Instrumentation Amplifiers

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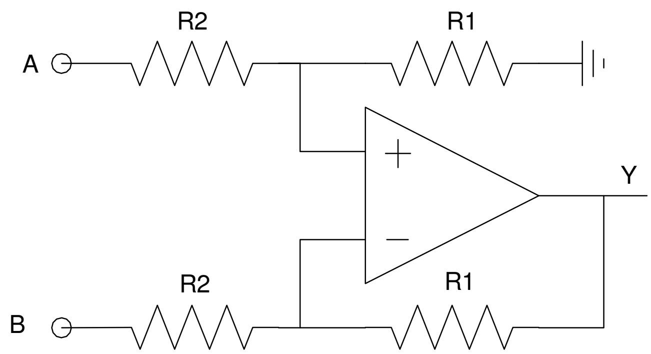
The transfer function for an instrumentation amplfier is



$$Y = \left(\frac{R_1}{R_2}\right)(A - B)$$

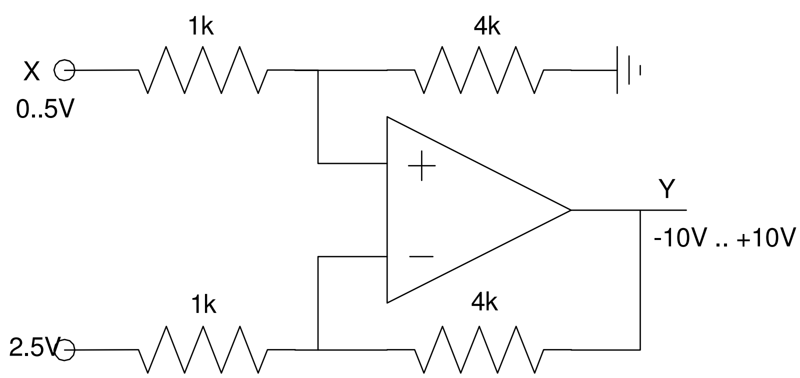
Case 1: Voltage Amplifation

Design a circuit to convert a 0..5V signal in to a +/- 10V signal.

- X = 0..5V analog
- Y = -10 .. +10V analog
- Y = 4X - 10

Solution: Rewrite this as

$$Y = 4(X - 2.5)$$



Level Shifter: 0..5V signal is amplified to -10V .. +10V

Case 2: V = f(R)

Assume R varies from 2000 Ohms to 2200 Ohms. Design a circuit which outputs

- -10V when R = 2000 Ohms
- +10V when R = 2200 Ohms

Solution: Convert R to a voltage using a voltage divider. Assume a 2100 Ohm resistor

R = 2000 Ohms:

$$V_x = \left(\frac{2000}{2000+2100}\right)10V = 4.878V$$

Y = -10V

R = 2200 Ohms

$$V_x = \left(\frac{2200}{2200+2100}\right)10V = 5.116V$$

Y = +10V

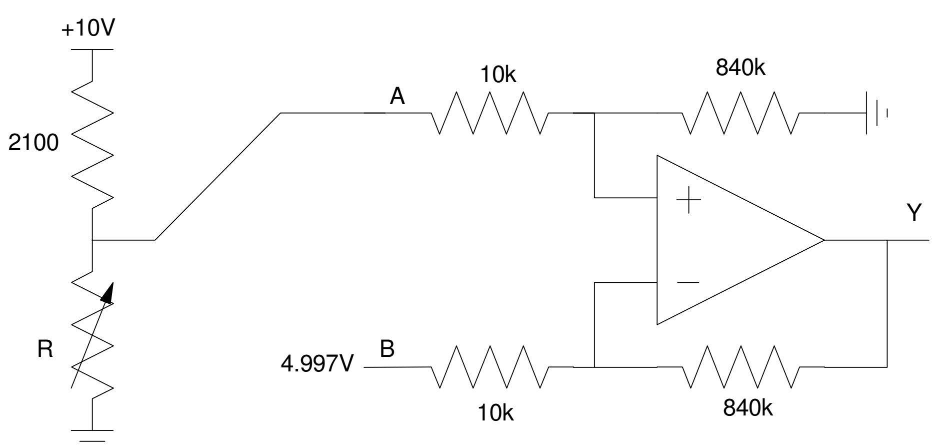
The gain you need is

$$gain = \left(\frac{\text{change in output}}{\text{change in input}}\right) = \left(\frac{10V-(-10V)}{5.116V-4.878V}\right)$$

$$gain = 83.95$$

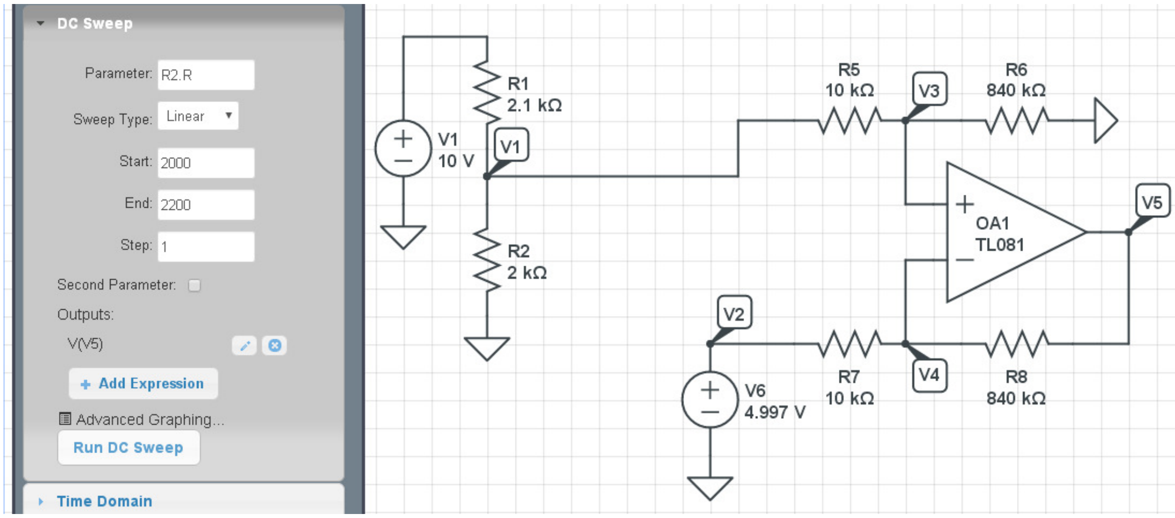
The output should be 0V (midband) when the input is midband

$$V_b = \left(\frac{4.878V+5.116V}{2}\right) = 4.997V$$

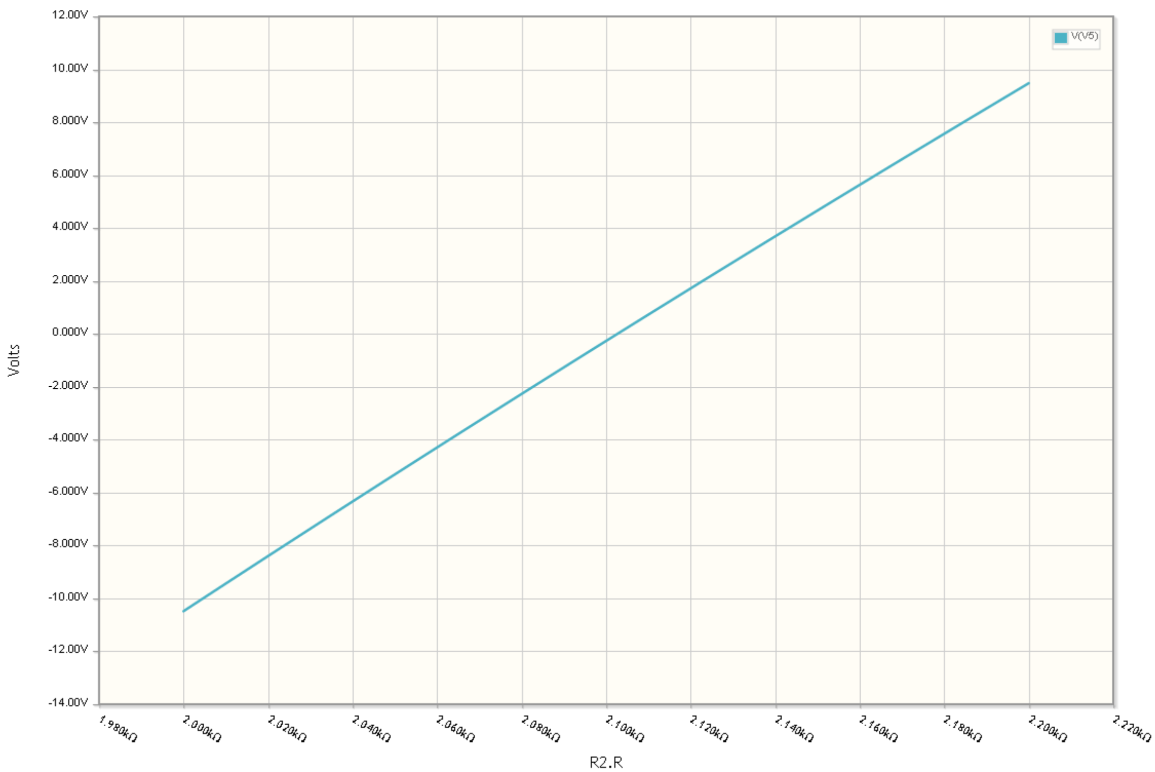


Instrumentation Amplifier: Y goes from -10V to +10V as R goes from 2000 to 2200 Ohms

In CircuitLab you can check by doing a DC Sweep on R2



This results in the output voltage shown below. Note that the range isn't *quite* 0V to 10V. This is due to the loading of R5 and R6 on V1 (the larger R5 and R6 are, the less the loading).



Output voltage as R sweeps from 2000 to 2200 Ohms

Case 3: RTD Temperature Sensor.

The temperature-resistance relationship of an RTD is

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

where T is the temperature in degrees celsius. Design a circuit which outputs

- 0V at 0C
- +10V at +100C

Solution: Assume a voltage divider with a 1000 Ohm resistor.

At 0C

- R = 1000 Ohms
- Va = 5.00 V
- Vy = 0.00V

At +100C

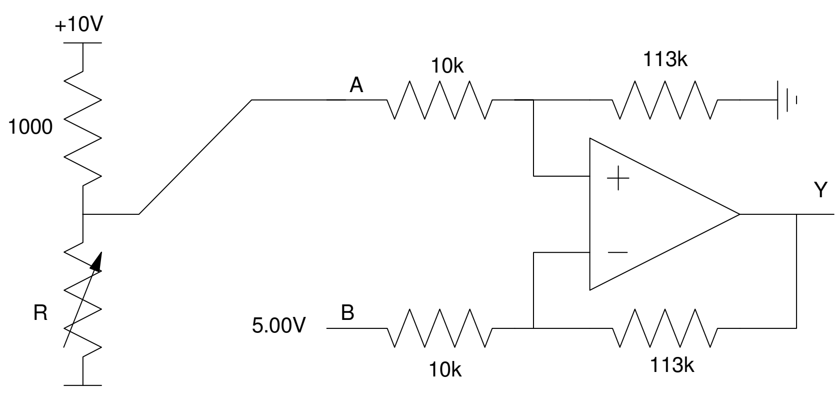
- R = 1430 Ohms
- Va = 5.885V
- Vy = +10.00V

As the input voltage increases, the output voltage increases. Connect the voltage divider to A.

The output is 0V when Va = 5.00V. Make B = 5.00V

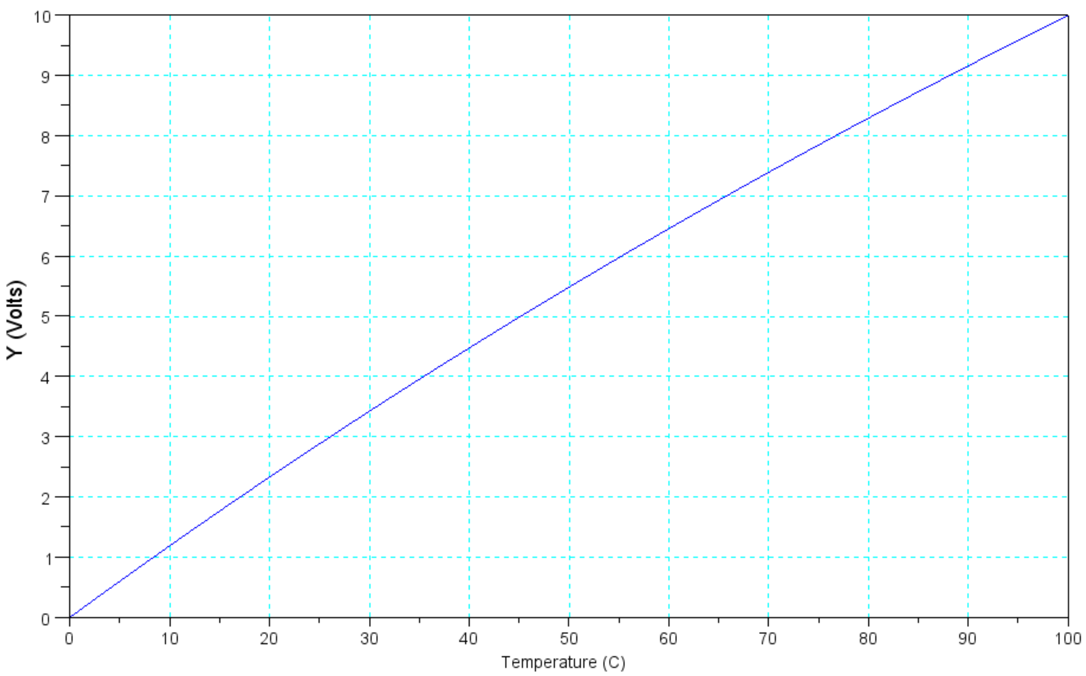
The gain needed is

$$gain = \left(\frac{\text{change in output}}{\text{change in input}}\right) = \left(\frac{10V-0V}{5.885V-5.00V}\right) = 11.30$$



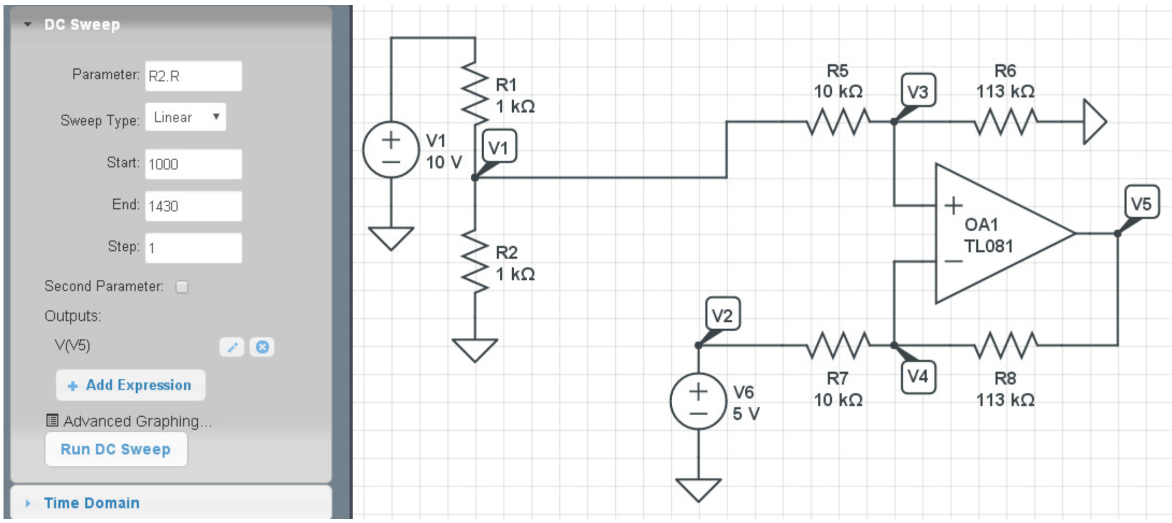
Checking the results in Matlab:

```
T = [0:0.1:100]';

R = 1000 * (1 + 0.0043*T);

Va = R ./ (1000 + R) * 10;

Y = 11.3 * (Va - 5.00);

plot(T,Y);

xlabel('Temperature (C)');
ylabel('Y (Volts)');
```

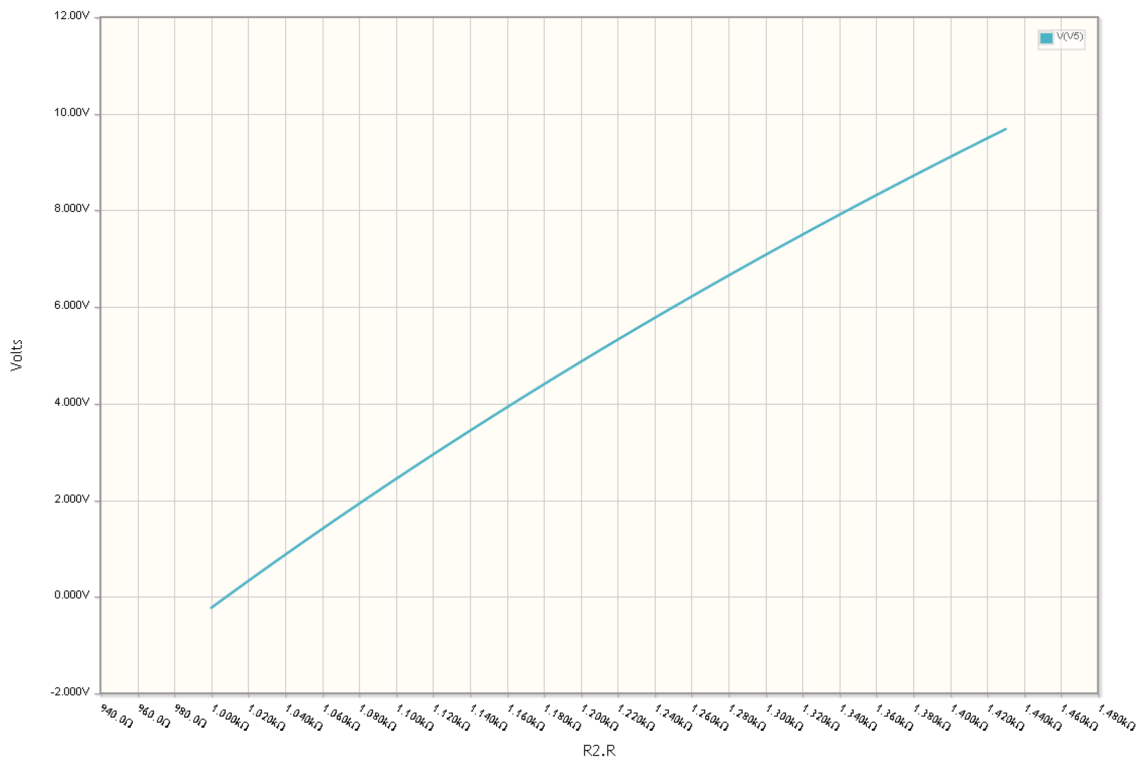


Checking the results in CircuitLab, note that

- The output voltage is slightly off
- This is due to the loading of R5 and R6 on V1



A DC Sweep us run with R2 varying frmo 1000 to 1430 Ohms (0C < T < 100C)



Resulting Output Voltage as R varies from 1000 to 1430 Ohms

Case 4: Thermistor Temperature Sensor.

The temperature-resistance relationship of a thermistor is

$$R \approx 1000\ \exp\left(\frac{3905}{T+273} - \frac{3905}{298}\right)\ \Omega$$

where T is the temperature in degrees celsius. Design a circuit which outputs

- 0V at 0C
- +10V at +40C

Solution: Assume a voltage divider with a 1000 Ohm resistor.

At 0C

- R = 3320.125 Ohms
- Vb = 7.6853 V
- Vy = 0.00V

At +40C

- R = 533.664 Ohms
- Vb = 3.4797V
- Vy = +10.00V

As the input voltage decreases, the output voltage increases. Connect the voltage divider to B.

The output is 0V when Va = 7.6853V. Make A = 7.6853V

The gain needed is

$$gain = \left(\frac{10V - 0V}{3.4797V - 7.6853V}\right) = -2.3778$$

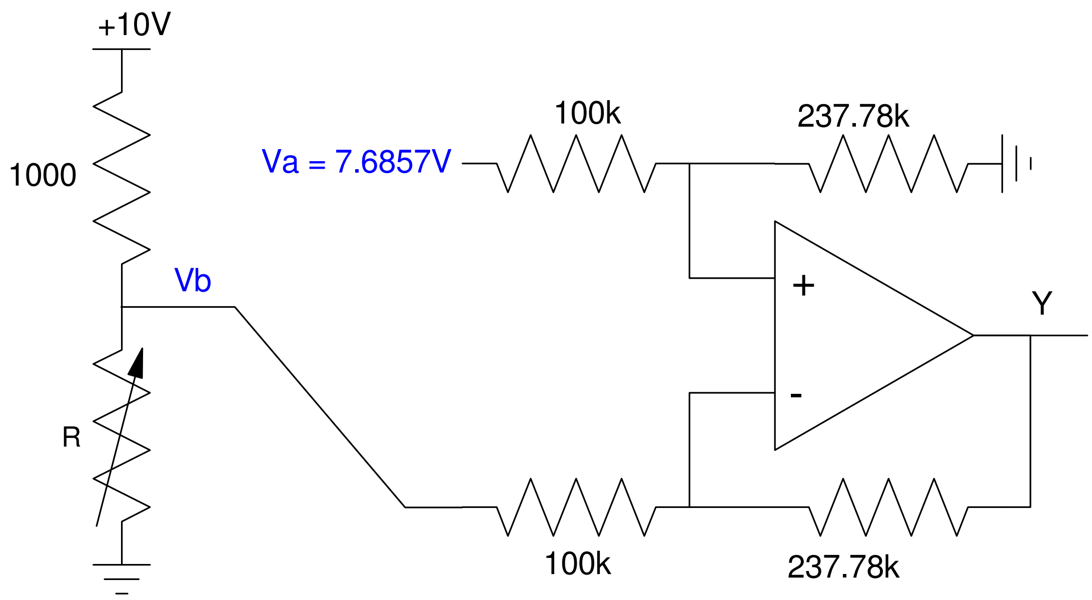
The minus sign is taken care of by connecting to the minus input (B).

The gain comes from the resistor ratio

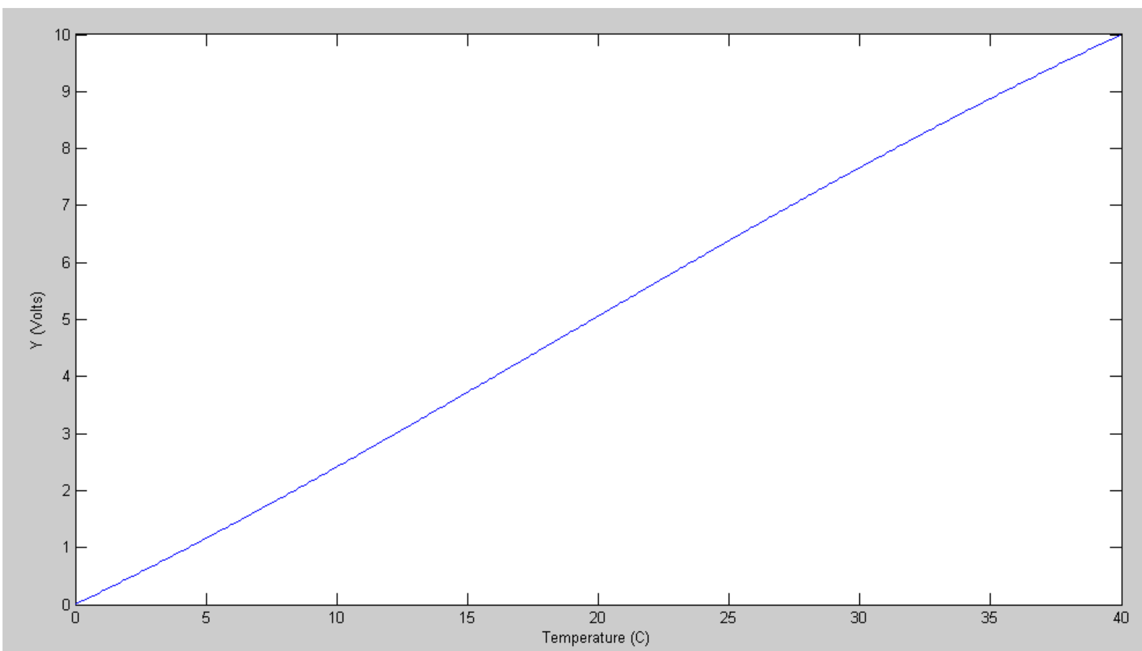
Let R1 = 100k, R2 = 237.78k

Note: You can check your results in Matlab.

```
T = [0:0.1:40]';
R = 1000 * exp( 3905 ./(T + 273)  -   3905/298 );
Va = R ./ (1000 + R) * 10;
Y = 2.3778 * (7.6853 - Va);
plot(T,Y);
xlabel('Temperature (C)');
ylabel('Y (Volts)');
```



Instrumentation Amplifier to output 0V @ 0C, 10V @ 40C

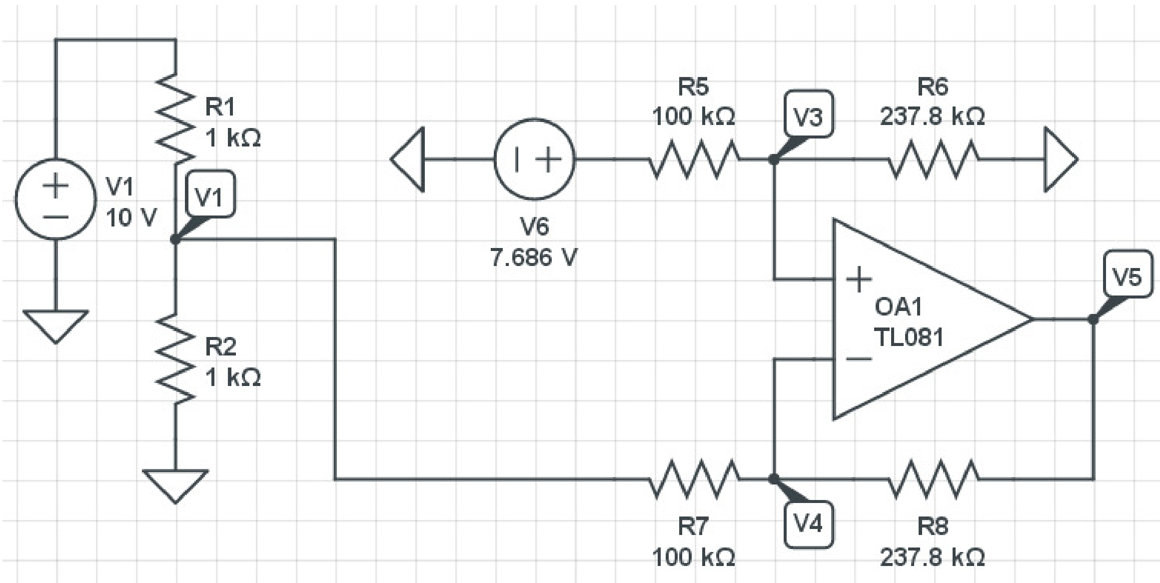


Output Voltages vs. Temperature

Note that the output goes from 0V to 10V as temperature goes from 0C to +40C as desired.

In CircuitLab, check

- The left endpoint (0C or R2 = 3320.125 Ohms)
- The midpoint (20C or R2 = 1250.593 Ohms)
- The right endpoint (40C or R2 = 533.664 Ohms)



V(V1)	7.668 V
V(V3)	5.410 V
V(V4)	5.410 V
V(V5)	42.32 mV

Output (V5) at 0C = 0.04232V (0V ideally)

V(V1)	5.556 V
V(V3)	5.410 V
V(V4)	5.410 V
V(V5)	5.064 V

Output (V5) at +20C = 5.064V (5.000V ideally)

V(V1)	3.486 V
V(V3)	5.410 V
V(V4)	5.410 V
V(V5)	9.985 V

Output (V5) at +40C = 9.985V (10.000V ideally)