LM35 Temperature sensor
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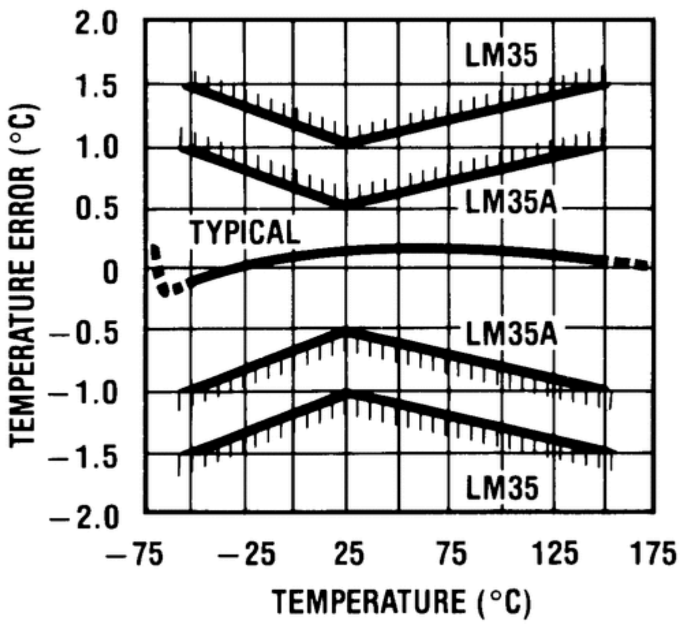
This file focuses on explaining the working of LM35 and giving a brief explanation about the working of temperature sensors in general. It also explains how to wire the sensor up to a microcontroller and how to take/interpret readings with a few recommendations to avoid errors or bad readings.

1. Temperature sensor and its working

In general, a temperature sensor is a device which is designed specifically to measure the hotness or coldness of an object. The Internet of Things (IoT) is revolutionizing how we interact with the world around us, and temperature sensors play a crucial role in this transformation. LM35 is one of the widely used precision temperature sensors that outputs an analogue voltage directly proportional to the temperature in degrees Celsius. It uses the basic principle of a diode, whereas the temperature increases, the voltage across a diode increases at a known rate. By precisely amplifying the voltage change, it is easy to generate an analog signal that is directly proportional to temperature.

This device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. It provides thermal shutdown for a circuit or component used in a specific project and battery protection from overheating and can also be used in HVAC applications as a temperature measurement device.



2. LM35 Specifications

Operating Voltage: 4 V to 30 V

Output Voltage: 10mV/°C

Sensitivity: 10mV/°C

Linearity Error: ±1°C (for 0°C to +100°C)

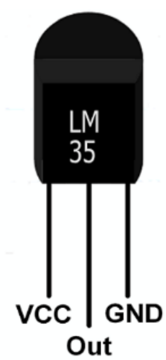
Operating Temperature: -55°C to +150°C

Output Impedance: 100 Ω

Power Consumption: 60 µA (typical)

Output Type: Analog

Accuracy: ±1°C (typical)



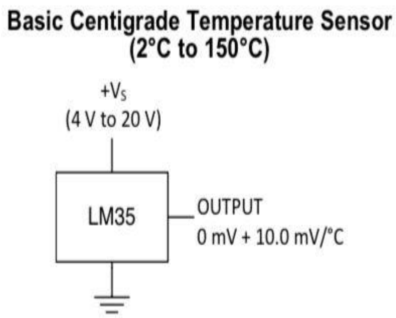
Features

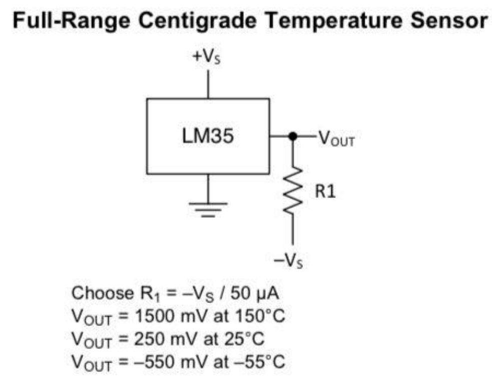
Calibrated directly in Degree Celsius (Centigrade)

Suitable for remote applications

Low cost due to wafer-level trimming

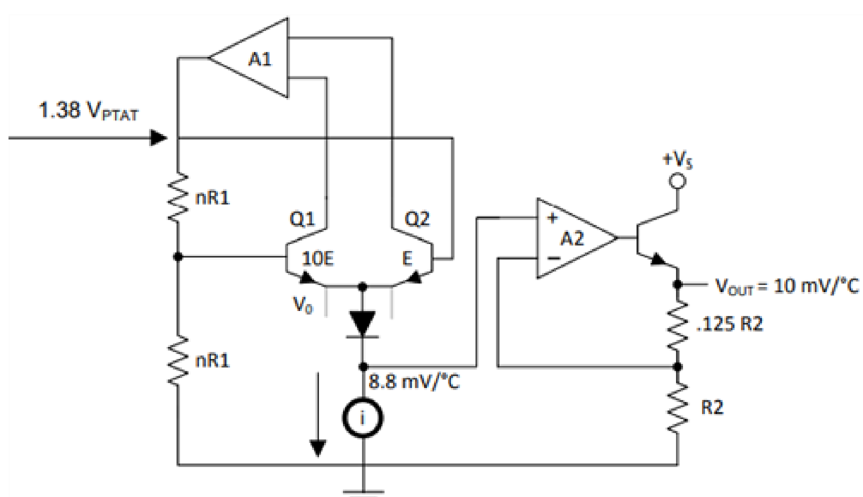
Minimum and Maximum Input Voltage is 35V and -2V respectively.



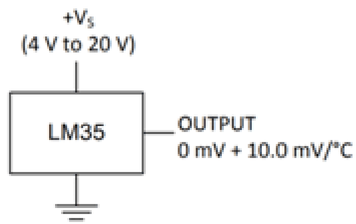


3. Pin explanations and Taking Measurements

There are three pins: VCC, GND and Out. VCC is the power supply pin of the LM35 temperature sensor IC that can be connected to 4V or 32V of the supply, GND is the ground pin of the LM35 temperature sensor IC and it should be connected to the supply ground and OUT is the temperature sensor analog output pin. This is the analog output pin of the temperature sensor, the output voltage on this pin is directly proportional to the temperature. The LM35 temperature sensor uses the basic principle of a diode to measure known temperature values. As we all know from semiconductor physics, as the temperature increases the voltage across a diode increases at a known rate. By accurately amplifying the voltage change, we can easily generate a voltage signal that is directly proportional to the surrounding temperature. The screenshot below shows the internal schematic of the LM35 temperature sensor IC according to the datasheet.



Power the IC by applying a regulated voltage like +5V (V_S) to the input pin and connected the ground pin to the ground of the circuit. Now, you can measure the temperature in form of voltage as shown below.



Steps to calculate temperature using LM35 temperature sensor

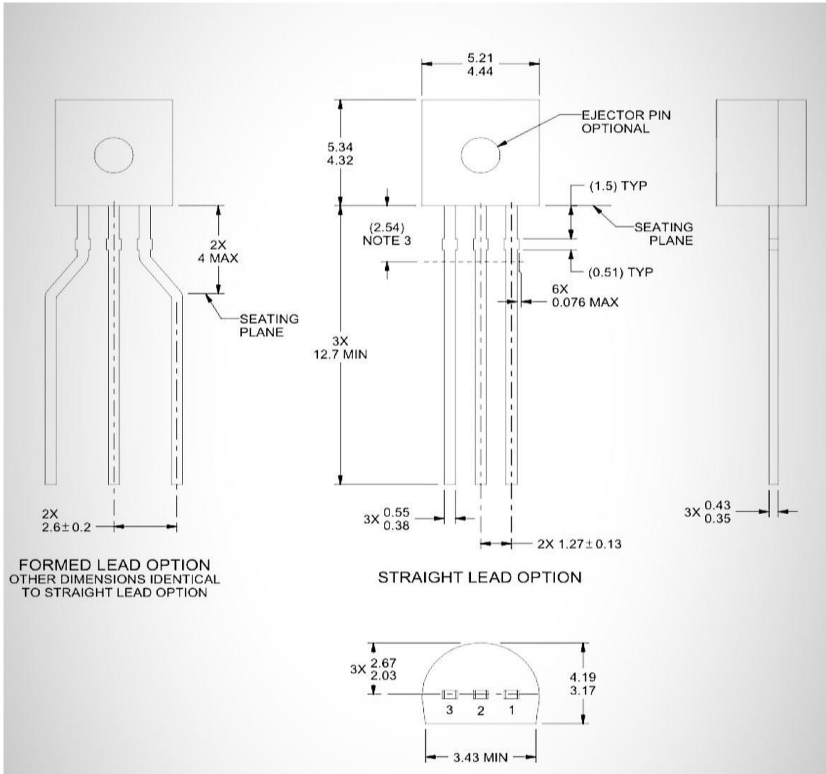
- Build circuit.
- Power LM35 VCC to +5-20 volts and GND to ground.
- Connect Vout to analog to digital converter input.
- Sample the ADC reading, vout output voltage.
- Convert the voltage to temperature.

Formula to convert voltage to temperature

The formula to convert the voltage to centigrade temperature for LM35 is Centigrade Temperature = Voltage Read by ADC / 10 mV(mills Volt)

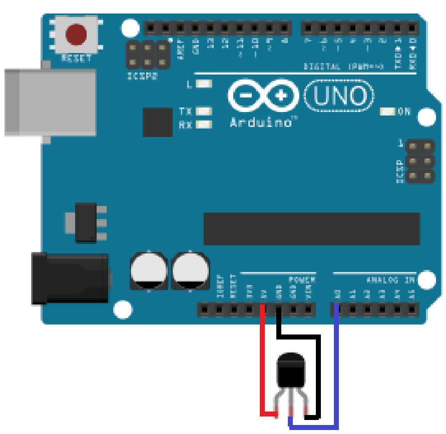
PARAMETER	VALUE
Accuracy at 25°C	±0.5°C
Accuracy from –55 °C to 150°C	±1°C
Temperature Slope	10 mV/°C

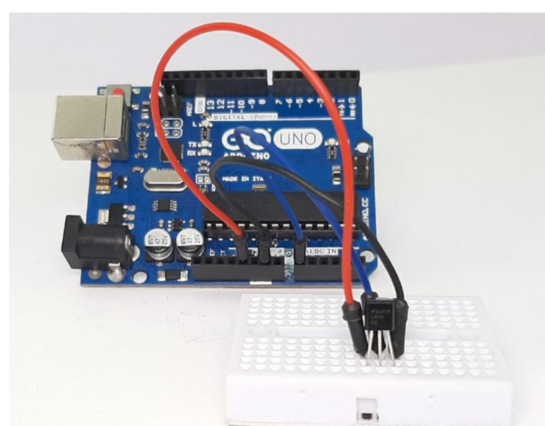
Accuracy level decreases for temperature between 2 degrees to 25-degree centigrade.



4.Wiring LM35 with a microcontroller

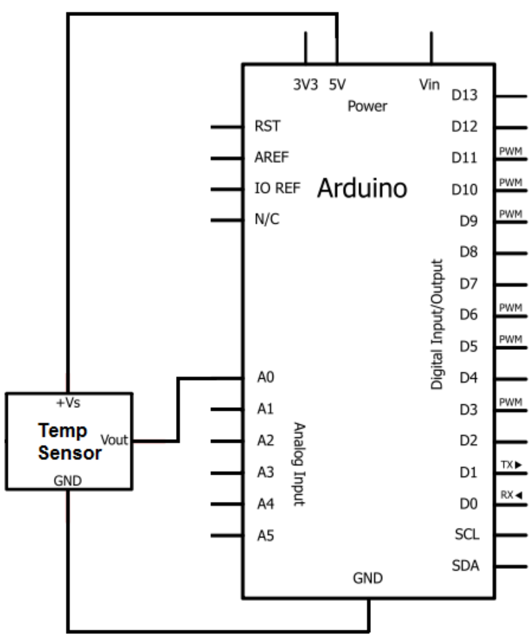
Here's how the connections will look for Arduino Uno





LM35 Sensor Pinout Configuration

Pin Number	Pin Name	Description
1	Vcc	Input voltage is +5V for typical applications
2	Analog Out	There will be increase in 10mV for raise of every 1°C. Can range from -1V(-55°C) to 6V(150°C)
3	Ground	Connected to ground of circuit



5. Errors and Bad Readings

- **Accuracy:** The LM35 itself dissipates a small amount of power, which can heat the sensor and lead to inaccurate readings. This effect is usually negligible at low temperatures but can become significant at higher temperatures. Different batches of LM35 sensors may have slightly different accuracy specifications. It is important to consult the datasheet for the specific LM35 you are using to determine its guaranteed accuracy.
- **Ambient temperature:** The ambient temperature can affect the accuracy of the LM35, especially if the sensor is not properly insulated. It is important to account for the ambient temperature when interpreting the LM35 readings.
- **Airflow:** Airflow can also affect the accuracy of the LM35. If the sensor is in a stagnant environment, the heat it dissipates may not be able to dissipate properly, leading to inaccurate readings.

Here are a few steps we can take to obtain a stable temperature reading.

1.Adding Filter Capacitor at power rails of LM35: The fluctuation of temperature output might be the noise available in the power supply so it's better to use an electrolytic capacitor at the power supply i.e. connected to Vcc and GND of LM35. Let's say adding 10uF to the power supply will stabilise output to some extent.

2.Adding resistance between the output pin and GND pin: According to the datasheet of LM35, it has low sinking capability, as a result, its output becomes more sensitive to electromagnetic interference. 1K or 2K resistor between output and GND can solve this issue to some extent and also solve self-heating errors.

3.Taking average reading rather than a single reading: Fluctuation or drift is one of the major issues of the Arduino sensors. One way to make fluctuation less is by trying to calculate the average reading instead of a single reading.