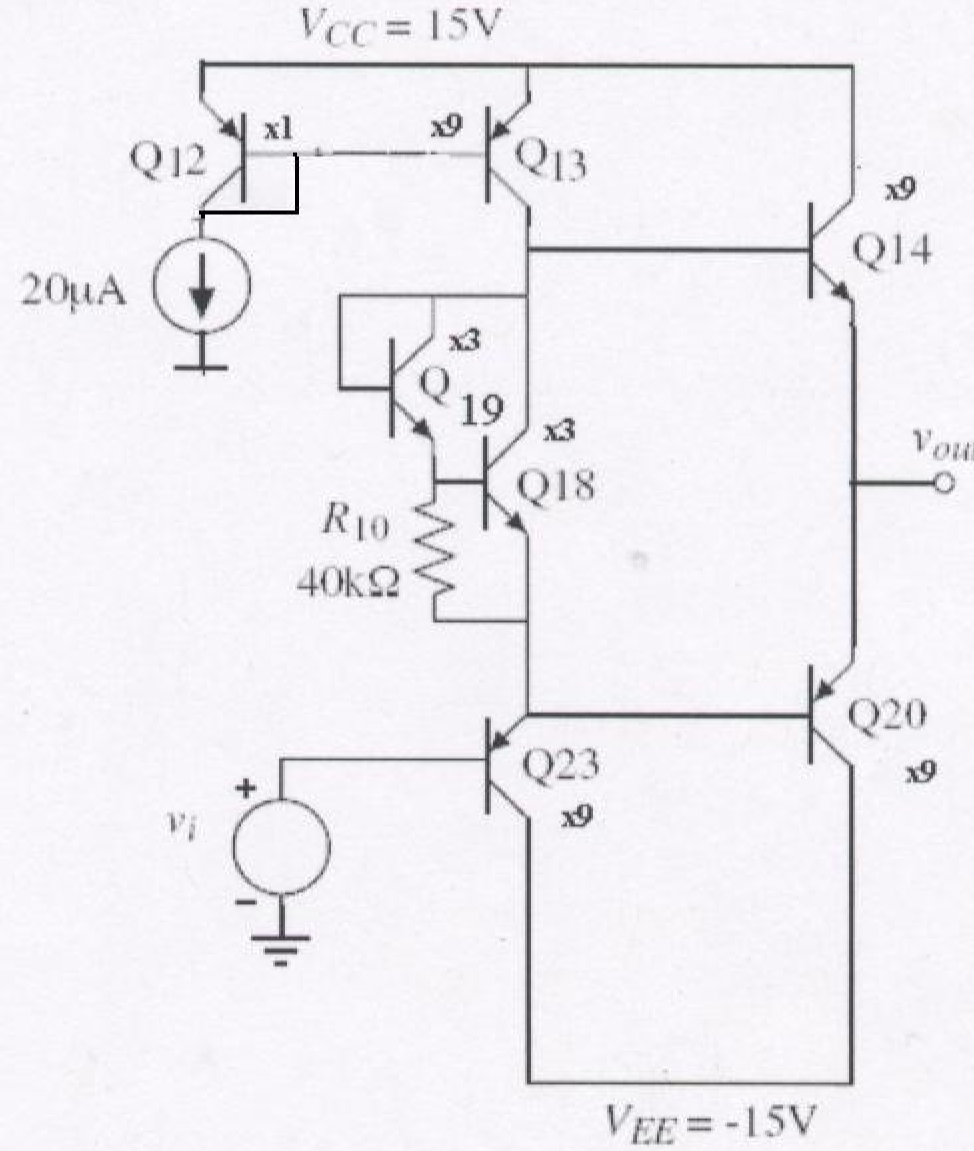
EXAMINATION NO. 1

NAME____ SCORE________/100

INSTRUCTIONS: This exam is closed book with one sheet of notes permitted. The exam consists of 4 questions for a total of 100 points. Please show your work leading to your answers so that maximum partial credit may be given where appropriate. Be sure to turn in your exam with the problems in numerical order, firmly attached together.

Problem 1 - (25 points)

An push-pull output stage is shown. Assume that $\beta_N = \beta_P = 100$, $V_t = 26$mV, and $I_s = 1.11$fA, VBE(on) = 0.6V, VCE(sat) = 0.2V.



a.) Find the dc value of the collector currents when $v_{OUT} = 0$.

b.) If RL=1K, what is the ±peak output voltage of this amplifier? What is the maximum output current that can be delivered to the 1K resistive load?

c.) What is the maximum average power delivered to the load? What is the average power drawn from the sources? What is the efficiency of the circuit?

a) $I_{C13} = 9 \times I_{C12} =$ **180μA**

$I_{C23} = 180\ \mu A$

$I_{C19} = \frac{0.6}{40k} =$ **15μA**

$I_{C18} = 180 - 15 =$ **165μA**

$I_{C14} = I_{C20} = 3 \times \sqrt{I_{C19} \times I_{C18}} =$ **149.2μA**

b) $v_{out\,max} = 15 - V_{BE14} - V_{CE13} = 15 - 0.6 - 0.2 =$ **14.2V**

$v_{out\,min} = -15 + 0.2 + 0.6 =$ **-14.2V**

$R = 1k$ $\quad i_{out\,max} = \dfrac{15 - 0.2 - V_t \ln \frac{I_{out\,max}}{R_L}}{R_L}$ $\rightarrow i_{out\,max} =$ **14.07**

$V_{BE14} = 0.7$

c) $P_L = \frac{1}{2} I_o^2 \times R_L =$ **99mW**

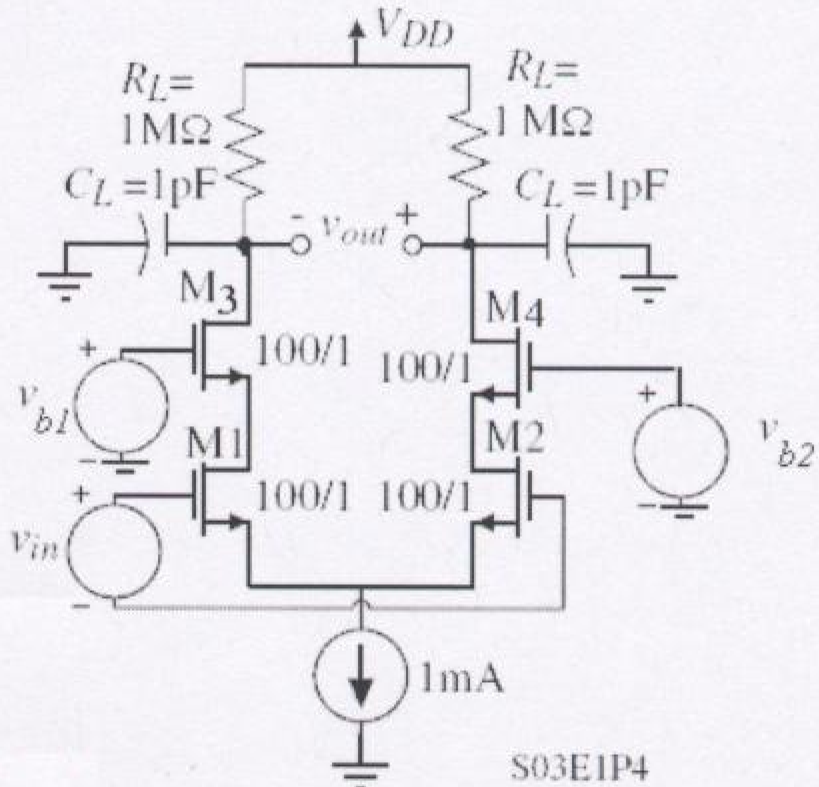
$P_{supply} = \frac{1}{\pi} \times (2V_{cc} \times \hat{I}_o) =$ **134mW**

$\eta = \frac{P_L}{P_{supply}} \times 100 =$ **73.68**

Problem 2 - (25 points)

Find the midband gain and the -3dB frequency of the differential amplifier shown.

Assume the parameters of the NMOS transistors are K_N'=100V/µA^2, V_{TN} = 0.7V, and Cgs = 0.2pF and Cgd = 20fF, Lamda =0.04V-1.



MBG $= g_{m1}((r_{o3} g_{m3} r_{o1}) \| R_L)$

$g_{m1} = g_{m3} = \sqrt{2K' \frac{W}{L} I_D}$ = 3.162 mS

I_D = 500µA

$r_{o1} = r_{o3} = \frac{1}{\lambda I} = 50k\Omega$

$\frac{v_{out}}{v_{in}} = 3.162m \times ((3.162 \times 50 \times 50) \| 1000) = 2806.9$

Rout = 887.7k

$C_{out} = C_L + C_{gd3} = 1.02\,pF$

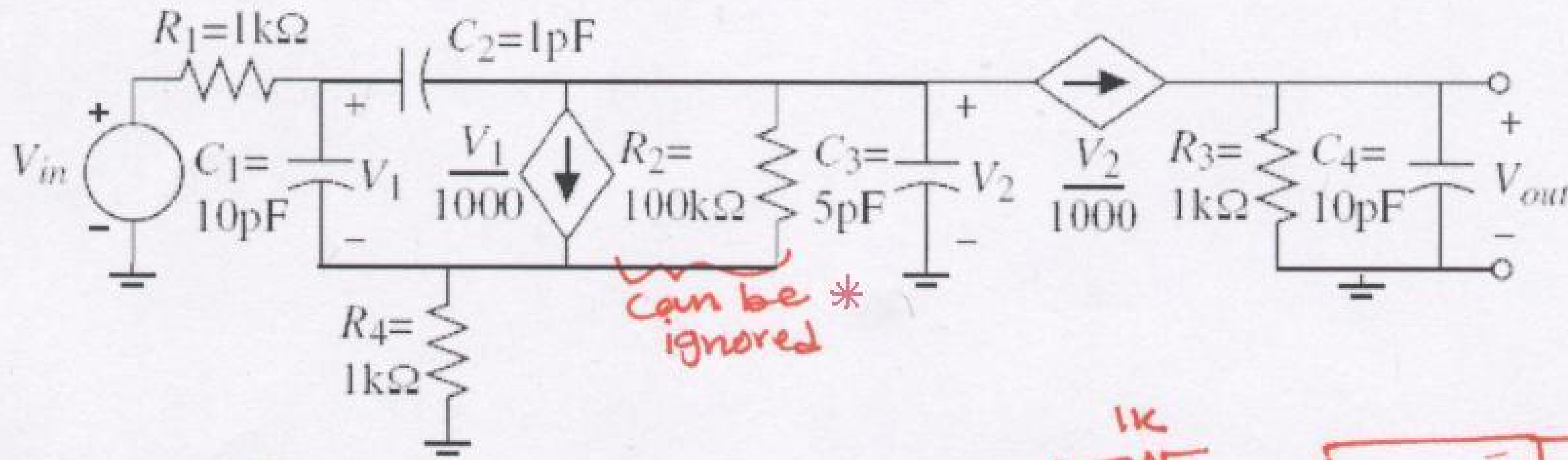
$R_{out} = 887.7k$

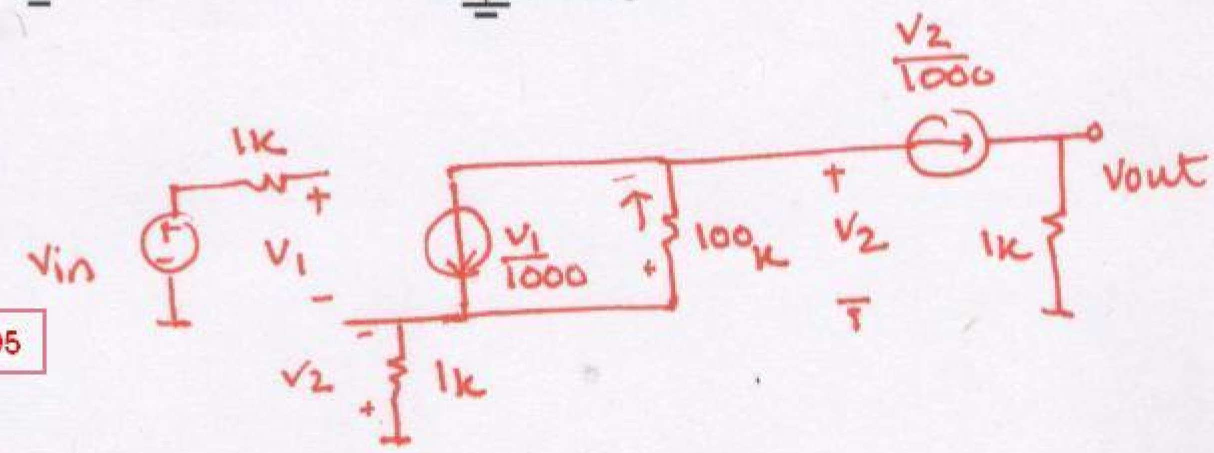
$\rightarrow f_{-3dB} = \frac{1}{2\pi} \times \omega_{-3dB} = 175.8\,kHz$

$\omega_{-3dB} = \frac{1}{1.02p \times 887.7k} = 1.10\ \frac{Mrad}{sec}$

Problem 3 - (25 points)

Find the midband voltage gain, the –3dB frequency and the magnitude of sum of all the poles in Hertz for the circuit shown (Assume zeros are not dominant).





$$\frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_2} \times \frac{V_2}{V_1} \times \frac{V_1}{V_{in}}$$

$$= 1 \times \frac{V_2}{V_1} \times \frac{V_1}{V_{in}} = -\frac{102}{102} \times \frac{102}{202} = -0.495$$

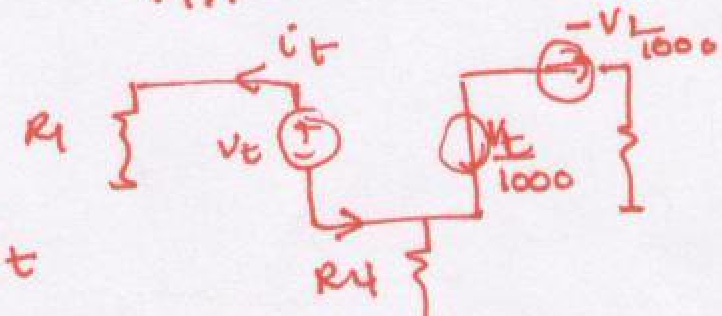
$$V_{in} = V_1 + \frac{-V_2}{1000} \times 1k \rightarrow V_{in} = V_1 + \frac{V_1 \times \frac{100}{102}}{1000} \times 1000 \rightarrow \frac{V_{in}}{V_1} = \frac{202}{102}$$

$$+V_2 + \left(\frac{V_2}{1000} + \frac{V_1}{1000}\right) \times 100k + V_2 = 0 \rightarrow V_1 \times 100 = -V_2(102) \rightarrow \frac{V_1}{V_2} = -\frac{102}{100}$$

* ignore R_2: $\frac{V_{out}}{V_2} = 1$ $V_{in} = 2V_1$, $V_2 = -V_1$ $\rightarrow \frac{V_{out}}{V_{in}} = 1 \times (-1) \times \frac{1}{2} = -0.5$

Open Circuit τ

τ_1 (for C_1)

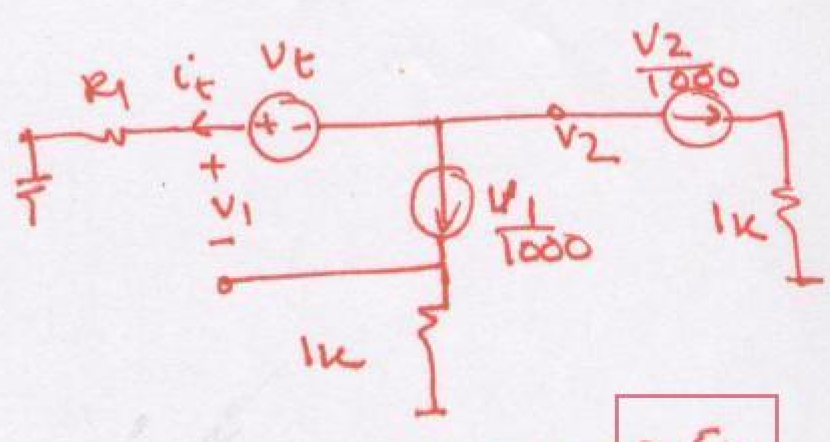


$$\left(-i_t + \frac{V_t}{1000}\right) \times R_4 + V_t = R_1 i_t$$

$$\rightarrow 2V_t = (R_1 + R_4) \rightarrow \frac{V_t}{i_t} = 1k\Omega$$

$$\rightarrow \tau_1 = 1k \times 10pF = 10nsec$$

τ_2 (for C_2)



$$i_t + \frac{V_1}{1000} + \frac{V_2}{1000} = 0$$

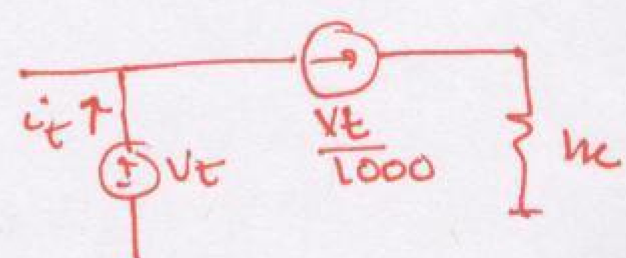
$$V_1 = R_1 i_t - V_1 \rightarrow 2V_1 = R_1 i_t$$

$$V_2 = 2V_1 - V_t$$

$$\rightarrow i_t + \frac{i_t}{2} + \frac{R_1 i_t - V_t}{1000} = 0 \rightarrow 2.5\, i_t = \frac{V_t}{1000} \rightarrow \frac{V_t}{i_t} = 2.5k$$

$$\rightarrow \tau_2 = 1pF \times 2.5k = 2.5nsec$$

τ_3 (for C_3) $\frac{V_t}{i_t} = 1000$



$$\rightarrow \tau_3 = 1k \times 5pF = 5nsec$$

τ_4 (for C_4) $= 1k \times 10pF = 10nsec$

$$\rightarrow \tau = 10n + 2.5 + 5 + 10 = 27.5nsec$$

$\omega_{-3dB} = 36.4 Mrad/sec$ $f = 5.79 MHz$

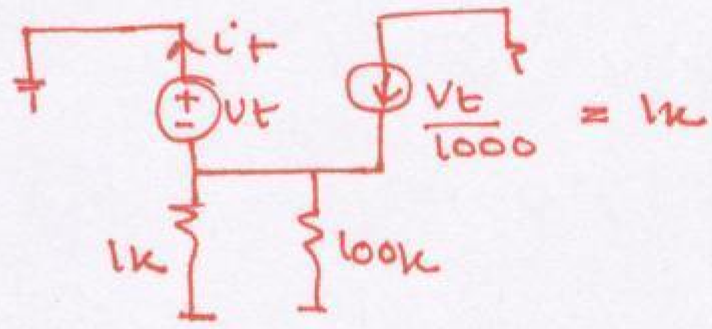
Extra Sheet

$$\sum_{i=1}^{n} p_i = \sum \frac{1}{\tau_{sc}}$$

Short circuit

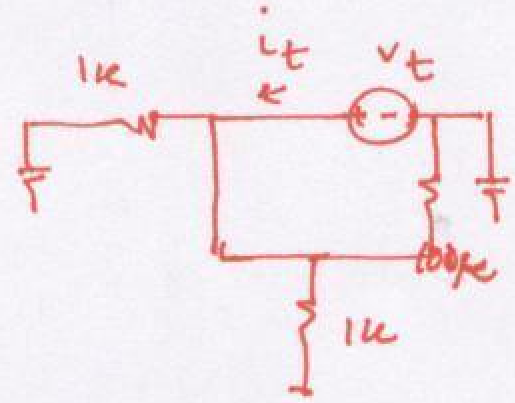
τ_{S1} $R_{S1} = 1k \| 1k \| 100k \simeq$ **500Ω**

$\rightarrow \tau_1 = 0.5 \times 10pF =$ **5 nsec**



τ_{S2} $R_{S2} = 1k \| 1k \| 100k =$ **500Ω**

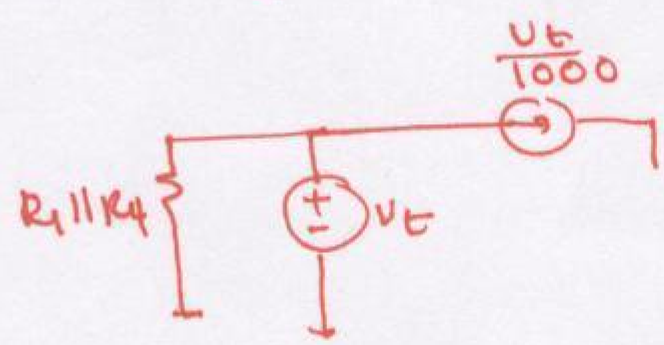
$\rightarrow \tau_2 = 0.5k \times 1pF =$ **0.5 nsec**



τ_{S3} :

$R_{S3} = R_1 \| R_4 \| 1k =$ **333.3Ω**

$\rightarrow \tau_3 = 5pF \times 0.33 =$ **1.67 nsec**



τ_{S4} : $R_{S4} =$ **1k**

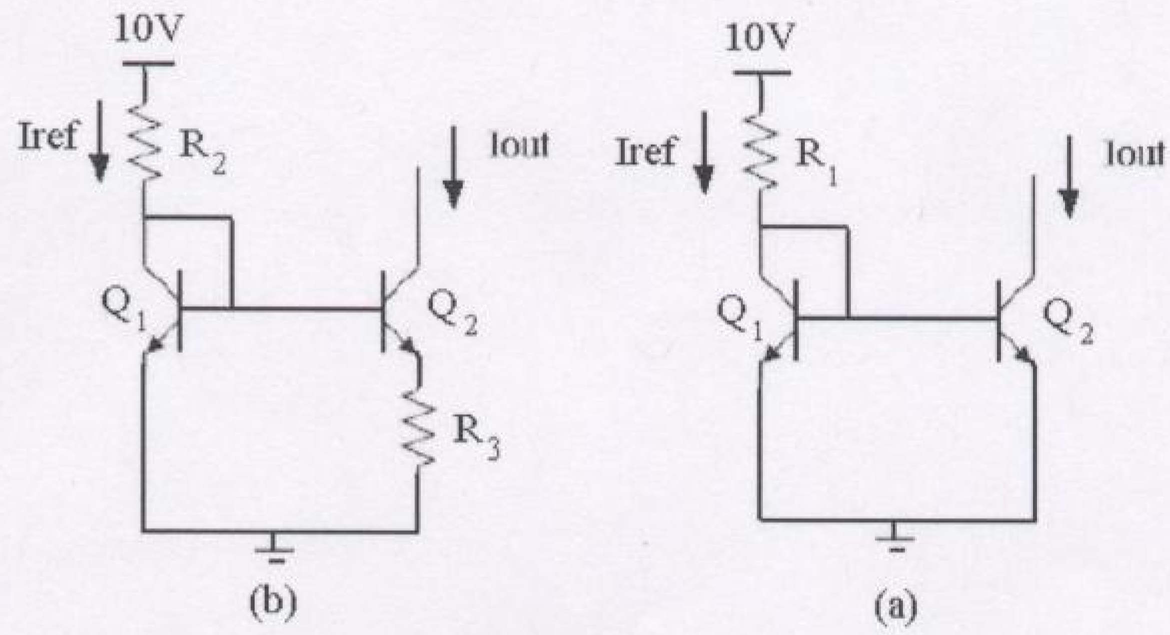
$\rightarrow \tau_{S4} = 1k \times 10pF =$ **10 nsec**

$$\rightarrow \sum_{i=1}^{n} p_i = \left(\frac{1}{5} + \frac{1}{0.5} + \frac{1}{1.67} + \frac{1}{10}\right) \times 10^9 = \boxed{2.89 \times 10^9} \text{ rad/sec}$$

$$\sum_{i=1}^{n} p_i = \boxed{461.3} \text{ MHz}$$

Problem 4 - (25 points)

(a) Find the values of the resistances(R1, R2, and R3) such that Iout=10uA for both circuits. Assume that $\beta_N = 100, V_t = 26mV$, and VBE= 0.7V for Ic=1mA.
(b) By comparing the values of the resistances, explain the advantage of circuit b.
(c) Compare the output resistances of the two circuits and explain the second advantage of circuit b. Assume VA=10V.(Circuit b is a Widlar current source)



(a) Iref = 10μA $\quad V_{BE} = V_t \ln \frac{I_c}{I_s}$

$\rightarrow 0.7 - V_{BE} = 26mV \ln \frac{1mA}{I_{ref}} \rightarrow$ VBE ≈ 0.58V

$R_1 = \frac{10 - 0.58}{10\mu A} =$ 942kΩ

Iout = 10μA

pick Iref = 1mA $\rightarrow R_2 = \frac{10 - 0.7}{1mA} =$ 9.3k

$V_{BE2} = 0.58V \rightarrow R_3 = \frac{0.7 - 0.58}{10\mu A} =$ 12kΩ

(b) Circuit b is better for having smaller resistances → easier to fabricate

(c) $R_{out(a)} = r_o$

$R_{out(b)} = r_o(1 + g_{m2}(R_3 \| r_{\pi 1}))$

circuit b has larger output resistance → better for current source