The material we have covered so far this semester is summarized (but NOT limited to) below:

1. Understand the difference between AC & DC signals.
2. Understand how to analyze circuit (with or without cap in it) to obtain transfer function.
3. Understand how to plot the Bode plots from an equation or circuit.
4. Amplifiers:
   a) Understand how to apply Amplifier models (voltage, current, etc.) to multistage amplifiers
   b) Analyze single input Amplifier (with model) for transfer function.
   c) Analyze amplifier’s gain in different configurations (inverting, noninverting, voltage follower)
   d) Understand frequency response of amplifiers for single amplifiers
   e) Compensation of real op-amp imperfections (Slew Rate, Clipping, Input bias currents, Voltage offset, frequency limitations, finite gain)
5. Diodes:
   a) Analyze diode circuit using ideal model
   b) Analyze diode circuit using constant voltage drop model
   c) Analyze diode circuit with both DC and AC signals

1. (a) Find \( I_{D1}, I_{D2}, I_{D3} \) and \( V_o \) using constant voltage drop method with \( n=1, V_T=25mV, \) and \( V_{DB}=0.7V. \)
   (b) Find \( V_{o,\text{total}} \) if the 3V source has 0.5sin(wt) noise.

\[ +9V \]
\[ 5.3k \]
\[ 2.3mA \]
\[ +3V \]
\[ -0.7 \]
\[ V_o \]
\[ D1 \text{ off, } D2 \text{ on, } D3 \text{ off: } \]
\[ D3 \text{ has to be off because current is not allowed to flow in that direction through the diode.} \]
\[ +9 - I_{D2}(5.3k) - 3.7 = 0 \]
\[ I_{D2} = \frac{(9-3.7)}{5.3k} = \frac{5.3}{5.3k} = 1mA \]
\[ \Rightarrow D2 \text{ on} \]

Check \( V_{o1} \):
\[ +3V + 0.7 - V_{o1} - 9 = 0 \]
\[ V_{o1} = -9 + 3 + 0.7 = -5.3 < 0.7 \]
\[ \therefore D1 \text{ is off} \]
\[ I_{D1} = 0 \]
\[ I_{D2} = 1mA \]
\[ I_{D3} = 0 \]
\[ V_o = 3.7V \]

Ac analysis:
- remove DC source (V=0 is a wire)
- \[ \frac{V_o}{I_D} \]
- \[ V_o = \frac{hV_I}{I_D} = \frac{(1)(25m)}{1m} = 25 \]
- \[ V_o = 0.5 \sin(wt) \]
- \[ V_{\text{total}} = 3.7 + 0.5 \sin(wt) \]

\[ V_{\text{total}} = 3.7 + 0.5 \sin(wt) \] V
Assume D1 on, D2 off:

\[ V_o = 3 + I_{P3} (1k) \]

\[ V_{loop} = -I_{D1} (1k) + 10 - 0.7 - 3 - I_{D3} (1k) = 0 \]

\[ \Rightarrow I : \]

\[ -I_{D1} + I_m + I_{D3} = 0 \]

\[ I_{D1} = (I_m + I_{D3}) \]

\[ \therefore -(I_m + I_{D3})(1k) + 6.3 - I_{D3}(1k) = 0 \]

\[ -1 (-2k)I_{D3} + 6.3 = 0 \]

\[ I_{D3} = \frac{5.3}{2k} = 2.65m > 0 \]

\[ \therefore D3 \text{ is on} \Rightarrow V_o = 3 + 1k (2.65m) \]

\[ V_o = 5.65V \]

Check \( V_{D2} \):

\[ -V_{D2} - 3 - I_{D3} (1k) = 0 \]

\[ V_{D2} = -3 - 1k (2.65m) = -5.65 < 0 \]

\[ \therefore D2 \text{ is off} \]

AC analysis:

\[ r_d = \frac{hV_I}{I_{D3}} = \frac{(1)(2.65m)}{2.65m} = 9.4 \Omega \]

\[ V_o = \frac{0.55 \sin(\omega t)(1k + r_d)}{1k + r_d + 1k} = 0.25 \sin(\omega t) \]

\[ V_{total} = 5.65 + 0.25 \sin(\omega t) \]
2. Sketch Bode Plots for \( H(s) = \frac{-1 \times 10^{14}(s^2)}{(s + 10k)^2(s + 100k)} \)

**Standard Form:** \( \frac{-1 \times 10^{14}(s^2)}{(10k)^2(\frac{s}{10k} + 1)^2(\frac{s}{100k} + 1)} \)

Critical frequencies:

Origin \( (\times 2) \), \( 10k \), \( 100k \)

At \( \omega = 1 \):
\[
-1 \times 10^{14} \frac{1}{(10k)^2(100k)(\frac{1}{10k} + 1)^2(\frac{1}{100k} + 1)} = 10^{14} \implies 20 \log(10) = 20 \text{dB}
\]

**Magnitude:**

- 2 at origin / zeroes \( \left( -20 \text{dB/decade} \right) \)
- \( 10k \) / pole \( \left( +20 \text{dB/decade} \right) \)
- \( 100k \) / pole \( -20 \text{dB/decade} \)

**Phase:**

- \(-90^\circ\) sign starts phase at \( \pm 180^\circ \)
- 2 at origin / zeroes \( 2(-90^\circ) = -180^\circ \)
- \( 10k \) / pole \( -45^\circ / \text{Decade} \times 2 \)
- \( 100k < \omega < 1 \text{Meg} \) / pole \( -45^\circ / \text{Decade} \)

Bandwidth is from \( 10k \) to \( 100k \).
4. \( H(s) = \frac{10k(10)\left(\frac{s}{10} + 1\right)}{1k\left(\frac{s}{100} + 1\right)\left(\frac{s}{1k} + 1\right)} = \frac{\left(\frac{s}{10} + 1\right)}{\left(\frac{s}{1k} + 1\right)\left(\frac{s}{100} + 1\right)} \)

Break freq: \( \omega = 10, 100, 1k \)

5. \( H(s) = \frac{100s^2}{(s+1)10\left(\frac{s}{10} + 1\right)} = \frac{10s^2}{(s+1)} \)

Break freq: \( \omega = 1, 10 \) phase starts at 180°

slope starts at +40dB/dec.

@ \( \omega = 1 \rightarrow 20 \log (10) = 20 \text{dB} \)
3. (a) Use voltage amplifier model to find voltage gain. \( A_{v0} = 20 \), \( R_1 = 10k\Omega \), \( R_c = 2k\Omega \).

\[ V_L = \frac{40V_3 (100)}{4,100} \]

\[ V_3 = \frac{40V \cdot 2k}{6k+2k} \]

\[ V_L = \frac{40(100)}{4,100} \cdot \frac{40}{1} \cdot \frac{1}{2} \approx 5V \]

(b) Find \( A_v = \frac{V_L}{V_3} \). Express your answer as a ratio (V/V) and in dB. [Round the answer to a whole number]

(c) For the input \( V_s = \sin(\omega t) \). State the maximum output value at \( V_L \).

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(c) Amplitude \( \Rightarrow \) maximum output will be the peak value: \( \text{gain} \cdot V_s = 5V \) \( V_L = 5V \) \( V_{\text{peak}} = 5V \)

(checking for clipping \( \Rightarrow \) \( V_L = \frac{40 \cdot (4k)}{2k} = 40V < +12V \)

\( V_s = V_{\text{max}} \)
4 (a) You are given the following characteristics for a real amplifier:
- Input offset voltage, \( V_{ios} = 4 \text{mV} \)
- Input offset current, \( I_{ios} = 100 \text{nA} \)
- Input bias current, \( I_{ib} = 1 \text{\mu A} \)
- Input Resistance, \( R_i = 1 \text{MS} \)
- Output Resistance, \( R_o = 50 \Omega \)
- Open-loop gain, \( A_v = 180 \text{dB} \)
- Unity-gain bandwidth, \( f_T = 11 \text{MHz} \)
- Output-swing limits, within 2Volts of supply
- Slow Rate, \( SR = 2 \text{V/\mu sec} \)

Given the following circuit with the operational amplifier powered at \( \pm 10 \text{V} \):

\[ \begin{align*}
\text{Given the following circuit with the operational amplifier powered at } & \pm 10 \text{V:} \\
\text{Find the ideal gain of the above circuit:} & \\
\frac{V_o}{V_{in}} = -5k & = -10 \text{V/V} \Rightarrow 20 \text{dB} \\
\text{For small input signals, what is the bandwidth} & \\
\text{of the circuit:} & \\
f_{3dB_{new}} = 11 \text{MHz} & \text{Hz} \Rightarrow R_2 = 11 \text{MHz} \\
\text{If a circuit needs to operate up to 5MHz,} & \\
\text{what is the maximum gain I can achieve using an} & \\
\text{inverting amplifier configuration?} & \\
f_{3dB_{new}} = 5 \text{MHz} = 11 \text{MHz} & \Rightarrow R_2 \frac{R_2}{R_1} = 5 = 2.2 \\
(\text{e.g. } & R_1 = 1k, R_2 = 2.2k) \end{align*} \]
4. (cont)

iv) If the above circuit is operated to produce the maximum possible peak voltage,

a) what is the bandwidth?

b) what is the maximum peak voltage value for the input?

da) \( f_{\text{max}} = \frac{SE}{V_p^2 \cdot \pi} = \frac{2}{1 \times 10^6 \cdot (8)(2) \pi} = 39.8 \text{ KHz} \)

b) maximum peak voltage = +8V output max.
Using ideal gain = -10 \( \frac{V}{V} \)

\[ \left| \frac{V_o}{V_{\text{in}}} \right| = 10 \Rightarrow V_{\text{in}} = \frac{V_o}{10} = \frac{8}{10} = 0.8 \text{V max} \]

v) Find the effect of the input offset voltage when \( V_{\text{in}} = 0 \text{V}. \)

\( V_{\text{offset}} = 4 \text{mV} \)

vi) How should the circuit above be modified to minimize the effect of the input bias current?

(Draw the circuit)
4. (b) You are given the following characteristics for a real amplifier:

- Input offset voltage, \( V_{os} = 3 \text{mV} \)
- Input offset current, \( I_{os} = 100 \text{nA} \)
- Input bias current, \( I_{b} = 1 \mu \text{A} \)
- Input Resistance, \( R_i = 1 \text{M} \Omega \)
- Output Resistance, \( R_o = 50 \Omega \)
- Open-loop gain, \( A_{vo} = 180 \text{dB} \)
- Unity-gain bandwidth, \( f_t = 15 \text{MHz} \)
- Output swing limits, within 2 Volts of power supply
- Slew Rate, \( SR = 4 \frac{V}{\mu \text{sec}} \)

If a circuit needs to operate at 5MHz using the above specifications for an operational amplifier and having a power supply of ±15V, what is the maximum gain that can be achieved using an:

ii) Non-inverting amplifier

\[
\frac{f_{3db,new}}{f_{3db,old}} = \frac{15 \times 10^6}{(1 + \frac{R_i}{R_o})} = \left(1 + \frac{R_i}{R_o}\right) = \frac{15 \times 10^6}{5 \times 10^5} = 3V
\]

Given the following circuit with the operational amplifier powered at ±15V.

![Circuit Diagram](image)

i) Find the ideal gain of the above circuit:

\[
\frac{V_o}{V_{in}} = \left(1 + \frac{18k}{2k}\right) = 10 \frac{V}{V}
\]

ii) For small input signals, what is the bandwidth of the circuit

\[
f_{3db,new} = \frac{15 \times 10^6}{10} = 1.5 \text{MHz}
\]

iii) What is the bandwidth when the circuit is operated to produce the maximum possible peak voltage value?

\[
f_s = \frac{4}{10 \times 10^{-6} (13 \pi)} = 98 \text{kHz}
\]

iv) What is the maximum amplitude of the input?

\[
\frac{V_o}{V_{in}} = 10 \frac{V}{V} \Rightarrow V_{in} = \frac{V_o}{10} = \frac{13}{10} = 1.3V
\]

v) For \( V_{in} = 0.001 \sin(2\pi 90k) \), what is the ideal value for the peak to peak voltage value at the output?

\[
V_{pp} = 2(0.001)(10) = 0.02V_{pp}
\]

vi) For \( V_{in} = 0.001 \sin(2\pi 90k) \), what is the peak voltage value at the output considering the input offset voltage?

\[
V_{pp} = 2(0.001)(10) + 3m(10) = 0.02 + 0.03 = 0.05V
\]
vii) How should the circuit above be modified to minimize the effect of the input bias current? Draw the schematic of the modified circuit and state values of added component(s).

\[ V_{\text{in}} \quad 2 \, \text{kΩ} \quad \text{−} \quad \text{−} \quad 36\,\text{kΩ} \quad \text{+} \quad V_{o} \]

\[ 2 \, \text{kΩ} \parallel 18 \, \text{kΩ} \parallel 1\,\text{MΩ} \approx \frac{2 \text{kΩ} (18 \text{kΩ})}{20 \text{kΩ}} = 1.8 \, \text{kΩ} \]