Show all work. Clearly indicate final answer(s).

CHEATSHEET MUST BE TURNED IN WITH TEST OR A ZERO WILL BE RECEIVED FOR ENTIRE TEST!

1. (30 points) Sketch the magnitude and phase plots (straight line and actual) for the following transfer function: 
   \[ G(s)H(s) = \frac{0.016s}{1 + \frac{s}{63}} \]

2. (15 points) Determine \( I_3 \) for the circuit shown to the right when the diodes are ideal.

3. (25 points) For the amplifier to the right:
   a. Find the values of \( R_1 \) and \( R_2 \) to achieve maximum symmetrical output swing.
   b. Determine the value of that swing achieved in part (a).
   c. Draw the ac and dc load lines.

4. (25 points) Analyze the circuit shown to the right and determine the following:
   a. \( I_{CQ} \) and \( V_{CEQ} \)
   b. Maximum undistorted output voltage swing
   c. Power supplied from power supply
   d. Voltage gain

5. (25 points) Design an EF (CC) Class A amplifier with an 8\( \Omega \) load and \( R_{in}=5k\Omega \) using a Darlington pair that has a combined \( \beta \) of 8000 and \( V_{BE}=1.4V \). Determine all component values and find \( A_i \) and \( P_{out} \) when \( V_{CC}=24V \). Use the circuit shown to the right.

6. (20 points) A differential amplifier has \( A_d=200 \), a differential voltage input of 3mV, a common-mode voltage input of 15mV and a CMRR of 95dB. Calculate the differential voltage and common-mode voltage at the output.
7. (20 points) What is the output of the level shifter shown to the right if \( V_{BB} = 8V, R_B = 5k\Omega, V_{CC} = 10V, \) the current source provides 4mA, \( R_E = 800\Omega, V_{BE} = 0.7V \) and \( \beta = 100? \)

8. (20 points) Design a multiple output current mirror of the type shown to the right, where \( I_2 = 10mA, I_3 = 1mA, I_4 = 0.1mA, I_5 = 100\mu A, \) and \( I_6 = 50\mu A. \) Assume the transistors are identical and have \( \beta(s) = 100. \)

9. (30 points) Calculate \( f_H \) for a common emitter amplifier with the following values: \( f_T = 500MHz, \beta = 400, C_{ob} = C_{b'e} = 0.5pF, I_C = 5mA, R_L = R_C = 7k\Omega, R_B = 20k\Omega \) and \( R_S = 2k\Omega. \) Hint: All standard assumptions apply when simplifying the small signal circuit.

10. (20 points) Determine the low frequency cutoff (in Hz) of the amplifier shown to the right when \( V_{CC} = 16V, R_{in} = 4k\Omega, \ R_C = R_L = 6k\Omega, \ R_E = 300\Omega, \ R_S = 2k\Omega, \) and \( C_B = C_C = 0.2\mu F. \)
\( G(s) H(s) = \frac{0.0165 e^{s}}{(1 + 0.628^2)(1 + 0.625^2)} \)

Let: \( 62.8 \approx 62.5 \approx 63 \)
\( G_0 = 1 \)

\( G(s) H(s) \approx \frac{0.0165}{(1 + 0.63^2)} \)

Single zero \( @ 0 \)

Magnitude straight line starts \( @ +20 \)dB/sec \( \rightarrow -20 \)dB/sec \( @ \omega = 63 \)

Phase straight line starts \( @ 90^\circ, -135^\circ \) \( @ 63 \)

\( |G(s)| = 0.0165 e^{s} \)

\( \phi = 90 - 3\tan^{-1}\left(\frac{0.63}{63}\right) \)

\( \left| G(s) H(s) \right| = -36 \) dB

| \( \omega \) | \( |G(s)| \) | \( 20 \log |G(s)| \) | \( \phi \) |
|---|---|---|---|
| 63 | 0.356 | -9 | -45 |
| 6 | 9.5 \times 10^{-2} | -20.5 | -74 |
| 630 | 9.9 \times 10^{-2} | -40.1 | -163 |
| 32 | 0.348 | -8.8 | 9 |
| 126 | 0.180 | -14.9 | -100 |
| 10^3 | 0.159 | | |
| 10^4 | -169 | | |
| 10^5 | -179 | \( \approx -180 \) (179.9) | |

\( \omega / \omega_0 = 10^5 \) rad/s

\( \left| G(s) H(s) \right| = 4 \times 10^{-7} \) \( \approx -128 \) dB

128 dB gain margin \( \Rightarrow G_0 = 2.5 \times 10^5 \)
(P3-15)

\[ I_3 = \frac{50 I_1}{50 + 80} = \frac{7.3 mA}{180} \approx \frac{40.8}{123 mA} \]

\[ I_1 = \frac{50 I_1 + 10}{40.8} \approx 123 mA \]
\[ V_{BE} = 0.7 \text{V} \]
\[ B = 100 \]
\[ R_{dc} = R_c + R_E = 500 \Omega \]
\[ R_{ac} = R_c = 300 \Omega \]

\[ I_{cq} = \frac{V_{cc}}{R_{ac} + R_{dc}} = \frac{20}{500 + 300} = 0.25 \text{mA} \]

\[ R_B = 0.1 \times R_E = 0.1 \times 500 = 2 \text{k}\Omega \]

\[ V_{BB} = V_{BE} + I_{cq} \left[ \frac{R_E}{B} + R_E \right] = 0.7 + (0.25 \text{mA}) \left[ \frac{2 \text{k}}{100} + 0.2 \text{k} \right] = 6.2 \text{V} \]

\[ R_1 = \frac{R_B \times V_{cc}}{V_{cc} - V_{BB}} = \frac{(2 \text{k})(20)}{20 - 6.2} = 2.9 \text{k}\Omega \]

\[ R_2 = \frac{R_B \times V_{cc}}{V_{BB}} = \frac{(2 \text{k})(20)}{6.2} = 6.45 \text{k}\Omega \]

\[ V_{pp} (\text{symm}) = 2I_{cq} \times R_c = 2(0.25 \text{mA})(300 \Omega) = 15 \text{V}_{pp} \]

\[ V_{CES} = V_{cc} - I_{cq} \times R_{dc} = 20 - (25 \text{mA})(0.5 \text{k}) = 7.5 \text{V} \]

\[ V_c = V_{CES} + I_{cq} \times R_{ac} = 7.5 + (25 \text{mA})(0.3 \text{k}) = 15 \text{V} \]

\[ I_c = \frac{V_c}{R_{ac}} = \frac{15}{0.3 \text{k}} = 50 \text{mA} \text{ (or } 2I_{cq}) \]
\[ \frac{P1}{P5.15} \]

\[ \text{Given: } C_E = C_C = \infty \]
\[ R_1 = 22k \Omega \]
\[ R_2 = 240k \Omega \]
\[ R_C = 4k \Omega \]
\[ R_E = 200k \Omega \]
\[ R_L = 4k \Omega \]
\[ V_{BE} = 0.6V \]
\[ V_{CC} = 20V \]
\[ \beta = 300 \]

\[ \text{ANALYSIS} \]
\[ \text{Assume } i_C = i_E \]

\[ a) \quad I_{CQ} \times V_{CEQ} \]
\[ R_E = \frac{R_1 \times R_2}{1 + R_1} \approx 20.2k \Omega \]
\[ V_{BB} = \frac{R_1 \times V_{CC}}{R_1 + R_2} = \frac{(22k)(20)}{22k + 240k} \approx 1.68V \]
\[ I_{CQ} = \frac{V_{BB} - V_{BE}}{R_E/\beta + R_E} \approx \frac{1.68 - 0.6}{20.2k \times 300 + 0.2k} \approx 4.04mA \]
\[ V_{CEQ} = V_{CC} - I_{CQ} R_C = 20 - (4.04m)(2.2k) = 3.03V \]

\[ b) \text{ max } V_{opp} \text{ (undistorted)} \]
\[ V_{oc} = V_{CEQ} + I_{CQ} R_{ac} = 3.03 + (4.04m)(2.2k) = 11.92V \]
\[ I_{CC} = \frac{V_{oc}}{R_{ac}} = \frac{11.92}{2.2k} = 5.42mA \]
\[ \therefore I_{CQ} \text{ in upper half of ac @} \]
\[ V_{opp} = 2\sqrt{0.95} I_{CQ} - 1\times R_{L} \times \frac{1}{R_{L} + R_E} \]
\[ = 2\sqrt{0.95}(5.42mA) - (4.04m)(2K) \]
\[ V_{opp} = 4.44V \]
a) $P_{dc} = \frac{V_{cc}^2}{R_1+R_2} + V_{ceq}I_{cQ} + I_{cQ}^2(R_c+R_E)$

$$= \frac{20^2}{26.2K} + (3.03)(4.04m) + (4.04m)^2(4.2K)$$

$$= (1.53 + 12.24 + 68.55)mW$$

$P_{dc} \approx 82.32mW$

d) $A_v = -\frac{R_c}{1/\beta} \quad ; \quad \beta = \frac{V_t}{I_{cQ}} = \frac{26m}{4.04m} = 6.41/\Omega$

$$A_v = -\frac{4.41/\Omega}{6.41/\Omega + 200} = -9.69 V/V$$

e) $I_{cc} = \frac{V_{cc}^2}{R_{dc}} = \frac{20}{4.2K} = 4.76mA$
EF (cc)

\[ R_{in} = R_E \parallel \beta (r_{e2} + (R_{E11}R_L)) \]

\[ R_{in} = R_E \parallel \beta (R_{E11}R_L) = R_E \parallel 32K \]

\[ 5k = R_E (32k) \quad (5k)(32k) = R_E (32k - 5k) \quad 160 = 27R_E \]

\[ R_E = 5.93K \Omega \]

\[ R_{ac} = R_{E11}R_L = 4.5 \Omega \quad R_{dc} = R_E = 8 \Omega \]

\[ I_{CQ} = \frac{V_{cc}}{R_{dc} + R_{ac}} = \frac{24}{12} = 2A \quad r_c = \frac{V_I}{I_{CQ}} = \frac{26m}{13m} = 2 \Omega \] Assumption ok

\[ V_{BB} = V_{BB} + I_{CQ} (R_E + R_E) = 1.4 + (2) (5.93k \frac{8k}{8k + 8}) = 18.9V \]

\[ R_1 = \frac{R_E}{1 - \frac{V_{BB}}{V_{cc}}} = \frac{5.93k}{1 - 18.9/24} = 27.9K \Omega \]

\[ R_2 = \frac{R_E V_{cc}}{V_{BB}} = \frac{(5.93k)(24)}{18.9} = 7.53K \Omega \]

Current division:

\[ I_{M} = \frac{R_E I_{CQ}}{R_E + r_L} = \frac{I_{CQ}}{2} = 1A \]

\[ P_{out} = \left( \frac{0.9I_{M}^2}{\sqrt{2}} \right) R_L = \frac{1}{2} (0.9)^2 (8) = 3.24W \]

\[ A_i = \frac{R_E}{R_E + r_2 + (R_{E11}R_L)} \quad \frac{R_E}{R_{E11}R_L} = \frac{(5.93k)}{(5.93k + 4)(1/2)} = 425A/A \]
Given

\[ \text{CMRR} = 95 \text{ dB} \]
\[ A_d = 200 \]
\[ V_{di} = 3 \text{ mV} \]
\[ V_{ci} = 15 \text{ mV} \]

\[ \text{CMRR} = 20 \log \left| \frac{A_d}{A_c} \right| \quad \therefore \quad \left| \frac{A_d}{A_c} \right| = 10^{\frac{95}{20}} \]

\[ \left| A_d \right| = \left| A_d \right| 10^{-\left(\frac{95}{20}\right)} = (200) 10^{-5.5} = 3.52 \times 10^{-3} \]
\[ A_c = -3.52 \times 10^{-3}, \quad A_d = -200 \]

\[ V_{od} = V_{di} A_d = (3 \text{ mV})(200) = 0.6 \text{ V} \]
\[ V_{oc} = V_{ci} A_c = (15 \text{ mV})(3.52 \times 10^{-3}) = -53.44 \text{ V} \]

Accept

\[ V_{od} = \frac{V_{di} A_d}{2} \]

worked this way on T2 review.
Given:
\[ V_{BB} = 8\,\text{V} \]
\[ R_B = 5\,\text{k}\Omega \]
\[ V_{CE} = 10\,\text{V} \]
\[ I = 4\,\text{mA} \]
\[ R_E = 800\,\Omega \]
\[ V_{BE} = 0.7\,\text{V} \]
\[ \beta = 100 \]

Want: \[ V_{out} \]

\[ I_g = \frac{I_c}{\beta} \]

\[ V_{out} = V_{BB} - \frac{R_E I_c}{\beta} - I_E R_E - V_{BE} \]

If: assume \[ I_c = I_E \] (\(\alpha = 1\)) \[ I_c = I_E = I = 4\,\text{mA} \]

\[ V_{out} = 8 - \frac{(5\,\text{k})(4\,\text{mA})}{100} - (4\,\text{mA})(0.8\,\text{k}) - 0.7 = 3.9\,\text{V} \]

If use \[ I_c = \alpha I_E \]

\[ \alpha = \frac{\beta}{\beta + 1} = \frac{100}{101} = 0.99 \]

\[ I_c = (0.99)(4\,\text{mA}) = 3.96\,\text{mA} \]

\[ V_{out} = 8 - \frac{(5\,\text{k})(3.96\,\text{mA})}{100} - (3.96\,\text{mA})(0.8\,\text{k}) - 0.7 = 3.93\,\text{V} \]
Problem 5.64

\[ V_{cc} = 20V \]

Let \( I_{REF} = I_{C1} \) (neglect base currents)

\( Q_1: V_B = V_C \) (assume \( V_{BE} = 0.7V \))

\[ V_E = 0 \rightarrow V_B = 0.7V = V_C \]

\( Q_1 \) and \( Q_2 \) form simple current mirror, so \( I_{REF} \approx I_2 = 10mA \)

\[ I_{REF} = \frac{V_{cc} - V_C}{R} \] \( R = \frac{V_{cc} - V_C}{I_{REF}} = \frac{20 - 0.7}{10mA} = 1.93K\Omega \)

(from 5.63, Mod) \( I_{out} = V_T \ln \left( \frac{I_{REF}}{I_{out}} \right) \); \( R = \frac{V_T}{I_{out}} \ln \left( \frac{I_{REF}}{I_{out}} \right) \), assume room temp

\( Q_3: R_3 = \frac{26 mV}{1mA} \ln \left( \frac{10m}{1m} \right) = 60 \Omega \)

\( Q_4: R_4 = \frac{26 mV}{0.1mA} \ln \left( \frac{10m}{0.1m} \right) = 1.2K\Omega \)

\( Q_5: R_5 = \frac{26 mV}{0.1mA} \ln \left( \frac{10m}{0.1m} \right) = 1.2K\Omega \) (100μA = 0.1mA)

\( Q_6: R_6 = \frac{26 mV}{0.05mA} \ln \left( \frac{10m}{0.05m} \right) = 2.7K\Omega \)
Given: \( f_T = 5\,\text{GHz} \)
\[ \beta = 400 \]
\[ C_{bb} = C_{bc} = 0.5\,\text{pF} \]
\[ I_C = 5\,\text{mA} \]
\[ R_L = R_C = 7\,\text{k}\Omega \]
\[ R_E = 20\,\text{k}\Omega \]
\[ R_S = 2\,\text{k}\Omega \]

Want: \( f_H \)

External caps shorts at high frequencies

Small signal model at high frequencies

Assumptions:
- \( r_e \) large → ignore
- \( r_{bb} \) small → ignore
- \( C_{be} \) small → ignore
- \( r_{bc} \) large → ignore

Simplified model: Using Miller theorem:

\[
C_{M1} = C_{bc}(1 - A_V)
\]
\[
C_{M2} = C_{bc}(1 - \frac{1}{A_V})
\]

\[
\frac{r_e}{I_C} = \frac{2.6\,\text{mV}}{5\,\text{mA}} = 5.2\,\Omega, \quad \frac{A_V(CE)}{r_C} = \frac{R_{C1}R_L}{r_C} = \frac{7\,\text{k}\Omega}{5.2} = 1.3\,\text{k}\Omega
\]

\[
r_T = 400(5.2) = 2.08\,\text{k}\Omega
\]
\[ P10.29 \]

\[ C_{M1} = (0.5 \mu F) (1 - (-0.73)) = 337 \mu F \]

\[ C_{M2} = (0.5 \mu F) (1 - \frac{1}{-0.73}) = 0.5 \mu F \]

\[ C_{62} = \frac{1}{2 \pi f_{T} \sqrt{C}} = \frac{5 \mu F}{2 \pi (5 \times 10^{-3} \times 2 \mu F)} = 61.2 \mu F \]

\[ C_{i1} = C_{62} = C_{M1} = 61.2 \mu F + 337 \mu F = 398.2 \mu F \]

Open circuit time constants:

\[ R_S = 0 \]

\[ V_{S2} = 0 \]

\[ g_m V_{be} = 0 \]

\[ C_{i1} R_{L} \]

**Input:**

\[ R = R_{S} / / R_{L} / / R_{T} = 2k / / 2k / / 2.08k = 971 \Omega \]

\[ T_{in} = C_{in} R = (398.2 \mu F \times 971) = 0.387 \mu s \]

\[ f_{in} = \frac{1}{412 k Hz} \]

**Output:**

\[ R = R_{C} / / R_{L} = 7k / / 7k = 3.5 k \]

\[ T_{out} = C_{out} R = (0.5 \mu F) (3.5 k) = 1.75 \mu s \]

\[ f_{out} = 90.9 \text{ MHz} \]

Note: \[ f_{out} > 10 f_{in} \]

So \( f_{in} \) is dominant and

\[ f_h = 412 \text{ kHz} \]
Given: \( V_{cc} = 16V \)
\( R_{c} = R_{L} = 6K \Omega \)
\( R_{E} = 300 \Omega \)
\( R_{S} = 2K \Omega \)
\( C_{B} = C_{E} = 0.24F \)
\( R_{in} = 4K \Omega \)

\[ f_{L} \]

\( R_{in} = R_{B} \parallel \left( (r_{\pi} + \beta R_{E}) \right) = 4K \Omega \)

Method of Short Ckt + 2 (\( V_{e} \) shorts, \( I_{b} = 0 \), \( \beta \) = 0)

\( C_{c} (C_{B} \) shorts): \( R_{cc} = R_{C} + R_{L} = 12K \Omega \)
\( C_{b} (C_{E} \) shorts): \( R_{cb} = R_{S} + \left[ R_{B} \parallel (r_{\pi} + \beta R_{E}) \right] = R_{S} + R_{in} = 6K \Omega \)

\[ f_{cc} = \frac{1}{2\pi R_{cc} C_{cc}} = \frac{1}{2\pi \times (0.24)(12K)} = 66.3 \text{Hz} \]

\[ f_{cb} = \frac{1}{2\pi R_{cb} C_{cb}} = \frac{1}{2\pi \times (0.24)(6K)} = 132.6 \text{Hz} \]

Less than a decade apart, so

\[ f_{L} = \sqrt{f_{cc}^2 + f_{cb}^2} \approx 148.3 \text{Hz} \]