Electronics II
Physics 3620 / 6620

Jan 28, 2009
Part 1
Operational Amplifiers
Some History

1964: The First Linear IC
The μA702 Op-Amp
12 Transistors
Designer: Bob Widlar

Fairchild
0.60 Inches

1965: A Best-Seller
The μA709 Op-Amp
14 Transistors
Designer: Bob Widlar
2 Minute Quiz

Name________________________

Section _____

- What is the voltage measured by the blue probe (#1)?
- What is the voltage measured by the green probe (#2)?
- What is the voltage measured by the red probe (#3)?
Answers

• The green probe: 10V
• The red probe: 1V
• The blue probe: 0V
• Voltage Divider:

\[ V = \frac{R_2}{R_1 + R_2}10V \]
What can you do with infinite gain?

- The goal of amplifier designers: huge gain.
- What are the problems and opportunities associated with infinite gain?
- First, we need a model.
Op-Amp

\[ V_{in} = V_1 - V_2 \]
Ideal Op-Amp Model

- Gain is infinite
  \[ A = \frac{V_{OUT}}{V_+ - V_-} = \frac{V_{OUT}}{V_{IN}} \rightarrow \infty \]
- Input resistance is infinite
  \[ R_{IN} \rightarrow \infty \]
- Output resistance is zero
  \[ R_{OUT} = 0 \]
- Input voltage is zero
  \[ V_{IN} = 0 \]
- Input current is zero
  \[ I_+ = 0 \quad I_- = 0 \]
Ideal Op-Amp Continued

- Bandwidth is also infinite. Thus, an ideal op-amp works the same at all frequencies.
Feedback

• Like most engineered systems, the op-amp uses feedback to realize its potential value.
• Feedback comes in two forms
  – Positive Feedback
  – Negative Feedback
• It seems like positive feedback might be best, but negative feedback makes the op-amp work
Feedback Examples
From a Zoology Course

• You just ate a Krispy Kreme donut and your blood glucose levels are on the rise. In response to this rise, the pancreas is releasing insulin into the bloodstream stimulating storage of glucose. As a result, blood glucose levels begin to drop. Is this an example of positive or negative feedback?

• A woman is in labor, pressure receptors in the birth canal send messages to her brain that result in increased contraction of the uterus and increased pressure in the birth canal. Is this positive or negative feedback?
Feedback: Valve Example

• As the water nears the specified level, the valve is closed.
• Negative feedback is most commonly used to control systems.
Golden Rules for Op-Amps

- The output attempts to do whatever is necessary to make the voltage difference between the two inputs zero. (Negative Feedback is Required)
- The inputs draw no current.
Positive and Negative Feedback

- Connecting the output to the positive input is positive feedback.
- Connecting the output to the negative input is negative feedback.
Op-Amp Configurations

• Buffer or Voltage Follower
  – No voltage difference between the output and the input
  – Draws no current, so it puts no load on the source
  – Used to isolate sources from loads
Op-Amp Configurations

- Non-Inverting Amplifier
  - No voltage difference between inputs
  - Resistors act like voltage divider

\[
V_1 = V_2
\]

\[
V_2 = \frac{R_2}{R_1 + R_2} V_O
\]
Op-Amp Configurations

- Non-Inverting Amplifier Continued
  - Combining the two equations for the voltages gives us the relationship between input and output

\[ V_{OUT} = V_{IN} \left(1 + \frac{R_1}{R_2}\right) \]
Op-Amp Configurations

- Inverting Op-Amp
  - Current through $R_1$ equals the current through $R_f$
  - No current in the inputs
  - The voltage at both inputs is zero

\[ V_2 = 0 \]
Op-Amp Configurations

- Inverting Op-Amp Continued
  - Current through $R_1$
    \[ I_1 = \frac{V_1 - 0}{R_1} = \frac{V_1}{R_1} \]
  - Current through $R_f$
    \[ I_2 = -\frac{V_o - 0}{R_f} = -\frac{V_o}{R_f} \]
Op-Amp Configurations

Why the minus sign for the current through $R_f$?
- The convention for Ohm’s Law is that the current flows from the high voltage to the low voltage for a resistor.
- Here the current flows from the low voltage (ground) to the high voltage ($V_O$).
Op-Amp Configurations

- Inverting Op-Amp Continued
  - The current through $R_1$ must equal the current through $R_2$ since there is no current in the inputs.
  - Combining the two equations for the currents

$$V_{OUT} = -V_{IN} \frac{R_f}{R_1}$$
Op-Amp Configurations

- Inverting Summing Amplifier
  - Each input resistor contributes to the current.

\[ V_{OUT} = -V_1 \frac{R_f}{R_1} - V_2 \frac{R_f}{R_2} - V_3 \frac{R_f}{R_3} \]
Op-Amps: Practical Issues

- We use real op-amps: LF351
- Note the pin connections for the IC

Note: Literally a Black Box
Op-Amps: Practical Issues

• Op-Amps require power
  – 351 requires Vcc of ±12-15V
  – Others may require only positive or both positive and negative voltages
  – Output voltage is limited to $-V_{CC} < V_{OUT} < +V_{CC}$
  – Usually filter capacitors are connected to power to reduce noise