Programming “Arduino” Sketches

Analog, Digital & PWM Outputs/ Temperature Sensors

Instructor / Facilitator - Alan Rux

Temperature Sensors *analog output lecture*

- **Temperature Sensors** measure the amount of heat energy or even coldness that is generated by an object or system
- **Temperature Sensors** consists of two basic physical types:

  Contact Temperature Sensor

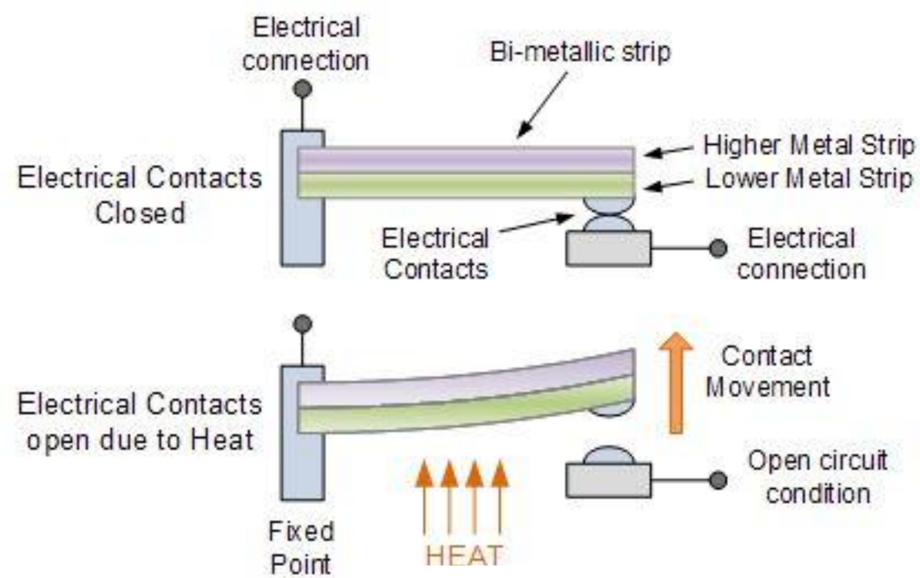
  Non-contact Temperature Sensor

- three groups of sensors, ***Electro-mechanical***, ***Resistive*** and ***Electronic***

Temperature Sensors

- ***Electro-mechanical:***

 There are two main types of bi-metallic strips based mainly upon their movement when subjected to temperature changes. There are the “snap-action” types that produce an instantaneous “ON/OFF” or “OFF/ON” type action on the electrical contacts at a set temperature point, and the slower “creep-action” types that gradually change their position as the temperature changes.



On/Off Thermostat

Temperature Sensors

- ***Resistive/*** **Thermistor:**

  temperature sensor, whose name is a combination of the words **THERM-**ally sensitive res-**ISTOR**. A thermistor is a special type of resistor which changes its physical resistance when exposed to changes in temperature

Thermistor

A Resistive RTD

- **Resistive Temperature Detectors (RTD):**

  precision temperature sensors made from high-purity conducting metals such as platinum, copper or nickel wound into a coil and whose electrical resistance changes as a function of temperature, similar to that of the thermistor

Resistive/ Thermistor

VISHAY www.vishay.com

NTCLE100E3

Vishay BCcomponents

NTC Thermistors, Radial Leaded, Standard Precision

QUICK REFERENCE DATA		
PARAMETER	**VALUE**	**UNIT**
Resistance value at 25 °C	3.3 to 470K	Ω
Tolerance on R_{25}-value	± 2; ± 3; ± 5	%
$B_{25/85}$-value	2880 to 4570	K
Tolerance on $B_{25/85}$-value	± 0.5 to ± 3	%
Operating temperature range:		
At zero power dissipation; continuously	- 40 to + 125	°C
At zero power dissipation; for short periods	≤ 150	°C
Response time (in oil)	≈ 1.2	s
Thermal time constant τ (for information only)	15	s
Dissipation factor δ (for information only)	7 8.5 (for R_{25}-value ≤ 680 Ω)	mW/K
Maximum power dissipation at 55 °C	500	mW
Climatic category (LCT/UCT/days)	40/125/56	-
Weight	≈ 0.3	g

FEATURES

- Accuracy over a wide temperature range
- High stability over a long life
- Excellent price/performance ratio
- UL recognized, file E148885
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

RoHS COMPLIANT

APPLICATIONS

- Temperature measurement, sensing and control, temperature compensation in industrial and consumer electronics

DESCRIPTION

These thermistors have a negative temperature coefficient. The device consists of a chip with two solid copper tin plated leads. It is grey lacquered and color coded, but not insulated.

PACKAGING

The thermistors are packed in bulk or tape on reel; see code numbers and relevant packaging quantities.

DESIGN-IN SUPPORT

For complete Curve Computation, visit: www.vishay.com/resistors-non-linear/curve-computation-list/

MARKING

The thermistors are marked with colored bands; see dimensions drawing and "Electrical data and ordering information".

Resistive/ Thermistor

RESISTANCE VALUES AT IN	
T_{OPER} (°C)	PART NUMBER NTCLE100E3102*** R_T (Ω)
- 40	23 342
- 35	17 336
- 30	13 018
- 25	9877
- 20	7569
- 15	5855
- 10	4569
- 5	3596
0	2854
5	2282
10	1838
15	1491
20	1217
25	1000

25	1000
30	826.6
35	687.3
40	574.6
45	482.7
50	407.4
55	345.2
60	293.7
65	250.8
70	214.9
75	184.7
80	159.3
85	137.7
90	119.4
95	103.8

negative temperature coefficient

Temperature sensors: thermistors

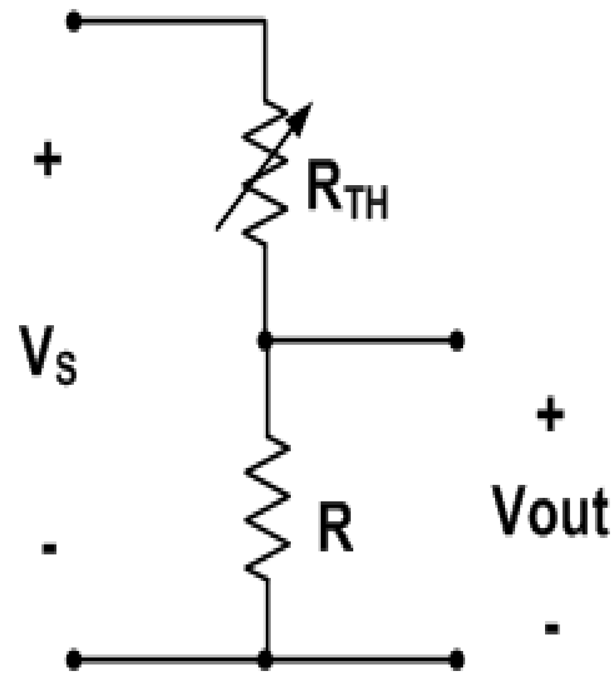
- *Thermistors* are sensors whose resistance changes as a function of temperature
  - Thermistors are classified as either *NTC* (negative temperature coefficient) or *PTC* (positive temperature coefficient)
  - Resistance increases with temperature for PTCs; Resistance decreases with temperature for NTCs
- A resistance variation is generally not directly useful; information is generally relayed with voltage
  - We need to convert the resistance change to a voltage change

Initial Design Concept

- **Use voltage divider to convert resistance variation to voltage variation**

$$V_{out} = V_S \cdot \frac{R}{R + R_{TH}}$$

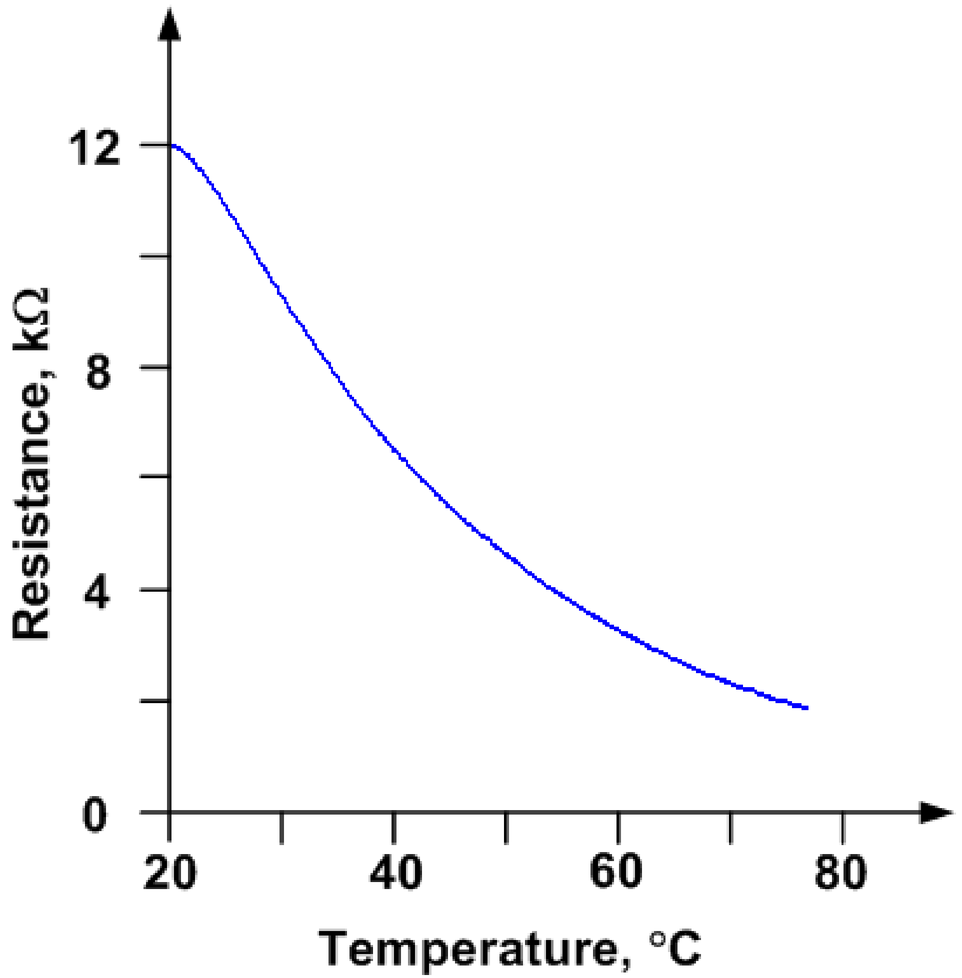
  - **Design problem: choose V_s and R to obtain desired variation in V_{out} for a given variation in temperature**



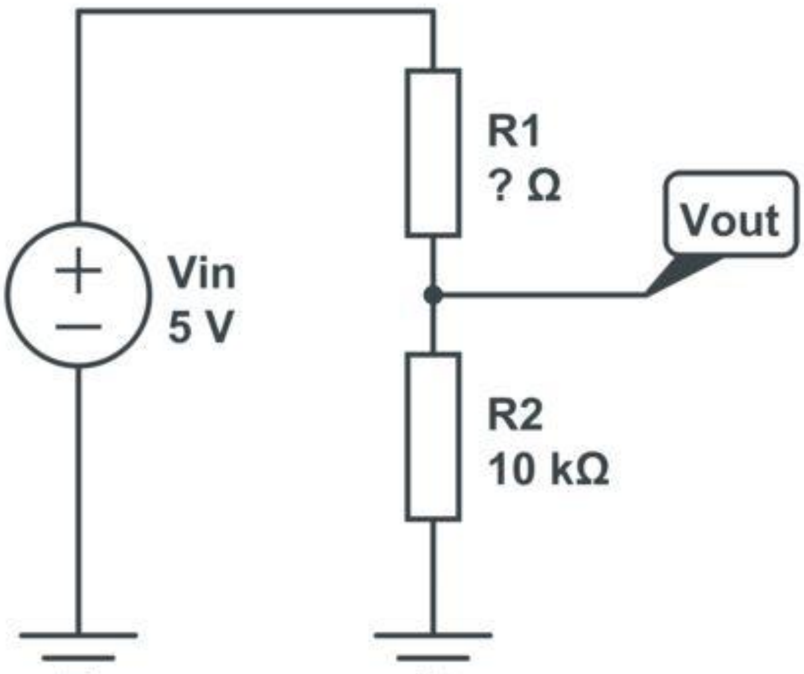
Example thermistor characteristics

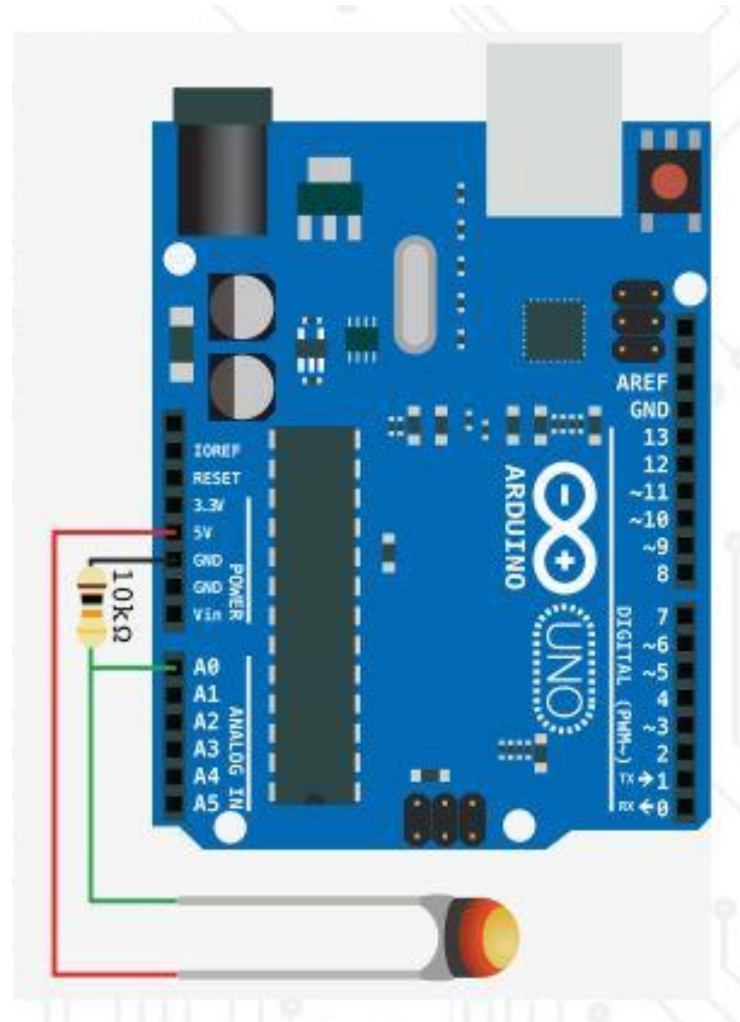
- NTC 10KΩ @ 25°C
  - Negative temperature coefficient thermistor with (nominal) resistance of 10kΩ at 25°C

- Response:



Thermistor, NTC, 10K @25c + Arduino





Thermistor, NTC, 10K @25c + Arduino

Steinhart-Hart Method

$$\frac{1}{T} = A + B\ln(R) + C(\ln(R))^3$$

Steinhart-Hart Equation

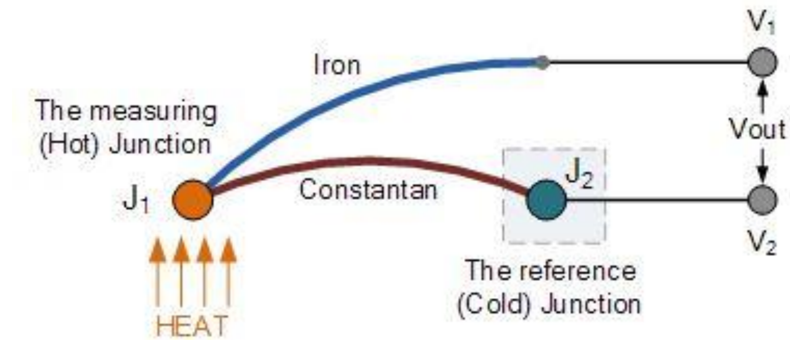
Sketch

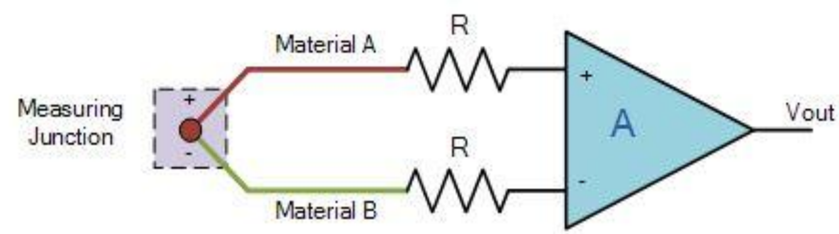
```
#include <Thermistor.h>
Thermistor temp(0);
void setup() {
Serial.begin(9600);
}
void loop() {
int temperature = temp.getTemp();
Serial.print("The sensor temperature is: ");
Serial.print(temperature);
Serial.println("*C");
delay(1000);
}
```

Temperature Sensors

- ***Electronic/* Thermocouple:**

  thermoelectric sensors that basically consists of two junctions of dissimilar metals, such as copper and constantan that are welded or crimped together. One junction is kept at a constant temperature called the reference (Cold) junction, while the other the measuring (Hot) junction. When the two junctions are at different temperatures, a voltage is developed across the junction which is used to measure the temperature sensor





Precision Centigrade Temperature Sensor **LM35**

- Calibrated directly in degrees Celsius (Centigrade)
- Linear a 10.0 mV/C scale factor
- 0.5%C accuracy guaranteeable
- Rated for full -55 to +150C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 mA current drain
- Low self-heating, 0.08C in still air
- Nonlinearity only +/- .25C typical
- Low impedance output, 0.1 ohm for 1 mA load

TO-92 transistor package.

Precision Centigrade Temperature Sensor **LM35 Data Sheets**

Product Folder | Sample & Buy | Technical Documents | Tools & Software | Support & Community

TEXAS INSTRUMENTS

LM35

www.ti.com

SNIS159D – AUGUST 1999 – REVISED OCTOBER 2013

LM35 Precision Centigrade Temperature Sensors

FEATURES

- Calibrated Directly in ° Celsius (Centigrade)
- Linear + 10 mV/°C Scale Factor
- 0.5°C Ensured Accuracy (at +25°C)
- Rated for Full −55°C to +150°C Range

DESCRIPTION

The LM35 series are precision integrated-circuit temperature sensors, with an output voltage linearly proportional to the Centigrade temperature. Thus the LM35 has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from the

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National Semiconductor

November 2000

LM35
Precision Centigrade Temperature Sensors

General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range, while the LM35C is rated for a −40° to +110°C range (−10° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

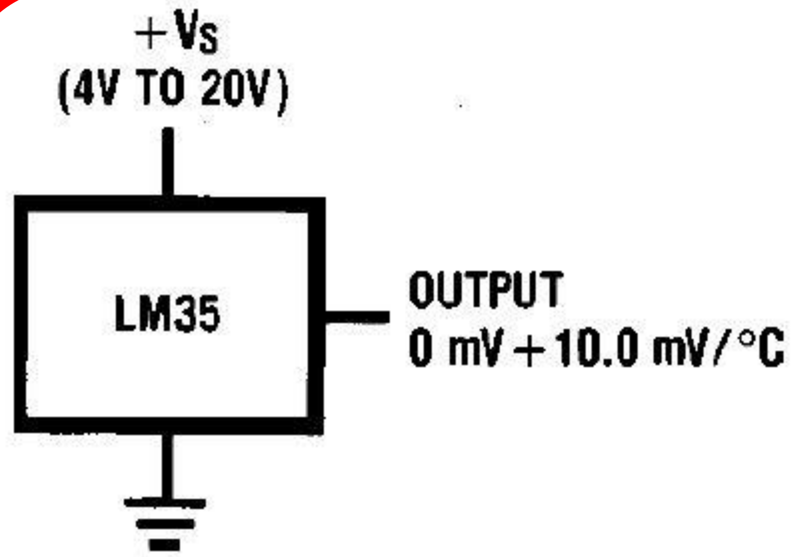
- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only ±¼°C typical
- Low impedance output, 0.1 Ω for 1 mA load

LM35 Precision Centigrade Temperature Sens

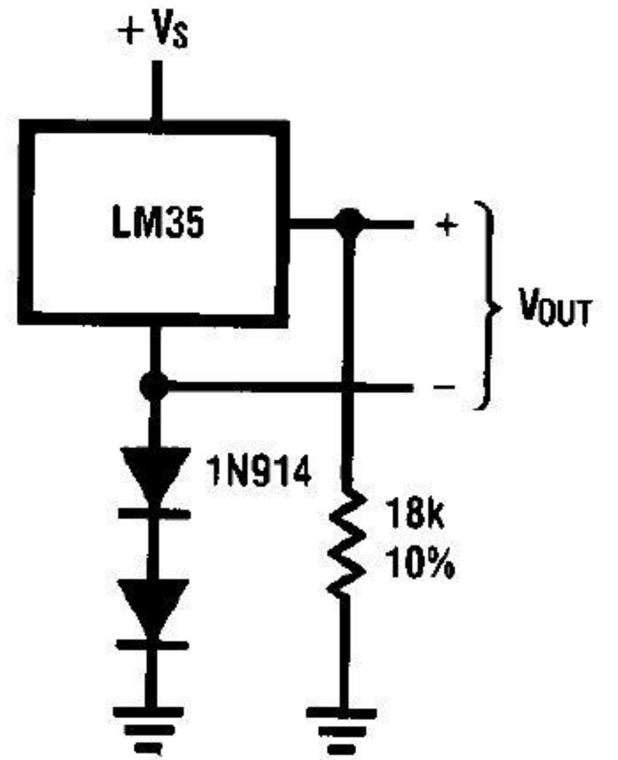
Read the Data Sheets

Temperature Sensor **LM35**
Typical Applications

- Basic Centigrade Temperature
- Sensor (+2 degrees C to +150 degrees C)



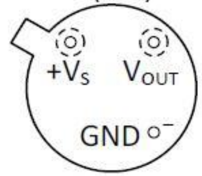
- Temperature Sensor, Single Supply
- -55 degrees to +150 degrees C



LM35 pin out connections

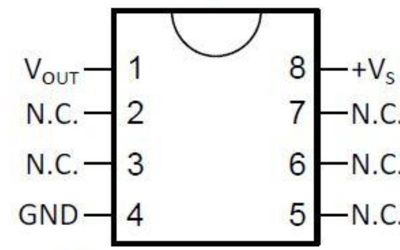
CONNECTION DIAGRAMS

METAL CAN PACKAGE
TO (NDV)



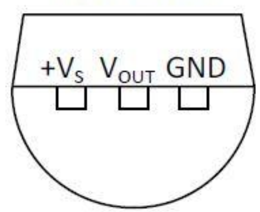
Case is connected to negative pin (GND)

SMALL-OUTLINE MOLDED PACKAGE
SOIC-8 (D)
TOP VIEW

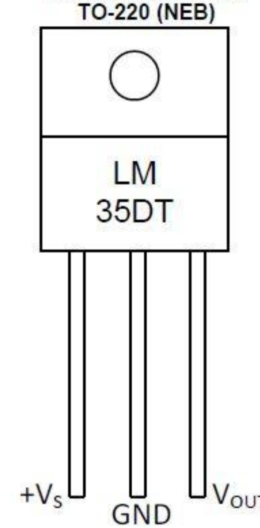


N.C. = No connection

PLASTIC PACKAGE
TO-92 (LP)
BOTTOM VIEW



PLASTIC PACKAGE
TO-220 (NEB)



Tab is connected to the negative pin (GND).

Precision Centigrade Temperature Sensor **LM35**

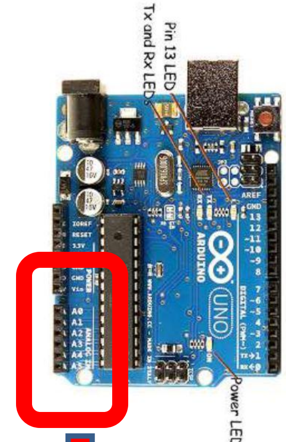
- The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature.

- Linear a 10.0 mV/degree C scale factor
- 2 degrees C = +20mv., 100 degrees C = +1.0 volts (1000 mv.)

- The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01°C of the surface temperature.

“ Arduino Platform”

Analog Inputs



- Six Channels A/D converter Pins A0 to A5
- Input voltage **= 0v. To + 5v**
- 1024 bits conversion (0-1023)

  (10 bit DAC) **.004,889 volts / step**
- Example: 0 bits = 0 volts, 256 bits = + 1.25v

  512 bits = +2.5 v, 1023 bits = + 5 volts
- 100 degrees **C** = **1.000,000 volts**
- **100 degrees = DAC count of 200**

  (about 2 bits count / degree C)

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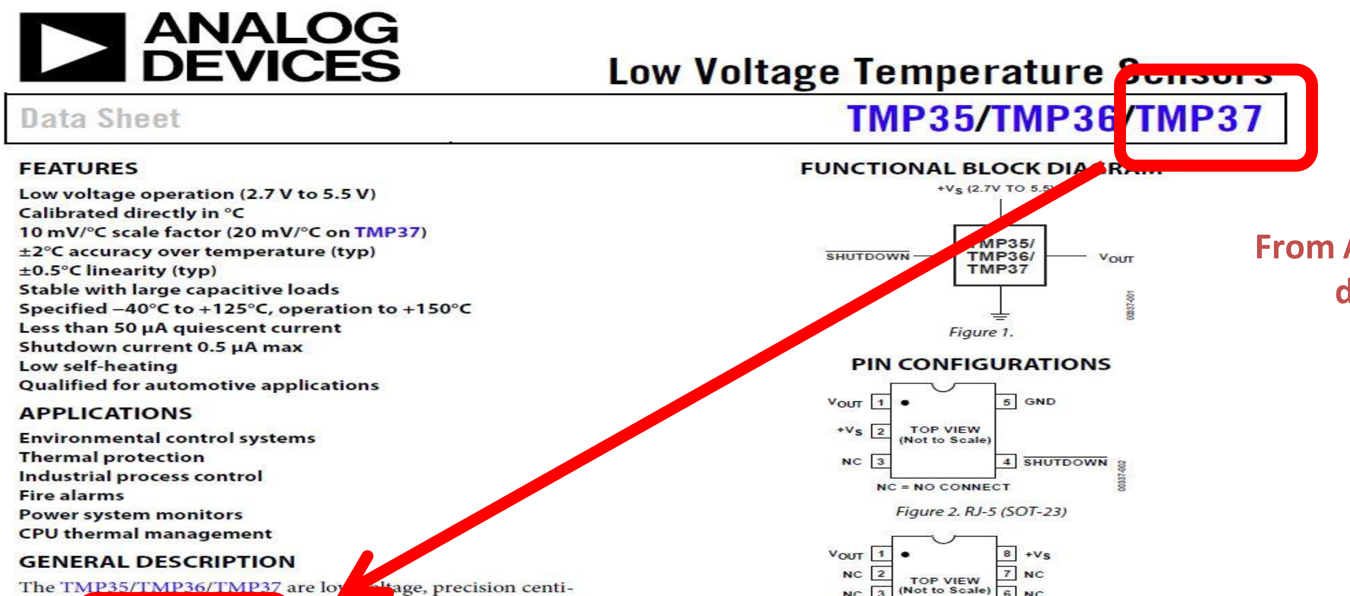
Checking the temperature sensors that are available from manufactures and suppliers – from Analog Devices



ANALOG DEVICES

Low Voltage Temperature Sensors

Data Sheet **TMP35/TMP36/TMP37**

FEATURES

Low voltage operation (2.7 V to 5.5 V)
Calibrated directly in °C
10 mV/°C scale factor (20 mV/°C on TMP37)
±2°C accuracy over temperature (typ)
±0.5°C linearity (typ)
Stable with large capacitive loads
Specified −40°C to +125°C, operation to +150°C
Less than 50 µA quiescent current
Shutdown current 0.5 µA max
Low self-heating
Qualified for automotive applications

APPLICATIONS

Environmental control systems
Thermal protection
Industrial process control
Fire alarms
Power system monitors
CPU thermal management

GENERAL DESCRIPTION

The TMP35/TMP36/TMP37 are low voltage, precision centi-

FUNCTIONAL BLOCK DIAGRAM

Figure 1.

PIN CONFIGURATIONS

Figure 2. RJ-5 (SOT-23)

From Analog Devices data sheet

- The TMP37 is intended for applications over the range of 5°C to 100°C and provides an output scale factor of **20 mV/°C.** The TMP37 provides a 500 mV output at 25°C. Operation extends to 150°C with reduced accuracy for all devices when operating from a 5 V supply. The TMP35/TMP36/TMP37 are available in low cost 3-lead TO-92

From Analog Devices data sheet

Table 4. TMP3x Output Characteristics

Sensor	Offset Voltage (V)	Output Voltage Scaling (mV/°C)	Output Voltage @ 25°C (mV)
TMP35	0	10	250
TMP36	0.5	10	750
TMP37	0	20	500

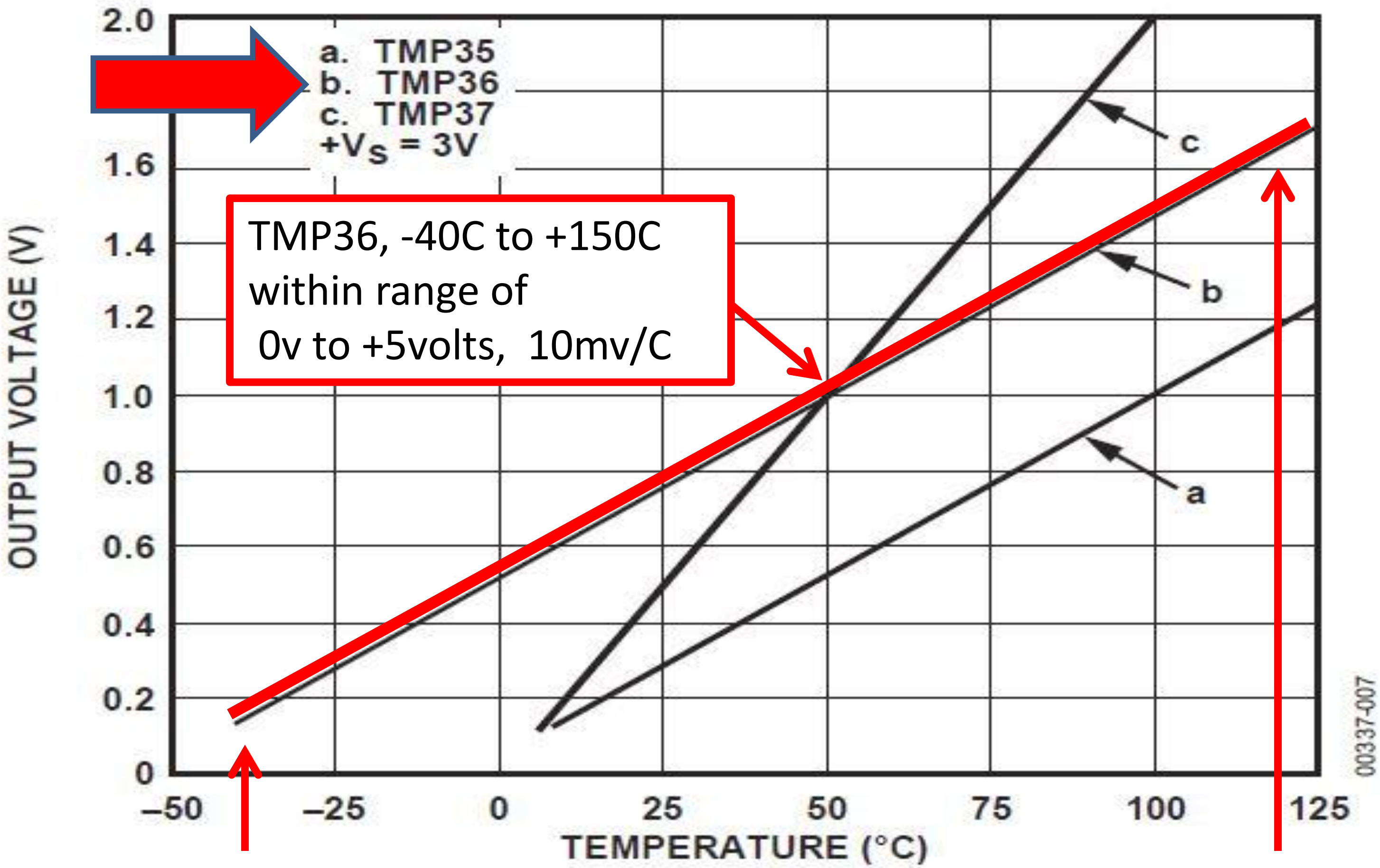
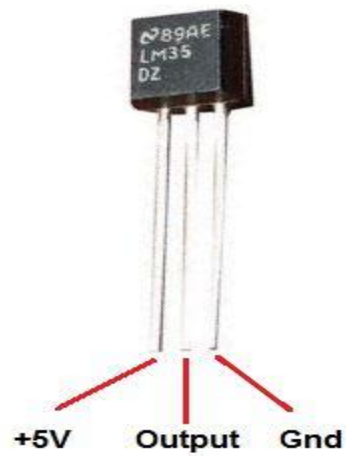


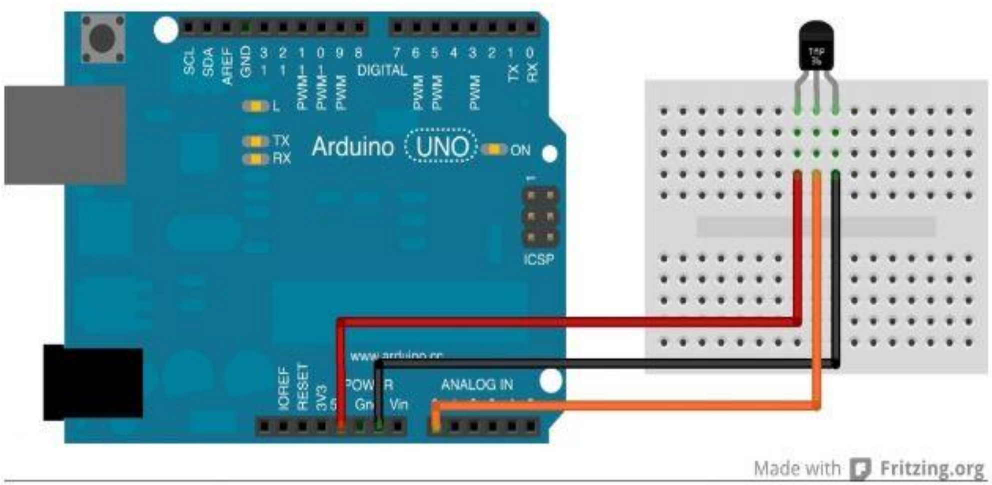
Figure 6. Output Voltage vs. Temperature

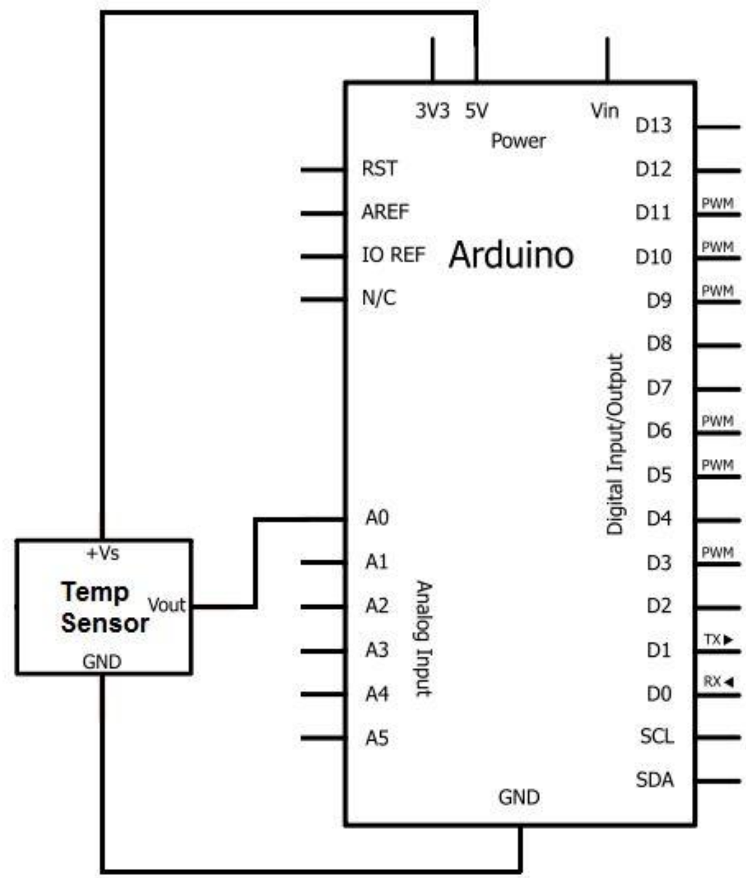
Using LM35 Sensor

Check your +5v. on the
Arduino Board with ADK
Value may change

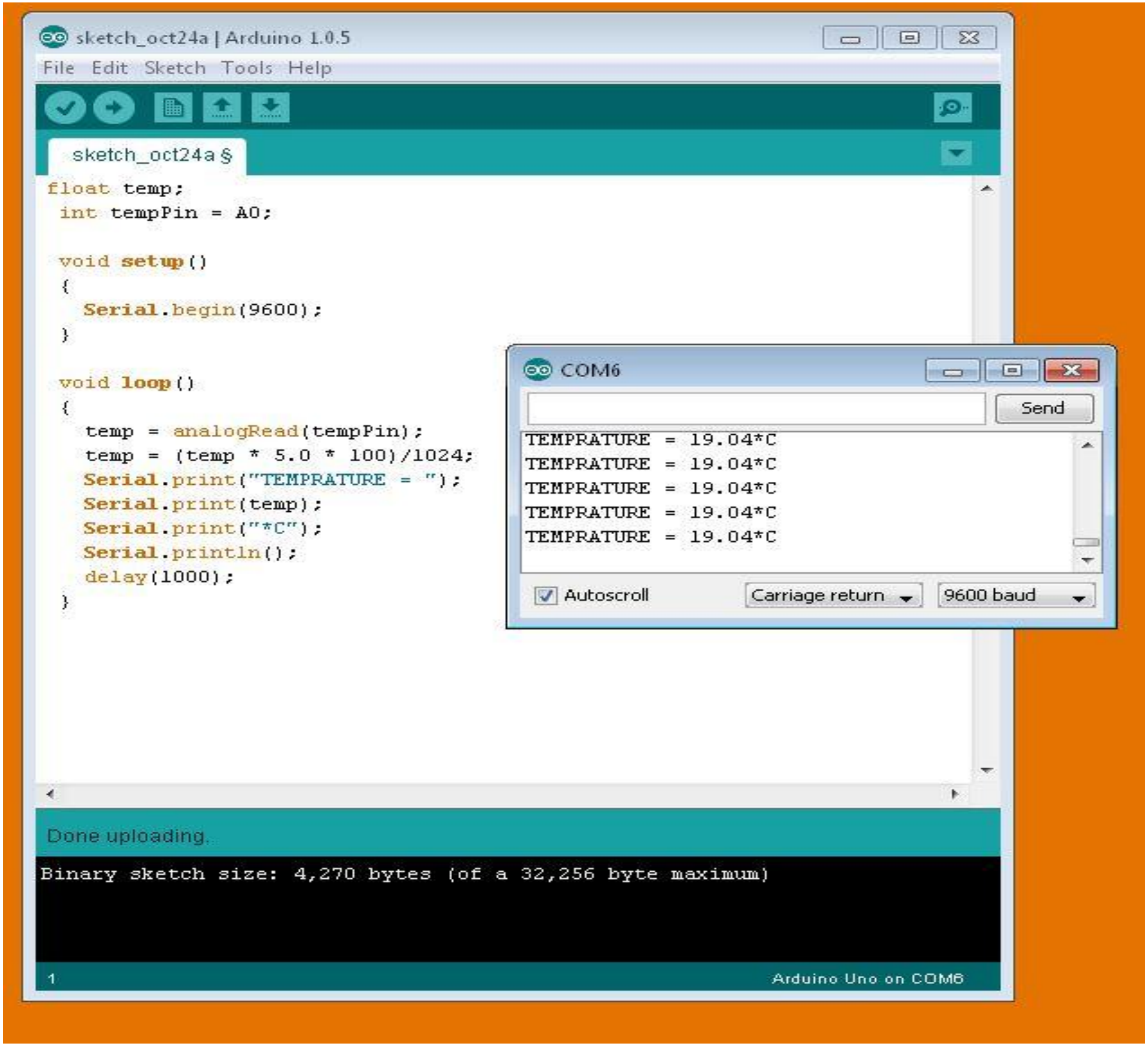
$$tempC = \frac{5.0 * val * 100}{1024}$$







Using LM35 Sensor output to Serial Monitor



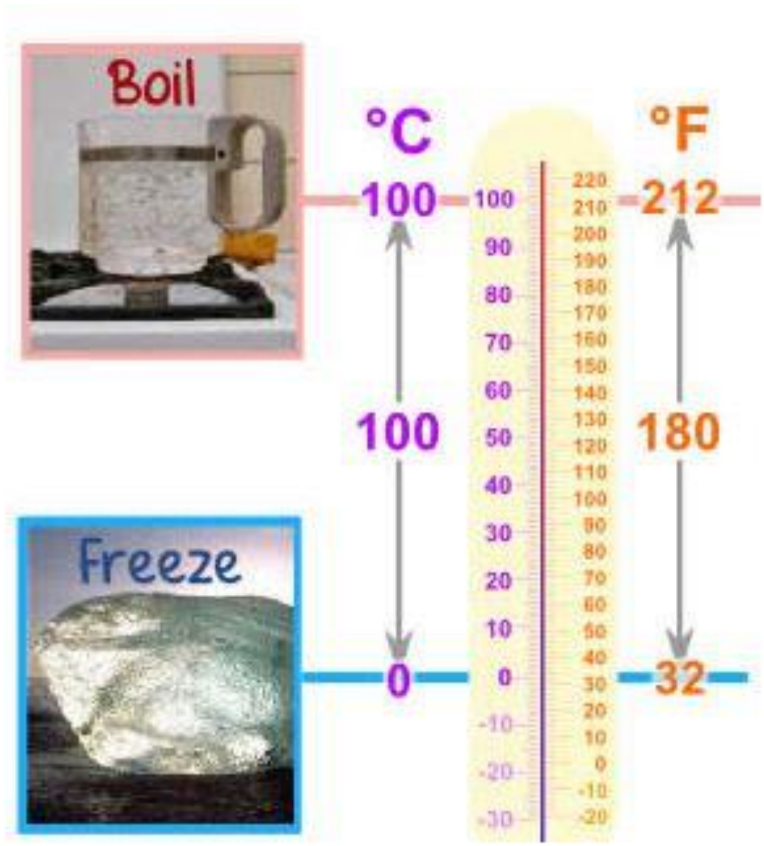
Using LM35 Sensor output to Serial Monitor

DIY

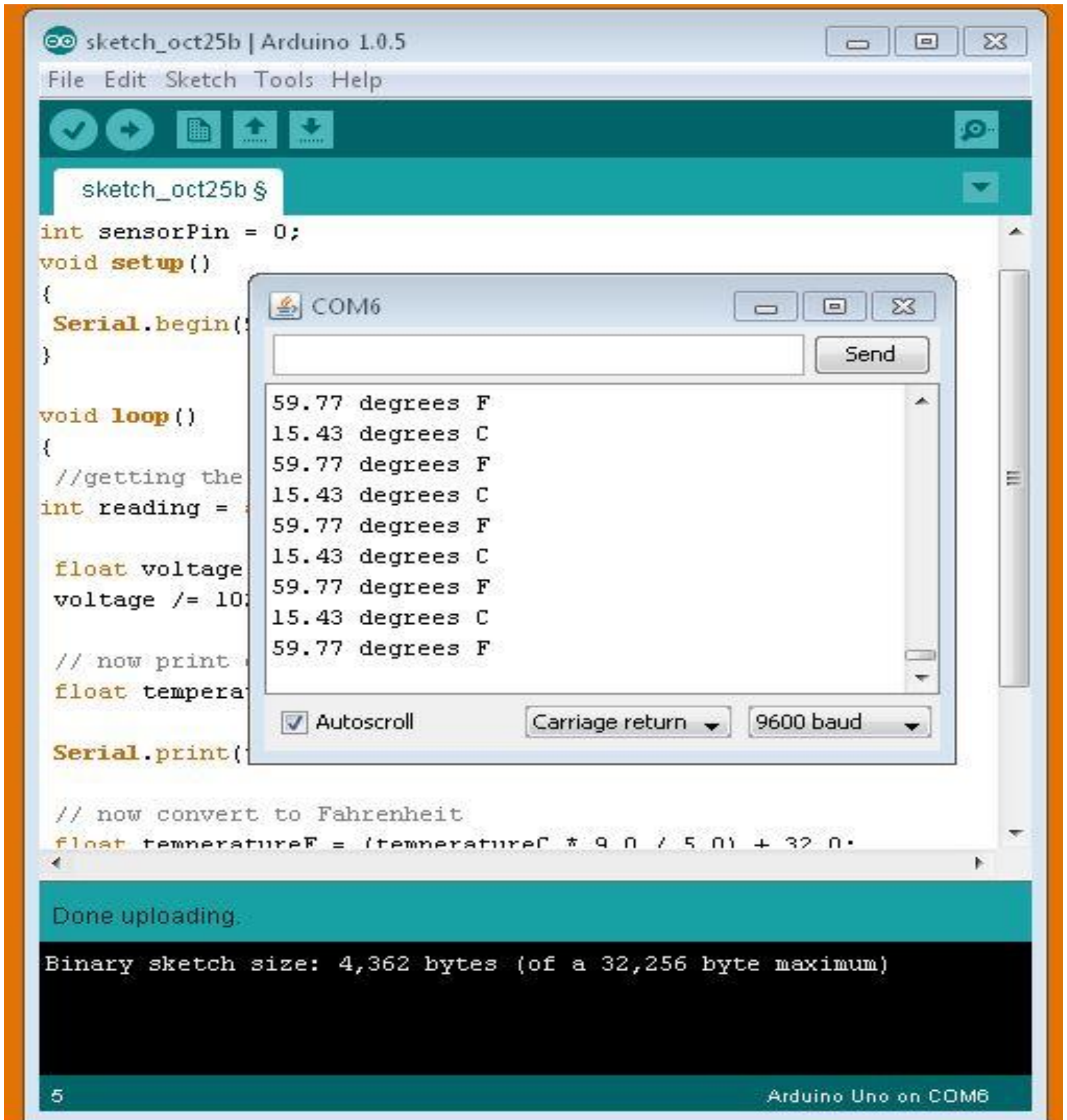
- On serial monitor display both degrees in C & F

Celsius to Fahrenheit: $(°C \times {}^{9}/_{5}) + 32 = °F$
Fahrenheit to Celsius: $(°F - 32) \times {}^{5}/_{9} = °C$

Celsius to Fahrenheit: $°C \times 1.8 + 32 = °F$
Fahrenheit to Celsius: $(°F - 32) / 1.8 = °C$



DIY On serial monitor, display both degrees in C & F



DIY

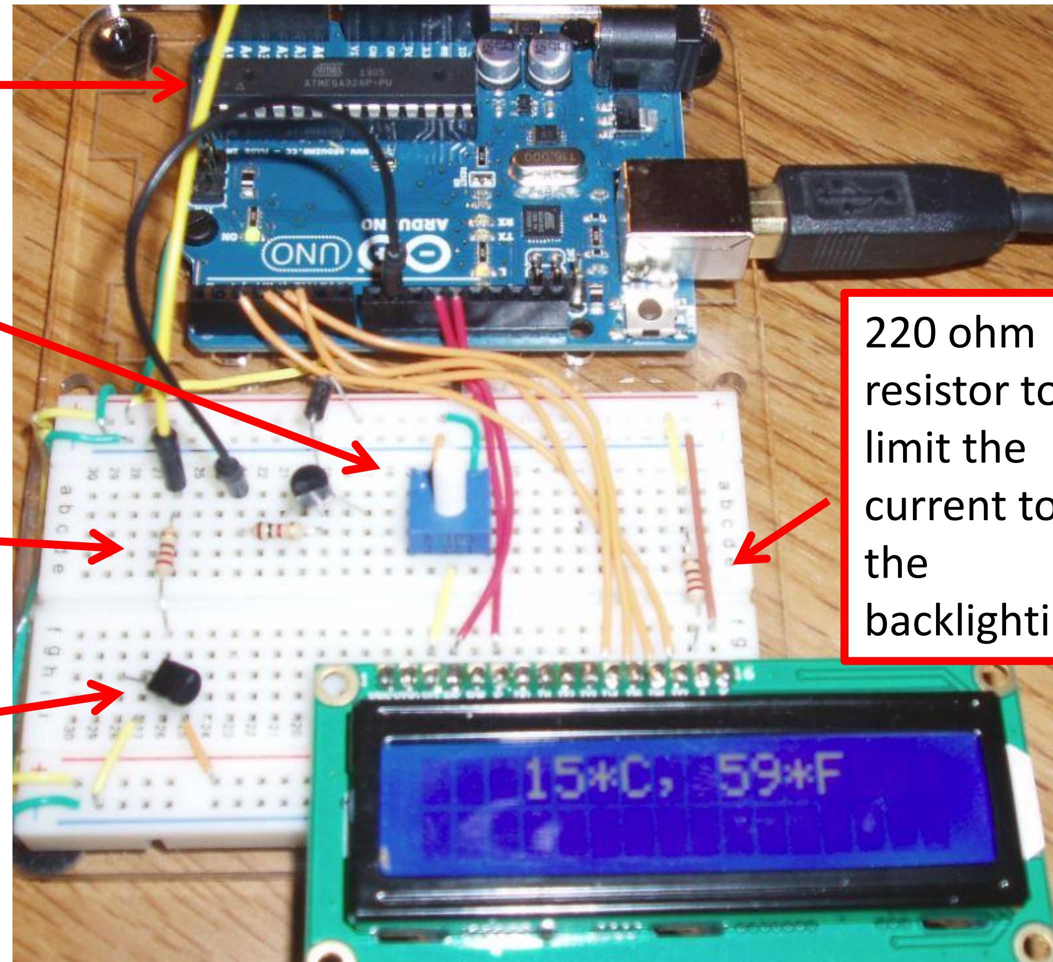
display both degrees in C & F on your **LCD**

Wire to A0 pin

LED contrast pot.

220 ohms input protection resistor

LM35 Temp. sensor

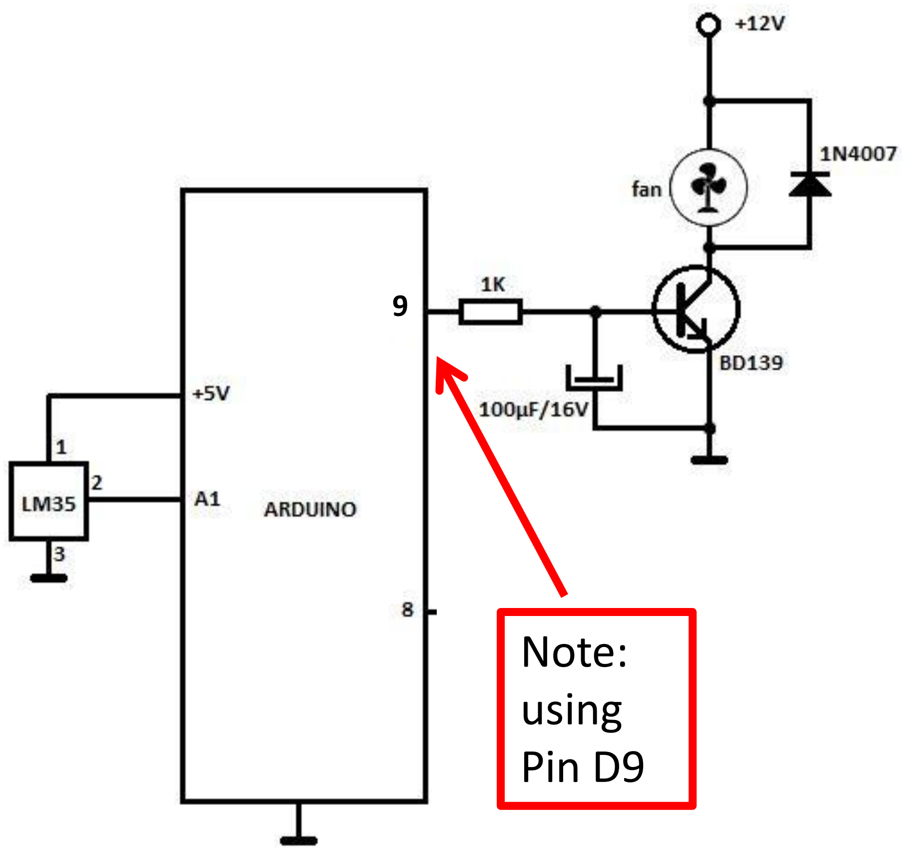


220 ohm resistor to limit the current to the backlighting

DIY Temperature Controlled Fan

step **one**

- Use LM35 sensor to detect temperature in a room
- Display room Temp. on LCD
- Control small DC Fan on/off with Lamp driver circuit
- Set trip point on temperature reading to turn fan on.
- Display “Fan” status on LCD (ON / OFF)

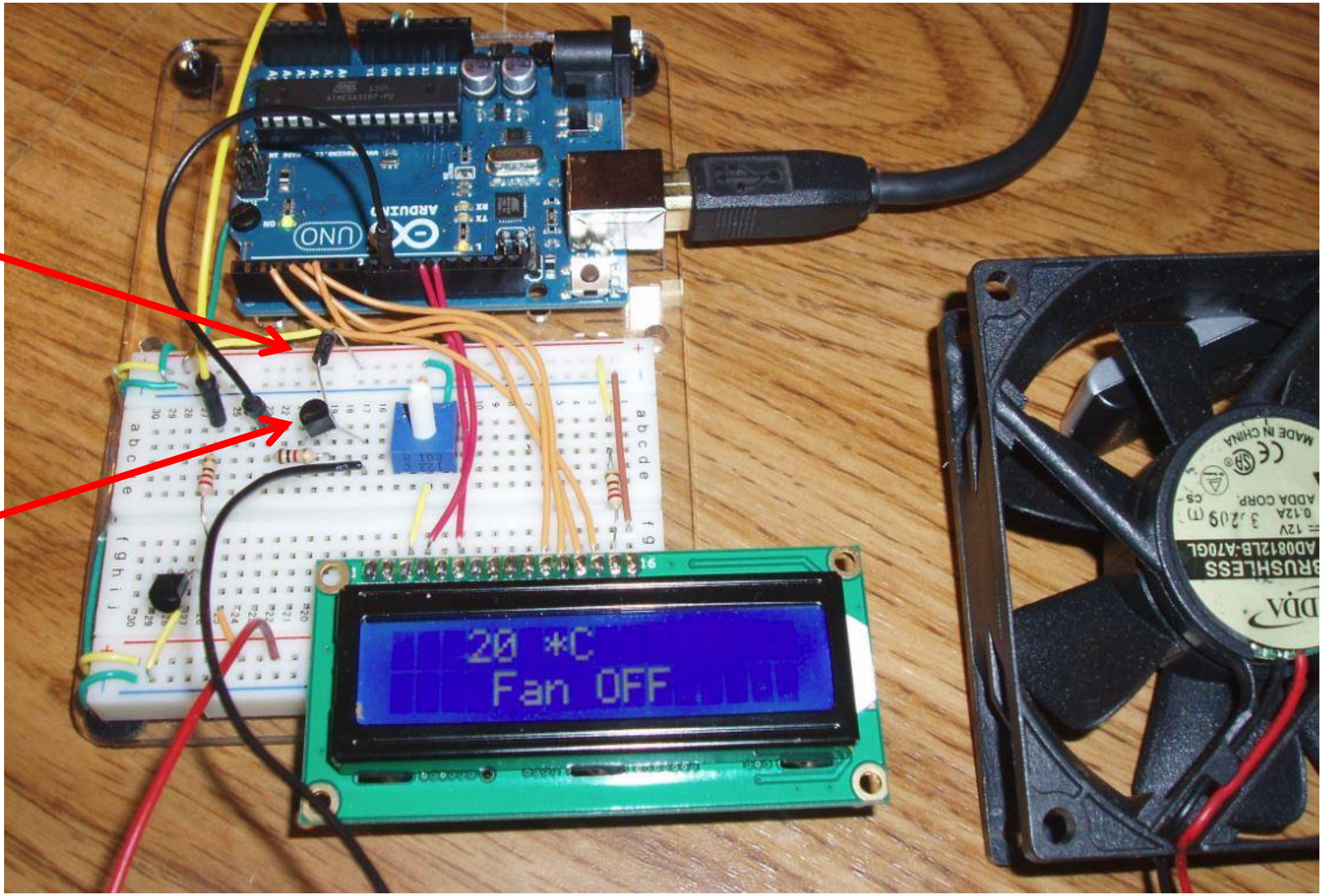


Note:
using
Pin D9

DIY Temperature Controlled Fan

Freewheeling Diode across FAN

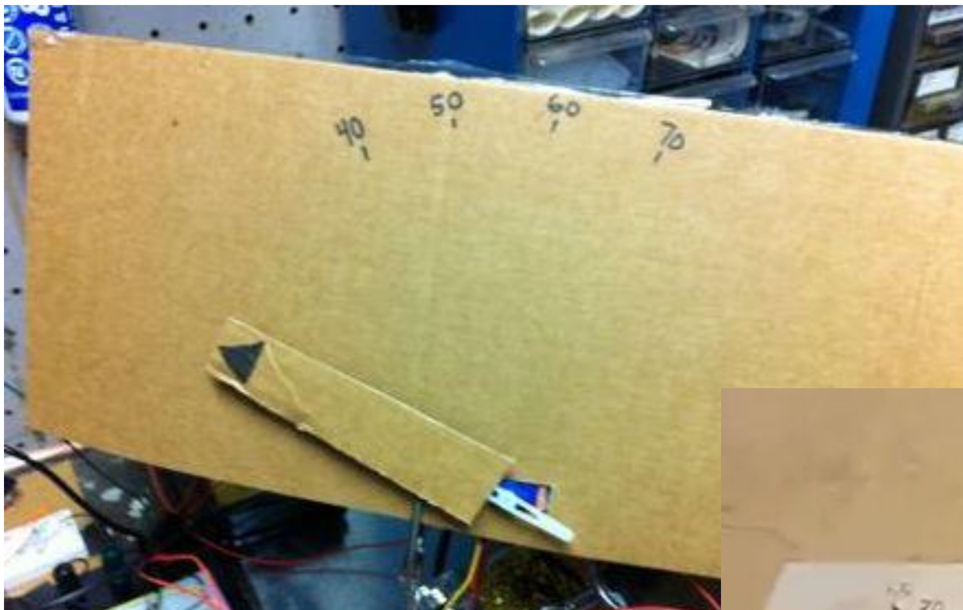
Lamp Driver transistor



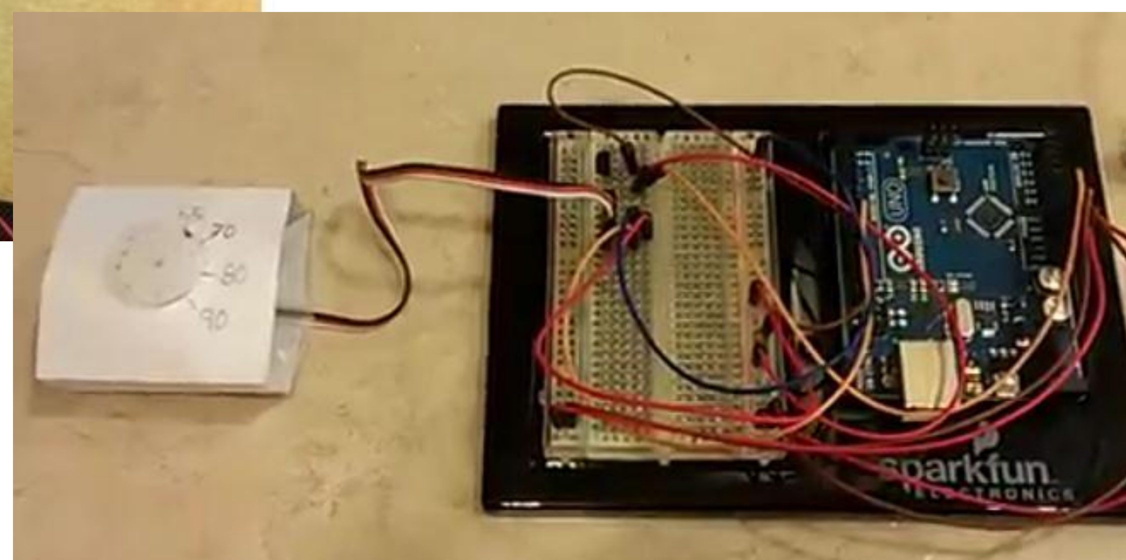
DIY ASDE project

Analog Wall **Thermometer**

using LM35 temp. sensor & servo motor



Learning Starts by Doing

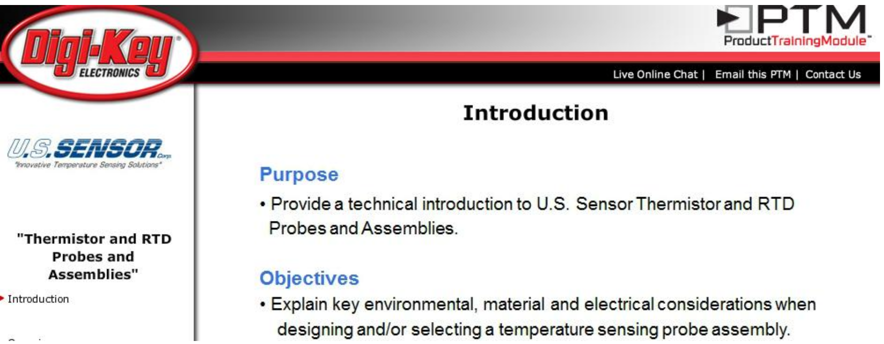


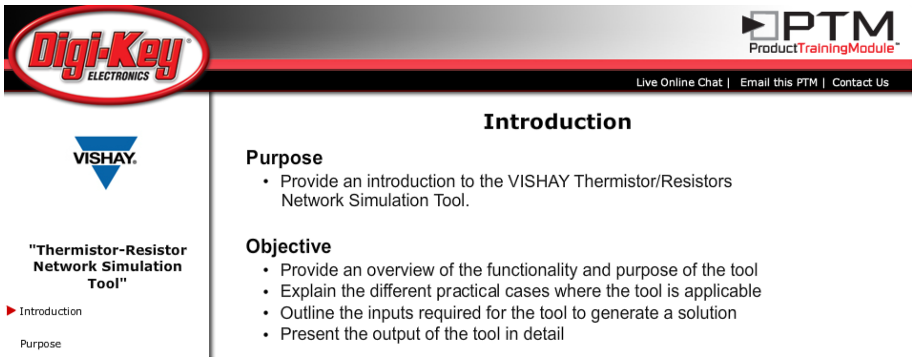
flipped discussion topics

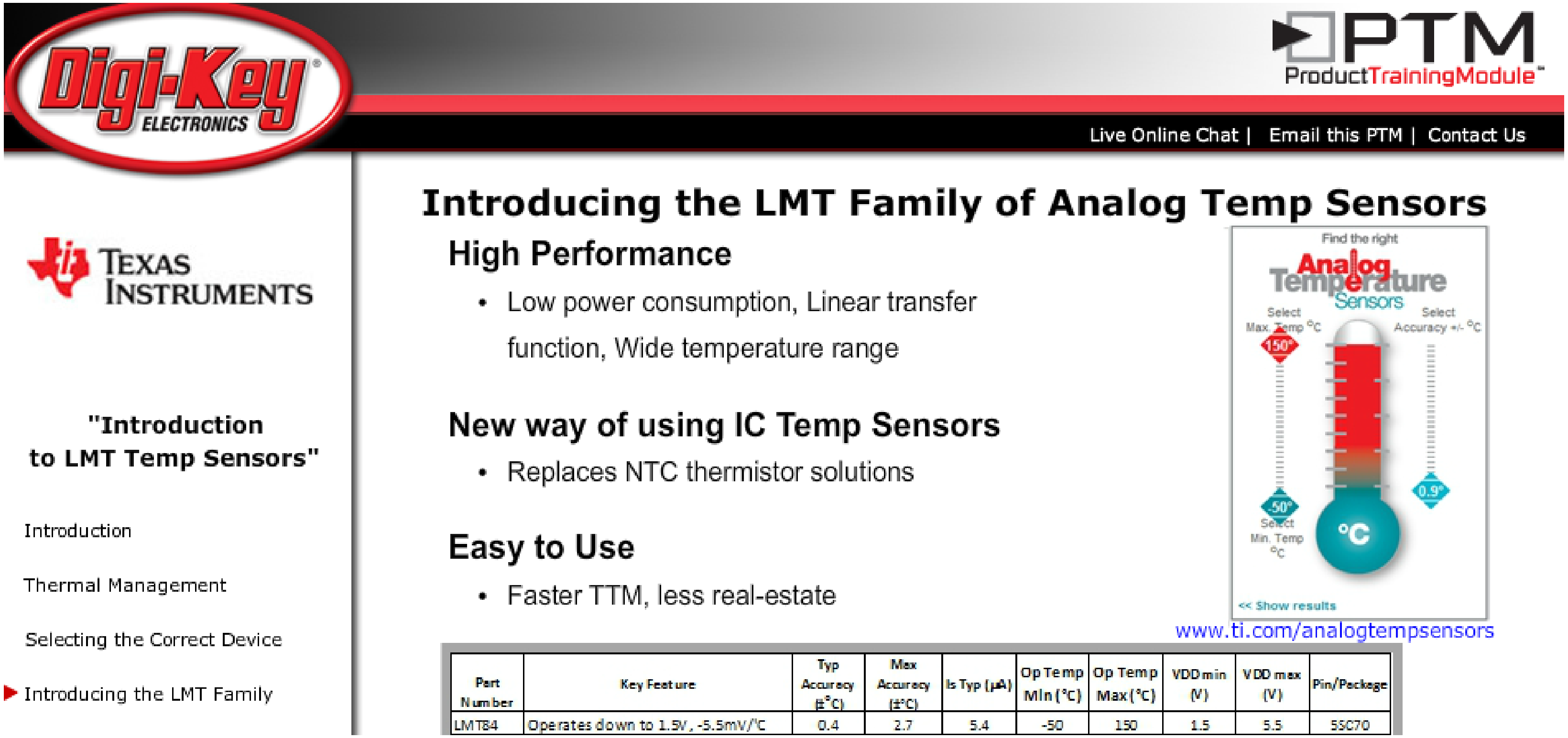
Temperature Sensors

- What types are available ?
- advantages and disadvantages of types
- *LM35 and TMP 35 – TMP37* Applications
- Thermistor and RTD & Others
- Design and Selection Tools from suppliers
- Data Sheets and Application Notes
- Cost

flipped discussion topics







Part Number	Key Feature	Typ Accuracy (±°C)	Max Accuracy (±°C)	Is Typ (μA)	Op Temp Min (°C)	Op Temp Max (°C)	VDD min (V)	VDD max (V)	Pin/Package
LMT84	Operates down to 1.5V, -5.5mV/°C	0.4	2.7	5.4	-50	150	1.5	5.5	5SC70

DIY Temperature Controlled Fan

step **two** & **three** on fan control

2. Program a **two speed fan controller** with two temperature trip points
- Use PWM to change the speed of the Fan
3. Program a **variable speed** fan controller. After the temp. reaches a set trip point the fan turns on, the higher the temp. the faster the fan turns. Start at 28*C and max at 36*C.

*Let the **Fun** & **Learning Begin***