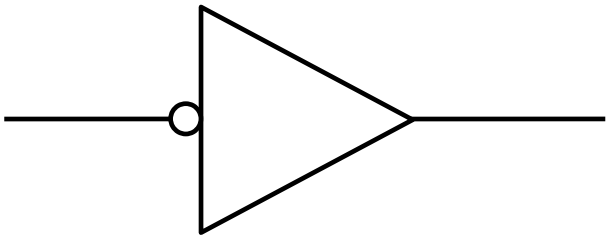
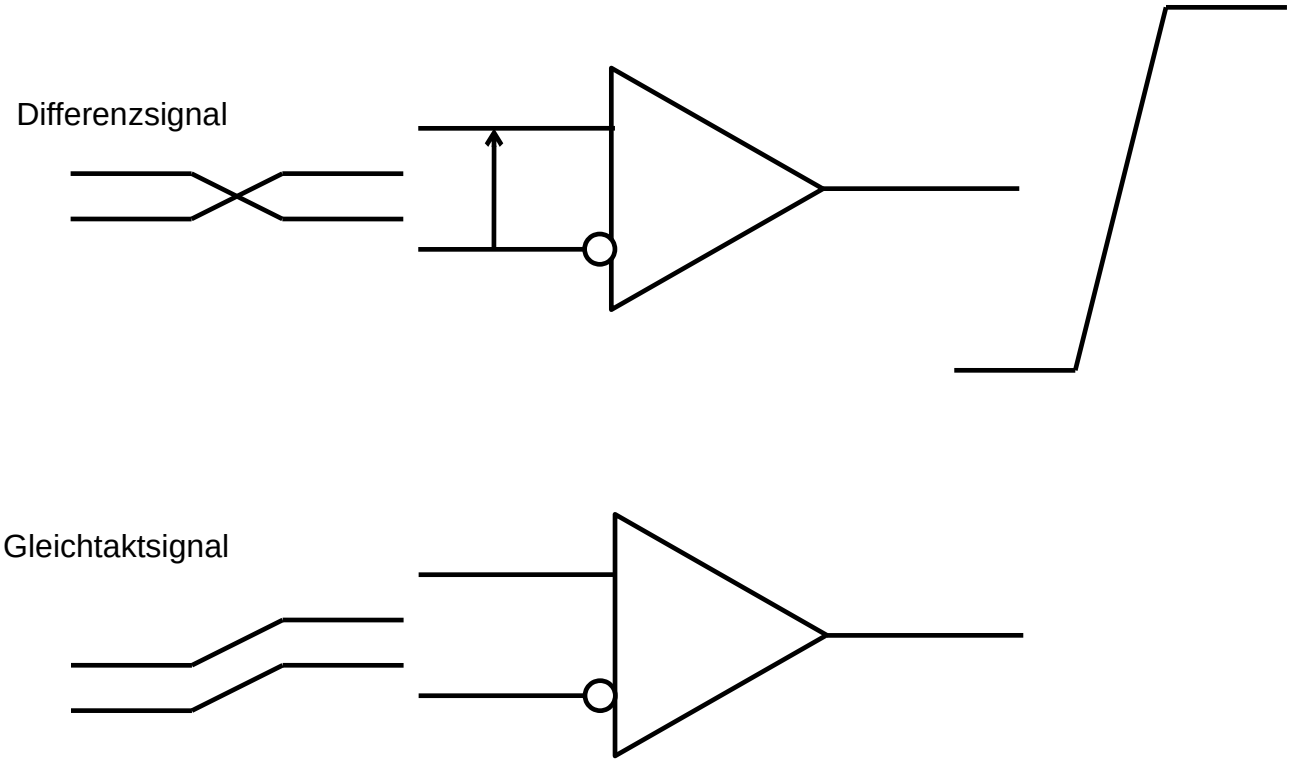
Differenzverstärker

- Bis jetzt - Single-Ended Verstärker

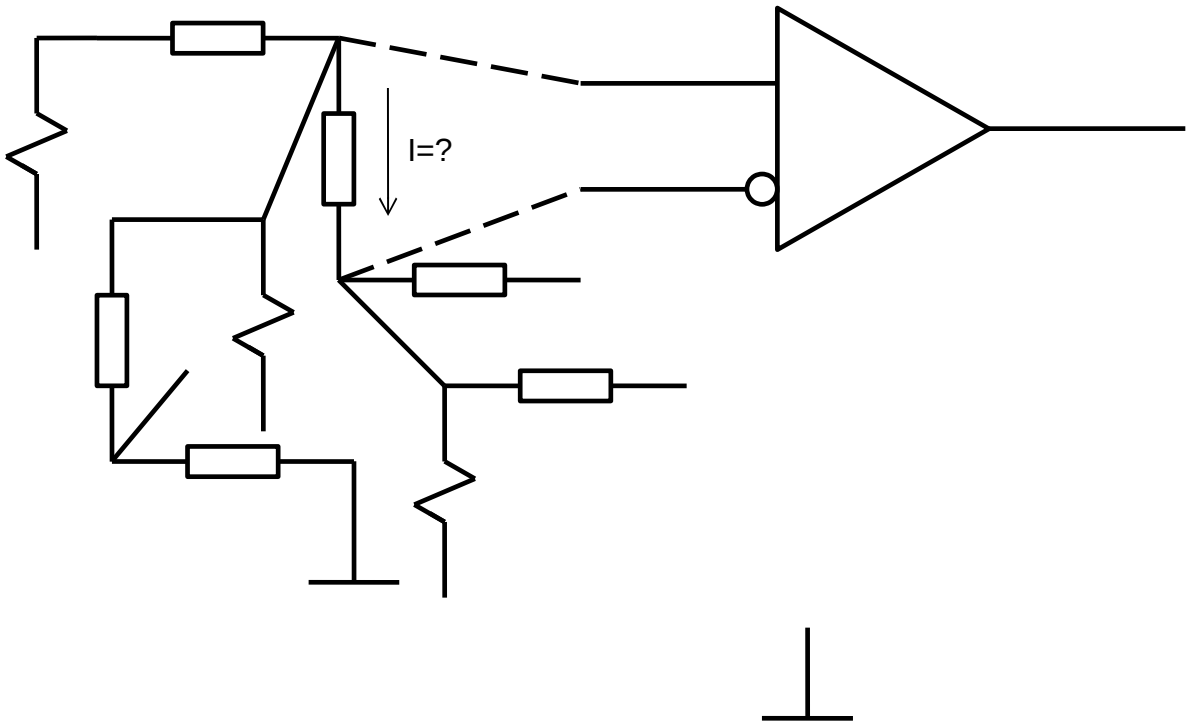


- Differenzverstärker

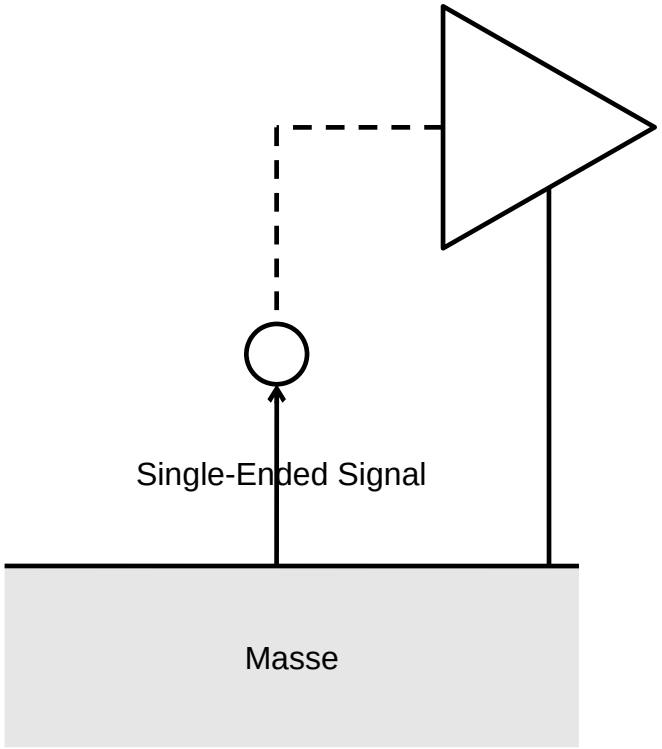


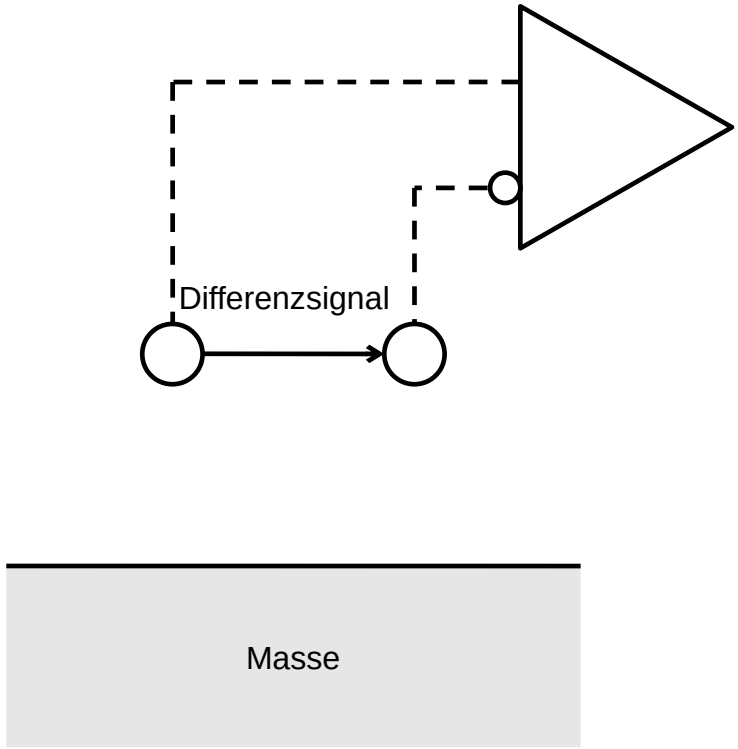
Anwendungen

Relative Messungen

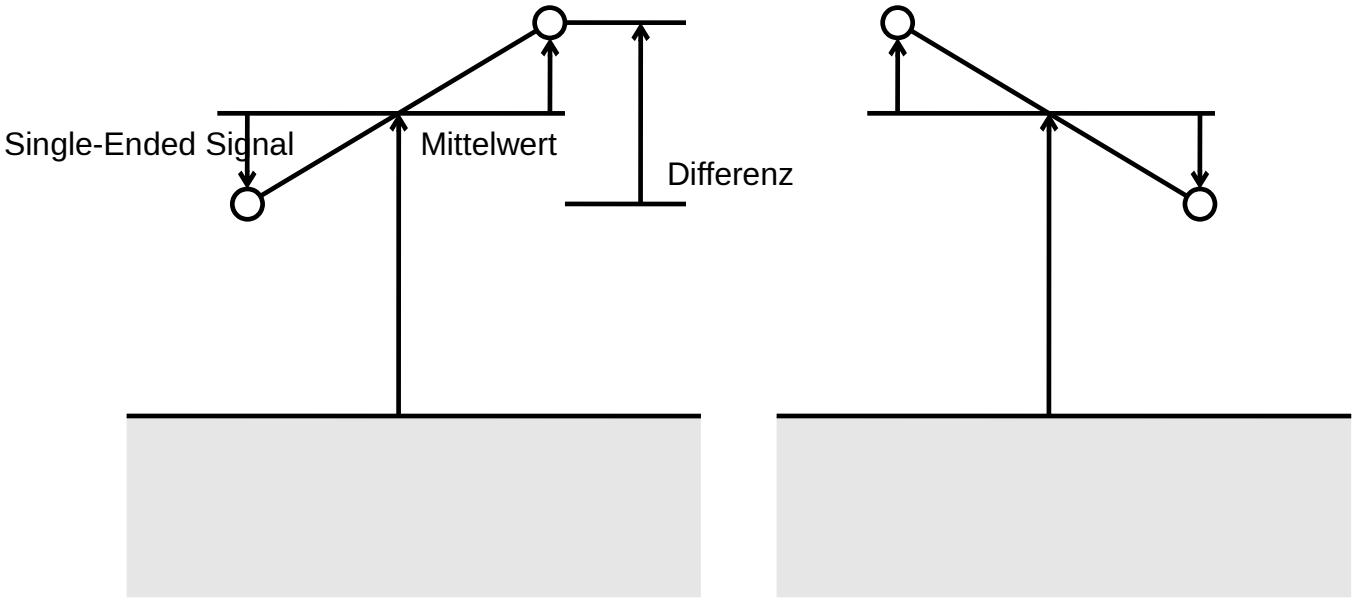


Differentielle Signalbearbeitung

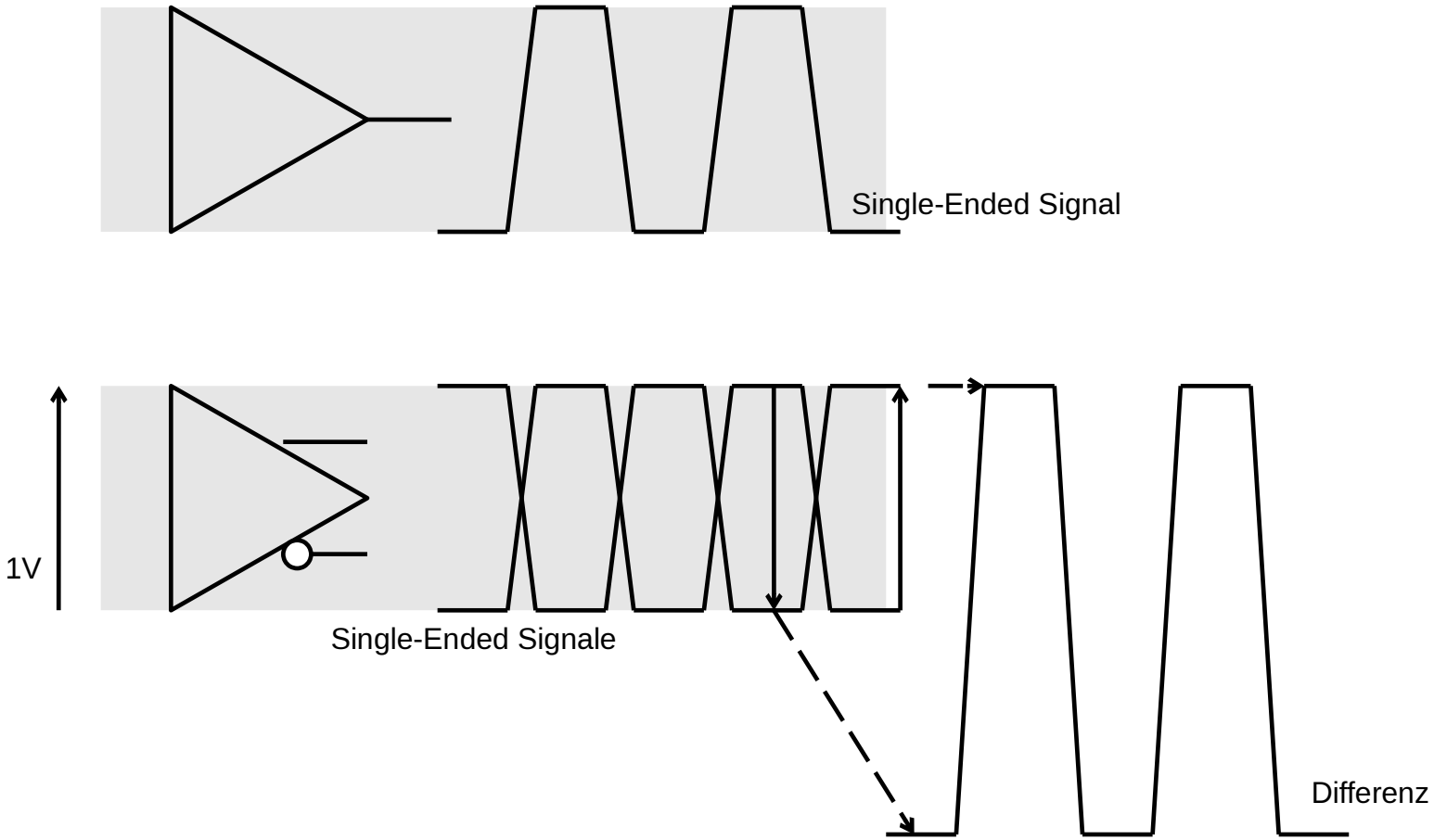




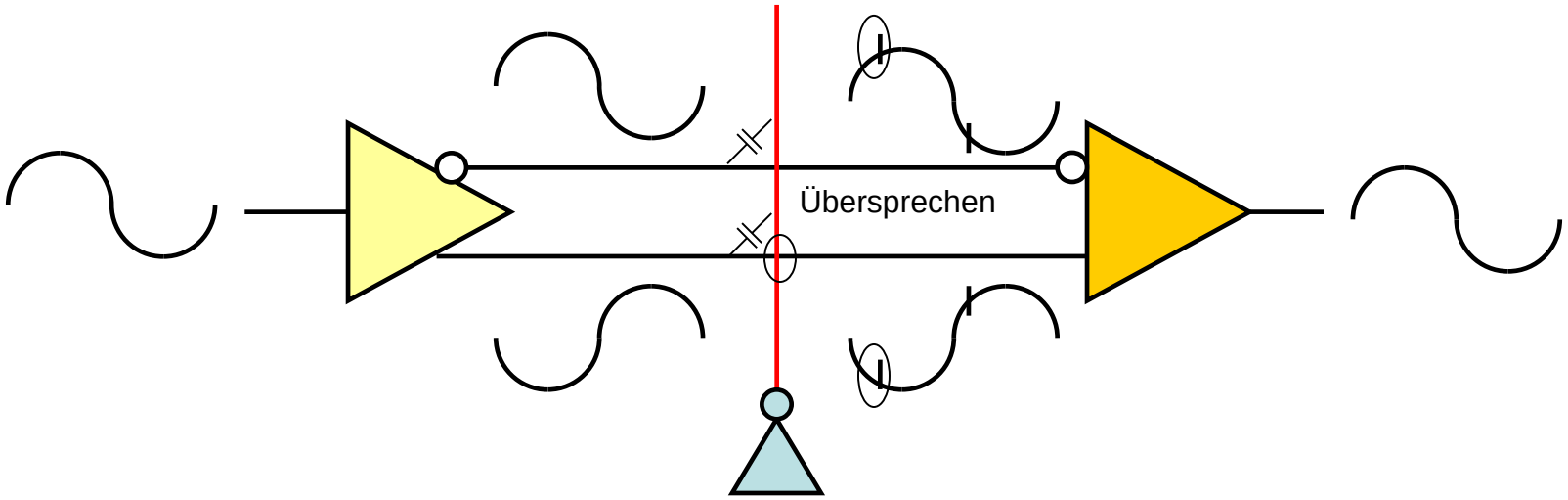
- Vorteil: Die Amplitude des Differenzsignals ist zweimal höher als die Single-Ended Amplitude



- …

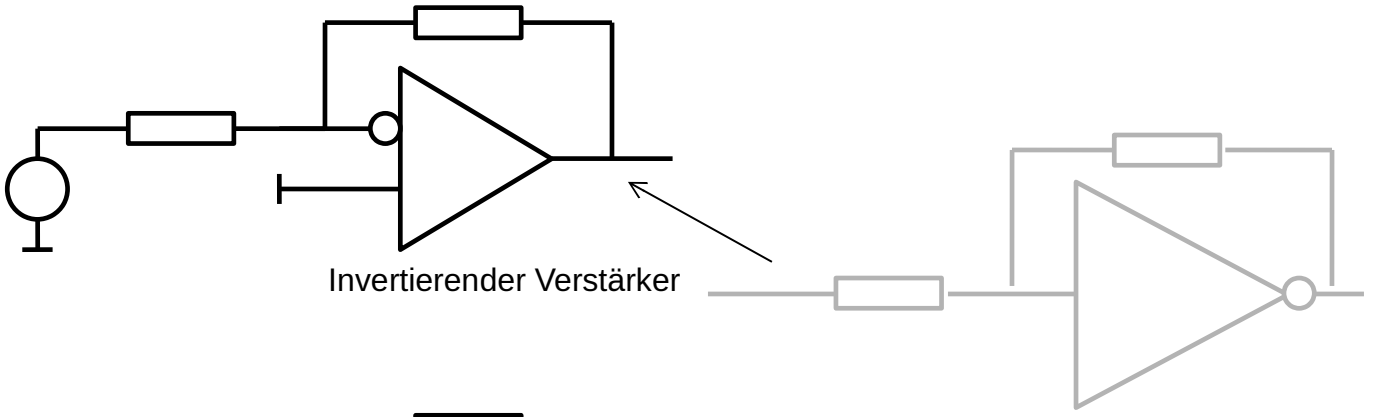

Single-Ended Signal
1V
Single-Ended Signale
Differenz

- Eine externe Störung beeinflusst ein Differenzsignal nicht



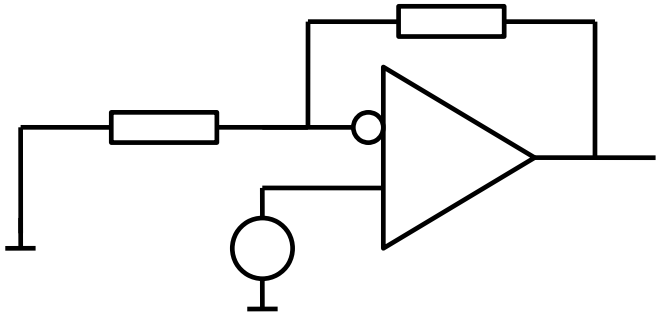
Operationsverstärker

- Operationsverstärker
- Mit dem Operationsverstärker lassen sich verschieden Schaltungen mit der Rückkopplung realisieren, Verstärker, Filter, Oszillatoren



Invertierender Verstärker

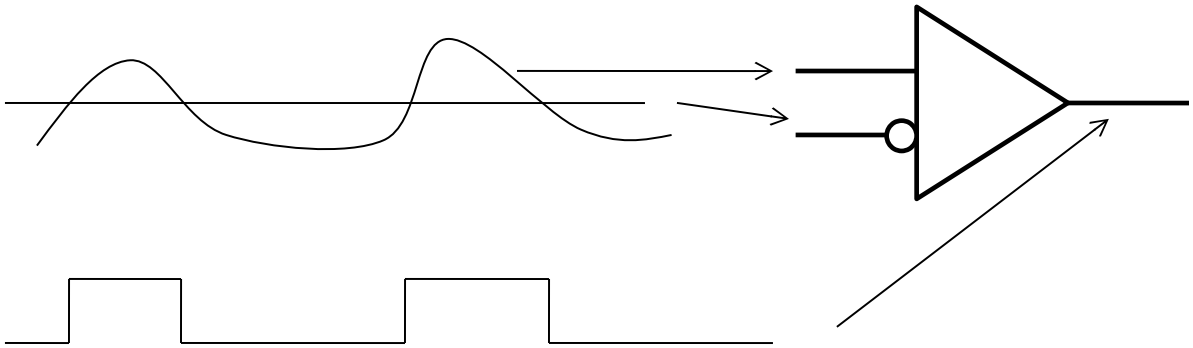
Variante mit dem Single-Ended Verstärker



Nichtinvertierender Verstärker

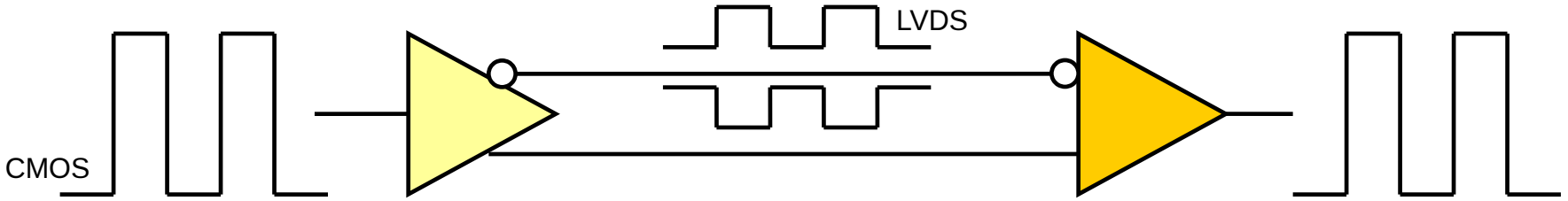
Operationsverstärker

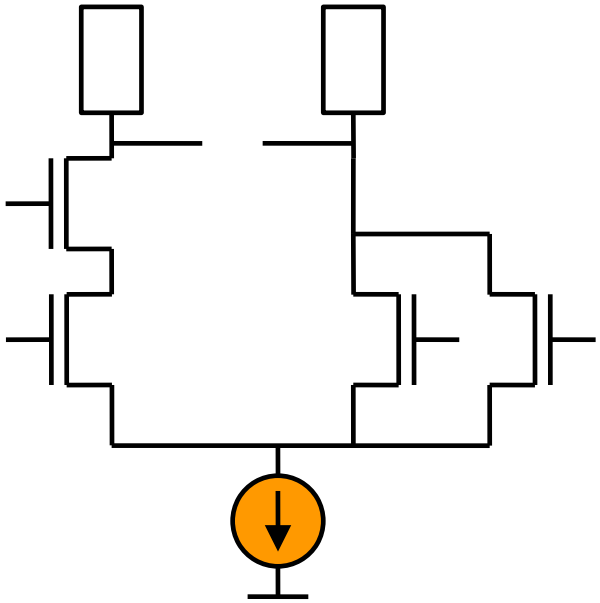
- Komparator

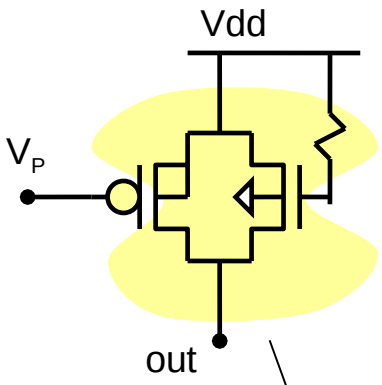


Digitale Schaltungen

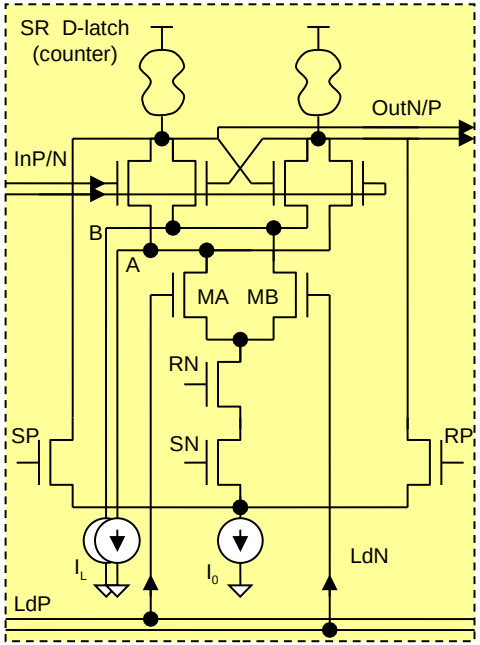
- Empfänger und Treiber für differentielle Datenübertragung
- Logische Bauteile, wie Gatter, oder Flipflops



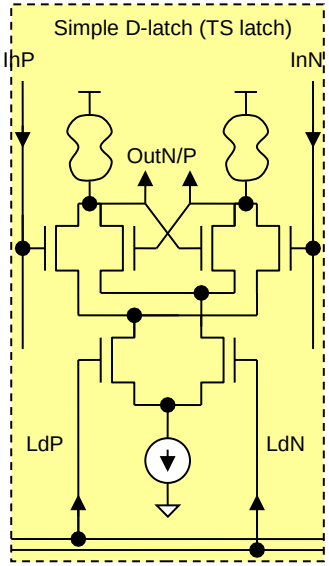




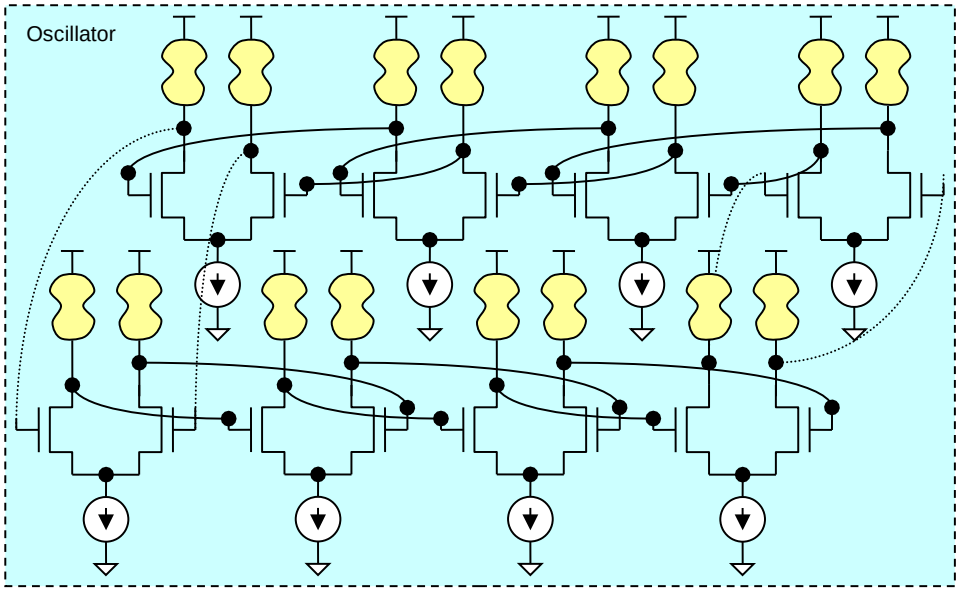
SR-Latch



D-Latch



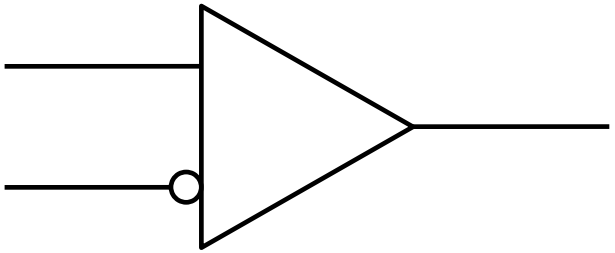
Ringoszillator



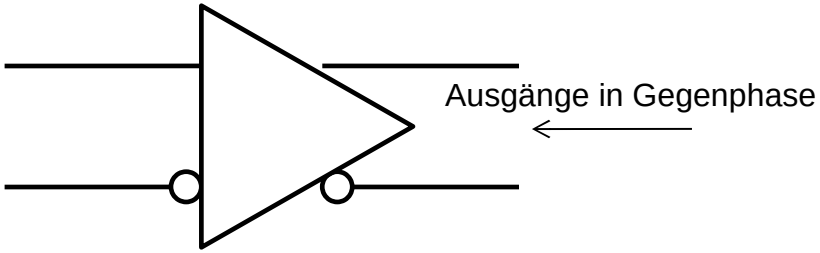
Klassifizierung

- Differenzverstärker werden nach dem Eingangs/Ausgangs-Typ klassifiziert

Operationsverstärker
Eingang differentiell, Ausgang single-ended

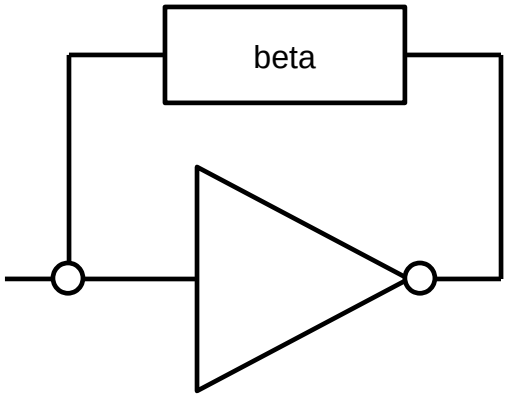


Symmetrischer (fully-differential) Differenzverstärker
Eingang und Ausgang differentiell

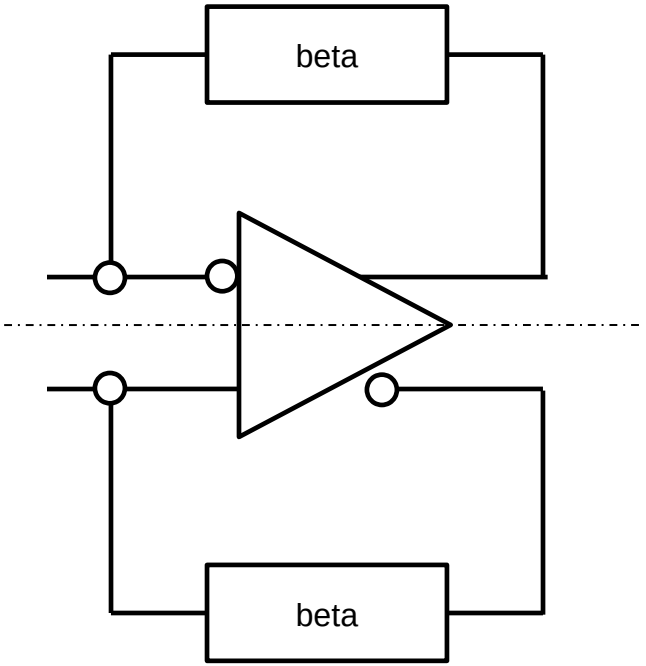


Klassifizierung

- Symmetrische Verstärker werden für differentielle Signalverarbeitung benutzt



Single-Ended Schaltung

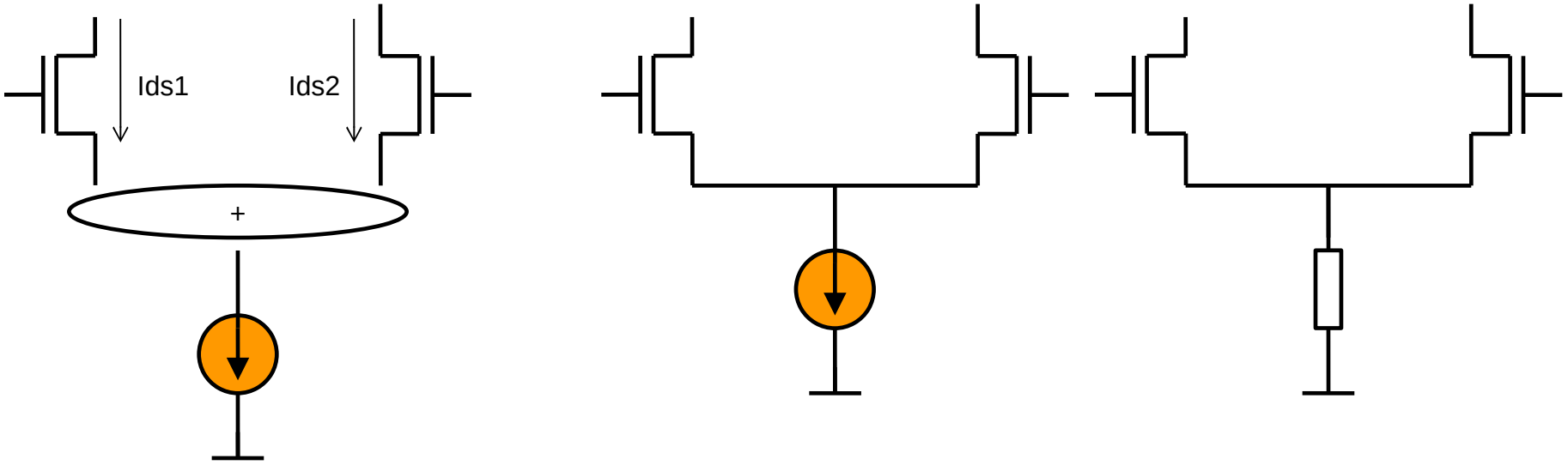


Differenzschaltung

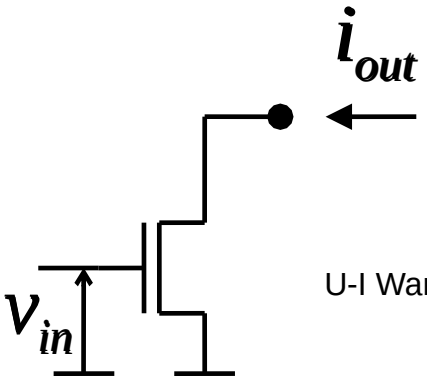
Implementierung

Differenzpaar

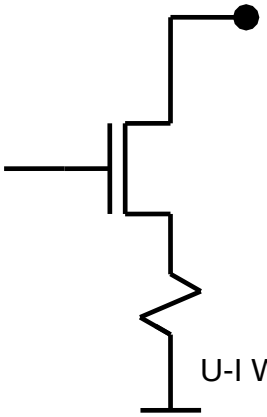
- Grundkomponente eines Differenzverstärkers ist ein Differenzpaar
- Bias: Stromquelle oder ein größer Widerstand
- Ziel: Summe von Ids Strömen konstant
- Stromanstieg in einem Transistor -> Stromabfall im anderen



- ….

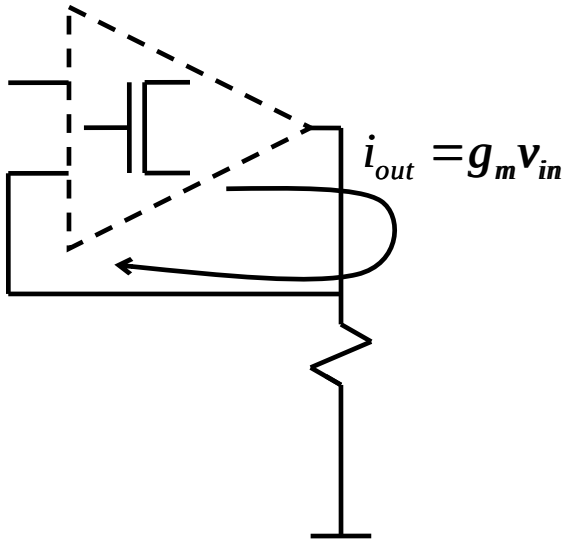


U-I Wandler



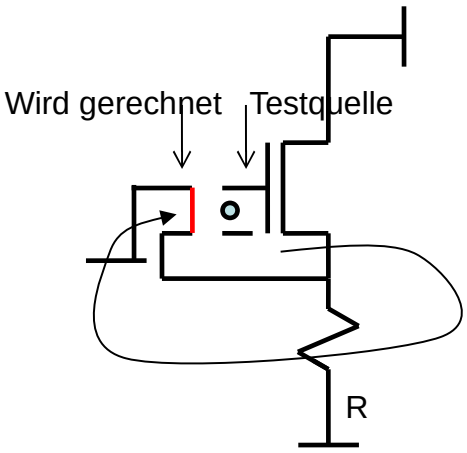
U-I Wandler mit Source-Widerstand

$\Leftrightarrow$



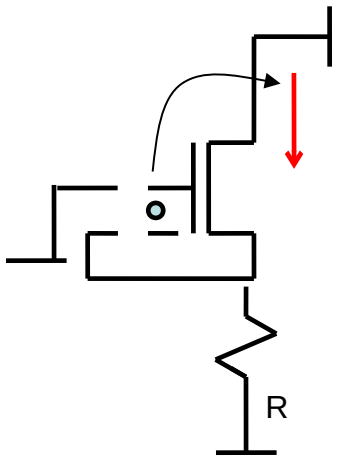
Linearer Spannung-Strom Wandler

Schleifenverstärkung βAol



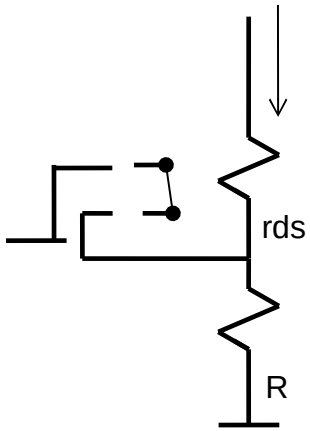
$$\beta A_{OL} = -g_m (R \parallel r_{ds}) \sim -g_m R$$

Verstärkung ohne GK



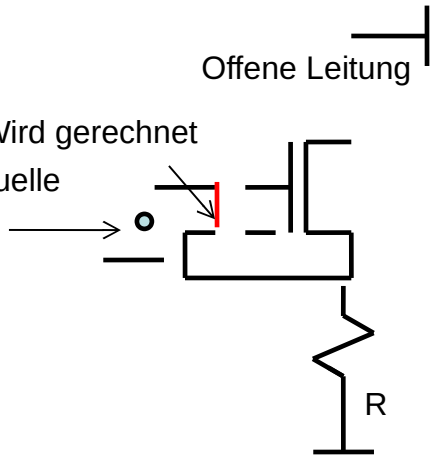
$$A_{OL} = g_m$$

Widerstand ohne RK



$$R_{out0} = r_{ds} + R$$

Verstärkung am Eingang



$$A_{IN} = 1$$

Verstärkung mit RK

$$G = \frac{A_{IN} A_{OL}}{1 + \beta A_{OL}}$$

$$G = \frac{g_m}{1 + g_m R}$$

Widerstand mit RK

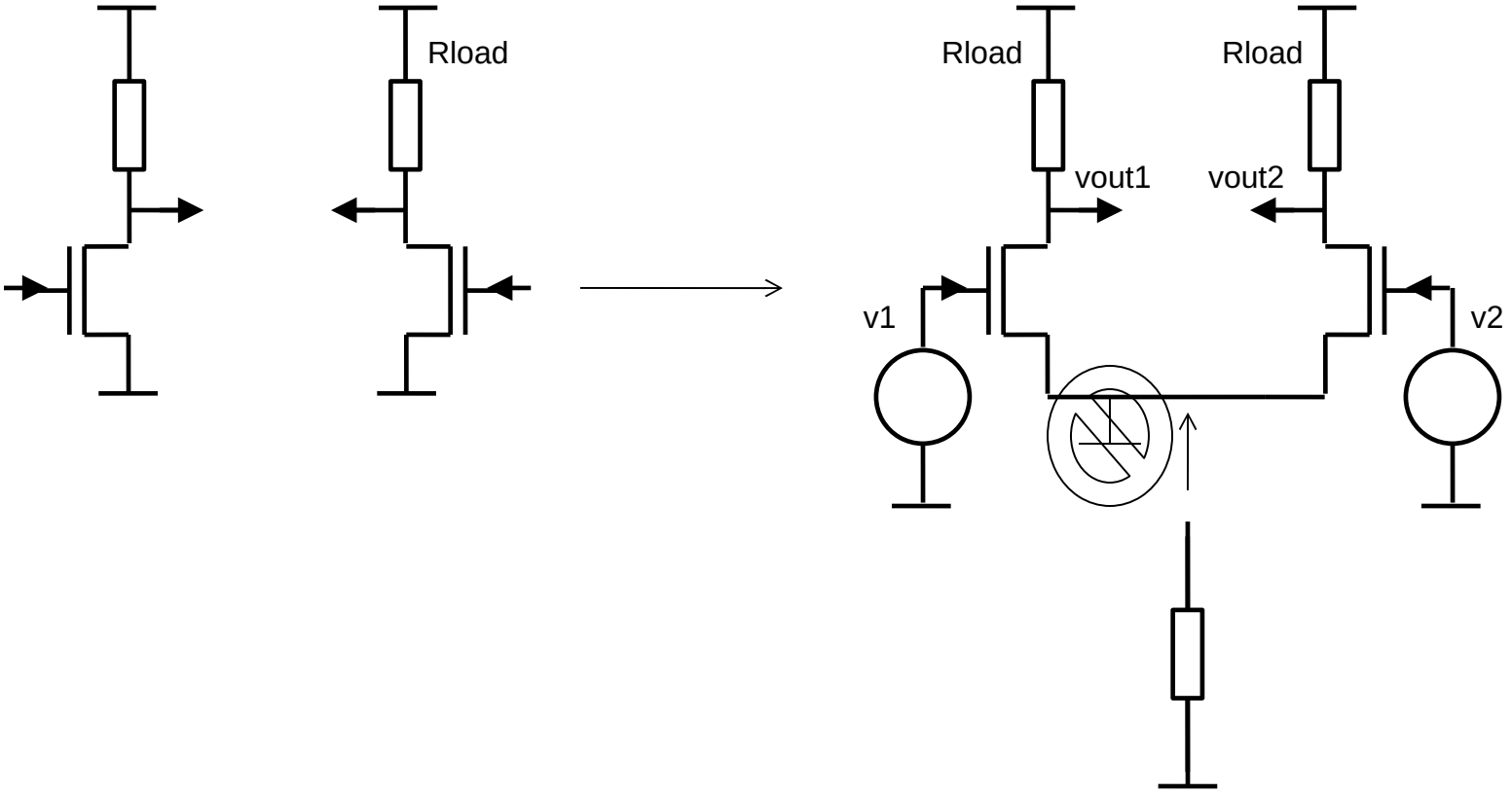
$$R_{out} = R_{out0} \frac{1 + \beta A_{SC}}{1 + \beta A_{OC}}$$

$$R_{out} = (R + r_{ds})\left[1 + g_m (R \parallel r_{ds})\right] = R g_m r_{ds}$$

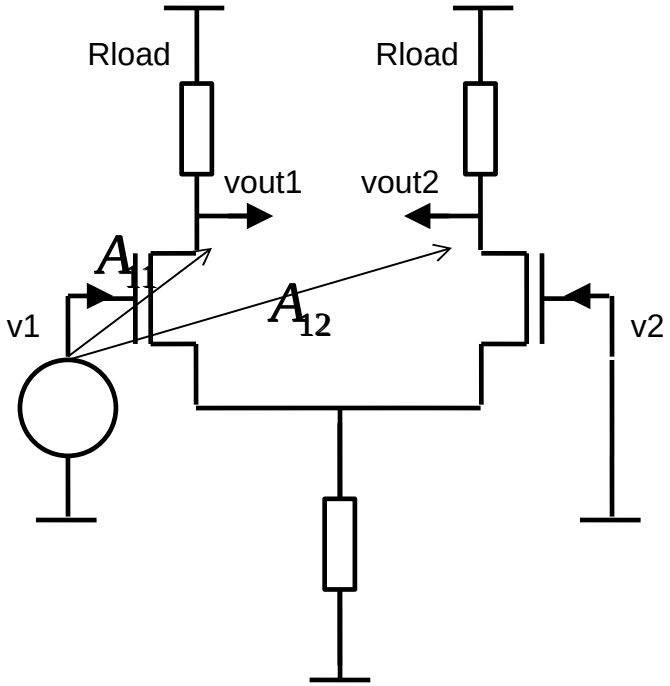
Differenzverstärker

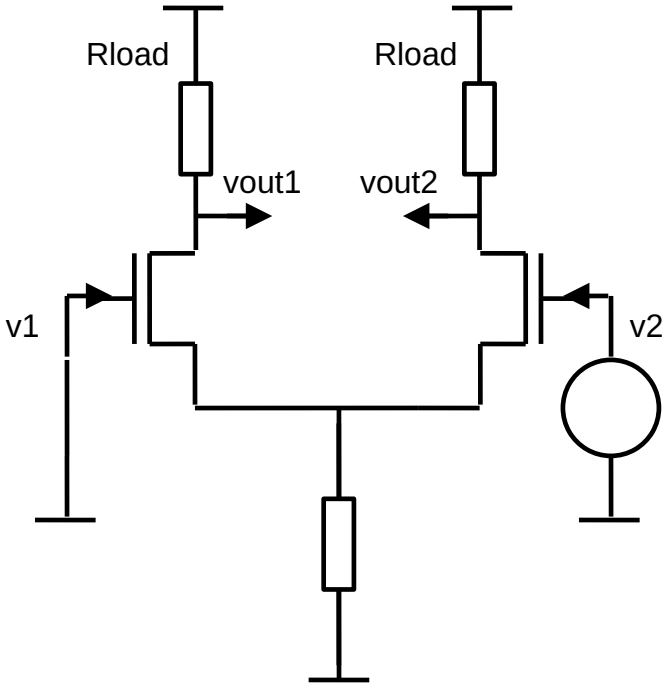
- Symmetrischer Differenzverstärker

Zwei single-ended Verstärker



- Symmetrischer Differenzverstärker
- Superposition
- Asymmetrie





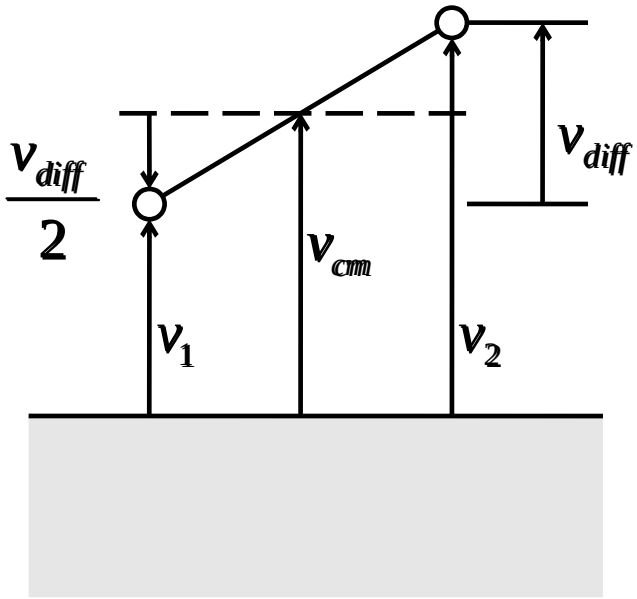
$$v_{out1} = A_{11} v_1$$

$$v_{out2} = A_{12} v_1$$

$$v_{out1} = A_{21} v_2$$

$$v_{out2} = A_{22} v_2$$

Differenz und Common Mode



$$v_{diff} = v_2 - v_1$$

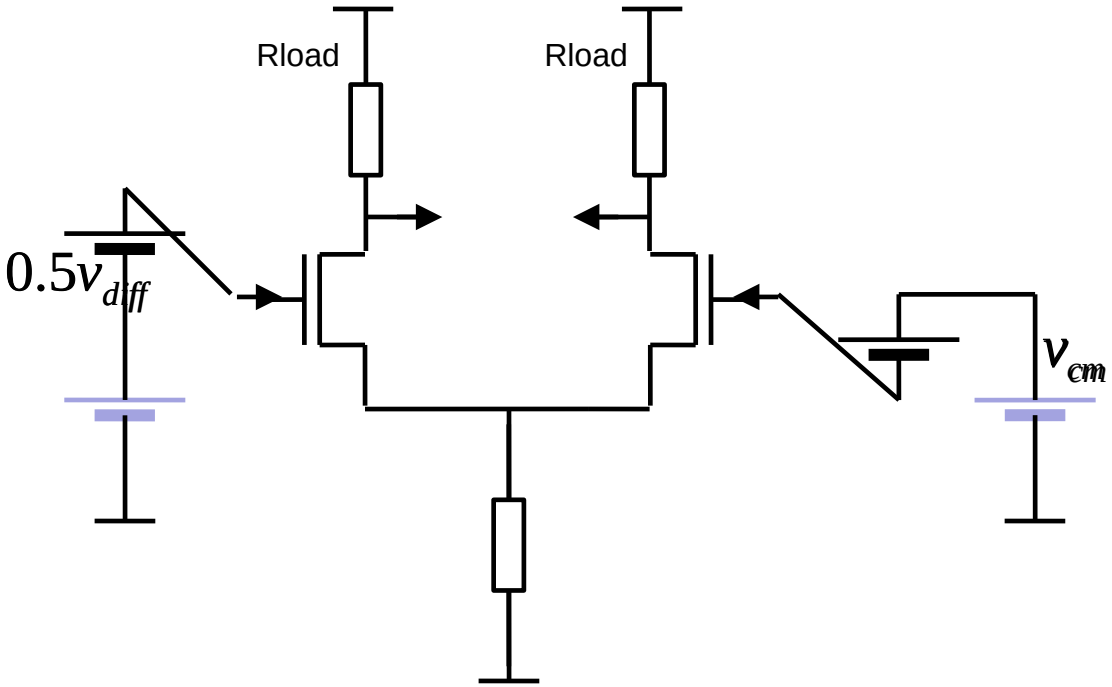
$$v_{cm} = \frac{v_1 + v_2}{2}$$

$$v_1 = v_{cm} + \frac{v_{diff}}{2}$$

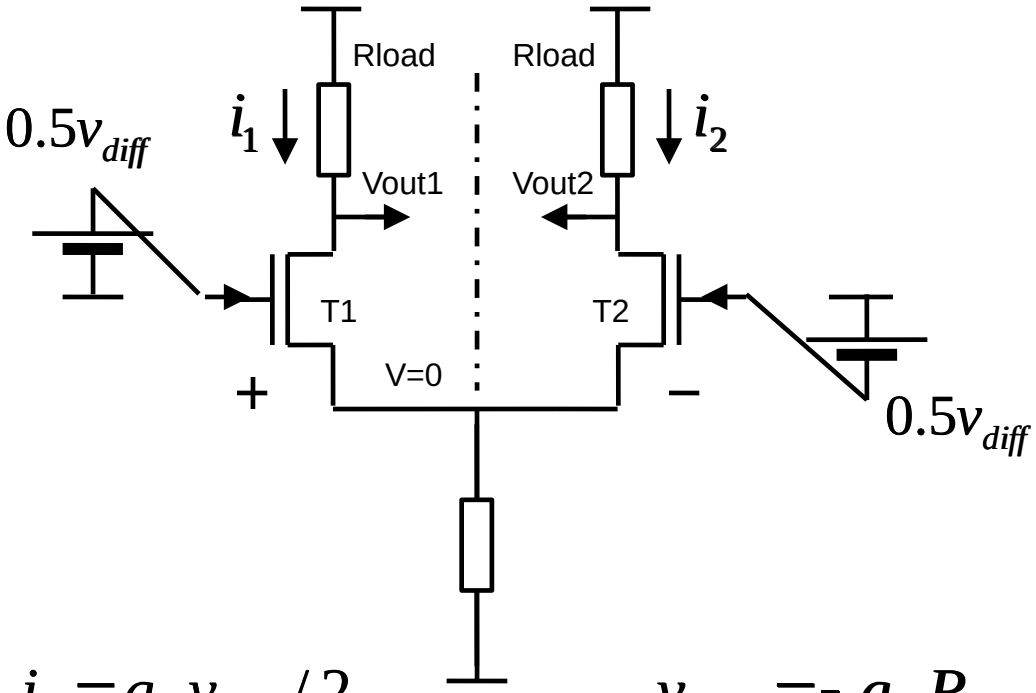
$$v_2 = v_{cm} - \frac{v_{diff}}{2}$$

Differenzverstärker

- Symmetrischer Differenzverstärker



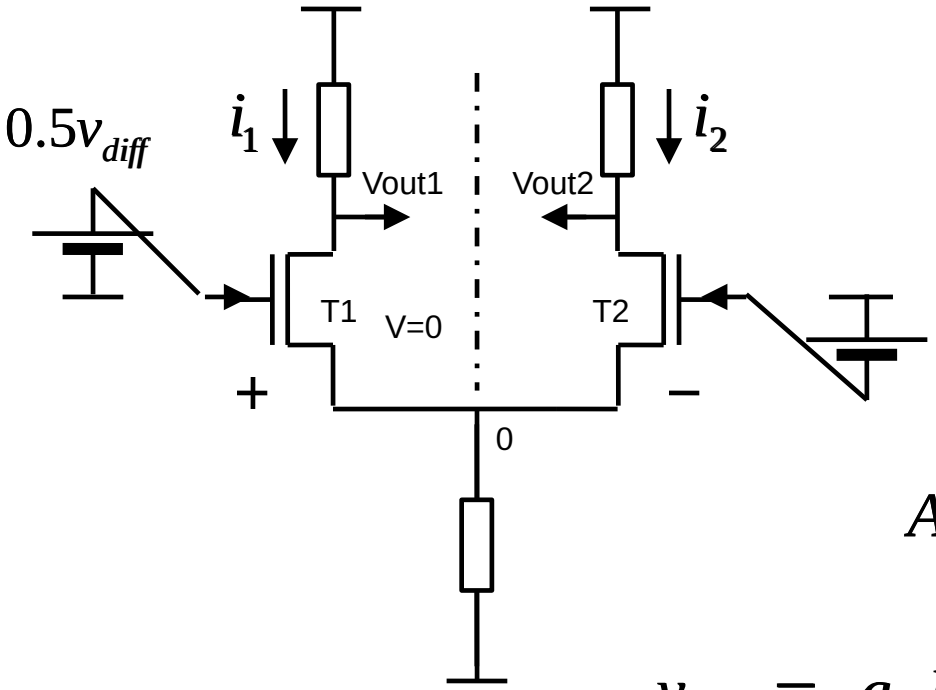
- Differenzverstärkung



$$i_1 = g_m v_{diff} / 2 \qquad v_{out1} = - g_m R_{load} v_{diff} / 2$$

$$i_2 = - g_m v_{diff} / 2 \qquad v_{out2} = g_m R_{load} v_{diff} / 2$$

- Differenzverstärkung

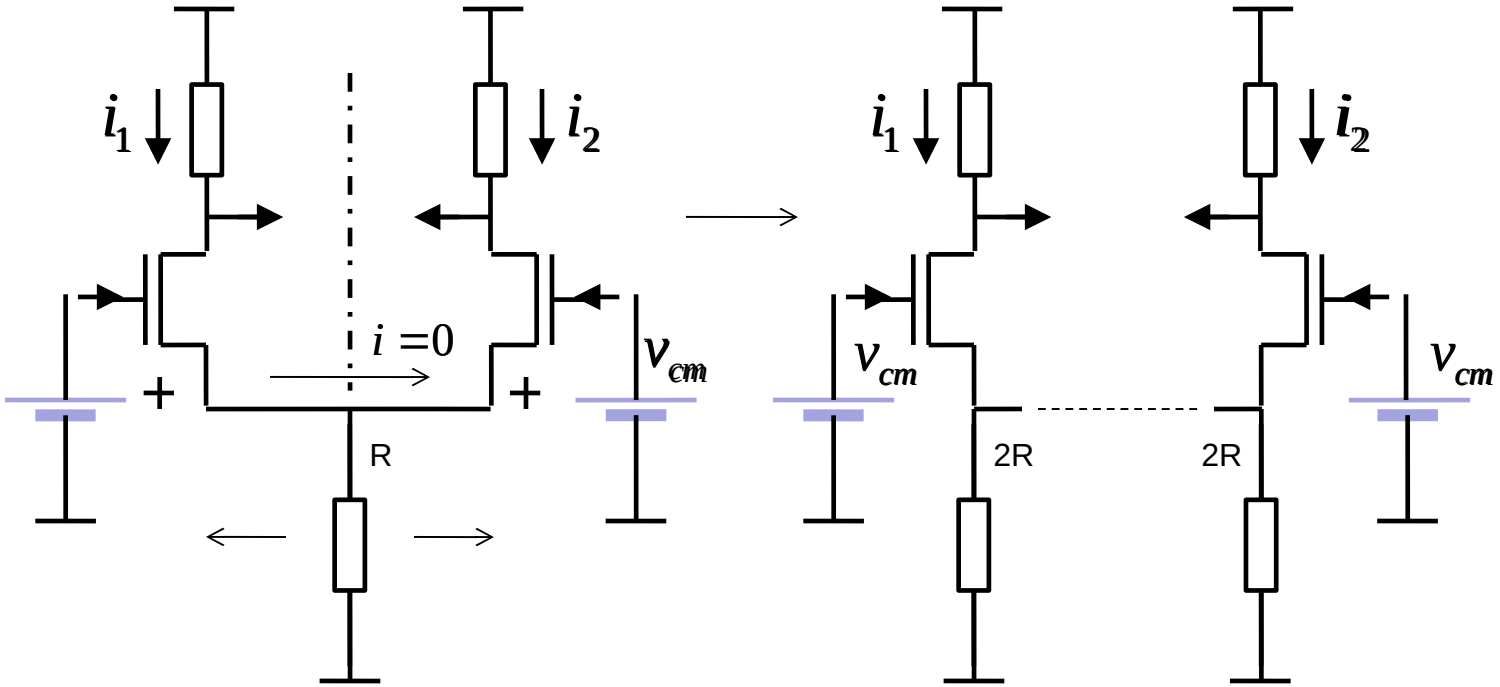


$$A_{diff} = (v_{out1} - v_{out2}) / v_{diff} = - g_m R_{load}$$

$$v_{out1} = - g_m R_{load} v_{diff} / 2$$

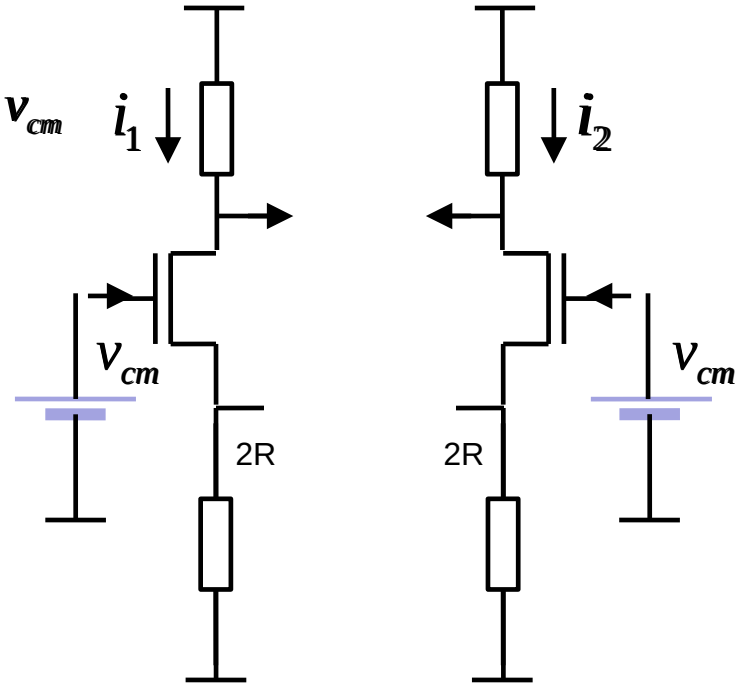
$$v_{out2} = g_m R_{load} v_{diff} / 2$$

- Gleichtaktverstärkung



- Gleichtaktverstärkung

$$i_1 = i_2 = \frac{g_m}{1 + g_m 2R} v_{cm}$$



$$v_{out1} = v_{out2} = - \frac{g_m R_{load}}{1 + g_m 2R} v_{cm}$$

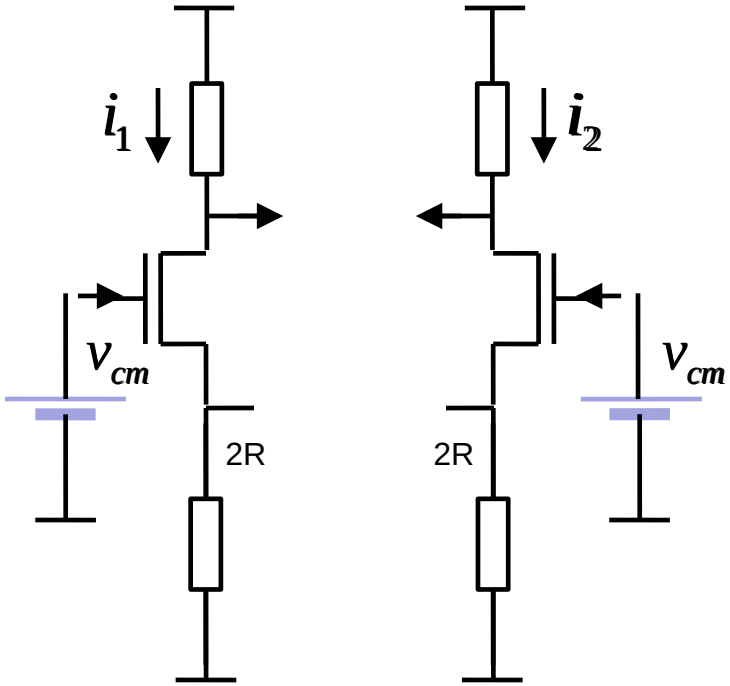
$$A_{cm} = (v_{out1} - v_{out2}) / v_{cm} = 0$$

- Gleichtaktunterdrückung

$$A_{diff} = (v_{out1} - v_{out2}) / v_{diff} = - g_m R_{load}$$

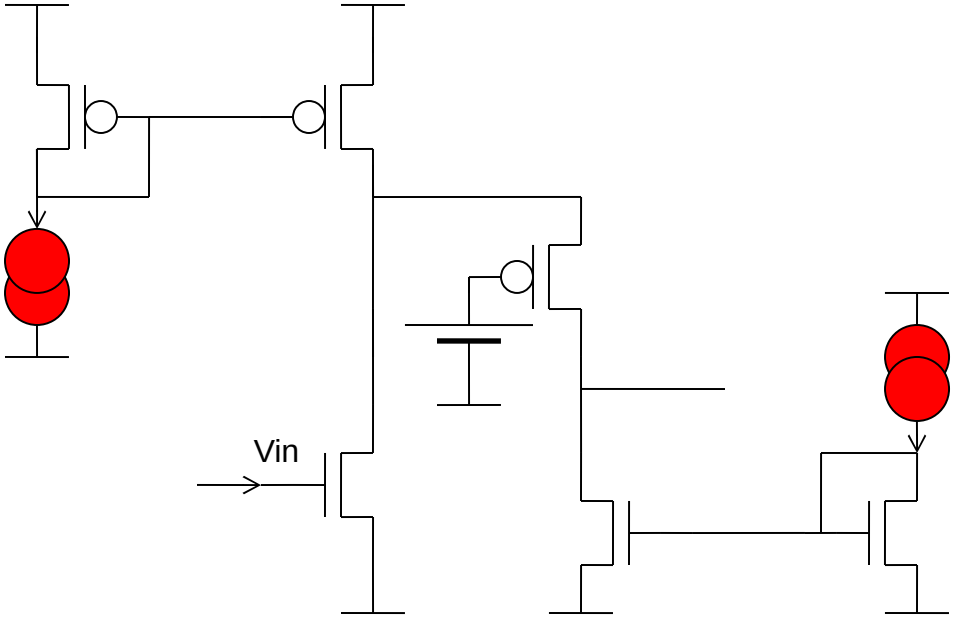
$$A_{cm} = (v_{out1} - v_{out2}) / v_{cm} = 0$$

$$CMRR = A_{diff} / A_{cm} = \infty$$

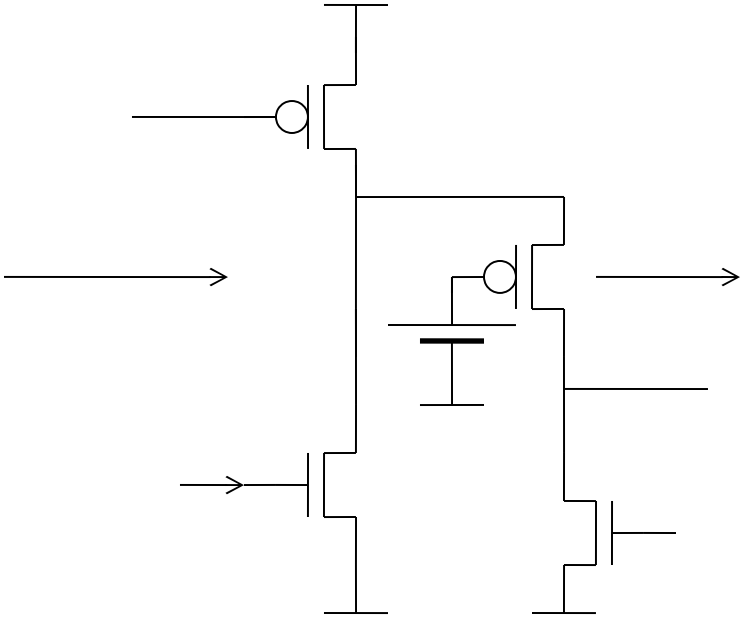


Differenzverstärker

- Komplexere Formen



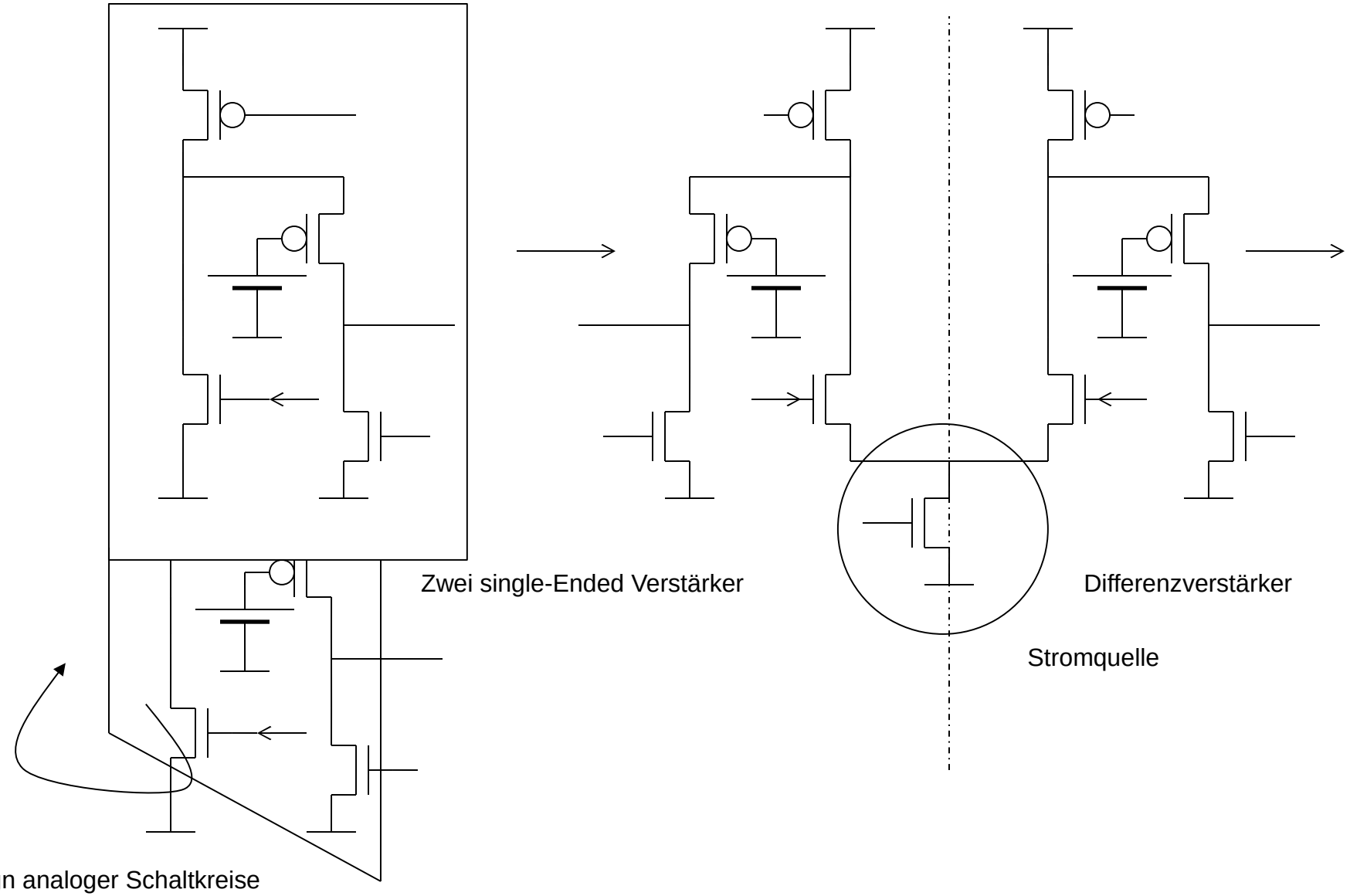
Vollständige Single-Ended Schaltung (gefaltete Kaskode)



Vereinfacht

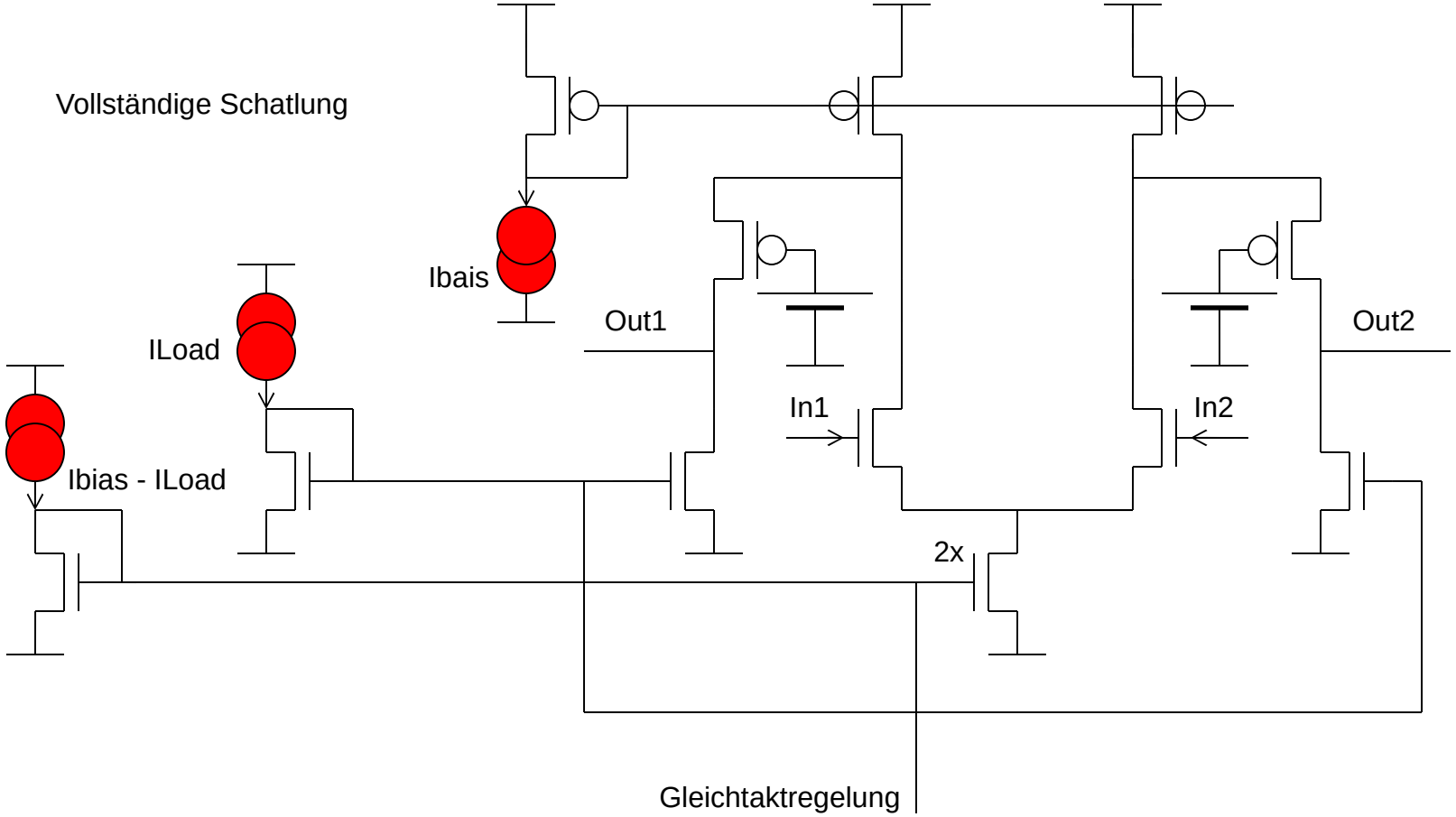
Differenzverstärker

- Komplexere Formen

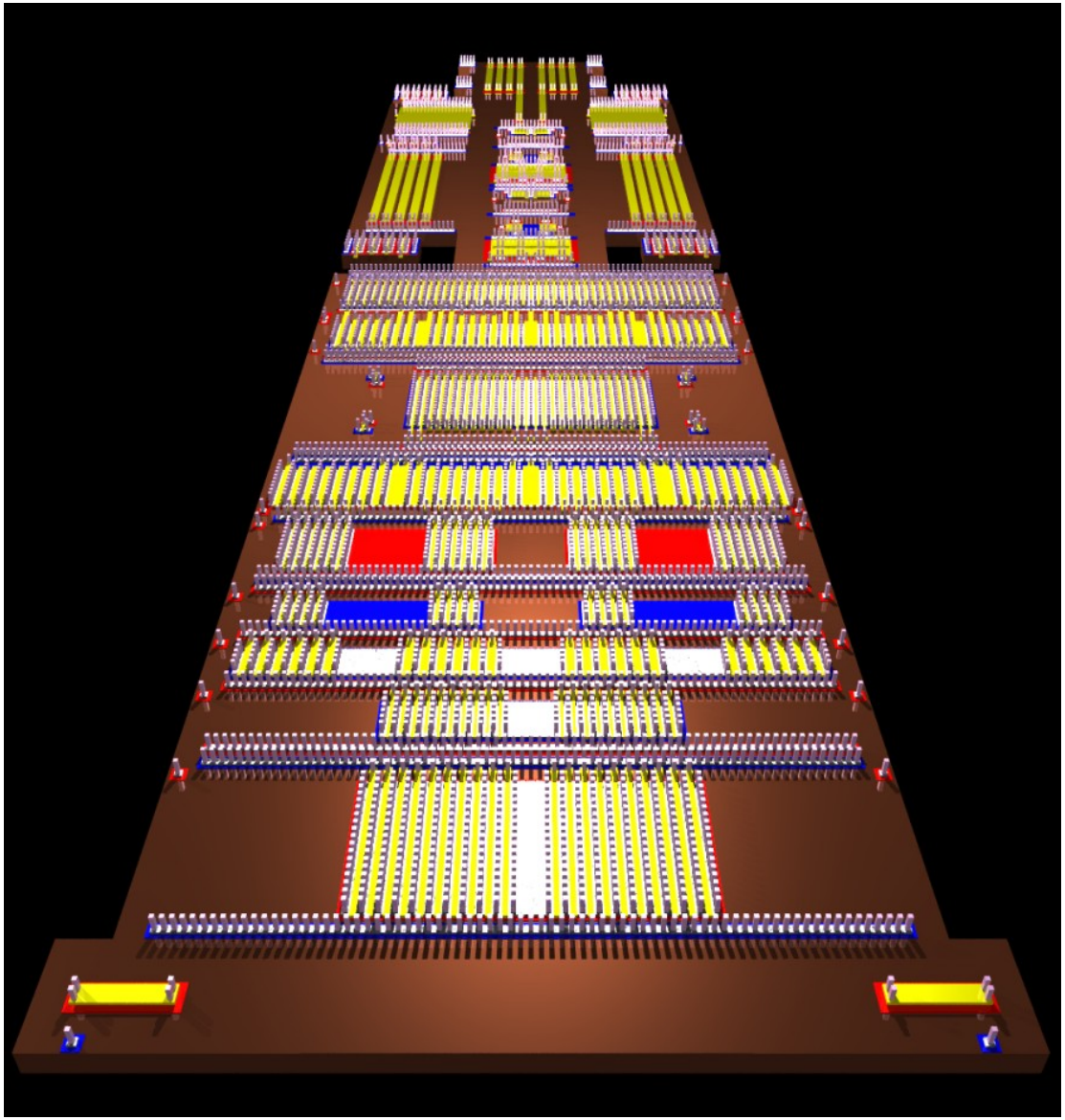


Differenzverstärker

- Komplexere Formen



Layout

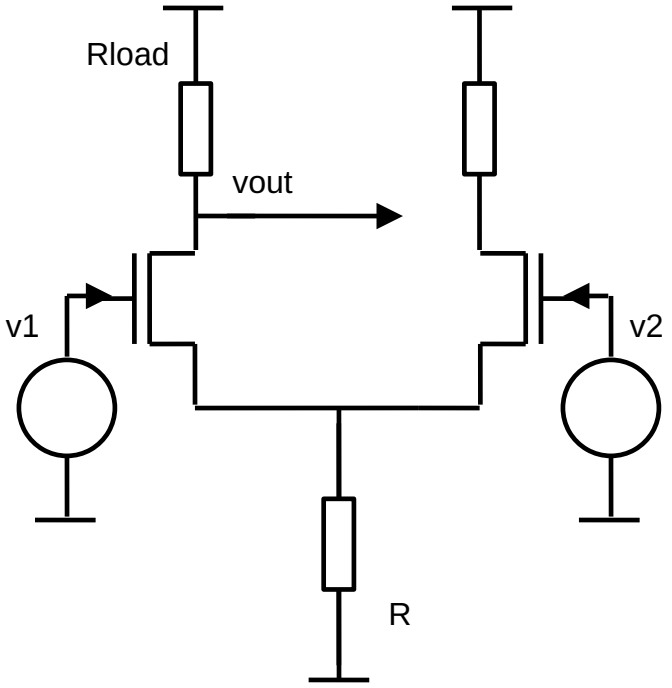


- Operationsverstärker (Single-Ended Ausgang) – einfachste Variante

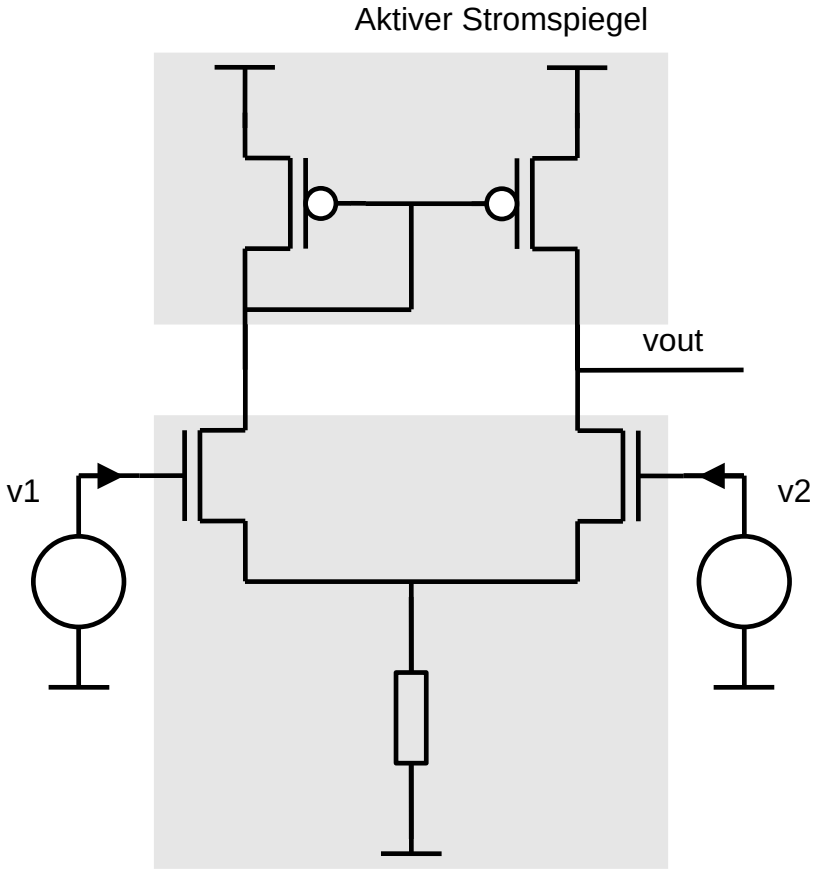
$$A_{diff} = v_{out} / v_{diff} = - g_m R_{load} / 2$$

$$A_{cm} = v_{out} / v_{cm} = - \frac{g_m R_{load}}{1 + g_m 2R}$$

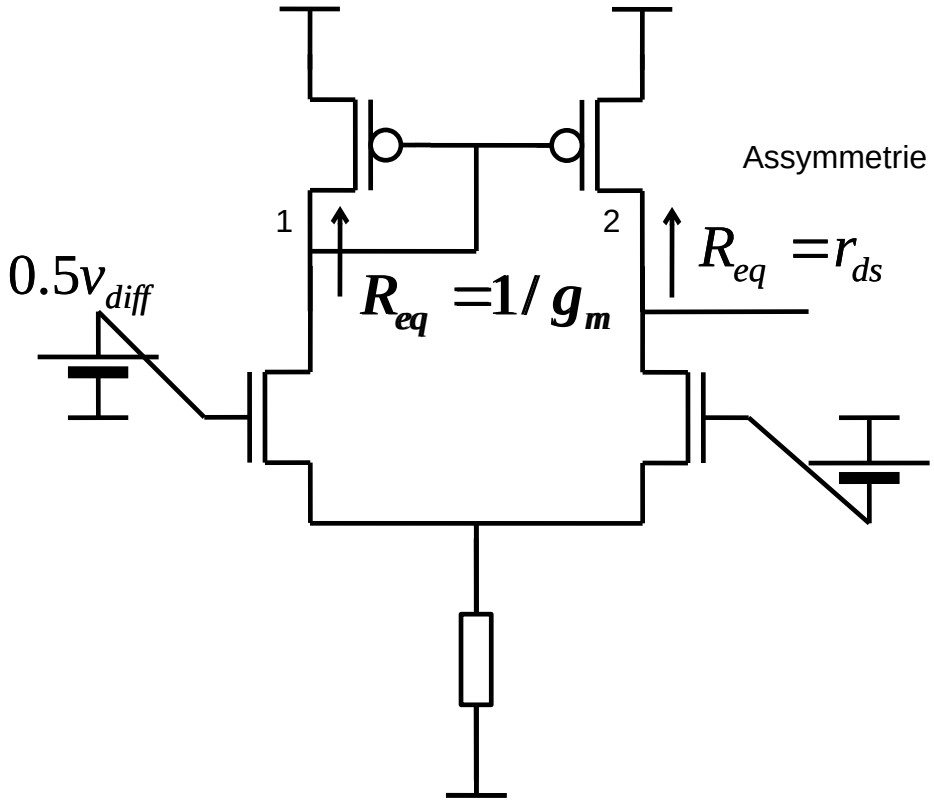
$$CMRR = A_{diff} / A_{cm} = (1 + g_m 2R) / 2$$



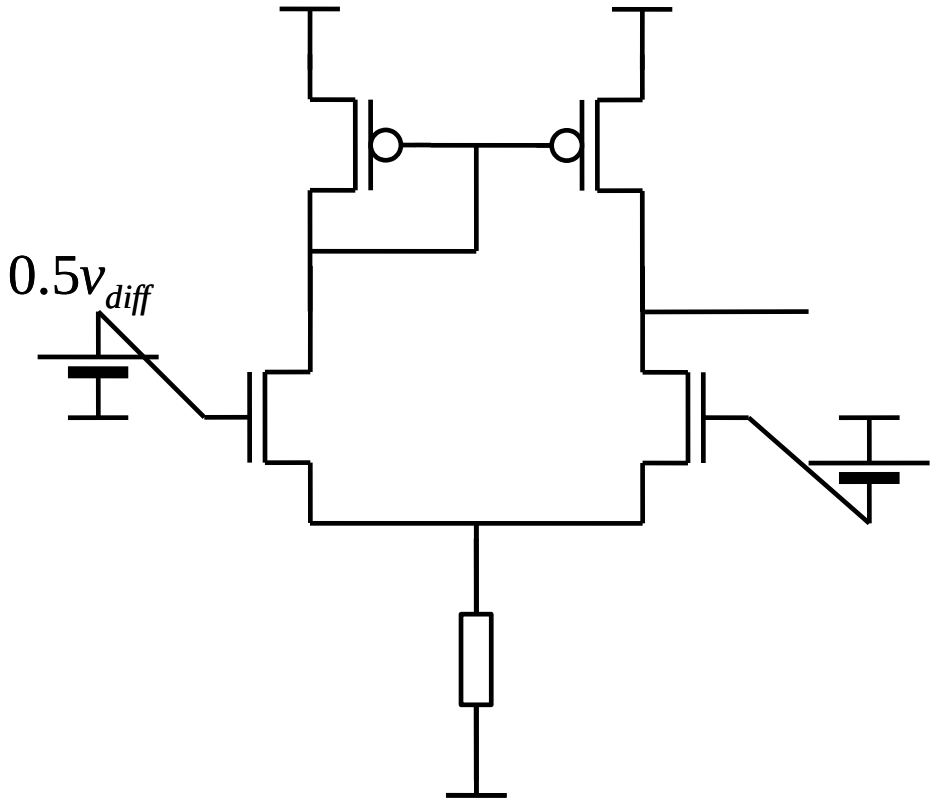
- Operationsverstärker – Standardschaltung



Differenzverstärkung



Thevenin Quelle



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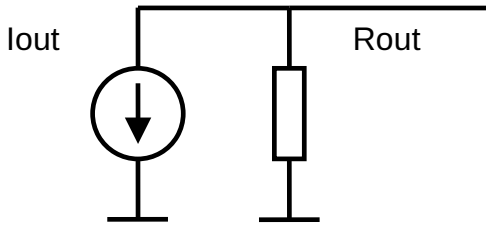
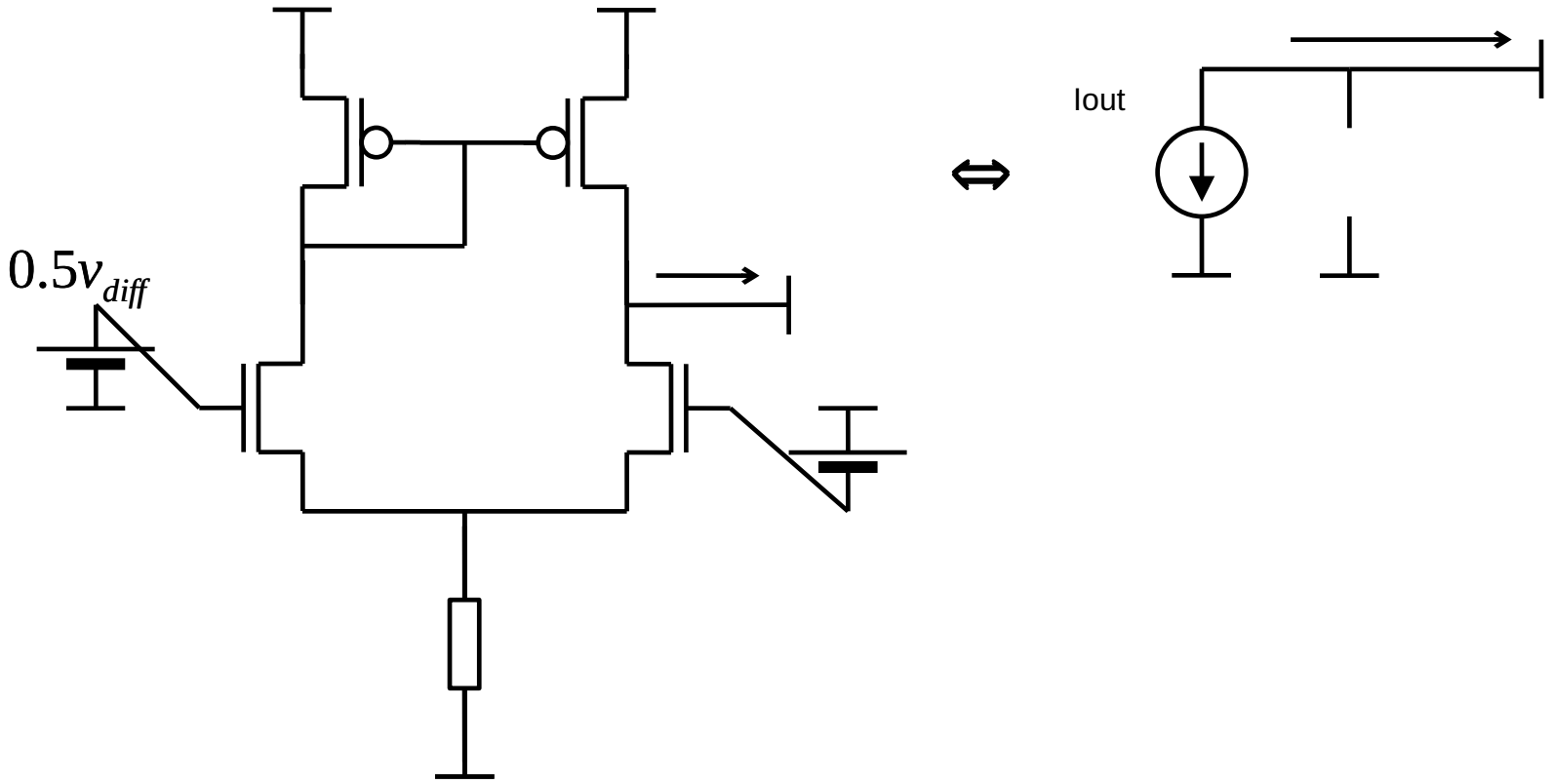


$$v_{out} = i_{out} R_{out}$$

Thevenin Quelle



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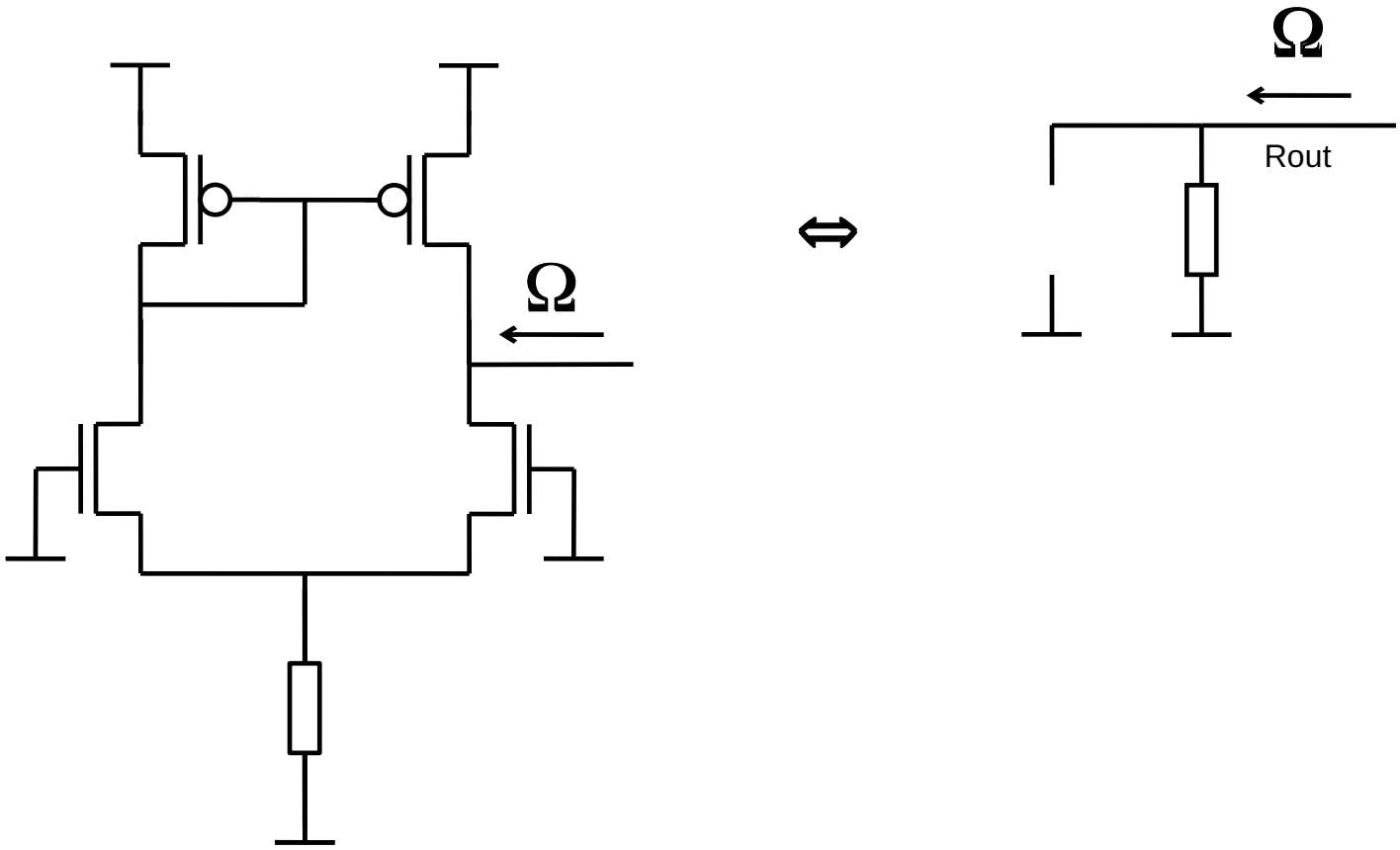

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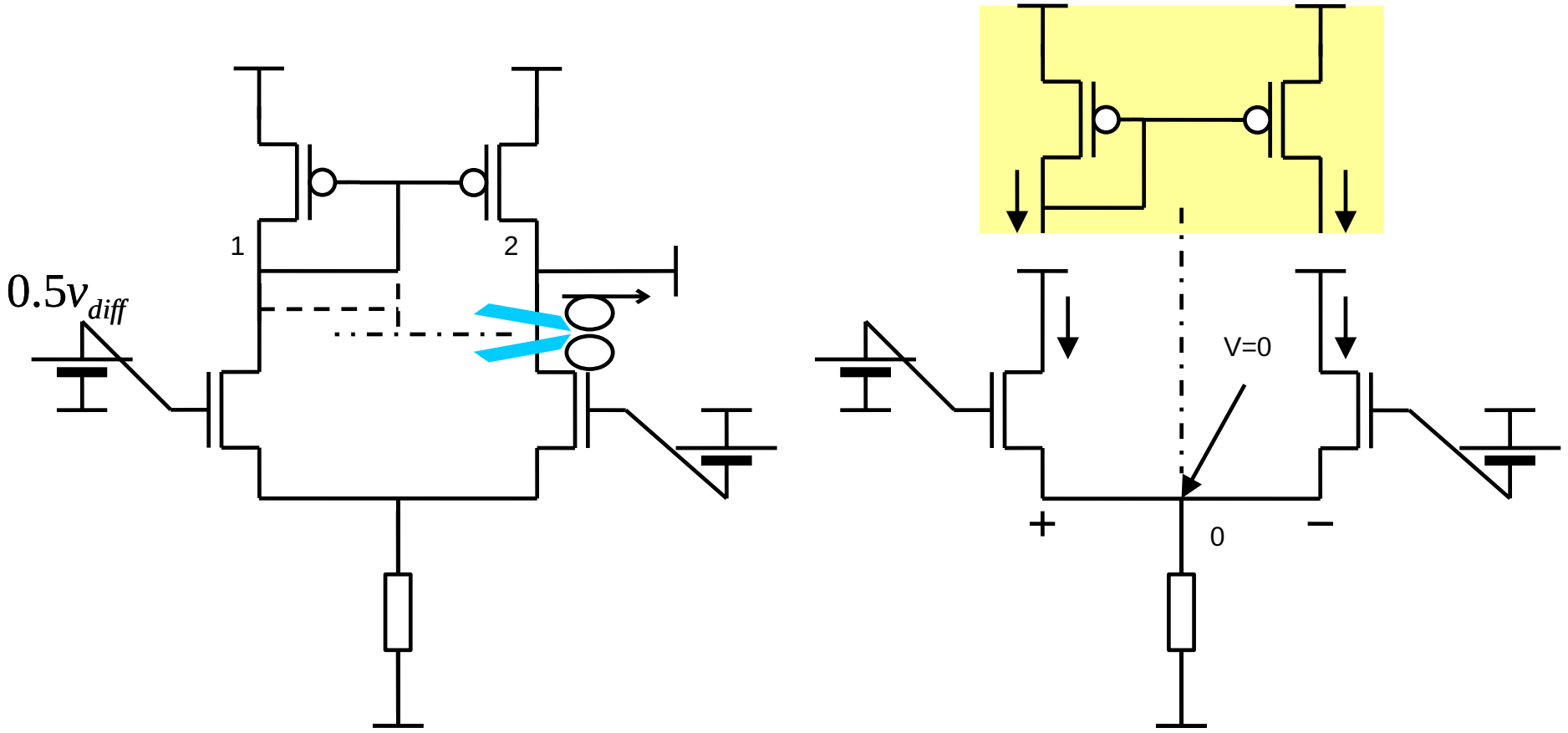
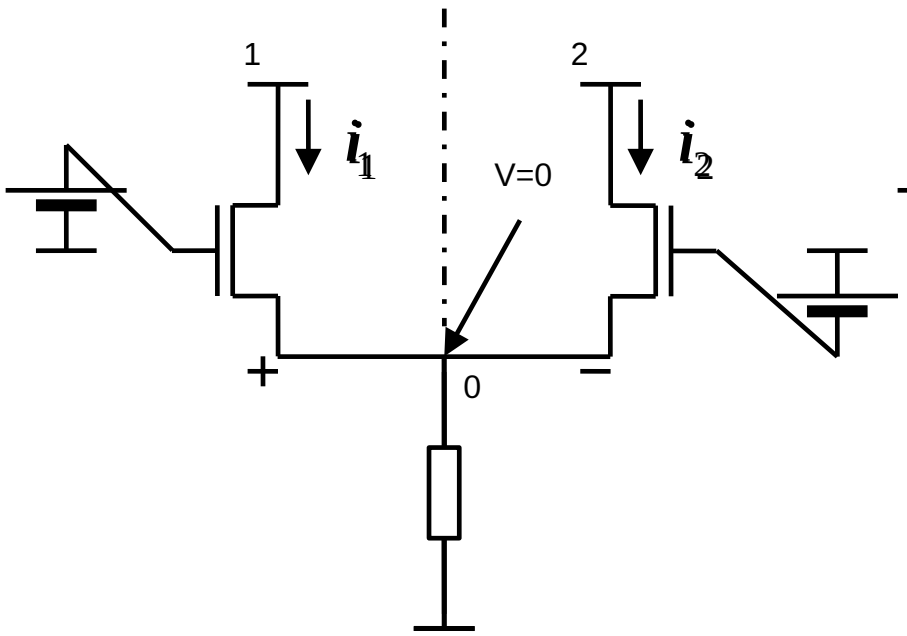
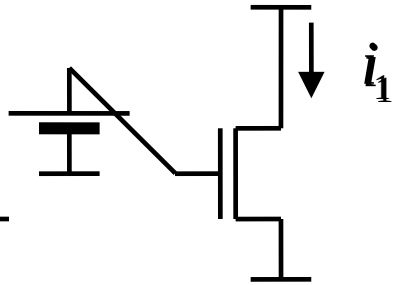
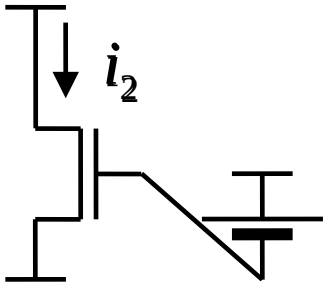


Differentielle Stromverstärkung

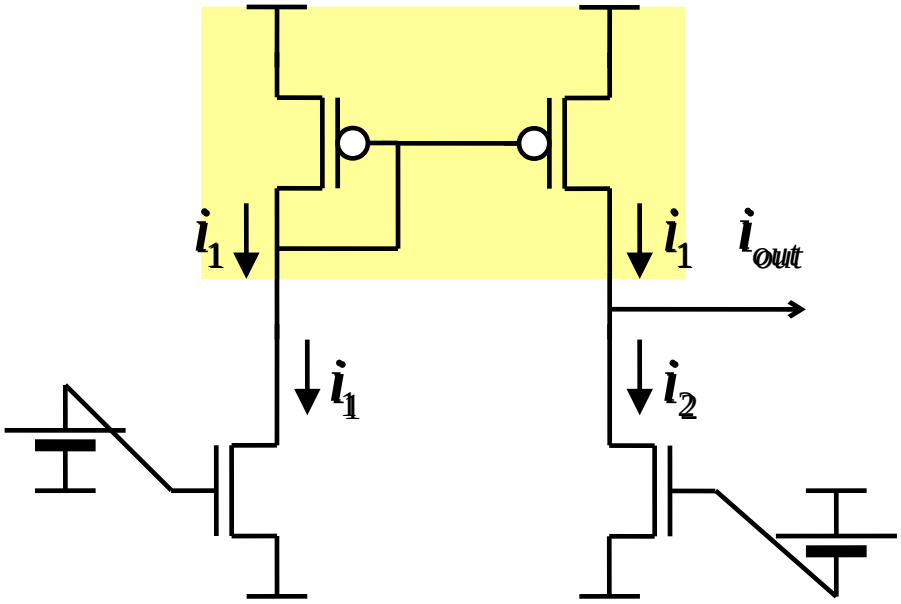


$$i_1 = g_m \frac{v_{diff}}{2} \qquad i_2 = -g_m \frac{v_{diff}}{2}$$





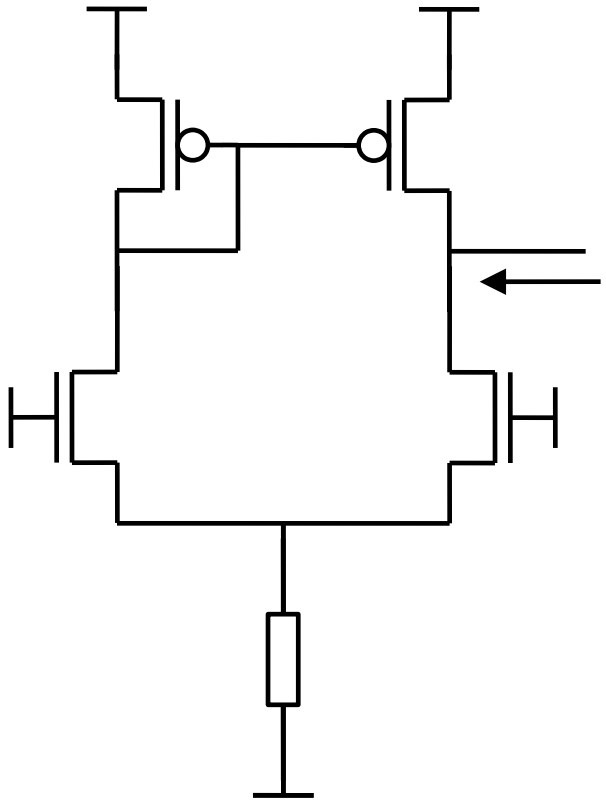
Differentielle Stromverstärkung



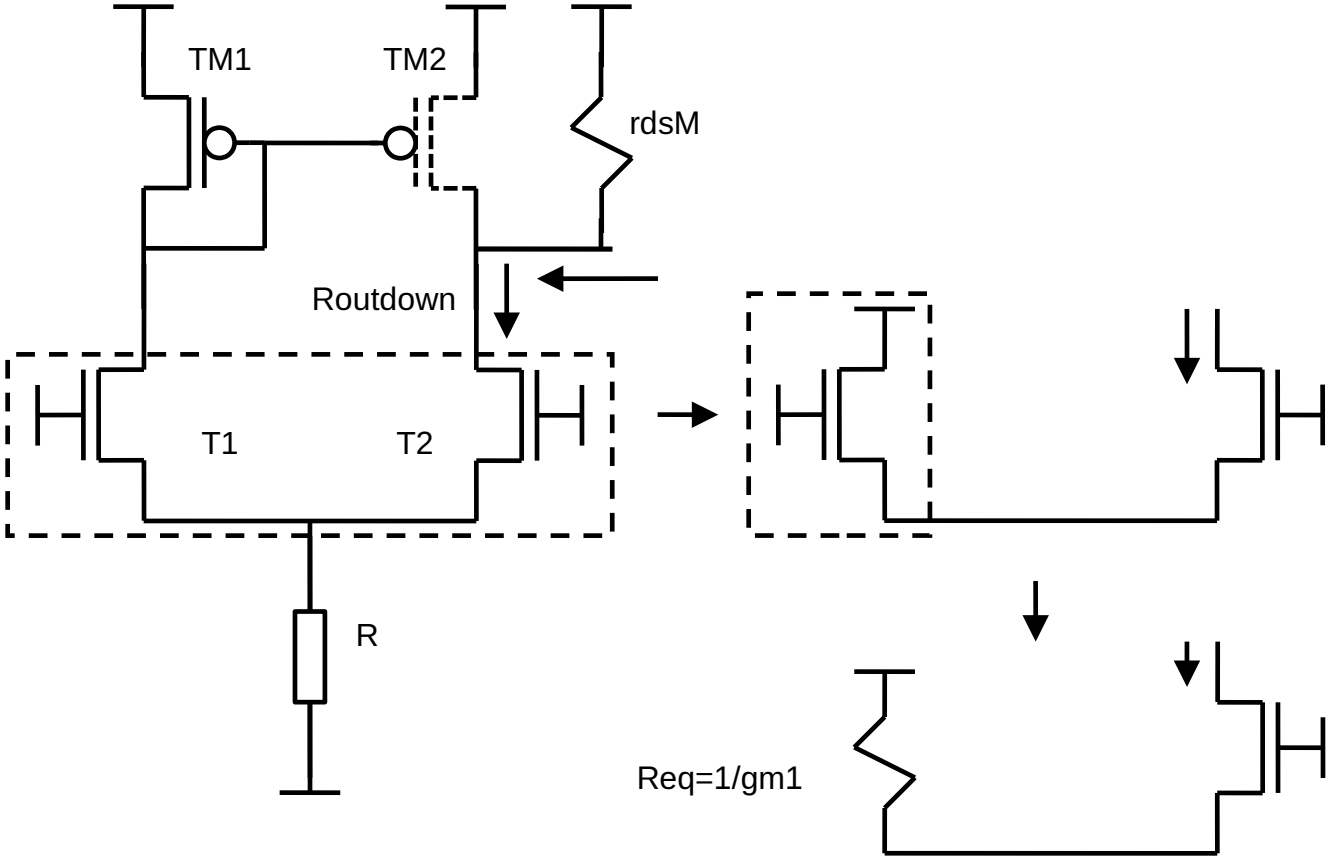
$$i_{out} = i_1 - i_2 = g_m v_{diff}$$

$$G_{mdiff} = g_m$$

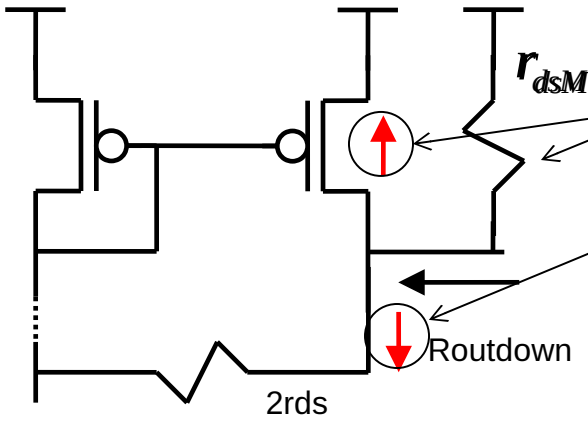
Ausgangswiderstand



Ausgangswiderstand



$$R_{out}|_{down} = (R_{eq} + r_{ds2})(1 + g_{m2}R_{eq}) \qquad R_{out}|_{down} \sim 2r_{ds}$$



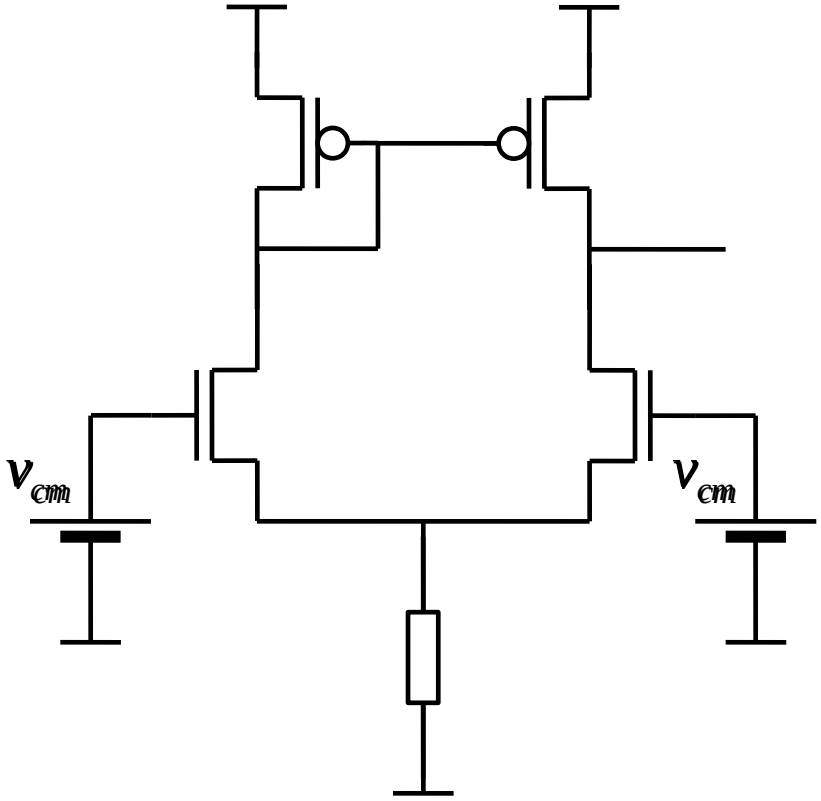
$$R_{out} = (r_{dsM} \parallel \frac{R_{out}|_{down}}{2})$$

$$R_{out} = (r_{dsM} \parallel \frac{2r_{ds}}{2})$$

$$R_{out} = r_{ds} \parallel r_{dsM}$$

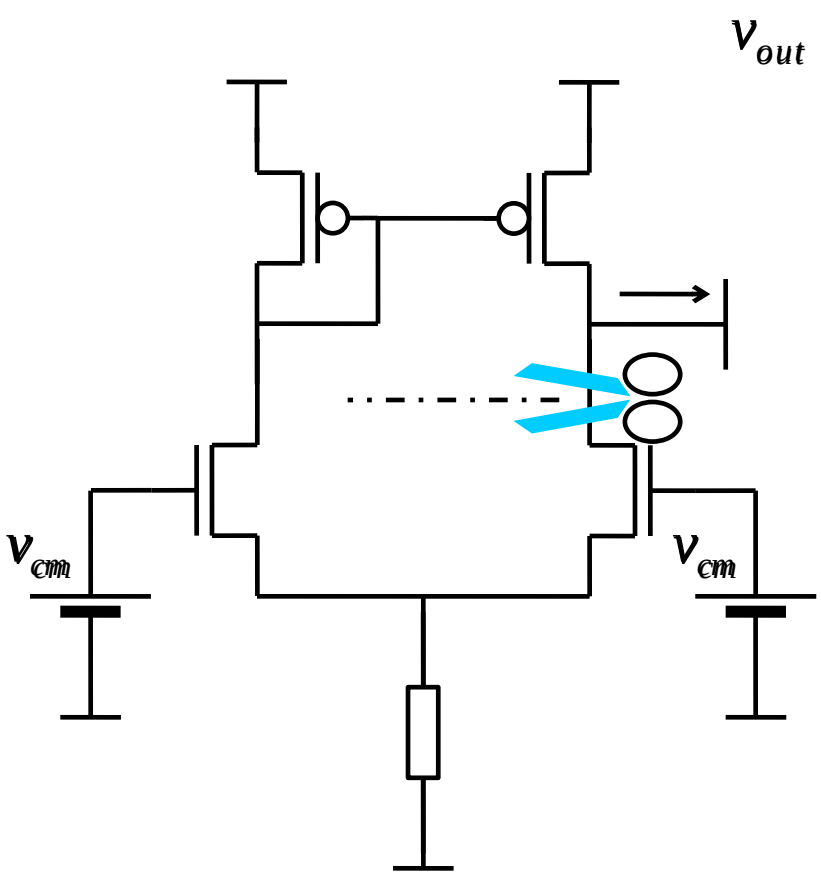
$$A_{diff} = G_{mdiff} R_{out}, \Rightarrow \quad A_{diff} = g_m (r_{ds} \parallel r_{dsM})$$

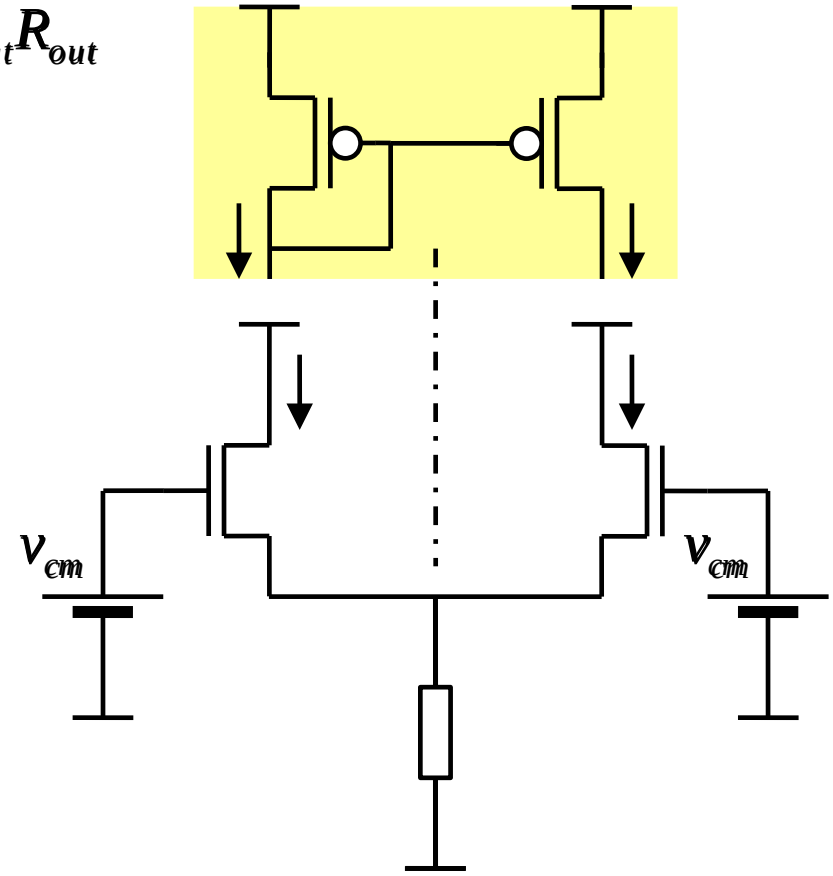
Common-Mode Verstärkung



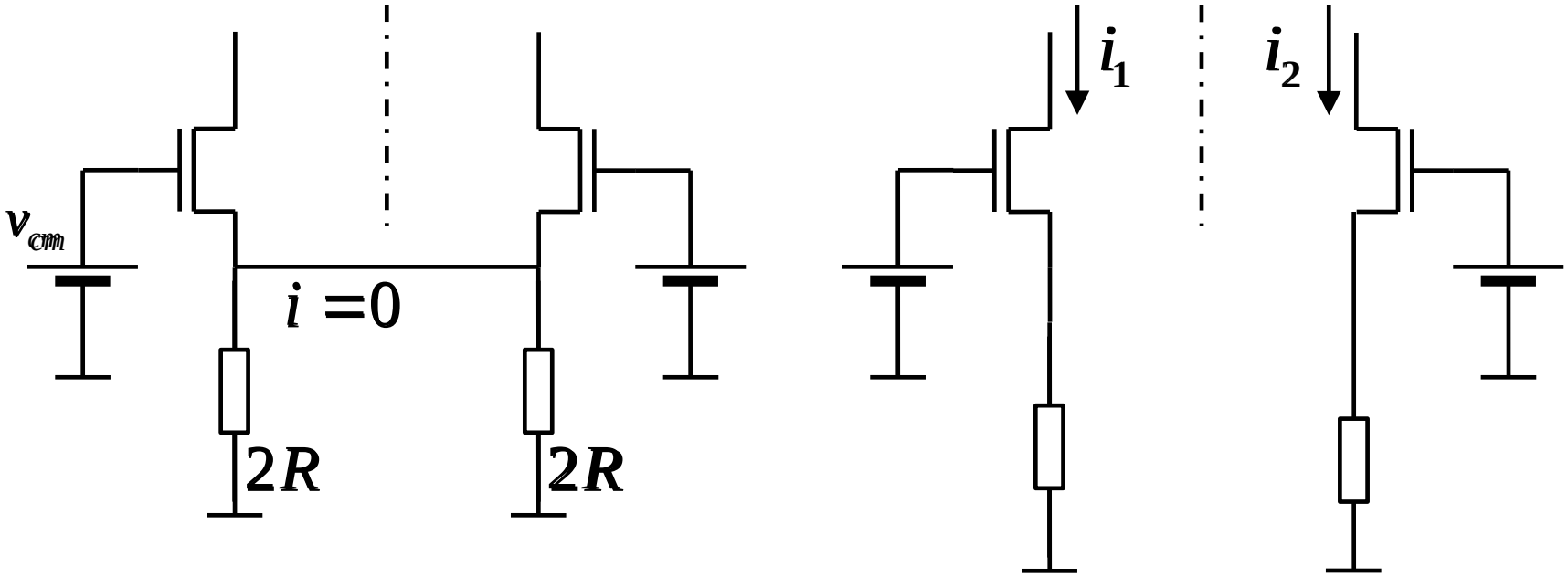
Common-Mode Verstärkung

$$v_{out} = I_{out} R_{out}$$



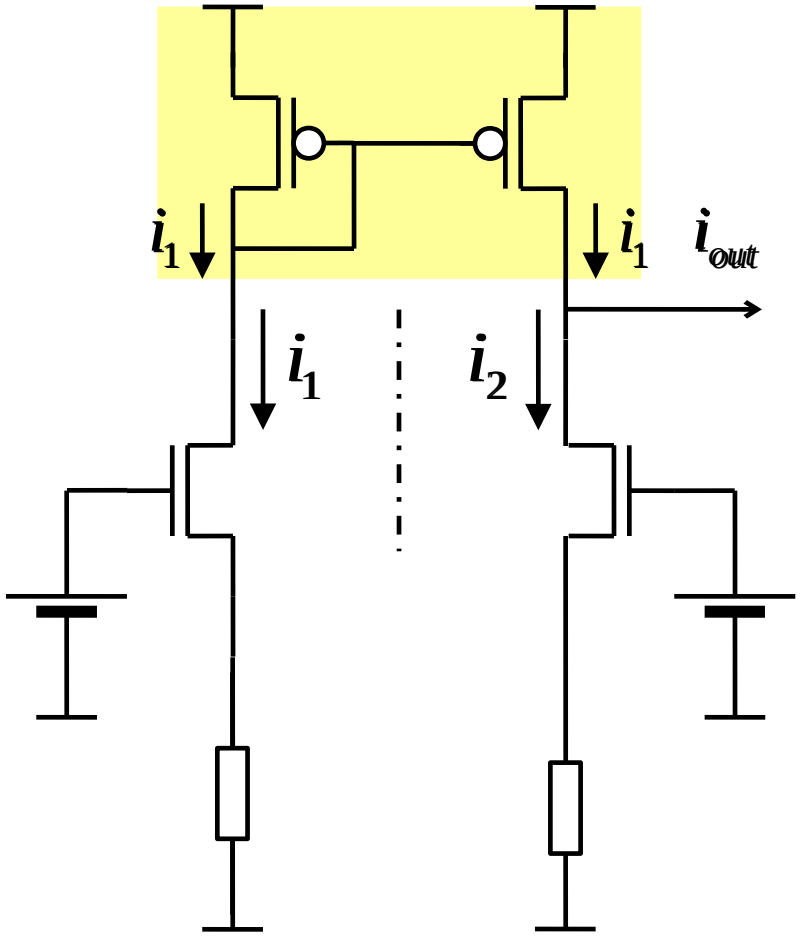


Common-Mode Verstärkung



$$i_1, i_2 = v_{cm} g_m / (1 + 2 g_m R)$$

Common-Mode Verstärkung

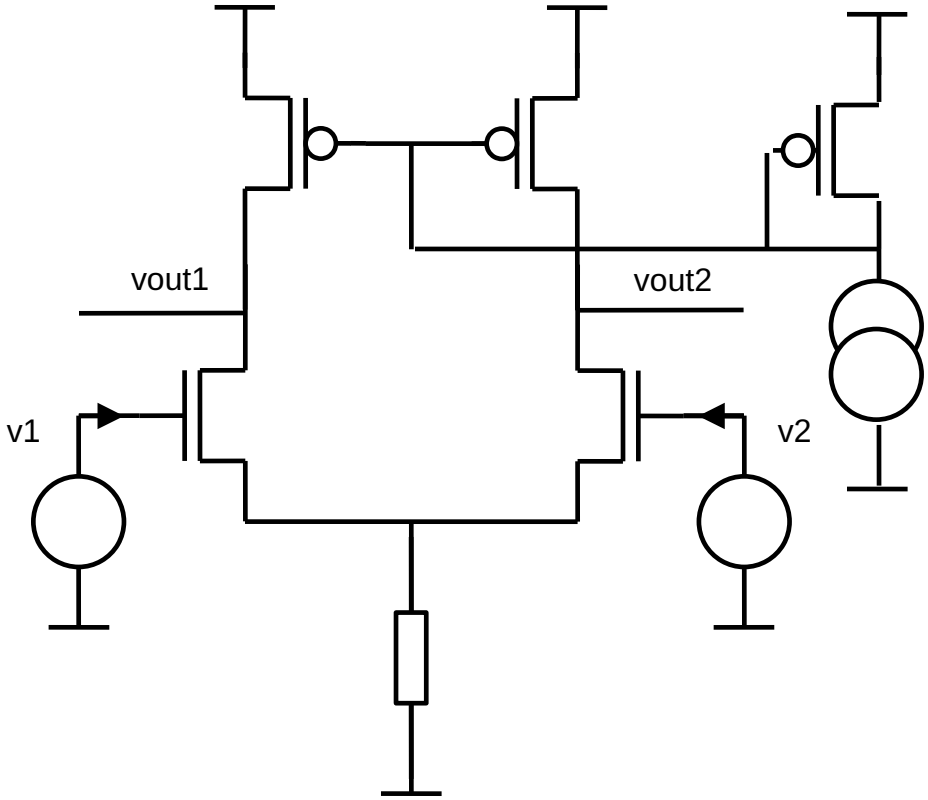


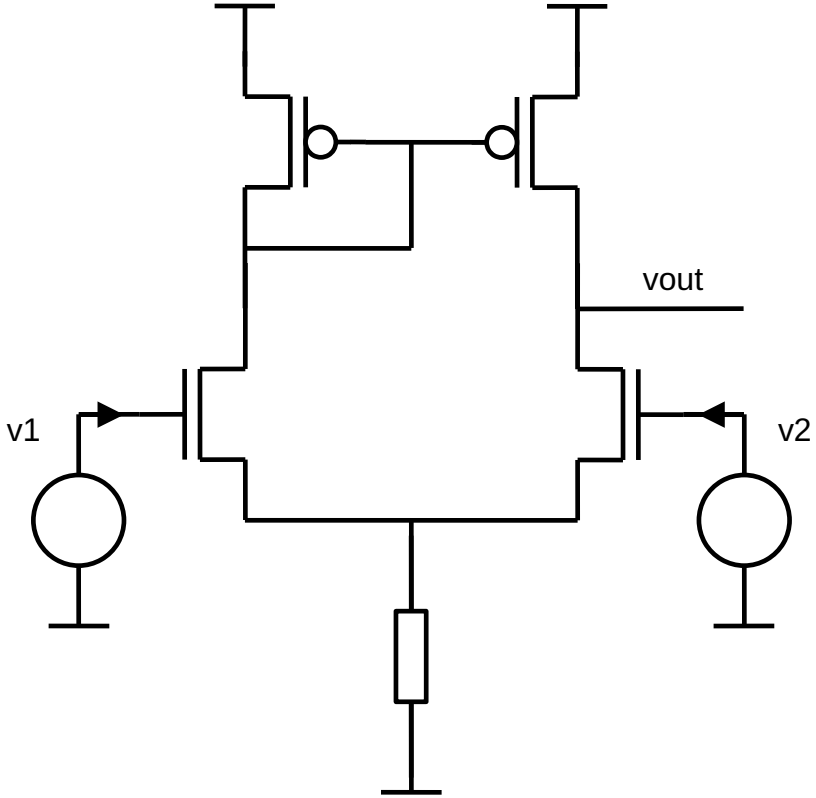
$$i_1, i_2 = v_{cm} g_m / (1 + 2 g_m R) \qquad i_{out} = i_1 - i_2 = 0$$

$$A_{cm} = 0$$

Differenzverstärker

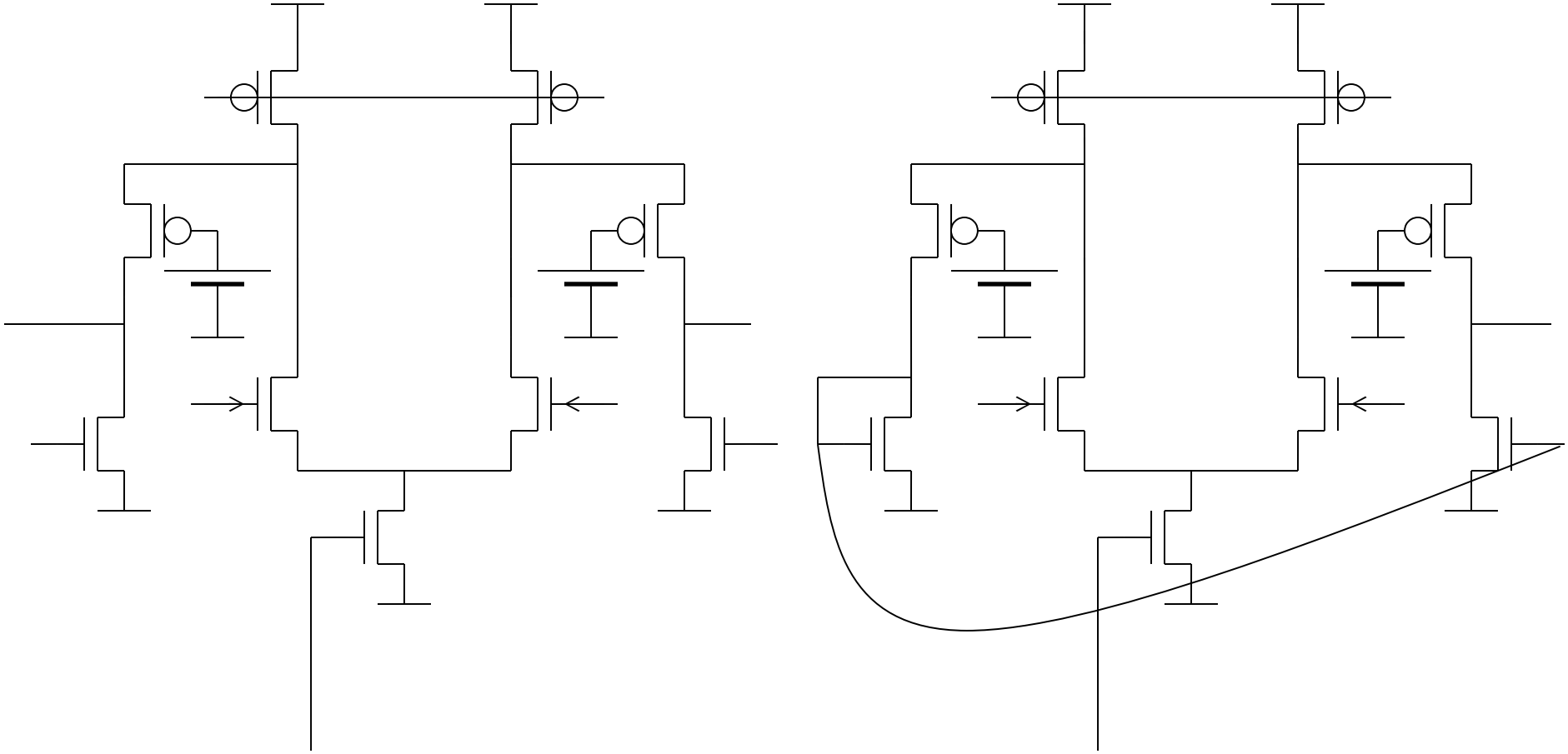
- Vergleich: symmetrischer- und Operationsverstärker





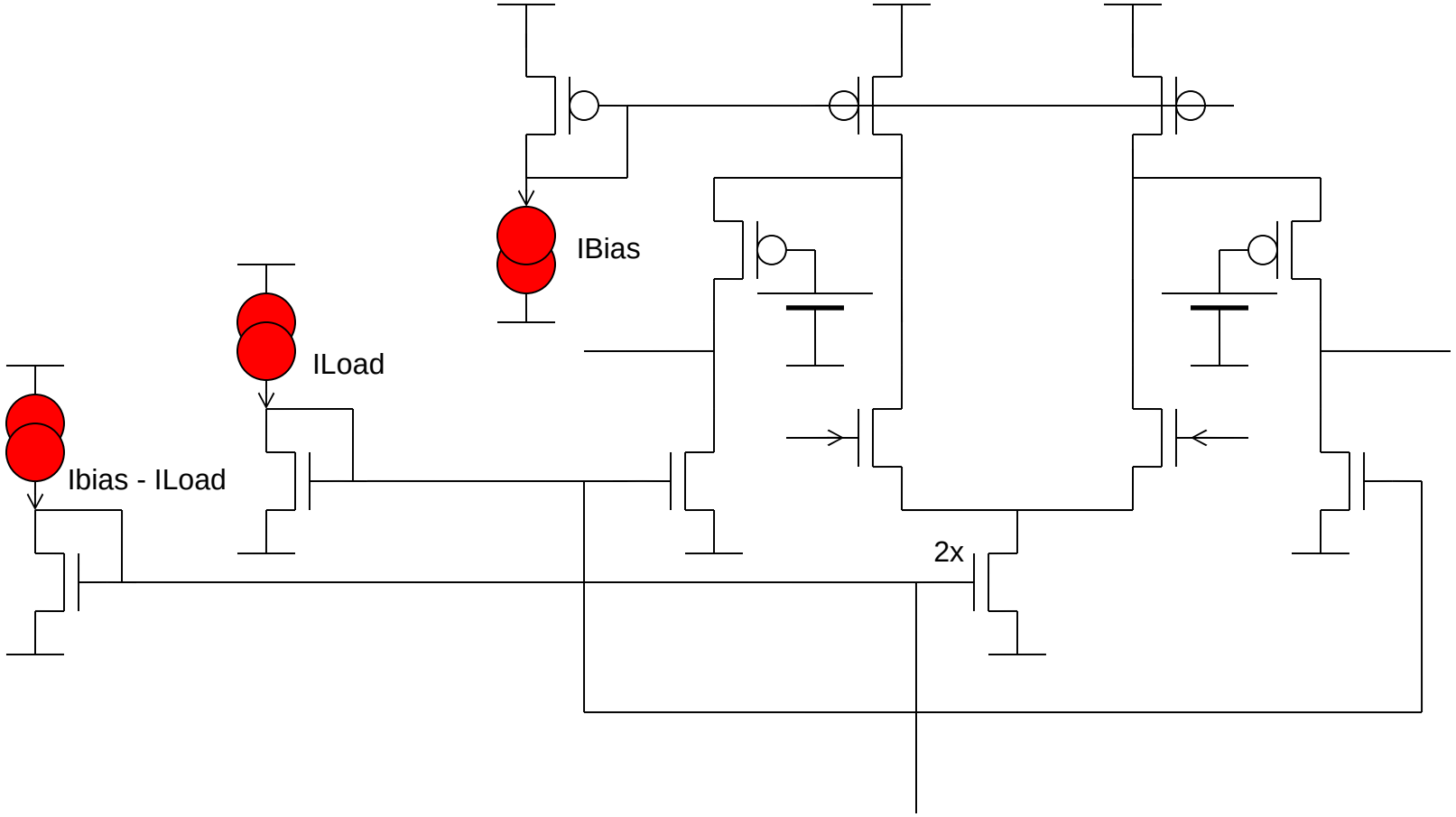
Differenzverstärker

- Symmetrischer- und Operationsverstärker mit Kaskode



Differenzverstärker

- Symmetrischer Verstärker mit Kaskode



Differenzverstärker

- Operationsverstärker mit Kaskode