Aalto University
School of Electrical
Engineering

ELEC-C9610 Basics in Electronics

Lecture 4: Operational Amplifier

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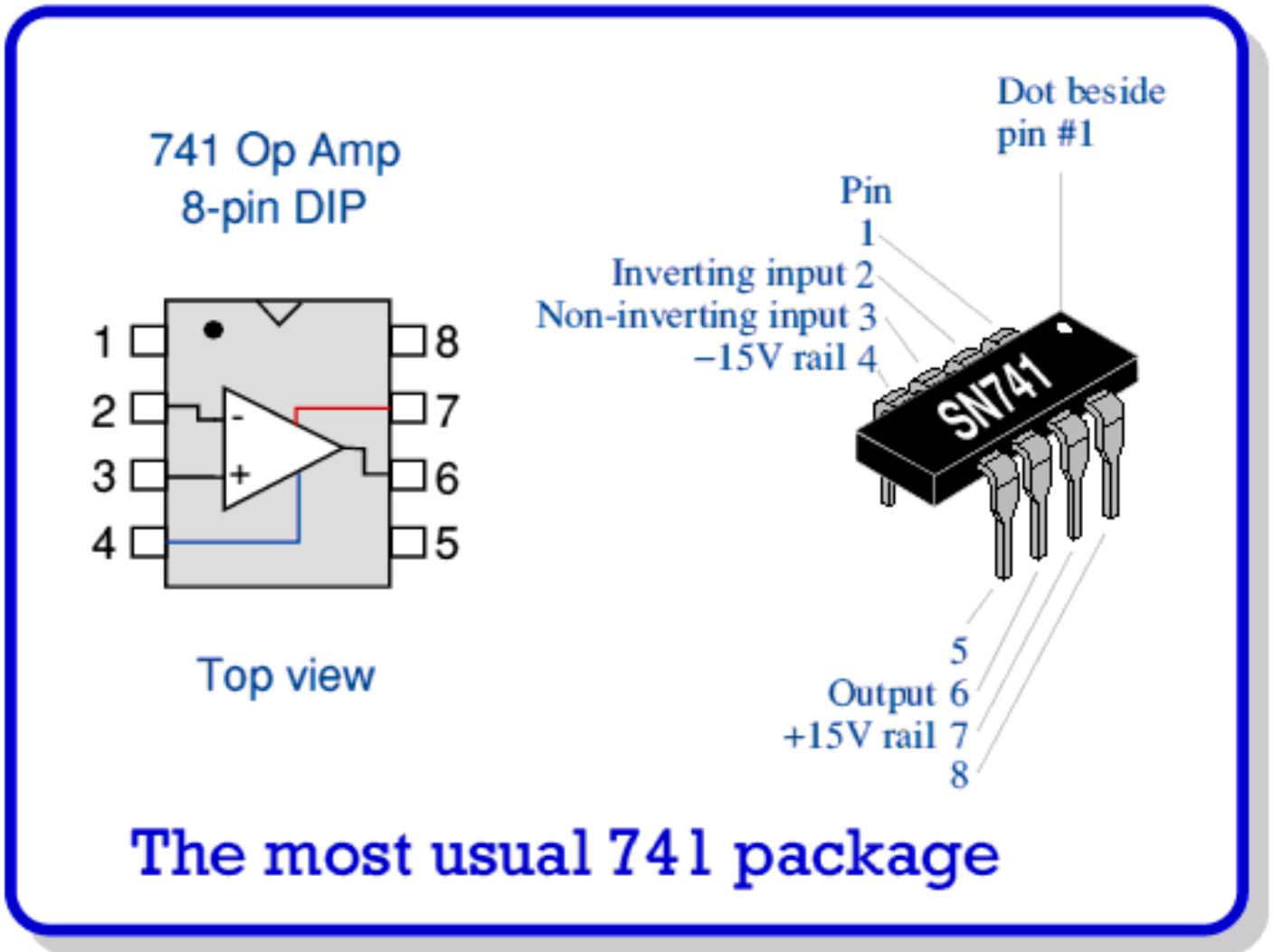
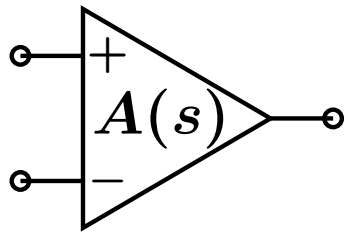
Operational amplifier



Operational amplifier

Operational amplifier is versatile and widely used component.

otto		anto
input		output
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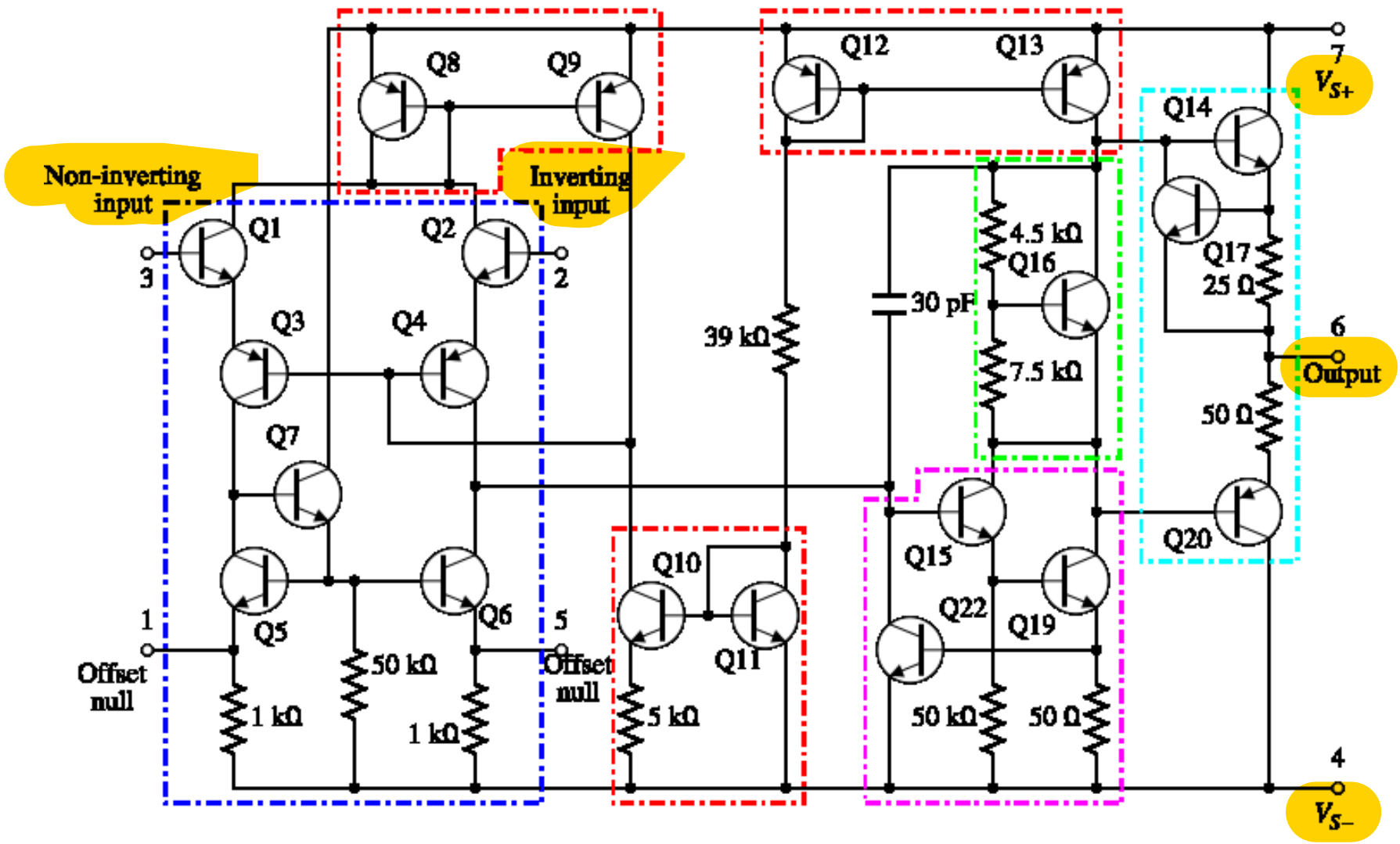
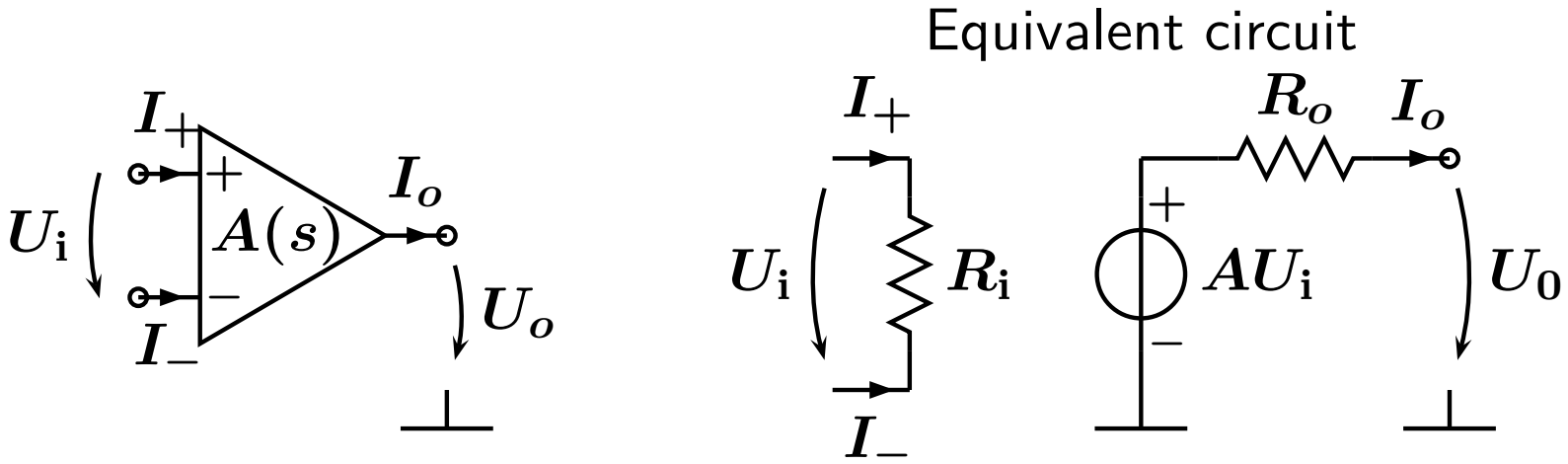
- Voltage difference between the plus and minus inputs comes to output amplified by voltage transfer function $\boldsymbol{A}(\boldsymbol{s}) = \boldsymbol{A}(\mathbf{j}\boldsymbol{\omega})$. Operational amplifier works as a voltage amplifier.
- Operational amplifier is basically always used with feedback (there is some other component too between the input and output node of the opamp).
- In stable feedback, input voltage compensates the change in output voltage.

*Transistor level model for an operational amplifier



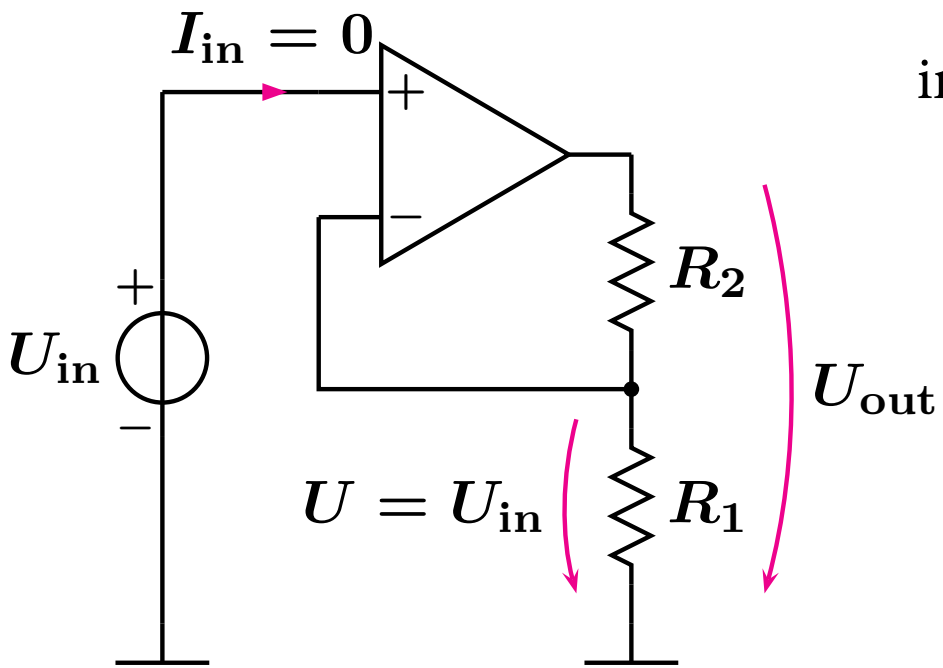
Ideal operational amplifier



- $A(s) = \infty$ (real, doesn't depend on frequency, value is infinity)
- $R_\mathrm{i} = \infty$: Input impedance is infinite, i.e., currents to input nodes are zero ($I_+ = I_- = 0$).
- Basis of analysis: Virtual short circuit between the input nodes, $U_+ = U_-$.
- Output resistance R_0 is zero and output current I_0 is determined by external circuit (I_0 assumed to be unlimited).

Non-inverting amplifier

The current I_{in} in input of the opamp is zero $\Rightarrow$ the circuit doesn't load the previous stage.

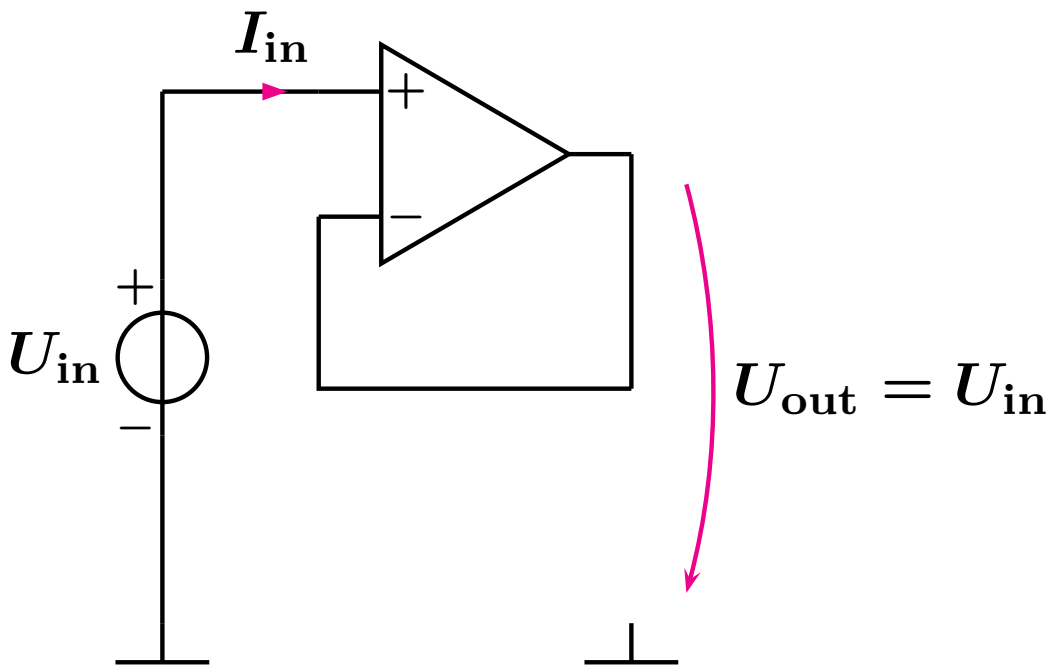


Circuit to increase voltage

$$U_{out} = \frac{R_1 + R_2}{R_1} U_{in} = \left(1 + \frac{R_2}{R_1}\right) U_{in}$$

Special case for the previous: Voltage follower

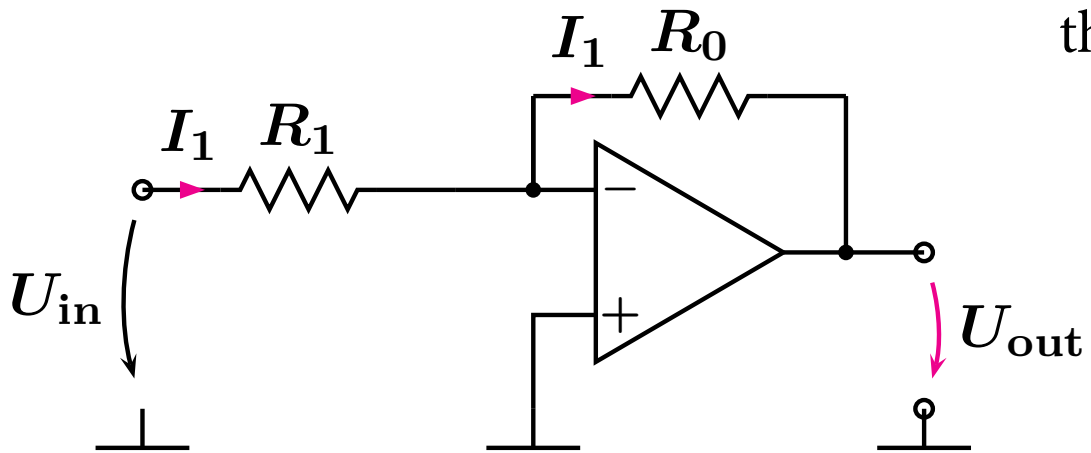
Voltage follower is used, if we want to eliminate the loading of cascaded blocks.



Inverting amplifier

No current to input of the operational amplifier.

Circuit to invert the voltage

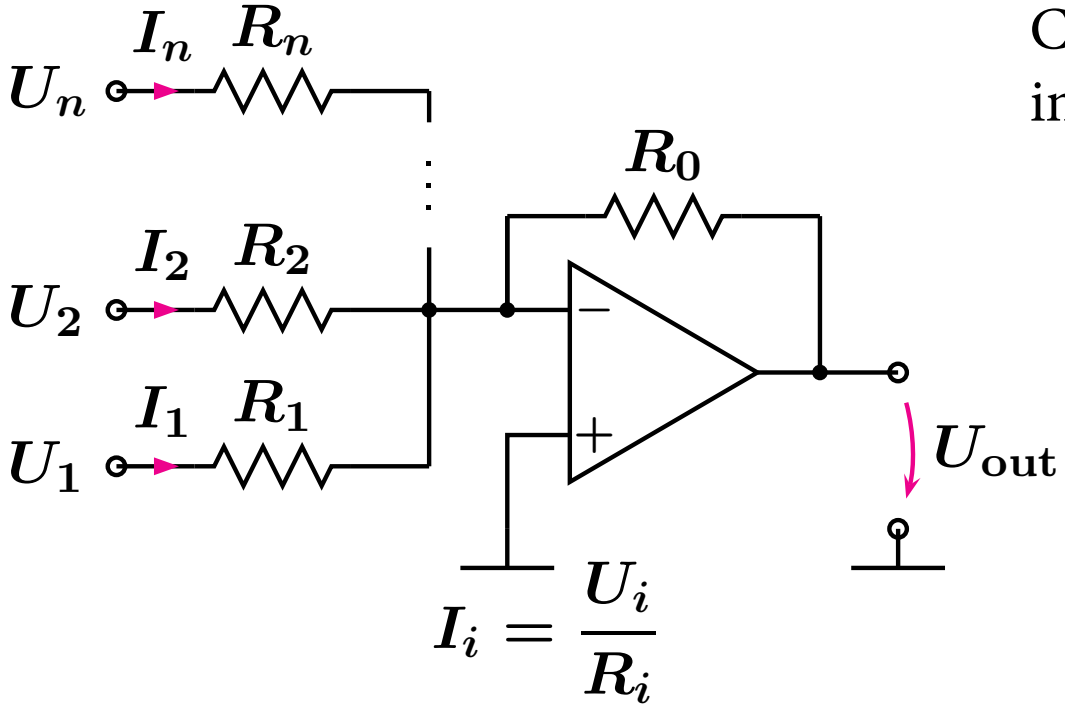


$$I_1 = \frac{U_{in}}{R_1}$$

$$U_{out} = -\frac{R_0}{R_1} U_{in}$$

Summing amplifier

Let's add more inputs to inverting amplifier.
The plus node is connected to ground, which means that the voltage in minus node is also zero. Therefore, we can sum all inputs so that they don't disturb others.



Circuit to sum input voltages

$$U_{out} = -\left(\frac{U_1}{R_1} + \frac{U_2}{R_2} + \cdots + \frac{U_n}{R_n}\right) R_0$$

*Nonidealities of operational amplifier

- **Finite, frequency dependent gain**
  - DC gain A_0 of transfer function $A(s)$ is finite.
  - Transfer function $A(s)$ has poles and zeros $\rightarrow$ frequency compensation.
- **Finite resistances**: Input resistance is not infinite and output resistance is not zero.
- **Finite output voltage**: Output voltage cannot be larger than supply voltage.
- **Finite slew rate**: Output voltage can change only at finite speed - otherwise signal becomes distorted
- **Bias currents**: Due to the bias currents, all inputs should have a DC-path to well-defined DC-voltage.
- **Distortion**: Nonlinearity of operational amplifier causes distortion.
- **Noise**: All resistive and active components produce noise.