Instrumentation Amplifiers

EE 206 Circuits I

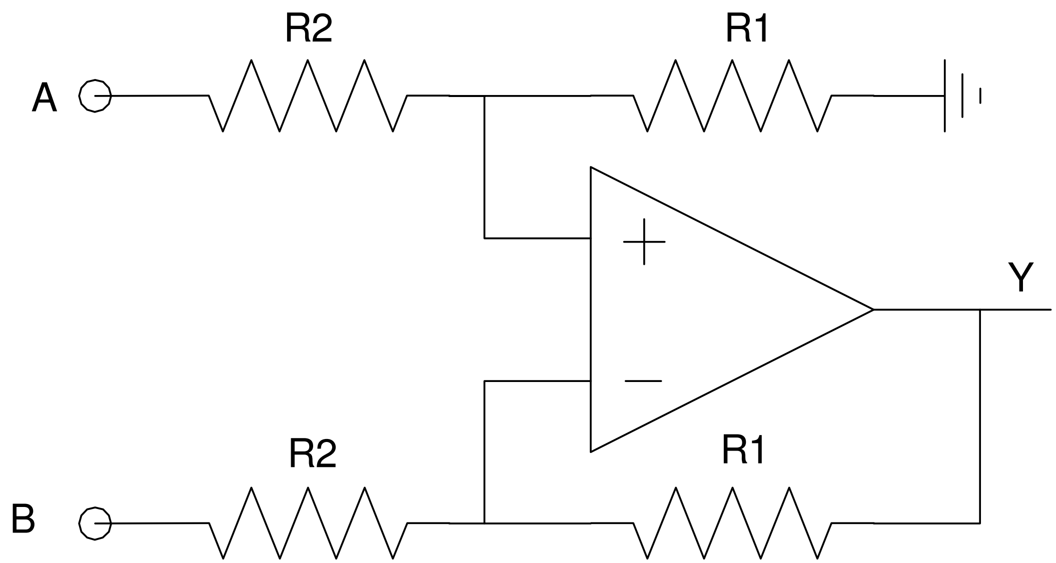
Jake Glower - Lecture #15

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

Instrumentation Amplifiers

- Very verstitile op-amp ciruit
- Used extensively with sensors (instrumetnation)

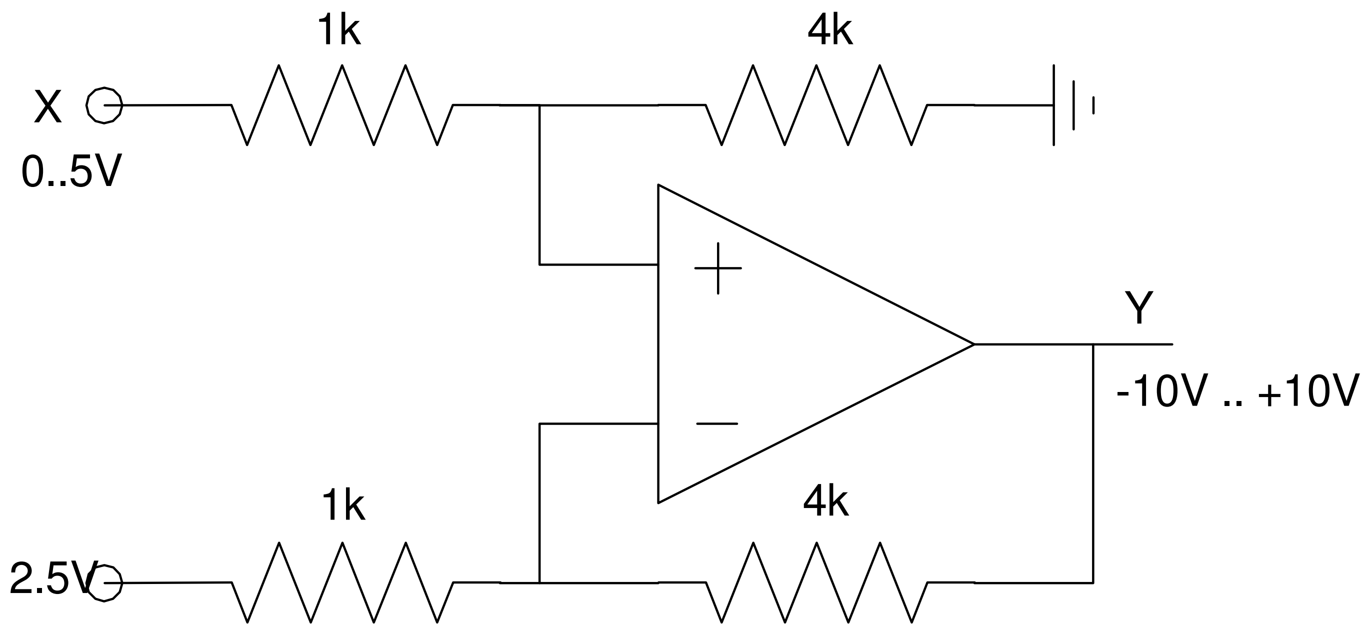
$$Y = \left(\frac{R_1}{R_2}\right)(A - B)$$



Case 1: Voltage Amplification

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

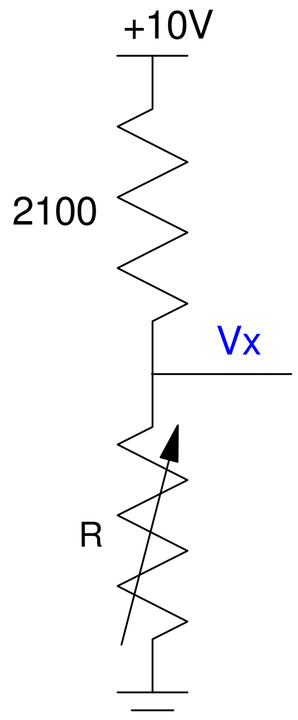
- X = 0..5V analog
- Y = -10 .. +10V analog
- $y = 4x - 10 = 4(x - 2.5)$



Case 2: V = f(R) (OhmMeter)

Output

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



Solution:

- Convert R to a voltage
- Assume a 2100 Ohm resistor

R = 2000 Ohms (Y = -10V)

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

R = 2200 Ohms (Y = +10V)

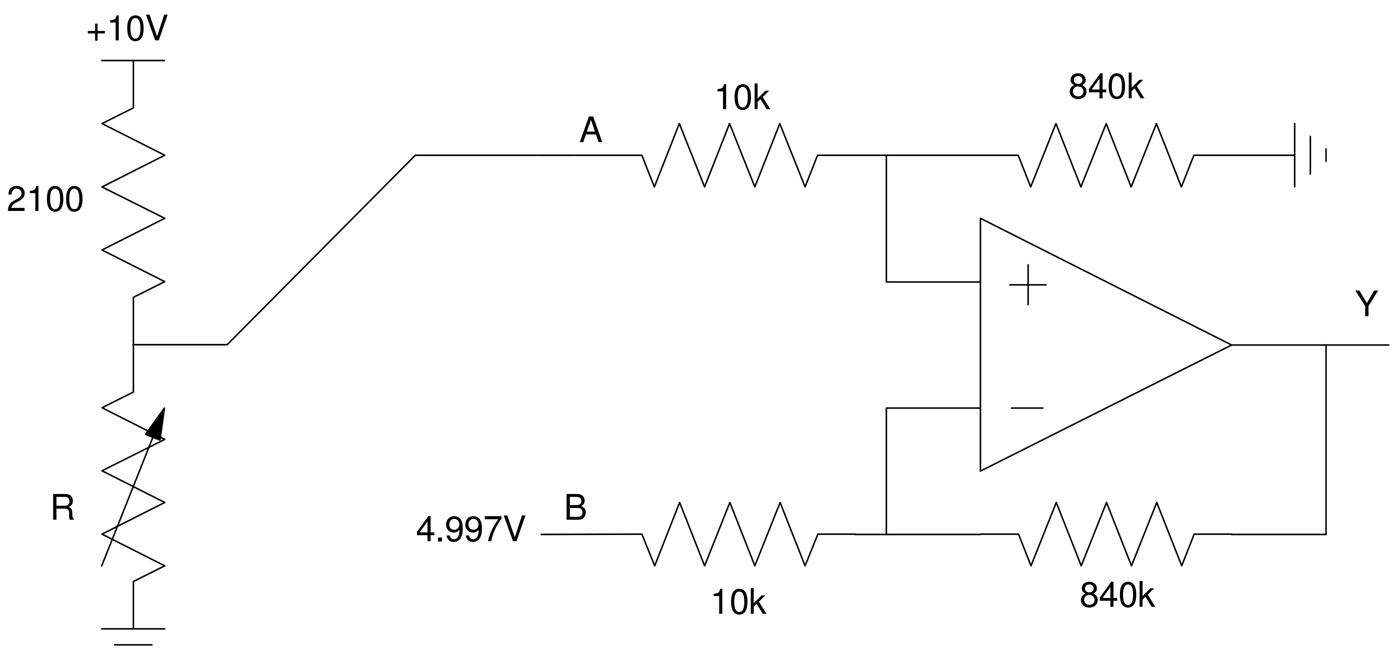
$$V_x = \left(\frac{2200}{2200+2100}\right)10V = 5.116V$$

The gain you need is

$$gain = \left(\frac{\text{change in output}}{\text{change in input}}\right) = \left(\frac{10V-(-10V)}{5.116V-4.878V}\right) = 83.95$$

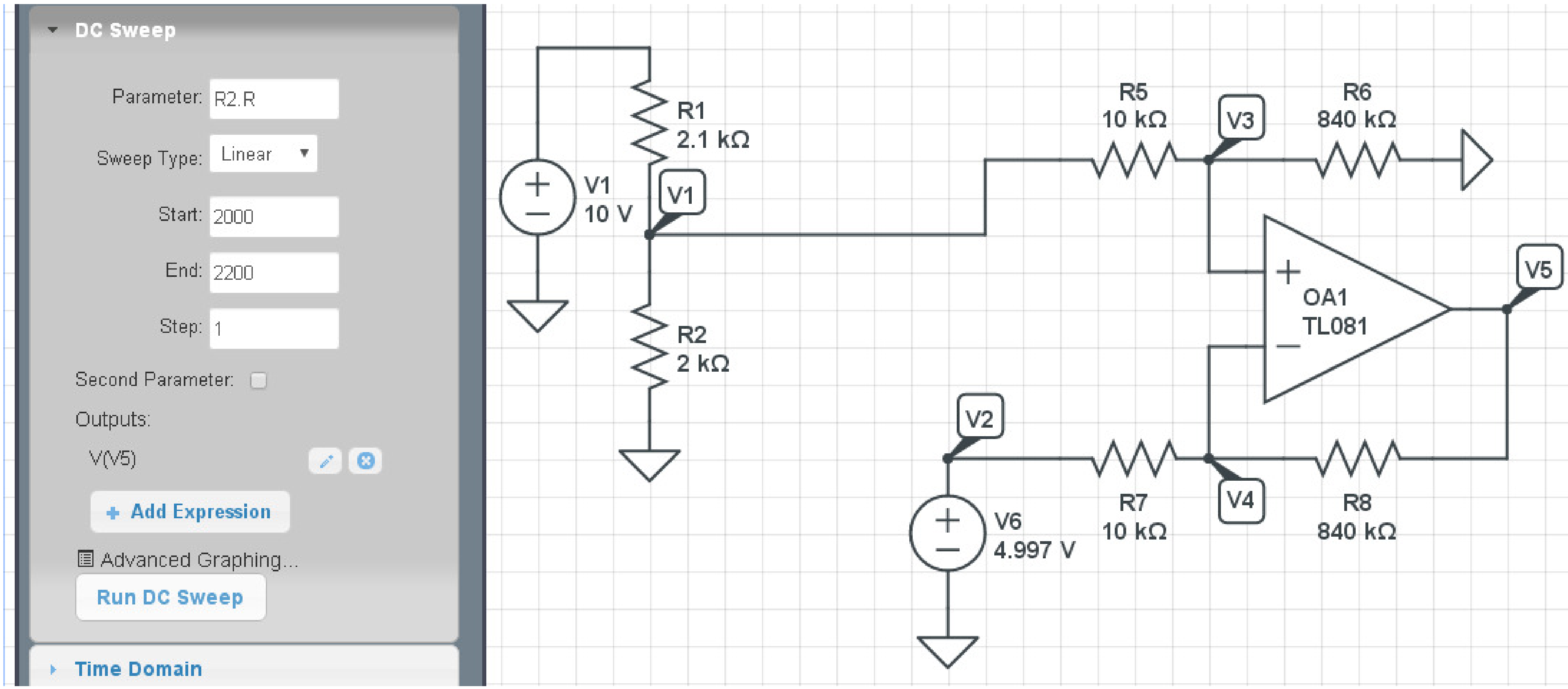
The output should be 0V (midband) when the input is midband

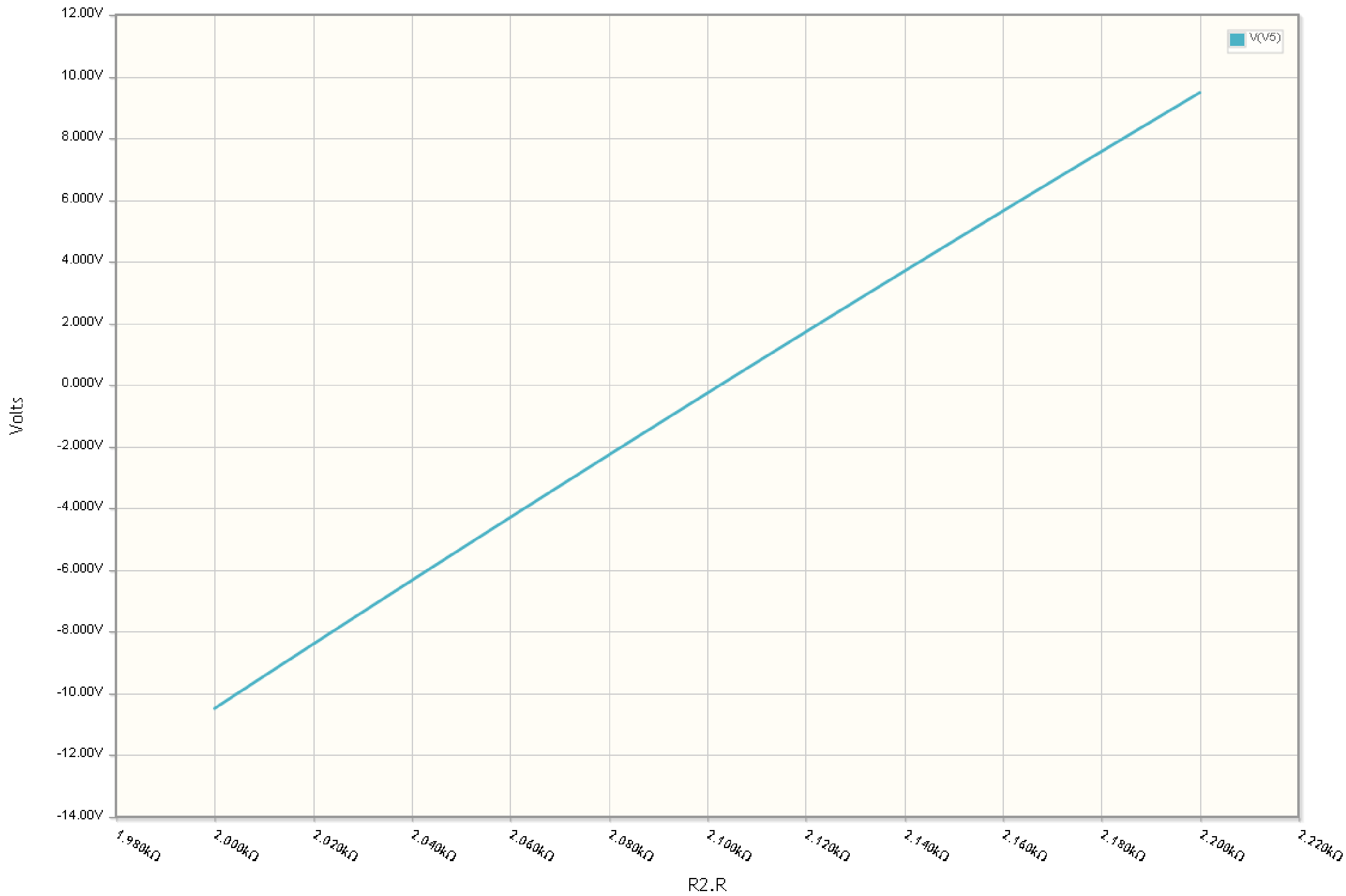
$$V_b = \left(\frac{4.878V+5.116V}{2}\right) = 4.997V$$



Verification: Use CircuitLab

- Sweep R2 from 2000 to 2200 Ohms
- V5 should vary from -10V to +10V





V(V5)
12.00V
10.00V
8.000V
6.000V
4.000V
2.000V
0.000V
-2.000V
-4.000V
-6.000V
-8.000V
-10.00V
-12.00V
-14.00V
Volts
1.980kΩ
2.000kΩ
2.020kΩ
2.040kΩ
2.060kΩ
2.080kΩ
2.100kΩ
2.120kΩ
2.140kΩ
2.160kΩ
2.180kΩ
2.200kΩ
2.220kΩ
R2.R

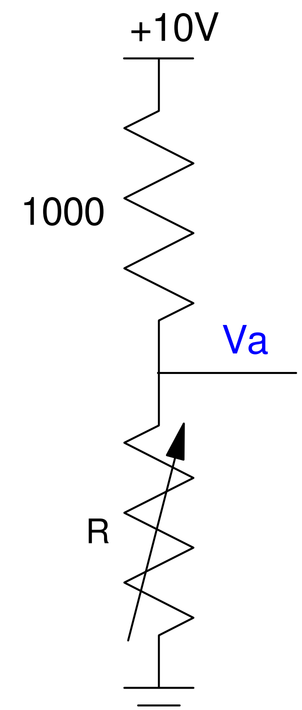
Case 3: RTD Temperature Sensor.

The temperature-resistance relationship of an RTD is: (T = Celsius)

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

Design a circuit which outputs

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



Solution: Convert R to V using a voltage divider

At 0C (Vy = 0.00V)

- R = 1000 Ohms
- Va = 5.00 V

At +100C (Vy = +10.00V)

- R = 1430 Ohms
- Va = 5.885V

As Va goes up, Y goes up

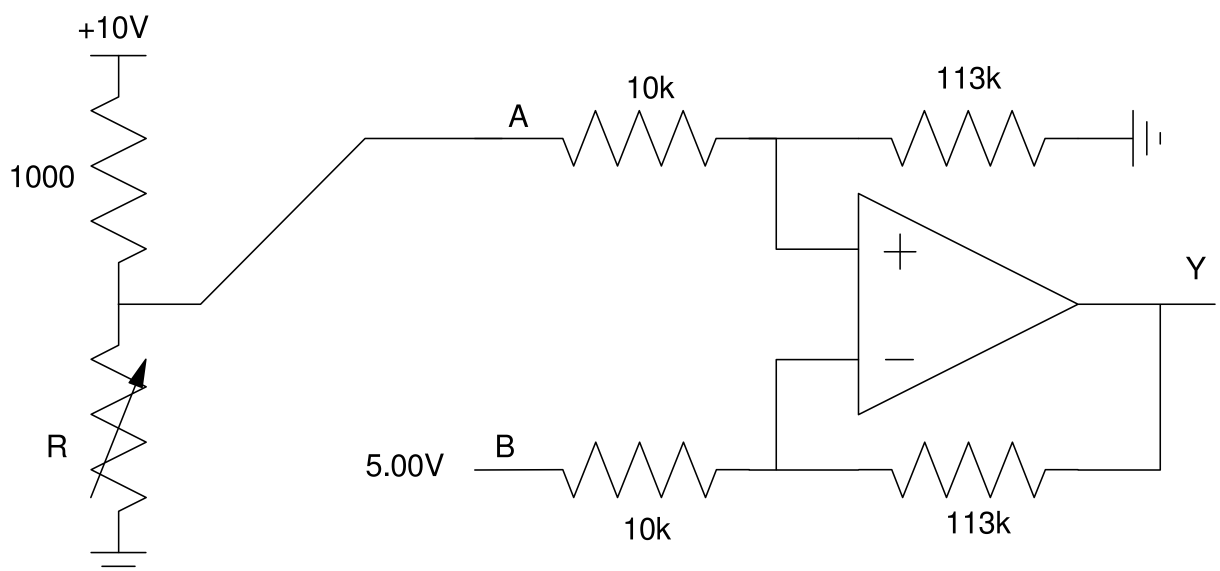
- Connect Va to the + input

The output is 0V when Va = 5.00V

- Make B = 5.00V

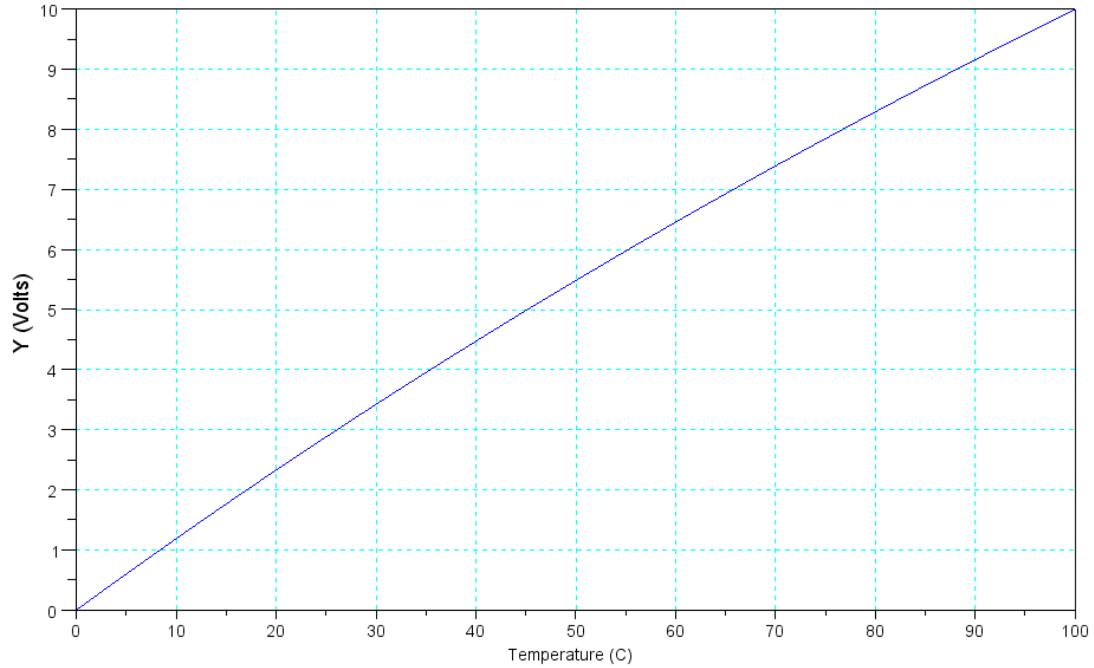
The gain needed is

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



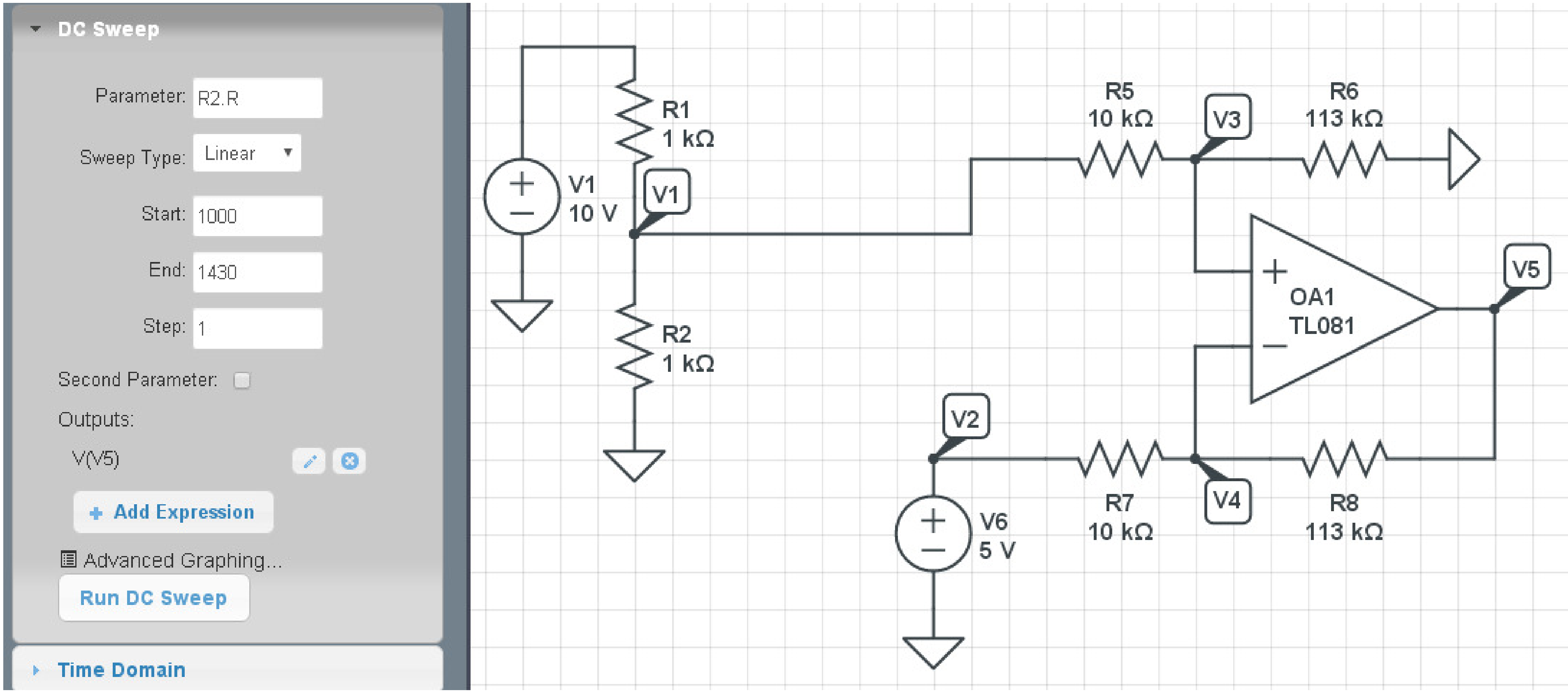
Check the results in Matlab:

```
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)');
```



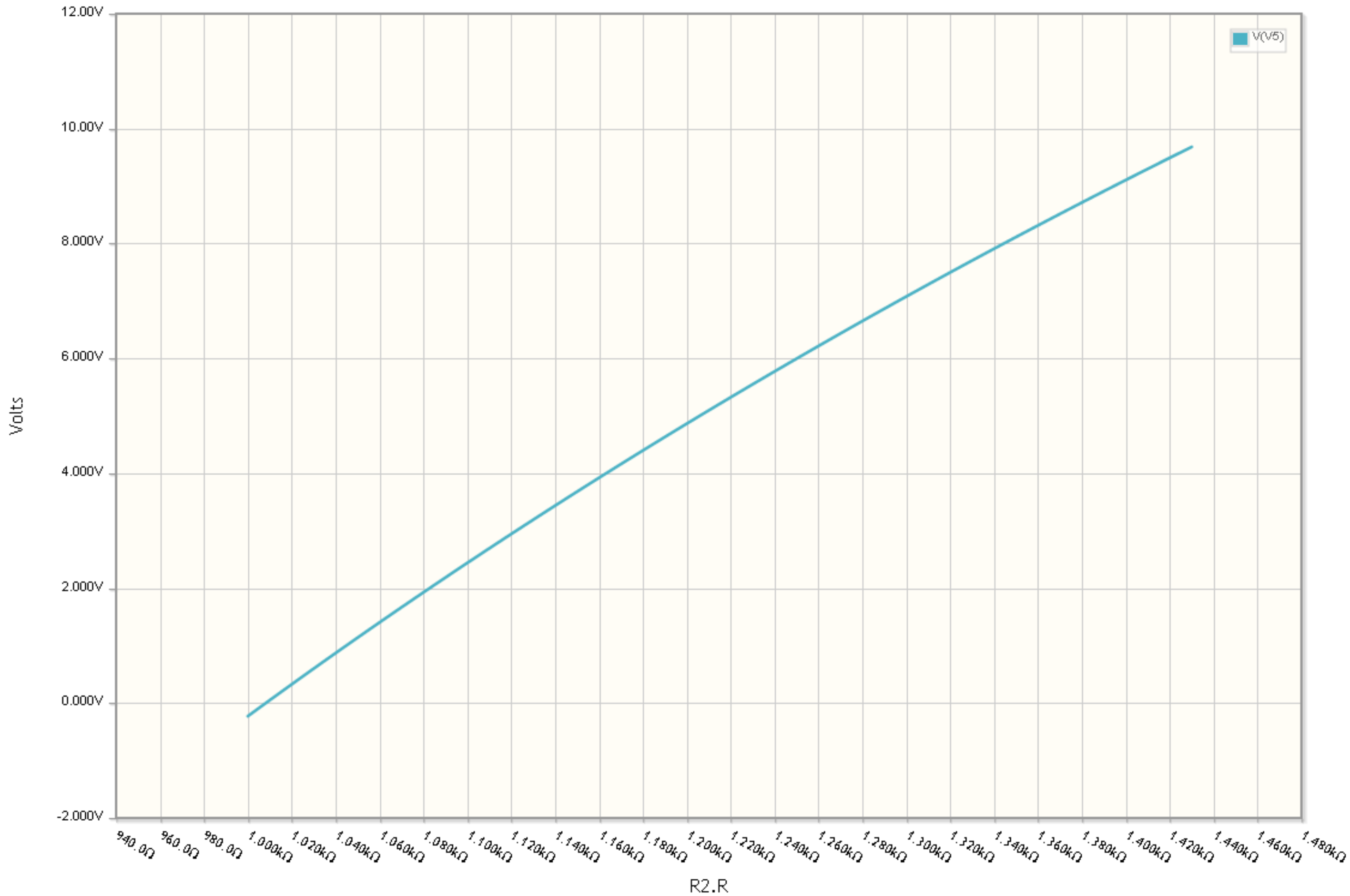
Check the results in CircuitLab, note that

- Sweep R2 from 1000 Ohms (0C) to 1430 Ohms (+100C)



The results is close but slightly off

- R5 and R6 change R2 (Loading)



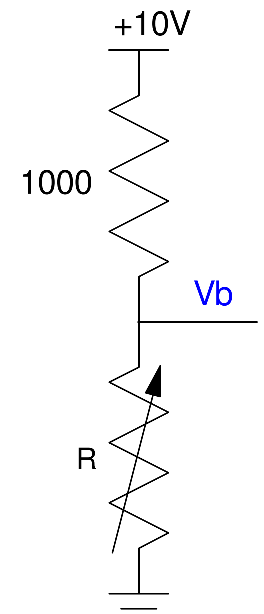
Case 4: Thermistor Temperature Sensor.

The temperature-resistance relationship of a thermistor is (T = degrees C)

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

Design a circuit which outputs

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



Solution: Use a voltage divider to convert T ro V

At 0C (Vy = 0.00V)

- R = 3320.125 Ohms
- Vb = 7.6853 V

At +40C (Vy = 10.00V)

- R = 533.664 Ohms
- Vb = 3.4797V

As Vb goes down, Y goes up

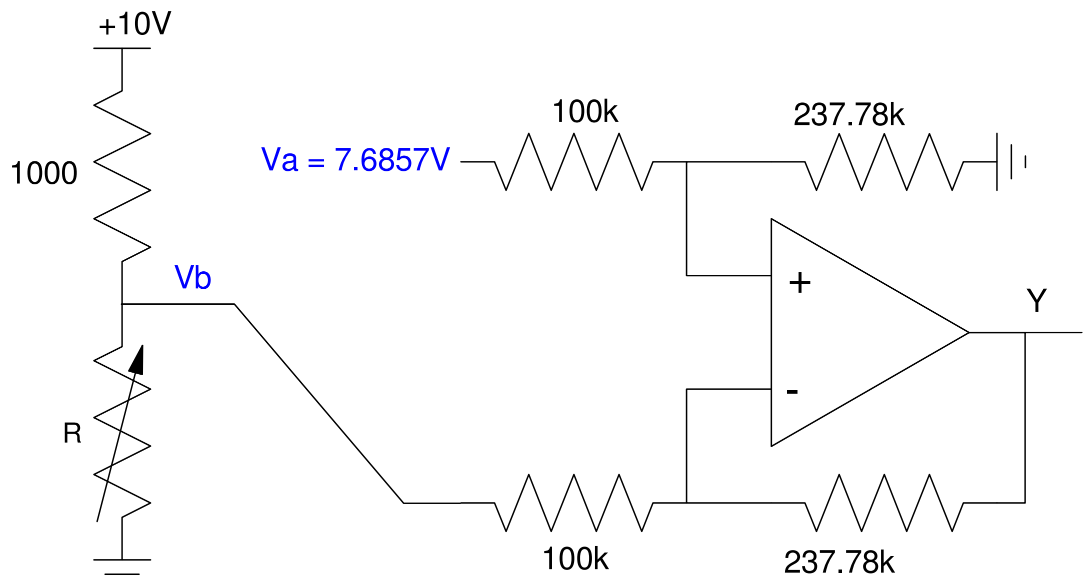
- Connect Vb to the minis input (B)

The output is 0V when Vb = 7.6853V

- Make A = 7.6853V

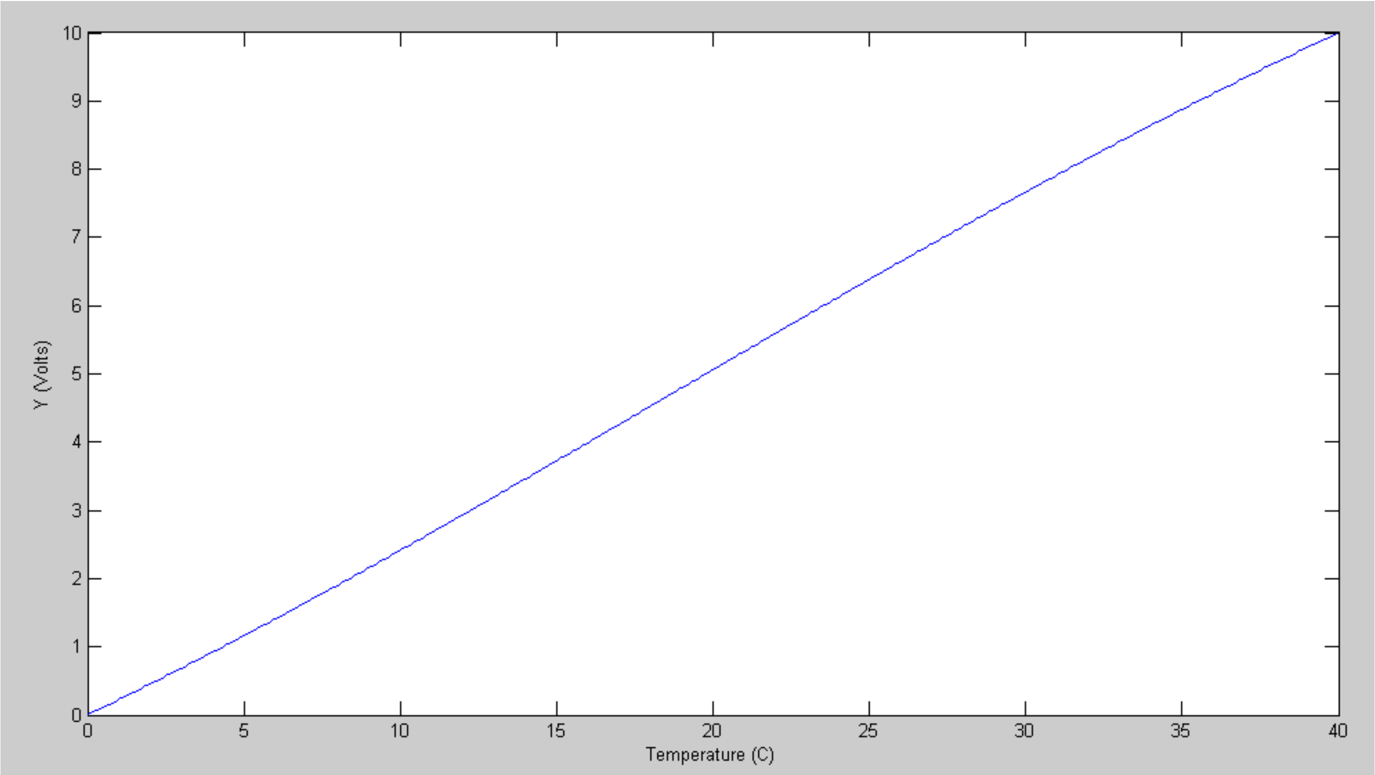
The gain needed is

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



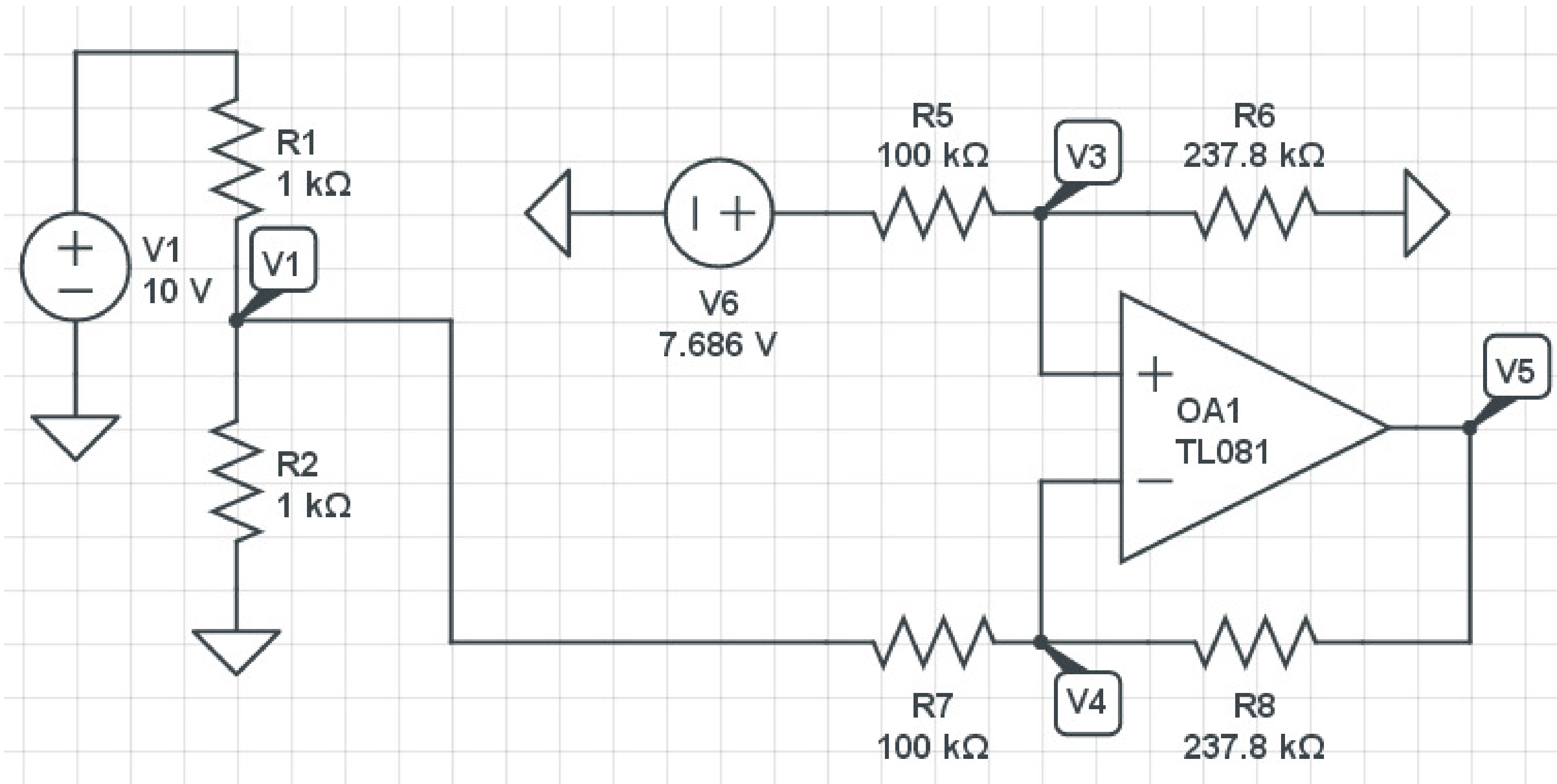
Checking in Matlab.

```
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);
```



Checking 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)