Operational Amplifiers

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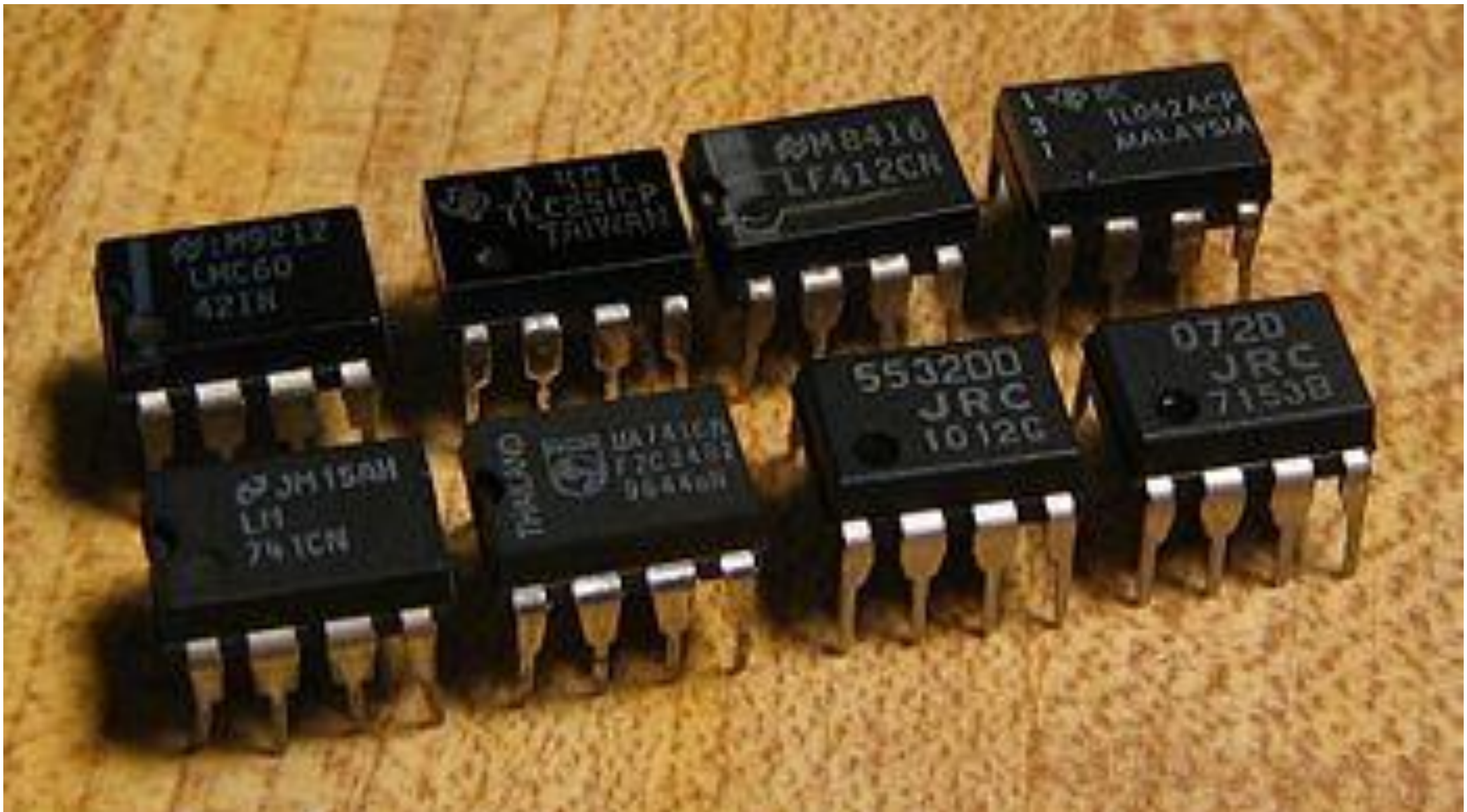
Operational Amplifier



An operational amplifier, often called an op-amp , is a DC-coupled high-gain electronic voltage amplifier with differential inputs and, usually, a single output.

Typically the output of the op-amp is controlled either by negative feedback, which largely determines the magnitude of its output voltage gain, or by positive feedback, which facilitates regenerative gain and oscillation.

High input impedance at the input terminals and low output impedance are important typical characteristics.

History

1941: First (vacuum tube) Op-Amp

1947: First Op-Amp with an explicit non-inverting input

1948: First chopper-stabilized Op-Amp

1961: First discrete IC Op-Amps

1962: First Op-Amps in potted modules

1963: First monolithic IC op-amp

1966: First varactor bridge Op-Amps

1968: Release of the µA741 - would be seen as a nearly ubiquitous chip

1970: First high-speed, low-input current FET design

1972: Single sided supply Op-Amps being produced

The First "Real" OpAmp
The K2-W

The K2-W Tube OpAmp

- **Invented by Julie Loebe and George Philbrick (early 1950's)**
- **The first "mass production" OpAmp...**
- **Cost (in 1950's) approximately $22.00...**
- **Basic specifications comparison to 741 and LT1037...**

Parameters	K2-W OpAmp	741 OpAmp	LT1037 OpAmp
Power Supplies	+/- 300 VDC, 6.3 VAC (filaments)	+/- 15V	+/- 15V
Open-Loop Gain	$1.5X10^4$	$5X10^4$	$30X10^6$
V_{out} Swing	+/- 50V	+/- 12V	+/- 13.5 V
I_{out}	+/- 1 mA	25 mA	25 mA
I_{drain}	5 mA (no load)	1.7 mA	2.7 mA
R_L(min)	50 KΩ	none (SC protect)	none (SC protect)
Slew Rate	+/- 12 V/µSec	+/- 0.5 V/µS	15 V/µS

Applications

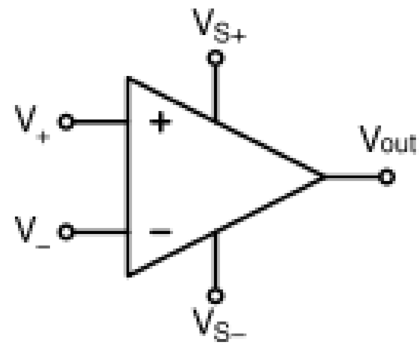
- Use in electronics system design
- Linear circuits: non-inverting amplifier, inverting amplifier, adder, integrator, instrumentation amplifier…
- Nonlinear circuits: log amps, multipliers…

Other Applications

- audio- and video-frequency pre-amplifiers and buffers
- voltage comparators
- differential amplifiers
- differentiators and integrators
- active filters
- precision rectifiers
- precision peak detectors
- voltage and current regulators
- analog calculators
- analog-to-digital converters
- digital-to-analog converter
- voltage clamps
- oscillators and waveform generators

The Circuit Symbol

Circuit representation:



- V+: non-inverting input
- V−: inverting input
- Vout: output
- Vs+: positive power supply
- Vs−: negative power supply

The Ideal Op-Amp

The Op-Amp produces an output voltage that is the difference between the two input terminals, multiplied by the gain A.

1) The input impedance is infinite - i.e. no current ever flows into either input of the op-amp.

2) The output impedance is zero - i.e. the op-amp can drive any load impedance to any voltage.

3) The open-loop gain (A) is infinite.

4) The bandwidth is infinite.

5) The output voltage is zero when the input voltage difference is zero.

Op-Amps Types

- General Purpose
- Precision
- Low power
- Micropower
- Nanopower
- Low noise
- Low offset
- High output power
- High speed
- Buffers
- Comparators
- Low cost

Some Example Devices

- LM741 (general purpose)
- LT1056 (JFET input)
- LMC660 (CMOS - low power)
- LT1220/1221 (high speed)
- LM675 (medium power)
- LM12 (high output power)
- LM311 (comparator)

Practical Properties

- **Open-loop Voltage Gain A**
- **Input Resistance R_{in}**
- **Output Resistance R_{out}**
- **Common Mode Rejection Ratio (CMRR)**
- **Input Offset Voltage V_{os}**
- **Input Bias Current I_B**
- **Input Offset Current I_{os}**
- **Power Supply Rejection Ratio (PSRR)**
- **Output Voltage Swing**
- **Bandwidth (BW)**
- **Slew Rate (SR)**

Negative Feedback: What is it?

- The gain of the circuit is made less sensitive to the values of individual components.
- Nonlinear distortion can be reduced.
- The effects of noise can be reduced.
- The input and output impedances of the amplifier can be modified.
- The bandwidth of the amplifier can be extended.

Golden Rules

Op-Amp circuits are generally fairly intuitive if you remember the basic "rules" of op-amp operation!

- The operational amplifier is ideal, and then its input voltage is determined by the formula:

$$\Delta V = \frac{V_{out}}{A} = \frac{V_{out}}{\infty} = 0$$

- The input current of op-amp is equal to:

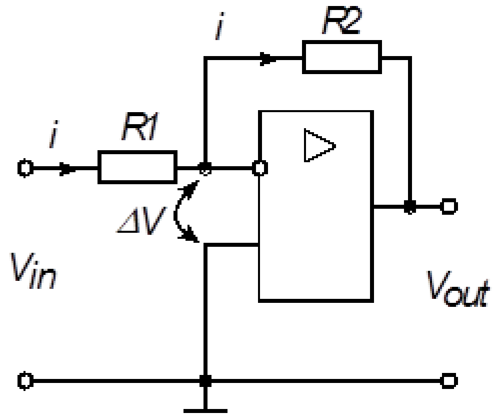
$$I_{in} = \frac{V_{in}}{R_{in}} = \frac{V_{in}}{\infty} = 0$$

because the op amp can be regarded as having infinite input resistance.

Applications
of Operational Amplifiers

- INVERTING AMPLIFIER
- NONINVERTING AMPLIFIER
- VOLTAGE FOLLOWER
- INVERTING ADDER
- NONINVERTING ADDER

Inverting Amplifier



$$i = \frac{V_{in}}{R_1}$$

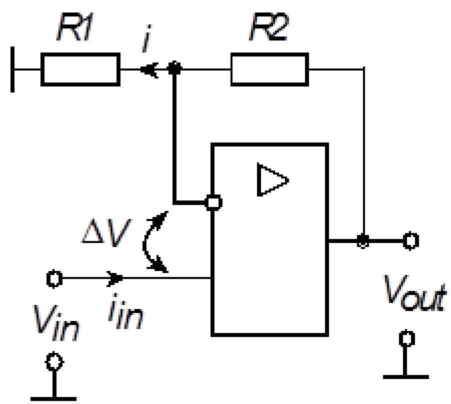
$$V_{out} = -iR_2 = -\frac{V_{in}}{R_1} R_2$$

$$G = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

The inverting input voltage is ‘virtually’ zero, because $\Delta V = 0$!

This circuit then, is simply an inverting amplifier but it is sometimes called a **scale changer** or simply, a **scaler**.

Noninverting Amplifier

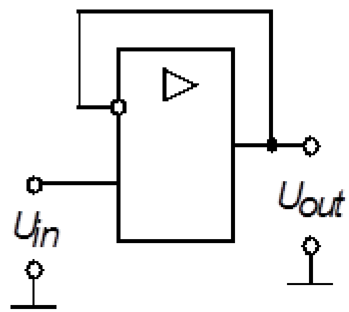


$$i = \frac{V_{in}}{R_1} \qquad V_{R1} = \frac{R_1}{R_1 + R_2} V_{out}$$

$$G_V = \frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1}$$

Figure shows how an op-amp can be connected as a noninverting amplifier circuit, which produces an amplified output signal without the phase inversion.

Voltage Follower



$$G = \frac{V_{out}}{V_{in}} = 1 + \frac{R_2}{R_1}$$

$$G_V = 1 + \frac{0}{R_1} = 1 + \frac{R_2}{\infty} = 1$$

This circuit is called a **voltage follower** or **buffer**.

General characteristics of buffer: voltage gain = 1;

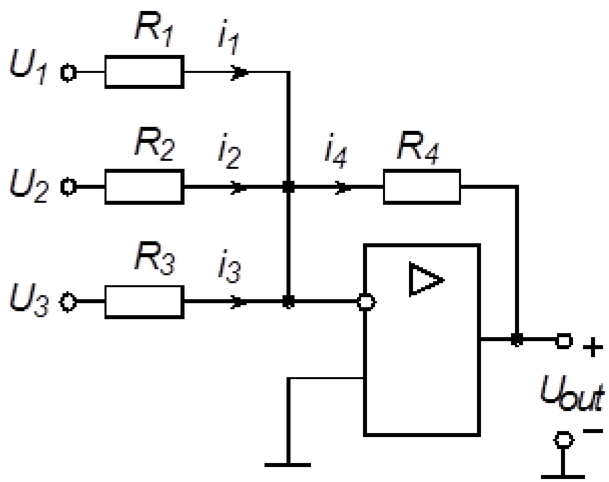
input impedance $\to \infty$;

output impedance $\to 0$;

current gain $\to \infty$;

power gain $\to \infty$.

Inverting Adder



$$i_1 = \frac{V_1}{R_1} \qquad i_2 = \frac{V_2}{R_2} \qquad i_3 = \frac{V_3}{R_3}$$

$$i_4 = i_1 + i_2 + i_3$$

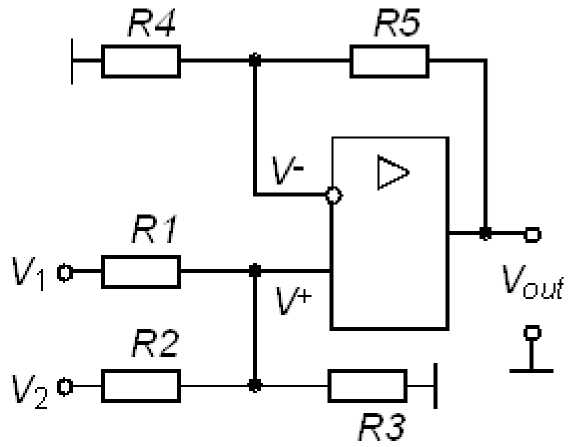
$$U_{out} = -iR_4$$

$$V_{out} = -\left(\frac{R_4}{R_1}V_1 + \frac{R_4}{R_2}V_2 + \frac{R_4}{R_3}V_3\right)$$

By resistor choice the inputs can have different **weightings** at the output.

There can be more than three inputs to an inverting adder.

Noninverting Adder



$$i_1 = \frac{V_1 - V^+}{R_1} \qquad i_2 = \frac{V_2 - V^+}{R_2} \qquad i = i_1 + i_2$$

$$V^+ = iR_3 \qquad V^+ = \left(\frac{V_1 - V^+}{R_1} + \frac{V_2 - V^+}{R_2}\right) \cdot R_3$$

$$V^+ = \frac{R_2 \parallel R_3}{R_1 + (R_2 \parallel R_3)} V_1 + \frac{R_1 \parallel R_3}{R_2 + (R_1 \parallel R_3)} V_2$$

$$V_{out} = \left(1 + \frac{R_5}{R_4}\right) \cdot V^+ = \left(1 + \frac{R_5}{R_4}\right)\left(\frac{R_2 \parallel R_3}{R_1 + (R_2 \parallel R_3)} V_1 + \frac{R_1 \parallel R_3}{R_2 + (R_1 \parallel R_3)} V_2\right)$$

By resistor choice the inputs can have different **weightings** at the output.

Conclusion

This presentation describes the basic principles of analogue integrated circuits, including operational amplifiers.

Author hopes that this material will help students to get basic understanding of the principles of analogue electronics.

The End