(1) Op amp

A certain op amp has a maximum output voltage range from $-10$ to $+10$V. The slew-rate limit is SR = 2 V/μs. This op amp is used in the circuit below. $R_1 = 1kΩ$, $R_2 = 3kΩ$, $R_3 = 2kΩ$, $R_4 = 2kΩ$.

(a) What is the overall circuit gain ($V_o/V_i$)?

(b) Assume a sinusoidal input signal $V_i$ with an amplitude of 3V and frequency 1kHz. Plot the output wave-form to scale against time (i.e. $V_o(t)$)?

(c) Assume a sinusoidal input signal $V_i$ with an amplitude of 10V and frequency 1kHz. Plot the output wave-form to scale against time (i.e. $V_o(t)$)?

(d) Assume a sinusoidal input signal $V_i$ with an amplitude of 3V and frequency 1MHz. Plot the output wave-form to scale against time (i.e. $V_o(t)$)?

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(a) Ideal op amp

\[ V_+ = V_- = V_x \]
\[ I_+ = I_- = 0 \]

\[ I_+ = 0 \Rightarrow V_x = \frac{R_4}{R_3 + R_4} V_i \]

\[ 0 - \frac{V_x}{R_1} = \frac{V_x - V_o}{R_2} \Rightarrow -\frac{1}{R_2} + \frac{1}{R_1} = \frac{V_o}{R_2} \]

\[ V_x = \frac{R_1}{R_1 + R_2} V_o \]

\[ \frac{V_o}{V_x} = \frac{R_1 + R_2}{R_1 R_2} \]

(b) 0.5ms 1ms

(c) Max change 2 V/μs
(2) Consider the circuit shown below for the case $R=10k\Omega$. The power supply $V^+$ has a dc value of 10V on which is superimposed a 60-Hz sinusoid of 1-V peak amplitude. (This "signal" component of the power supply voltage is an imperfection in the power supply design. It is known as the power-supply ripple.) Calculate both the dc voltage of the diode and the amplitude of the sine wave signal appearing across it. Assume the diode to have a 0.7-V drop at 1-mA current and $n = 2$.

\[ I_D = I_{Do} \left( e^{\frac{V^+}{0.7}} - 1 \right) \]
\[ 1 \text{mA} = I_{Do} \left( e^{\frac{0.7}{2 \times 0.025} - 1} \right) \]
\[ \Rightarrow I_{Do} = 1.42 \times e^{-9} \text{ at diode (graphical method)} \]

\[ \text{DC:} \]
\[ 10 V \]
\[ 10 \text{k}\Omega \]
\[ \rightarrow \]
\[ V_D = 0.7 V \]
\[ I_D = \frac{10 - 0.7}{10 \text{k}\Omega} = 0.93 \text{ mA} \]
\[ 10V - I_D \times 10\text{k}\Omega - V_D = 0 \Rightarrow \text{graphical method for accurate solution.} \]
\[ 10 - 10 \times 0.93 \times e^{-9} \times (e^{\frac{V_D}{0.05} - 1}) \]

\[ \text{Ac.:} \]
\[ \frac{V_D}{V_{in}} = \frac{2 \times 0.025}{0.93 \text{mA}} = \frac{0.50 \times 10^{-1}}{0.93 \times 10^{-3}} \sim 50 \Omega \]
\[ V_D = \frac{R_D}{R_D + 10\text{k}\Omega} \times V_{in} = \frac{50}{50 + 10000} \times 1 = 5 \text{ mV} \] amplitude at output.
(3) Assume $R_1=300\,k\Omega$, $R_2=300\,k\Omega$, $R_C=0$, $R_c=1\,k\Omega$ $V_{CC}=3\,V$

(a) Try to simplify the circuit using Thevenin Equivalent circuit.

(b) Calculate $I_c$ and $V_C$ assuming ideal transistor $V_{BE}=0.7\,V$ and $\beta=100$

(c) Calculate $I_c$ and $V_C$ assuming real transistor with characteristics given below.

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\begin{align*}
I_b &= 1.5 - 0.7 \times \frac{1.5 \, V}{150 \, k\Omega} = 0.8 \times \frac{1.5 \, V}{150 \, k\Omega} \approx 5 \, \mu A \\
I_C &= \beta I_b = 500 \times 5 \, \mu A = 2.5 \, mA \\
V_c &= 3\,V - 1\,k\Omega \times I_c \\
&= 3\,V - 10^3 \times 0.5 \times 10^{-3} \\
V_c &= 2.5\,V \\

V_{TH} - I_B R_{TH} - V_{BE} &= 0 \\
1.5 - I_B 150 \times 10^3 &= V_{BE} \\
graphics \Rightarrow I_B = 4 \, \mu A \\

V_C - R_C I_C - V_{CE} &= 0 \\
3 - 10^3 I_C &= V_{CE} \\
graphics \Rightarrow V_C \approx 2.5 \, V, \quad I_C = 0.4 \, mA
\end{align*}
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