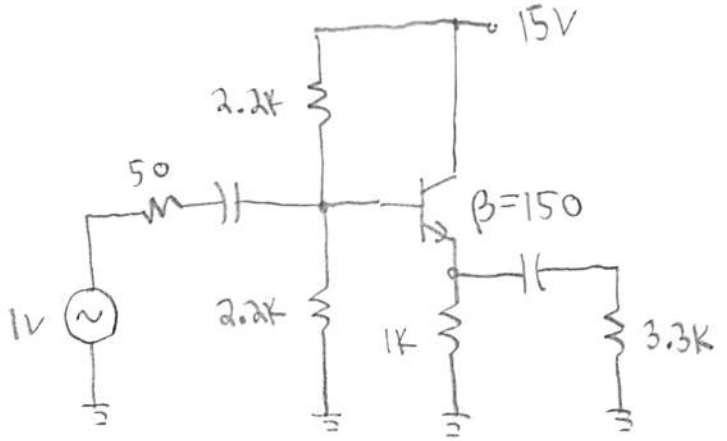
ECE 248
HW4 Solutions

Total = 100 pts

11.3 Emitter follower!

(+9) $\frac{V_{OUT}}{V_S} = \frac{R_{IN}}{R_{IN}+R_S}$ $\boxed{\frac{V_{OUT}}{V_{IN}}}$ $\uparrow$ $\frac{r_e}{r_e+r_e'}$



$r_e = 1000 \,//\, 3300 = \underline{767.4}$

$\rightarrow V_{BB} = 15\,\frac{2.2K}{4.4K} = 7.5V$

r_e'? Stiff divider? $2.2K \,//\, 2.2K = 1.1K$ ✓

$\frac{151}{100} \times 1K = 1.51K$

$I_{EQ} = \frac{7.5-0.7}{1K} = \underline{6.8mA}$

$r_e' = \frac{.026}{6.8\times10^{-3}} = \underline{3.82\Omega}$

$\Rightarrow \frac{V_{OUT}}{V_{IN}} = \frac{767.4}{767.4+3.82} = \underline{0.995}$

$R_{IN} = \underbrace{(2.2K \,//\, 2.2K)}_{1.1K} \,//\, \underbrace{[151(3.82+767.4)]}_{116.5K} = \underline{1.09K}$

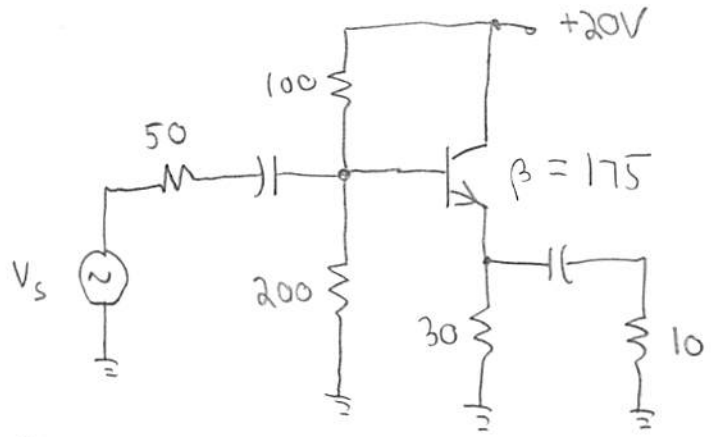
$\Rightarrow \frac{V_{OUT}}{V_S} = \frac{1090}{1090+50} \times .995 = \boxed{0.95}$

11.8 (+9)

$$\frac{V_{OUT}}{V_S} = \frac{R_{IN}}{R_{IN}+R_S} \times \frac{r_e}{r_e + r_e'}$$

$r_e = 30 // 10 = \underline{\underline{7.5}}$

r_e' ?



Stiff divider?

$100 // 200 = 67$

$\frac{176}{100}\,30 = 52.8$

NOT stiff, but close enough $\rightarrow V_{BB} = 20\,\frac{200}{300} = \underline{\underline{13.33}}$

$I_{EQ} = \frac{13.33 - 0.7}{30} = 0.42A$

$r_e' = \frac{.026V}{.42A} = \underline{\underline{.062\Omega}}$

$R_{IN} = \underbrace{(100//200)}_{67} // \underbrace{[176(.062+7.5)]}_{1331}$

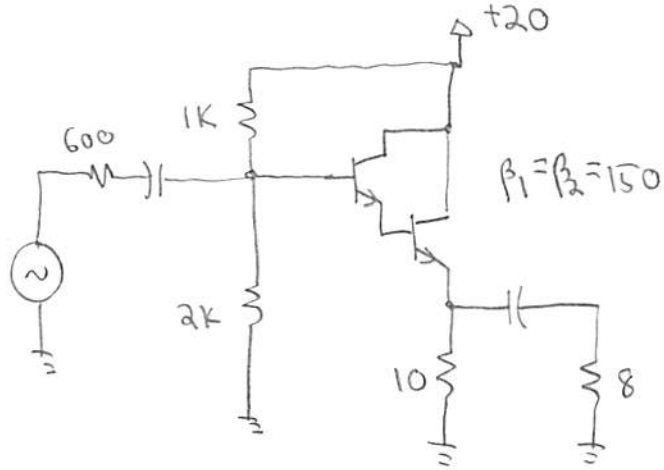
$= \underline{\underline{63.8\Omega}}$

$\Rightarrow \frac{V_{OUT}}{V_S} = \frac{63.8}{63.8+50} \times \frac{7.5}{7.5+.062} = \boxed{0.556}$

11.17 (+9)

$R_{base} = (150 \times 150 + 1)(r_e' + r_e)$

? ↗ ↑ $10 // 8 = 4.44$



- Stiff divider?

$1K // 2K = 667$

$\frac{(22501)}{100}\,10 = 2250$ ✓

$V_{BB} = 20\,\frac{2K}{3K} = 13.33V$

$I_{EQ} = \frac{13.33 - 1.4}{10} = 1.19A \Rightarrow r_e' = \frac{.026}{1.19}A$

$= \underline{\underline{.022\Omega}}$

$R_{base} = 22501\,(.022 + 4.44)$

$= \boxed{100.4K}$

11.XX For previous problem, $\frac{4.44}{4.44+.022} = \underline{0.995}$

(+9)

$$\frac{V_{OUT}}{V_S} = \frac{R_{IN}}{R_{IN}+R_S}\boxed{\frac{r_e}{r_e+r_e'}}$$

$$R_{IN} = (1K // 2K) // \underbrace{R_{base}}_{100,4K} = \underbrace{.667K}_{} = \underline{0.663K}$$

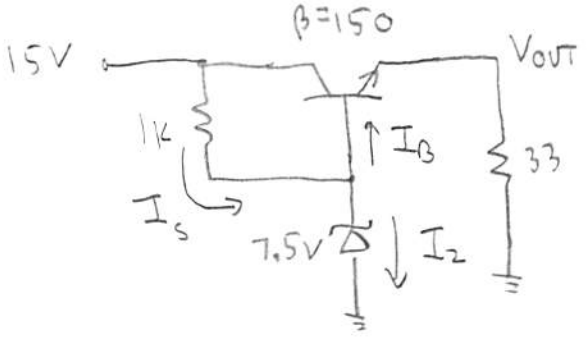
$$= \frac{663}{663+600} \times .995 = \boxed{0.52}$$

11.19

(+5)

$V_{OUT} = V_Z - 0.7$

$= \boxed{6.8V}$



$I_Z = I_S - I_B$

$= \underbrace{\frac{15-7.5}{1K}}_{7.5mA} - \underbrace{\frac{1}{151} \times \frac{6.8V}{.033K}}_{1.36mA}$

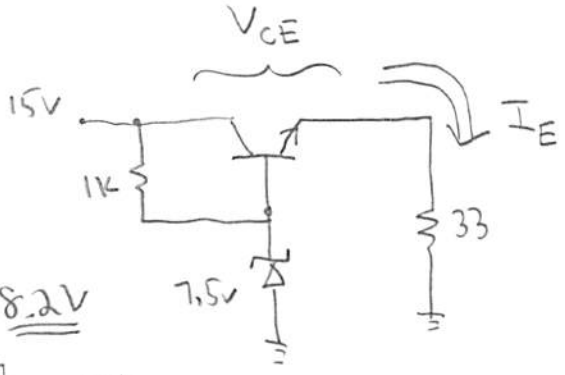
$= \boxed{6.14\ mA}$

11.28

(+5)

$P = I_E V_{CE}$

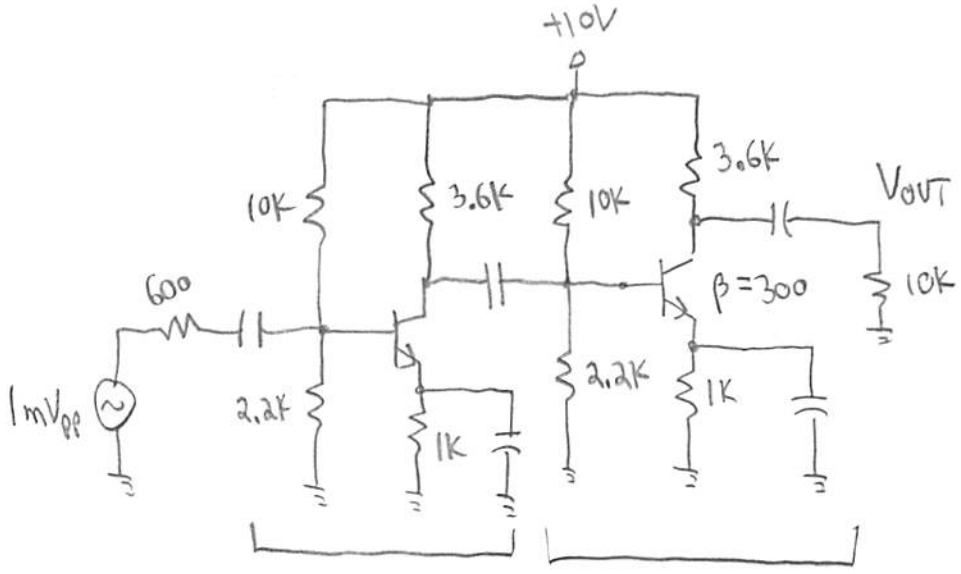
$I_E = \frac{7.5-0.7}{33} = \underline{0.21A}$



$V_{CE} = V_C - V_E = 15 - (7.5-0.7) = \underline{8.2V}$

$P = (0.21A)(8.2V) = \boxed{1.72W}$ ← Gets pretty warm!

10.9 (+9)



- $V_{OUT} = \frac{V_{OUT}}{V_S} V_S$

$= \frac{R_{IN}}{R_{IN}+R_S} A_1 A_2 V_S$

- Start with A_2:

Stiff divider? $10K // 2.2K = 1.8K$, $\frac{301}{100} \times 1K = 3.01K$ ✓

$A_1 = -\alpha \frac{R_C // R_{IN2}}{r_{e1}'}$ $A_2 = -\alpha \frac{R_C // R_L}{r_{e2}'}$

$\rightarrow V_{BB} = 10 \frac{2.2K}{12.2K} = 1.8V \Rightarrow I_{EQ} = \frac{1.8-0.7}{1K} = \underline{1.1mA} \Rightarrow r_{e2}' = \frac{.026}{1.1mA} = \underline{.0236K}$

$\rightarrow r_{C2} = 3.6K // 10K = \underline{2.65K}$

$\Rightarrow A_2 = -\frac{300}{301} \cdot \frac{2.65K}{.0236K} = \underline{-111.9}$, $R_{IN2} = (10K // 2.2K) // 301(.0236K)$

$= \underline{1.44K}$

- Now compute A_1:

Stiff divider? YES (same circuit as A_2)

$\rightarrow r_{e1}' = r_{e2}' = \underline{.0236K}$

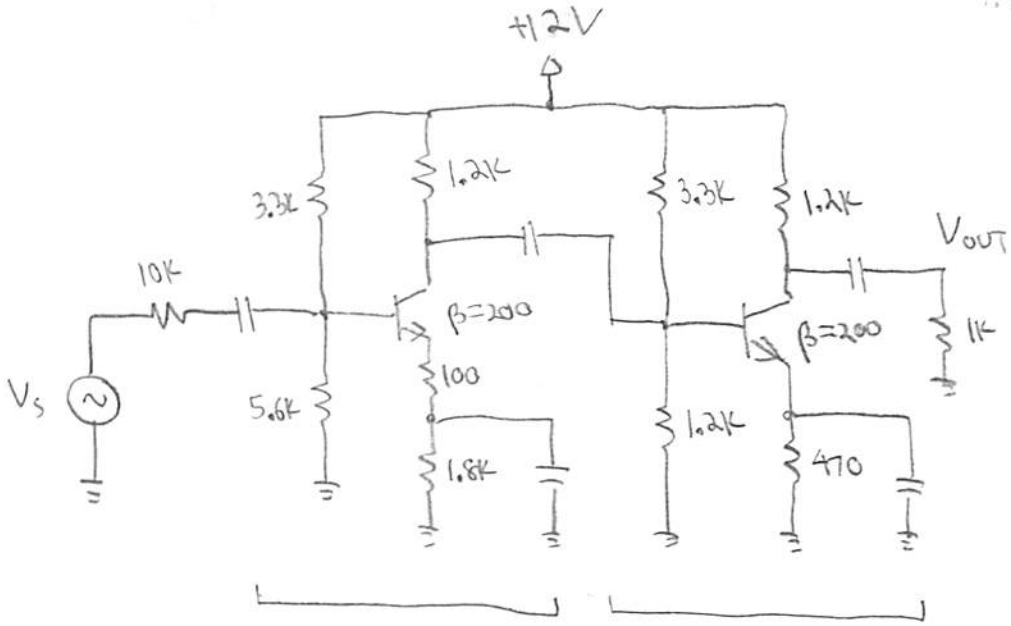
$\rightarrow r_{C1} = 3.6K // 1.44K = \underline{1.03K}$

$\Rightarrow A_1 = -\frac{300}{301} \frac{1.03K}{.0236K} = \underline{-43.5}$ $R_{IN1} = R_{IN2} = \underline{1.44K}$ (same circuit)

SO, $V_{OUT} = \frac{1.44K}{1.44K + 0.6K} (-43.5)(-111.9) \cdot 1mV_{pp} = 3436 mV_{pp}$

$= \boxed{3.44 V_{pp}}$

10.XX (+9)



→ start with A_2

- stiff divider?

$3.3K \,//\, 1.2K = 0.88K$

$\frac{201}{100}\,.47K = 0.94K$ ✓

- $V_{BB} = 12\,\frac{1.2K}{1.2K+3.3K} = 3.2V$

$I_{EQ} = \frac{3.2-0.7}{.47K} = \underline{5.32\,mA}$

$r_{e2}' = \frac{.026V}{5.32mA} = \underline{.0049\,K}$

- $r_c = 1.2K \,//\, 1K = \underline{0.545K}$

- $A_2 = -\frac{200}{201}\,\frac{0.545K}{.0049K} = \underline{-110.7}$ ✓

$A_1 = -\alpha\,\frac{R_c \,//\, R_{IN2}}{r_{e1}' + R_e}$ $\qquad A_2 = -\alpha\,\frac{R_c \,//\, R_L}{r_{e2}'}$

$R_{IN2} = (3.3K \,//\, 1.2K) \,//\, (201)(.0049K)$

$= \underline{0.465K}$

→ Compute A_1

- stiff divider? $3.3K \,//\, 5.6K = 2.08K$

$\frac{201}{100}\,1.9K = 3.82K$ ✓

- $V_{BB} = 12\,\frac{5.6K}{5.6K+3.3K} = 7.55V \rightarrow I_{EQ} = \frac{7.55-0.7}{1.9K} = \underline{3.61\,mA}$

$r_{e1}' = \frac{.026V}{3.61mA} = \underline{.0072\,K}$

- $r_c = 1.2K \,//\, 0.465K = \underline{0.335K}$

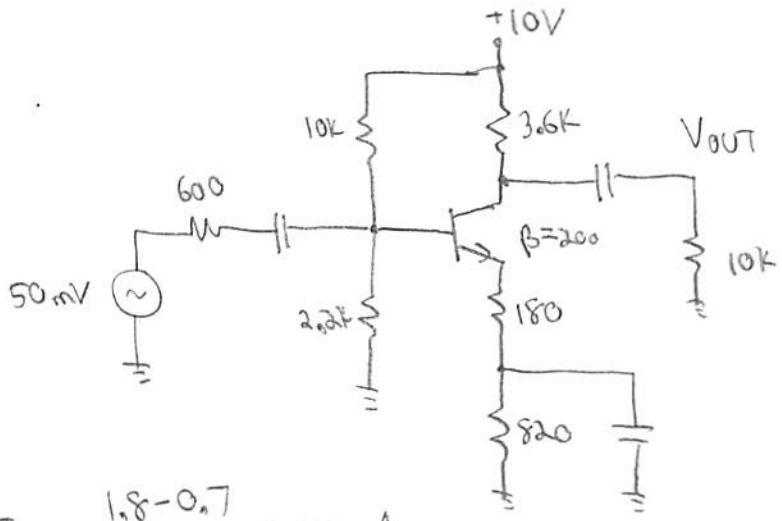
- $A_1 = -\frac{200}{201}\,\frac{0.335K}{.0072K + 0.1K} = \underline{-3.1}$

$R_{IN} = (3.3K \,//\, 5.6K) \,//\, 201\,(.0072K + .1K)$

$= \underline{1.89\,K}$

$$\Rightarrow \frac{V_{OUT}}{V_S} = \frac{R_{IN}}{R_{IN}+R_S} A_1 A_2 = \frac{1.89K}{1.89+10K}(-3.1)(-110.7) = \boxed{54.5}$$

10.9 (+9)



- stiff divider?

$10K \,//\, 2.2K = 1.8K$

$\frac{201}{100} \times 1K = 2.01K$ ✓

- $V_{BB} = 10 \frac{2.2K}{2.2K+10K} = 1.8V \Rightarrow I_{EQ} = \frac{1.8-0.7}{1K} = \underline{1.1mA}$

$r_e' = \frac{.026V}{1.1mA} = \underline{.0236K}$

$\alpha = \frac{200}{201} = .995$

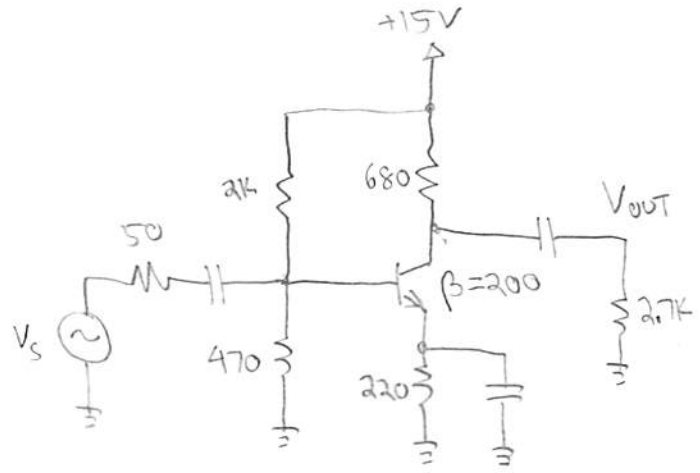
- $r_c = 3.6K \,//\, 10K = 2.65K$

- $A = -\alpha \frac{r_c}{r_e'+R_e} = -0.995 \frac{2.65K}{(.0236K+.18K)} = \underline{-12.95}$

- $R_{IN} = (10K \,//\, 2.2K) \,//\, \underbrace{201(.0236K+.18K)}_{40.9K} = \underline{1.73K}$

$$\Rightarrow V_{OUT} = 50mV \frac{1.73K}{1.73K+.6K} \times (-12.95) = \boxed{-481mV}$$

12.3 (+9)



STEP 1 Q-Point

- stiff divider? $2K // .47K = 0.38K$; $\frac{201}{100}(.22K) = 0.44K$ ✓
- $V_{BB} = 15\,\frac{.47K}{.47K + 2K} = 2.85V$

$\rightarrow I_{EQ} = \frac{2.85 - 0.7}{220} = \boxed{.0098A}$

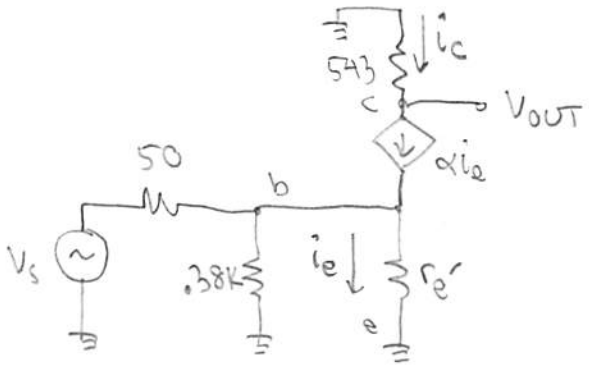
$\alpha = \frac{200}{201} = .995$

- $V_c = 15 - 0.995\,(.0098A)(680\Omega) = 8.37V$

  $V_E = 2.15V$

$V_{CEQ} = 8.37 - 2.15 = \boxed{6.22V}$

STEP 2 AC analysis



$r_c = 680 // 2700 = \underline{543\Omega}$

- $V_{OUT} = -i_c r_c = -\alpha i_e r_c$

$$\boxed{i_e = -\frac{V_{OUT}}{\alpha r_c}}$$

- $V_{ce} = V_c - V_e = V_{OUT} - 0 = \boxed{V_{OUT}}$

STEP 3 Cut-off vs Saturation

Cut-off: $i_e = -I_{EQ} \rightarrow -\frac{V_{OUT}}{\alpha r_c} = -I_{EQ} \rightarrow$ Max $V_{OUT} = \alpha I_{EQ} r_c$

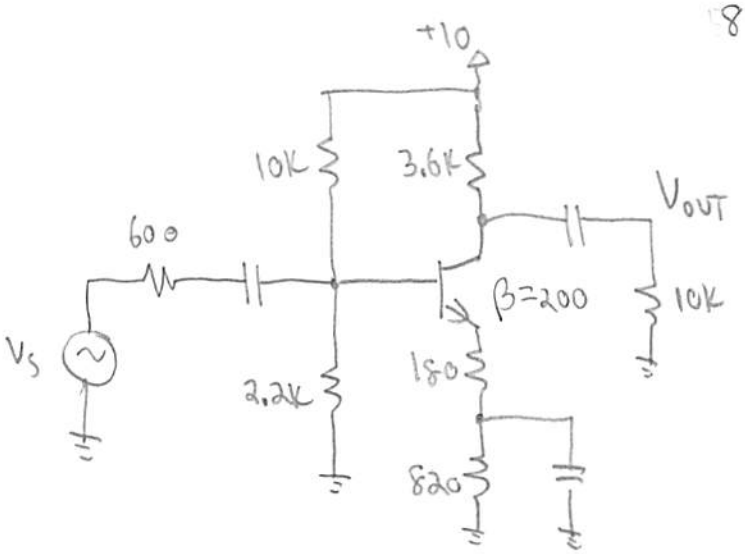
$= .995\,(.0098A)(543\Omega)$

$= \underline{5.3V} \leftarrow$ MP

Saturation: $V_{ce} = -V_{CEQ} \rightarrow V_{OUT} = -V_{CEQ} \rightarrow$ Max $V_{OUT} = \underline{-6.22V}$

$\boxed{MPP = 10.6V_{pp}}$

10.2 (+9)



STEP 1 Q-Point

- Stiff divider? $10K // 2.2K = 1.8K$

  $\frac{201}{100} \times 1K = 2.01K$ ✓

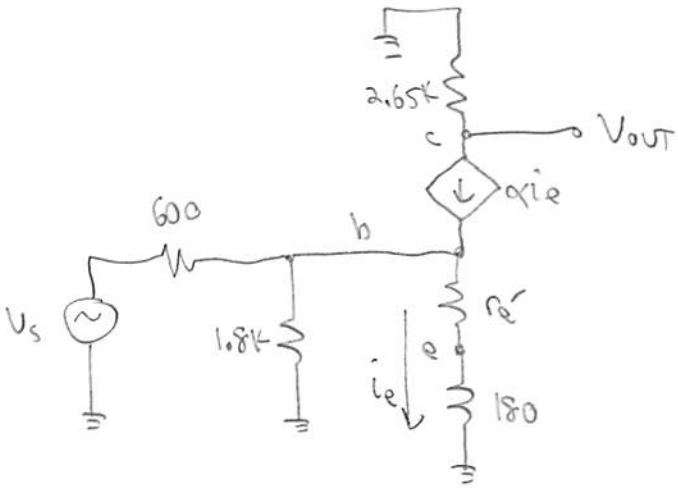
- $V_{BB} = 10 \frac{2.2K}{2.2K + 10K} = 1.8V$

$I_{EQ} = \frac{1.8 - 0.7}{1K} = \boxed{1.1mA}$

$\alpha = \frac{200}{201} = 0.995$

- $V_C = 10 - .995\,(1.1mA)(3.6K) = 6.06V$

$V_{CEQ} = 6.06 - 1.1V = \boxed{4.96V}$



STEP 2 AC analysis

$r_c = 3.6K // 10K = 2.65K$

- $v_{out} = -i_c r_c = -\alpha i_e r_c$

$\boxed{i_e = -\frac{v_{out}}{\alpha r_c}}$

- $v_{ce} = v_c - v_e = v_{out} - i_e R_e = v_{out} - \left(-\frac{v_{out}}{\alpha r_c}\right) R_e = \boxed{v_{out}\left(1 + \frac{R_e}{\alpha r_c}\right)}$

STEP 3 Cut-off vs. Saturation

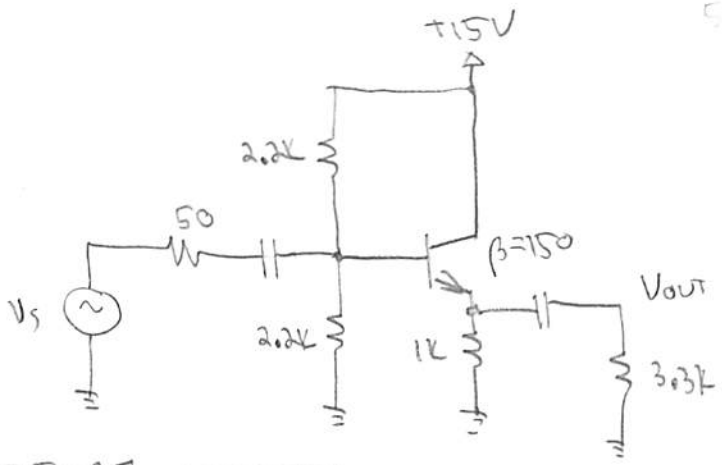
Cut-off: $i_e = -I_{EQ} \rightarrow \frac{-v_{out}}{\alpha r_c} = -I_{EQ} \rightarrow v_{out} = \alpha I_{EQ} r_c = .995\,(1.1mA)(2.65K) = \underline{2.9V}$

Saturation: $v_{ce} = -V_{CEQ} \rightarrow v_{out}\left(1 + \frac{R_e}{\alpha r_c}\right) = -V_{CEQ}$

$v_{out} = \frac{-4.96V}{1 + \frac{.18K}{.995 \times 2.65K}} = \underline{-4.64V}$

$\boxed{MP = 2.9V}$

11.x (+9)



STEP 1 Q-Point

- stiff divider? $2.2K \,//\, 2.2K = 1.1K$ ✓

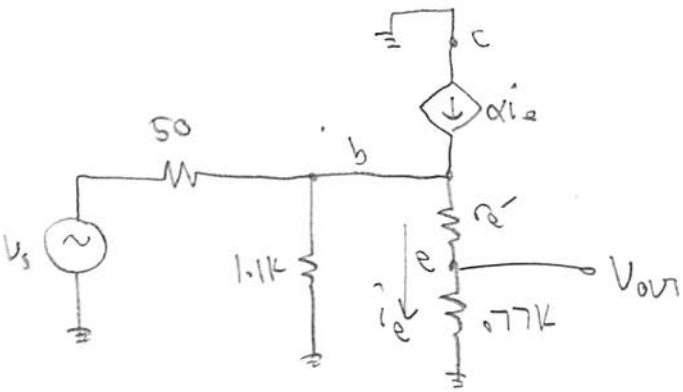
  $\frac{151}{100} \times 1K = 1.51K$ ✓

- $V_{BB} = 15 \cdot \frac{2.2K}{2.2K + 2.2K} = 7.5V \rightarrow I_{EQ} = \frac{7.5 - 0.7}{1K} = \boxed{6.8\,mA}$

- $V_{CEQ} = V_C - V_E = 15 - 6.8V = \boxed{8.2V}$

STEP 2 AC analysis

$r_e = 1K \,//\, 3.3K = 0.77K$



- $V_{out} = i_e r_e \rightarrow \boxed{i_e = \frac{V_{out}}{r_e}}$

- $V_{ce} = V_c - V_e = 0 - V_{out} = \boxed{-V_{out}}$

STEP 3 Cut-off vs. saturation

Cutoff: $i_e = -I_{EQ} \Rightarrow \frac{V_{out}}{r_e} = -I_{EQ}$

Max $V_{out} = -(6.8\,mA)(0.77K) = \underline{-5.24V}$ ←

saturation: $v_{ce} = -V_{CEQ} \Rightarrow -v_{out} = -V_{CEQ}$

Max $v_{out} = \underline{8.2V}$

$\boxed{MP = 5.24V}$