

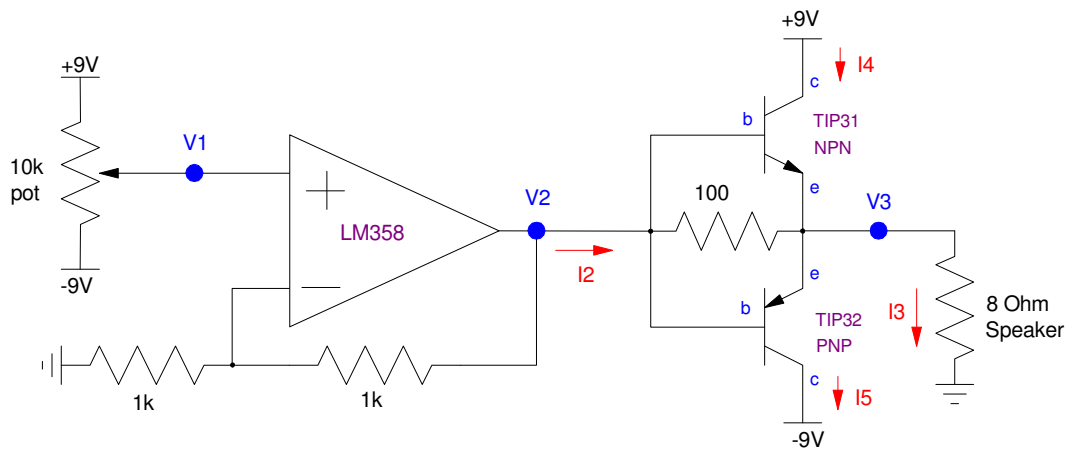
# ECE 320 - Homework #8

Push-Pull Amplifiers, Filters, Transistor Amplifiers (DC)

## Push-Pull Amplifier

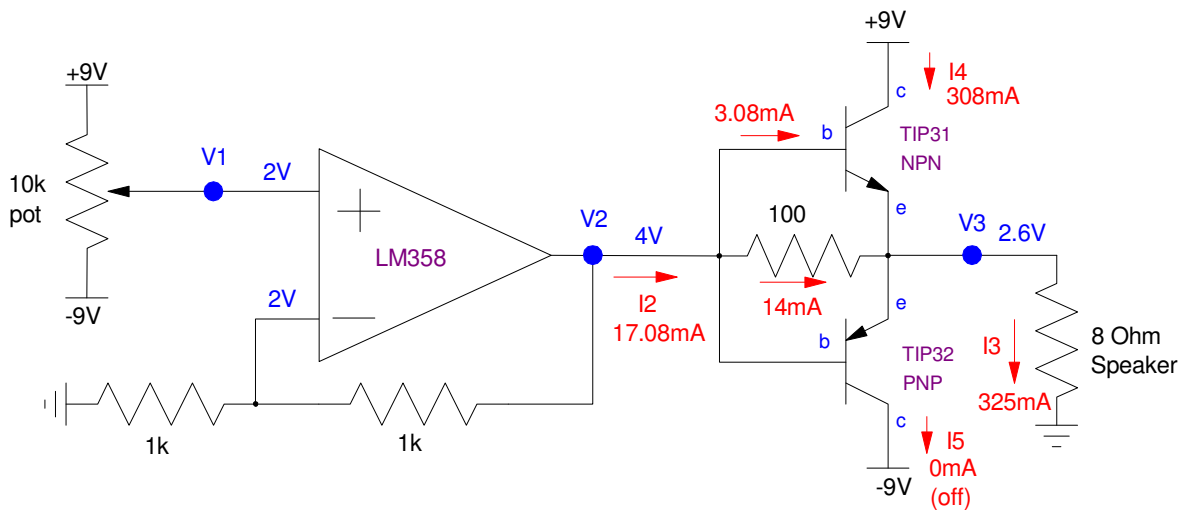
1) Determine the voltages and currents for the following circuit when  $V_1 = 2V$ . Assume the transistors have the following characteristics

|       |     | beta | Vbe  | Vce(sat) | Ic(max) |
|-------|-----|------|------|----------|---------|
| TIP31 | NPN | 100  | 1.4V | 0.9V     | 3A      |
| TIP32 | PNP | 100  | 1.4V | 0.9V     | 3A      |



note:

- Start with the voltages
- Then find the currents so that they balance

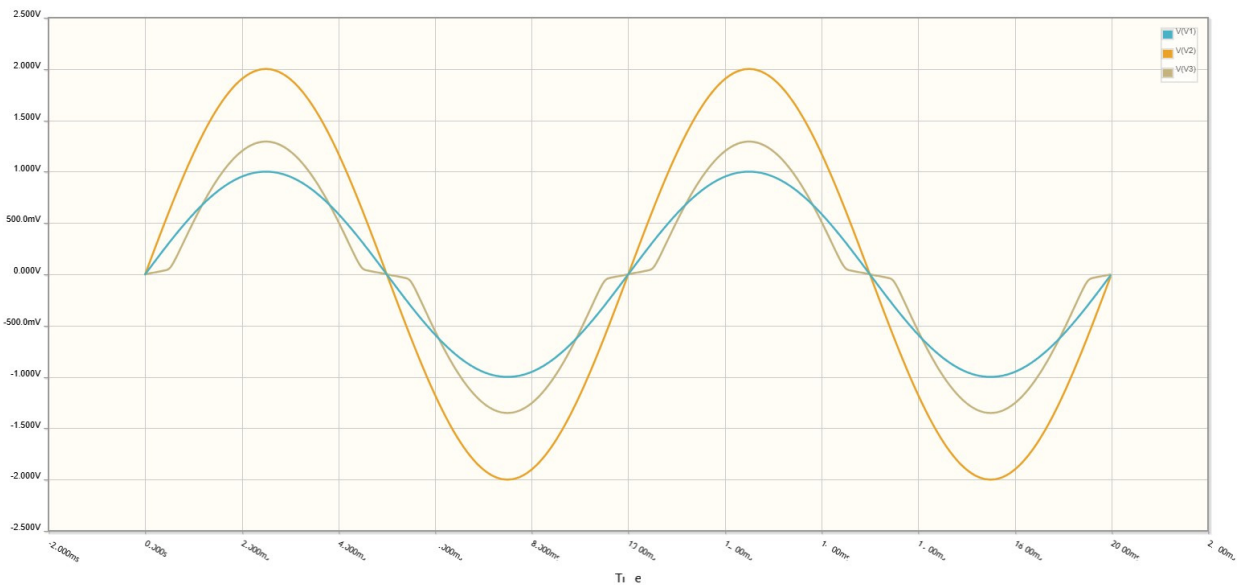
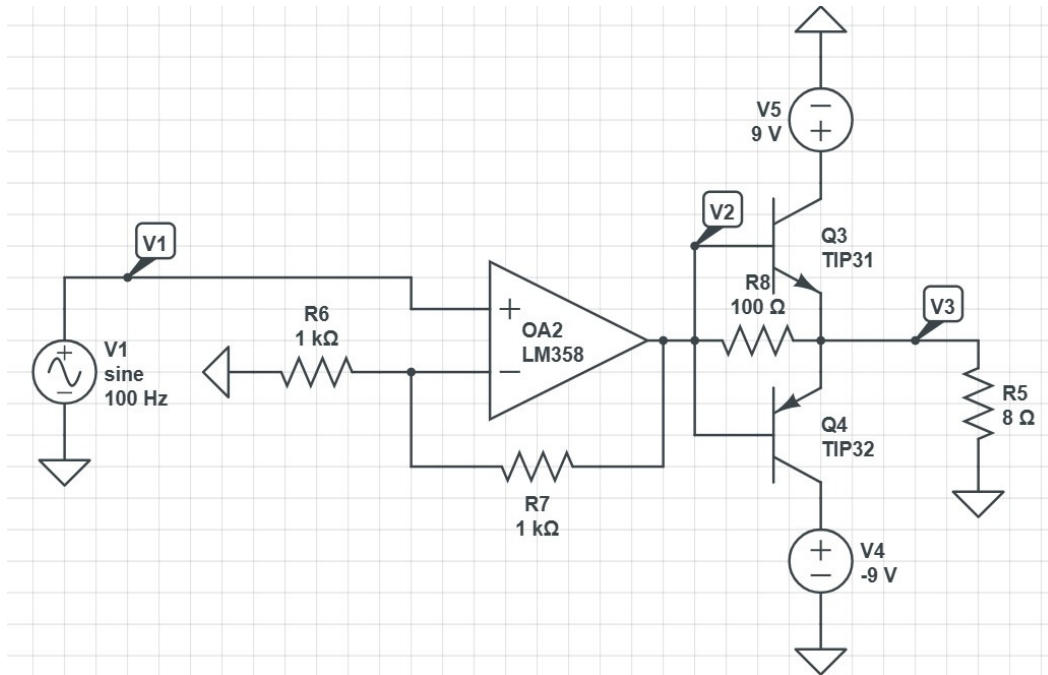


2) Simulate this circuit in CircuitLab with V1 being a 2Vp 100Hz sine wave

- Include a graph of V2(t) and V3(t) using a transient simulation

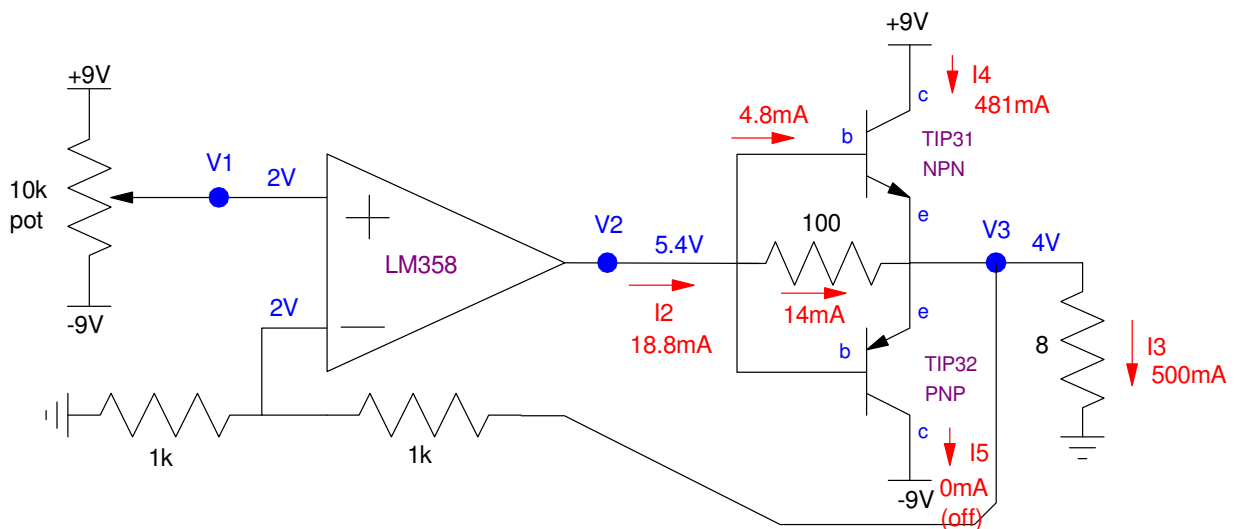
Note: The output shows crossover distortion

- grey line (V3)



The diagram shows a Class B push-pull amplifier circuit. An LM358 op-amp is configured as a voltage follower. Its non-inverting input is connected to a +9V supply through a 10k potentiometer (V1) and to ground through a 1k resistor. The inverting input is connected to the output (V2) through a 100Ω resistor and to ground through a 1k resistor. The output (V2) drives the bases of two transistors: a TIP31 NPN and a TIP32 PNP. The TIP31 emitter is connected to +9V (current I4) and its collector to the output node (V3). The TIP32 emitter is connected to -9V (current I5) and its collector to the output node (V3). A 100Ω resistor is between the op-amp output and the TIP31 base. A 10k resistor is between the output node (V3) and ground (current I3). The output is also connected to a load resistor (8Ω) to ground.

Then find the currents so everything balances

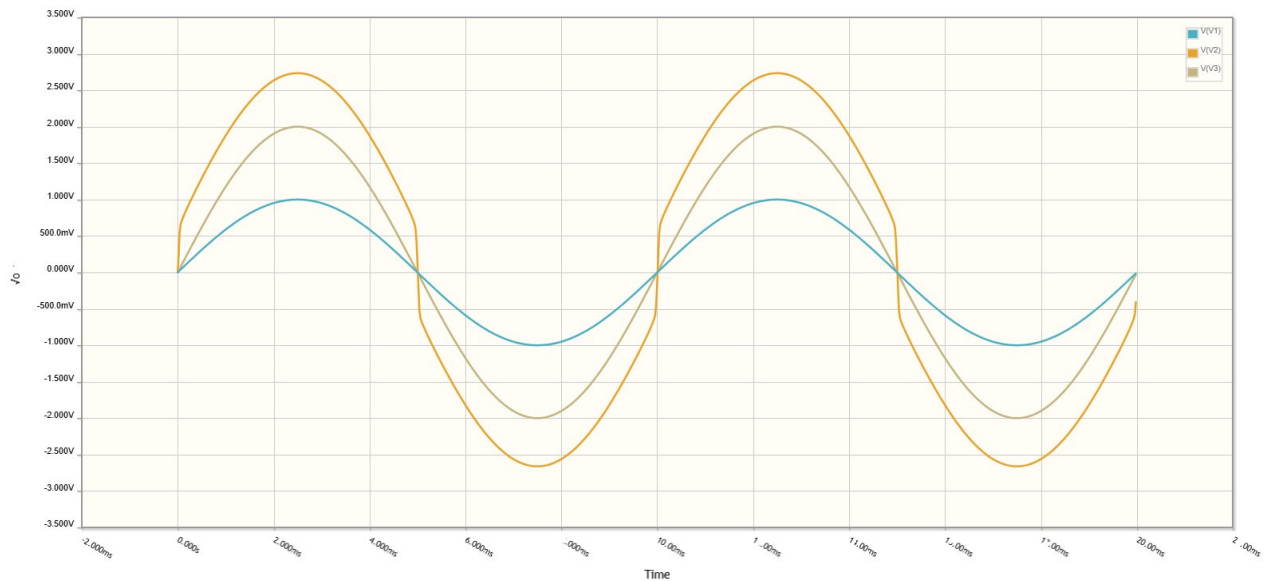
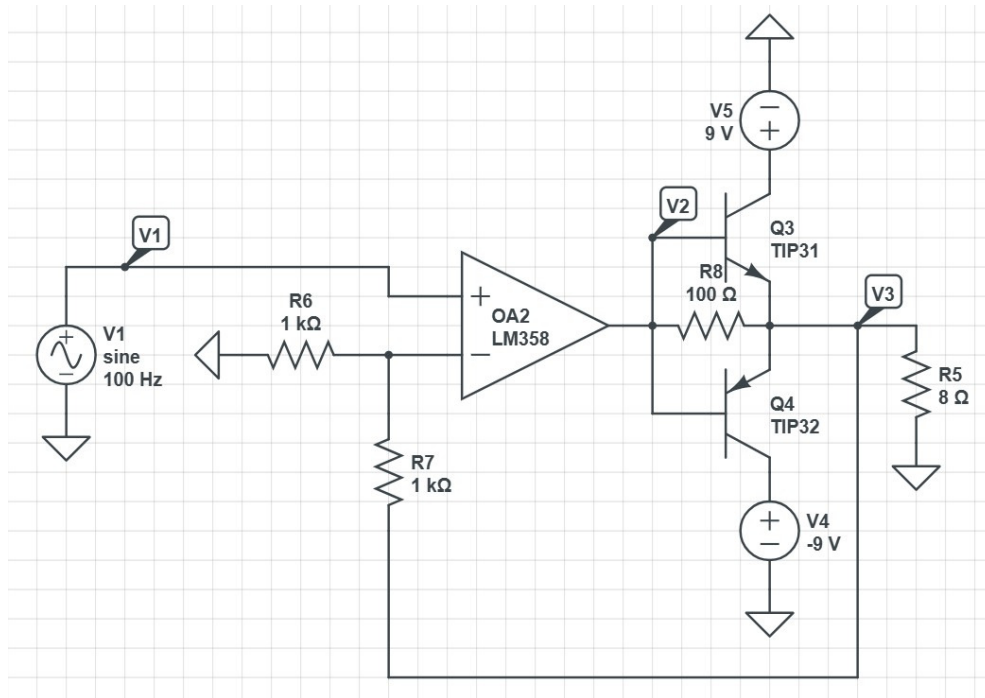


4) Simulate this circuit in CircuitLab with V1 being a 2Vp 100Hz sine wave

- Include a graph of V2(t) and V3(t) using a transient simulation

Note

- The output no longer has crossover distortion (grey line)
- V2 has a jump at the zero crossings as you switch from push (+) to pull (-)



## Filter Analysis

5) Let

$$Y = \left( \frac{10}{(s+2)(s+3)} \right) X$$

a) What is the differential equation relating X and Y?

Cross multiply and multiply out the polynomials

$$(s+2)(s+3)Y = (10)X$$

$$(s^2 + 6s + 5)Y = 10X$$

'sY' means 'the derivative of y'. Using Lagrange's notation

$$y'' + 6y' + 5y = 10x$$

or Leibniz's notation:

$$\frac{d^2y}{dt^2} + 6\frac{dy}{dt} + 5y = 10x$$

b) Find y(t) assuming

$$x(t) = 2 + 3 \sin(4t)$$

Use superposition. This is a linear system, meaning

$$f(a+b) = f(a) + f(b)$$

Solve this as two separate problems

$$x(t) = 2$$

$$Y = \left( \frac{10}{(s+2)(s+3)} \right) X$$

This is true everywhere. For this particular x(t), using phasor analysis

$$s = 0$$

$$X = 2$$

$$Y = \left( \frac{10}{(s+2)(s+3)} \right)_{s=0} \cdot (2)$$

$$Y = 3.3333$$

meaning

$$y(t) = 3.3333$$

$$x(t) = 3 \sin(4t)$$

$$s = j4$$

$$X = 0 - j3$$

phasors: *real = cosine, -imag = sine*

$$Y = \left( \frac{10}{(s+2)(s+3)} \right)_{s=j4} \cdot (0 - j3)$$

$$Y = -1.2 + j0.6$$

meaning

$$y(t) = -1.2 \cos(4t) - 0.6 \sin(4t)$$

The total answer is the DC term and the AC term

$$y(t) = 3.3333 - 1.2 \cos(4t) - 0.6 \sin(4t)$$

## Filter Design

6) Design an active filter to implement

$$Y = \left( \frac{10}{(s+2)(s+3)} \right) X$$

There are several solutions. One way is add a 2-stage RC filter along with an noninverting amplifier

$$Y = \left( \frac{6}{(s+2)(s+3)} \right) \left( \frac{10}{60} \right) X$$

Use two RC filters. Filter #1

$$R_1 = 10k$$

$$\frac{1}{R_1 C_1} = 2$$

$$C_1 = 5\mu F$$

Filter #2: Make R2 10x R1 to reduce loading

$$R_2 = 100k$$

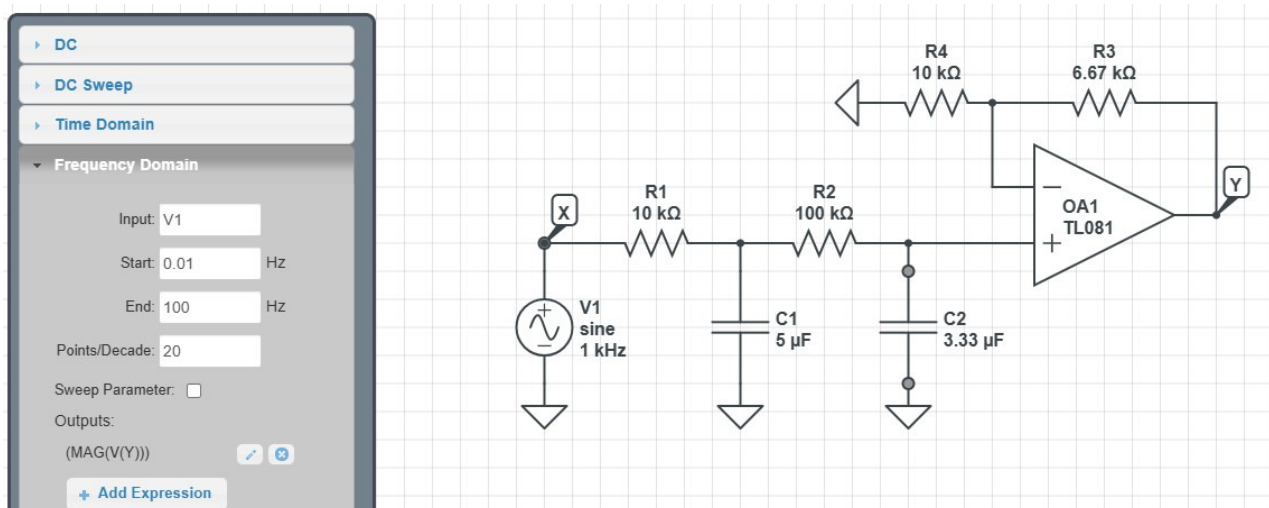
$$\frac{1}{R_2 C_2} = 3$$

$$C_2 = 3.33\mu F$$

For a gain of 10/6, use a noninverting amplifier

$$\text{gain} = 1.667 = \left( 1 + \frac{R_3}{R_4} \right)$$

Let  $R_4 = 10k$ ,  $R_3 = 6.67k$

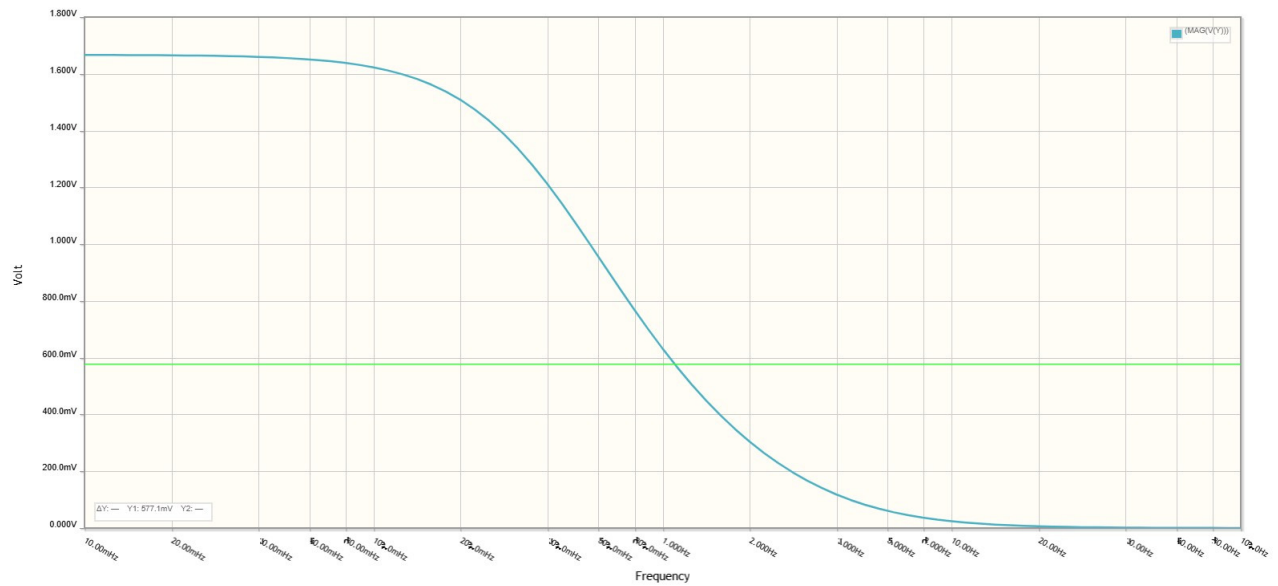


7) Verify the gain of your design using CircuitLab

- Run a frequency domain sweep from 0.1 to 10 rad/sec

The gain drops to 70% (1/2 power) at about 0.4Hz

- 2.5 rad/sec
- poles at ( $s = -2$ ,  $s = -3$ )



8) Design an active filter to implement

$$Y = \left( \frac{20}{s^2 + 2s + 17} \right) X$$

Factor

$$Y = \left( \frac{20}{(s+1+j4)(s+1-j4)} \right) X$$

$$Y = \left( \frac{20}{(s+4.123\angle 75.96^\circ)(s+4.123\angle -75.96^\circ)} \right) X$$

The magnitude of the pole tells you the RC time constant

$$\frac{1}{RC} = 4.123$$

Let  $R = 100k$

$$C = 2.525\mu F$$

The gain sets the angle of the poles

$$3 - k = 2 \cos \theta$$

$$k = 2.515$$

$$k = 2.515 = \left( 1 + \frac{R_3}{R_4} \right)$$

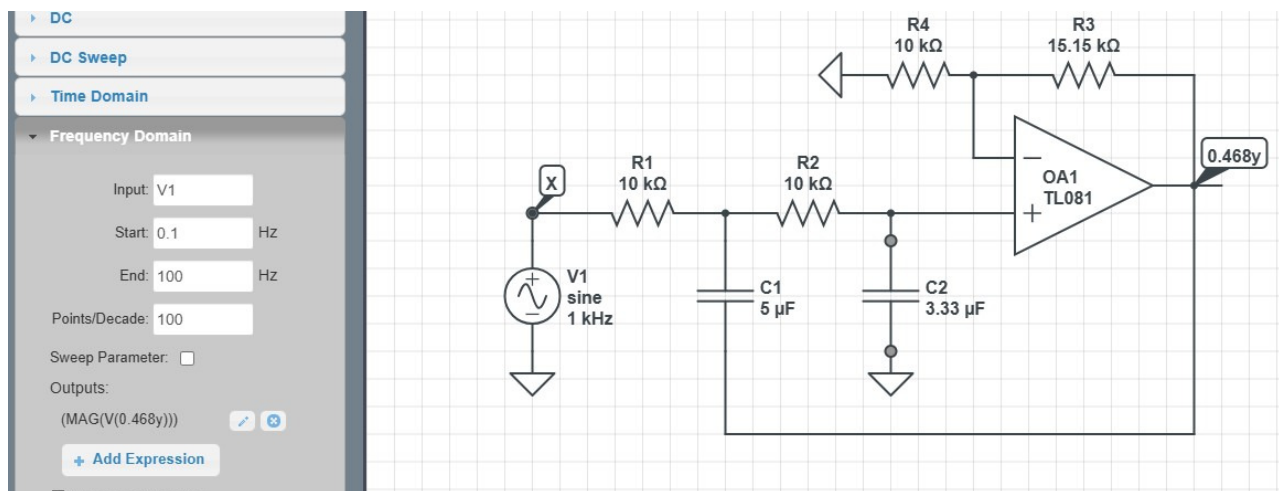
Let  $R_4 = 10k$

$$R_3 = 15.15k$$

This provides a DC gain of 2.515. It *should* be 20/17.

- option 1) Add a gain of 2.138 to get y
- option 2) Call the output 0.468y

Going with the latter option

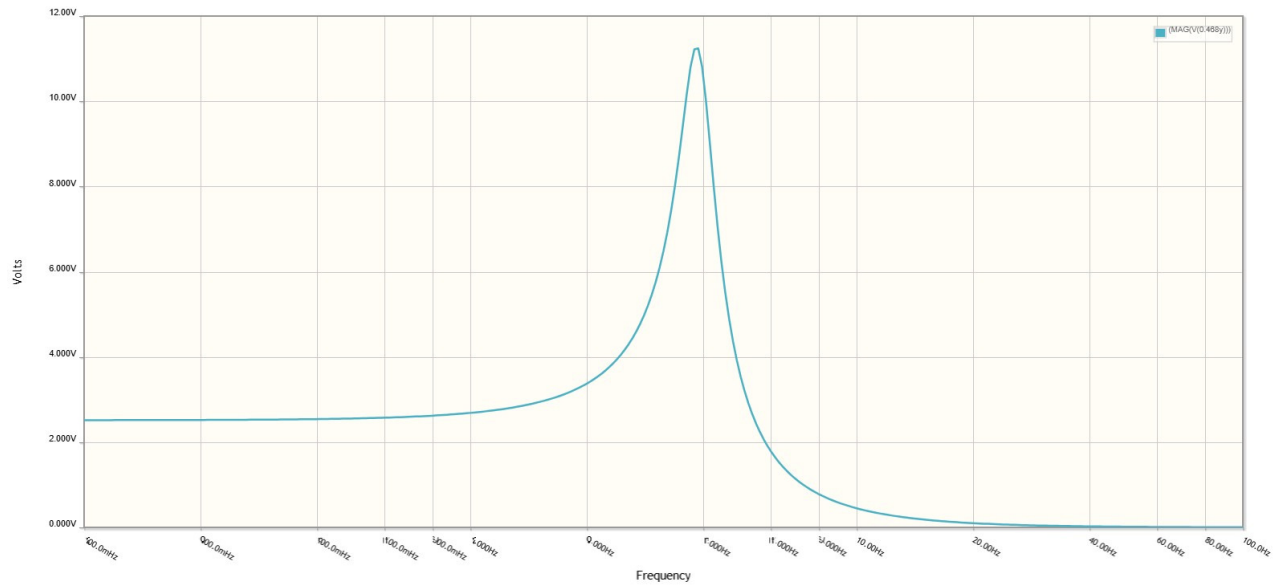


9) Verify the gain of your design using CircuitLab

- Run a frequency domain sweep from 0.1 to 10 rad/sec

The complex pole results in a resonance at 4 rad/sec

- 0.637Hz
- the complex part of the pole



## CE Amplifiers (DC Analysis)

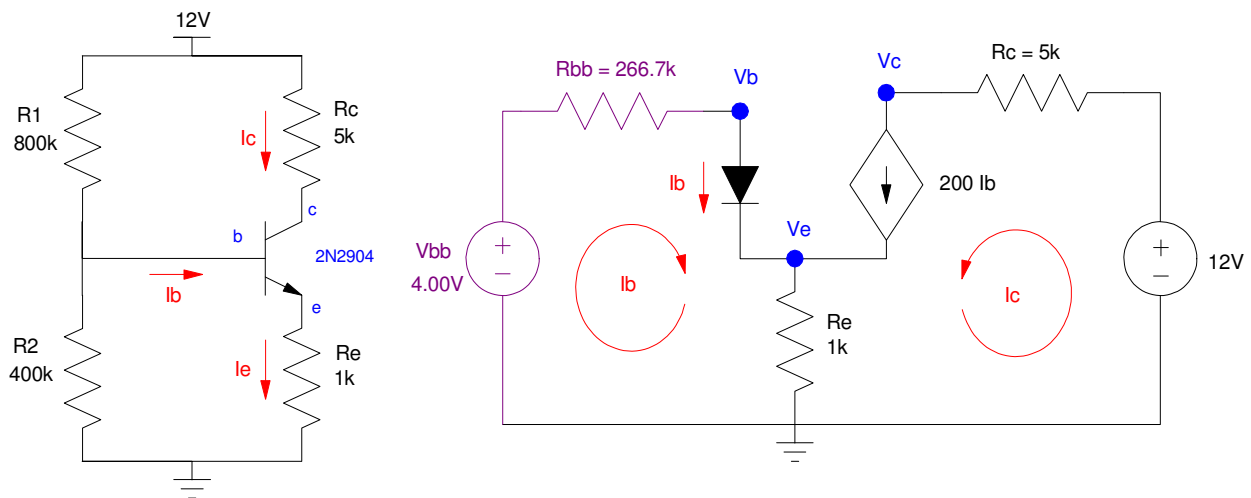
10) Determine the Q point for the following CE amplifier. Assume a 2N3904 NPN transistor

- $\beta = 200$
- $V_{be} = 0.7V$
- $V_{ce(sat)} = 0.2V$

Start with replacing  $R_1$  &  $R_2$  with their Thevenin equivalent

$$V_{bb} \equiv V_{th} = \left( \frac{R_2}{R_2 + R_1} \right) 12V = 4.00V$$

$$R_{bb} \equiv R_{th} = R_1 || R_2 = 266.7k\Omega$$



Do the loop equation around  $I_b$

$$V_{bb} = I_b R_{bb} + 0.7V + (I_b + \beta I_b) = 0$$

$$I_b = \left( \frac{V_{bb} - 0.7}{R_{bb} + (1 + \beta)R_e} \right)$$

$$I_b = 7.056\mu A$$

$$I_c = 200I_b = 1.411mA$$

Now find the voltages

$$V_e = R_e \cdot (I_b + I_c) = 1.418V$$

$$V_b = V_e + 0.7 = 2.118V$$

$$V_c = 12 - I_c R_c = 4.944V$$

$$V_{ce} = 2.825V$$

11) Change R1 and R2 so that

- The Q point is stabilized for variations in  $\beta$ , and
- The Q-point is at  $V_{ce} = +6V$

Start with stabilizing the Q-point

$$(1 + \beta)R_e \gg R_{bb}$$

$$201k\Omega \gg R_{bb}$$

Let  $R_{bb} = 20k$ . For  $V_{ce} = 6.00V$

$$12V = I_c R_c + V_{ce} + (I_b + \beta I_b) R_e$$

$$12V = 200I_b R_c + V_{ce} + 201I_b R_e$$

$$I_b = 4.996\mu A$$

$$I_c = 999.2\mu A$$

$V_{bb}$  is then

$$V_{bb} = (I_b + I_e)R_e + 0.7 + I_b R_{bb}$$

$$V_{bb} = 1.804V$$

Now find R1 and R2

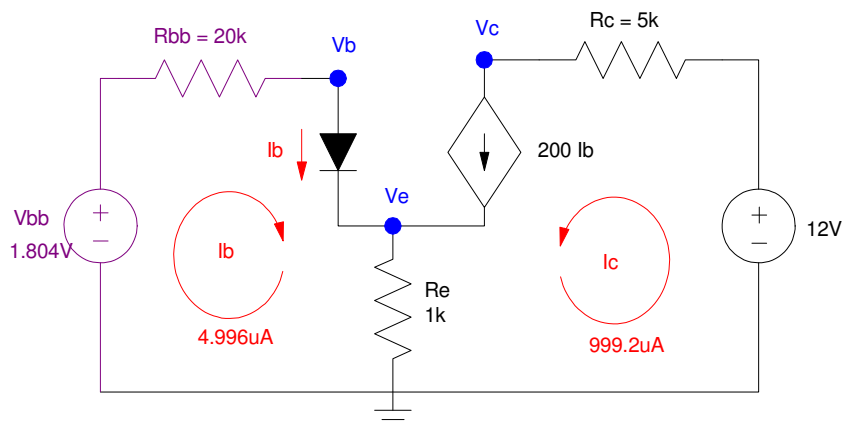
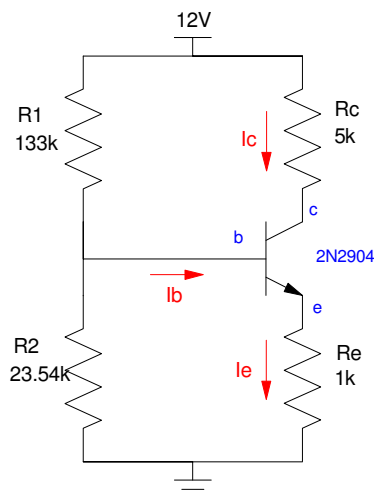
$$R_{bb} = R_1 || R_2 = \left( \frac{R_1 R_2}{R_1 + R_2} \right) = 20k\Omega$$

$$V_{bb} = 1.804V = \left( \frac{R_2}{R_1 + R_2} \right) 12V$$

Solving

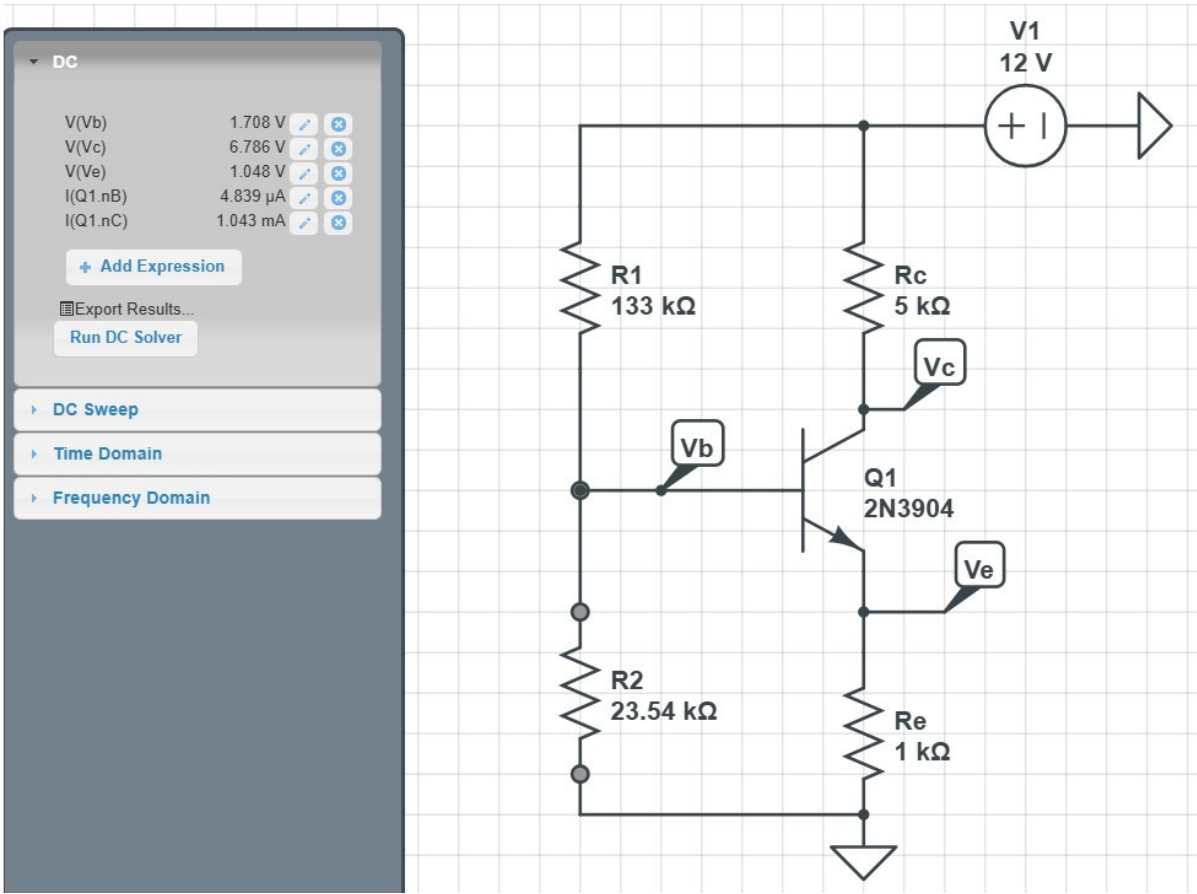
$$R_1 = 133.0k\Omega$$

$$R_2 = 23.54k\Omega$$



12) Verify your calculations for problem #11 using CircuitLab

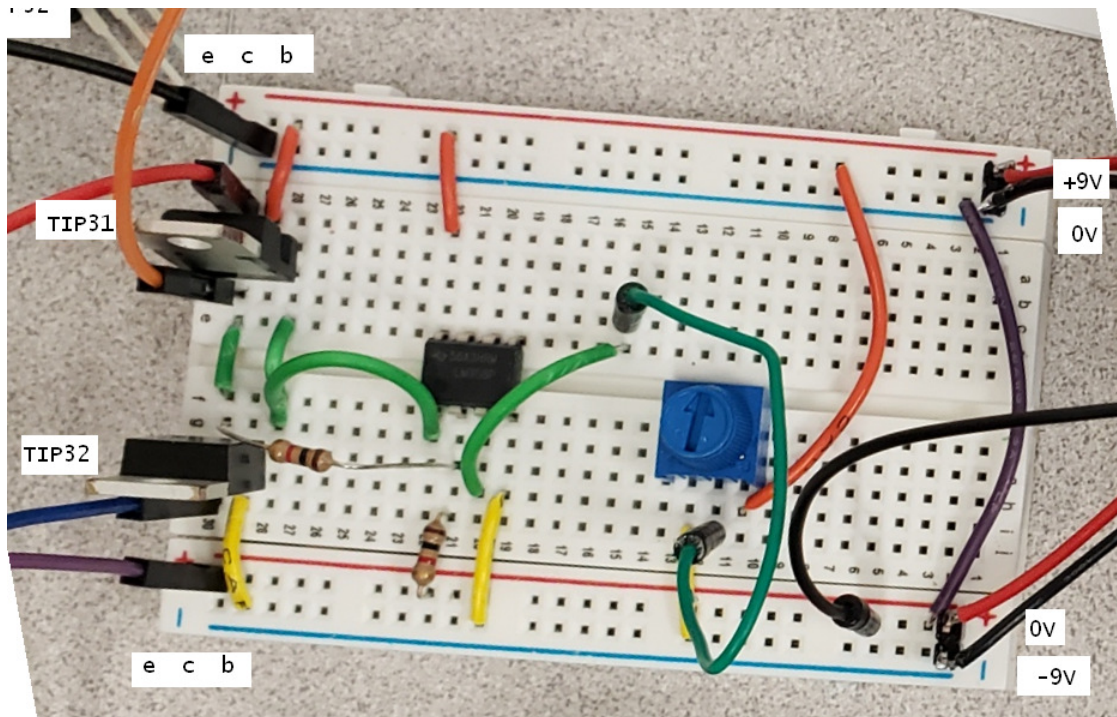
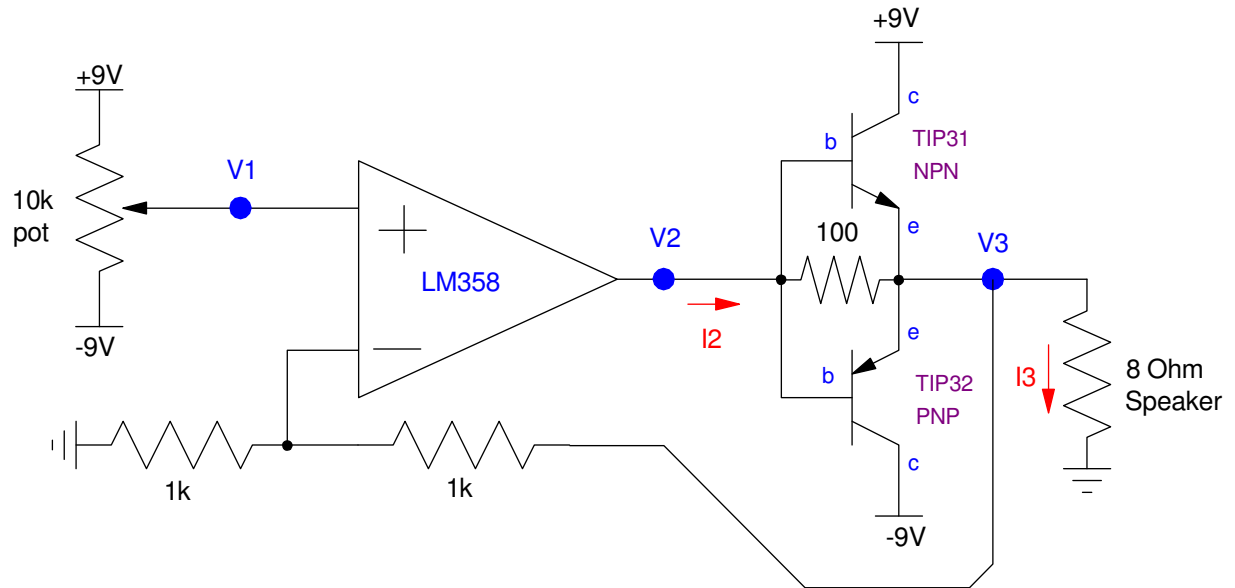
|     | Calculation   | Simulation    |
|-----|---------------|---------------|
| Vb  | 1.804 V       | 1.708 V       |
| Vc  | 7.004 V       | 6.786 V       |
| Ve  | 1.004 V       | 1.048 V       |
| Vce | 6.000 V       | 5.738 V       |
| Ib  | 4.996 $\mu$ A | 4.839 $\mu$ A |
| Ic  | 999.2 $\mu$ A | 1043 $\mu$ A  |



## Lab

13) Build the following push-pull amplifier with your lab kit

- Include a photo of your breadboard for full credit
- Use  $\pm 9V$  to power this circuit, similar to homework #7



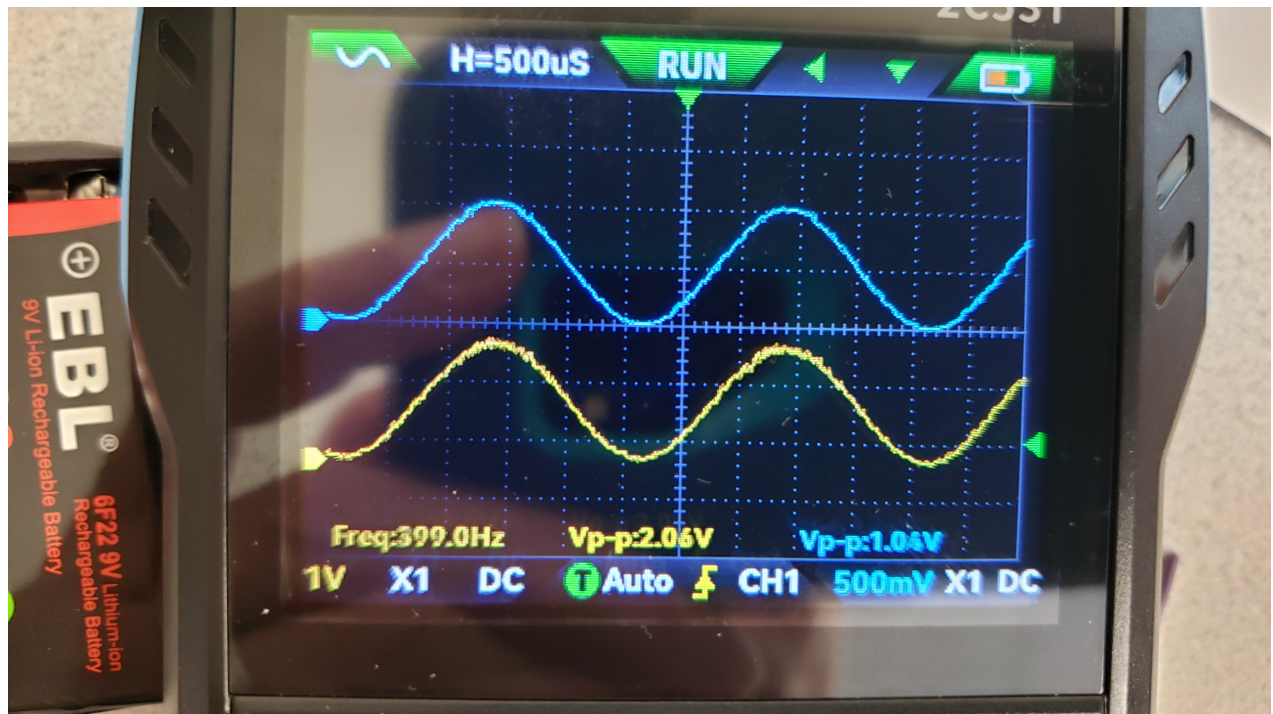
14) Measure the voltage at V1, V2, and V3 using your FNRSI meter for

- V1 = +1V
- V1 = 0V
- V1 = -1V

| V1       | V2 | V3       |
|----------|----|----------|
| 0.5150V  |    | 1.0289V  |
| -0.8750V |    | -1.7411V |
|          |    |          |

15) Change V1 to a 1Vp 200Hz sine wave. Measure the voltages at V2 and V3 using your FNRSI oscilloscope

- Use your FNRSI meter to output a sine wave
- Include a photo of the oscilloscope traces



16) Change V1 to an audio signal from your cell phone or computer playing a YouTube video. Demonstrate your working amplifier

- Photo of an oscilloscope trace at V3 works
- YouTube video showing your amplifier also works

Signal at the speaker

- Note: no crossover distortion
- Good clean audio
- 

