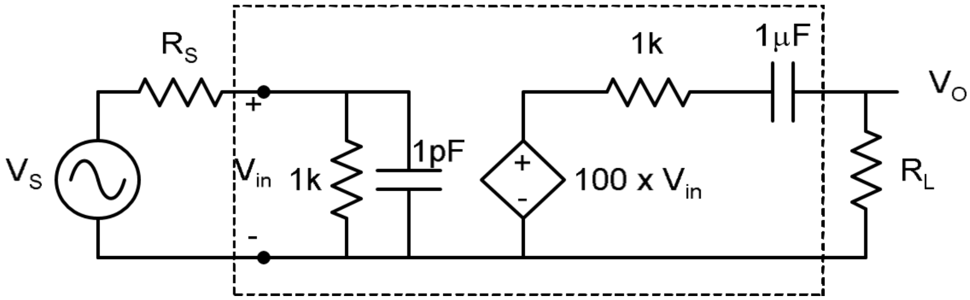
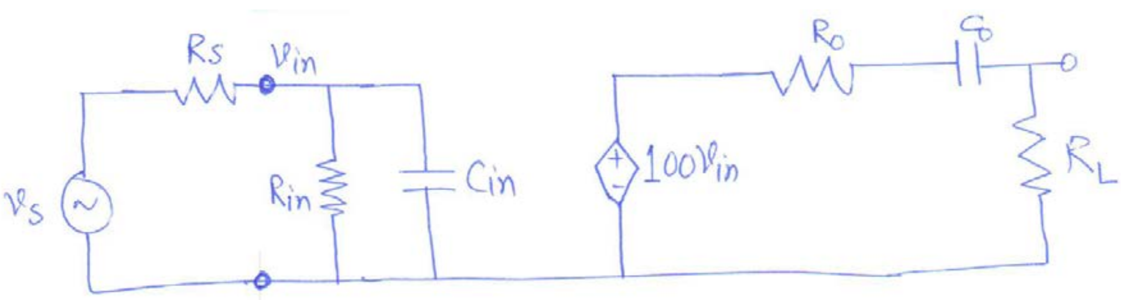
EE210-HW1 Solution

Q.1 For the equivalent circuit of the amplifier shown in the figure, determine the mid-band voltage gain, lower and upper cutoff frequencies for a source (R_S) and load resistance (R_L) of 1kΩ.



Sol.1:



$$v_{in} = \left(\frac{R_{in}}{R_{in} + R_s} * v_s\right) * \left[\frac{1}{1 + j\omega C_{in}(R_{in} \| R_s)}\right]$$

$$v_o = (100\ v_{in}) * \left[\frac{R_L}{R_L + \left(R_0 + \frac{1}{j\omega C_0}\right)}\right] = (100\ v_{in}) * \left[\frac{j\omega C_0 R_L}{1 + j\omega C_0(R_L + R_0)}\right]$$

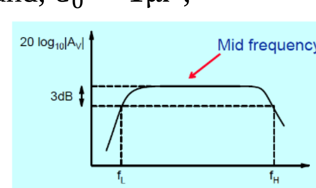
$$A_v = \frac{v_0}{v_s} = 100 * \left(\frac{R_{in}}{R_{in} + R_s}\right) * \left[\frac{1}{1 + j\omega C_{in}(R_{in} \| R_s)}\right] * \left[\frac{j\omega C_0 R_L}{1 + j\omega C_0(R_L + R_0)}\right]$$

- Mid-band voltage gain

$$A_v = 100 * \left(\frac{R_{in}}{R_{in} + R_s}\right) * \left(\frac{R_L}{R_L + R_0}\right)$$

For given values of $R_s = 1K\Omega$, $R_L = 1K\Omega$, $R_{in} = 1K\Omega$, $C_{in} = 1pF$, $R_0 = 1K\Omega$ and, $C_0 = 1\mu F$,

- Mid-band voltage gain $A_v = 100 * \left(\frac{1}{2}\right) * \left(\frac{1}{2}\right) = 25$
- Lower and upper cut-off frequencies,



$$A_v = 25 * \left(\frac{1}{1 + j\frac{f}{3.18 * 10^8}}\right) * \left(\frac{j\frac{f}{79.57}}{1 + j\frac{f}{79.57}}\right) \rightarrow f_L = 79.57\ Hz, f_H = 3.18 * 10^8\ Hz$$

Q.2 An amplifier's input-output relationship is described by the expression: $v_o = K_1(v_{in} + K_2)^2$. Determine the expression for second harmonic distortion. Assuming input is a sinusoid, determine the maximum output voltage swing such that harmonic distortion is less than 5% for $K_1 = 5V^{-1}$ and $K_2 = 1V$.

Sol.2: Given $K_1 = 5V^{-1}$ and $K_2 = 1V$.

$$v_o = K_1(v_{in} + K_2)^2$$

Let $v_{in} = a_o \sin(wt)$, then

$$v_o = K_1(v_{in}^2 + K_2^2 + 2K_2 v_{in}) = K_1\left(a_o^2 \sin^2(wt) + K_2 + 2K_2 a_o sin(wt)\right)$$

$$= K_1\left[a_o^2\left(\frac{1-\cos(2wt)}{2}\right) + K_2 + 2K_2 a_o \sin(wt)\right]$$

Second harmonic distortion is

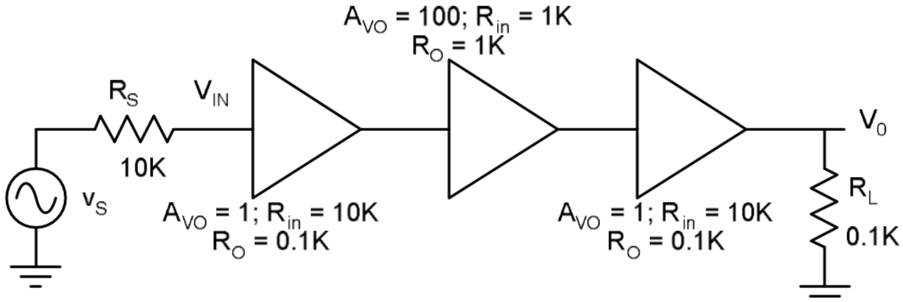
$$HD_2 = \frac{\frac{a_o^2}{2}}{2K_2 a_o} = \frac{a_o}{4K_2}$$

For second harmonic distortion (HD_2) to be within 5%,

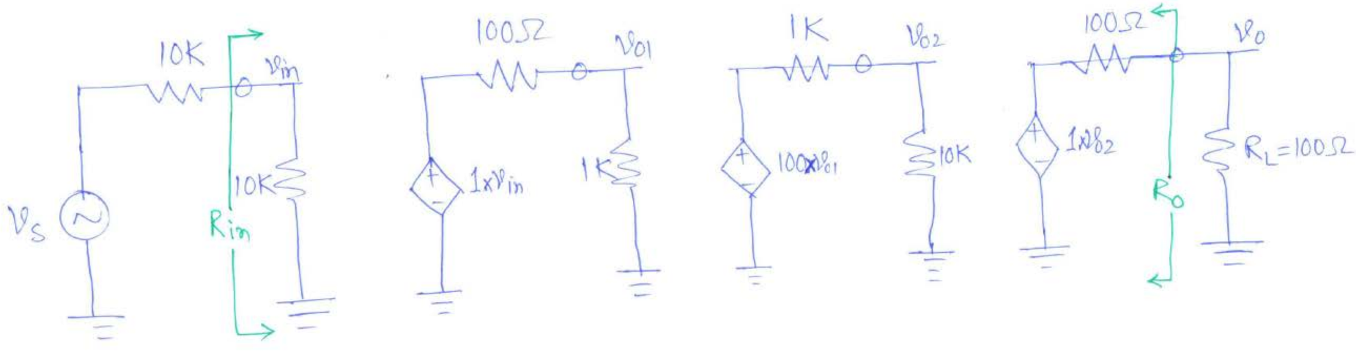
$$HD_2 = 0.05 = \frac{a_o}{4*1} \rightarrow a_o = 0.2V$$

The magnitude of the first harmonic in output $= K_1(2K_2 a_o) = 5*2*0.2 = 2V$. Thus, maximum voltage swing = ± 2V = 4V.

Q.3 (i) Determine the overall voltage gain, input resistance and output resistance of the amplifier shown below. **(ii)** First and third amplifiers at input and output respectively, are unity gain buffers to provide overall high input resistance and low output resistance. What will be the overall gain, if these unity gain buffers are removed?



Sol.3: (i)



$$\frac{v_o}{v_s} = \frac{v_o}{v_{o2}} * \frac{v_{o2}}{v_{o1}} * \frac{v_{o1}}{v_{in}} * \frac{v_{in}}{v_s}$$

$$\frac{v_o}{v_s} = \left(1 * \frac{100}{100+100}\right) * \left(100 * \frac{10K}{10K+1K}\right) * \left(1 * \frac{1K}{1K+100}\right) * \left(\frac{10K}{10K+10K}\right)$$

$$\frac{v_o}{v_s} = 20.66$$

$$R_{in} = 10K\Omega \text{ and } R_o = 100\Omega$$

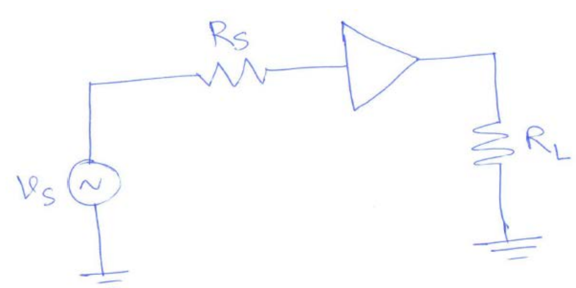
(ii) If unity gain buffers were not used, then $\frac{v_o}{v_s}$ would be 0.826.

Q.4 Two amplifiers A and B have the following characteristics:

A: A_{VO} = 100, R_{IN} = 1$k\Omega$, R_O = 1 $k\Omega$; B: A_{VO} = 10, R_{IN} = 100 $k\Omega$, R_O = 0.1 $k\Omega$

Create two examples (with appropriate source and load resistances), one where A provides higher voltage gain and one where B provides a higher voltage gain.

Sol.4: Amplifier A has higher gain but lower R_{in} and higher R_o compared to B. Gain obtained using A will suffer if R_s is close to R_{in}, R_L is close to R_o.



Suppose R_s = 100Ω (<< R_{in} of A) and R_L = 10KΩ (>> R_o of A), then for Amplifier A:

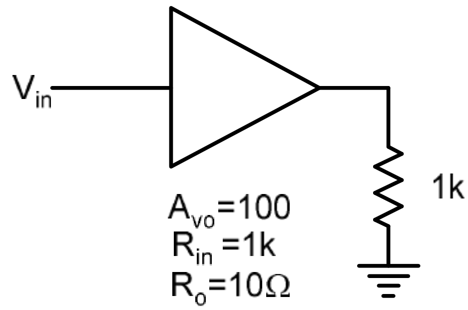
$$A_V = 100 * \left(\frac{R_{in}}{R_{in}+R_s}\right) * \left(\frac{R_L}{R_o+R_L}\right) = 82.64$$

For Amplifier B: A_V =9.89

Next, Suppose R_s = 10KΩ (> R_{in} of A) and R_L=0.1KΩ (< R_o of A), then for Amplifier A: A_V = 0.826

For Amplifier B: A_V = 4.5

Q.5 The amplifier shown in the figure has a maximum output current drive capability of $1mA$. Sketch qualitatively the output, when the magnitude of a sinusoidal input is $5mV$ and when it is $20mV$.



Sol.5: Assuming Rs = 0,

$$v_o = A_{v_o}\left(\frac{R_L}{R_O + R_L}\right) * v_{in} \approx 100V_{in}$$

If $v_{in} = 5mV\sin(wt)$, then

$$v_o = 0.5V\sin(wt)$$

$$i_o = 0.5mA\sin(wt)$$

Since i_o is within limit, so v_o is undistorted.

On the other hand, if $v_{in} = 20mV\sin(wt)$, then,

$$v_o = 2V\sin(wt)$$

$$i_o = 2mA\sin(wt)$$

When v_o exceeds, current limit is reached and output saturates to i_{limit}*R_L.