EPE2165—Analog Electronic Exam #1

14 July, 2022

1. (10 points) Figure 1 depicts an amplifier composed of a cascade of three stages. The amplifier is fed by a signal source with a source resistance of $100\,\mathrm{k\Omega}$ and delivers its output into a load resistance of $100\,\Omega$. The first stage has a relatively high input resistance and a modest gain factor of 10. The second stage has a higher gain factor of 100 but a lower input resistance. Finally, the last, or output, stage has unity gain but a low output resistance. Calculate the overall gain of the amplifier. Express your answer in dB.

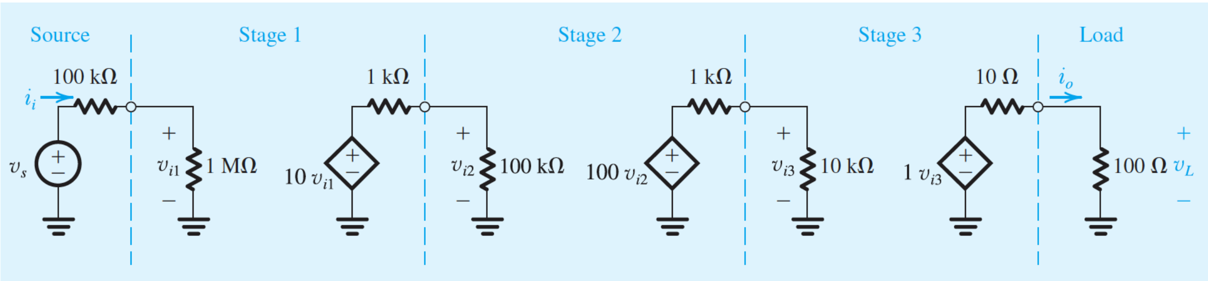


FIGURE 1. Three-stage amplifier

Solution:

- The fraction of the source signal that appears at the the input terminal is given by Equation (1)

$$\frac{v_{i1}}{v_s} = \frac{1\,\mathrm{M\Omega}}{1\,\mathrm{M\Omega} + 100\,\mathrm{k\Omega}} = 0.909V/V \tag{1}$$

- The voltage gain of the first stage is calculated by considering the input resistance of the second stage (Equation (2))

$$A_{v1} \equiv \frac{v_{i2}}{v_{i1}} = 10\frac{10\,\mathrm{k\Omega}}{100\,\mathrm{k\Omega} + 1\,\mathrm{k\Omega}} = 9.9V/V \tag{2}$$

- In the same manners, the voltage gain of the second stage is given by Equation (3)

$$A_{v1} \equiv \frac{v_{i3}}{v_{i2}} = 100\frac{10\,\mathrm{k\Omega}}{10\,\mathrm{k\Omega} + 1\,\mathrm{k\Omega}} = 90.9V/V \tag{3}$$

- The voltage gain of the output stage is given Equation (4)

$$A_{v1} \equiv \frac{v_L}{v_{i3}} = \frac{100\,\Omega}{100\,\Omega + 10\,\Omega} = 0.909V/V \tag{4}$$

- The overall gain is the product of the three gains (Equation (5))

$$\begin{aligned} A_v &= fracv_L v_{i1} = A_{v1}A_{v2}A_{v3} = 818V/V = 818V/V \\ &= 20log(818) = 58.25\,\text{dB} \end{aligned} \tag{5}$$

2. Consider a half-wave rectifier circuit shown in Figure 2. Let v_s be a sinusoid with 10V

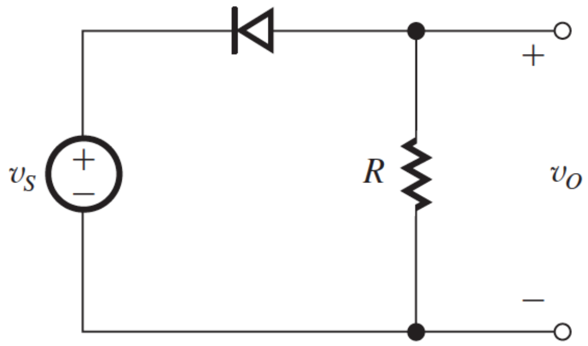


FIGURE 2

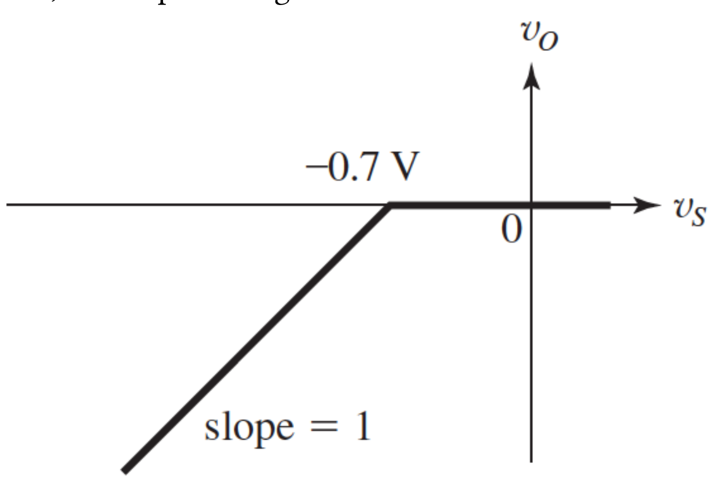
peak amplitude, and let $R = 1\,\text{k}\Omega$. Use the constant-voltage-drop diode model with $V_D = 0.7V$ and:

(a) (5 points) Sketch the transfer characteristic.

Solution: Assuming a constant voltage drop model for the diode, the output voltage is:

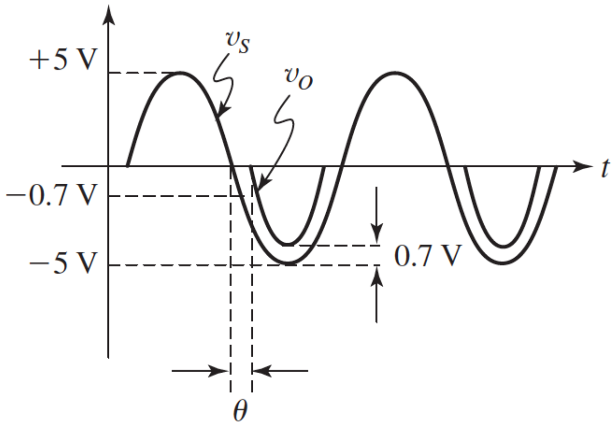
$$v_o = \begin{cases} v_s + V_D, & \text{if } v_s < -V_D. \\ 0, & \text{otherwise.} \end{cases} \tag{6}$$

Thus, the output voltage can be sketched as



(b) (5 points) Sketch the waveform of v_O.

Solution: The output voltages can be sketched as follows:



Please note that if the the amplitude $A_s = 10V$, then sinusoidal swings between +5V and -5V.

(c) (5 points) Find the peak current in the diode.

Solution: Peak current in diode is:

$$\frac{5V - V_D}{R} \tag{7}$$

(d) (5 points) Find the PIV of the diode

Solution: PIV occurs when v_S is at its peak and $v_O = 0$. Thus, $PIV = 5V$

3. The transistors in the circuit of Figure 3 have $k_n = k_p = 2mA/V^2$ and $V_{tn} = \text{-}Vtp = 0.4V$. Find v_O for each of the following cases:

(a) (5 points) $v_I = 0V$

Solution: When $v_I = 0V$, all transistors are in the cut off mode and $v_O = 0V$

(b) (5 points) $v_I = 1V$

Solution: When $v_I = 1V$, the the transistor Q_P will not conduct. In this case, the transistor Q_P effectively acts as if it was entirely removed and the circuit can be simplified as follow

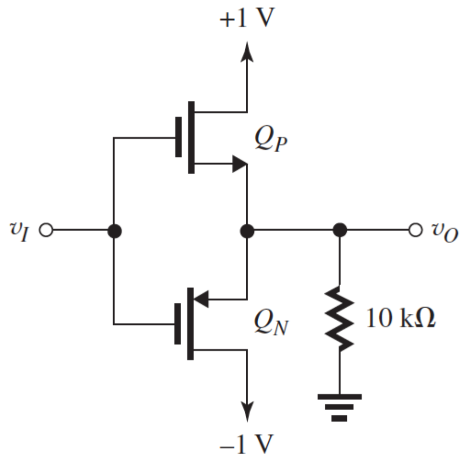
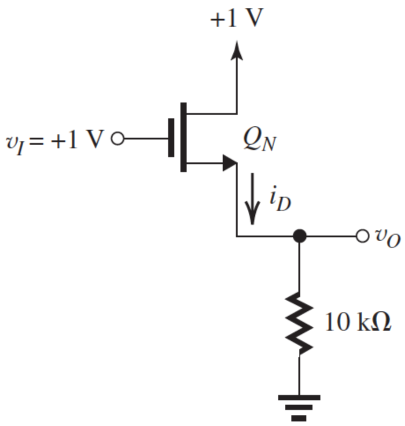


FIGURE 3



Note that, in this simplified circuit the voltage $V_{GD} = 0V$, thus the transistor is in the saturation mode. Consequently, as shown in Equation (8)

$$i_D = \frac{1}{2}k_n(v_{GS} - V_{tn})^2 \tag{8}$$

The current i_D can be inferred from the circuit as (Equation (9))

$$i_D = \frac{v_O}{R} = \frac{v_O}{10K} \tag{9}$$

Considering that

$$v_{GS} = v_I - v_O = 1 - v_0 \tag{10}$$

then, combining Equation (9) and Equation (10),

$$\begin{aligned} \tfrac{v_O}{10K} &= \tfrac{1}{2} \times 2(1 - v_O - 0.4)^2 \\ &= (0.6 - v_O)^2 \\ &= 0.36 - 1.2v_O + v_O^2 \end{aligned} \tag{11}$$

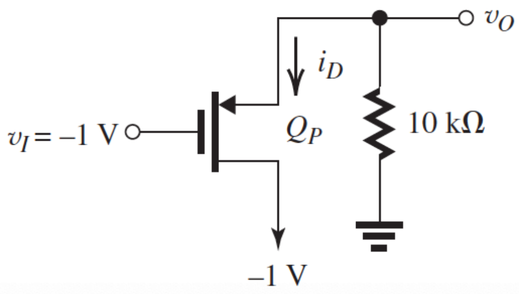
Equation (11) can be simplified as

$$v_O^2 - 1.3v_O + 0.36 = 0 \tag{12}$$

Equation (12) has two solutions: $v_O = 0.775V$ and $v_O = 0.4V$. The first solution is impossible since that would imply that $v_{GS} = 1 - 0.775 = 0.225$, which is not possible since it would be less than V_{tn}. Thus, only $v_O = 0.4V$ is the only realistic solution.

(c) (5 points) $v_I = -1V$

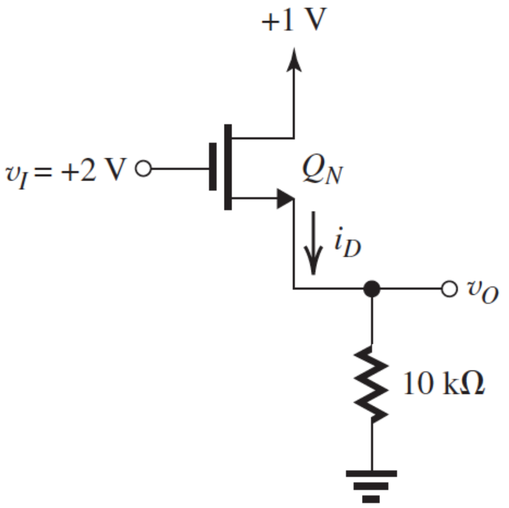
Solution: In this case, the transistor Q_N does not conduct; thus, the circuit can be simplified as shown below



In this case, the transistor will be in saturation as well. As in the previous answer $v_0 = -0.4$. Please note that, since Q_P is p-transistor, the output voltages is negative compared to that obtained in the previous question.

(d) (5 points) $v_I = -2V$

Solution: with $v_I = -1V$, Q_P does not conduct, and as done in the previous question, it can be simplified as



In this case, $v_{GD} = 1V$—which is greater than V_{tn}, thus, the the transistor will operate in the triode region and its current is expressed by

$$i_D = k_n \left[(v_{GS} - V_{tn})v_{DS} - \frac{1}{2}v_{DS}^2 \right] \tag{13}$$

As in the previous question, we can obtain the following relationships

$$\begin{cases} i_D = \dfrac{v_O}{10K} = 0.1v_O \\ v_{GS} = 2 - v_O \\ v_{DS} = 1 - v_O \end{cases}$$

combining Equation (13) and **??** d, we obtain

$$\begin{aligned} 0.1v_O &= 2\left[(1.6 - v_0)(1 - v_O) - \tfrac{1}{2}(1 - v_O)^2\right] \\ &= 2\left[1.6 - 2.6v_O + v_O^2 - \tfrac{1}{2} + v_O - \tfrac{1}{2}v_O^2\right] \\ &= v_O^2 - 3.2v_O + 2.2 \end{aligned} \tag{14}$$

Equation (14) can be rearranged as

$$v_O^2 - 3.3v_O + 2.2 = 0 \tag{15}$$

And it has two solutions

$$v_O = \frac{3.3 \pm \sqrt{3.3^2 - 8.8}}{2} \tag{16}$$

Solving Equation (16) gives $v_O = 2.37V$ or $v_O = 0.927$. Solution $v_O = 2.37V$ is not possible and only $v_O = 0.927$ is realistic.