35 sensor output is 264mV and is connected to the non-inverting input of the TS1001. With a gain of 4.75, the TS1001 generates a 1.254V output voltage. The output of the TS1001 is connected to the non-inverting input of the TS9001-1 that then switches to a HIGH state at its output, turns on the MOSFET which, in turn, turns on the fan.

Discussion and Results

In order to design this circuit, here's the step-by-step procedure:

1. Choose the ambient trip temperature to sense T in degree Celsius;
2. Compute the LM35's output voltage, V_{OUT} , based on (1) as:

$$V_{OUT} = T^{\circ}C \times 10\text{mV}/^{\circ}C \quad (\text{Eq 1})$$

3. Calculate the gain, G , necessary to achieve a 1.252V voltage on the output of the TS1001 based on (2) as:

$$G = 1.252\text{V}/V_{OUT} \quad (\text{Eq 2})$$

4. Calculate the feedback total resistance, R_T , as:

$$R_T = R_4 + R_5 \quad (\text{Eq 3})$$

5. Solve for R_4 and R_5 by taking into account the non-inverting gain equation of the op-amp, Equation 3, and the value of G from Step (3). The non-inverting equation is:

$$G = 1 + R_5/R_4 \quad (\text{Eq 4})$$

When the fan is energized, total current consumption of the circuit from the USB-supplied 5V is 200.14mA. The TS9001-1, TS6001, and the TS1001 altogether consume only 0.02% of the total power consumption. To further minimize the current consumption, the feedback resistor values of the TS1001 can be increased. For instance, if the feedback resistance is doubled, the current on the feedback is halved. This results in a reduction of supply current by 2.5 μ A. In this particular case, with a total resistance of 248.3k Ω and an output voltage of 1.254V on the output of the TS1001, the current on the feedback is 5 μ A. At a maximum output voltage of 2.5V, the current is 10.1 μ A.

In this circuit, the input-referred hysteresis of the TS9001-1 is 3mV; hence, the rising threshold or V_{THR} is at 1.254V, which corresponds to a 26.4 $^{\circ}$ C temperature. The falling threshold or V_{THF} is at 1.251V, which corresponds to a 26.3 $^{\circ}$ C temperature. However, if one wishes to turn off the fan at a lower temperature relative to its turn off temperature, additional hysteresis can be added to the comparator. Please refer to the Applications Information section of the TS9001-1 product datasheet for a detailed explanation on how to increase comparator hysteresis.

The MOSFET selected should be able to handle the fan maximum current specification. Since the output of the TS9001-1 switches to a full-scale 5V, the MOSFET does not need to be an ultra-low threshold voltage type.

In order to maintain an accurate gain G and accurate trip points or V_{THR} and V_{THF} , metal-film resistors with 1% tolerance were used in the circuit and are recommended.

Conclusion

The combination of these three low-supply precision analog IC's produces a USB-powered thermostat/fan controller with < 0.8 $^{\circ}$ C error. In summary, the TS9001, the TS1001, and the TS6001-2.5 are excellent choices for this application as well as other temperature sensing applications.

For additional information, please follow the links to the corresponding product pages:

- [TS1001 Op Amp](#)
- [TS6001 Voltage Reference](#)
- [TS9001 Analog Comparator + Reference](#)

Contact: Touchstone Semiconductor Applications
Applications@TouchstoneSemi.com
+1 (408) 383-9363