Operational Amplifiers
Dimensioning

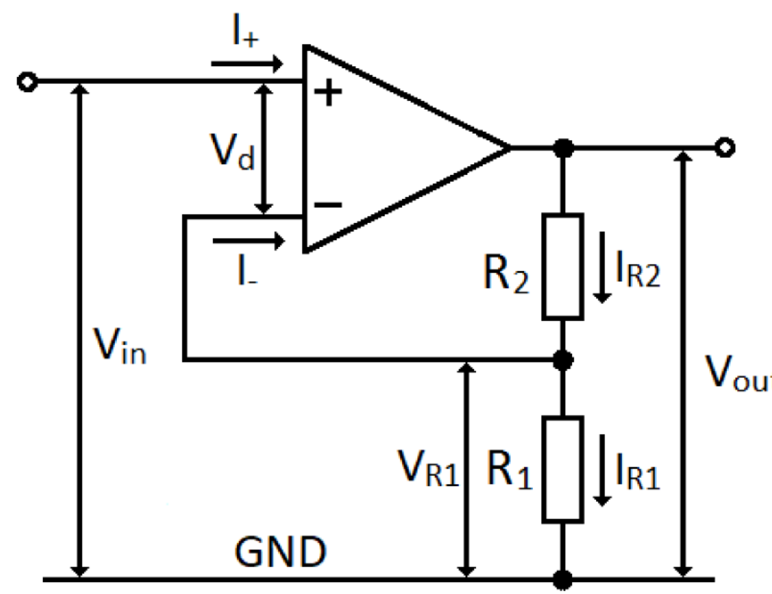
Applied Mechatronics

Module 5.3.2

by Wolfgang Neff

Non-Inverting Amplifier (1)

- Derivation of the Basic Equations
  - Known Quantities
    - $V_d = 0\ V$
    - $I_+ = 0\ A$
    - $I_- = 0\ A$
    - $V_+ = V_{in}$
    - $V_- = V_{in}$
    - $V_{R1} = V_{in}$
    - $I_{R1} = I_{R2} = I_R$



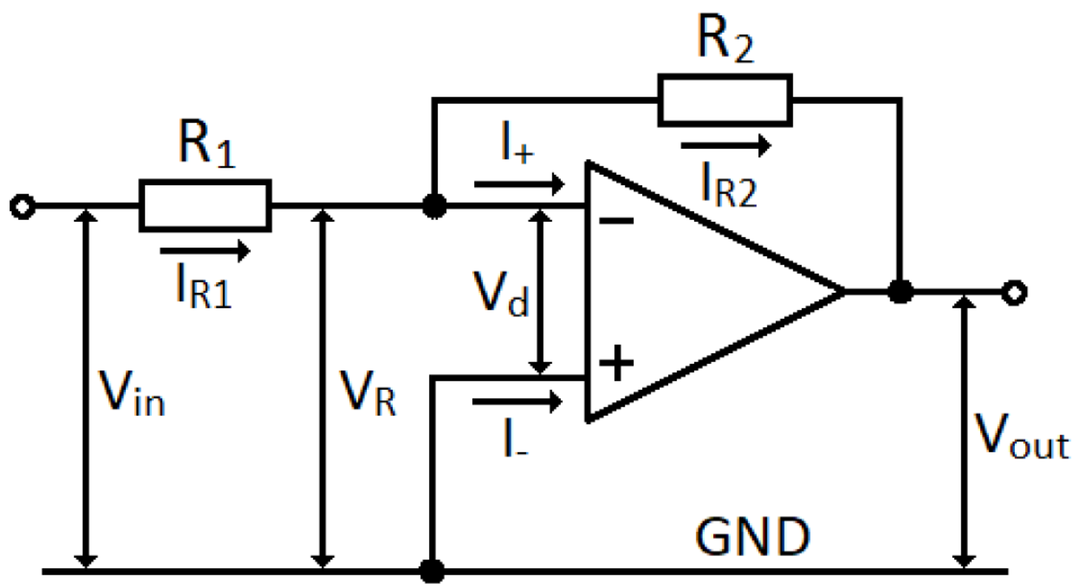
Cf. [SEY14] Ch. 2.11
Reihenschaltung von W.

Non-Inverting Amplifier (2)

- Derivation of the Basic Equations (continued)
  - Derivation
    - $I_{R_1} = \frac{V_{R_1}}{R_1} = \frac{V_{in}}{R_1}$
    - $I_R = \frac{V_{out}}{R_1+R_2}$
    - $\frac{V_{in}}{R_1} = \frac{V_{out}}{R_1+R_2} \rightarrow V_{out} = \frac{R_1+R_2}{R_1} V_{in} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$
    - $V_{out} = A_{CL} \cdot V_{in}$
    - $A_{CL} = 1 + \frac{R_2}{R_1}$

Inverting Amplifier (1)

- Derivation of the Basic Equations
  - Known Quantities
    - $V_d = 0\ V$
    - $I_+ = 0\ A$
    - $I_- = 0\ A$
    - $V_+ = 0\ V$
    - $V_- = 0\ V$
    - $V_R = 0\ V$
    - $I_{R1} = I_{R2}$

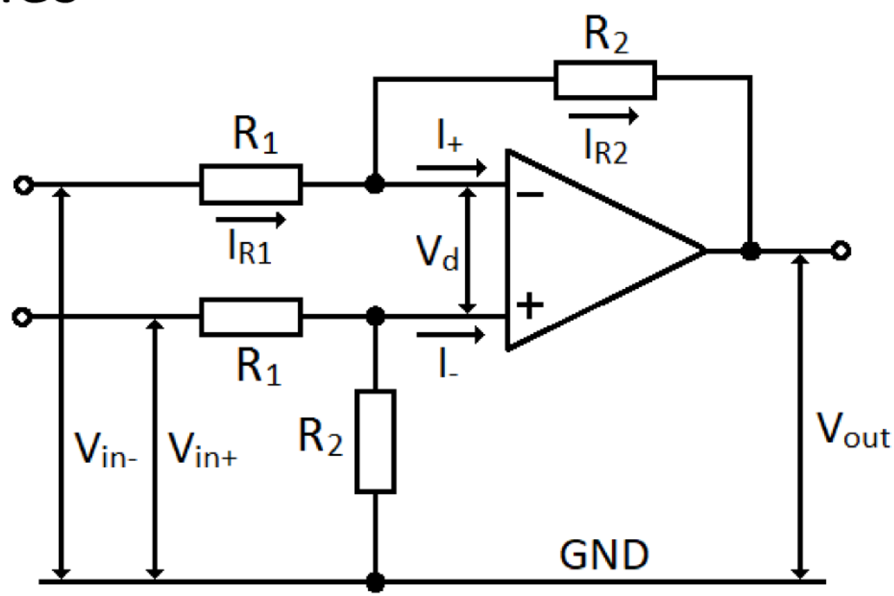


Inverting Amplifier (2)

- Derivation of the Basic Equations (continued)
  - Derivation
    - $I_{R_1} = \frac{V_{in} - V_R}{R_1} = \frac{V_{in}}{R_1}$
    - $I_{R_2} = \frac{V_R - V_{out}}{R_2} = \frac{-V_{out}}{R_2}$
    - $\frac{V_{in}}{R_1} = -\frac{V_{out}}{R_2} \rightarrow V_{out} = -\frac{R_2}{R_1} V_{in}$
    - $V_{out} = -A_{CL} \cdot V_{in}$
    - $A_{CL} = \frac{R_2}{R_1}$

Differential Amplifier (1)

- Derivation of the Basic Equations
  - Known Quantities
    - $Vd = 0\ V$
    - $I_+ = 0\ A$
    - $I_- = 0\ A$
    - $V_- = V_+$
    - $I_{R1} = I_{R2}$



Differential Amplifier (2)

- Derivation of the Basic Equations (continued)
  - Derivation
    - $V_+ = \frac{R_2}{R_1+R_2} V_{in_+}$
    - $I_{R_1} = \frac{V_{in_-} - V_+}{R_1}; I_{R_2} = \frac{V_+ - V_{out}}{R_2}$
    - $\frac{V_{in_-} - V_+}{R_1} = \frac{V_+ - V_{out}}{R_2} \rightarrow \frac{R_2}{R_1}\left(V_{in_-} - V_+\right) = V_+ - V_{out}$
    - $V_{out} = V_+ - \frac{R_2}{R_1}\left(V_{in_-} - V_+\right) = V_+ + \frac{R_2}{R_1} V_+ - \frac{R_2}{R_1} V_{in_-}$
    - $V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_+ - \frac{R_2}{R_1} V_{in_-}$

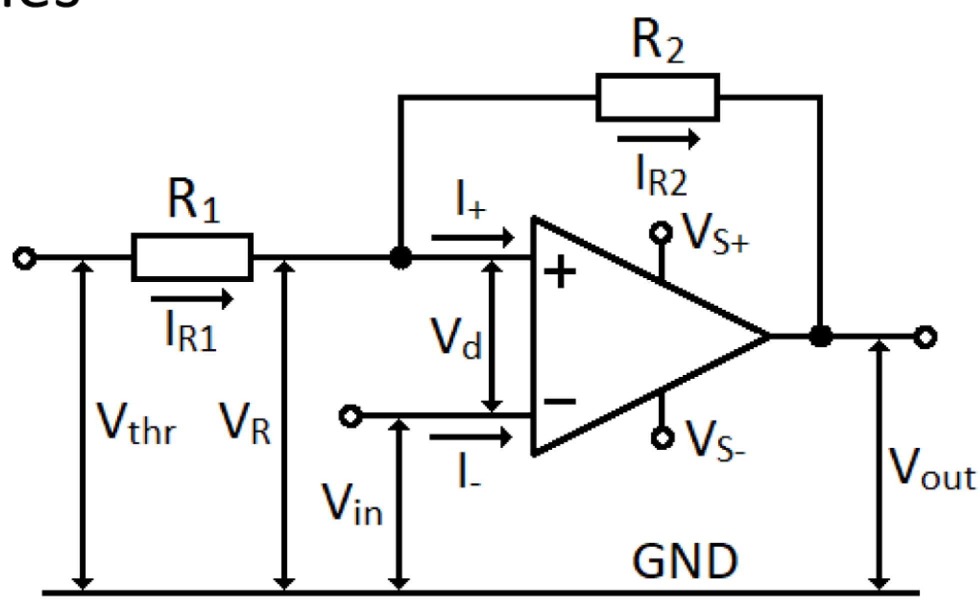
Cf. [SEY14] Ch. 2.11 p. 36
Spannungsteilter

Differential Amplifier (3)

- Derivation of the Basic Equations (finished)
  - Derivation
    - $V_{out} = \left(1 + \frac{R_2}{R_1}\right) \frac{R_2}{R_1 + R_2} V_{in_+} - \frac{R_2}{R_1} V_{in_-}$
    - $V_{out} = \frac{R_1 + R_2}{R_1} \frac{R_2}{R_1 + R_2} V_{in_+} - \frac{R_2}{R_1} V_{in_-}$
    - $V_{out} = \frac{R_2}{R_1} V_{in_+} - \frac{R_2}{R_1} V_{in_-} = \frac{R_2}{R_1} \left(V_{in_+} - V_{in_-}\right)$
    - $V_{out} = A_{CL} \left(V_{in_+} - V_{in_-}\right)$
    - $A_{CL} = \frac{R_2}{R_1}$

Schmitt Trigger (1)

- Derivation of the Basic Equations
  - Known Quantities
    - $V_d = 0\ V$
    - $I_+ = 0\ A$
    - $I_- = 0\ A$
    - $V_R = V_{in}$
    - $I_{R1} = I_{R2} = I_R$



Schmitt Trigger (2)

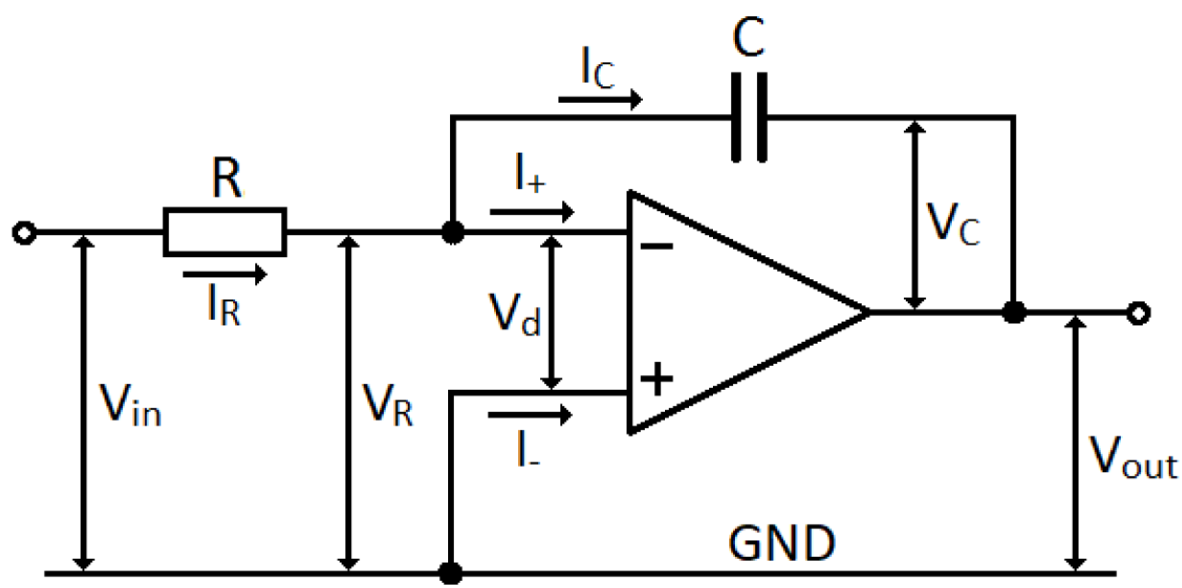
- Derivation of the Basic Equations (continued)
  - Derivation
    - $I_{R_1} = \frac{V_{thr} - V_R}{R_1}; I_R = \frac{V_{thr} - V_{out}}{R_1 + R_2}$
    - $\frac{V_{thr} - V_{in}}{R_1} = \frac{V_{thr} - V_{out}}{R_1 + R_2}$
    - Case 1:
      - $V_{in} = V_{HT} \rightarrow V_{out} = V_{S_+}$
      - $\frac{V_{thr} - V_{HT}}{R_1} = \frac{V_{thr} - V_{S+}}{R_1 + R_2} \rightarrow V_{HT} = V_{thr} - \frac{R_1}{R_1 + R_2}\left(V_{thr} - V_{S_+}\right)$
      - $V_{HT} = V_{thr} + \frac{R_1}{R_1 + R_2}\left(V_{S_+} - V_{thr}\right)$

Schmitt Trigger (3)

- Derivation of the Basic Equations (finished)
  - Derivation
    - Case 2:
      - $V_{in} = V_{LT} \rightarrow V_{out} = V_{S_-}$
      - $V_{HT} \rightarrow V_{LT}; V_{S_+} \rightarrow V_{S_-}$
      - $V_{LT} = V_{thr} + \frac{R_1}{R_1+R_2}\left(V_{S_-} - V_{thr}\right)$

Integrator (1)

- Derivation of the Basic Equations
  - Known Quantities
    - $V_d = 0\ V$
    - $I_+ = 0\ A$
    - $I_- = 0\ A$
    - $V_R = 0\ V$
    - $I_C = I_R$



Integrator (2)

- Derivation of the Basic Equations (continued)
  - Fundamentals
    - $Q = I \cdot t$
    - $V = \frac{Q}{C}$
  - Derivation
    - $\Delta Q = I_R \cdot \Delta t$
    - $Q = Q_0 + \Delta Q$
    - $I_R = \frac{V_{in}}{R}$

Cf. [SEY14] Ch. 5.1
Elektrische Ladung

Cf. [SEY14] Ch. 5.7
Kondensator an Gleichsp.

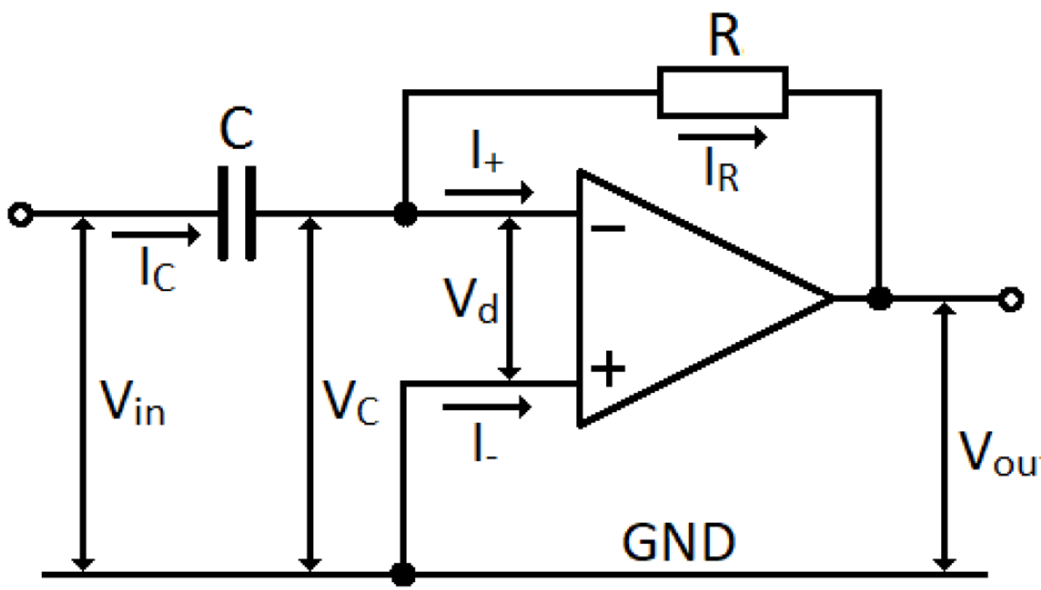
Integrator (3)

- Derivation of the Basic Equations (finished)
  - Derivation
    - $V_C = \frac{Q}{C} = \frac{Q_0+\Delta Q}{C} = \frac{Q_0}{C} + \frac{I_R \cdot \Delta t}{C} = V_{C_0} + \frac{V_{in}}{R \cdot C} \cdot \Delta t$
    - $V_c = V_R - V_{out} = -V_{out}$
    - $-V_{out} = V_{C_0} + \frac{V_{in}}{R \cdot C} \cdot \Delta t \rightarrow V_{out} - V_{out_0} = -\frac{1}{R \cdot C} V_{in} \cdot \Delta t$
    - $\Delta V_{out} = -\frac{1}{R \cdot C} V_{in} \cdot \Delta t$
    - $v_{out}(t) = -\frac{1}{R \cdot C} \cdot \int_0^t v_{in}(t) dt + v_{out}(0)$

V_{in} depends on time → Integral calculus needed

Differentiator (1)

- Derivation of the Basic Equations
  - Known Quantities
    - $V_d = 0\ V$
    - $I_+ = 0\ A$
    - $I_- = 0\ A$
    - $V_C = 0\ V$
    - $I_C = I_R$



Differentiator (2)

- Derivation of the Basic Equations (continued)
  - Derivation
    - $\Delta V_{in} = \frac{\Delta Q}{C} \rightarrow \Delta Q = C \cdot \Delta V_{in}$
    - $\Delta Q = I_c \cdot \Delta t \rightarrow I_C = \frac{\Delta Q}{\Delta t}$
    - $I_C = I_R = \frac{V_C - V_{out}}{R} = -\frac{V_{out}}{R} \rightarrow -\frac{V_{out}}{R} = \frac{C \cdot \Delta V_{in}}{\Delta t}$
    - $V_{out} = -R \cdot C \cdot \frac{\Delta V_{in}}{\Delta t}$
    - $v_{out}(t) = -R \cdot C \cdot \frac{dv_{in}(t)}{dt}$

V_{in} depends on time →
Differential calculus needed

Bibliography

- [SEY14]: SEYR, SIGURD and SCHWAIGER, HERBERT, 2014, Elektrotechnik Grundlagen mit angewandter Mathematik. Wien : Jugend & Volk. ISBN 978-3-7100-2873-1.
- [BRI13]: BRIEGLER, ADOLF and others, 2013, Elektrotechnik Fachkunde 1. Wien : Jugend & Volk. ISBN 978-3-7100-2911-0.