 

Vcc cannot exceed 5 V

Vin cannot be negative

**Amplifiers**

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|  | input terminal, output terminal, both referenced to a common reference (ground) – Vref, GND  Vpos, Vsupply, or VCC, or VDD.  Vneg, Vss, or VEE  They are also known as the rails of an amplifier.  Made with resistors, capacitors, and transistors. |
|  | Real voltage amplifiers   1. Input current is nonzero, which mean it has a finite power gain. This input current leads to a loading effect, because the input voltage of the amplifier is now smaller than the source voltage if the source has any resistance. 2. Output voltage will vary if the loading at the output varies. The putout can amplify a range of load resistances. 3. The output voltage is also limited range, cannot exceed positive/negative supply rails. |
|  | Rin = vin / Iin  Rout = vout / Iout |
|  |  |

When several ideal amplifiers are placed in cascade, the gain increases, Av= Av1\*Av2…

**Op Amps**

|  |  |  |  |
| --- | --- | --- | --- |
| Op Amp Characteristics | Parameter | Typical Range | Ideal Op Amp |
| Linear input-output response | Open-loop gain A | 104 to 108 | Infinity |
| High input resistance | Input resistance Ri | 106 to 1013 | Infinity |
| Low output resistance | Output resistance Ro | 1 to 100 | 0 |
| Very high gain | Supply voltage Vcc | 5 to 24 V | As specified |

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| **Nonideal op-amp** |  |
| **Inverting amplifier** |  |
| **Non-inverting amplifier** |  |
| **Voltage follower**  **[Op-Amp Unity-Gain Buffer.svg](http://en.wikipedia.org/wiki/File:Op-Amp_Unity-Gain_Buffer.svg)** |  |
| **Difference amplifier** |  |
| **Summing amplifier**  Op-Amp Summing Amplifier.svg | If  If  Output is inverted |
| **Instrumentation amplifier** |  |
| **Low pass passive filter**  **http://upload.wikimedia.org/wikipedia/commons/thumb/3/3b/RC_Divider.svg/200px-RC_Divider.svg.png**  **Low pass active filter**  **http://upload.wikimedia.org/wikipedia/commons/thumb/5/59/Active_Lowpass_Filter_RC.svg/300px-Active_Lowpass_Filter_RC.svg.png** | **High pass passive filter**  **http://upload.wikimedia.org/wikipedia/commons/thumb/f/fe/High_pass_filter.svg/210px-High_pass_filter.svg.png**  **Low pass active filter**  **http://upload.wikimedia.org/wikipedia/commons/thumb/8/87/Active_Highpass_Filter_RC.png/300px-Active_Highpass_Filter_RC.png** |
| **Relaxation oscillator**  File:OpAmpHystereticOscillator.svg | At time t, V- = 0 and Vout = Vdd |
| **Comparator**  Op-Amp Comparator.svg |  |
| **Non-inverting Schmitt trigger**  http://upload.wikimedia.org/wikipedia/commons/thumb/6/64/Op-Amp_Schmitt_Trigger.svg/300px-Op-Amp_Schmitt_Trigger.svg.png |  |
| **Inverting Schmitt trigger**  http://upload.wikimedia.org/wikipedia/commons/thumb/2/26/Op-Amp_Inverting_Schmitt_Trigger.svg/300px-Op-Amp_Inverting_Schmitt_Trigger.svg.png |  |
| **Inverting integrator**  [Op-Amp Integrating Amplifier.svg](http://en.wikipedia.org/wiki/File:Op-Amp_Integrating_Amplifier.svg) | **Inverting differentiator**  [Op-Amp Differentiating Amplifier.svg](http://en.wikipedia.org/wiki/File:Op-Amp_Differentiating_Amplifier.svg) |



MOSFET

 characteristic

 ideal

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| **Inverter** |  |
| **NAND** | **! (A&B) = !A || !B** |
| **NOR** | **! (A||B) = !A & !B** |
| **XOR**  [File:XOR from NAND.svg](http://upload.wikimedia.org/wikipedia/commons/f/fa/XOR_from_NAND.svg)  using NAND  File:XOR from NOR.svg  Using NOR | (A || !B) & (!A || B) = (A & B) || (!A & !B) |
| **XNOR**  File:XNOR Using NAND.png  using NAND  File:XNOR using NOR.svg  using NOR | (A||B) & (!A || !B) |

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| **Capacitor**    At DC, capacitor looks like an open circuit  Voltage across a capacitor must be continuous (no abrupt change) | Natural response |
| **Inductor**  At DC, inductor looks like a short circuit  Current through an inductor must be continuous (no abrupt change)  Inductors add together in the same way the resistors do. | Natural response |

**Phasor**

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| --- | --- |
|  | A\cdot \cos(\omega t + \theta) = A \cdot \frac{e^{i(\omega t + \theta)} + e^{-i(\omega t + \theta)}}{2},  \begin{align} A\cdot \cos(\omega t + \theta) &= \operatorname{Re} \left\{ A\cdot e^{i(\omega t + \theta)}\right\} \\ &= \operatorname{Re} \left\{ A e^{i\theta} \cdot e^{i\omega t}\right\}. \end{align} |