Midterm 1 Exam

Name: _____________________                                                   Max:   50 Points

Question 1 (2 points each unless noted otherwise)

1. A linear power supply consists of a transformer with 7.4-VAC secondary, full-wave bridge rectifier, and smoothing capacitor. What is the approximate output voltage? Take $V_y = 1.1$ V into account.

   (a) 9.4 V  
   (b) 8.3 V  
   (c) 7.4 V  
   (d) 14.8 V

**Answer:** The peak secondary output voltage is $V_m = \sqrt{2} \cdot (7.4)$ V. For a full-wave bridge, the dc output voltage is then $V_m = \sqrt{2} \cdot (7.4) - 2(1.1) = 8.265 \approx 8.3$ V. Thus, option (b).

2. An engineer measures the bandwidth of the circuit shown by sweeping across a range of frequencies and measuring the output amplitude. She uses a $\times 1$ probe rather than a $\times 10$ probe. What is the measured bandwidth?

   (a) About the same as the true bandwidth  
   (b) About 2 times smaller than the true bandwidth  
   (c) About $\sqrt{2}$ times larger than the true bandwidth  
   (d) About 2 times larger than the true bandwidth  
   (e) Need additional information

**Answer:** A standard, $\times 1$ scope probe has an internal resistance of 1MΩ. This about the same as the 910K. Thus, the resistance that $C$ sees will be about 2 times smaller once the probe is connected. This will increase the bandwidth by a factor 2. Thus, option (d).

3. Which of the following depicts the correct current direction? Circle one.

4. The output voltage of a three-terminal voltage regulator is 3.3 V @ 5 mA load, and 3.25 V @ 3 A load. What is the regulator’s output resistance?

   (a) $\approx 27$ mΩ  
   (b) $\approx 1$ K  
   (c) $\approx 1.1$ Ω  
   (d) $\approx 17$ mΩ

**Answer:** $R = \Delta V / \Delta I = 0.05 / 2.995 \approx 17$ mΩ, so (d)
5. An engineer measures the (step response) rise time of an amplifier as $t_r = 5$ ms. Estimate the 3- dB bandwidth of the amplifier.

**Answer:**

\[ BW \cong \frac{0.35}{t_r} = \frac{0.35}{5 \times 10^{-3}} = 70 \text{ Hz} \]

6. Consider the amplifier shown. $V_{in} = 1.5$ V, what is $V_{out}$? Assume ideal op-amps.

**Answer:**

Gain of 1st amplifier is $A_f = -(30)/10 = -3$ and gain of 2nd amplifier is $-1$. Thus, overall gain is $(-3)(-1) = 3$. The output voltage is thus $V_{out} = 1.5 \times 3 = 4.5$ V.

7. The output of the circuit shown is

(a) Sine wave with frequency $\omega$ rad/s
(b) Triangular wave with frequency $\omega$ rad/s
(c) Square wave with frequency $\omega/2\pi$ Hz
(d) Need additional information

**Answer:** With no feedback, the circuit is highly non-linear and operates as a comparator, comparing the input amplitude against 0 V. The output is a square wave with frequency $\omega/2\pi$ Hz, so the answer is (c).

8. What is the voltage gain $A_v = v_o/v_s$ of the amplifier shown if $g_m = 0.04$ S and $r_o = 100$K?

(a) $\approx 364$
(b) $\approx -364$
(c) $-400$
(d) $400$
(e) Need additional information (i.e., $r_\pi$)

**Answer:**

$A_v = -g_m(r_o||10K) = -0.04(100K||10K) = -363.6 \approx -364$ so (b) is the correct answer.
9. The op-amp in the circuit is ideal, except for non-zero input bias currents. Further, \( R_1 = 10K \) and \( R_2 = 30K \). What should \( R_3 \)'s value be?

- (a) \( R_1 + R_2 = 40K \)
- (b) \( R_1 || R_2 = 7.5K \)
- (c) 10K
- (d) 30K

**Answer:** \( R_3 \) compensates for input bias currents and a rule of thumb is to choose \( R_3 = R_1 || R_2 \), so the answer is (b).

10. What is the 3-dB bandwidth of the circuit shown?

- (a) \( \approx 8 \) kHz
- (b) 31.83 kHz
- (c) 15.92 kHz
- (d) 100 kHz

**Answer:** \( C_1 \) sees an equivalent resistance \( R = R_2 = 10K \) and the time-constant is \( \tau = RC = 10 \mu s \), so the bandwidth is \( 1/(2\pi\tau) = 15.92 \) kHz, and (c) is the answer.

11. Consider a linear power supply consisting of a transformer, a full-wave bridge rectifier and a smoothing capacitor. Increasing the smoothing capacitor by 50% will

- (a) Reduce both ripple voltage and maximum inrush current by 50%
- (b) Reduce ripple voltage by 50% and increase maximum inrush current by 50%
- (c) Reduce ripple voltage by 50% and leave maximum inrush current unaffected
- (d) Reduce ripple voltage by 50% and increase maximum inrush current by 100%

**Answer:** (b)

12. Estimate the current through the blue LED in the circuit shown.

- (a) \( \approx 7.5 \) mA
- (b) \( \approx 13 \) mA
- (c) \( \approx 16 \) mA
- (d) \( \approx 18 \) mA

**Answer:** \( V_r \) for a Si diode is nominally 0.7 V, but LEDs are made from other semiconductor material and LEDs' turn-on voltages are different. In particular, blue LEDs have \( V_r \approx 3.5 \) V. Thus, the current in the circuit is \( I \approx (6 - 3.5)/330 \approx 7.5 \) mA, and the answer is (d).
Question 2. A certain linear regulator IC has 500 mV ripple voltage at its input, and the output ripple is to be less than 1 mV. What ripple rejection ratio (in dB) should the regulator have? (2 points)

Required rejection ratio is \( \frac{550 \text{ mV}}{1 \text{ mV}} = 550 = 20 \log_{10} 550 = 54.8 \approx 55 \text{ dB} \)

Question 3. Given that two frequencies are separated by 2.2 decades, and the lower frequency is 45 kHz, what is the second frequency? (2 points)

\[ 2.2 = \log_{10}(x/(45 \times 10^3)) \Rightarrow x = 7.13 \text{ MHz} \]

Question 4. In the circuit shown, the op-amp is ideal, except for an input bias current \( I_b = +1 \text{ nA} \). Further, \( R_F = 10 \text{K}, R_1 = 100 \Omega \) and \( C = 1 \mu F \). The switch is opened at \( t = 0 \). What is the output voltage after 5 seconds? (5 points)

Solution For \( t \geq 0 \), the voltage across the capacitor is \( v_C = (-I_b \Delta t)/C \) which is \( -(1 \times 10^{-9}) (5) = -5 \text{ mV} \) for \( t = 5 \text{ s} \). The gain of the amplifier is \( 1 + R_F/R_1 = 101 \), so that the output voltage is \(-505 \text{ mV} \).

Question 5. What is \( v_o \) in the following circuit if \( v_{REF} = 1.2 \text{ V}, R_1 = 680 \Omega, \) and \( R_2 = 200 \Omega \)? (3 points)

Solution The current through \( R_2 \) is \( 1.2/200 = 6 \text{ mA} \), which also flows through \( R_1 \). Thus, the output voltage is \( 1.2 + 0.006 \times 680 = 5.28 \text{ V} \).
Question 6. What is the 3-dB bandwidth of the amplifier shown if \( r_\pi = 2.5 \, \text{K}, r_o = 100 \, \text{K}, g_m = 40 \, \text{mS}, \) and \( C_L = C_F = 1 \, \text{nF}? \)  \( \) (4 points)

Solution: If one turns off \( V_I, \) it is shorted to ground and \( C_L \) is in parallel with \( C_F \) so the effective capacitance is 2 nF. This capacitor sees an equivalent resistance \( r_o = 100 \, \text{K}. \) With \( V_I \) off, \( g_m v_\pi = 0, \) and the current source is effectively removed from the circuit. The time-constant is \( \tau = RC = (2 \, \text{nF})(100 \, \text{K}) = 200 \, \mu \text{s}. \) The bandwidth is \( 1/(2\pi\tau) = 795.8 \, \text{Hz}. \)

Question 7 In the circuit shown, \( v_I = 0, \) the op-amp is ideal, except that it has an offset voltage \( V_{OS} = +10 \, \text{mV}. \) What is \( v_O? \) \( \) (4 points)

Solution The equivalent circuit with \( v_I = 0 \) and the offset voltage indicated, is shown. With respect to its offset voltage, the gain of the amplifier is 6, so that \( v_O = +60 \, \text{mV} \)

Question 8 In the circuit shown, the constant current source forces a dc current of 1 mA through \( R \) and \( D. \) The coupling capacitor is large enough so that it is effectively a short at the ac source’s frequency. The amplitude of the ac source is 10 mV. Determine the amplitude of the (ac) output voltage. The frequency is low enough so that one can ignore the diode junction- and diffusion capacitances. \( \) (4 points)

Solution The diode’s small-signal resistance is \( 1/(40I) = 25 \, \Omega. \) This forms a voltage divider with the \( R \) so that the ac output voltage is 5 mV.
Question 9 Consider the circuit shown. Assume $V_{PS} = 4.5$ V, and $R = 180$ Ω. Also shown are the LED’s voltage-current characteristics. Draw the circuit’s dc load line on the characteristics and find $I_D$ and $V_D$ (4 points)

Solution. On the voltage axis, mark the supply voltage: 4.5 V. On the current axis, mark the maximum current that can flow through the resistor: $I = 4.5/180 = 25$ mA. Connect the two points to get the dc load line. The dc load line intersects the diode $V$-$I$ curve at around $I_D \approx 12.5$ mA and $V_D \approx 3$ V.