Temperature Sensors

ECE 321: Electronics II

Lecture #4

Please visit Bison Academy for corresponding lecture notes, homework sets, and solutions

Sensors

Sensors convert something you want to measure into something you can measure.

Typically the output is a resistance

- Thermistor: Resistance changes with temperature:
- CdS Cell: Resistance changes with light level
- Gas Sensors: Resistance changes with gas levels

If you can measure resistance, you can measure about anything

- Replace the resistor with a sensor

Digikey: ECE Toy Store

Sensors, Transducers - 4188 New Products

- Accessories (4936 items)
- Amplifiers (802 items)
- Camera Modules (324 items)
- Color Sensors (194 items)
- Current Sensors (2366 items)
- Encoders (8623 items)
- Float, Level Sensors (992 items)
- Flow Sensors (340 items)
- Force Sensors (379 items)
- Gas Sensors (435 items)
- Humidity, Moisture Sensors (608 items)
- Image Sensors, Camera (1528 items)
- IrDA Transceiver Modules (303 items)
- LVDT Transducers (Linear Variable Differential Transformer) (146 items)
- Magnetic Sensors - Compass, Magnetic Field (Modules) (24 items)
- Magnetic Sensors - Linear, Compass (ICs) (1508 items)
- Magnetic Sensors - Position, Proximity, Speed (Modules) (4565 items)

Temperature Sensors

- Temperature is hard to measure
- Resistance is easy to measure

Temperature Sensors are devices whose resistance varies with temperature

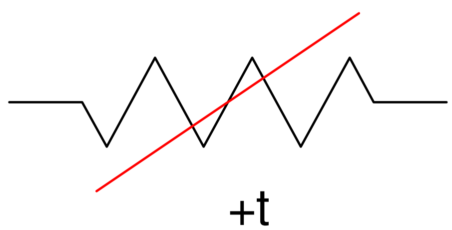
- Resistive Temperature Device (RTD)
- Thermistor

Other temperature sensors exist: we'll just look at these two.

RTD: "Resistance Temperature Device"

Description: In metals, at 0K the resistance is low due to electrons traveling unhindered in the conduction bands. As temperature increases, the atoms vibrate and impede the electron flow. Hence, resistance increases as temperature increases.

Symbol:



Model: A polynomial model is often used:

$$R = R_0(1 + a_1 T + a_2 T^2 + a_3 T^3 + ...)$$

A 1st-Order Model is used for simplicity (with less accuracy)

$$R = R_0(1 + aT)$$

Be	a = 2.5%/C	most sensitive
Ni	a = 0.681%/C	
Fe	a = 0.651%/C	
Cu	a = 0.43%/C	
Al	a = 0.429%/C	
Pt	a = 0.385%/C	
Nd	a = 0.16%/C	least sensitive

Example: Find the resistance of a Copper RTD at 25C

- R(5C) = 10k.

Solution: Using the model

$$R = R_0(1 + a \cdot T)$$

Since Ro is defined at 5C, at 25C T=+20.

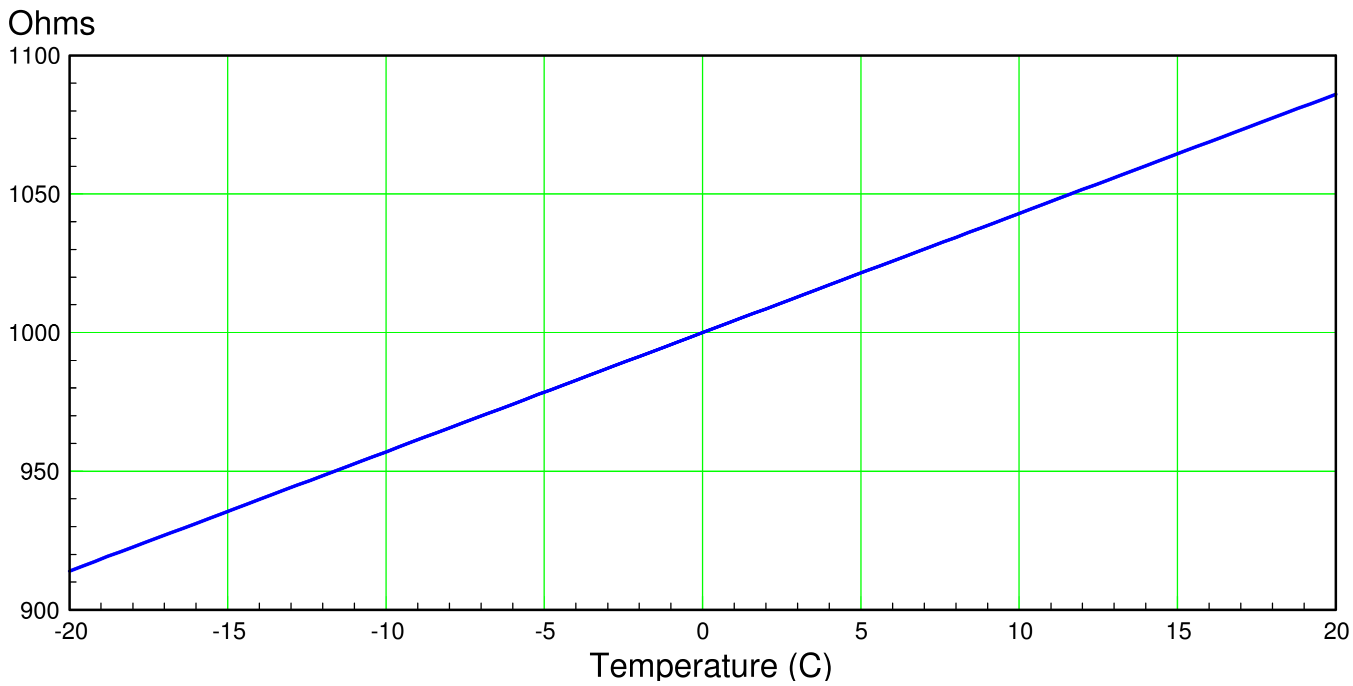
$$R = 10,000 \cdot (1 + 0.0043 \cdot 20C) = 10,860\Omega$$

Example 2: Design a circuit to output

- -10V at -20C
- +10V at +20C

Assume a copper RTD with (T in Celsius)

$$R = 1000\,(1 + 0.0043T)\ \Omega$$



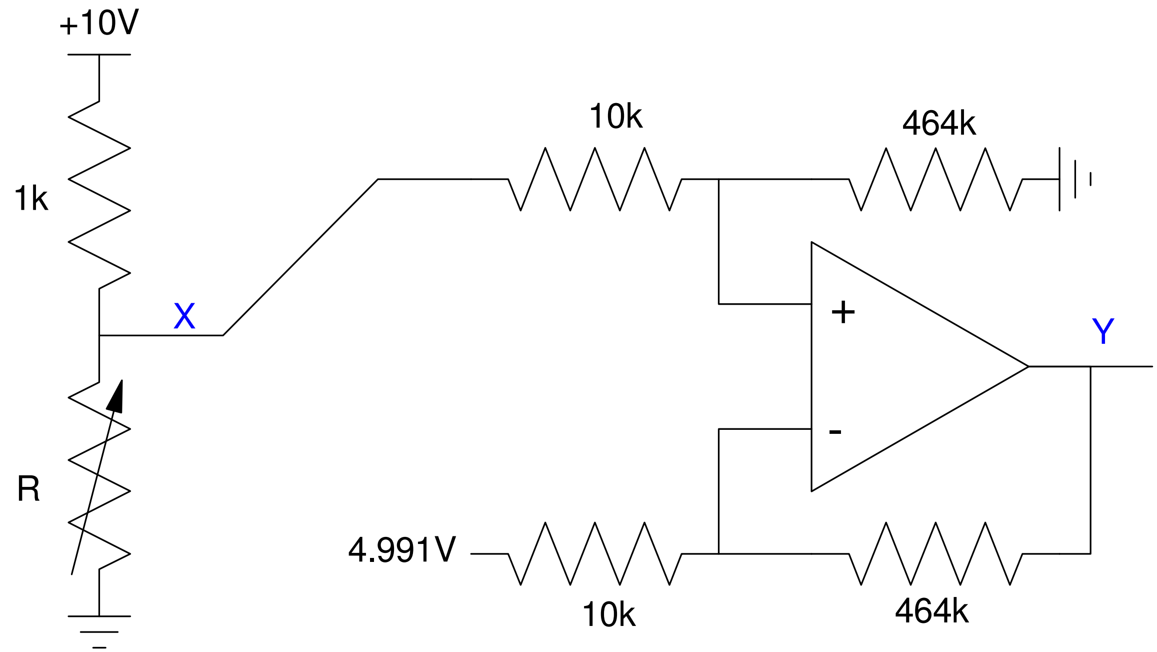
Analysis:

At -20C,

- R = 914 Ohms
- X = 4.775V
- Y = -10V

At +20C

- R = 1086 Ohms
- X = 5.206V
- Y = +10V

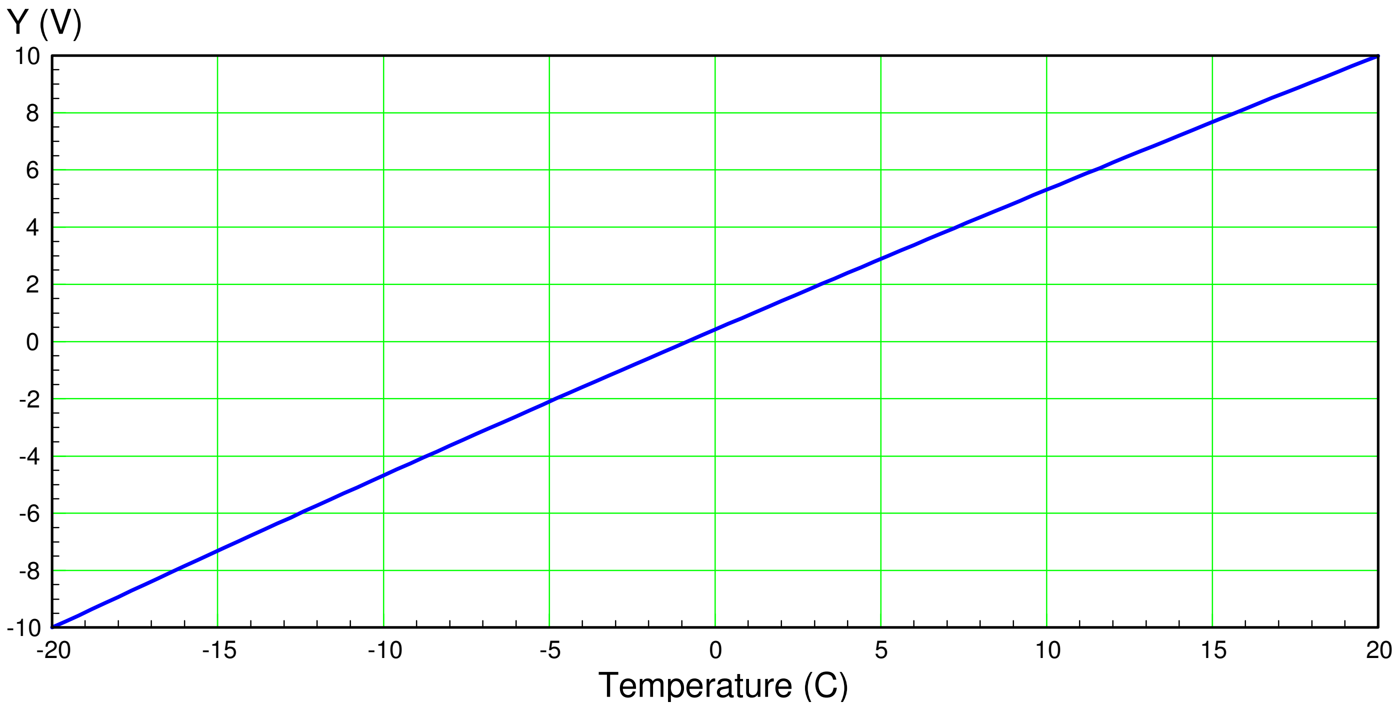


$$gain = \left(\frac{10V-(-10V)}{5.206V-4.775V}\right) = 46.42$$

$$offset = \left(\frac{5.206V+4.775V}{2}\right) = 4.991V$$

Checking in Matlab:

```
T = [-20:0.1:20];
R = 1000 * (1 + 0.0043*T);
X = R ./ (1000 + R) * 10;
Y = 46.42 * (X - 4.991);
plot(T,Y);
xlabel('Temperature (C)');
ylabel('Y (Volts)');
```



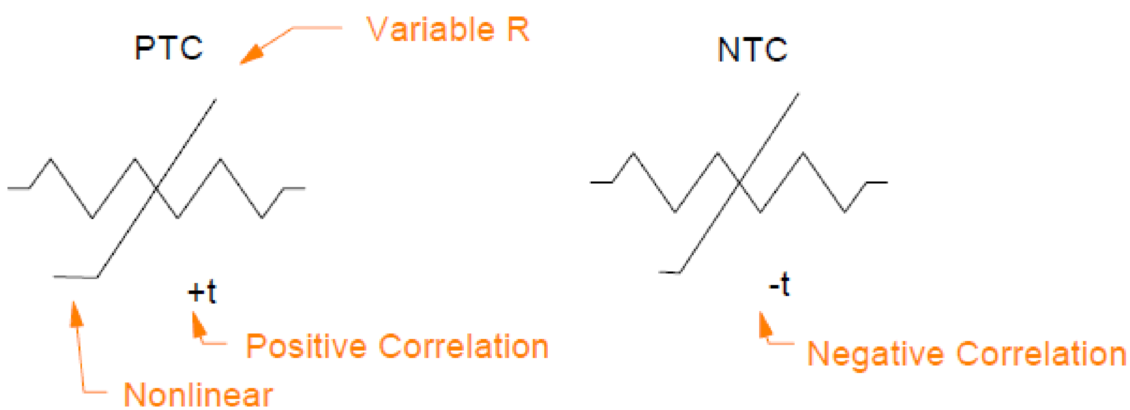
Thermistors

Thermistors are semiconductors (as opposed to metals).

There are two types:

- NTC: Resistance drops with temperature (temperature sensor)
- PTC: Resistance increases with temperature (resettable fuse)

Symbol:



Thermister Model:

2-Parameter Model:

$$R = \exp\left(A + \frac{B}{T}\right)$$ ±0.3C over 50C

3-parameter Model:

$$R = \exp\left(A + \frac{B}{T} + \frac{C}{T^3}\right)$$ ±0.01C over 100C

4-Parameter Model:

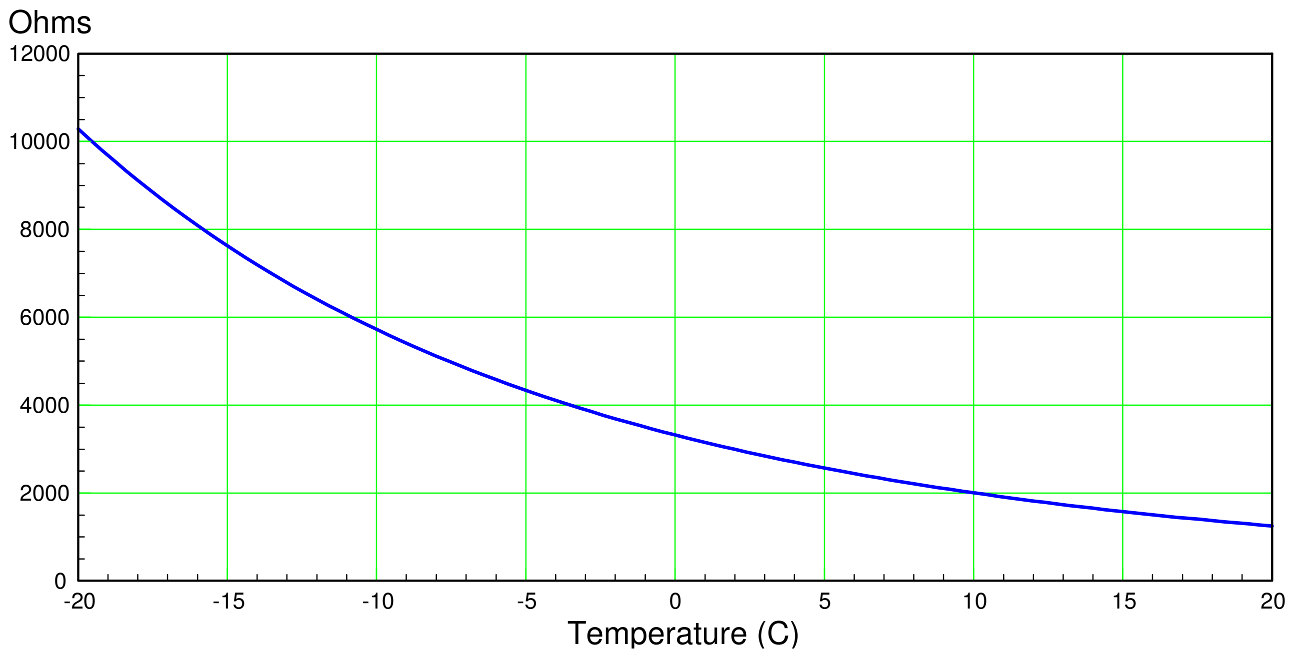
$$R = \exp\left(A + \frac{B}{T} + \frac{C}{T^2} + \frac{D}{T^3}\right)$$ ±0.00015C over 100C

Example: Design a circuit to output

- -10V at -20C
- +10V at +20C

Assume a thermistor with (T in Kelvin)

$$R = 1000 \cdot \exp\left(\frac{3905}{T} - \frac{3905}{298}\right)\ \Omega$$



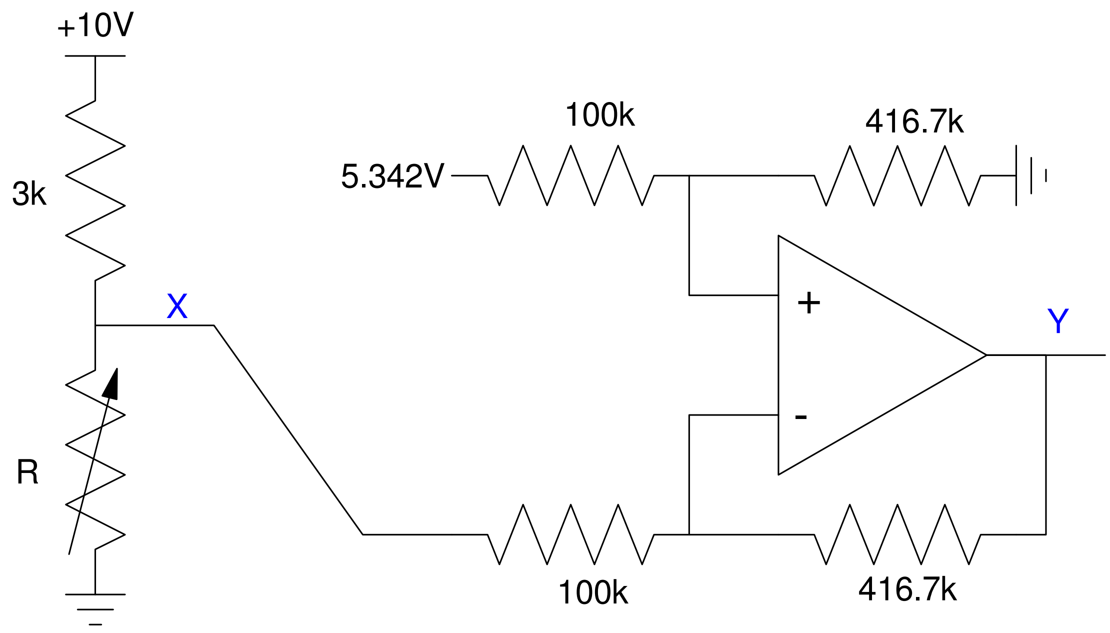
Analysis:

At -20C (253K)

- R = 10,285 Ohms
- X = 7.742V
- Y = -10V

At +20C

- R = 1,251 Ohms
- X = 2.942V
- Y = +10V

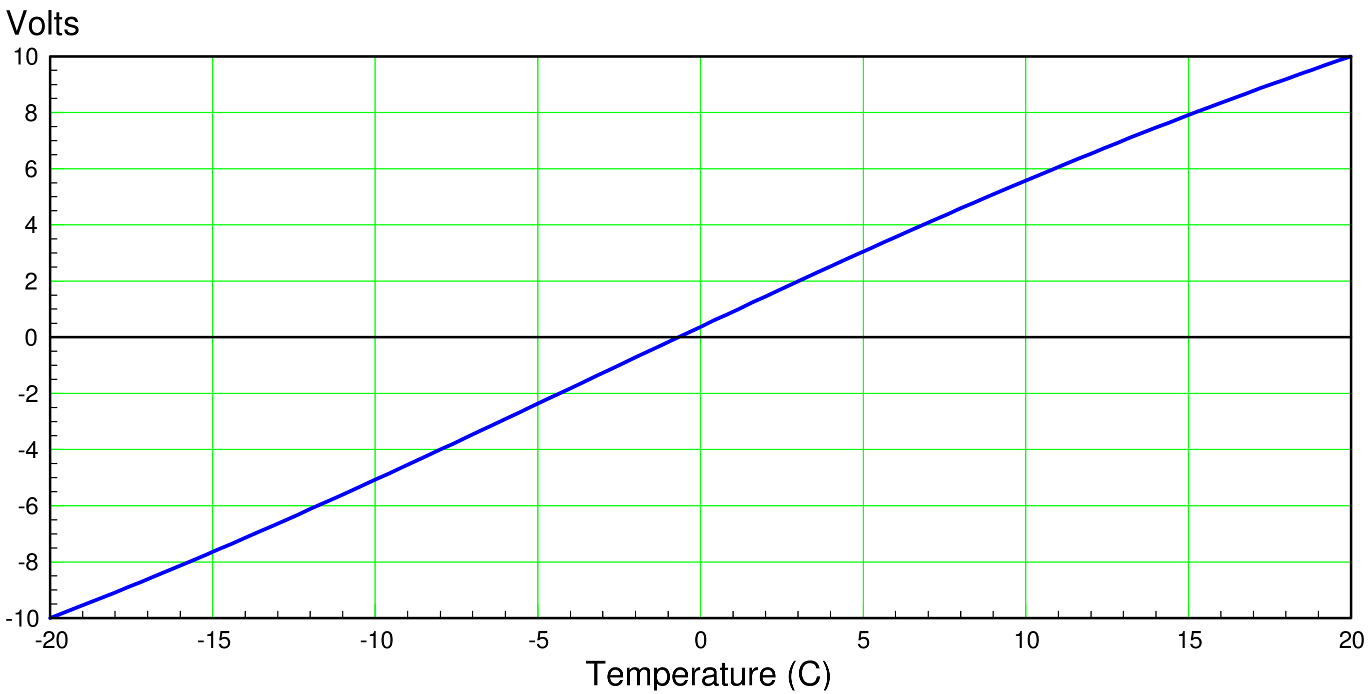


$$gain = \left(\frac{10V-(-10V)}{2.942V-7.742V}\right) = -4.167$$

$$offset = \left(\frac{7.742V+2.942V}{2}\right) = 5.342V$$

Checking in Matlab:

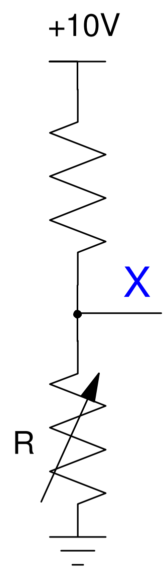
```
T = [-20:0.4:20]';
R = 1000 * exp( 3905 ./ (T + 273)  -  3905/298 );
X = R ./ (3000 + R) * 10;
Y = 4.167 * ( 5.342 - X );
plot(T,Y);
xlabel('Temperature (C)');
ylabel('Y (Volts)');
```

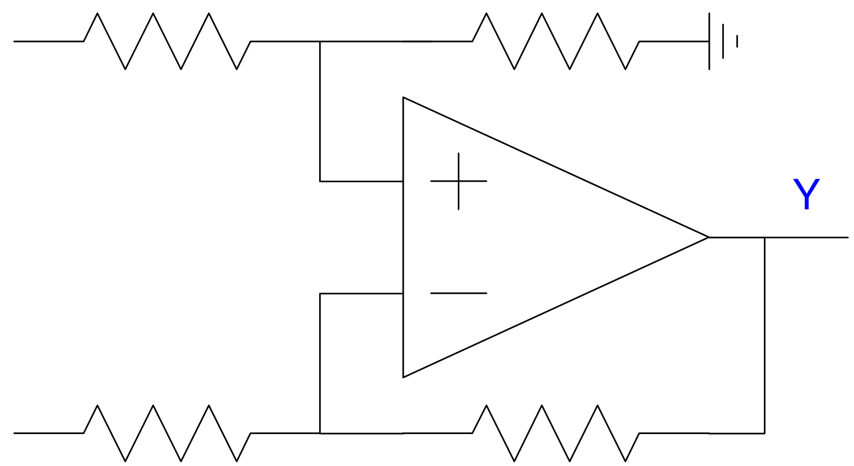


Handout

Design a circuit which outputs

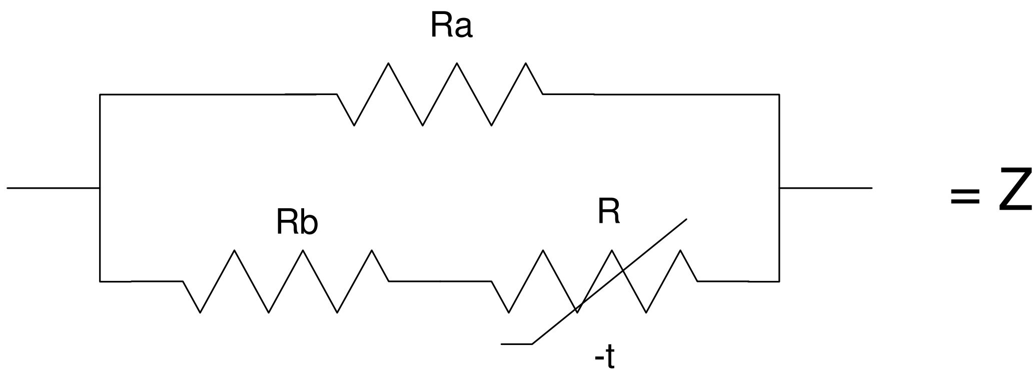
- 0V at 0C (R = 3320)
- 10V at 40C (R = 533)





Linearizing Circuits:

Since R is strongly nonlinear, a circuit which linearizes the resistance vs. temperature relationship would be nice. One such circuit is



Example: Assume

$$R = 1000 \cdot \exp\left(\frac{3905}{T} - \frac{3905}{298}\right)\ \Omega$$

Find Ra and Rb so that

$$Z_{10C} = \left(\frac{Z_{20C}+Z_{0C}}{2}\right)$$

Solution: fminsearch()

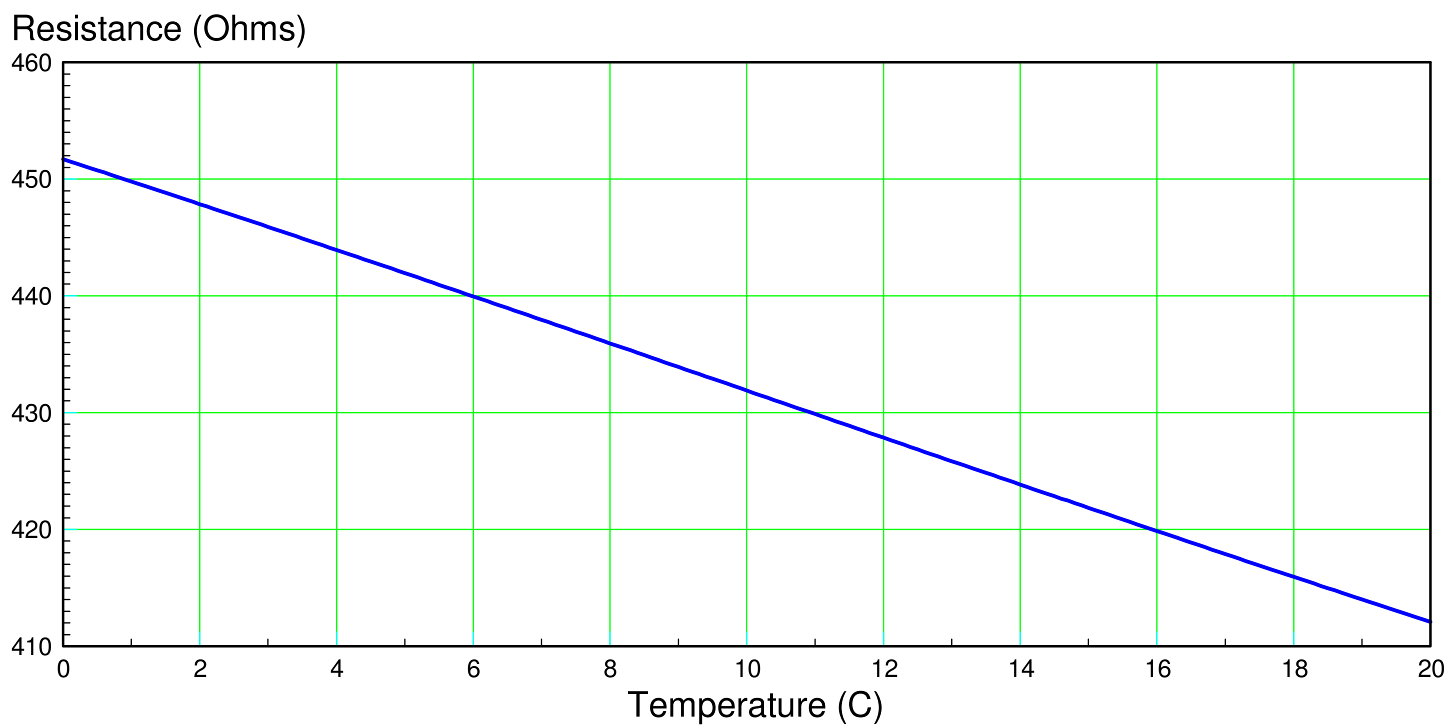
```
[Ra, e] = fminsearch('Thermistor',1000)

Ra =  504.4401

e =  1.2991e-015
```

- Rb = 1000
- Ra = Ra=504.44

```
function [ J ] = Thermistor( Z )
   Ra = Z;
   Rb = 1000;

   R0  = 1000*exp(3905/273 - 3905/298);
   R10 = 1000*exp(3905/283 - 3905/298);
   R20 = 1000*exp(3905/293 - 3905/298);

% Z = R1 R2 / (R1 + R2)

   Z0  = (R0  + Rb)*(Ra) / (R0 + Ra + Rb);
   Z10 = (R10 + Rb)*(Ra) / (R10 + Ra + Rb);
   Z20 = (R20 + Rb)*(Ra) / (R20 + Ra + Rb);

   E = Z10 - (Z0 + Z20)/2;

   J = E*E;

 end
```

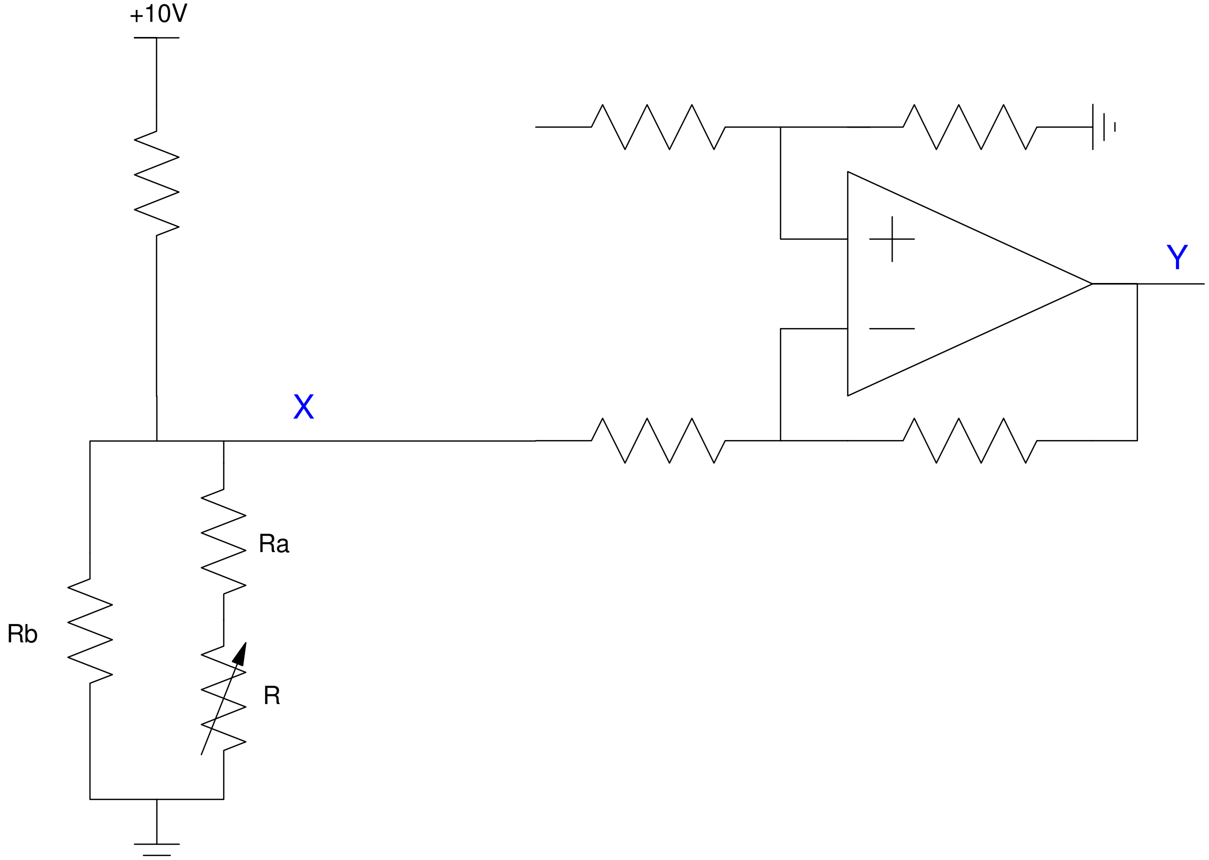
Resulting R vs. Temperature

```
T = [0:0.01:20]';
K = T + 273;
R = 1000*exp(3905 ./ K  -  3905/298);
Z = Ra * (R + Rb) ./ (R + Ra + Rb);
plot(T,Z)
```



Uses of Linearizing Circuit

- More linear Y vs. Temperature



Resolution (Voltage Output)

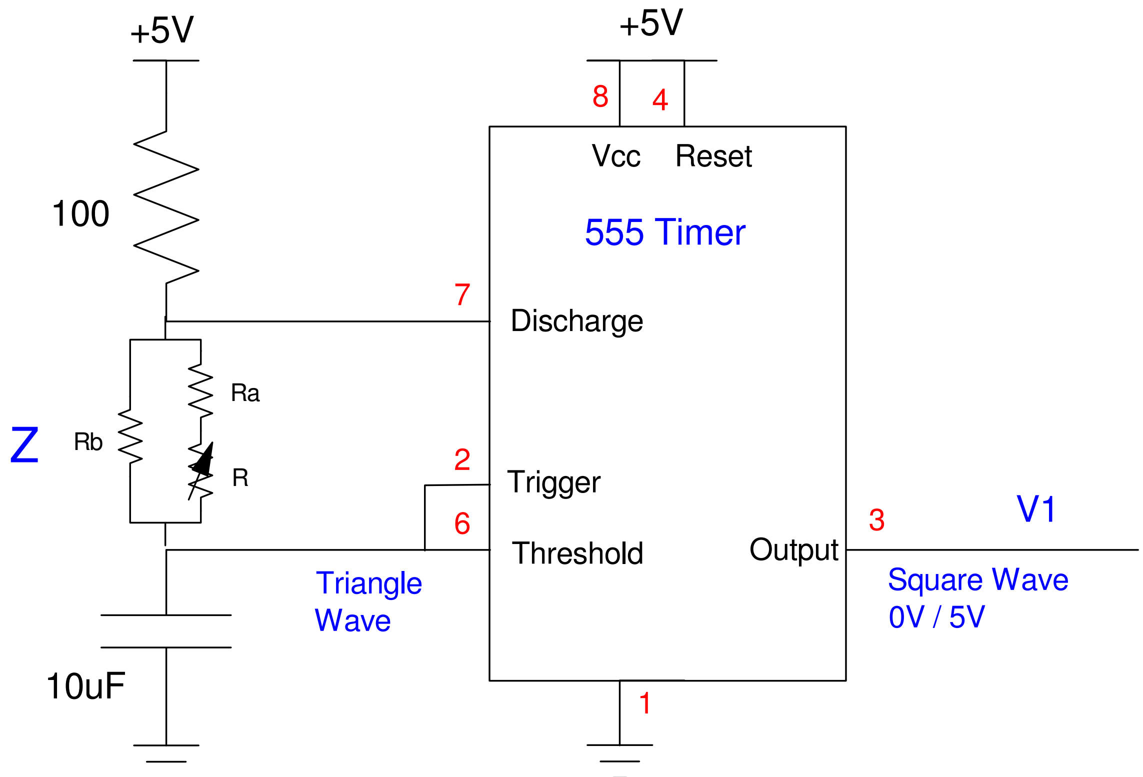
- Smallest change in temperature you can detect
- Assume 10-bit A/D (0..1023) for 0..10V

Voltage Out

- 0C to +30C produces 0V .. 10V out
- 10-bit A/D (0 .. 1023)
- $dV = \left(\frac{10V}{1023}\right) = 9.775mV$ *resolution in voltage*
- $^{0}C = \left(\frac{30^{0}C}{10V}\right) \cdot 9.887mV$
- $dT = 0.02933\ ^{0}C$ *resolution in degrees C*

Uses of Linearizing Circuit

- 555 Timer
- t(on) = (100 + Z)*C*ln(2)
- t(off) = Z*C*ln(2)



Period is proportional to Z

- Z = linearizing network
- period = (100 + 2Z)*C*ln(2)

Resultion (frequency output)

- Assume Z = 430 (+11C), C = 10uF

$$t_{on+off} = (100 + Z) \cdot C \cdot \ln(2) + Z \cdot C \cdot \ln(2)$$

$$t_{on+off} = 2.70ms \qquad 375Hz$$

$$dt = 100ns \qquad 10MHz\ clock$$

$$t + dt \Rightarrow Z = 430.0180\Omega$$

$$dZ = 0.0180\Omega$$

you can measure resistance to 0.0180 Ohms

$$dT = \left(\frac{20C}{40\Omega}\right) \cdot 0.0180\Omega$$

$$dT = 0.009\ {}^{0}C$$

you can measure temperature to 0.009 degrees C

Summary

RTDs and Thermistors are useful sensors for measuring temperature

- RTD $R = R_0 \cdot (1 + \alpha T)\Omega$
- Thermistor $R = R_{25} \cdot \exp\left(\frac{B}{T+273} - \frac{B}{298}\right)\Omega$

With a linearizing circuit, you can make the resistance of a thermistor roughly linear over a small temperature range

With an instrumentation amplifier, you can output a voltage that's proportional to temperature over a small temperature range