AN835

COMBINING THREE VERY LOW SUPPLY CURRENT ANALOG ICs INTO A USB-POWERED THERMOSTAT

1. Introduction

In areas where ambient temperatures reach in the high 80 degrees Fahrenheit, such as Central America, South America, Asia, the Middle East, and certain areas in the United States, a portable fan would help. It may seem challenging to those new to the world of analog circuits and analog circuit design to conceptualize a solution using fundamental circuits and ICs; however, the following provides a step-by-step implementation of a basic temperature-based fan thermostat/controller. This approach makes use of the popular USB port available in many portable devices to create a USB-powered fan thermostat/controller that can bring relief to the user. By using a simple temperature sensor coupled with a simple low power circuit that consists of the TS6001-2.5 voltage reference, the TS1001 low power operational amplifier, and the TS9001 comparator, you may find the design of a 5V USB-powered fan thermostat/controller to be easy, interesting, and useful.

2. Overview

The TS9001-1's low input offset voltage (VOS) and low input current (IIN+/-) create a circuit with outstanding input sensitivity while consuming only 0.68µA of supply current. An internal 1.252V reference voltage allows for simple interface and less components for setting the threshold voltage for the comparator. Its rail-to-rail inputs support a wide range of input common-mode bias configurations and the widest possible range of input signals. In addition, the precision dc specifications of the TS1001, such as its low 0.5mV input offset voltage, its low 0.025nA input bias current, and its high open-loop gain of 90dB all combine to produce an output voltage that represents the input temperature accurately. The TS6001 2.5-V precision voltage reference operates as a low-dropout regulator in this circuit and its line regulation performance eliminates the need for additional bypass capacitances on the TS1001 and the TS9001-1. Figure 1 illustrates the complete circuit.

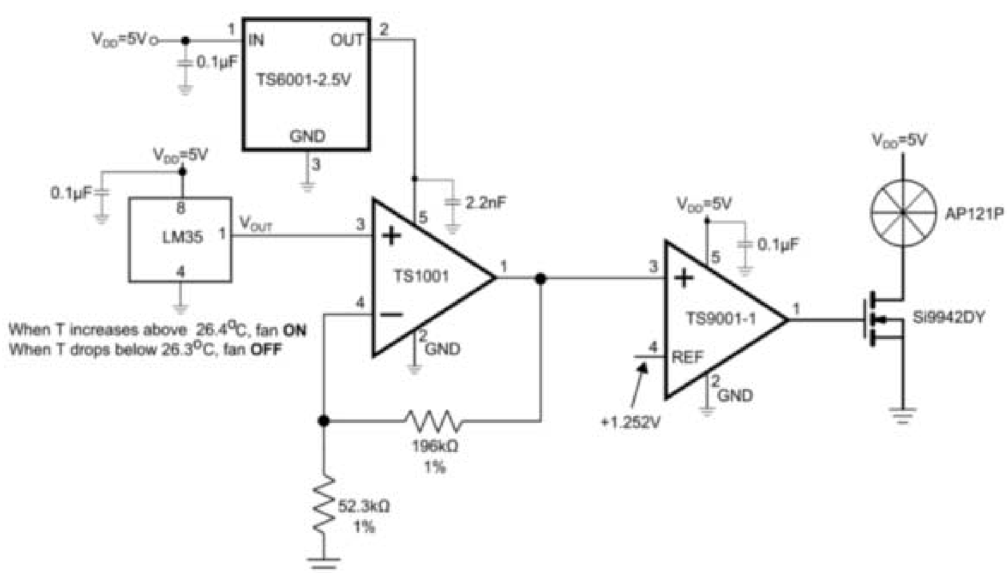


Figure 1. Very Low Supply Current, USB-Powered Thermostat/Fan Controller Circuit

2.1. 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/ºC. This particular temperature sensor provides a linear output response with a maximum output voltage of 1500mV corresponding to a 150ºC ambient temperature. However, given that the hottest temperature achieved on earth is approximately 60ºC, 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.

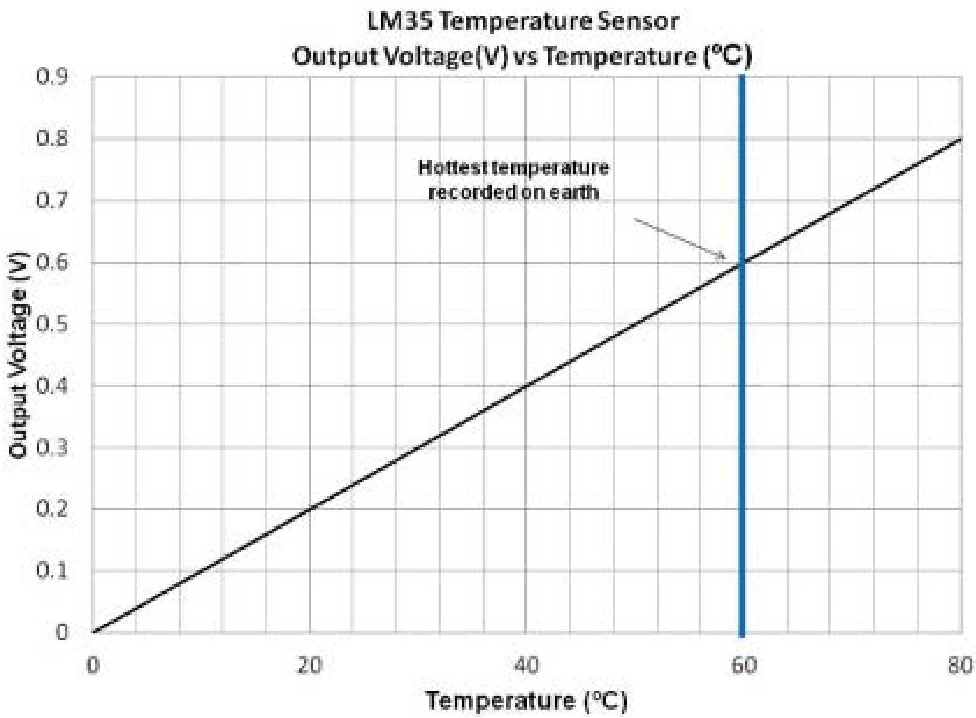


Figure 2. LM35 Temperature Sensor Transfer Curve

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 26.4ºC, the LM35 sensor output is 264mV and is connected to 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.

2.2. 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:

$$V_{OUT} = T°C \times 10mV / °C$$

Equation 1.

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

$$G = 1.252 V / V_{OUT}$$

Equation 2.

4. Calculate the feedback total resistance:

$$R_T = R4 + R5$$

Equation 3.

5. Solve for R4 and R5 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:

$$G = 1 + R5 / R4$$

Equation 4.

When the fan is energized, total current consumption of the circuit from the USB-supplied 5V is 200.14 mA. 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 µA. In this particular case, with a total resistance of 248.3 kΩ and an output voltage of 1.254 V on the output of the TS1001, the current on the feedback is 5 µA. At a maximum output voltage of 2.5 V, the current is 10.1 µA.

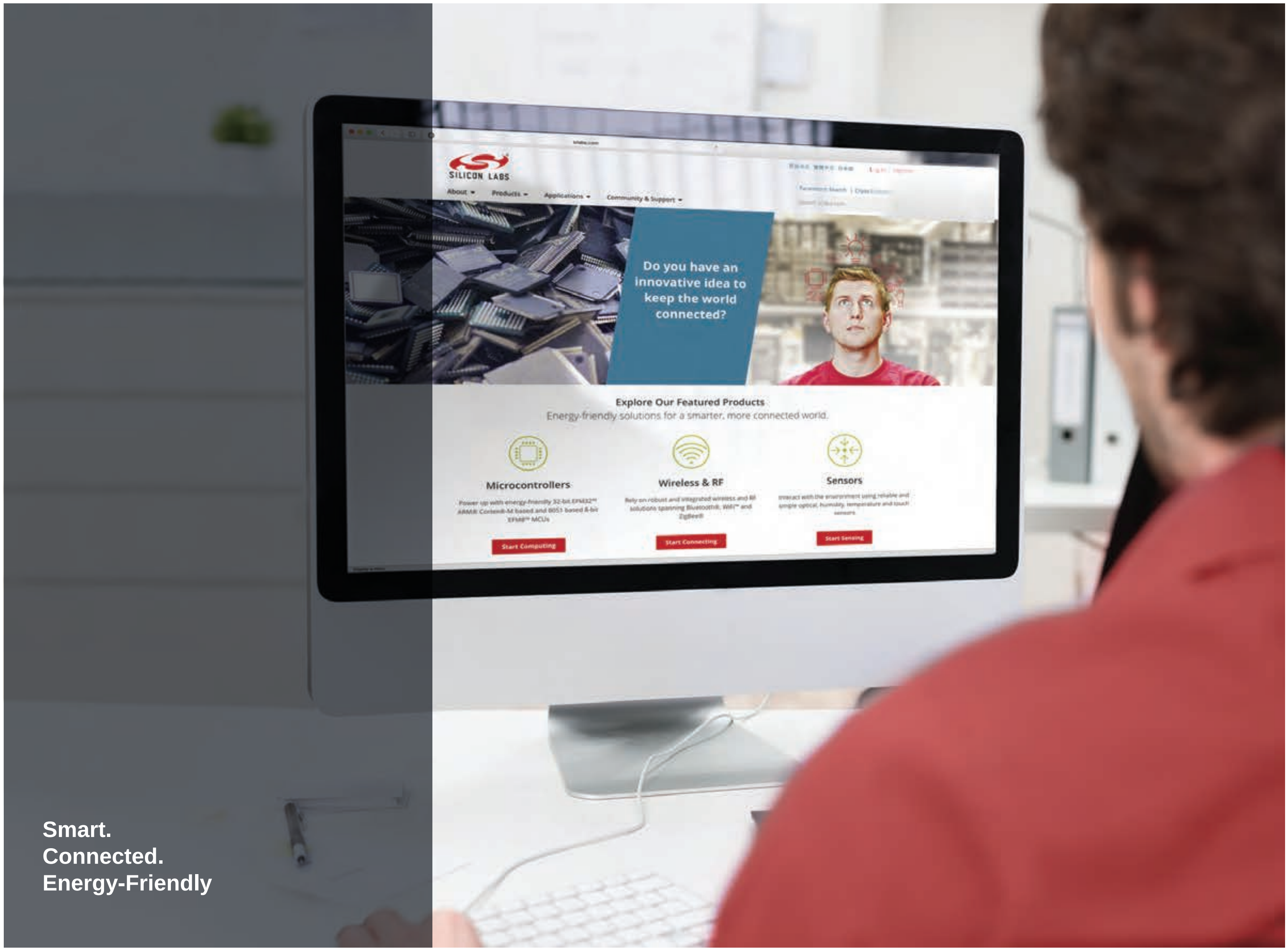
In this circuit, the input-referred hysteresis of the TS9001-1 is 3mV; hence, the rising threshold or VTHR is at 1.254V, which corresponds to a 26.4ºC temperature. The falling threshold or VTHF is at 1.251V, which corresponds to a 26.3 ºC temperature. However, if one wishes to turn off the fan at a lower 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 VTHR and VTHF, metal-film resistors with 1% tolerance were used in the circuit and are recommended.

3. Conclusion

The combination of these three low-supply precision analog IC's produces a USB-powered thermostat/fan controller with < 0.8 ºC 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, see documentation on the TS1001 Op Amp, TS6001 Voltage Reference, and TS9001 Analog Comparator + Reference, or contact Silicon Labs.



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