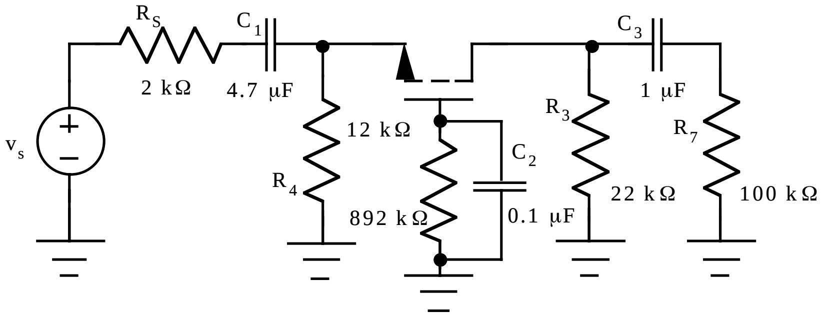
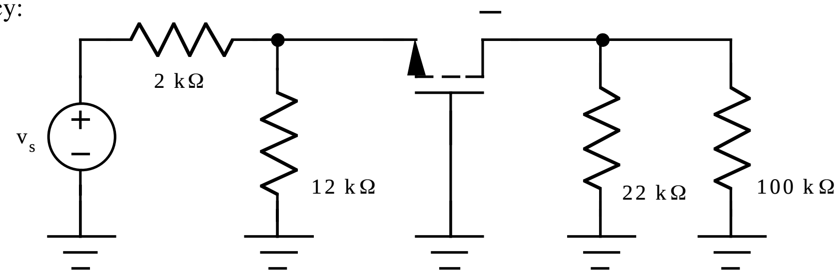
Homework Assignment No. 10 - Solutions

1.) Problem 17.14 of the text.



Low Frequency:



Mid-band:

$$g_m = \frac{2(0.1\text{mA})}{1\text{V}} = 0.200\text{mS} \;\; | \;\; \frac{1}{g_m} = 5000\Omega \;\; | \;\; \mathbf{v}_{th} = \frac{12\text{k}\Omega}{12\text{k}\Omega + 2\text{k}\Omega}\mathbf{v_s} = 0.857\mathbf{v_s}$$

$$R_{th} = 12\text{k}\Omega \| 2\text{k}\Omega = 1.71\text{k}\Omega \;\; | \;\; R_L = 22\text{k}\Omega \| 100\text{k}\Omega = 18.0\text{k}\Omega$$

$$A_{mid} = 0.857\frac{R_L}{R_{th} + \frac{1}{g_m}} = 0.857\frac{18.0\text{k}\Omega}{1.71\text{k}\Omega + 5\text{k}\Omega} = 2.30 \quad (7.24\text{dB})$$

$$\omega_1 = \frac{1}{4.7\text{x}10^{-6}\left(2\text{k}\Omega + 12\text{k}\Omega \| 5\text{k}\Omega\right)} = 38.5\frac{\text{rad}}{\text{s}} \;\; | \;\; \omega_2 = \text{doesn't matter since } i_g = 0!$$

$$\omega_3 = \frac{1}{10^{-7}\left(100\text{k}\Omega + 22\text{k}\Omega\right)} = 82.0\frac{\text{rad}}{\text{s}} \;\; | \;\; f_L \approx \frac{1}{2\pi}(38.5 + 82.0) = 19.2\text{Hz}$$

2.) Problem 17.17 of the text.

$$\text{SCTC requires: } \omega_L \cong \sum_{i=1}^{3}\frac{1}{R_{is}C_i} = 2\pi(500) = 3140\frac{\text{rad}}{\text{s}}$$

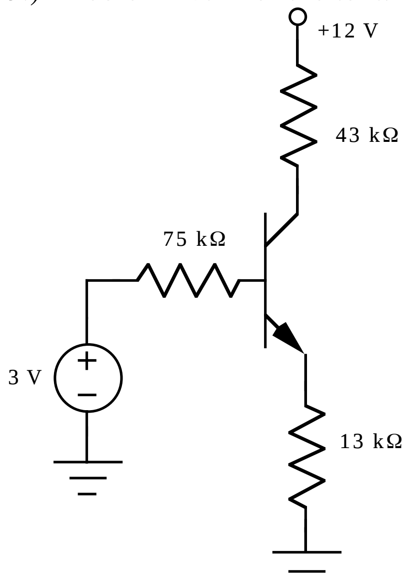
$$\omega_1 = \frac{1}{\left(10^{-7}\text{F}\right)\left(2.43\text{M}\Omega + 1\text{k}\Omega\right)} = 4.11\frac{\text{rad}}{\text{s}} \;\; | \;\; \omega_2 = \frac{1}{\left(10^{-7}\text{F}\right)\left(43\text{k}\Omega + 1\text{M}\Omega\right)} = 9.59\frac{\text{rad}}{\text{s}}$$

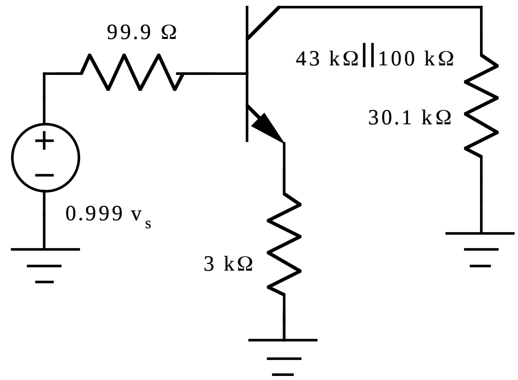
$$\omega_1 + \omega_2 << \omega_L \;\; | \;\; \omega_3 \text{ will be dominant} \rightarrow \omega_3 \cong \omega_L$$

$$\omega_3 = \frac{1}{C_3\left(R_4 \left\| \frac{1}{g_m}\right.\right)} \;\; | \;\; g_m = \frac{2I_{DS}}{V_{GS} - V_{TN}} = \frac{2(0.2\text{mA})}{1\text{V}} = 0.400\text{mS} \;\; | \;\; \frac{1}{g_m} = 2.50\text{k}\Omega$$

$$C_3 = \frac{1}{3140\left(13\text{k}\Omega \| 2.5\text{k}\Omega\right)} = 0.152\ \mu\text{F} \rightarrow 0.15\ \mu\text{F from Appendix C}$$

3.) Problem 17.41 of the text.





$$I_B = \frac{3-0.7}{75k\Omega + 101(13k\Omega)} = 1.657\mu A \ \ | \ \ I_C = 166\mu A \ \ | \ \ V_{CE} = 12 - 43k\Omega(I_C) - 13k\Omega\left(\frac{I_C}{\alpha_F}\right) = 2.70V$$

$$2.70V \geq 0.7V \ \text{ Forward - active region is correct.} \ \ | \ \ r_\pi = \frac{100(0.025)}{0.166\ mA} = 15.1\ k\Omega$$

$$g_m = 40(0.166\ mA) = 6.63mS \ \ | \ \ C_\pi = \frac{6.63mS}{2\pi(3x10^8)} - 0.5 = 3.02\ pF \ \ | \ \ r_x = 300\Omega \ \ | \ \ C_\mu = 0.5pF$$

$$\mathbf{v_{th}} = \frac{75k\Omega}{75k\Omega + 100\Omega}\mathbf{v_s} = 0.999\mathbf{v_s} \ \ | \ \ R_{th} = 75k\Omega \| 100\Omega = 99.9\Omega \ \ | \ \ R_L = 43k\Omega \| 100k\Omega = 30.1k\Omega$$

$$A_{mid} = 0.999\frac{-100(30.1k\Omega)}{99.9\Omega + 300\Omega + 15.1k\Omega + 101(3k\Omega)} = -9.44$$

Short-Circuit Time Constants

$$R_{1S} = 100\Omega + 75k\Omega \| [300\Omega + 15.1k\Omega + 101(3k\Omega)] = 60.8k\Omega$$

$$R_{2S} = 43k\Omega + 100k\Omega = 143k\Omega$$

$$R_{3S} = 10k\Omega \left\| \left(3k\Omega + \frac{15.1k\Omega + 99.9\Omega}{101}\right) \right. = 2.40k\Omega$$

$$f_L \approx \frac{1}{2\pi}\left[\frac{1}{(60.8k\Omega)(1\mu F)} + \frac{1}{(143k\Omega)(0.1\mu F)} + \frac{1}{(2.40k\Omega)(2.2\mu F)}\right] = 43.9Hz$$

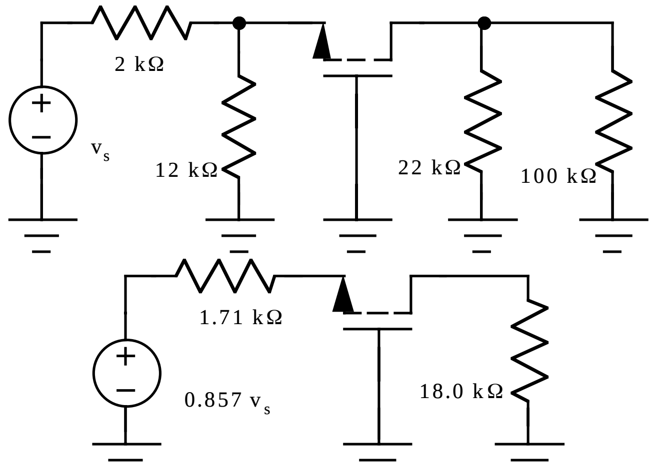
Open-Circuit Time Constants

Using the result in Table 17.2 on page 944: $R_{th} + r_x = 99.9\Omega + 300\Omega = 400\Omega$

$$C_{TB} = \frac{3.02pF}{1 + (6.63mS)(3k\Omega)}\left(1 + \frac{3k\Omega}{400\Omega}\right) + 0.5pF\left[1 + \frac{(6.63mS)(30.1k\Omega)}{1 + (6.63mS)(3k\Omega)} + \frac{30.1k\Omega}{400\Omega}\right]$$

$$C_{TB} = 44.1pF \qquad f_H = \frac{1}{2\pi(400\Omega)(44.1pF)} = 9.02\ MHz$$

4.) Problem 17.48 of the text.



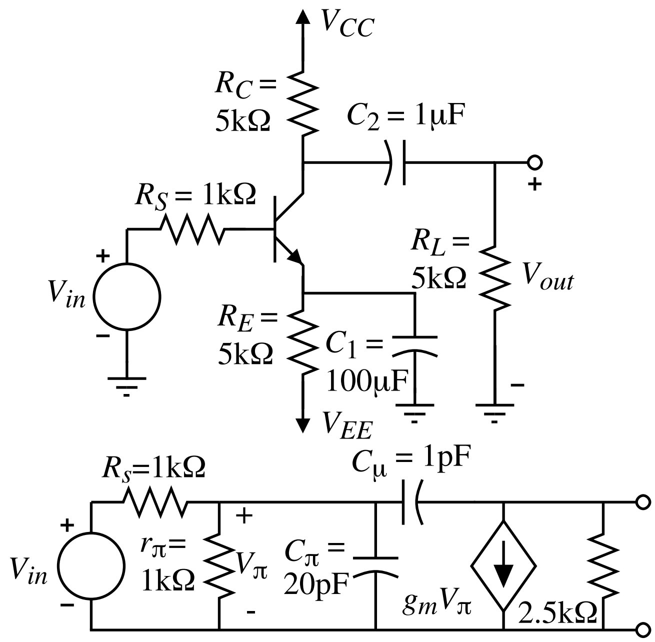
$$\mathbf{v_{th}} = \frac{12k\Omega}{12k\Omega + 2k\Omega}\mathbf{v_s} = 0.857\mathbf{v_s} \quad | \quad R_{th} = 12k\Omega \| 2k\Omega = 1.71k\Omega \quad | \quad R_L = 22k\Omega \| 100k\Omega = 18.0k\Omega$$

$$g_m = \frac{2(0.1mA)}{1V} = 0.2mS \quad | \quad C_{GS} = 3.0pF \quad | \quad C_{GD} = 0.6pF$$

$$A_{mid} = 0.857\frac{R_L}{R_{th} + \frac{1}{g_m}} = 0.857\frac{18.0k\Omega}{1.71k\Omega + \frac{1}{0.2mS}} = +2.30$$

$$f_H = \frac{1}{2\pi}\left(\frac{1}{\frac{C_{GS}}{G_{th} + g_m} + C_{GD}R_L}\right) = \frac{1}{2\pi}\left(\frac{1}{\frac{3.0pF}{(0.5848 + 0.2)mS} + 0.6pF(18.0k\Omega)}\right) = 10.9 \text{ MHz}$$

5.) A BJT transistor amplifier is shown. If g_m = 100mA/V, r_π = 1kΩ, C_μ = 1pF, and C_π = 20pF, find numerical values for the midband gain (MBG) and the upper -3dB frequency (ω_H).



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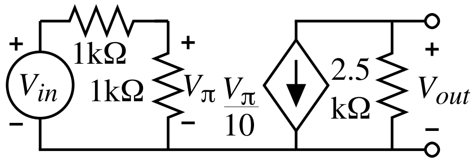
Solution

Midband gain: Small signal model-



$$\text{MGB} = (0.5)\left(\frac{-2500}{10}\right) = -125 \text{ V/V}$$

High frequency response:

1.) Use the Miller approach.

$$\frac{V_o}{V_\pi} = -g_m(2.5\text{k}\Omega) = -250$$

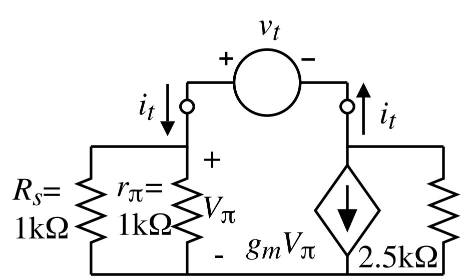
$C_{eq} = C_\pi + (251)C_\mu$ = 20pf + 251·1pF = 271pF and R_{eq} = 1K||1K = 500Ω

$$\therefore \quad \omega_H = \frac{1}{500 \cdot 271\text{pF}} = 7.38\text{x}10^6 \text{ rads/sec} \Rightarrow f_H = 1.175 \text{ MHz}$$

2.) Open-Circuit Time Constant Approach.

$R_{C\pi} = R_s || r_\pi$ = 500Ω

$R_{C\mu}$ = ? See model.



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$$v_t = V_\pi + (i_t + g_mV_\pi)2.5\text{k}\Omega$$

$$= V_\pi(1 + g_m2.5\text{k}\Omega) + i_t\, 2.5\text{k}\Omega$$

$$= i_t\,(R_s||r_\pi)(1 + g_m2.5\text{k}\Omega) + i_t\, 2.5\text{k}\Omega$$

$$\therefore \quad R_{C\mu} = \frac{v_t}{i_t} = 0.5\text{k}\Omega(251) + 2.5\text{k}\Omega = 128\text{k}\Omega$$

$$\omega_H = \frac{1}{R_{C\pi}C_\pi + R_{C\mu}C_\mu} = \frac{10^9}{0.5\text{x}20 + 128\text{x}1} = 7.246\text{x}10^6 \text{ rads/sec.} \Rightarrow f_H = 1.15 \text{ MHz}$$

The open-circuit time constant approach agrees reasonably well with the Miller approach.