
Instrumentation Amplifiers

ECE 211 Circuits I

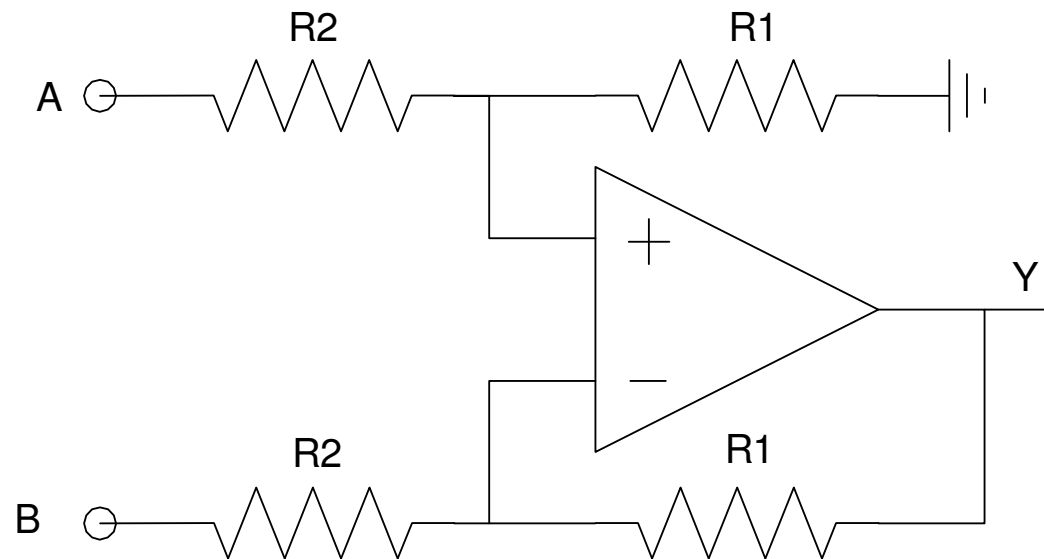
Lecture #15

Please visit [Bison Academy](#) for corresponding
lecture notes, homework sets, and solutions

Instrumentation Amplifiers

- Very versatile op-amp circuit
- Used extensively with sensors (instrumentation)

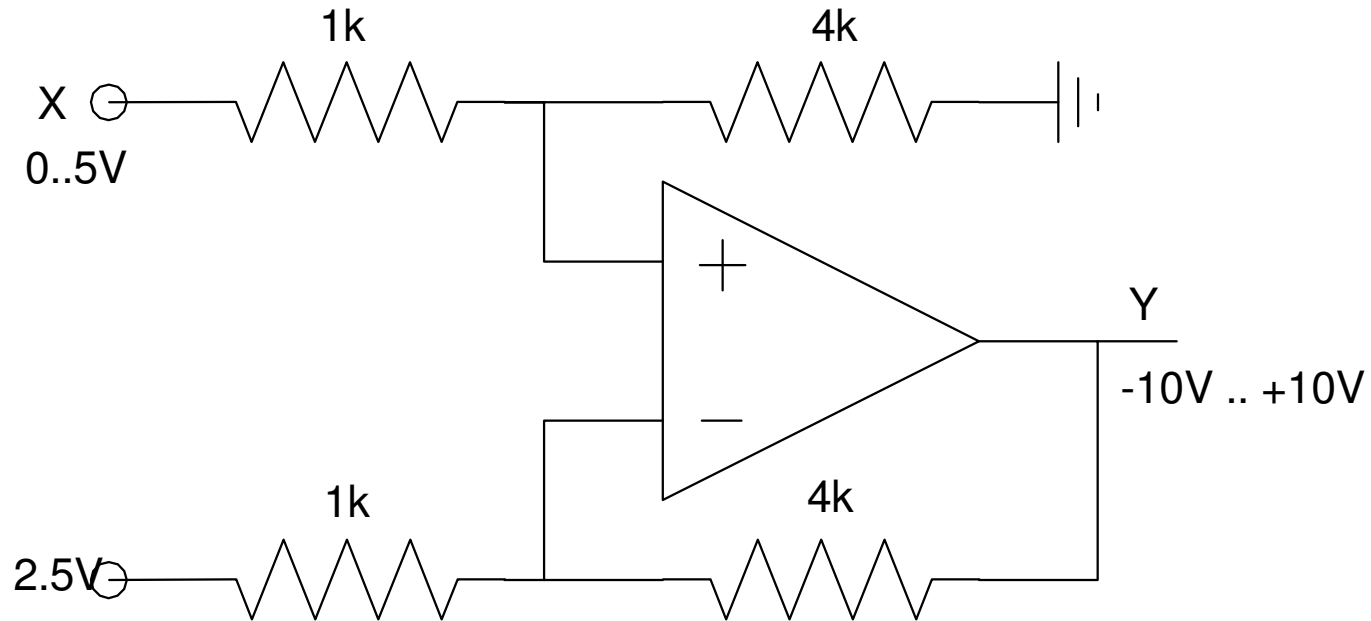
$$Y = \left(\frac{R_1}{R_2} \right) (A - B)$$



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:

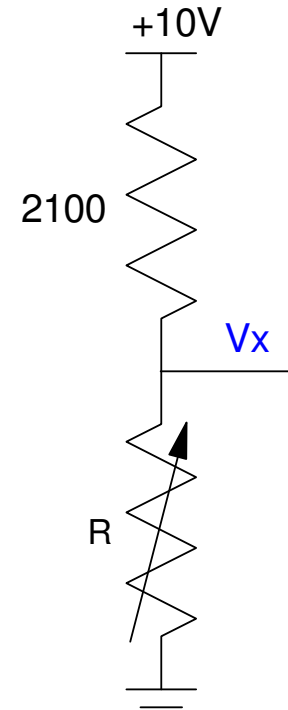
- Convert R to a voltage
- Assume a 2100 Ohm resistor

$R = 2000$ Ohms ($Y = -10V$)

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

$R = 2200$ Ohms ($Y = +10V$)

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

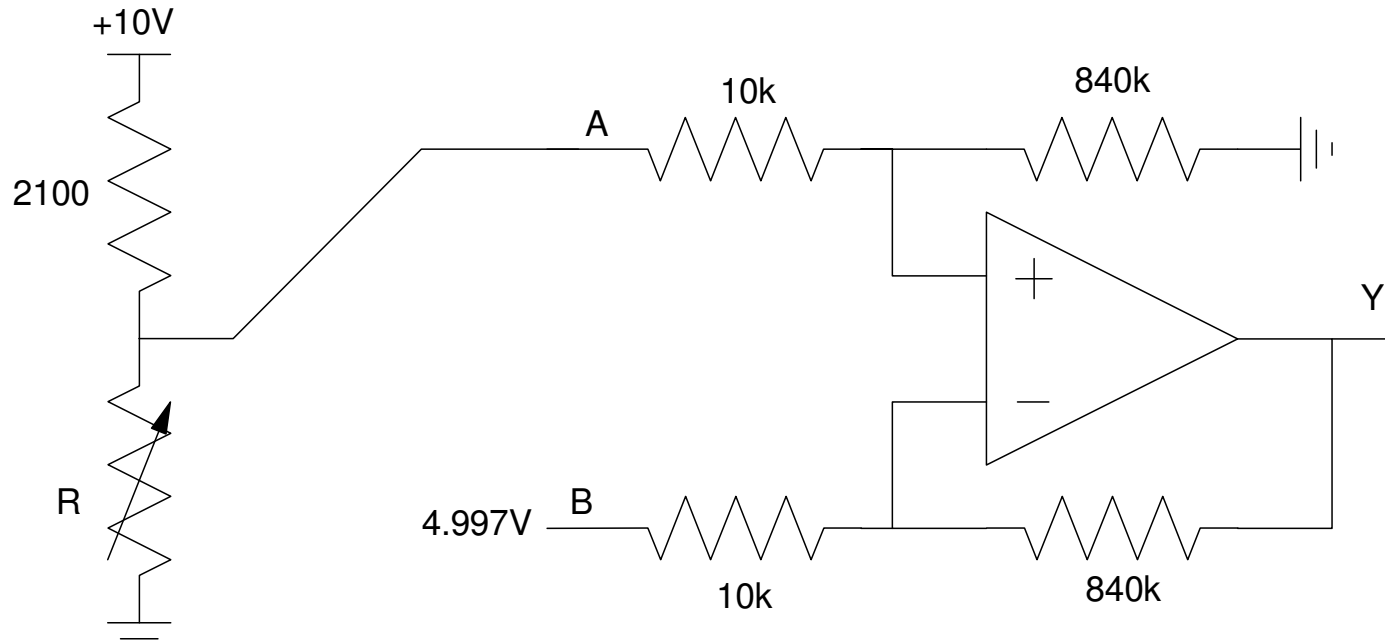


The gain you need is

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

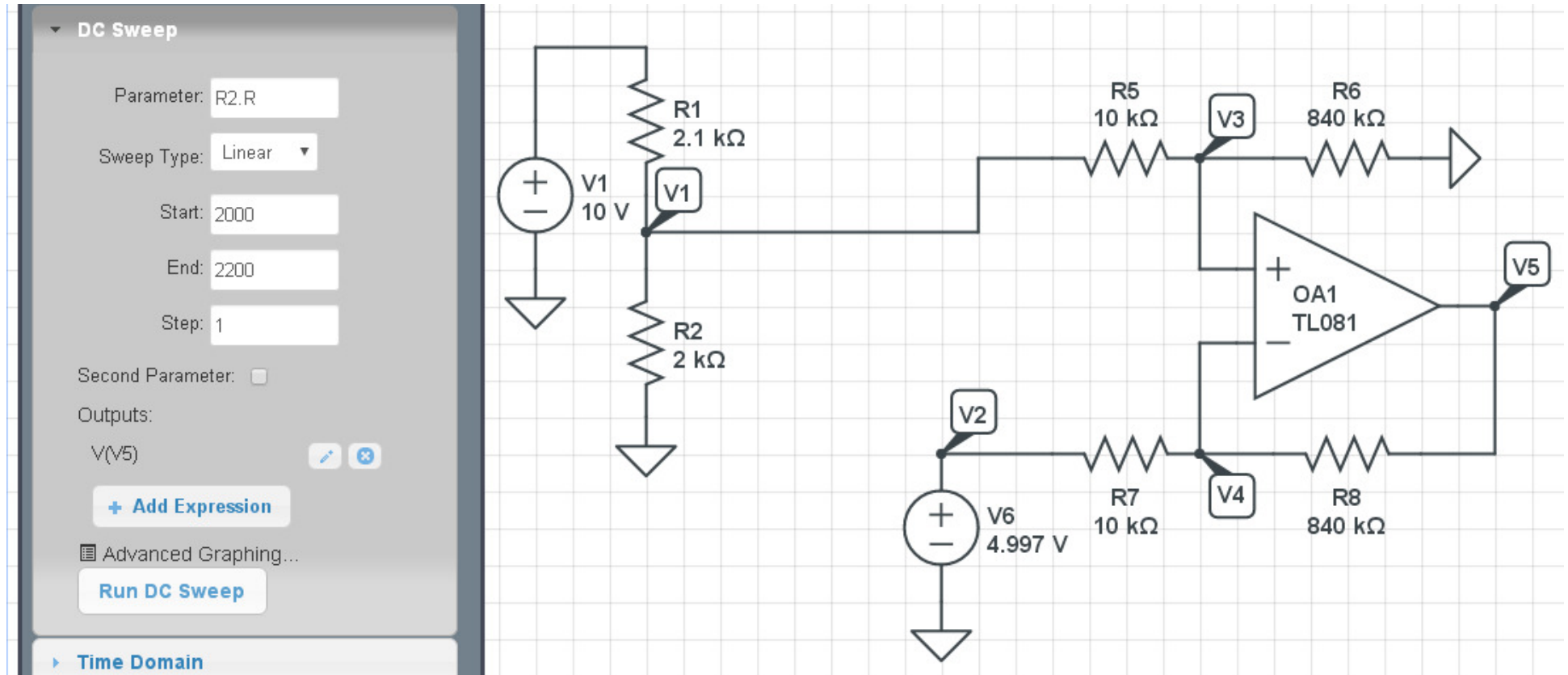
The output should be 0V (midband) when the input is midband

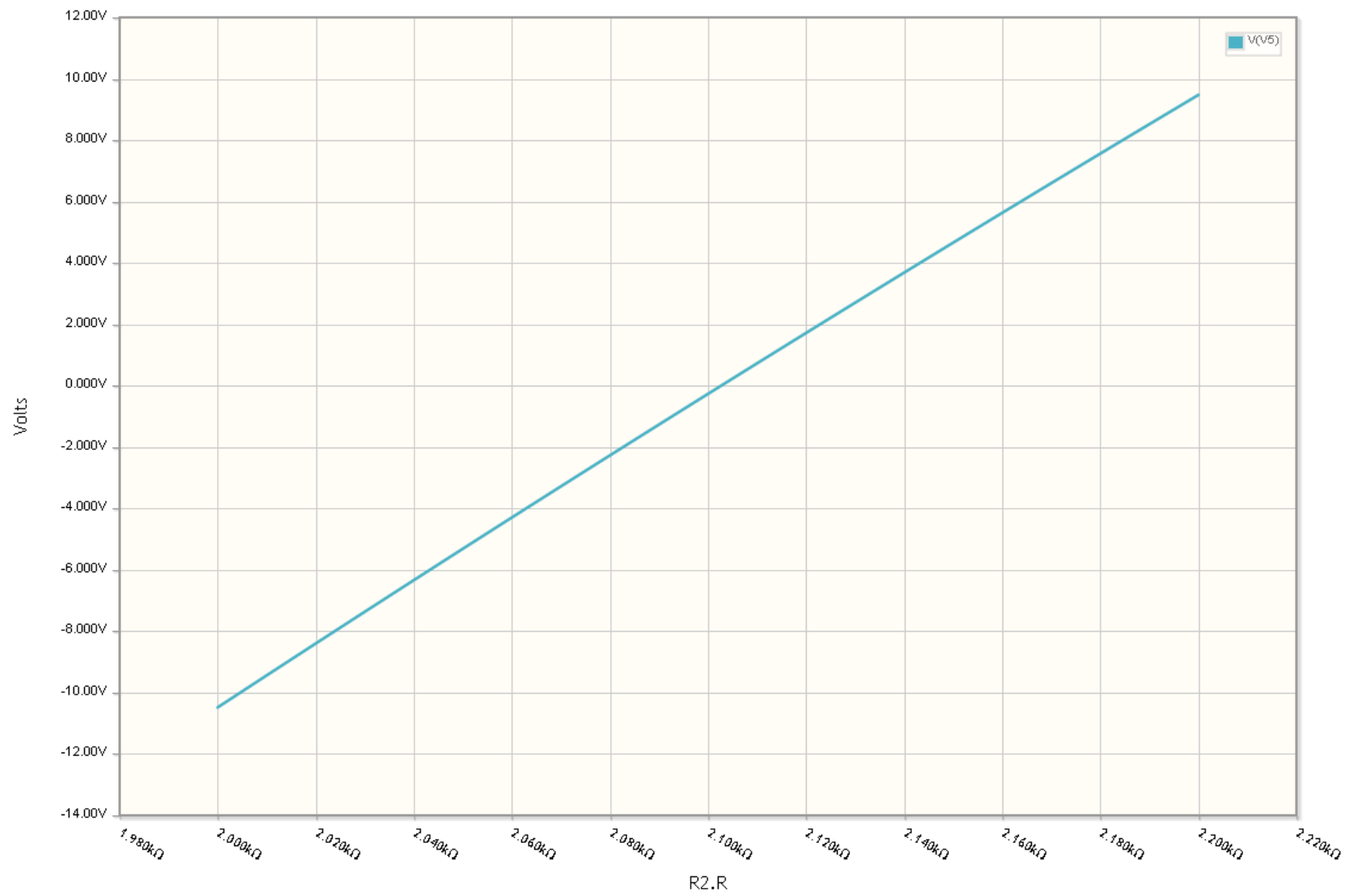
$$V_b = \left(\frac{4.878V + 5.116V}{2} \right) = 4.997V$$



Verification: Use CircuitLab

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





Case 3: RTD Temperature Sensor.

The temperature-resistance relationship of an RTD is: ($T = \text{Celsius}$)

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

Design a circuit which outputs

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

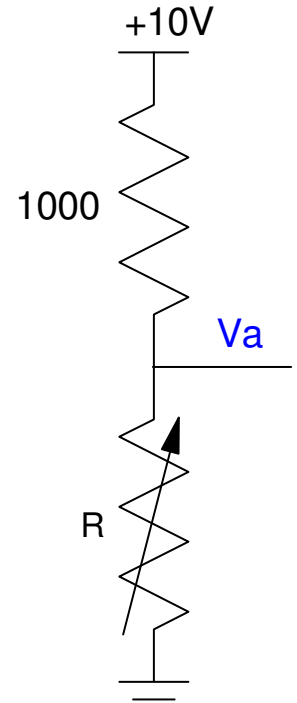
Solution: Convert R to V using a voltage divider

At 0C ($V_y = 0.00V$)

- $R = 1000 \, \text{Ohms}$
- $V_a = 5.00 \, V$

At +100C ($V_y = +10.00V$)

- $R = 1430 \, \text{Ohms}$
- $V_a = 5.885V$



As V_a goes up, Y goes up

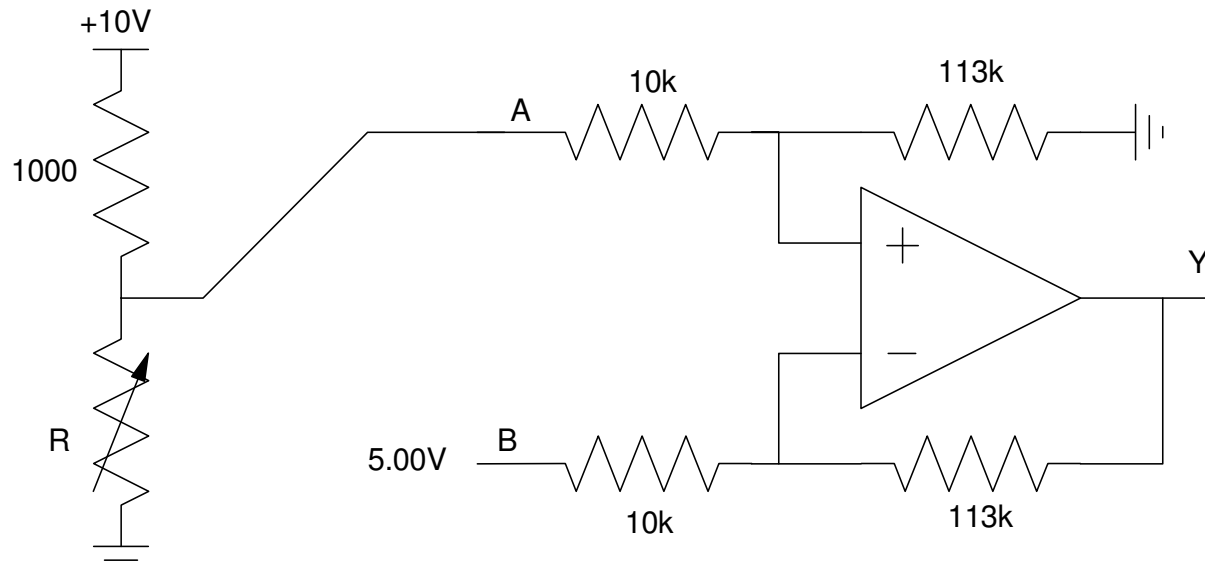
- Connect V_a to the + input

The output is 0V when $V_a = 5.00V$

- Make $B = 5.00V$

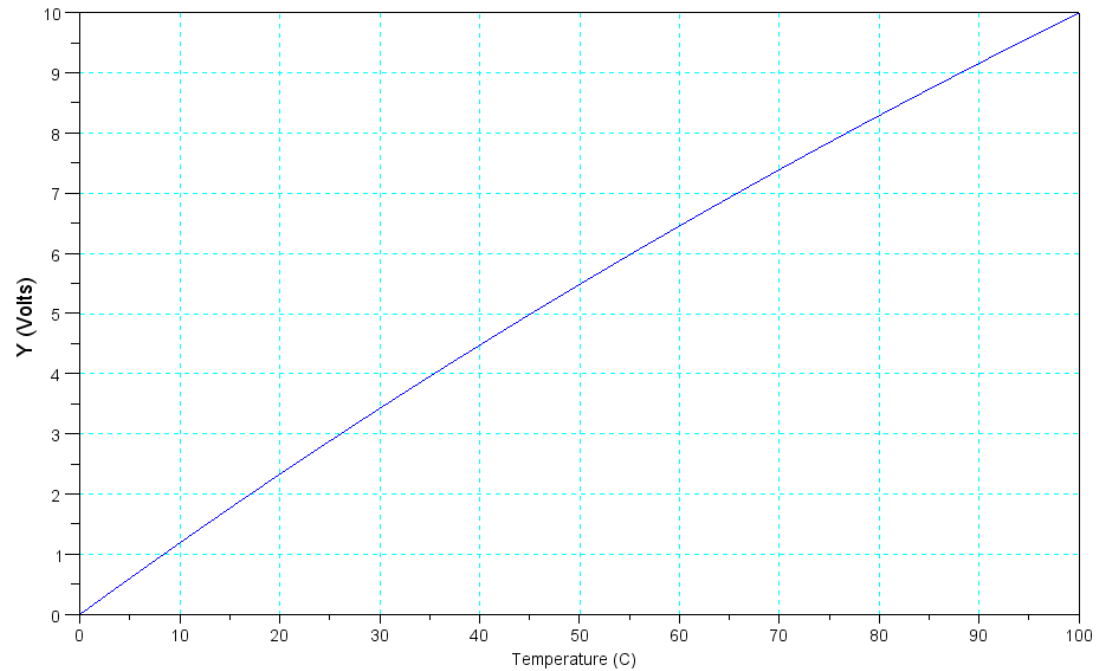
The gain needed is

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



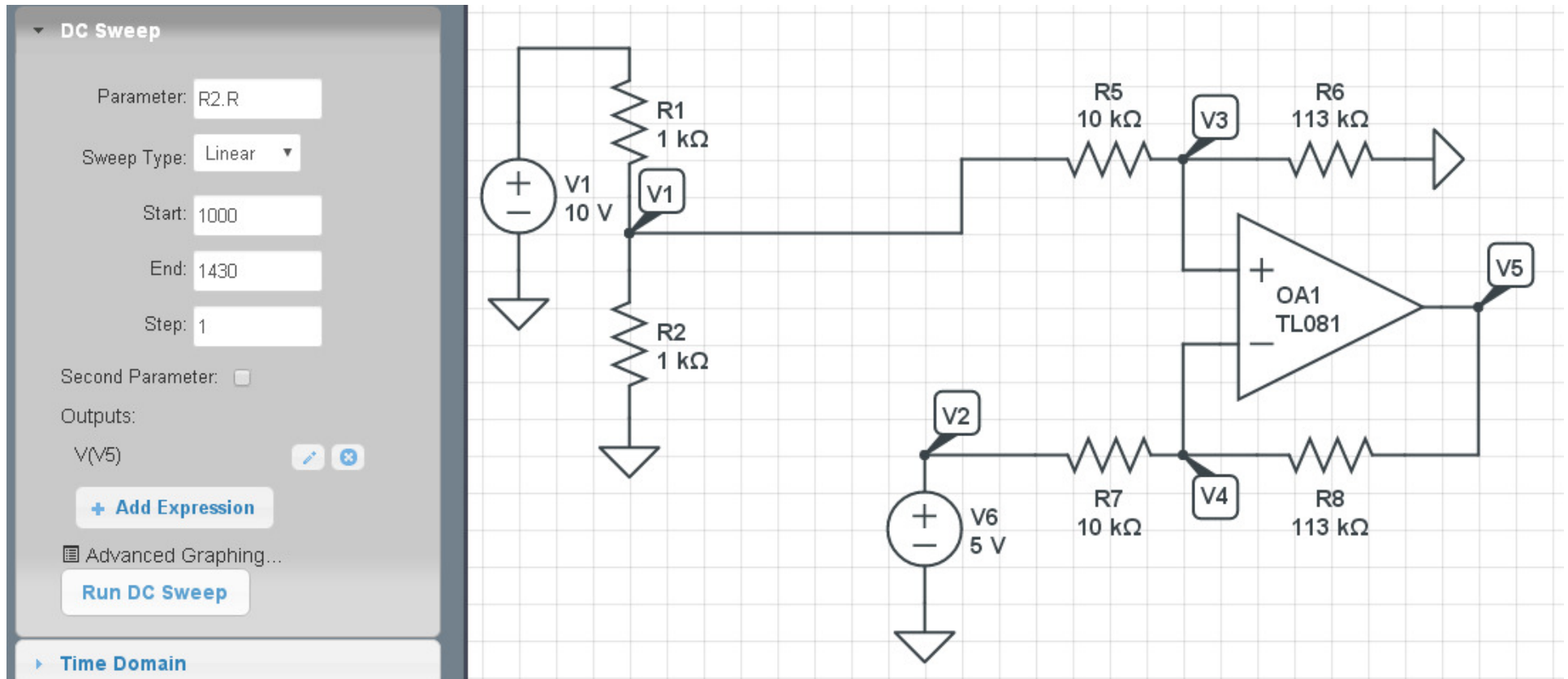
Check the results in Matlab:

```
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)');
```



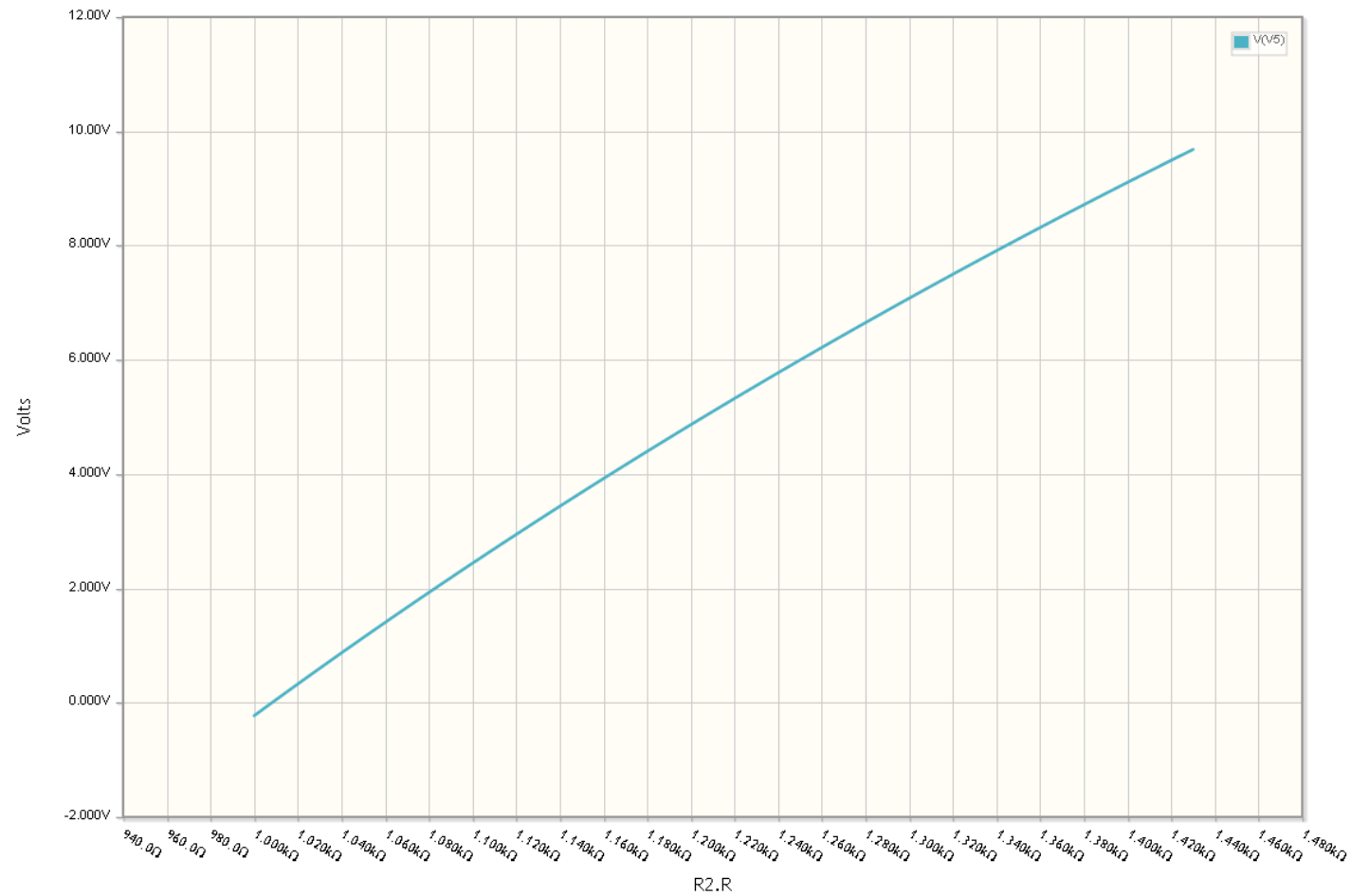
Check the results in CircuitLab, note that

- 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

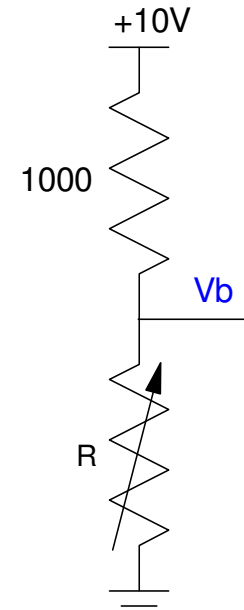
Solution: Use a voltage divider to convert T to V

At 0C ($V_y = 0.00V$)

- $R = 3320.125 \text{ Ohms}$
- $V_b = 7.6853 \text{ V}$

At +40C ($V_y = 10.00V$)

- $R = 533.664 \text{ Ohms}$
- $V_b = 3.4797V$



As V_b goes down, Y goes up

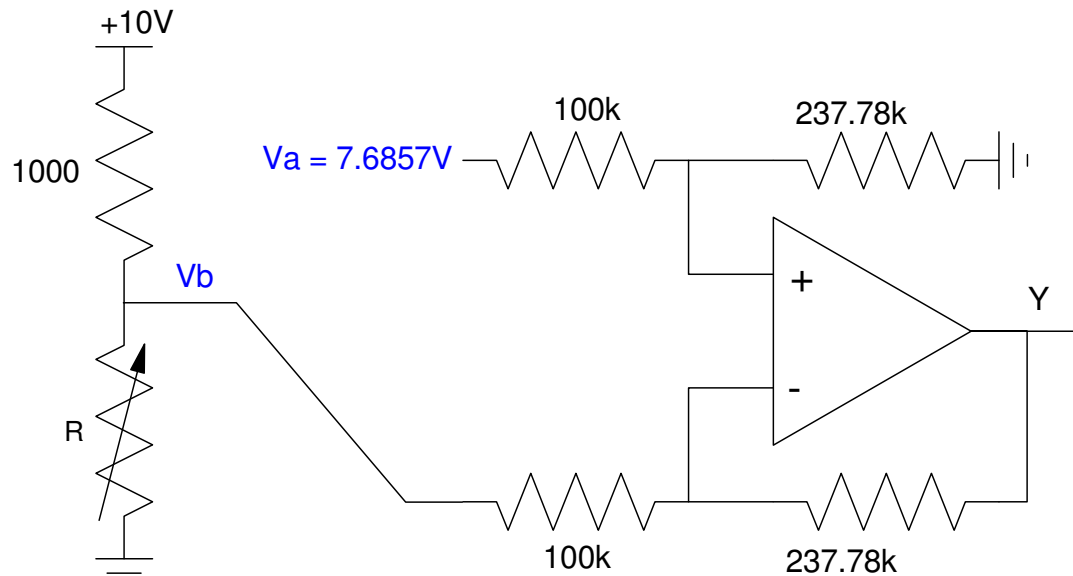
- Connect V_b to the minus input (B)

The output is 0V when $V_b = 7.6853V$

- Make $A = 7.6853V$

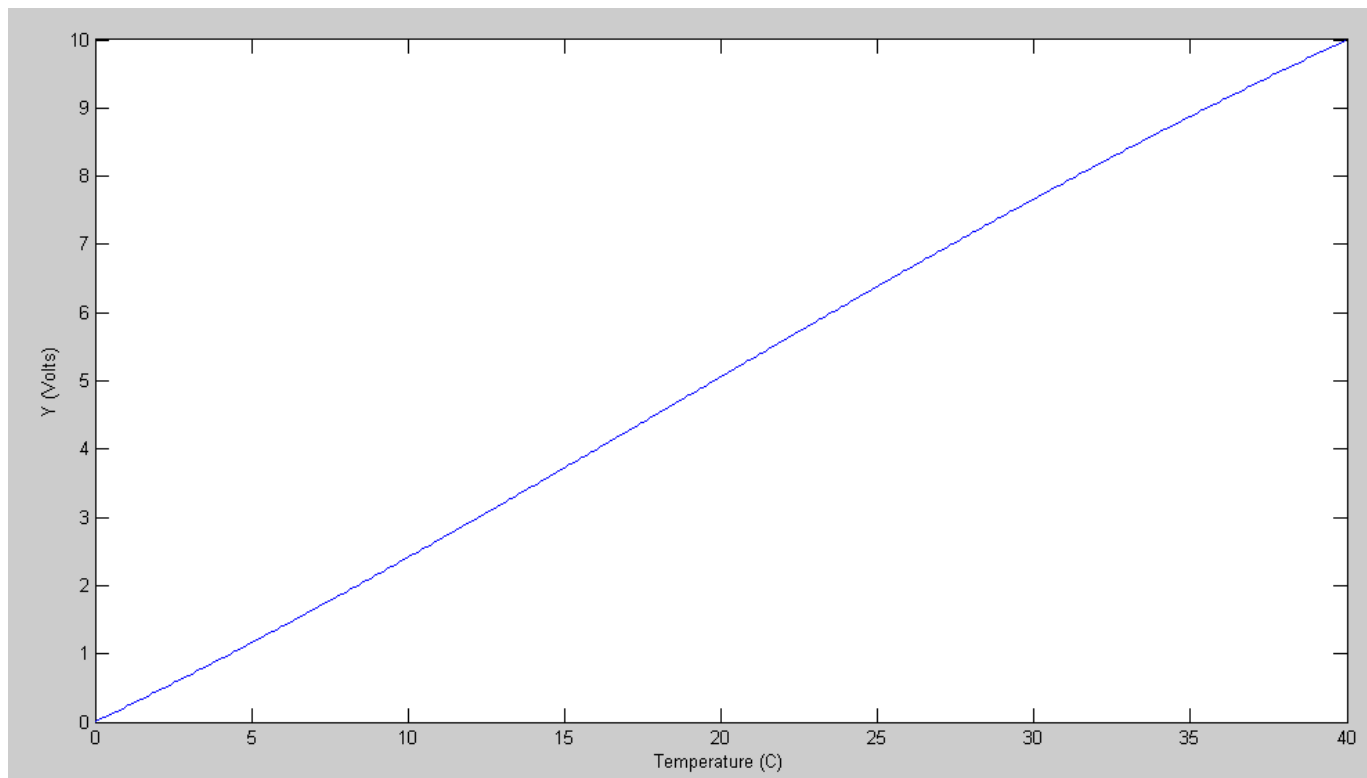
The gain needed is

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



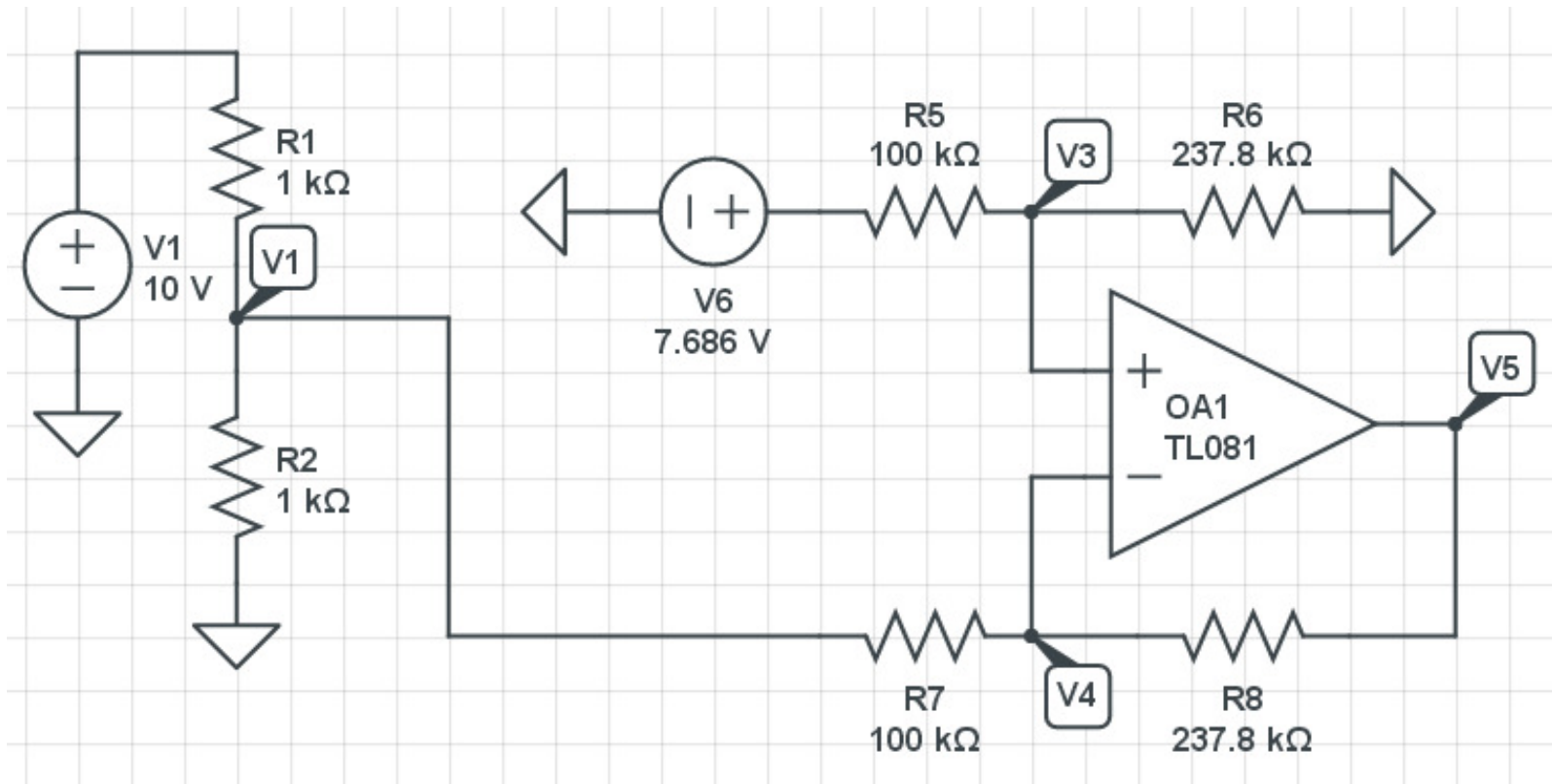
Checking in Matlab.

```
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 $R2 = 3320.125 \text{ Ohms}$)
- The midpoint (20C or $R2 = 1250.593 \text{ Ohms}$)
- The right endpoint (40C or $R2 = 533.664 \text{ Ohms}$)



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)
