Midterm 3 Exam

Name: _____________________                                                   Max:   50 Points

Question 1 Determine $y_{21}$ and $y_{22}$ for the circuit shown (a). The model that defines the $y$-parameters is in (b). (6 points)

Solution For $y_{21}$, set $v_2 = 0$ by shorting it. Then $i_1 = v_1/Z_{c1} = sC_1 v_1$ and $i_2 = -i_1$, so that

$$i_2 = y_{21} v_1$$
$$-sC_1 v_1 = y_{21} v_1$$
$$y_{21} = -sC_1$$

For $y_{22}$, set $v_1 = 0$ by shorting it. Then $C_1$ and $C_2$ are in parallel and their parallel impedance is $1/s(C_1 + C_2)$. Consequently, their admittance is $s(C_1 + C_2)$, so that $y_{22} = s(C_1 + C_2)$.

Question 2 For the BJT in the amplifier shown, $\beta = 100$, and is biased at $I_C = 1$ mA. Ignore the BJT’s parasitic capacitances. Further, $C_{C1} \to \infty$, and $R_S = 6K$. Estimate the lower 3-dB bandwidth if $C_{c2} = 1 \mu F$. (6 points)

Solution $g_m = 40I_C, r_\pi = \beta/g_m = 2.5K$. Using BJT scaling, $C_{C1}$ sees a resistance $R_i$ to its right where

$$R_i = \left(r_\pi + (1 + \beta)(10K||10K)\right)||100K = 84K$$

The total resistance the capacitor sees is $R_S + R_i = 90K$, and the time constant is $\tau = (90K)(0.1 \mu F) = 9$ ms. The 3-dB bandwidth is thus $B = 1/(2\pi \tau) = 17.7$ Hz.
Question 3 Consider the CE BJT amplifier below.

Estimate the upper 3 dB bandwidth of the amplifier. Start by drawing a hybrid-\(\pi\) small signal model of the amplifier and be sure to include \(C_\pi\), \(C_\mu\), and \(g_m\). (8 points)

**Solution**

The Miller effect transforms \(C_\mu\) to a value \(C_M = (1 + |A_M|)C_\mu\) where \(A_M = -g_m(R_L\|R_C)\), the gain “working across” \(C_\mu\). That is

\[
C_M = (1 + 136)(21 \text{ pF}) = 2.88 \text{ nF}
\]

The Miller capacitance is in parallel with \(C_\pi\). A small signal model is

The time constant is \(\tau = (C_\pi + C_M)(R_1\|R_2\|r_\pi\|R_s) = (3 \times 10^{-12})(795 \Omega) = 2.4 \mu s\). The upper 3 dB frequency is then

\[
f_H = \frac{1}{2\pi\tau} = 66.3 \text{ kHz}
\]
**Question 4** Consider the transfer function shown. Sketch the Bode magnitude plot of the function. Be sure to add all pertinent details (slopes, breakpoints, midband gain, etc.). For the frequency axis, use rad/s.  

\[ T(s) = \frac{5 \times 10^5 s}{(s + 100)(s + 50,000)} \]

**Solution**

\[ T(s) = \frac{5 \times 10^5 s}{(s + 100)(s + 50,000)} = \frac{5 \times 10^5 s}{100(50,000)} \cdot \frac{s}{\frac{s}{100} + 1}\left(\frac{s}{50,000} + 1\right) \]

\[ = 0.1 \frac{s}{\left(\frac{s}{100} + 1\right)\left(\frac{s}{50,000} + 1\right)} \]

The transfer junction has zero at the origin, a pole at \( s = 100 \) and a pole at \( s = 50,000 \), and one can draw the Bode plot and all the breakpoint and slopes from this. The remaining bit of information is the midband gain. One method for finding this is to simply evaluate \( |T(j\omega)| \) somewhere in the midband. That is, well past the pole at 100 rad/s but not close to the pole at 50,000 rad/s. A good choice is \( \omega = 1,000 \) rad/s.

\[ |T|_{s=j(1,000)} = 0.1 \frac{1,000}{\sqrt{1 + \left(\frac{1,000}{100}\right)^2} \sqrt{1 + \left(\frac{1,000}{50,000}\right)^2}} \approx 10 \equiv 20 \text{ dB} \]
**Question 5** The circuit shown is the frontend of the IR receiver lab in this course. Ignore the MOFET’s capacitances. $R_1 = R_2 = 680K$, $R_p = 47K$, and $R_s = 5.6K$.

(a) Determine $C_{C1}$ so that the circuit has a 3-dB bandwidth of 1.1 kHz. (5 points)

(b) If $V_{TN} = 1.9 V$, what is the current through $R_s$? (1 point)

(c) If the photocurrent from a 5-kHz IR transmitter is $1 \mu A$, what is the signal voltage $v_o$? (1 point)

**Solution**

(a) The time constant for 1.1 kHz is $\tau = 145 \mu s$ and $C_c$ sees $R_p + R_1 || R_2 = 387K$. Consequently $C_c = \tau / 387K = 374 pF$. In a practical circuit one would use 390 pF.

(b) $V_G = 7.5 - V_{TN} = 5.6 V$, so that the current through $R_s = 5.6 / 5.6K = 1 mA$.

(c) The signal voltage across $R_p$ is $(10 \mu A)(47K) = 47 mV$. The MOSFET is a follower, so this is essentially the same as $v_o$. 

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Question 6 The maximum current, voltage, and power ratings for the MOSFET are 4 A, 60 V, and 40 W, respectively.

(a) Sketch and label the SOA for the MOSFET using linear voltage and current scales. (4 points)
(b) For the amplifier determine $R_D$ and sketch the load line that produces maximum power in the transistor for $V_{DD} = 50$ V. Be sure to clearly indicate all important points on the load line. (5 points)

Solution
The plot below shows the SOA and a load line that is anchored at $V_{DD} = 50$ V and touches the maximum power hyperbola but still stays in the SOA. It touches the SOA at $V_{DD}/2 = 25$ V. The power dissipation is 40 W so that $I_D$ at this point is $40/25 = 1.6$ A. From this it follows that $I_{D(max)} = 3.2$ A as indicated. The slope of the load line is $-3.2/50$ and this equals $-1/R_D$ so that $R_D = 50/3.2 = 15.63$ Ω.
Question 7  Consider a BJT with a rated power of 115 W at $T_{\text{case}} = 25 ^\circ \text{C}$, and a maximum allowable junction temperature $T_{j,\text{max}} = 200 ^\circ \text{C}$. The transistor is mounted on a heat sink with parameters $\theta_{\text{case-sink}} = 1 ^\circ \text{C}/\text{W}$, and $\theta_{\text{sink-amb}} = 4 ^\circ \text{C}/\text{W}$. Determine how much power the BJT can safely dissipate at an ambient temperature of $T_A = 25 ^\circ \text{C}$. (8 points)

$Hint$, first show that the thermal resistance from the device/junction to the case is 1.52 $^\circ \text{C}/\text{W}$.

Solution

The thermal resistance from the device/junction to the case is not given explicitly, so we need to determine it before proceeding. The BJT is rated at 25 W at $T_{j,\text{max}} = 200 ^\circ \text{C}$ and a thermal model and the calculation of $\theta_{\text{dev-case}}$ is then

$$T_j = T_A + P_D (\theta_{\text{dev-case}})$$

$$200 = 25 + 115 (\theta_{\text{dev-case}})$$

$$\theta_{\text{dev-case}} = 1.52 \hspace{1pt} ^\circ \text{C}/\text{W}$$

(2 points)

Now we can determine the maximum allowable power dissipation when the BJT is mounted on a heat skink with the given parameters. A thermal model for the problem is shown below.

$$P_{D,\text{max}} = \frac{T_{j,\text{max}} - T_A}{(\theta_{\text{dev-case}} + \theta_{\text{case-sink}} + \theta_{\text{sink-amb}})}$$

$$= \frac{200 - 25}{1.52 + 1 + 4}$$

$$= 26.8 \text{W}$$

(6 points)