SLEW RATE, OPEN AND CLOSED LOOP CONFIGURATIONS
INTEGRATED CIRCUITS

An integrated circuit (IC) is a miniature, low-cost electronic circuit consisting of active and passive components fabricated together on a single crystal of silicon. The active components are transistors and diodes and passive components are resistors and capacitors.
Advantages of integrated circuits

1. Miniaturization and hence increased equipment density.
2. Cost reduction due to batch processing.
3. Increased system reliability due to the elimination of soldered joints.
5. Matched devices.
6. Increased operating speeds.
7. Reduction in power consumption.
Classification of ICs

Integrated Circuits

Monolithic Circuits

Bipolar
- P-n- junction isolation

Unipolar
- Dielectric isolation

Hybrid Circuits

MOSFET

JFET
## IC CHIP SIZE & CIRCUIT COMPLEXITY

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Gate Level</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Invention of transistor (Ge)</td>
<td></td>
<td>1947</td>
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<tr>
<td>Development of silicon transistor</td>
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<td>1955 – 1959</td>
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<tr>
<td>Silicon planar technology (Si)</td>
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<td>1959</td>
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<tr>
<td>SSI</td>
<td>3 to 30 gates/chip approx. or 100 transistor/chip (Logic gates, Flip-flops)</td>
<td>1960 – 1960</td>
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<tr>
<td>MSI</td>
<td>30 to 300 gates/chip approx. or 1000 transistor/chip (Counters, Multiplexers, Adders)</td>
<td>1965 – 1970</td>
</tr>
<tr>
<td>LSI</td>
<td>300 to 3000 gates/chip approx. or 1000 – 20,000 transistor/chip (8-bit Microprocessor, ROM, RAM)</td>
<td>1970 – 1980</td>
</tr>
<tr>
<td>Parameter</td>
<td>Gate Level</td>
<td>Year</td>
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<tr>
<td>VLSI</td>
<td>More than 3000 gates/chip approx. or 20,000 – 1,000,000 transistor/chip (16 and 32 bit Microprocessors)</td>
<td>1980 – 1990</td>
</tr>
<tr>
<td>ULSI</td>
<td>$10^6$ – $10^7$ transistors/Chip (Special Processors, Virtual reality, Smart sensors)</td>
<td>1990 - 2000</td>
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<tr>
<td>GSI</td>
<td>&gt; $10^7$ transistors/Chip</td>
<td>2000</td>
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Aluminium is preferred for metallization

1. It is a good conductor
2. It is easy to deposit aluminium films using vacuum deposition.
3. It makes good mechanical bonds with silicon
4. It forms a low resistance contact
IC packages available

1. Metal can package.
3. Ceramic flat package.
Characteristics of Op-Amp
An operational amplifier is a direct coupled high gain amplifier consisting of one or more differential amplifiers, followed by a level translator and an output stage.

It is a versatile device that can be used to amplify ac as well as dc input signals & designed for computing mathematical functions such as addition, subtraction, multiplication, integration & differentiation.
Op-amp symbol

Non-inverting input

inverting input

+5v

-5v

Output
Ideal characteristics of OPA

1. Open loop gain infinite
2. Input impedance infinite
3. Output impedance low
4. Bandwidth infinite
5. Zero offset, ie, $V_0=0$ when $V_1=V_2=0$
Inverting Op-Amp

\[ V_{OUT} = -V_{IN} \frac{R_f}{R_1} \]
Non-Inverting Amplifier

\[ V_{OUT} = V_N \left( 1 + \frac{R_1}{R_2} \right) \]
Voltage follower

\[ V_{\text{OUT}} = V_{\text{IN}} \]
Input offset current

The difference between the bias currents at the input terminals of the op-amp is called as input offset current. The input terminals conduct a small value of dc current to bias the input transistors. Since the input transistors cannot be made identical, there exists a difference in bias currents.
DC characteristics

Input offset voltage

A small voltage applied to the input terminals to make the output voltage as zero when the two input terminals are grounded is called input offset voltage.
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DC characteristics

Input bias current

Input bias current $I_B$ as the average value of the base currents entering into terminal of an op-amp

$I_B = I_{B_+} + I_{B_-}$
DC characteristics

THERMAL DRIFT

Bias current, offset current and offset voltage change with temperature. A circuit carefully nulled at 25°C may not remain so when the temperature rises to 35°C. This is called drift.
AC characteristics

Frequency Response

HIGH FREQUENCY MODEL OF OPAMP
AC characteristics

Frequency Response

**OPEN LOOP GAIN VS FREQUENCY**
Need for frequency compensation in practical op-amps

- Frequency compensation is needed when large bandwidth and lower closed loop gain is desired.
- Compensating networks are used to control the phase shift and hence to improve the stability.
Frequency compensation methods

- Dominant-pole compensation
- Pole-zero compensation
Slew rate

It is defined as the maximum rate of change of output voltage with time. The slew rate is specified in V/μsec

\[ \text{Slew rate} = S = \frac{dV_o}{dt} \bigg|_{\text{max}} \]

It is specified by the op-amp in unity gain condition.

The slew rate is caused due to limited charging rate of the compensation capacitor and current limiting and saturation of the internal stages of op-amp, when a high frequency large amplitude signal is applied.
It is given by \( \frac{dV_c}{dt} = \frac{I}{C} \)

For large charging rate, the capacitor should be small or the current should be large.

\[
S = \frac{I_{\text{max}}}{C}
\]

For 741 IC the charging current is 15 µA and the internal capacitor is 30 pF. \( S = 0.5V/ \mu\text{sec} \)
The modes of using an op-amp

- **Open Loop**: (The output assumes one of the two possible output states, that is $+V_{sat}$ or $-V_{sat}$ and the amplifier acts as a switch only).

- **Closed Loop**: (The utility of an op-amp can be greatly increased by providing negative feedback. The output in this case is not driven into saturation and the circuit behaves in a linear manner).
Open loop configuration of op-amp

- The voltage transfer curve indicates the inability of op-amp to work as a linear small signal amplifier in the open loop mode.
- Such an open loop behavior of the op-amp finds some rare applications like voltage comparator, zero crossing detector etc.
Open loop op-amp configurations

• The configuration in which output depends on input, but output has no effect on the input is called open loop configuration.
• No feedback from output to input is used in such configuration.
• The op-amp works as high gain amplifier
• The op-amp can be used in three modes in open loop configuration they are
  • Differential amplifier
  • Inverting amplifier
  • Non inverting amplifier
Why op-amp is generally not used in open loop mode?

As open loop gain of op-amp is very large, very small input voltage drives the op-amp voltage to the saturation level. Thus in open loop configuration, the output is at its positive saturation voltage \((+V_{\text{sat}})\) or negative saturation voltage \((-V_{\text{sat}})\) depending on which input \(V_1\) or \(V_2\) is more than the other. For a.c. input voltages, output may switch between positive and negative saturation voltages.
This indicates the inability of op-amp to work as a linear small signal amplifier in the open loop mode. Hence the op-amp in open loop configuration is not used for the linear applications.
Closed loop operation of op-amp

- The utility of the op-amp can be increased considerably by operating in closed loop mode.
- The closed loop operation is possible with the help of feedback. The feedback allows to feed some part of the output back to the input terminals.
- In the linear applications, the op-amp is always used with negative feedback.
- The negative feedback helps in controlling gain, which otherwise drives the op-amp out of its linear range, even for a small noise voltage at the input terminals.