1. An amplifier with a nominal gain $A = 1000 \text{ V/V}$ exhibits a gain change of 10% as the operating temperature changes from 25°C to 75°C. If it is required to constrain the change to 0.1% by applying negative feedback, what is the largest closed-loop gain possible? If three of these feedback amplifiers are placed in cascade, what overall gain and gain stability are achieved?

$$\frac{dA_f}{A_f} = 0.1\% \quad \text{and} \quad \frac{dA}{A} = 10\%$$

$$\frac{dA_f}{A_f} = \left( \frac{1}{1 + A\beta} \right) \cdot \frac{dA}{A} = 0.01 = \frac{1}{1 + A\beta}$$

$$A_f = \frac{A}{1 + A\beta} \quad \text{and the largest close-loop gain possible occurs when } A = 1000 \text{ V/V}$$

If three of these amplifiers are cascaded:

$$A_{\text{TOT}} = A_{f1} \times A_{f2} \times A_{f3} = 1000 \text{ V/V} \quad \text{and} \quad \frac{dA_1}{A_1} + \frac{dA_2}{A_2} + \frac{dA_3}{A_3} = 0.3\% \text{ maximum}$$

2. For the circuit below, let the differential amplifier $A_1$ have an infinite input resistance. Use small-signal analysis to obtain expressions for the open-loop gain $A \equiv \frac{I_o}{V_i}$, the feedback factor $\beta \equiv \frac{V_f}{I_o}$, and the closed-loop gain $A_f \equiv \frac{I_o}{V_s}$. If the loop gain is much greater than unity find an approximate expression for $A_f$. Neglect $r_o2$.
3. The noninverting buffer op-amp configuration shown below provides a direct implementation of the feedback loop shown on the right. Assuming that the op amp has infinite input resistance and zero output resistance, what is $\beta$? If $A=1000 \text{ V/V}$, what is the closed loop voltage gain? What is the amount of feedback (in dB)? For $V_s=1 \text{ V}$, find $V_o$ and $V_i$. If $A$ decreases by 10%, what is the corresponding percentage decrease in $A_f$?
Example #6

4. Low cost audio power amplifiers often avoid direct coupling of the loudspeaker to the output stage because any resulting dc bias current in the speaker can use up (and thereby waste) its limited mechanical dynamic range. Unfortunately, the coupling capacitor needed can be large! But feedback helps. For example, for an $8\Omega$ loudspeaker and $f_L=100$Hz, what size capacitor is needed? Now, if feedback is arranged around the amplifier and the speaker so that a closed loop gain $A_f=10$V/V is obtained from an amplifier whose open loop gain is $1000$V/V, what value of $f_L$ results? If the ultimate product design specification requires a $50$Hz cutoff, what capacitor can be used?

For an $8\Omega$ loudspeaker and $f_L=100$ Hz

$$f_L = \frac{1}{2\pi RC} \Rightarrow C = \frac{1}{2\pi \times 100 \times 8} = 199 \ \mu F$$

If feedback is used and: $A_f = 10$V/V,
A = 1000 V/V

$$A_f = \frac{A}{1 + \beta A} \Rightarrow 1 + \beta A = \frac{1000}{10} = 100$$

$$f_{Lf} = f_L / (1 + \beta A) = 100 / 100 = 1 \text{ Hz}$$

Since feedback reduces the effective $f_{Lf}$, then a smaller capacitor $C$ can be chosen for a larger value of $f_L$.
If $f_{Lf}$ must now be 50 Hz:

$$50 = \frac{f_L}{100} \Rightarrow f_L = 5 \text{ KHz} = \frac{1}{2\pi \times 8 \times C}$$

$$\Rightarrow C = 3.98 \ \mu F$$

5. A feedback amplifier is to be designed using a feedback loop connected around a two stage amplifier. The first stage is a direct coupled, small-signal amplifier with a high upper 3dB frequency. The second stage is a power output stage with a midband gain of 10V/V and upper and lower 3dB frequencies of 8kHz and 80Hz, respectively. The feedback amplifier should have a midband gain of 100V/V and an upper 3dB frequency of 40kHz. What is the required gain of the small-signal amplifier? What value of $\beta$ should be used? What does the lower 3dB frequency of the overall amplifier become?

with $f_L = 80$ Hz, $f_F = 8$ KHz.

$$A_F = \frac{A_1A_2}{1 + A_1A_2\beta} = 100$$

Require $f_{RF} = 40$ KHz $= (1 + A_1A_2\beta)$

$\Rightarrow 1 + A_1A_2\beta = 40 / 8 = 5$

and $A_F = \frac{A_1A_2}{5} = 100 \Rightarrow A_1A_2 = 500$

$\Rightarrow A_1 = 500 / A_2 = 500 / 10 = 50$

$1 + A_1A_2\beta = 5 \Rightarrow \beta = 4 / A_1A_2 = 4 / 500$

$\Rightarrow \beta = 0.008$

$$f_{LF} = f_L / (1 + A_1A_2\beta) = 80 / 5 = 16 \text{ Hz}$$
6. For the feedback voltage amplifier below let the op amp have an infinite input resistance, a zero output resistance, and a finite open loop gain \( A \equiv 10^4 \) V/V. If \( R_1 = 1k\Omega \), find the value of \( R_2 \) that results in a closed loop gain of 100 V/V. What does the gain become if \( R_1 \) is removed?

![Feedback Voltage Amplifier Diagram]

\[
\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2}
\]

and open-loop gain is

\[
A_f = \frac{A}{1 + \beta A} = \frac{A}{1 + \left( \frac{R_1}{R_1 + R_2} \right)}
\]

when: \( A >> 1 \) \( \Rightarrow A_f \approx \frac{R_1 + R_2}{R_1} \)

\[
A_f = 1 + \frac{R_2}{R_1}
\]

For: \( A_f = 100 \) V/V, \( A = 10^4 \), \( R_1 = 1 \) k\Omega

\[
100 = \frac{10^4}{1 + 10^4 \times \frac{1 \text{ K}}{1 \text{ K} + R_2}}
\]

\[
\Rightarrow 1 + \frac{10^3}{10^3 + R_2} = 10^2
\]

\[
\Rightarrow R_2 = 100.01 \text{ k}\Omega
\]

If we use the approximate result for \( A >> 1 \)

\[
100 = 1 + \frac{R_2}{1 \text{ K}} \Rightarrow R_2 = 99 \text{ k}\Omega
\]

If \( R_1 \) is removed:

\[
V_F = V_O \Rightarrow \beta = 1 \Rightarrow A_f = \frac{A}{1 + A} \approx 1
\]

7. A feedback amplifier utilizing voltage sampling and employing a basic voltage amplifier with a gain of 1000 V/V and an input resistance of 1000Ω has a closed loop input resistance of 10kΩ. What is the closed loop gain? If the basic amplifier is used to implement a unity-gain voltage buffer, what input resistance do you expect?

\[
A = 1000 \text{ V/A} \quad R_{in} = 1 \text{ k}\Omega \quad \text{and}
\]

\[
R_{in} = 10 \text{ k}\Omega
\]

\[
R_{in} = R_c(1 + A\beta) \Rightarrow 1 + A\beta = \frac{10 \text{ K}}{1 \text{ K}} = 10
\]

\[
A_f = \frac{A}{1 + A\beta} = \frac{1000}{10} = 100 \text{ V/V}
\]

For a unity gain buffer \( \beta = 1; R_{in} = R_c(1 + 1000 \times 1) = 1.001 \text{ M}\Omega \)
8. The active loaded differential amplifier in the figure below has a feedback network consisting of the voltage divider \((R_1, R_2)\), with \(R_1 + R_2 = 1\, \text{M}\Omega\). The devices are sized to operate at \(|V_{ov}| = 0.2\, \text{V}\). For all devices, \(|V_A| = 10\, \text{V}\). The input signal source has a zero dc component.

(a) Show that the feedback is negative.

(b) What do you expect the dc voltage at the gate of \(Q_2\) to be? At the output? (Neglect the Early effect)

(c) Find the \(A\) circuit. Derive an expression for \(A\) and find its value.

(d) Select values for \(R_1\) and \(R_2\) to obtain a closed loop voltage gain \(\frac{V_o}{V_s} = 5\, \text{V/V}\).

(e) Find the value of \(R_{out}\).

(f) Utilizing the open circuit, closed loop gain \((5\, \text{V/V})\) and the value of \(R_{out}\) found in (e), find the value of gain obtained when a resistance \(R_L = 10\, \text{k}\Omega\) is connected to the output.

(g) As an alternative approach to (f) above, redo the analysis of the \(A\) circuit including \(R_L\). Then utilize the values of \(R_1\) and \(R_2\) found in (d) to determine \(\beta\) and \(A_f\). Compare the value of \(A_f\) to that found in (f).

\[ V_{o}\text{out} = 200\, \mu\text{A} \]

\[ V_{out} = g_m (r_{o2} || r_{o4} || (R_1 + R_2)) \]

\[ g_m = \frac{2I_D}{V_{ov}} = \frac{2 \times 100 \, \mu\text{A}}{0.2} = 1 \, \text{mA/V} \]

\[ r_{o2} = r_{o4} = \frac{V_A}{I_D} = \frac{10}{100 \, \mu\text{A}} = 100 \, \text{k}\Omega \]

\[ R_s + R_i = 1\, \text{M}\Omega \]

\[ \Rightarrow A = 1 \, \text{m} \left(50 \, \text{K} || 1 \, \text{M}\right) = 47.61 \, \text{V/V} \]