EE210A Mid-Semester Exam <u>Solution</u>

Date – 22.02.2019

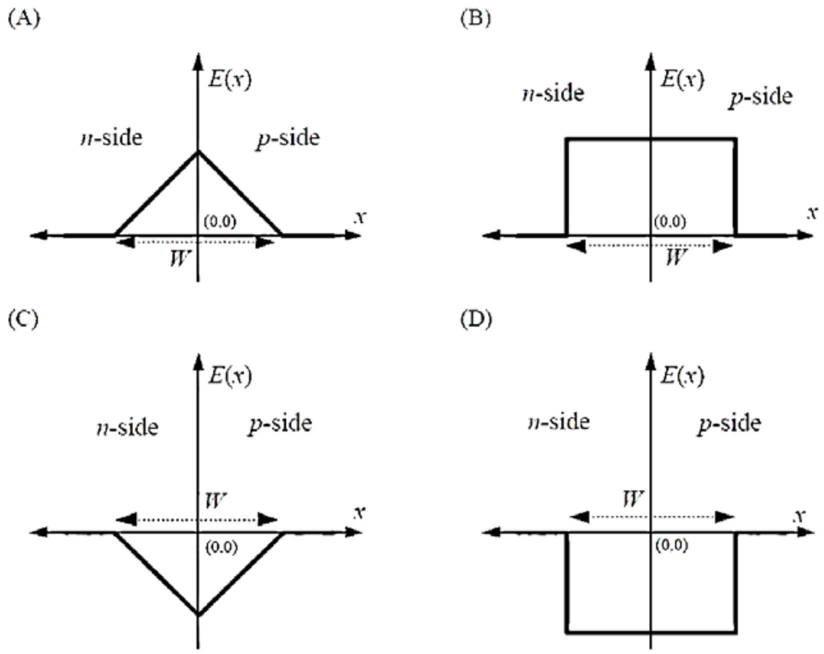
Name: ______________________________ **Roll No.:** _______________ **Section:** ________

Question No.	Max. Marks	Marks Obtained
Q1	3	
Q2	3	
Q3	3	
Q4	3	
Q5	3	
Q6	6	
Q7	3	
Q8	3	
Q9	3	
Q10	3	
Q11	5	
Q12	5	
Q13	10	
Q14	10	
Q15	17	
Total	80	

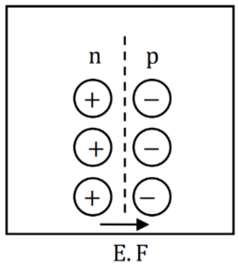
Rough Work

Part A: Diode – Device and Circuits

Q1. An abrupt *p*-*n* junction (located at $x = 0$) is uniformly doped on both p and n sides. The width of the depletion region is W and the electric field variation in the x-direction is $E(x)$. Which of the following figures represents the electric field profile near the *p*-*n* junction? [3]



Sol: We know that electric field is maximum at middle of the junction, so options (B), (D) can be eliminated. In any p-n junction, Electric field is always from n to p (since Vn > Vp).



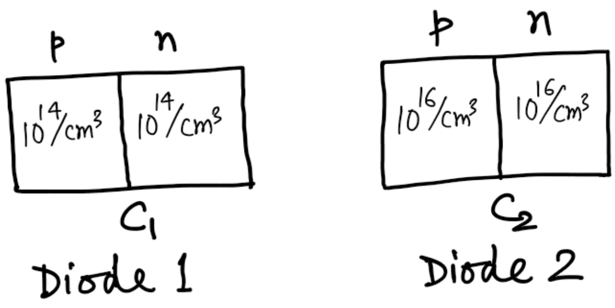
We know $E = -\nabla V$. In option (A) we have,

$$V_n - V_p = \int E.dx = +ve\ (Electric\ field\ is\ positive)$$

$$\text{Thus, } V_n > V_p$$

Q2. As shown, two silicon abrupt *p*-*n* junction diodes are fabricated with uniform doping concentrations. Assuming that the reverse bias voltage is $\gg V_{\mathrm{bi}}$ of the diodes, the ratio C_2/C_1 of their reverse bias capacitances for the same applied reverse bias, is _______. [3]

Sol: We know that,



$$C = \frac{\epsilon A}{W}$$

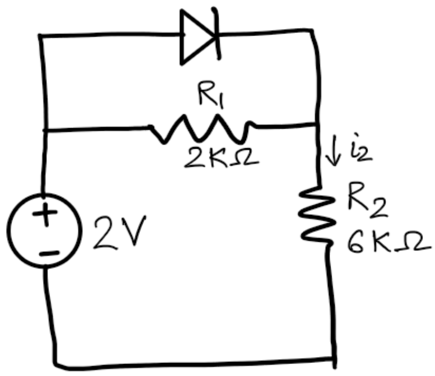
For an abrupt *p*-*n* junction, we have

$$W = \sqrt{\frac{2\epsilon * (V_{bi} + V_R) * \left(\frac{N_A + N_D}{N_D N_D}\right)}{q}}$$

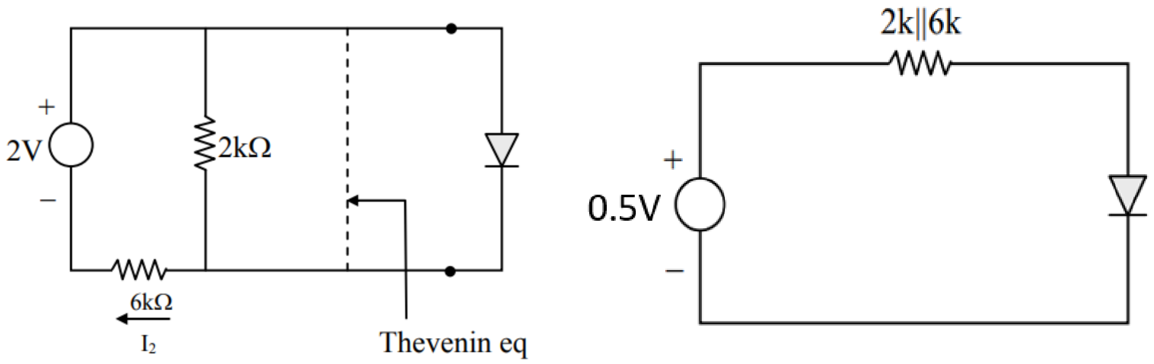
As $V_R \gg V_{bi}$,

$$\frac{C_2}{C_1} = \sqrt{\frac{\frac{N_{A2}N_{D2}}{(N_{A2} + N_{D2})}}{\frac{N_{A1}N_{D1}}{(N_{A1} + N_{D1})}}} = \sqrt{\frac{10^{16}}{10^{14}}} = 10$$

Q3. Assume that the diode in the figure has $V_{on} = 0.7\ V$, but is otherwise ideal. The magnitude of the current i_2 (in mA) is equal to ________. [3]



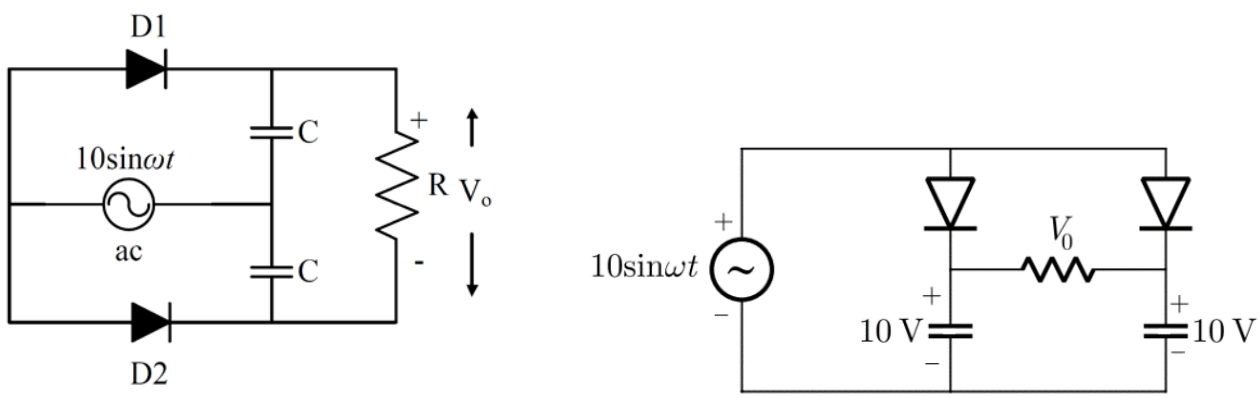
Sol.:



Diode needs at least 0.7V to turn on. With 0.5V at the terminals, diode will remain off. Thus,

$$I_2 = \frac{2V}{2k + 6k} = 0.25\ mA$$

Q4. The diodes D_1 and D_2 in the figure are ideal, and the capacitors are identical. The product RC is very large compared to the time period of the ac voltage. Assuming that the diodes do not breakdown in the reverse bias, the output voltage V_0 (in volt) at the steady state is __________.
[3]

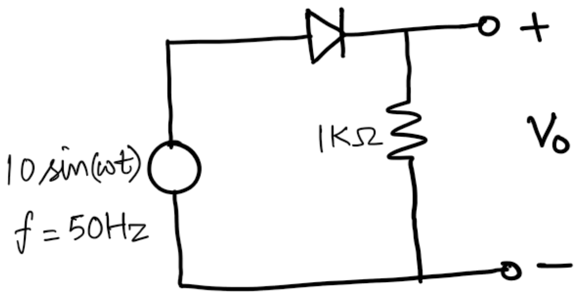


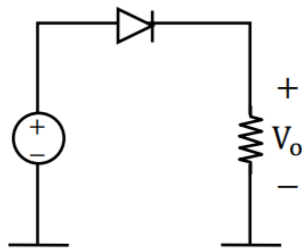
Sol: Since $\tau \gg T$, the circuit may be reduced as on the right side.
Diodes are ideal therefore during the positive half cycle of input, we have

$$V_0 = 10 - 10 = 0V$$

Also, for the negative half cycle of input diodes are reverse biased, therefore, $V_0 = 0V$.

Q5. The output V_0 of the diode circuit shown in the figure below is connected to an averaging DC voltmeter. The reading on the DC voltmeter in Volts, neglecting the voltage drop across the diode, is __________. [3]

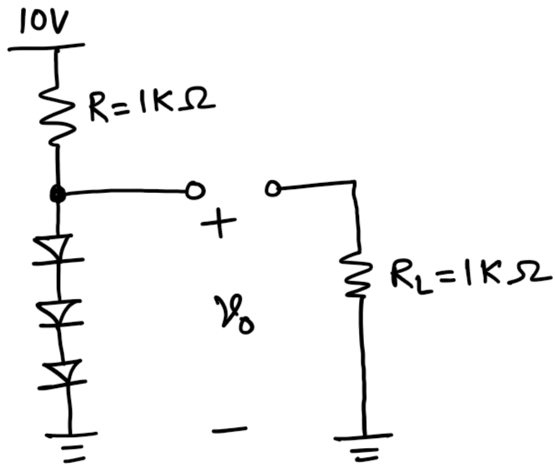




Sol: The circuit can be reduced as on the right side. This is a half wave rectifier. The average value of output voltage is

$$V_0 = \frac{1}{T}\int_0^{\frac{T}{2}} V_{peak} \sin \omega t \ dt = \frac{V_{peak}}{\pi} = \frac{10}{\pi} = 3.18V$$

Q6. Consider the circuit shown. A string of three diodes is used to provide a constant voltage of about 2.1 V. Calculate the percentage change in the regulated output voltage, (a) if there is a change of ±10% in the supply voltage, and (b) if supply voltage is fixed but a 1-kΩ load resistance is connected at the output. [6]



Sol.: The nominal value of current in the diode string is given by

$$I = \frac{10 - 2.1}{1} = 7.9 \, mA$$

Thus, each diode will have an incremental resistance of

$$r_d = \frac{V_T}{I} = \frac{26}{7.9} \cong 3.3 \, \Omega$$

The three diodes in series will have a total incremental resistance of

$$r = 3r_d = 9.9 \, \Omega$$

(a) This resistance, along with the resistance R, forms a voltage divider whose ratio can be used to calculate the change in output voltage due to ±10% (i.e., ±1V) change in supply voltage.

$$\Delta v_o = \pm 1V * \frac{r}{r + R} = \pm 9.8mV$$

That is corresponding to the ±1 V (±10%) change in supply voltage, the output voltage will change by ±9.8mV or $\frac{9.8mV}{2.1V} * 100 \cong \pm 0.5\%$. This implies a change of ~3.3mV (<<V_T) per diode, thus our use of the small signal model is justified.

(b) When a load resistance of 1kΩ is connected across the diode string, it draws a current of approximately 2.1mA. Thus the current in diodes decreases by 2.1mA, resulting in a decrease in voltage across the diode given by

$$\Delta v_o = -2.1V * r = -2.1 * 9.9 \cong -21 \, mV$$

Percentage change in the output voltage is $\frac{21mV}{2.1V} * 100 \cong 1\%$. Again, our small signal model is justified as change across each diode is ~7mV.

Part B: BJT – Device and Circuits

Q7. An *n-p-n* BJT is operating in the forward active region. If the reverse bias across the base-collector junction is increased, then [3]

a) the effective base width increases and common-emitter current gain increases
b) the effective base width increases and common-emitter current gain decreases
c) the effective base width decreases and common-emitter current gain increases
d) the effective base width decreases and common-emitter current gain decreases

Sol: If reverse bias across the base–collector junction increases ⇒ Effective Base width decreases. This results in decrease in the recombination in the base causing increase in β.

Q8. The Ebers-Moll model of a BJT is valid [3]

a) only in active mode
b) only in active and saturation modes
c) only in active and cut-off modes
d) in active, saturation and cut-off modes

Sol. (d).

Q9. Which one of the following statements is correct about an ac-coupled common-emitter amplifier operating in the mid-band region? [3]

a) The device capacitances behave like open circuits, whereas coupling/bypass capacitances behave like short circuits.
b) The device capacitances and coupling/bypass capacitances behave like open circuits.
c) The device capacitances and coupling/bypass capacitances behave like short circuits.
d) The device capacitances behave like short circuits, whereas coupling/bypass capacitances behave like open circuits.

Sol.: (a).

Q10. Consider the circuit shown below. Assume base-to-emitter voltage $V_{BE} = 0.7V$ and common-base current gain (α) of the transistor is unity. Determine the value of collector-emitter voltage V_{CE} (in volts). [3]

Sol.

$$\alpha = 1 \Rightarrow \beta = \infty \Rightarrow I_B = 0$$

$$V_B = \frac{18 * 16}{16 + 44} = 4.8V$$

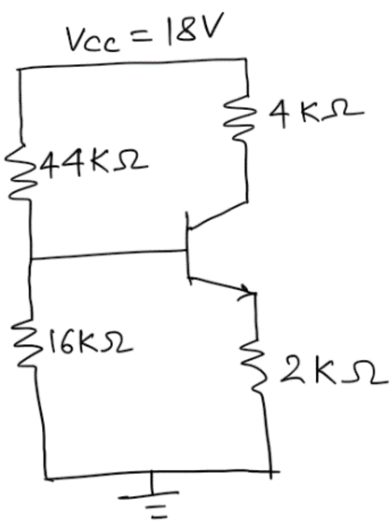
$$V_E = 4.8 - 0.7 = 4.1V$$

$$I_E = \frac{4.1}{2K} = 2.05mA$$

$$I_C = I_E = 2.05mA$$

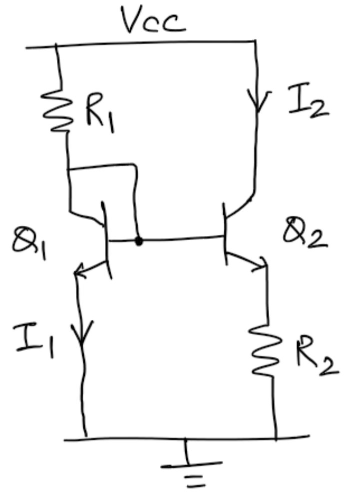
$$V_C = 18 - (4k * 2.05m) = 9.8V$$

$$V_{CE} = 9.8 - 4.1 = 5.7V$$



Q11. The resistor R_1 in the circuit shown below has been adjusted so that $I_1 = 1$ mA. The transistors Q_1 and Q_2 are perfectly matched and have very high current gain. The supply voltage V_{CC} is 6 V. Determine the value of R_2 (in Ω) for which I_2=100 μA. [5]

Sol:



$$I_c = I_s\, e^{\frac{V_{be}}{V_T}}$$

$$V_{be1} = V_T \ln \frac{I_1}{I_s}$$

$$V_{be2} = V_T \ln \frac{I_2}{I_s}$$

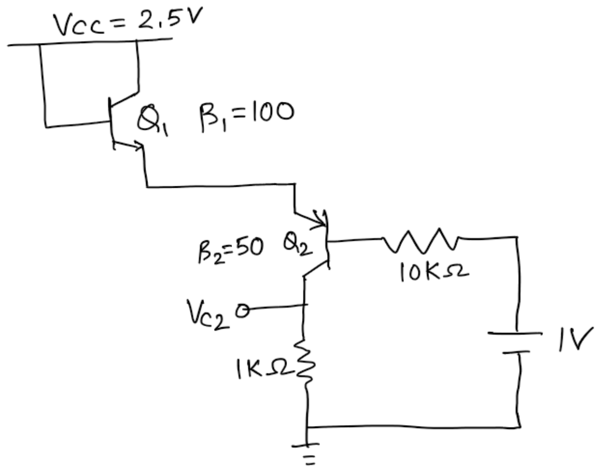
From the circuit,

$$V_{be1} = V_{be2} + I_2 R_2$$

$$R_2 = \frac{V_{be1} - V_{be2}}{I_2} = \frac{V_T \ln \frac{I_1}{I_2}}{I_2} = 598.67\, \Omega$$

Q12. Consider the circuit shown in the figure. Determine the value of the dc voltage V_{C2} (in volt). [5]

Sol:



$$V_{E1} = 2.5 - 0.7 = 1.8V$$

$$V_{B2} = V_{E1} - V_{EB2} = 1.8 - 0.7 = 1.1V$$

$$I_{B2} = \frac{V_{B2} - 1}{10K} = \frac{1.1 - 1}{10K} = 10\mu A$$

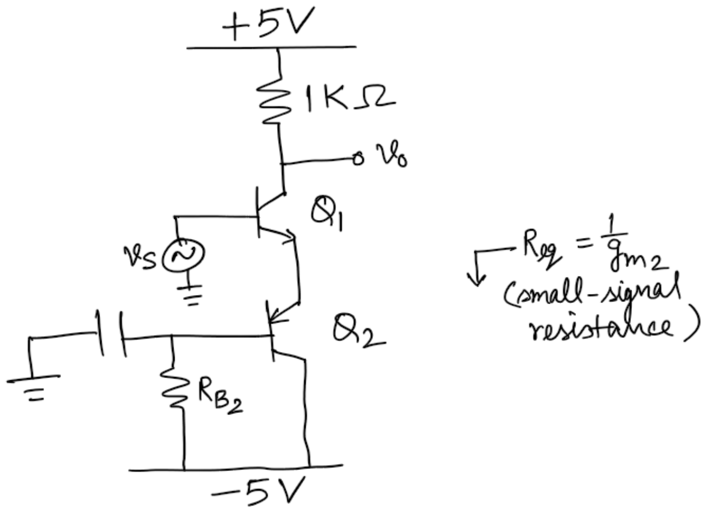
$$I_{C2} = \beta I_{B2} = 50 * 10\mu A = 0.5mA$$

$$V_{C2} = I_{C2} * 1k = 0.5V$$

Q13. In the circuit shown below, transistors Q_1 and Q_2 are biased at a collector current 2.6 mA. Assuming that transistor current gains are large, determine the magnitude of voltage gain ${}^{v_0}/_{v_s}$ in the mid-band frequency range. [10]

Sol.

We know that,



$$A_v = \frac{v_o}{v_s}$$

$$= -\frac{g_{m1} R_c}{1 + g_{m1} R_{eq}}$$

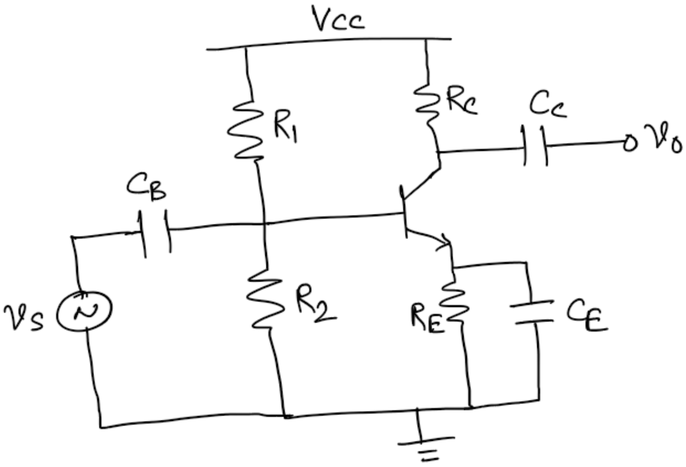
From the figure we have,

$$g_{m1} = g_{m2} = 1/R_{eq} = \frac{I_c}{V_T} = \frac{2.6mA}{26mV} = 10^{-1}$$

$$\Rightarrow A_v = -\frac{g_{m1} R_c}{2} = -50$$

Q14. For the amplifier shown below, I_C=1.3 mA, R_C =2kΩ, R_E=500Ω, V_T=26 mV, β =100, V_{CC}= 15V, $v_s = 0.01\sin(\omega t)$ V and C_B and C_E equal to 10µF.

(a) What is the small-signal voltage gain (A_V), from source to load? [4]
(b) What is the approximate value of A_v if C_E is removed? [4]
(c) What will be the approximate value of v_o if C_B is short-circuited? [2]



Sol.:

$$I_C = 1.3mA, g_m = \frac{I_C}{V_T} = 0.05\Omega^{-1}$$

$$V_{CE} = 15 - 1.3mA * 2.5k = 11.75V > 0.2V$$

(a) R_E is short circuit in small signal model.

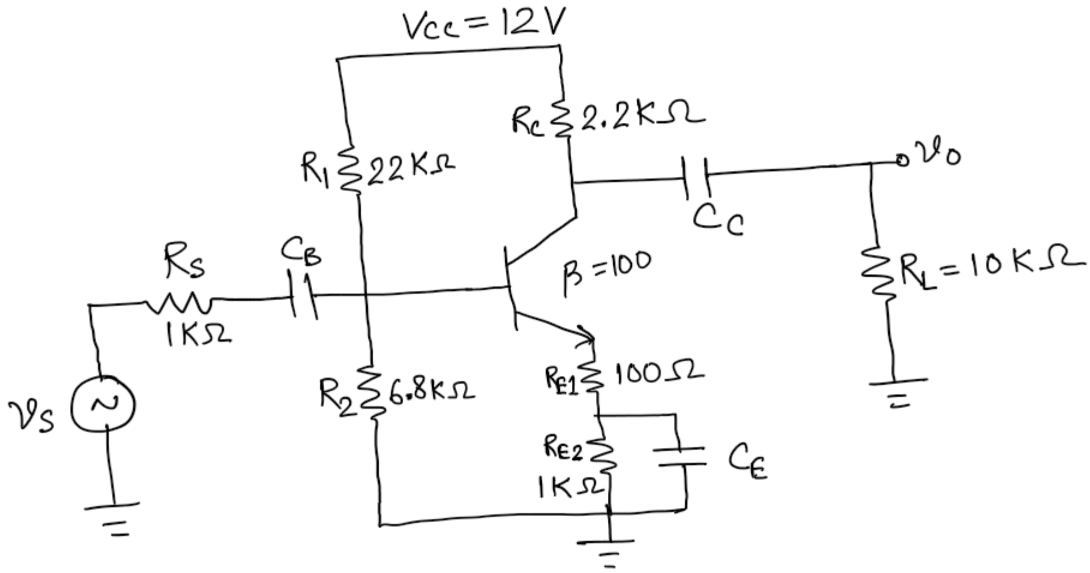
$$A_v = -g_m R_c = -100$$

(b) When C_E is removed, R_E will degrade the gain.

$$A_v = -\frac{g_m R_c}{1 + g_m R_E} = -\frac{100}{1 + 0.05 * 500} = -3.85$$

(c) If C_B is short circuited then no DC biasing at the base. $v_0 = 0$.

Q15. Design coupling and bypass capacitances to achieve dominant pole frequency of 1kHz. [17]



Sol.:

$$V_B = \frac{6.8}{6.8 + 22} * 12 = 2.83V$$
$$V_E = 2.83 - 0.7 = 2.13V$$
$$I_E = \frac{V_E}{R_{E1} + R_{E2}} = \frac{2.13}{1k + 100} = 1.94mA \cong I_C$$
$$V_{CE} = V_{CC} - I_C(R_C + R_{E1} + R_{E2}) = 12 - 1.94mA * (2.2k + 100 + 1k) = 5.6V > 0.2V$$
$$g_m = \frac{I_C}{V_T} = \frac{1.94mA}{26mV} = 0.075\Omega^{-1}$$
$$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.075} = 1.33k\Omega$$

Let's calculate cutoff frequency due to each capacitor separately. Make other capacitors short circuit. Note that C_E dominates the lower cutoff frequency. Thus, make other cutoff frequencies much smaller than f_L.

<u>(i) Cutoff frequency due to C_B:</u>

$$R_{eqB} = R_S + (R_1||R_2)||(r_\pi + \beta * R_{E1})$$

$$R_{eqB} = 1k + (5.19k)||(1.33k + 100 * 100) \cong 4.56k\Omega$$

$$f_B = \frac{1}{2\pi C_B R_{eqB}} \leq \frac{1kHz}{10} = 100$$
$$C_B \geq \frac{1}{2\pi * 100 * 4.56 * 10^3} = 0.35\mu F$$

Let's choose $C_B = 0.5\mu F$.

<u>(ii) Cutoff frequency due to C_C:</u>

$$R_{eqC} = R_C + R_L$$

$$R_{eqC} = 2.2k + 10k = 12.2k\Omega$$

$$f_C = \frac{1}{2\pi C_C R_{eqC}} \leq \frac{1kHz}{10} = 100$$
$$C_C \geq \frac{1}{2\pi * 100 * 12.2 * 10^3} = 0.13\mu F$$

Let's choose $C_C = 0.2\mu F$.

<u>(iii) Cutoff frequency due to C_E:</u>

$$R_{eqE} = R_{E2}||\left[R_{E1} + \frac{r_\pi + (R_S||R_1||R_2)}{1 + \beta}\right]$$

$$R_{eqE} = 1k||121 \cong 108\Omega$$

$$f_C = \frac{1}{2\pi C_E R_{eqE}} = 1kHz = 1000$$
$$C_E \geq \frac{1}{2\pi * 1000 * 108} = 1.5\mu F$$

Let's choose $C_E = 2\mu F$.