Example problem:

Given: op amp circuit as sketched;
\( V_i = 5 \cos(80 \pi t) \) mV (time \( t \) is in seconds)

Find: \( |V_o| \)

Solution.

Part 1 of circuit: passive RC filter (low-pass)
Part 2: non-inverting amp. (ex. 7.5)

Consider the amp (using example 7.5).
\[
G_2 = \frac{r_1 + r_2}{r_1} = \frac{15 + 2}{2} = 8.5.
\]

Now consider the low-pass filter...
\[
f_c = \frac{1}{2 \pi R_C} = \frac{1}{2 \pi \cdot 15 \cdot 10^3 \Omega \cdot 0.2 \cdot 10^{-6} F} = 53 \text{ Hz}.
\]

\[
f = \frac{\omega}{2 \pi} = 80 \pi = 2 \pi f_c \Rightarrow f = \frac{\omega}{2 \pi} = 40. \text{ Close to } f_c.
\]

For a low-pass filter, \( \frac{V_o}{V_i} = \frac{1}{1 + \left(\frac{f}{f_c}\right)^2} \) (7.33a).

\[
\frac{V_o}{V_i} = \frac{1}{\sqrt{1 + \left(\frac{80}{53}\right)^2}} \approx 0.18 = G_a.
\]

\[
|V_o| = G_1 \cdot G_2 \cdot |V_i| = 0.8 \cdot 85.9 \mu V = 6.84 \mu V \text{ Ans.}
\]
Example problem 2. Given: Circuit as sketched.

Current through the diode is \( i = I_0 \left( \exp \left( \frac{\lambda V}{N} \right) - 1 \right) \)

\( I_0 = 10^{-9} \text{A} \)

\( \lambda = 4 \text{V} \)

\( \text{NB: For } V_i \approx 1 \text{V}, \ \text{V}_0 \text{ as function of } V_i \).

| \( V_+ \approx V_- \) | \text{NB: This is always true when negative feedback is present}! |

Solution. Assume \( R \) much less than impedance of op. amp.

\( V_+ \approx 0 \)

\( V_- \approx V_+ = 0 \)

\( i = \frac{V_+ - V_-}{R} \approx \frac{V_i}{R} \) (current through \( R \))

Same current should pass through the diode.

\( i = I_0 \left( \exp \left[ \lambda (V_i - V_0) \right] - 1 \right) \)

\( \lambda = I_0 \left( \exp \left[ -\lambda V_0 \right] - 1 \right) \)

\( \frac{V_i}{R} = I_0 \left( \exp \left[ -\lambda V_0 \right] - 1 \right) \)

\( \frac{V_i}{R} \approx I_0 \exp \left[ -\lambda V_0 \right] - I_0 \)

\( \frac{V_i}{R} + 1 = \exp \left[ -\lambda V_0 \right] \)

\( -\lambda V_0 = \ln \left( \frac{V_i}{R I_0} + 1 \right) \)

\( V_0 = \frac{1}{\lambda} \ln \left( \frac{V_i}{R I_0} + 1 \right) \approx 0.025 \ln \left( \frac{V_i}{10^{-9} \text{A} R} + 1 \right) \)

Ans.
Note: If $R \ll 100 \text{ k} \Omega$, the first term in the ( ) is much greater than 1 ⇒

$$V_o \approx -0.025 \ln \frac{V_i}{10^-3 A \cdot R}$$

Example problem 3. Given: circuit as sketched,

$$V_{in} = 30 \sin (600n+9) + 60 \sin (2400n+46) + 9 \sin (3200n)$$

(voltage in $\mu$V). Find: $V_{out}$.

Solution. For all practical purposes, what is sketched is a high-pass filter.

$$f_c = \frac{1}{2\pi c} = \frac{1}{2\pi \cdot 10^{-3} \cdot 0.2 \cdot 10^{-9}} = 89.3 \text{ kHz} \quad (7.34)$$

For a high-pass filter, $\frac{V_o}{V_i} = \frac{f/f_c}{\sqrt{1+(f/f_c)^2}} \quad (7.34a)$

$\frac{V_o}{V_i}$ has to be calculated separately for each voltage component. Additionally, have to consider phase-shift: $\phi = 0 - \arctan \frac{f}{f_c} \quad (7.34b)$
For $30 \sin (600 \pi t)$, $f = \frac{600\pi}{2\pi} = 300 \text{ Hz}$.

$300 \ll f_c$, $\frac{f}{f_c} = \frac{300}{89300} \approx 0.0034$.

$$\frac{V_0}{V_c} = \frac{0.0034}{\sqrt{1 + 0.0034^2}} \approx 0.0034.$$  

$30 \cdot 0.0034 = 0.1 \text{ (mV)}$ - amplitude.

Phase shift is $\frac{\pi}{2} - \tan^{-1}(0.0034) \approx \frac{\pi}{2}$.

$30 \sin 600\pi t \rightarrow 0.1 \sin \left(600\pi t + \frac{\pi}{2}\right)$

Similarly, for other terms...

$6 \cos 2400\pi t$

$f = 1200 \text{ Hz}$

$\frac{f}{f_c} = 0.013$

$$\frac{V_0}{V_c} = \frac{0.013}{\sqrt{1 + 0.013^2}} \approx 0.013$$  

$\frac{\pi}{2} - \tan^{-1}(0.013) \approx \frac{\pi}{2} - 0.013$

$\approx 1.558$

$9 \sin 3200\pi t$

$f = 16000 \text{ Hz}$

$\frac{f}{f_c} = 0.179$

$$\frac{V_0}{V_c} = \frac{0.179}{\sqrt{1 + 0.179^2}} \approx 0.176$$  

$\frac{\pi}{2} - \tan^{-1}(0.179) \approx \frac{\pi}{2} - 0.177$

$\approx 1.394$

Final answer: a

$$[0.1 \sin (600\pi t + 1.57\pi) + 0.078 \cos (2400\pi t + 1.558\pi)$$

$$+ 1.584 \sin (3200\pi t + 1.394\pi)] \text{ mV}$$