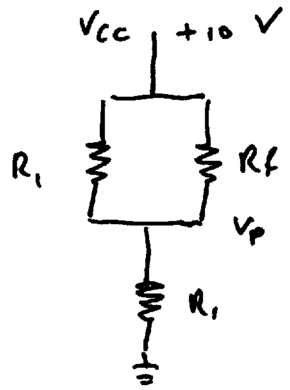
Electronics II Exam 2nd Call

21/7/2011

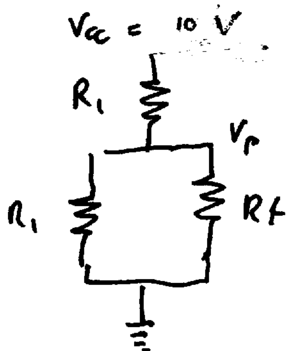
Question 1 a) See lecture notes

b) If $V_o = +V_{cc}$ we have

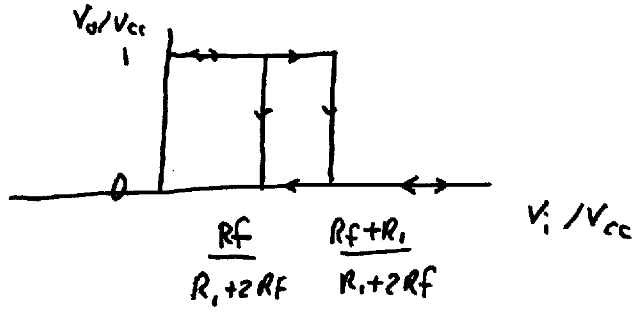


$$V_p = \frac{R_1}{R_1 + R_1 /\!/ R_f} V_{cc} = \frac{R_1 + R_f}{R_1 + 2R_f} V_{cc}$$

If $V_o = 0$ we have



$$V_p = \frac{R_1 /\!/ R_f}{R_1 + R_1 /\!/ R_f} = \frac{R_f}{R_1 + 2R_f} V_{cc}$$



Question 2 a) $A = \infty \Rightarrow V_p = V_n$ or saturation

$r_{in} = \infty$, $r_{out} = 0$

b) $V_p = \frac{R}{R + 1/j\omega C} V_i$, $V_n = V_p = \frac{R}{R + 1/j\omega C} V_i$

$$I_n \text{ (via } R_1) = \frac{V_i - V_n}{R_1} = \frac{V_i - \frac{R}{R + 1/j\omega C} V_i}{R_1}$$

$$V_0 = V_n - I_n R_1 = \frac{R}{R+1/j\omega C} V_i - \left(\frac{V_1 - \frac{R}{R+1/j\omega C} V_i}{R_1} \right) \times R_1$$

$$= -V_i + V_i \left(\frac{2R}{R+1/j\omega C}\right) = V_i \times \left(\frac{R - 1/j\omega C}{R+1/j\omega C}\right)$$

$$A_v = \frac{V_0}{V_i} = \frac{j\omega RC - 1}{j\omega RC + 1} = \frac{(-1+\omega^2R^2C^2) + j\,(2\omega RC)}{1+\omega^2R^2C^2}$$

$$\left|\frac{V_0}{V_i}\right| = \frac{|j\omega RC - 1|}{|j\omega RC+1|} = \frac{\sqrt{\omega^2R^2C^2+1}}{\sqrt{\omega^2R^2C^2+1}} = 1$$

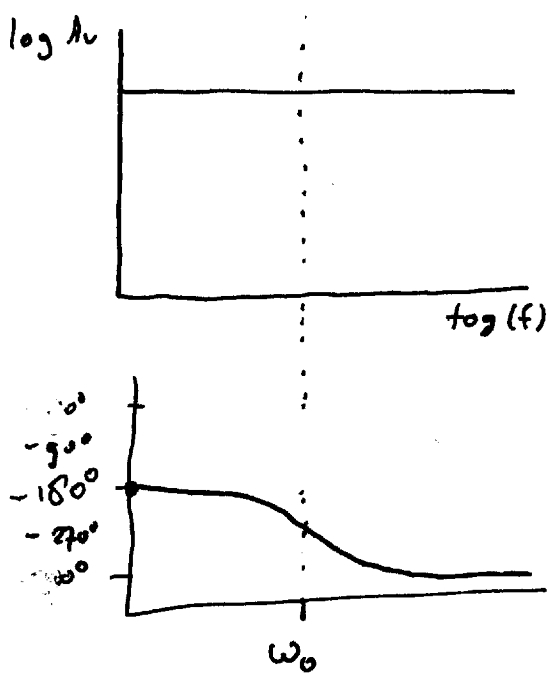
$$\phi_{V_0,V_i} = \tan^{-1}\left[\frac{Im(V_0/V_i)}{Re(V_0/V_i)}\right] = \tan^{-1}\left[\frac{2\omega RC}{(\omega RC)^2-1}\right]$$

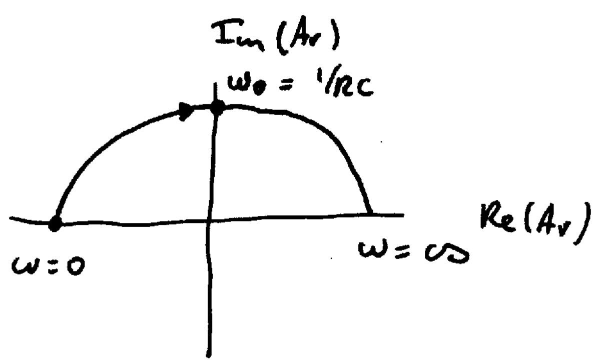
$$= 180^\circ - 2\tan^{-1}(\omega RC)$$

$\omega = 0 \Rightarrow \tan(\phi) = -0, \quad \phi = 180^\circ$

$\omega = \frac{1}{RC} \Rightarrow \tan(\phi) = \infty, \quad \phi = 90^\circ$

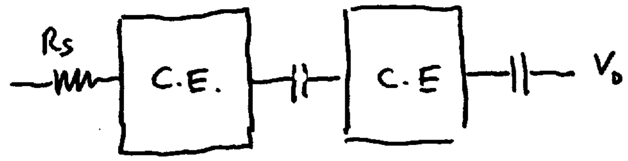
$\omega = \infty \Rightarrow \tan(\phi) = +0, \quad \phi = 0^\circ$



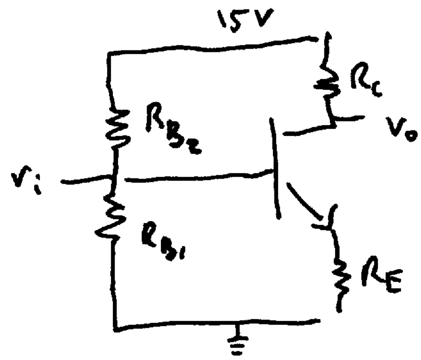


Question 3

a)



C.E. :



× 2

$\omega = 0 \Rightarrow$

—||— = open circuit

we have two equal, separated C.E. amplifiers

$$V_B = \frac{R_{B1}}{R_{B1} + R_{B2}} \times V_{cc} = \frac{2.2\,k\Omega}{24.2\,k\Omega} \times 15\,V = 1.36\,V$$

$$V_E = V_B - 0.7\,V = 0.66\,V$$

$$I_E = \frac{V_E}{R_E} = \frac{0.66\,V}{470\,\Omega} = 1.41\,mA$$

$$I_c = I_E = 1.41\,mA$$

$$V_c = V_{cc} - I_c \times R_c = 15\,V - 1.41\,mA \times 4.7\,k\Omega$$

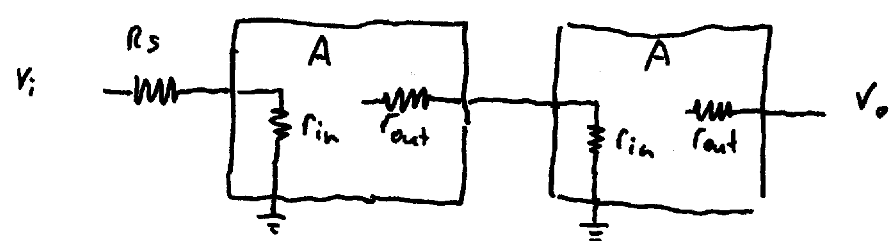
$$= 8.4\,V$$

$$r_e = 1/\frac{I_E}{25\,mV} = 1/\frac{1.41\,mA}{25\,mV} = 17.7\,\Omega$$

$$r_o = \frac{V_A}{I_c} = \frac{200\,V}{1.41\,mA} = 142\,k\Omega$$

$r_o' \approx \infty$ (E is not grounded!)

b) gain : $$\frac{v_o}{v_i} = -\frac{R_c}{R_E + r_e} = \frac{4.7\,k\Omega}{470\,\Omega + 17.7\,\Omega} = -9.64$$



$$\frac{v_o}{v_i} = \frac{r_{in}}{r_{in} + R_s} \times A \times \frac{r_{in}}{r_{out} + r_{in}} \times A$$

$r_{out} = R_{C2} \, // \, r_o' \Rightarrow \infty \approx R_{C2} = 4.7 \text{ k}\Omega$

$r_{in} = R_{B1} \, // \, R_{B2} \, // \, (\beta+1)(r_e + R_E)$

$= 2.2 \text{ k}\Omega \, // \, 22 \text{ k}\Omega \, // \, 100 \, (17.7 \, \Omega + 470 \, \Omega)$

$= 2.2 \text{ k}\Omega \, // \, 22 \text{ k}\Omega \, // \, 48.77 \text{ k}\Omega$

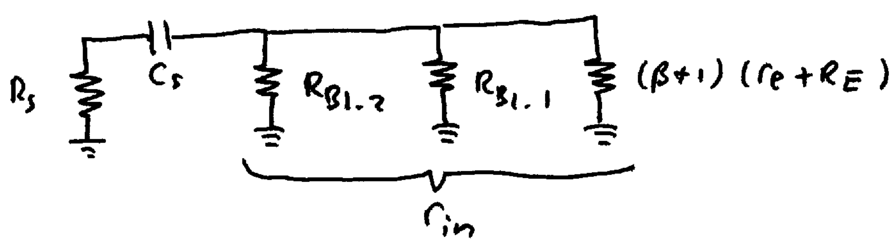
$= 1.92 \text{ k}\Omega$

$$\frac{v_o}{v_i} = \frac{1.92 \text{ k}\Omega}{1.92 \text{ k}\Omega + 1 \text{ k}\Omega} \times (-9.64) \times \frac{1.92 \text{ k}\Omega}{4.7 \text{ k}\Omega + 1.92 \text{ k}\Omega} \times (-9.64)$$

$= +17.7$

c) <u>low frequencies</u> : C_s, C_x, C_L are HPF's

C_s : $R_{eff} = R_s + r_{in} = 2.92 \text{ k}\Omega$



$\tau_s = C_s R_{eff} = 10 \, \mu F \times 2.92 \text{ k}\Omega = 29.2 \text{ ms}$

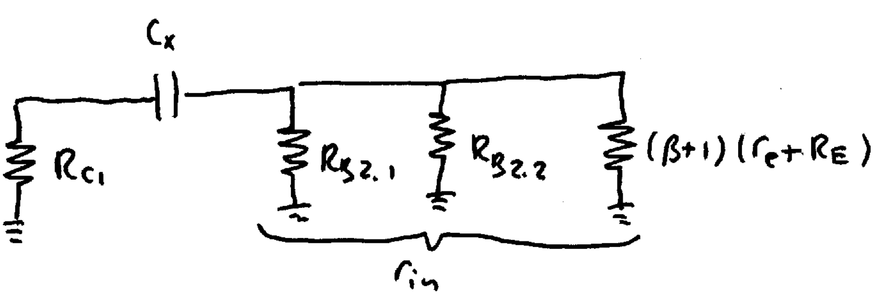
$f_s = \frac{1}{2\pi\tau_s} = 5.45 \text{ Hz}$

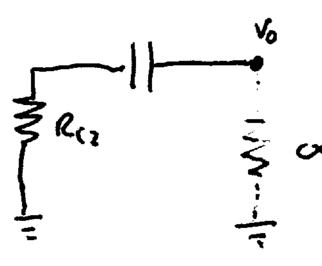
C_x : $R_{eff} = R_{C1} + r_{in} = 6.62 \text{ k}\Omega$

$\tau_x = C_x R_{eff} = 10 \, \mu F \times 6.62 \text{ k}\Omega = 66.2 \text{ ms}$

$f_x = \frac{1}{2\pi\tau_x} = 2.40 \text{ Hz}$

C_L : $R_{eff} = \infty$, $\tau_L = \infty$, $f_L = 0$

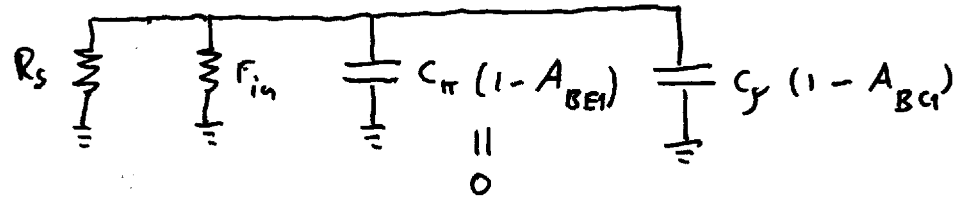




$$f_{total} = \sum_i f_i = 5.45\ Hz + 2.40\ Hz = 7.65\ Hz$$

High frequencies

- entrance C.E.1



$$A_{BE1} = 1$$

$$A_{BC1} = -9.64 \times \frac{r_{in}}{r_{out}+r_{in}} = -2.80$$

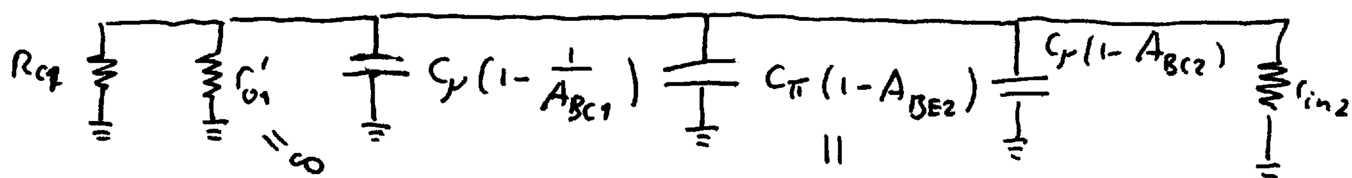
$$\tau_i = (R_s // r_{in}) \times C_\mu \times (1-A_{BC1})$$

$$= (1k\Omega // 1.92\ k\Omega) \times 5\ pF \times (3.80)$$

$$= 1.2 \times 10^{-8}\ s$$

$$f_i = \frac{1}{2\pi\tau_i} = 12.7\ MHz$$

- between C.E.1 and C.E.2



$$A_{BE2} = 1$$

$$A_{BC2} = -9.64$$

$$\tau_{i2} = (R_{c1} // r_{in2}) \times C_\mu \times \left(1 - \frac{1}{A_{BC1}} + 1 - A_{BC2}\right)$$

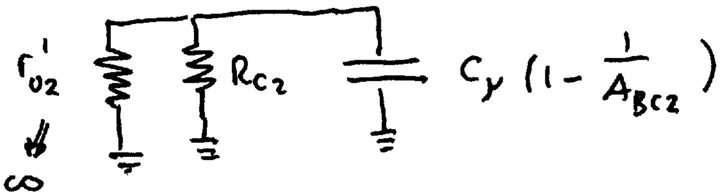
$$= (4.7\ k\Omega // 1.92\ k\Omega) \times 5\ pF \times \left(1 + \frac{1}{2.8} + 1 + 9.64\right)$$

$$= 1.36\ k\Omega \times 60\ pF$$

$$= 81.8\ ns$$

$$f_{i2} = \frac{1}{2\pi\tau} = 1.95\ MHz$$

• exit C.E.2



$$A_{BC2} = -9.64$$

$$\tau_o = R_{C2} \times C_y \times \left(1 - \frac{1}{A_{BC2}}\right)$$

$$= 4.7\ k\Omega \times 5\ pF \times \left(1 + \frac{1}{9.64}\right) =$$

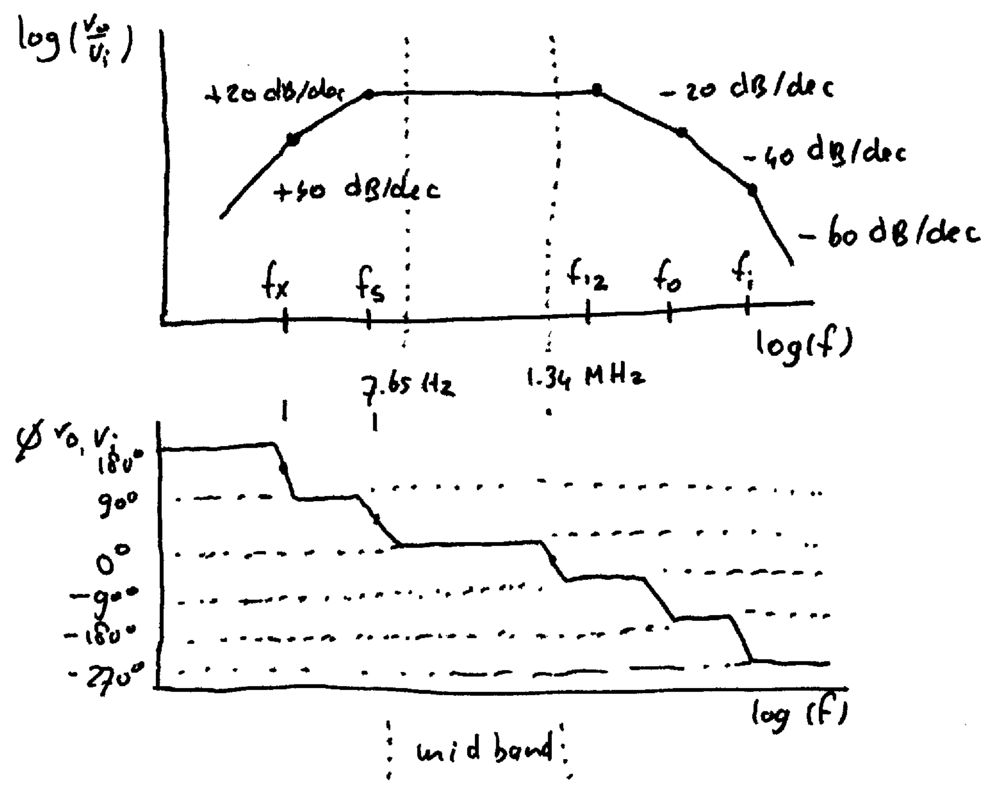
$$= 2.5\ 10^{-8}\ s$$

$$f_o = \frac{1}{2\pi \tau_o} = 6.13\ MHz$$

$$\tau_{total} = \sum \tau_i = \tau_i + \tau_{i2} + \tau_o$$

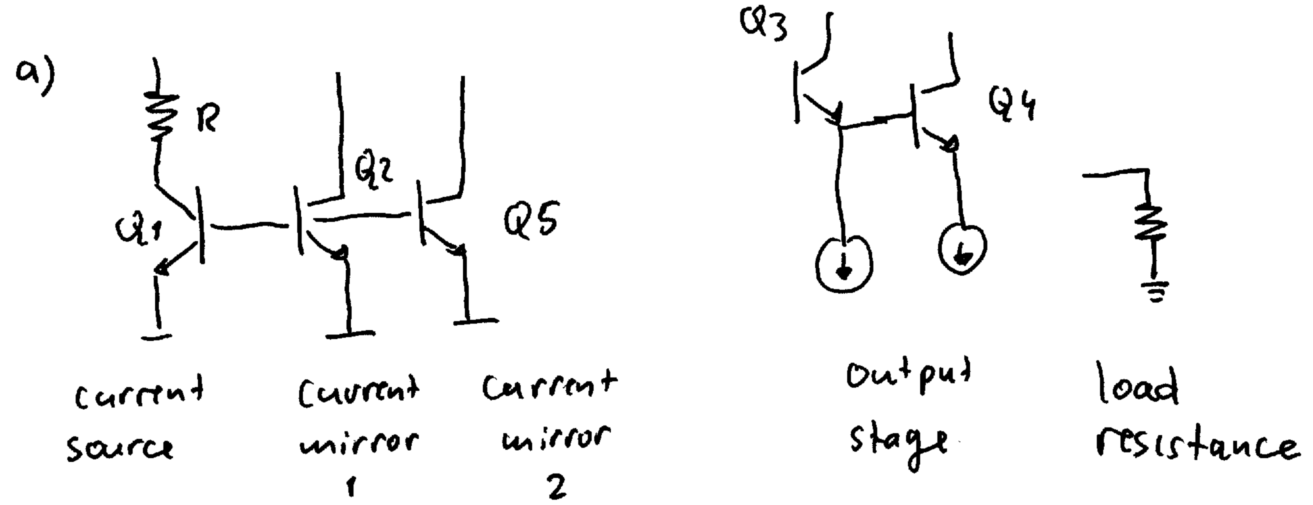
$$= 119\ ns$$

$$f_{total} = 1.34\ MHz$$



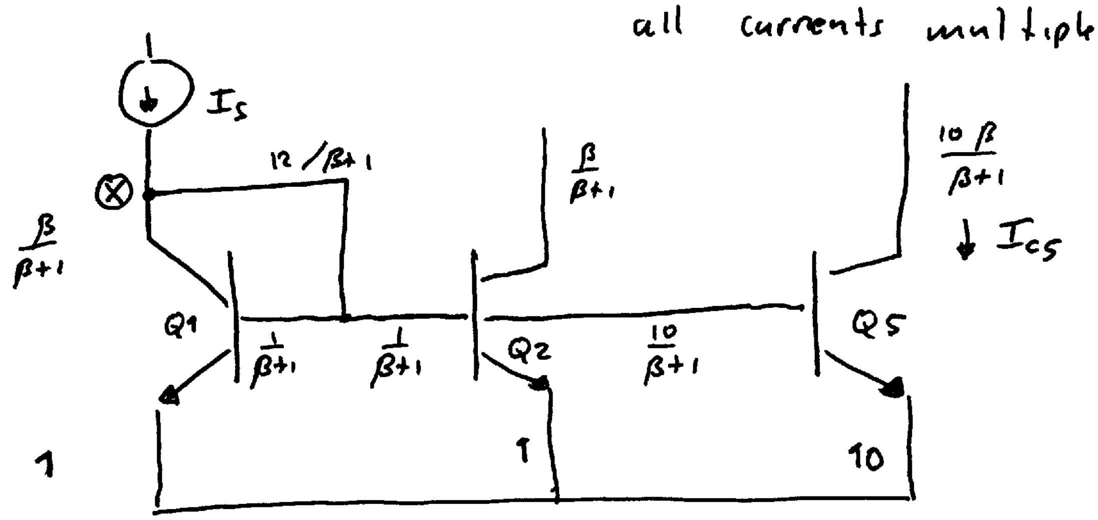
Question 4

a)



b)

all currents multiples of I_{E1}



In ⊗ :
$$I_s = \frac{\beta}{\beta+1} + \frac{12}{\beta+1} = \frac{\beta+12}{\beta+1} \times I_{E1} \qquad \left(I_{E1} = \frac{\beta+1}{\beta+12} I_s \right)$$

$$I_{C5} = \frac{10\beta}{\beta+1} I_{E1} = \frac{10\beta}{\beta+1} \cdot \frac{\beta+1}{\beta+12} I_s = 10 \frac{\beta}{\beta+12} I_s$$

$$I_{C2} = \frac{\beta}{\beta+1} I_{E1} = \frac{\beta}{\beta+1} \cdot \frac{\beta+1}{\beta+12} I_s = \frac{\beta}{\beta+12} I_s$$

$$I_{C3} = \frac{\beta}{\beta+1} I_{C2} = \frac{\beta^2}{(\beta+1)(\beta+12)} I_s$$

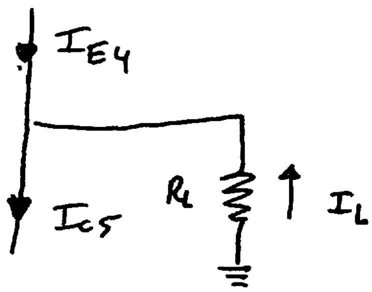
$$I_{C4} = \frac{\beta}{\beta+1} I_{C5} = 10 \frac{\beta^2}{(\beta+1)(\beta+12)} I_s$$

c) Class A (360° phase is passed)

d) - It is limited by V_{cc}

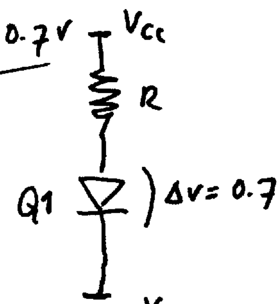
- It is limited by I_{cs}. Q4 cannot deliver negative current. Minimum is 0

For negative output voltage we have the situation here on the left



Ideally, $I_{cs} = \dfrac{V_{cc}}{R_L}$

But, $I_{cs} = 10\, I_s$, $I_s = \dfrac{V_{cc} - V_{EE} - 0.7V}{R}$



$$I_s \approx \frac{2\,V_{cc}}{R}$$

$$I_{cs} \approx \frac{20\,V_{cc}}{R} \overset{\text{ideally}}{=} \frac{V_{cc}}{R_L}$$

$$\Rightarrow \quad R = 20\,R_L \quad \text{ideally}$$

e) (Equal to example in lecture notes)

We assume maximum output, wit R as above

$$V_o = V_{cc} \sin \omega t$$

$$P_L(t) = V_o(t) \cdot \frac{V_o(t)}{R_L} = V_{cc}^2 \frac{\sin^2 \omega t}{R_L}$$

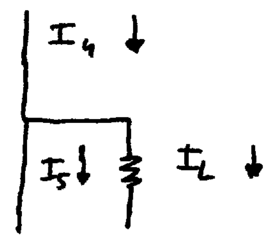
$$\overline{P_L} = \frac{1}{T}\int_0^T P_L(t)\,dt = \frac{1}{T}\int_0^T \frac{\sin^2 \omega t}{R_L}\,dt = \frac{V_{cc}^2}{2R_L}$$

power supplied by $-V_{EE}$ (only Q5) :

$$P_{EE} = \cdot V_{EE} \times I_{E5} = V_{cc} \times \frac{V_{cc}}{R_L} = \frac{V_{cc}^2}{R_L}$$

power supplied by $+V_{cc}$ (only Q4)

$$P_{cc}(t) = V_{cc}(t) \times I_{c4}(t) =$$



$$\left(I_{c4} = I_L + I_{c5} \right)$$

$$= V_{cc} \times \left(\frac{V_{cc} \sin \omega t}{R_L} + \frac{V_{cc}}{R_L} \right)$$

$$\overline{P_{cc}} = \frac{1}{T} \int_0^T P_{cc}(t)\, dt = \frac{1}{T} \int_0^T \left[\frac{V_{cc}^2 \sin \omega t}{R_L} + \frac{V_{cc}^2}{R_L} \right] dt$$

$$= \frac{V_{cc}^2}{R_L}$$

total power $\overline{P}_s = \overline{P}_{cc} + \overline{P}_{EE} = \frac{2 V_{cc}^2}{R_L}$

Efficiency $\eta = \frac{\overline{P}_L}{\overline{P}_s} = \frac{V_{cc}^2 / 2R_L}{2 V_{cc} / R_L} = 1/4 = 25\%$

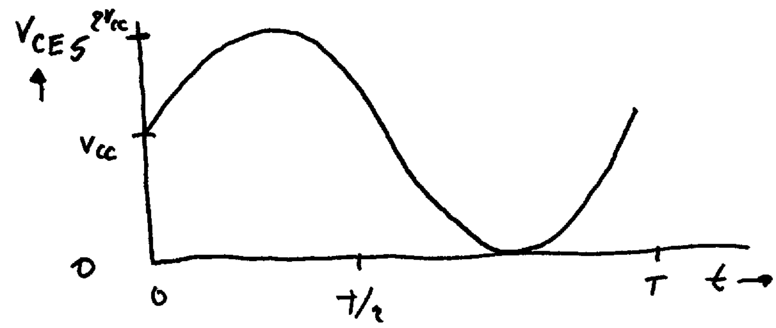
f) $R_L = 10\ \Omega$, $V_{cc} = 15\ V$

$$\overline{P}_L = \frac{(15\ V)^2}{2 \times 10\ \Omega} = 11.25\ W$$

$$\overline{P}_s = 45\ W$$

$$\overline{P}_{cc} = 22.5\ W, \quad \overline{P}_{EE} = 22.5\ W$$

Q5

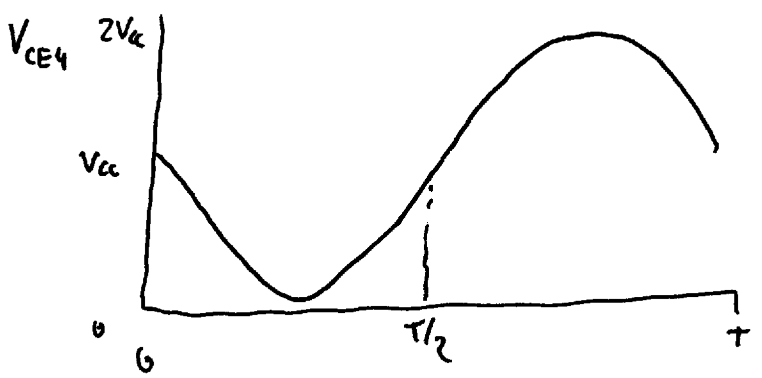


$$P_{Q5} = V_{CE5}(t) \times I_{C5}(t)$$

$$= V_{cc}(1 + \sin \omega t) \times \frac{V_{cc}}{R_L}$$

$$\overline{P_{Q5}} = \frac{1}{T}\int_0^T \frac{V_{cc}^2}{R_L}(1 + \sin \omega t)\, dt = \frac{V_{cc}^2}{R_L} = \frac{(15\,V)^2}{10\,\Omega} = 22.5\,W$$

Q4



Should give

$45\,W - 22.5\,W - 11.25\,W$

$= 11.25\,W$

$$P_{Q4}(t) = V_{CE4}(t) \times I_{C4}(t)$$

$$= V_{cc}(1 - \sin \omega t) \times \left(\frac{V_{cc} \sin \omega t}{R_L} + \frac{V_{cc}}{R_L}\right)$$

$$= \frac{V_{cc}^2}{R_L}(1 - \sin \omega t)(1 + \sin \omega t)$$

$$= \frac{V_{cc}^2}{R_L}(1 - 2 \sin \omega t + \sin^2 \omega t)$$

$$\overline{P_{Q4}} = \frac{1}{T}\int_0^T P_{Q4}(t) = \frac{V_{cc}^2}{R_L}\left(1 - \frac{1}{2}\right) = \frac{V_{cc}^2}{2R_L}$$ 11.25 W

9) Q4 : $T_4 = 25°C + \theta \times \bar{P}_{Q4}$

$= 25°C + 20°C/W \times 11.25\ W = 250°C$

burn !

Q5 : $T_5 = 25°C + \theta \times \bar{P}_{Q5}$

$= 25°C + 20°C/W \times 22.5\ W = 475°C$

burn !

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