EE 230
Lecture 11

Basic Feedback Configurations
Input/Output Impedance
Inverting Amplifiers
Summing Amplifiers
Quiz 9

Determine the voltage gain of this amplifier. Assume the Op Amp is ideal
And the number is ?
Determine the voltage gain of this amplifier. Assume the Op Amp is ideal.

Solution: \[ A_{VF} = 1 + \frac{R_2}{R_1} = 31 \]
Reminder: Exam 1 on Wednesday

Students may bring one sheet (front and back) of notes

There will be no 11:00 lectures next week but will resume the week of Feb 14

I will have limited email access after noon today so return email messages may be delayed

Laboratory 4 - Purpose
Finite Gain Feedback Amplifiers

Consider the following circuit

For $R_{IN} = \infty$ and $R_0 = 0$, this is an EXACT representation of Black feedback structure

$$A_{FB} = \frac{A}{1 + A\beta}$$

For $A$ large

$$A_{FB} \approx \frac{1}{\beta}$$

This is a Voltage Feedback Amplifier

Review from Last Time
Finite Gain Feedback Amplifiers

Consider the following circuit

\[
A_{FB} = \frac{A}{1 + A\beta}
\]

\[
A_{FB} \approx \frac{1}{\beta}
\]

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

\[
A_{FB} \approx \frac{1}{\beta} = 1 + \frac{R_2}{R_1}
\]

Observe this serves as a basic finite-gain noninverting amplifier
Review from Last Time

Basic Noninverting Amplifier

\[ A_{FB} = 1 + \frac{R_2}{R_1} \]

Gain can be accurately determined by resistors

Circuit has excellent linearity
Basic Noninverting Amplifier

Will you impress your boss if you were to use the more accurate gain expression

\[
\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_2}{R_1}
\]

instead of the approximation

\[
\frac{V_{OUT}}{V_{IN}} \approx 1 + \frac{R_2}{R_1}
\]
Input and Output Impedances with Feedback

\[ R_{\text{INF}} = ? \]
\[ R_{\text{OF}} = ? \]

Model of A amplifier including \( R_{\text{IN}} \) and \( R_0 \)

\[ \beta = \frac{R_1}{R_1 + R_2} \]
Approximate analysis for $R_{\text{INF}}$:

Assume

$$
\frac{V_{\text{OUT}}}{V_{\text{IN}}} = \frac{1 + \frac{R_2}{R_1}}{1 + \left(\frac{1}{A}\right) \left(1 + \frac{R_2}{R_1}\right)} = \frac{A_v}{1 + A_v \beta}
$$

$$
R_{\text{INF}} = \frac{V_{\text{IN}}}{I_{\text{IN}}}
$$

$$
V_{\text{IN}} = I_{\text{IN}} R_{\text{INF}} + \beta V_{\text{OUT}}
$$

$$
\frac{V_{\text{OUT}}}{V_{\text{IN}}} = \frac{A_v}{1 + A_v \beta}
$$

Note the dramatic increase (improvement) in $R_{\text{INF}}$ over what was already a very large $R_{\text{IN}}$.
Input and Output Impedances with Feedback

Approximate analysis for $R_{OF}$:

Assume $V_1 = -\beta V_{\text{TEST}}$

\[
R_{OF} = \frac{V_{\text{TEST}}}{I_{\text{TEST}}}
\]

\[
V_1 = -\beta V_{\text{TEST}}
\]

\[
I_{\text{TEST}} = \frac{V_{\text{TEST}} - A_v V_1 + V_{\text{TEST}} - V_1}{R_0} + \frac{V_{\text{TEST}} - V_1}{R_2}
\]

\[
R_{OF} = \frac{1}{\frac{1}{R_0} + \frac{1}{R_2} + \beta \left( \frac{A_v}{R_0} \frac{1}{R_2} \right)} \approx \frac{R_0}{1 + \beta A_v}
\]

Note the dramatic decrease (improvement) in $R_0$ over what was already a very low $R_0$.
Input and Output Impedances with Feedback

\[ R_{INF} = ? \]
\[ R_{OF} = ? \]

Exact analysis:
Consider amplifier as a two-port and use open/short analysis method.

Will find \( R_{INF}, R_{OF}, A_V \) almost identical to previous calculations.
Will see a small \( A_{VR} \) present but it plays almost no role since \( R_{INF} \) is so large (effectively unilateral).

\[ A_{VF} \approx \frac{1}{\beta} \]
\[ R_{OF} = \frac{R_0}{1+\beta A_V} \]
\[ R_{INF} = R_{IN} (1 + A_V \beta) \]
\[ A_{VRF} \approx \beta \]
Basic Linear Applications

Will now focus on introducing several useful linear circuits and will assume op amps are ideal

• Finite gain (feedback) amplifiers
• Summing amplifiers
• Integrators
• Filters
• And some others

Note: Essentially all linear applications of operational amplifiers involve large amounts of feedback though the concepts of feedback is often not emphasized
Basic Noninverting Amplifier
(already introduced)

![Circuit Diagram]

\[ A_V = \frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_2}{R_1} \]

\[ R_{IN} = \infty \]

\[ R_{OUT} = 0 \]
Buffer Amplifier

One of the most widely used Op Amp circuits

Provides a signal to a load that is not affected by a source impedance

This provides for decoupling between stages in many circuits

Special case of basic noninverting amplifier with $R_1=\infty$ and $R_2=0$

$$V_{OUT} = V_{IN} \left( 1 + \frac{R_2}{R_1} \right)$$
Buffer Amplifier Application

Goal: Drive $R_L$ with $V_{IN}$

With buffer amplifier

$$A_V = \frac{V_{OUT}}{V_{IN}} = \frac{R_L}{R_S + R_L} \neq 1$$

$$A_V = \frac{V_{OUT}}{V_{IN}} = 1$$
Basic Inverting Amplifier

\[ \frac{V_{IN}}{R_1} + \frac{V_{OUT}}{R_2} = 0 \]

\[ \frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1} \]

\[ R_{OUT} = 0 \]

\[ R_{IN} = R_1 \]

Input impedance of \( R_1 \) is unacceptable in many (but not all) applications.

This is not a voltage feedback amplifier (it is a feedback amplifier) of the type \( \text{note } R_{IN} \text{ is not high!} \)

Feedback concepts could be used to analyze this circuit but lots of detail required.
Limitations of Input Impedance of Basic Inverting Amplifier

\[ \frac{V_{\text{OUT}}}{V_{\text{IN}}} = -\frac{R_2}{R_1} \]

\[ R_{\text{IN}} = R_1 \]

Gain dependent on \( R_S \) and this is undesirable in many applications
Limitations of Input Impedance of Basic Inverting Amplifier

\[ \frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1 + R_S} \]

This circuit is itself useful

\[ \frac{V_{OUT}}{V_{IN}} = -\frac{R_2}{R_1} \]
Buffered Inverting Amplifier

\[ \frac{V_{\text{OUT}}}{V_{\text{IN}}} = -\frac{R_2}{R_1} \]

\[ R_{\text{IN}} = \infty \]

\[ R_{\text{OUT}} = 0 \]
Summing Amplifier

- Output is a weighted sum of the input voltages
- Any number of inputs can be used
- Gains from all inputs can be adjusted together with $R_F$
- Gain for input $V_i$ can be adjusted independently with $R_i$ for $1 \leq i \leq k$
- All weights are negative
- Input impedance on each input is $R_i$

\[
\frac{V_{OUT}}{R_F} + \frac{V_1}{R_1} + \frac{V_2}{R_2} + \ldots + \frac{V_k}{R_k} = 0
\]

\[
V_{OUT} = - \frac{R_F}{R_1} V_1 - \frac{R_F}{R_2} V_2 - \ldots - \frac{R_F}{R_k} V_k
\]
Summing Amplifier

\[ V_1 \rightarrow R_1 \rightarrow V_{OUT} \]
\[ V_2 \rightarrow R_2 \rightarrow V_{OUT} \]
\[ \vdots \]
\[ V_k \rightarrow R_k \rightarrow V_{OUT} \]

Behringer Commercial Mixer
Noninverting summing amplifier

\[ V_{\text{OUT}} = \frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2 + \ldots + \frac{R_F}{R_k} V_k \]

Weights are now all positive
Summing Amplifier with Inverting and Noninverting Weights

\[ V_{OUT1} = - \frac{R_{F1}}{R_1} V_1 - \frac{R_{F1}}{R_2} V_2 - \cdots - \frac{R_{F1}}{R_k} V_k \]

\[ V_{OUT} = -\frac{R_F}{R_{N1}} V_1 - \frac{R_F}{R_{N2}} V_2 - \cdots - \frac{R_F}{R_{Nm}} V_k + \frac{R_F}{R_{F2}} \left( \frac{R_{F1}}{R_1} V_1 + \frac{R_{F1}}{R_2} V_2 + \cdots + \frac{R_{F1}}{R_k} V_k \right) \]
End of Lecture 11