Op-amps and Popular ICs

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Outline

- Overview of Operational Amplifiers
- Basic Uses of Op-amps
  - Comparators and Amplifiers
  - Active Filters
  - Signal Generators
  - Miscellaneous Applications
- Popular Linear Integrated Circuits
  - Timers (555)
  - Voltage Multipliers (AD534)
  - Linear Voltage Regulators (78xx and 79xx)
Introduction

- First op-amp was developed by George A. Philbrick in 1948.
- Originally used to add, subtract, multiply, and even solve differential equations.
- The word “operational” stood for “mathematical operations.”
- As technology progressed, it has grown out of its original context to revolutionize certain areas of analog electronics.

General Purpose Op-amps

Dual voltage power supply via two 9V batteries
**Equivalent Circuit**

For real op-amps:
- \( A = 200,000 \) (or higher)
- Supply voltage = ±15 V
- \( v_{sat} = 13 \) V (saturation voltage)

**Basic Model of Op-amps**

For real op-amps:
- \( A = 200,000 \) (or higher)
- Supply voltage = ±15 V
- \( v_{sat} = 13 \) V (saturation voltage)

- When \( v_2 > v_1 \)
  \[ v_o = +V_{sat} = 13 \text{ V} \]
  \[ e = +V_{sat}/A = +65 \mu\text{V} \]

- When \( v_1 > v_2 \)
  \[ v_o = -V_{sat} = -13 \text{ V} \]
  \[ e = -V_{sat}/A = -65 \mu\text{V} \]

\( R_i \): Input impedance (ideally \( \infty \))
\( R_o \): Output impedance (ideally 0)
\( A \): Open loop gain (ideally \( \infty \))
Comparators

Inverting Amplifier

- Voltages:
  - Since $A \to \infty$, $e = v_o/A \approx 0$
  - $v_i = iR_1$ and $v_o = -iR_2$
- Closed loop gain:
  - $K = v_o/v_i = -R_2/R_1$

Note that
- $R_1 = 1k\Omega$; $R_2 = 2k\Omega$; $K = -2$
- When $v_i = 5V \Rightarrow v_o = -10V$
- When $v_i = -5V \Rightarrow v_o = +10V$
**Non-inverting Amplifier**

- **Voltages:**
  \[ v_i = iR_1 \text{ and } v_o = v_i + iR_2 \]

- **Closed loop gain:**
  \[ K = \frac{v_o}{v_i} = 1 + \frac{R_2}{R_1} \]

Note that
- \( R_1 = 1 \text{k}\Omega; R_2 = 1 \text{k}\Omega; K = +2 \)
- When \( v_i = 5 \text{V} \Rightarrow v_o = 10 \text{V} \)
- When \( v_i = -5 \text{V} \Rightarrow v_o = -10 \text{V} \)

**Isolation Amplifier**

- The closed loop gain is 1 and thus \( v_o = v_i \).
- It is used to isolate the signal source as the amplifier draws negligible current from the source.
- This amplifier has different names in the literature such as buffer amplifier, unity-gain amplifier, source follower, and voltage follower.
Adders (Mixers)

\[ V_o = \sum_{i=1}^{n} \frac{R_f}{R_i} \cdot V_i \]

\[ V_o = \left(1 + \frac{R_f}{R}\right) e = \left(1 + \frac{(n-1)R}{R}\right) \frac{1}{n} \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} V_i \]

Differential Amplifier

\[ V_o = \frac{R_2}{R_1} (V_2 - V_1) = k \cdot e \]

- Differential amplifier is used to amplify small signals buried in much larger signals.
- \( R_2 \) resistances must be equalized to increase common mode voltage rejection.
**Instrumentation Amplifier**

- Instrumentation amplifier is a versatile amplifier being used in almost every data acquisition system.
- Voltage gain is set by only one resistor.
- Output voltage does not depend on the voltage common to both $v_1$ and $v_2$ (common-mode voltage), only on their difference!

$\mathbf{v}_o = \left(1 + \frac{2}{R}\right)(v_2 - v_1)$

**Frequency Response**

$\mathbf{V}_i = E_i \cos(\omega t)$ → **Filter** → $\mathbf{V}_o = E_o \cos(\omega t + \phi)$

- $E_i$ is kept constant while the frequency ($\omega$) is being swept between 0 (DC) and $\omega_{\text{max}}$.
- $E_o$ and $\phi$ change as a function of $\omega$.
- $E_o/E_i = |V_o/V_i|$ (closed loop gain) and phase ($\phi$) are utilized to characterize the filter (Bode plots).
Ideal Filters

(A) Lowpass Filter:

\[ \frac{V_o}{V_i} \]

Cutoff frequency

Pass-band

Stop-band

\[ \omega_c \]

\[ \omega \]

(B) Highpass Filter:

\[ \frac{V_o}{V_i} \]

Pass-band

Stop-band

\[ \omega_c \]

\[ \omega \]

(C) Bandpass Filter:

\[ \frac{V_o}{V_i} \]

Pass-band

Stop-band

\[ \omega_1 \]

\[ \omega_2 \]

\[ \omega_3 \]

(D) Stopband (Notch) Filter:

\[ \frac{V_o}{V_i} \]

Pass-band

Stop-band

\[ \omega_1 \]

\[ \omega_2 \]

\[ \omega_3 \]
For this first-order lowpass filter, first choose cut-off frequency ($\omega_c$) [rad/s].

- Select the capacitance $C$, usually in between 0.001 and 0.1 $\mu$F.
- Calculate the resistance: $R = 1/(C\omega_c)$.
- For example, let $\omega_c = 628$ rad/s (=100 Hz); $C = 0.01$ $\mu$F. Then, $R = 160$ k$\Omega$.

\[
\left| \frac{v_o}{v_i} \right| = \frac{1}{\sqrt{1 + (RC)^2 \omega^2}}
\]
Highpass Filter

- For this first-order highpass filter, first choose cut-off frequency ($\omega_c$) [rad/s].
- Select the capacitance $C$, usually in between 0.001 and 0.1 $\mu$F.
- Calculate the resistance: $R = 1/(C\omega_c)$.
- For example, Let $\omega_c = 628$ rad/s (=100 Hz); $C = 0.01$ $\mu$F. Then, $R = 160$ k$\Omega$

\[
\frac{v_o}{v_i} = \frac{RC\omega}{\sqrt{1 + (RC)^2 \omega^2}}
\]

Example for Highpass Filter
Generalized Impedance Rule

\[ Z_A = R \]
\[ Z_B = 1/(Cs) \]

**Integrator:**

\[ \frac{E_o(s)}{E_i(s)} = G_1(s) = -\frac{Z_B(s)}{Z_A(s)} \]

Differentiator:

\[ \frac{E_o(s)}{E_i(s)} = \frac{1}{RC} s \]

\[ Z_A = 1/(Cs) \]
\[ Z_B = R \]
\[ \frac{E_o(s)}{E_i(s)} = -(RC)s \]

Sine Wave Generator

- The frequency of this Wien-bridge oscillator is \( \omega = 1/(RC) \).
- To ensure that the oscillations will start, one chooses \( R_2/R_1 \) slightly greater than 2.
- One important problem is that the amplitude of the oscillations is not stabilized in this topology.
Stable Oscillator

- The shown oscillator employs parameter variation technique to stabilize the amplitude.
- As a design example, let $\omega = 1$ kHz; $R = R_1 = 10k\Omega$; $R_2 = 50k\Omega$. Hence, $C = 1/(R\omega) = 16\mu F$.
- Potentiometer is adjusted until the oscillations start to grow.
- An isolation amplifier will be needed if a load is directly connected to the output.

Square Wave Generator

- The circuit is referred to as a free-running or astable multivibrator.
- The frequency of oscillations is $f = 1/(2R_1C)$. 
Triangle Wave Generator

First op-amp in this topology is an integrator while the second one serves as a comparator.

Other Applications

Light/Dark Sensor
- Relay closes when no light falls on LDR1.
- Light sensitivity is adjusted through pot P1.
- Anti-parallel diode D1 is used to avoid spark due to the inductive load (relay coil).
- To reverse action (light/dark), LDR1 and R1 are swapped.
Other Applications (Cont’d)

Low-power Audio Amplifier

Motor Control Application

- \( V_{\text{ref}} \) is the command voltage ranging between -2V and +2V.
- Simple P position controller with a gain of 10 is employed here.
- U01 (UA 759C) is an audio amplifier to drive motor.
- Supply voltage for all op-amps is 12V.
Multiplication plays an important role in amplitude modulation and demodulation.

High precision multipliers like AD534 require little or no manual calibration.
Op-amps are very versatile amplifiers.
They are precise, low-cost, and error tolerant.
Using op-amps, one can implement almost any desired function.
There exists a wide variety of specialized op-amps for different applications such as radio/video, sonar/radar, automation, automotive, instrumentation.
References


Internet Resources

- [http://www.iserv.net/~alexx/lib/tutorial.htm](http://www.iserv.net/~alexx/lib/tutorial.htm)
- [http://newton.ex.ac.uk/teaching/CDHW/Electronics2/ElectronicsResources.html](http://newton.ex.ac.uk/teaching/CDHW/Electronics2/ElectronicsResources.html)
- [http://www.uoguelph.ca/~antoon/gadgets/741/741.html](http://www.uoguelph.ca/~antoon/gadgets/741/741.html)