Problem Set 3 (Again)

October 30, 2017 10:57 AM

1) For the circuit shown in figure 1, use the 1/3rd rule with $V_B = V_{CC}/3$ to find R_{B1}, R_{B2}, R_C, and R_E given that V_{CC} = 15V and I_C = 2mA.

2) For the circuit shown in figure 1, use the 1/3rd rule with $V_E = V_{CC}/3$ to find R_{B1}, R_{B2}, R_C, and I_C given that R_E = 8kΩ and V_{CC} = 12V. (Answers: $R_{B1} \approx 146$ kΩ, $R_{B2} \approx 104$ kΩ, $R_C \approx 8$ kΩ, and $I_C \approx 0.5$ mA)

3) What are g_m and r_π for the transistors in P1 and P2 above? (Answers: P1 $g_m \approx 80$ mΩ^{-1} and $r_\pi \approx 1.25$ kΩ; P2 $g_m \approx 20$ mΩ^{-1} and $r_\pi \approx 5$ kΩ)

4) Assuming that a small-signal a.c. voltage source with a 50Ω source impedance is coupled to the amplifier of P2 above via a 10μF coupling capacitor and that R_E is by-passed using a 50μF capacitor and that the hybrid-π model has the following parameters c_π = 10pF, c_μ = 2pF, and r_o = ∞, what are A_M, ω_{3dBL}, and ω_{3dBH}? (Answers: $A_M \approx -158$, $\omega_{3dBL} \approx 400$/s, and $\omega_{3dBH} \approx 4.4\times10^7$/s)

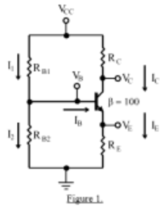


Figure 1.

Q1. First 1/3 rule: $V_B = \frac{1}{3}V_{CC}$, $V_C = \frac{2}{3}V_{CC}$, $I_1 = \frac{I_C}{\sqrt{\beta}}$

$V_{CC} = 15V$, $I_C = 2mA$

$V_C = \frac{2}{3}V_{CC} = 10V$, $V_B = \frac{1}{3}V_{CC} = 5V$, $V_E = V_B - 0.7 = 4.3V$

$I_C = \frac{V_{CC}-V_C}{R_C}$, $R_C = \frac{V_{CC}-V_C}{I_C} = \frac{5V}{2mA} = \boxed{2.5k\Omega}$

$I_B = \frac{1}{\beta}\cdot I_C = \frac{1}{100}\cdot 2mA = 20\mu A$

$I_E = I_C + I_B = 2.02mA$

$R_E = \frac{V_E}{I_E} = \frac{4.3V}{2.02mA} = \boxed{2.13k\Omega}$

$I_1 = \frac{I_E}{\sqrt{\beta}} = \frac{2.02mA}{\sqrt{100}} = 202\mu A$

$\frac{V_{CC}-V_B}{R_{B1}} = I_1$, $R_{B1} = \frac{V_{CC}-V_B}{I_1} = \frac{15-5}{202\mu A} = \boxed{49.5k\Omega}$

$I_2 = I_1 - I_B = 182\mu A$

$\frac{V_B}{R_{B2}} = I_2$, $R_{B2} = \frac{V_B}{I_2} = \boxed{27.47k\Omega}$

Q2: Second 1/3 rule: $V_E = \frac{1}{3}V_{CC}$, $V_C = \frac{2}{3}V_{CC}$, $I_1 = \frac{I_E}{\sqrt{\beta}}$

Given → $V_{CC} = 12V$, $R_E = 8k\Omega$

$V_E = 4V$, $V_C = 8V$, $V_B = 4.7V$

$I_E = \frac{V_E}{R_E} = \frac{4V}{8k\Omega} = 0.500 mA$

$I_B = \frac{1}{1+\beta}I_E = \frac{1}{101}(0.500mA) = 4.95\ \mu A$

$I_C = \beta I_B = \boxed{0.495mA}$

$\frac{V_{CC}-V_C}{R_C} = I_C$, $R_C = \frac{V_{CC}-V_C}{I_C} = \frac{12V-8V}{0.495mA} = \boxed{8.08k\Omega}$

$I_1 = \frac{I_E}{\sqrt{\beta}} = \frac{0.5mA}{10} = 50\mu A$

$\frac{V_{CC}-V_B}{R_{B1}} = I_1$, $R_{B1} = \frac{12V-4.7V}{50\mu A} = \boxed{146k\Omega}$

$I_2 = I_1 - I_B = 45.05\mu A$

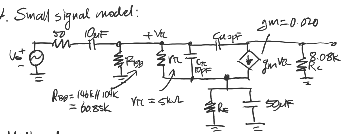
$\frac{V_B}{R_{B2}} = I_2$, $R_{B2} = \frac{V_B}{I_2} = \frac{4.7V}{45.05\mu A} = \boxed{104.33k\Omega}$

Q3. $g_m = \frac{I_C}{V_T}$, $r_\pi = \frac{\beta}{g_m}$

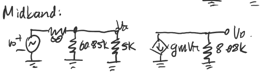
Part 1: $g_m = \frac{2mA}{25mV} = \boxed{0.080℧}$, $r_\pi = \frac{100}{\ }$ = $\boxed{1.25k\Omega}$

Part 2: $g_m = \frac{0.5mA}{25mV} = \boxed{0.020℧}$, $r_\pi = \frac{100}{\ }$ = $\boxed{5k\Omega}$

Q4. Small signal model:



Midband:

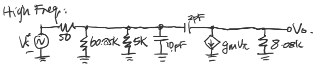


$V_\pi = \frac{(60.85k \parallel 5k)}{(60.85k\parallel 5k)+50}V_S = 0.989V_S$

$V_O = -g_m V_\pi\cdot(8.08k) = -(0.020)(0.989)V_S\cdot(8.08k)$

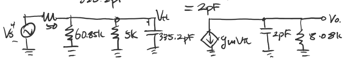
$\frac{V_O}{V_S} = \boxed{-159.822} = A_M$.

High Freq.:



$K = g_m\cdot 8.08k = 161.6$.

$C_{M1} = (1+K)C_\mu = 325.2pF$ $C_{M2} = \left(\frac{K}{K-1}\right)C_\mu = 2pF$



$\tau_{Hp1} = (50 \parallel 60.85k \parallel 5k)\cdot 335.2pF = 1.676\times10^{-8}s$

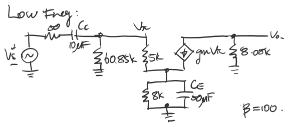
$\tau_{Hp2} = (8.08k)\cdot 2pF = 1.616\times10^{-8}s$.

$\tau_{H3dB} = \sqrt{\tau_{Hp1}^2 + \tau_{Hp2}^2}$

$\omega_{H3dB} = \boxed{42.95 Mrad/s.}$

$F_H(s) = \left(\frac{60M}{s+60M}\right)\left(\frac{62M}{s+62M}\right)$

Low Freq:



— SCTC test: —

$\tau_{SC}^{C_C} = (50 + (60.85k \parallel 5k))\cdot 10\mu F = 41ms.$ ✗

$\tau_{SC}^{C_E} = \left[(50 \parallel 60.85k + 5k)\left(\frac{1}{1+\beta}\right) \parallel 8k\right]\cdot 50\mu F = 2.484 ms.$ ←

— OSTC test —

$\tau_{OC}^{C_C} = [50 + 60.85k \parallel (5k + (1+\beta)(8k))]\cdot 10\mu F = 0.567s.$

$\omega_{Lp1} = 402.6\ rad/s$

$\omega_{Lp2} = 1.764 rad/s$

$\omega_{Lz1} = 0$

$\omega_{Lz2} = \frac{1}{8k\cdot 50\mu F} = 2.5 rad/s.$

$\omega_{L3dB} = (\omega_{Lp1}^2 + \omega_{Lp2}^2 - 2\omega_{Lz1}^2 - 2\omega_{Lz2}^2)^{\frac{1}{2}}$.

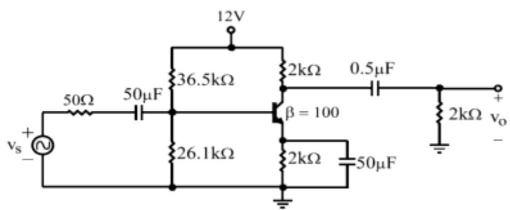
$= \boxed{402.6 rad/s.}$

$F_L(s) = \left(\frac{s+2.5}{s+402.6}\right)\left(\frac{s}{s+1.764}\right)$

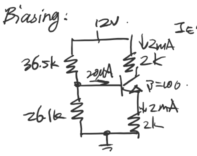
5) For the circuit shown in figure 2:

i. Draw the low frequency circuit, the midband circuit and the high frequency circuit and

ii. Derive the complete transfer function using $I_E \approx I_C$ = 2mA, c_π = 10pF, and c_μ = 2pF.



Biasing:



$I_E \approx I_C = 2mA$, $I_B = 20\mu A$.

$g_m = \frac{I_C}{V_T} = \frac{2mA}{25mV} = 0.080.$

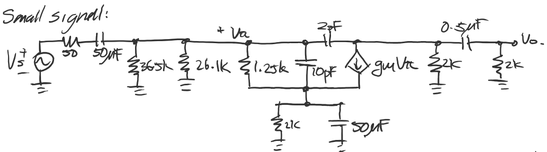
$r_\pi = \frac{\beta}{g_m} = 1.25k\Omega.$

$V_C = 8V$

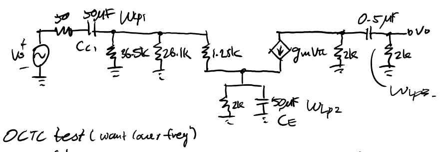
$V_E = 4V. \rightarrow V_B = 4.7V.$

$I_1 = 200\mu A$, $I_2 = 180\mu A$.

Small signal:



LF:



OCTC test (want lower freq)

$\tau_{OC}^{C_{C1}} = 50\mu F(50 + 36.5k \parallel 26.1k \parallel (1.25k + (1+\beta)2k)) = 0.710s$ ←

$\tau_{OC}^{C_E} = 50\mu F\cdot((36.5k \parallel 26.1k) + 1.25k)\cdot\left(\frac{1}{1+\beta}\right) \parallel 2k) = 0.008s$ ✗

SCTC test

$\tau_{SC}^{C_E} = 50\mu F\left[((50 \parallel 36.5k \parallel 26.1k) + (1.25k))\cdot\left(\frac{1}{1+\beta}\right) \parallel 2k\right] = 0.639ms.$

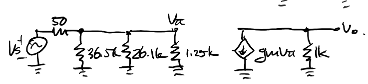
$\omega_{Lp1} = 1.408 rad/s$

$\omega_{Lp2} = 1619.6 rad/s$

$\omega_{Lz1} = \omega_{Lz3} = 0\ rad/s$

$\omega_{Lz2} = \frac{1}{2k\cdot 50\mu F} = 10 rad/s$

MB:



$A_M = \frac{V_\pi}{V_S}\frac{V_O}{V_\pi}$

$V_\pi = \frac{(36.5k \parallel 26.1k \parallel 1.25k)}{(36.5k \parallel 26.1k \parallel 12.5k) + 50}\cdot V_S$.

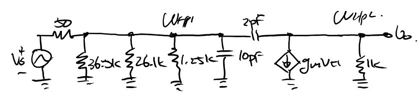
$= 0.959 V_S$.

$V_O = -g_m V_\pi \cdot 1k$

$= -(0.080)(1k)(0.959)V_S$

$\frac{V_O}{V_S} = \boxed{-76.681}$

HF:



$K = g_m\cdot 1k = 0.08(1k) = 80.$

→ $C_{M1} = 162\ pF$, $C_{M2} = 2pF$

$\tau_{HP1} = (10pF + 162\ pF)\cdot[50 \parallel 36.5k \parallel 26.1k \parallel 1.25k]$

$= 8.243\times10^{-9}s$ $\omega_{HP1} = 121.3 Mrad/s$

$\tau_{Hp2} = (2pF)(1k)$

$= 2\times10^{-9}s$ $\omega_{Hp2} = 500 Mrad/s$

$F_H(s) = \left(\frac{117.7M}{s+117.7M}\right)\left(\frac{500M}{s+500M}\right)$

$\omega_{Lp1} = 1.408$ rad/s

$\omega_{Lp2} = 1619.6$ rad/s

$\omega_{Lp3} = (4k \cdot 0.5\mu F)^{-1} = 500$ rad/s

$$F_L = \left(\frac{s}{s+1.408}\right)\left(\frac{s+10}{s+1620}\right)\left(\frac{s}{s+500}\right)$$

$\omega_{Lz1} = \omega_{Lz3} = 0$ rad/s

$$\omega_{Lz2} = \frac{1}{2k \cdot 50\mu F} = 10 \text{ rad/s}$$

$= -(0.080)(1k)(0.959)V_s$

$\frac{V_o}{V_s} = \boxed{-76.681}$

$= 2\times10^{-9}s$

$\omega_{Hp2} = 500M$ rad/s

$$F_H(s) = \left(\frac{117.7M}{s+117.7M}\right)\left(\frac{500M}{s+500M}\right)$$