# EEE 108L MICRO-ELECTRONICS 1 LAB 7

**Lab Session: Tuesday 3PM - 5:40PM**

**Student Name: Andrew Robertson**

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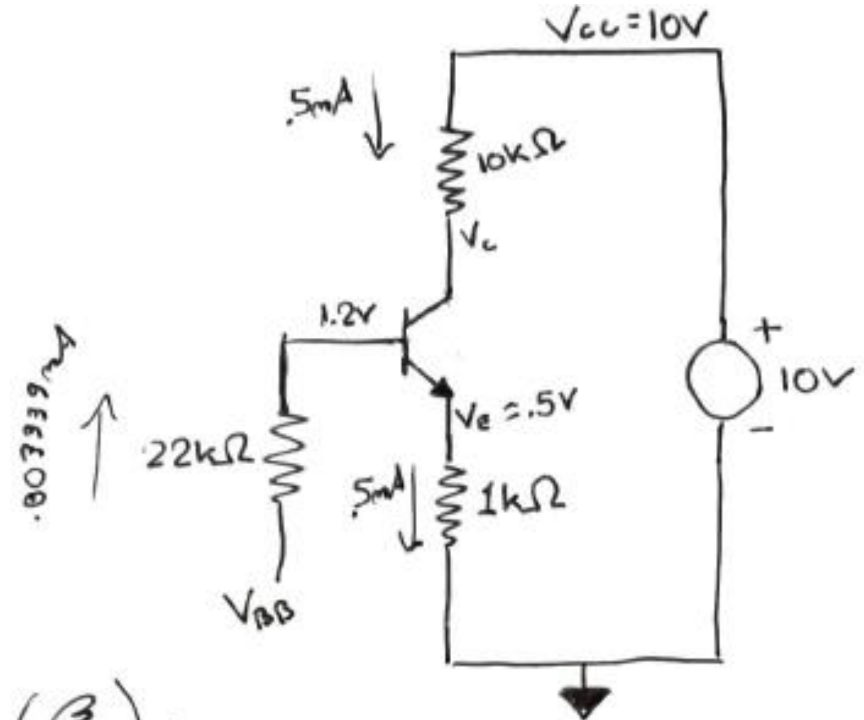
# PRE-LAB CALCULATIONS

STEP 1.




$i_c = \left(\frac{\beta}{\beta+1}\right) i_e$ $\quad .5\,mA = \left(\frac{150}{151}\right) i_e$ , $\quad i_e = .503337\,mA$

$(.003333\,mA \cdot 22k\Omega) + 1.2V = \boxed{1.273333\,V = V_{BB}}$

$\boxed{V_{RBB} = 73.3333\,mV}$

STEP 2.

$$1.2733 = I_B \cdot 22k + .7V + (I_B \cdot 225)1k$$

$$.5733 = I_B(22k + 225k)$$

$$I_B = 2.32 \mu A$$

$$I_c = 225 I_B = .522 mA$$

$$\frac{.522 mA}{.5 mA} = 1.044 = 4.4\%$$

STEP 3.

$$3) \left(\frac{-2mV}{°C}\right)(40°C) = 80mV$$

$$V_{BE} = .7 - 80mV = .62$$

$$\left(\frac{1.25\%}{°C}\right)(40°C) = 50\% \text{ increase in } \beta$$

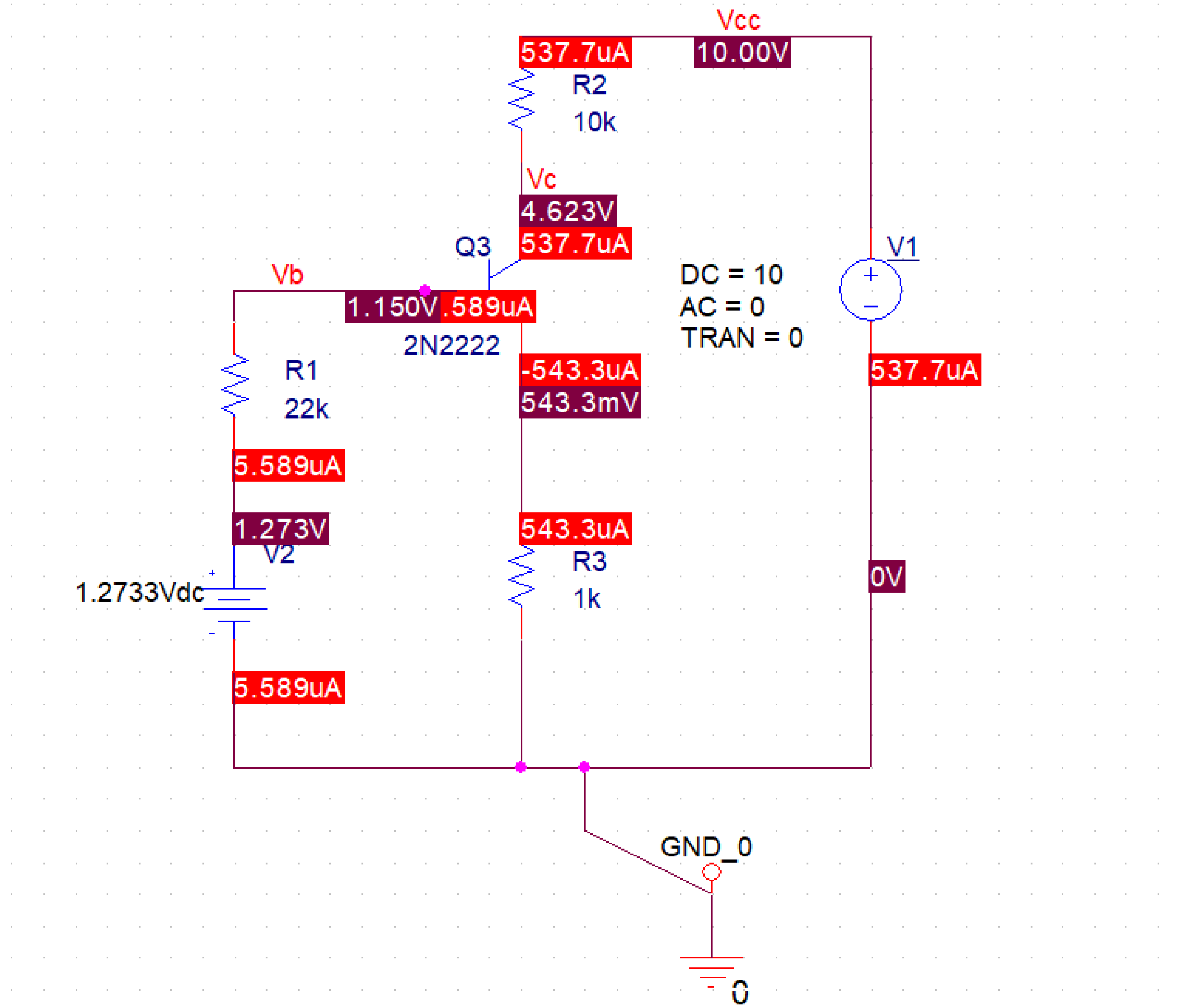
$$\boxed{\text{same as last step... } 4.4\% \text{ increase}}$$

STEP 4.

$$4) \frac{\Delta V_c}{\Delta V_B} = \boxed{\frac{V_{cc} - I_c R_c}{I_c R_E + V_{BE}}}$$

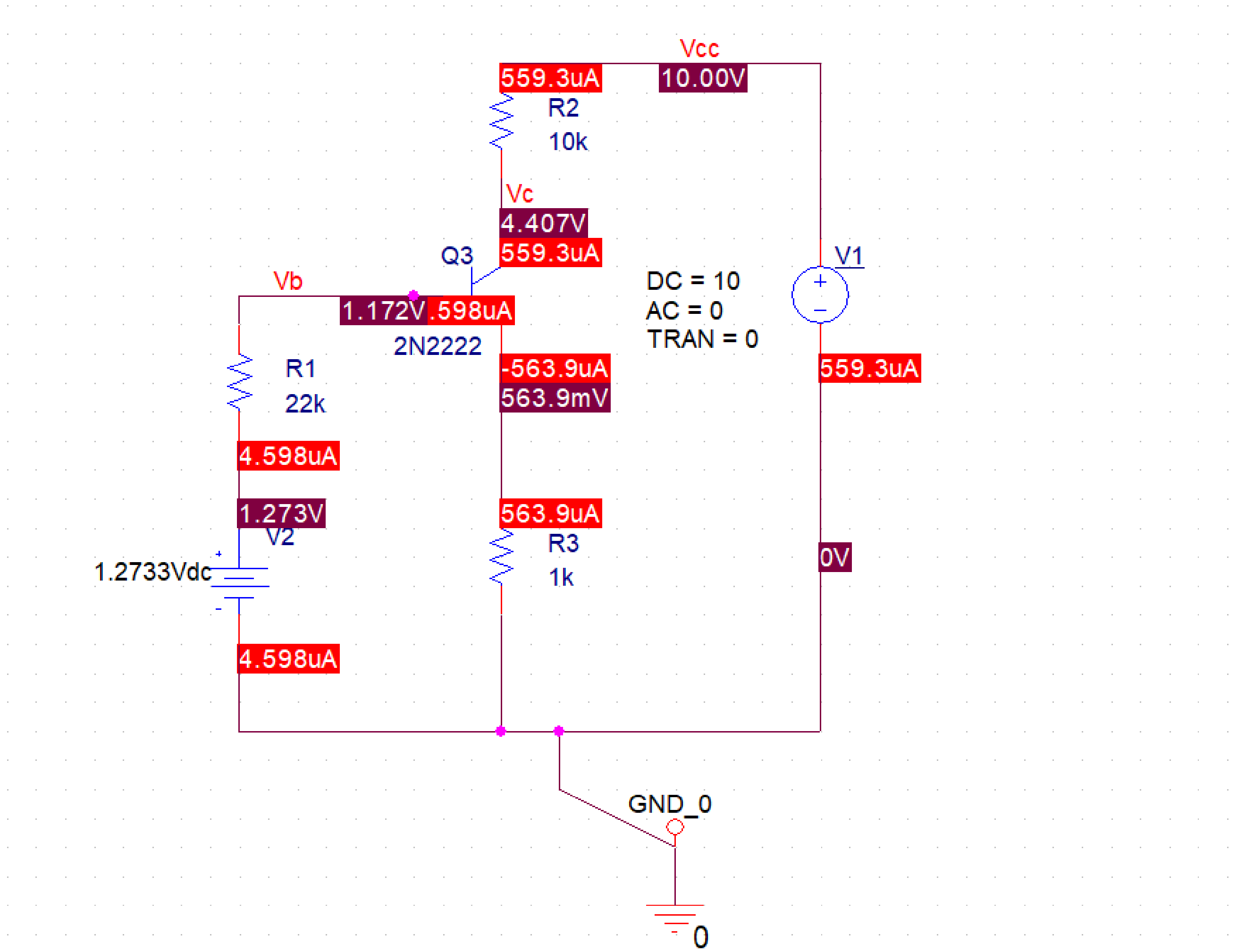
# SPICE SIMULATION

STEP 5.



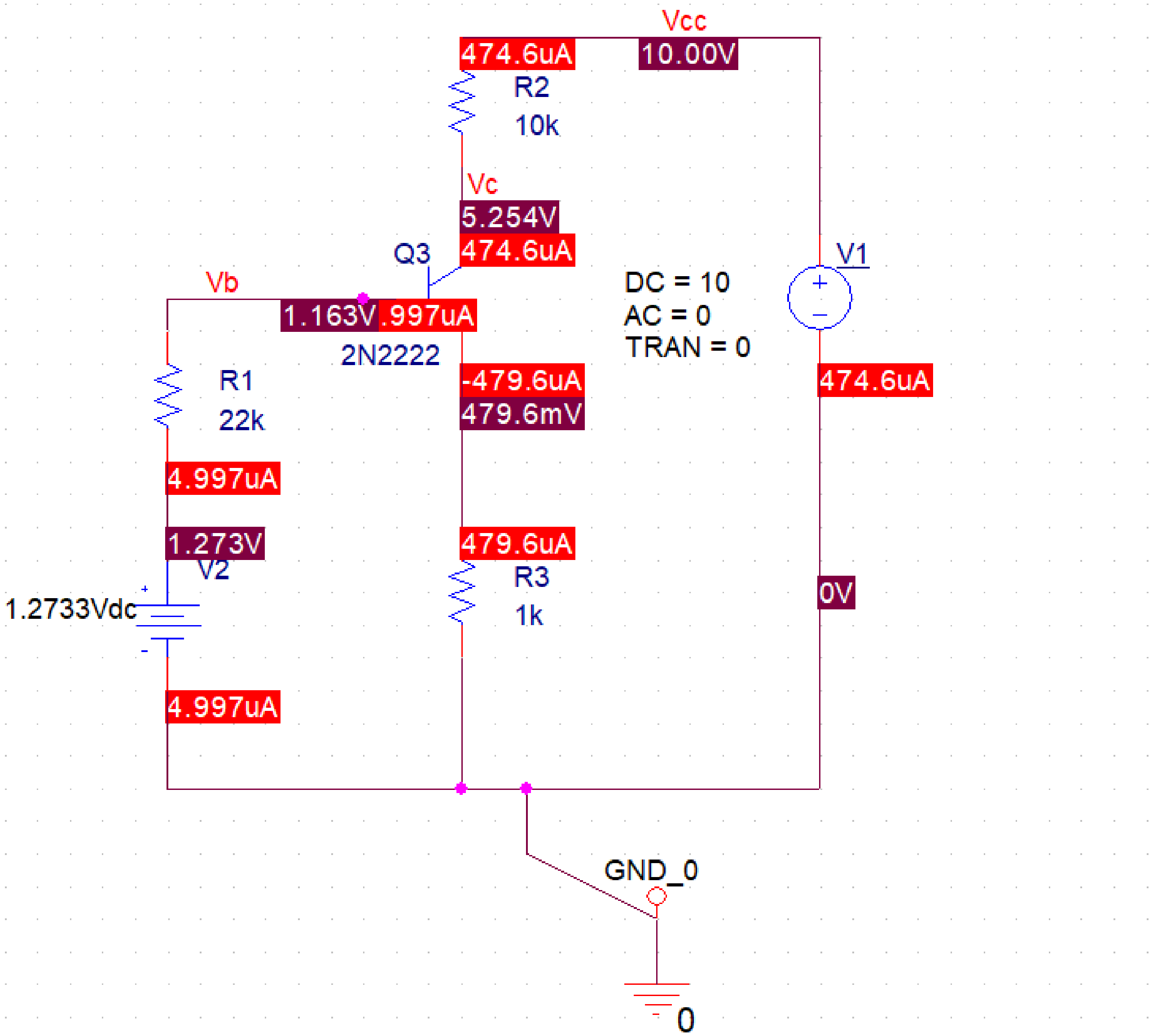

| VBB | VB | VE | VC | IC | IB | β |
|---|---|---|---|---|---|---|
| 1.2733V | 1.15V | .5433V | 4.623V | 537.7 micro | .589 micro | 150 |

STEP 6.



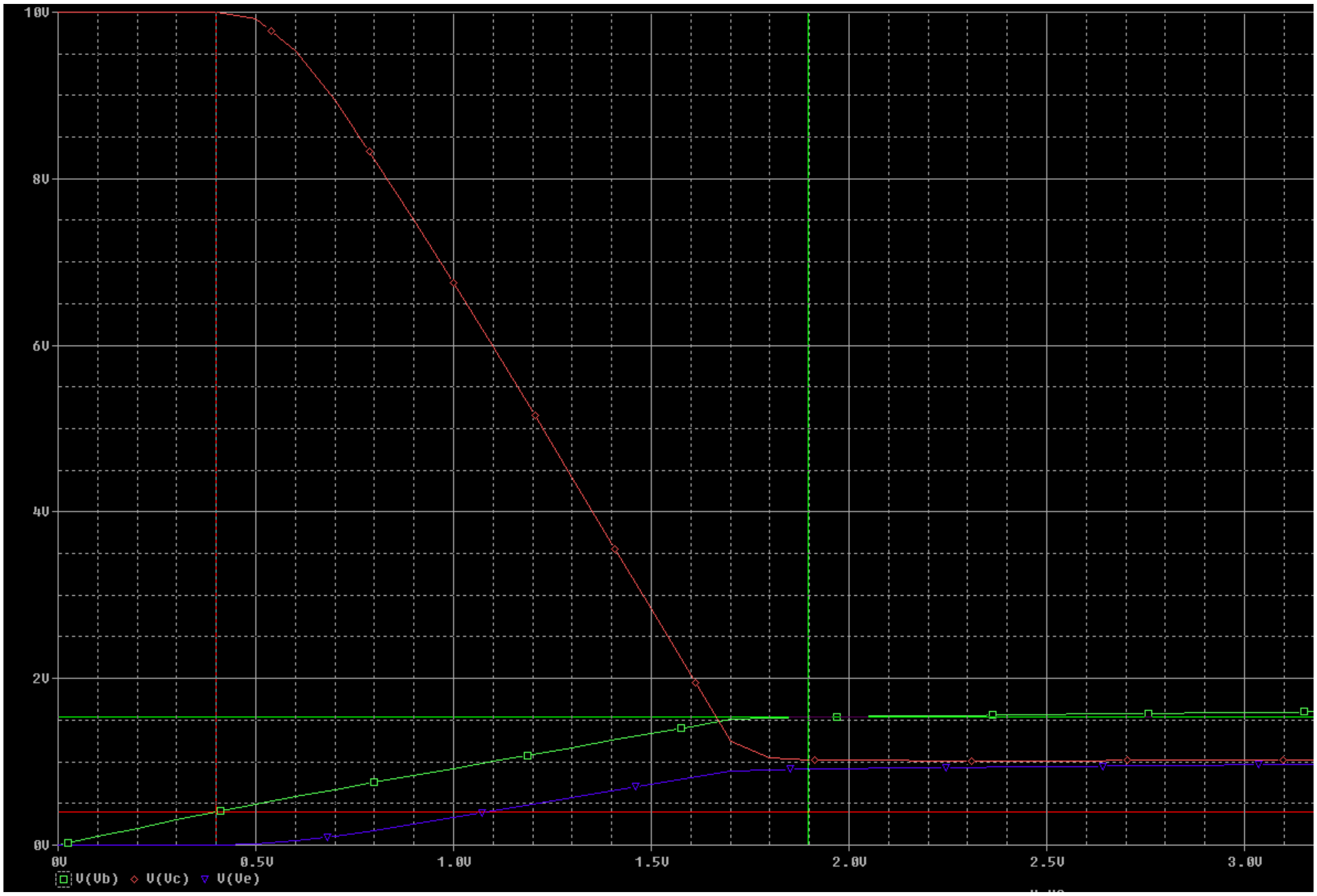

| VBB | VB | VE | VC | IC | IB | β |
|---|---|---|---|---|---|---|
| 1.2733V | 1.172V | .5639V | 4.407V | 559.3 micro | .598 micro | 225 |

STEP 7.

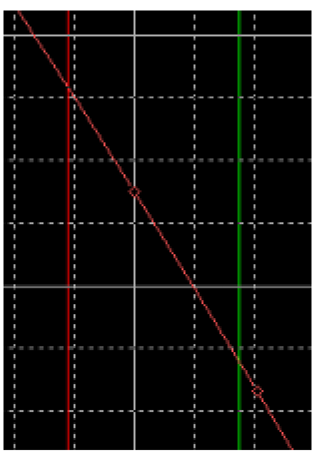



| VBB | VB | VE | VC | IC | IB | β |
|---|---|---|---|---|---|---|
| 1.2733V | 1.163V | .4796V | 5.254V | 474.6 micro | .997 micro | 150 |

STEP 8.




Note, the green cursor should be slightly more left here, at a point where Vb(green) and Vc(red) cross. There is no defined point where Vb is less than Vc so cutoff is technically not occurring however left of the red cursor the behavior is most certainly not the same as the forward active region and so it acts this way, forward active will be up to the (adjusted) green cursor, and saturation past that.



Using a small section of the forward active region, we can calculate $\frac{\Delta V_C}{\Delta V_B}$

$$\frac{7.5862 - 5.3846}{827.294 - 1.0689} \cong -9.1124$$

# EXPERIMENT

STEP 9.

a)

| $V_{BB}$ | $I_C$ | $V_C$ | $V_B$ |
|---|---|---|---|
| .5 | .0083 | 9.917 | .4978 |
| 1 | .3699 | 6.319 | .9586 |
| 1.5 | .805 | 1.992 | 1.413 |
| 2 | .9086 | .9592 | 1.549 |
| 2.5 | .908 | .9642 | 1.580 |
| 3.0 | .907 | .9780 | 1.608 |
| 3.5 | .905 | .9946 | 1.635 |
| 4.0 | .903 | 1.012 | 1.661 |
| 6.0 | | 1.038 | 1.757 |

mA

$$I_c = \frac{V_{cc} - V_c}{R_c} \qquad R_c = 9.95k$$

$$.5mA = \frac{10 - x}{9.95k}$$

$$4.975 = 10 - x$$

$$x = V_c = 5.025$$

| $V_{BB}$ | $I_C$ | $V_C$ | $V_B$ |
|---|---|---|---|
| 1.154 | .5002 | 5.023 | 1.1 |

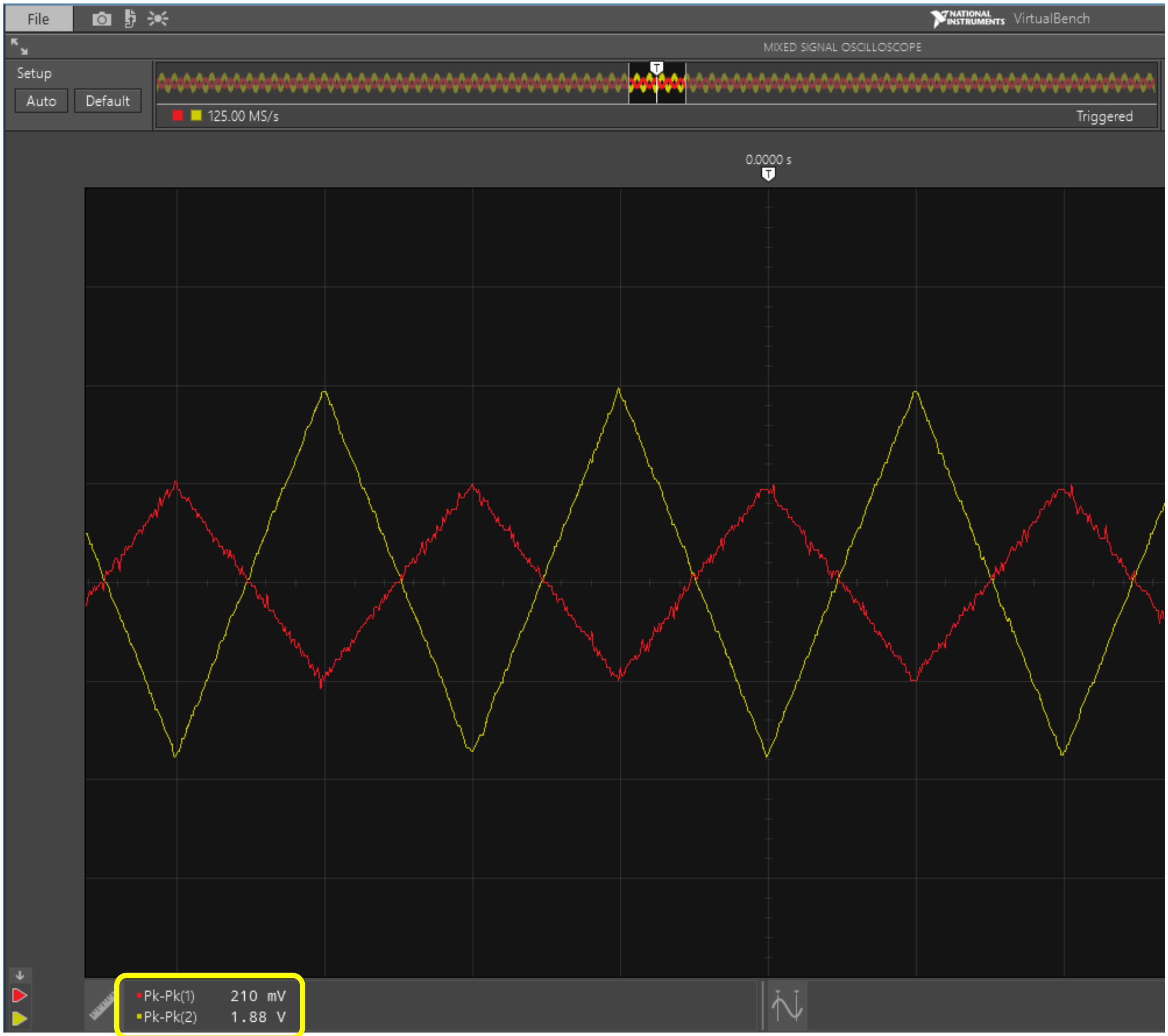
| $V_{BB}$ | $I_C$ | $V_C$ | $V_B$ |
|---|---|---|---|
| 1.27 | .6040 | 3.99 | 1.205 |

Calculating for $\frac{\Delta V_C}{\Delta V_B}$

$$\frac{5.023 - 3.99}{1.1 - 1.205} \cong -9.838$$

This is a similar value to the previous step.

STEP 10.



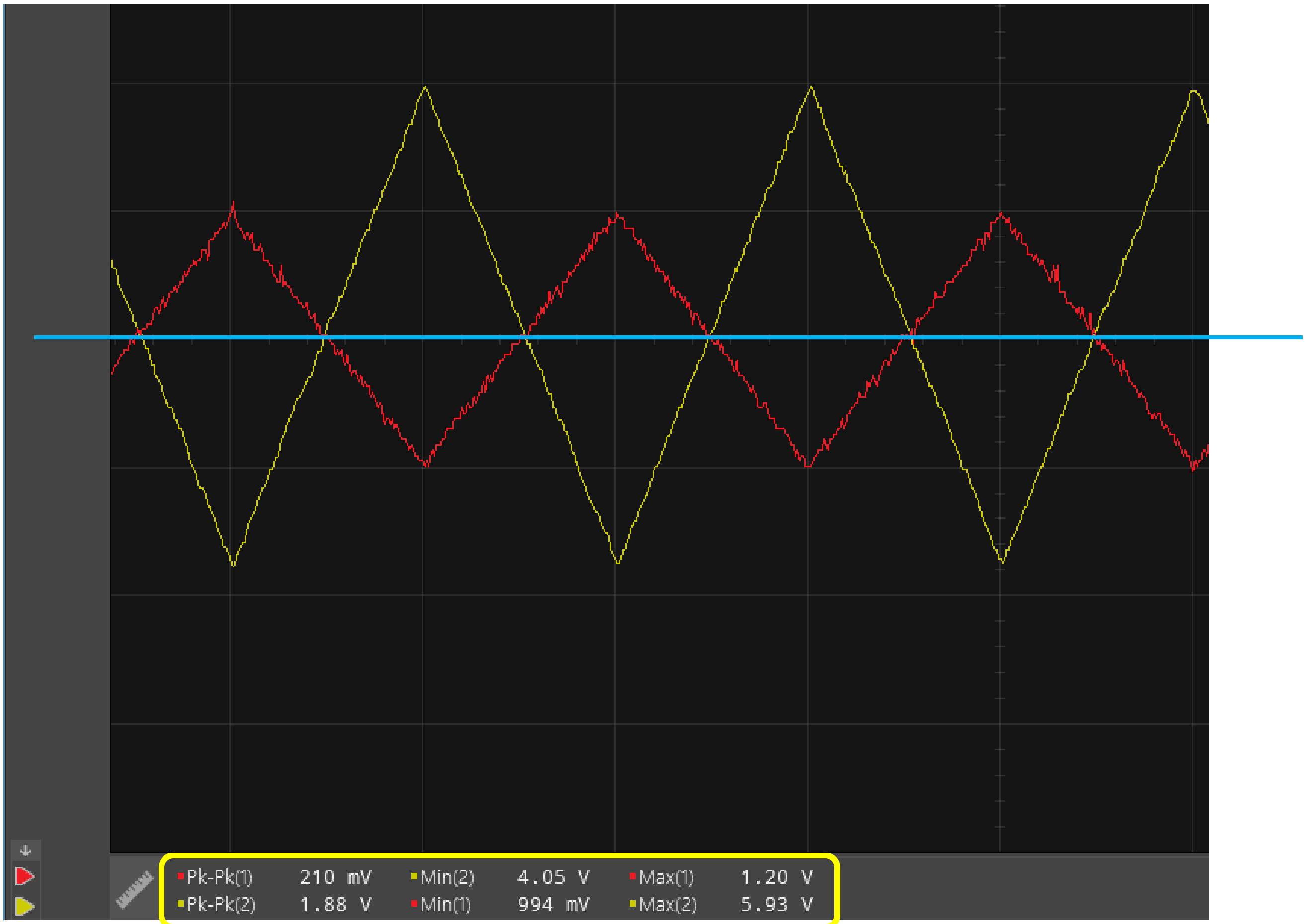

10) $C_1 = 1mF$

| $V_{BB}$ | $V_S$ | $V_B$ | $V_b$ | $V_C$ | $V_o$ |
|---|---|---|---|---|---|
| 1.154 | 200mV p-p | 1.048 | 210mV p-p | 4.999 | 1.82V p-p |

Small signal gain Vcp-p / Vbp-p : $\frac{1.88}{.210} \cong 8.95238$

This is again near the value in step 8

STEP 11.




The blue line indicates the DC bias, about 5v at the collector

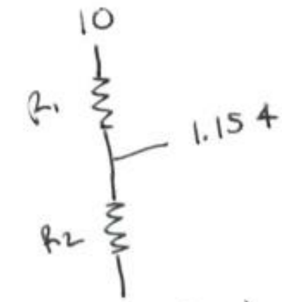
| | | | | | |
|---|---|---|---|---|---|
| Pk-Pk(1) | 210 mV | Min(2) | 4.05 V | Max(1) | 1.20 V |
| Pk-Pk(2) | 1.88 V | Min(1) | 994 mV | Max(2) | 5.93 V |

STEP 12.


Pk-Pk(1) 1.38 V
Min(2) 864 mV
Max(1) 1.67 V
Pk-Pk(2) 9.05 V
Min(1) 288 mV
Max(2) 9.92 V

STEP 13.

$$22k = \frac{R_2 R_1}{R_2 + R_1}$$




$$1.154 = \left(\frac{R_2}{R_2 + R_1}\right) 10$$

$$.1154 = \frac{R_2}{R_2 + R_1}$$

$$R_2 \boxed{R_1 = 190.641 \cdot 10^3} R_2$$

$$22k = (190.641 \cdot 10^3) \times \left(\frac{R_2}{R_2 + R_1}\right)$$

$$\frac{R_2 R_1}{R_2 + R_1} = (190.641 \cdot 10^3)\left(\frac{R_2}{R_2 + R_1}\right)$$

$$190.641 \cdot 10^3 = R_1$$

$$22k = \frac{R_1 R_2}{R_1 + R_2}$$

$$(22k)(R_1 + R_2) = R_1 R_2$$

$$(22k)(190.641k + R_2) = (190.641k)(R_2)$$

$$190.641k + R_2 = 8.66551 \cdot R_2$$

$$190.641k = 8.66551 \cdot R_2 - R_2$$

$$190.641k = (8.66551 - 1)R_2$$

$$\boxed{24.87k = R_2}$$

(Ran out of time to introduce these resistors to our circuit and test it)

# CONCLUSIONS

**Item 1.**

Considering the collector current of the transistor, comment on the agreement between the preliminary calculations of Step 1 and the SPICE simulations of Step 5. Describe how you arrived at the required value of $V_{BB}$ in Step 1, including the equations used and the assumptions made. What did SPICE do differently? (Hint: what values of $V_{BE}$ and $\beta$ did SPICE use?)

Seen in figures 2 and 3 of Appendix A, the model used a VBE (VJS) of .7. Beta was originally 150. Given these values we could first plug in our target current to Ic and Ie, using the given assumption of equivalence. We then use beta to find Ib. Knowing VBE we could then calculate Vb then finally VBB by adding the voltage drop of Rb to Vb.

**Item 2.**

Consider the effect of increasing the value of $\beta$ in the hand calculations and in the SPICE model (Steps 2 and 6). Was the effect on the collector current comparable? Comment on the sensitivity of the collector current to the value of $\beta$. How does this issue impact the design process, given that the $\beta$ of manufactured transistors varies significantly?

I'd say the results were comparable. Since the initial value of Ic wasn't exactly .5 mA as used in the prelab we'll need to compare percentages. The calculated change was 4.4% when beta was bumped by 50%. The simulated change is $\frac{559.3}{537.7} = 104.01\%$ so 4.01% change. Seems this will mainly just affect the extremes of the gain, the clipping points since Vc is changed

**Item 3.**

Consider the effect of increasing the temperature in both the preliminary calculations and in the SPICE model (Steps 3 and 7). Were the changes similar? Comment on the sensitivity of the collector current to the temperature. How does this issue impact the design process, given that the temperature of operation varies significantly?

This has a similar affect as Item 2 observed bu in the opposite direction. Higher temperatures mean a greater resistance overall, and lower current reflected this. I believe the circuits should be engineered with these factors in mind. Built to meet spec in the worst of reasonable conditions.

**Item 4.**

From the measured data of Step 9, calculate the beta of the transistor used.

$$i_c = \left(\frac{\beta}{\beta+1}\right) i_e \Rightarrow i_c = \left(\frac{\beta}{\beta+1}\right)(i_c + i_b)$$

$$i_c = \left(\frac{\beta}{\beta+1}\right)\left(i_c + \frac{V_{BB}-V_B}{R_B}\right)$$

$$.907m \cong \left(\frac{\beta}{\beta+1}\right)\left(.907m + \frac{3-1.608}{22k}\right)$$

$$.93478871 \cong \frac{\beta}{\beta+1}$$

$$(.93478871)^{-1} \cong \frac{\beta}{\beta}+\frac{1}{\beta}$$

$$((.93478871)^{-1}-1) \cong \frac{1}{\beta}$$

$$143.34 \cong \beta$$

**Item 5.**

In Steps 9 and 10, $V_{BB}$ was set to the same value (such that $I_C = 0.5\text{mA}$). In Step 9 the DC collector voltage was measured. In Step 10 the average value of the collector voltage was measured with an AC signal present. What conclusions can be drawn about the addition of a small signal to a biased circuit?

The small signal had virtually no affect on the circuit. VB and VC seemed unaffected.

**Item 6.**

Compare the small-signal gain $\frac{v_c}{v_b}$ measured in Step 10 to the slope of the transfer characteristic $\frac{\Delta V_C}{\Delta V_B}$ measured in Step 9. Explain their relationship.
How does the expression for the small-signal gain of a common-emitter amplifier with degeneration resemble the result of Step 4?

The small signal and large signal gain in the forward active region are very close. I believe this is because of the idea behind the small signal idea. Anything nonlinear in a small enough slice can be treated as linear.

**Item 7.**

Relate the shape of the clipped output waveform of Step 12 to the plot of $V_C$ generated in Step 8. How should the bias voltage at the collector be chosen for maximum symmetrical swing?

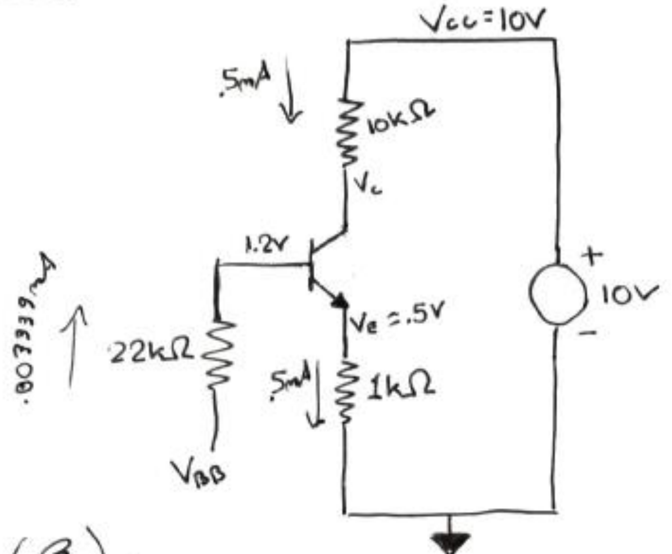
The top clipping point was roughly VCC and the bottom clipping point about one diode drop above 0V. It seems a good point for the collector voltage VC would be about half of VCC.

# APPENDIX A

**FIGURE 1**

Lab 7 Pre

1)

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4) $\frac{\Delta V_c}{\Delta V_B} = \boxed{\frac{V_{cc} - I_c R_c}{I_c R_E + V_{BE}}}$

FIGURE 2

```
 ****     BJT MODEL PARAMETERS

******************************************************************************



              X_Q3.model4
              NPN
       LEVEL    1
          IS  166.780000E-15
          EG    1.11
          BF  225
          NF    1.074
         VAF   78
         IKF     .5
         ISE    3.920000E-12
          NE    1.776
          BR    2.394
          NR    1.074
         VAR  500
          NC    1
         ISS    0
          RB     .676
         RBM     .676
          RE     .1
          RC     .654
         CJE   22.250000E-12
         VJE    1.333
         MJE     .522
         CJC    8.370000E-12
         VJC    1.333
         MJC     .518
        XCJC     .5
         CJS    0
         VJS     .7
         MJS     .5
          TF  454.400000E-12
         XTF   13.24
         VTF    4.83
         ITF     .2163
          TR  117.500000E-09
         XTB    2.34
          KF    0
          AF    1
          CN    2.42
           D     .87
```

**FIGURE 3**

```
****     BJT MODEL PARAMETERS


******************************************************************************




              X_Q3.model4
              NPN
       LEVEL    1
          IS  166.780000E-15
          EG    1.11
          BF  150
          NF    1.074
         VAF   78
         IKF     .5
         ISE    3.920000E-12
          NE    1.776
          BR    2.394
          NR    1.074
         VAR  500
          NC    1
         ISS    0
          RB     .676
         RBM     .676
          RE     .1
          RC     .654
         CJE   22.250000E-12
         VJE    1.333
         MJE     .522
         CJC    8.370000E-12
         VJC    1.333
         MJC     .518
        XCJC     .5
         CJS    0
         VJS     .7
         MJS     .5
          TF  454.400000E-12
         XTF   13.24
         VTF    4.83
         ITF     .2163
          TR  117.500000E-09
         XTB    2.34
          KF    0
          AF    1
          CN    2.42
           D     .87
```