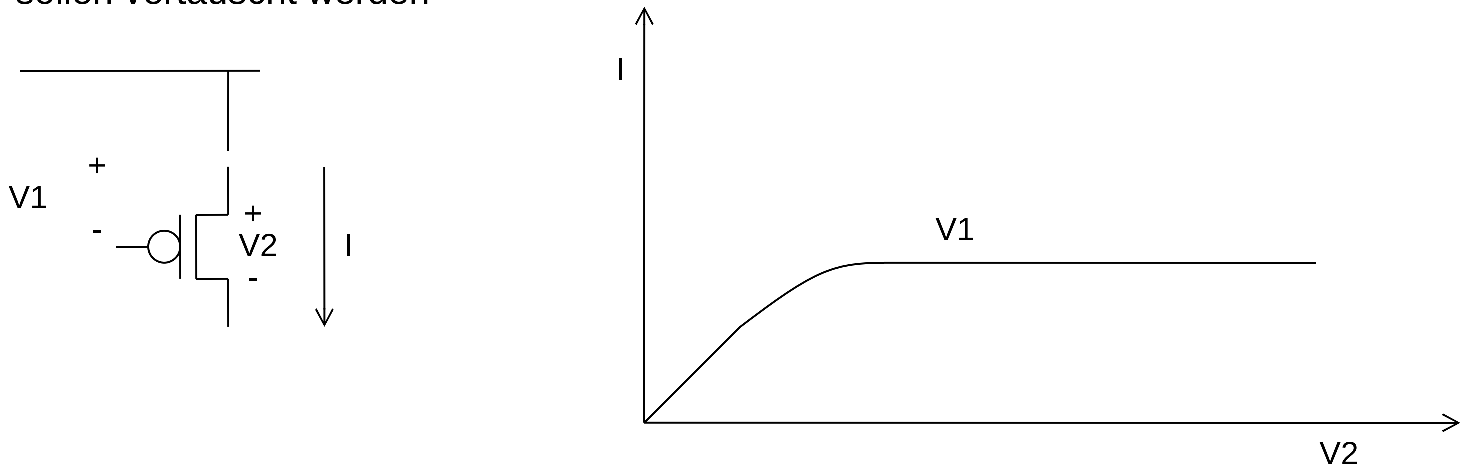
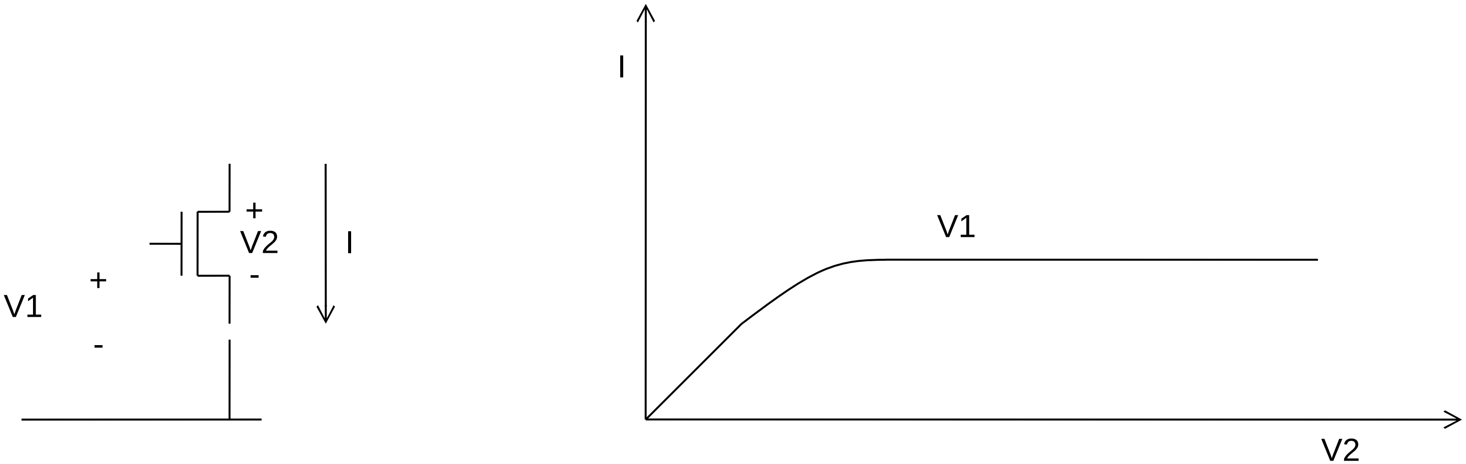
Vorlesung 5

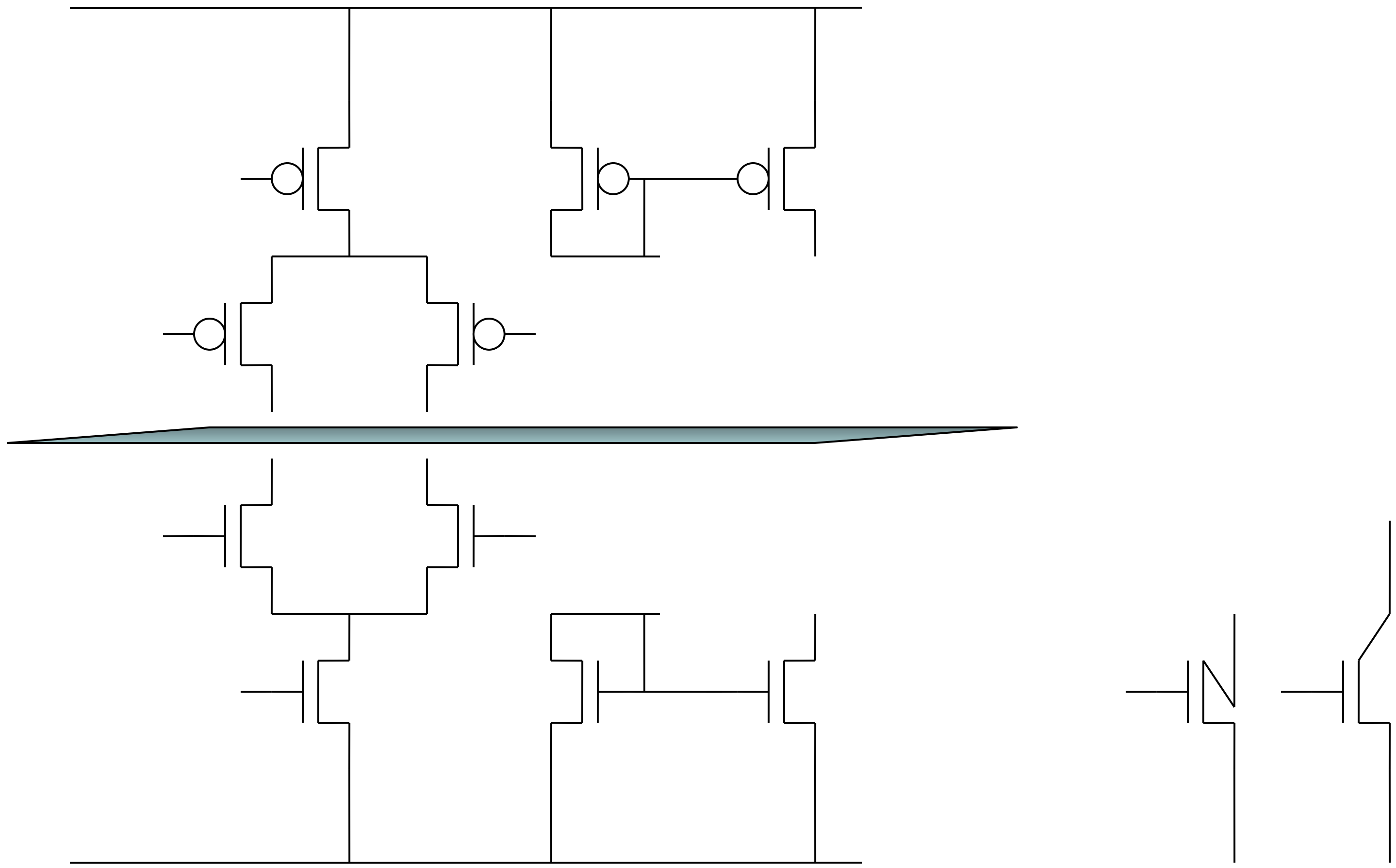
- PMOS und NMOS Kennlinien sind gleich aber die Indizes bei den Spannungen und Strömen sollen vertauscht werden





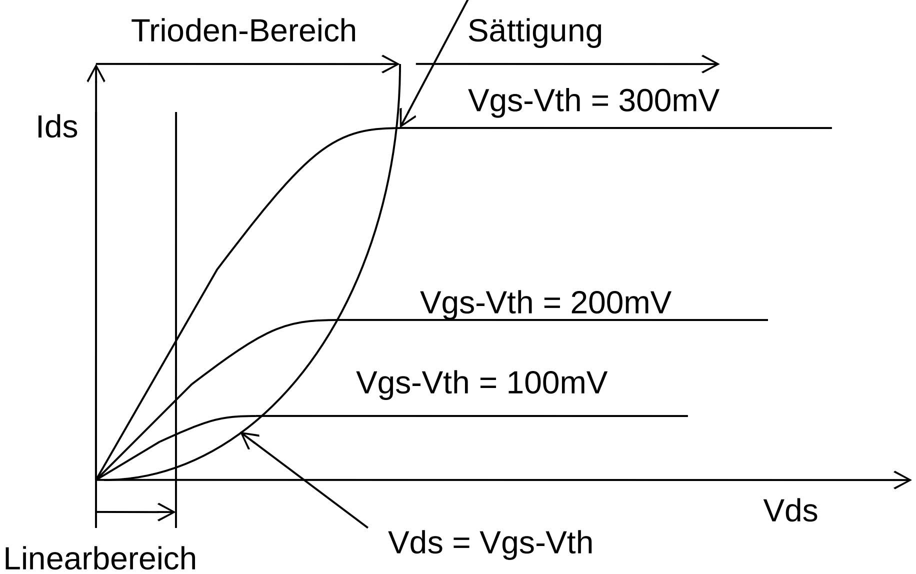
NMOS und PMOS

- NMOS und PMOS Schaltungen sind in der Regel Spiegelsymmetrisch
- Ströme fließen von oben nach unten



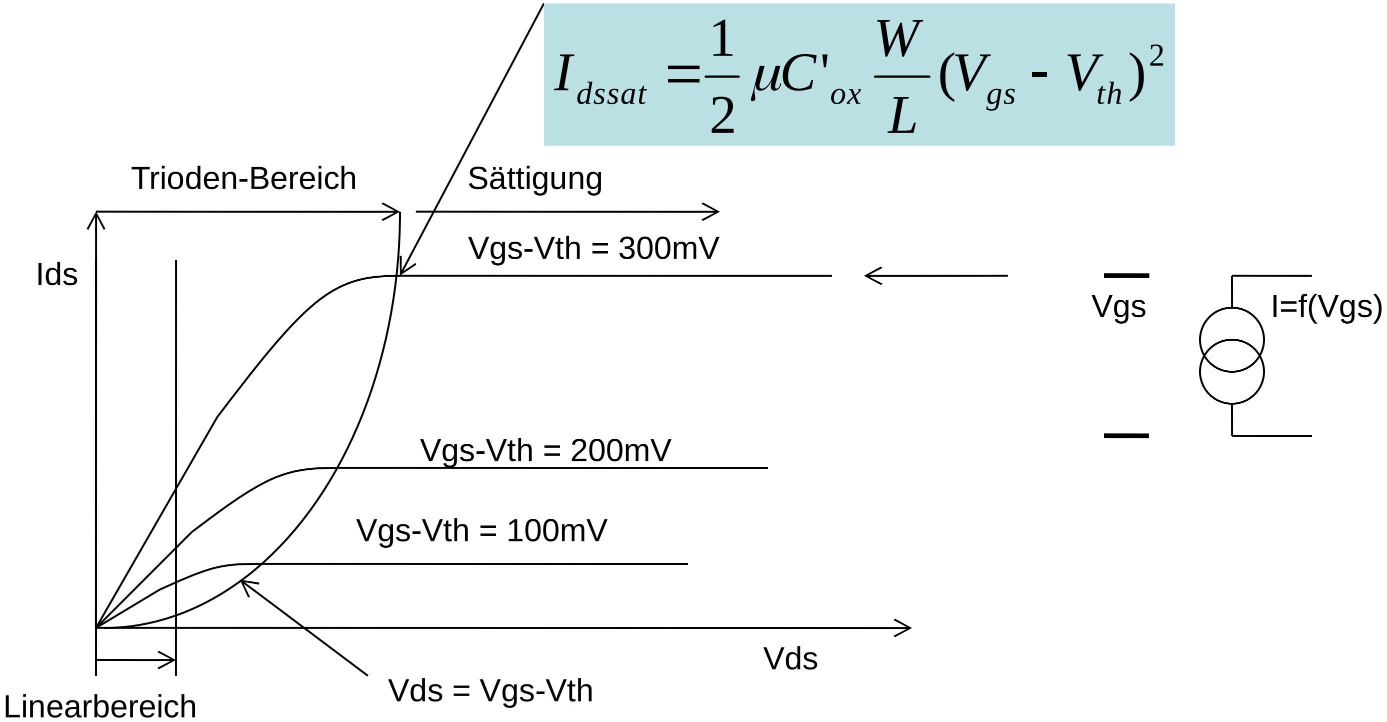
- Zwei Spannungen – Vgs und Vds und zwei Ströme Ids und Igs (Igs = 0)
- Ids als Funktion von Vds für verschiedene Vgs (Ausgangskennlinien)

$$I_{dssat} = \frac{1}{2} \mu C'_{ox} \frac{W}{L} (V_{gs} - V_{th})^2$$



- Sättigung: Strom von Vds praktisch unabhängig - Stromquelle

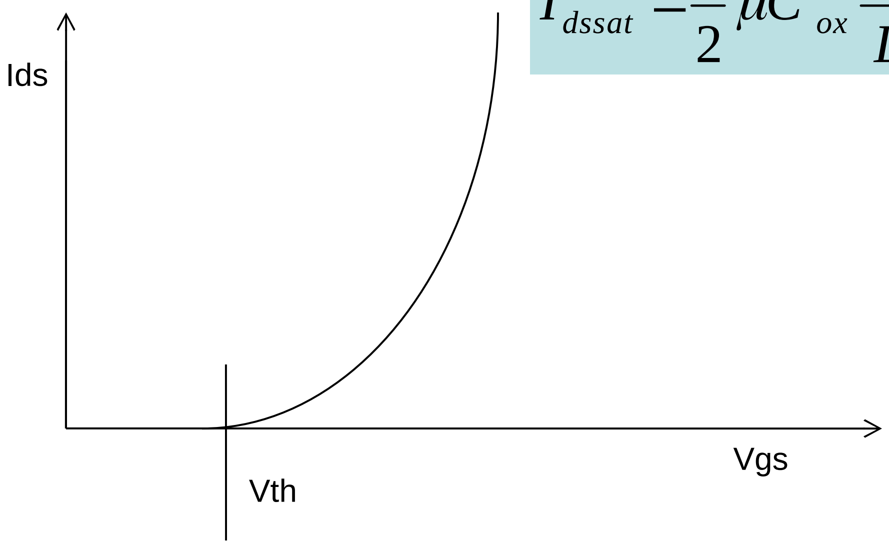
$$I_{dssat} = \frac{1}{2}\mu C'_{ox}\frac{W}{L}(V_{gs} - V_{th})^2$$



Idssat (Vgs) Kennlinie

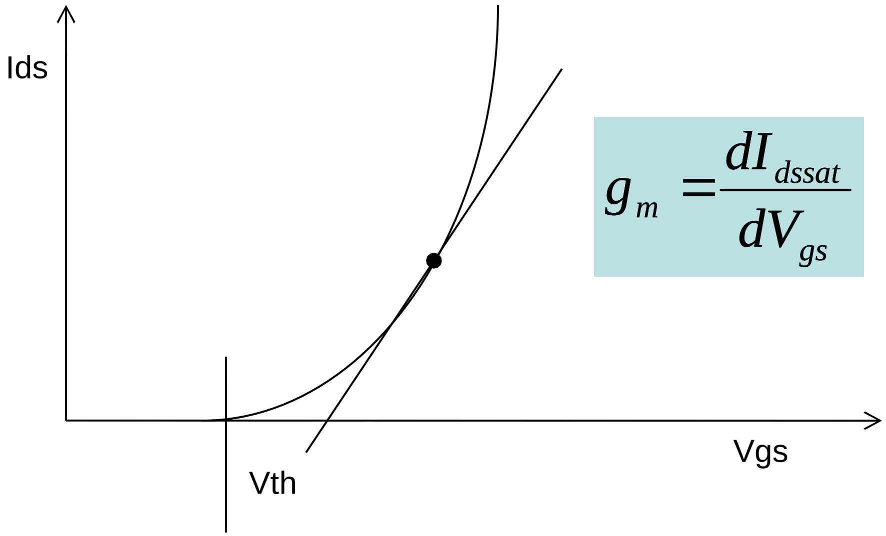
- …

$$I_{dssat} = \frac{1}{2} \mu C'_{ox} \frac{W}{L} (V_{gs} - V_{th})^2$$

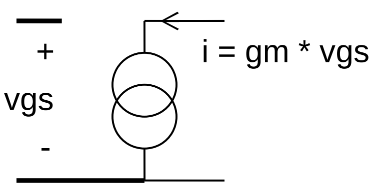


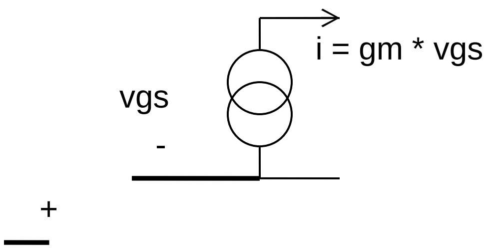
Gm - Transkonduktanz

- Die Eingangskennlinie wird im Bereich um den Arbeitspunkt linearisiert -> Kleinsignalmodell

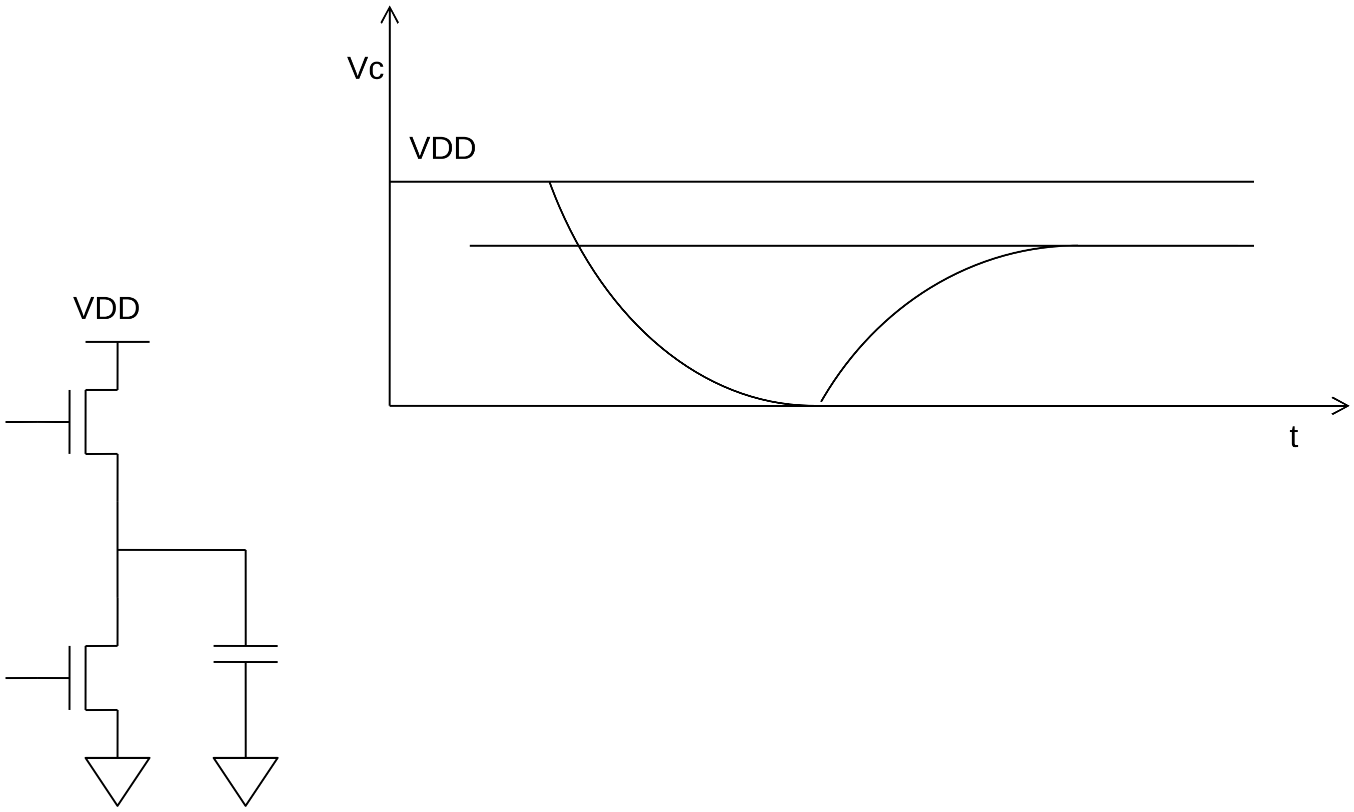


$$g_m = \frac{dI_{dssat}}{dV_{gs}}$$

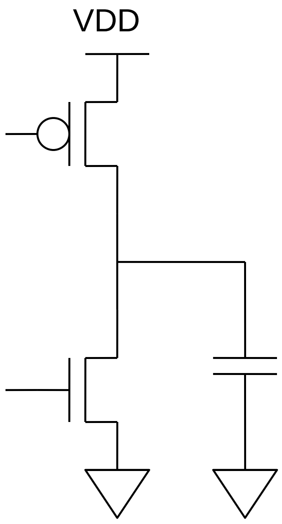


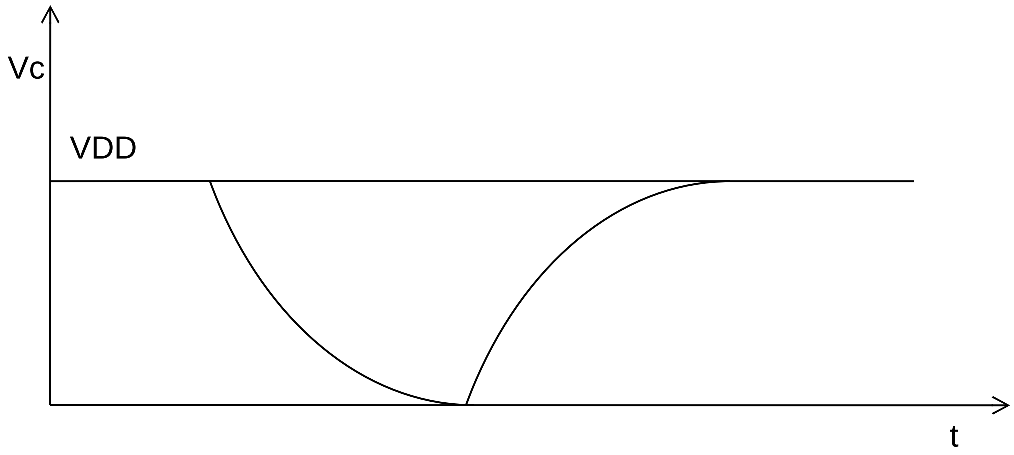


- NMOS



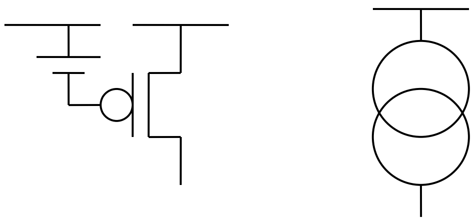
- PMOS

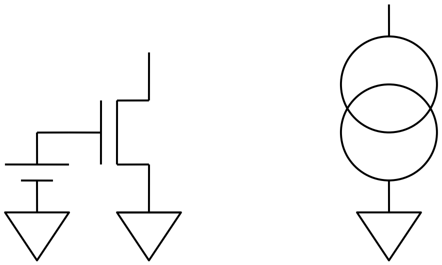




Warum brauchen wir NMOS und PMOS

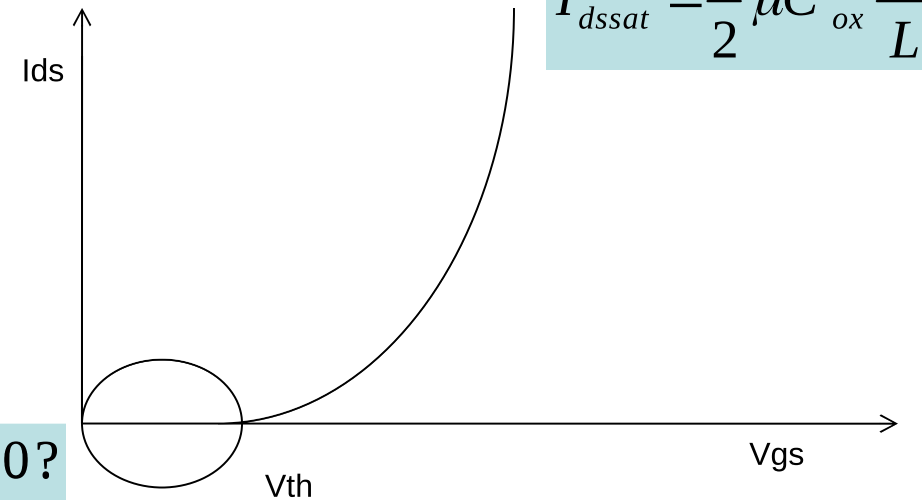
- Stromquellen





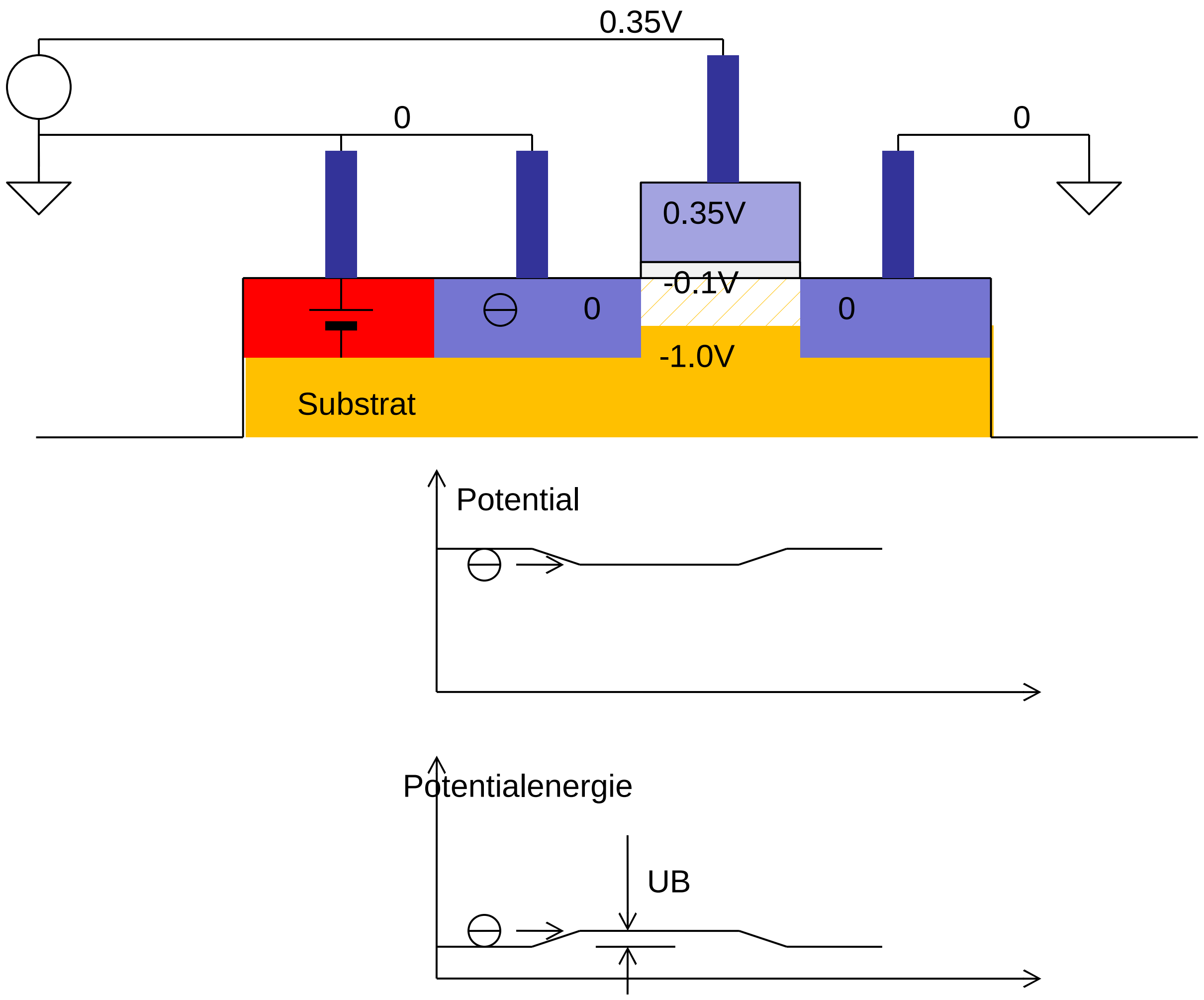
- Transistor

$$I_{dssat} = \frac{1}{2}\mu C'_{ox}\frac{W}{L}(V_{gs} - V_{th})^2$$

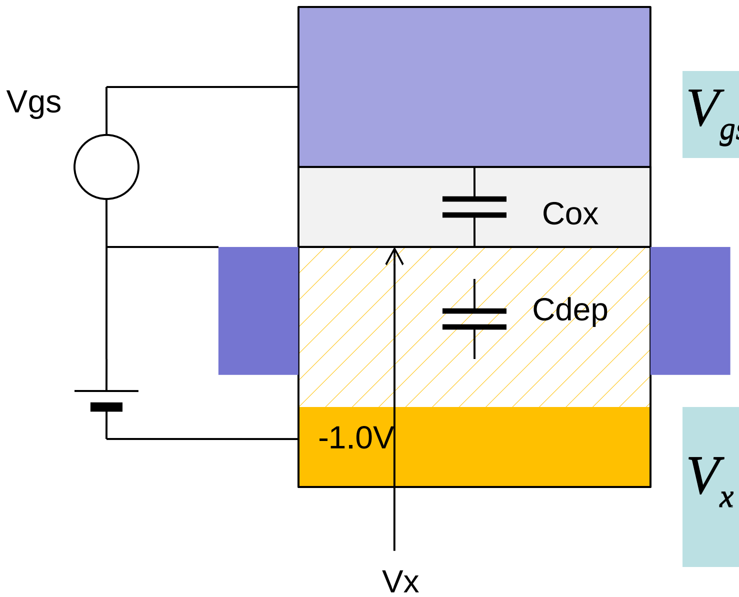


$$I_{dssat} = 0\,?$$

- Transistor


0.35V
0
0
0.35V
-0.1V
0
0
-1.0V
Substrat
Potential
Potentialenergie
UB

- Transistor

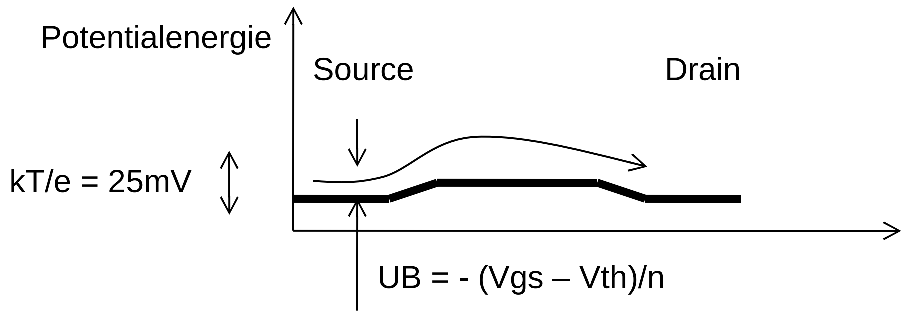


$$V_{gs} = V_{th} \Rightarrow V_x = 0$$

$$V_x = \frac{C_{ox}}{C_{dep} + C_{ox}} (V_{gs} - V_{th})$$

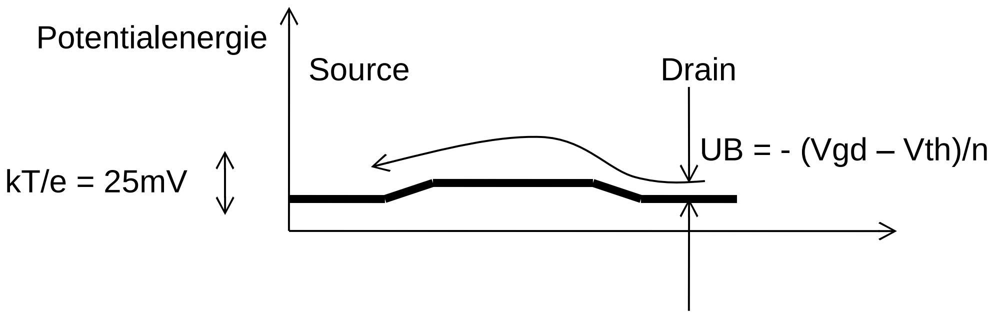
$$U_B = V_s - V_x = -\frac{C_{ox}}{C_{dep} + C_{ox}} (V_{gs} - V_{th}) = -\frac{(V_{gs} - V_{th})}{n}$$

- Transistor



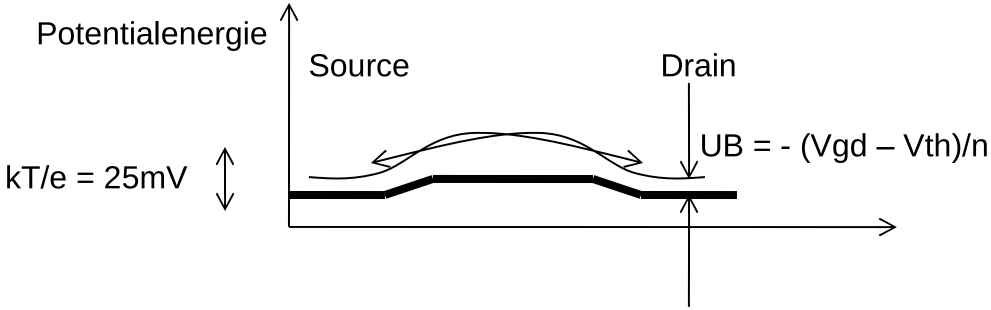
$$\Phi_{sd} = const \cdot e^{-U_B/U_T} = const \cdot e^{(V_{gs} - V_{th})/nU_T}$$

- Transistor



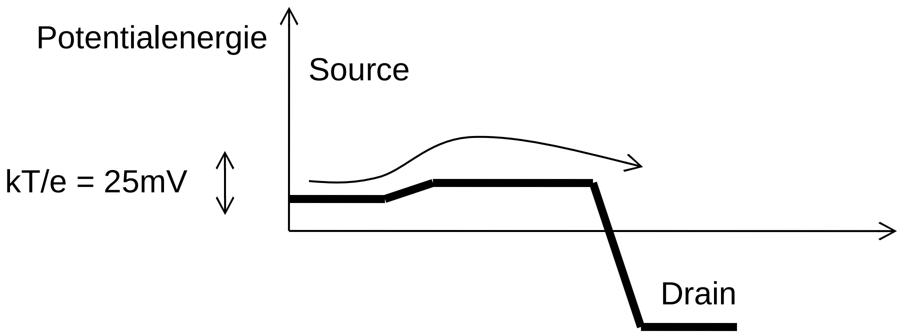
$$\Phi_{ds} = const \cdot e^{-U_B/U_T} = const \cdot e^{(V_{gd}-V_{th})/nU_T}$$

- Transistor



$$I_{ds} = e(\Phi_{sd} - \Phi_{ds}) = 0$$

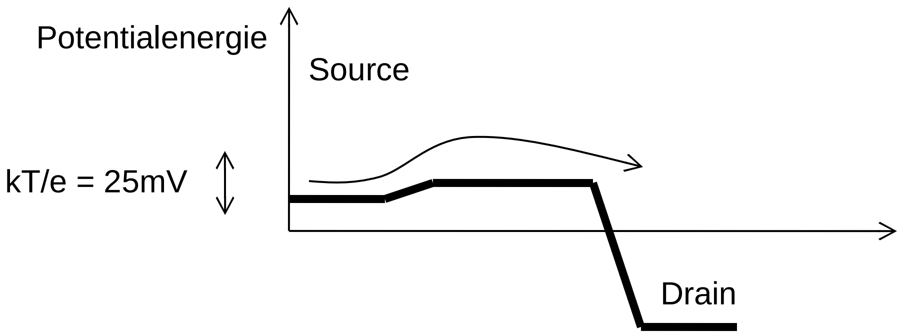
- Transistor



$$I_{ds} = const \cdot \left(e^{(V_{gs} - V_{th})/nU_T} - e^{(V_{gd} - V_{th})/nU_T} \right)$$

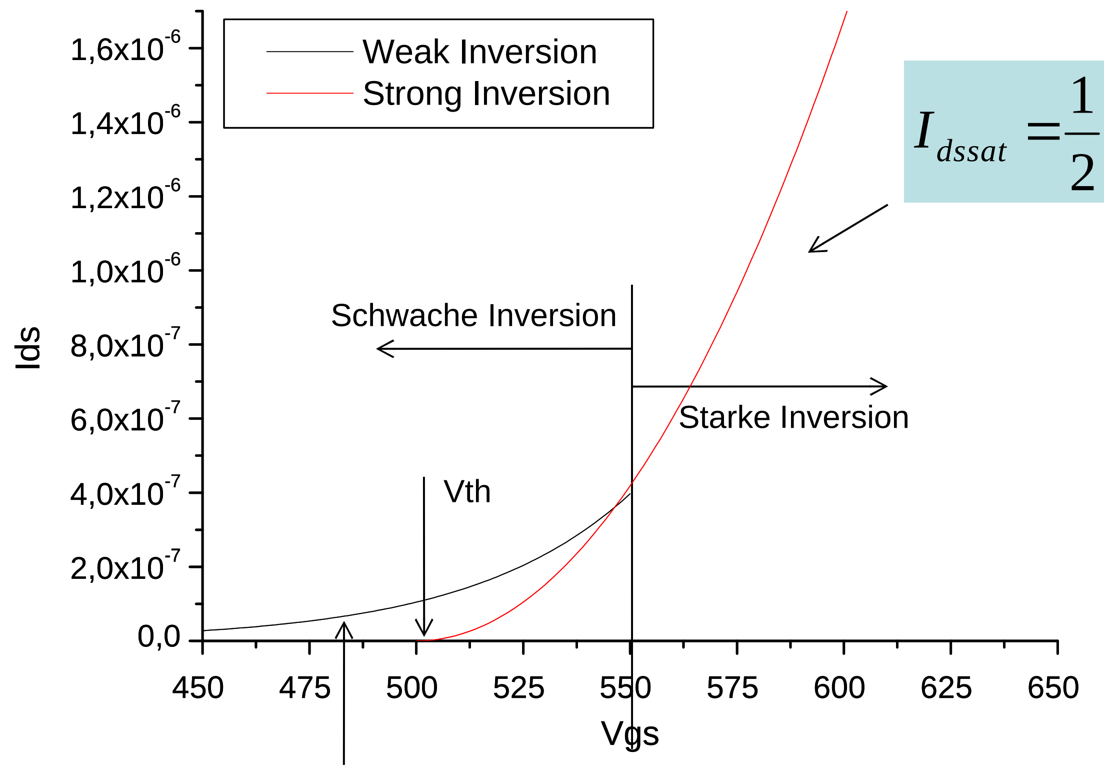
$$I_{ds} = const \cdot e^{(V_{gs} - V_{th})/nU_T} \left(1 - e^{-V_{ds}/nU_T} \right)$$

- Transistor



$$I_{dssat} = \frac{W}{L} \cdot C'_{ox} U_T^{\,2} \cdot (n-1) \cdot e^{(V_{gs}-V_{th})/nU_T}$$

- Transistor



$$I_{dssat} = \frac{1}{2}\mu C'_{ox}\frac{W}{L}(V_{gs} - V_{th})^2$$

$$I_{dssat} = \frac{W}{L} \cdot C'_{ox} U_T^{\ 2} \cdot (n-1) \cdot e^{(V_{gs} - V_{th})/nU_T}$$

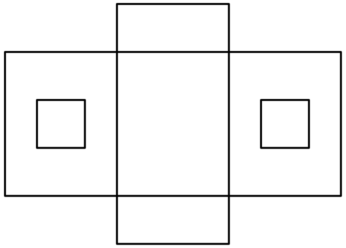
- Transistor

$$I_{dssat} = \frac{k}{2}(V_{gs} - V_{th})^2$$

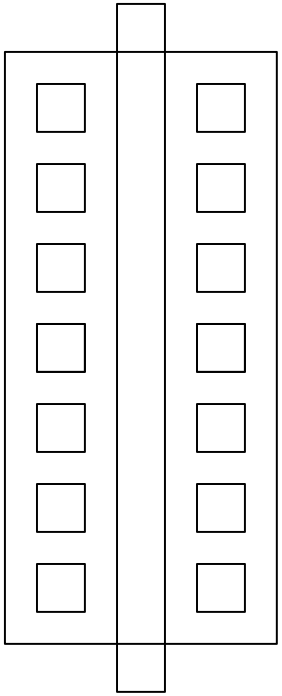
$$g_m = \sqrt{kI_{dssat}(W/L)}$$

$$I_{dssat} = const \cdot e^{(V_{gs} - V_{th})/nU_T}$$

$$g_m = I_{dssat} / nU_T$$

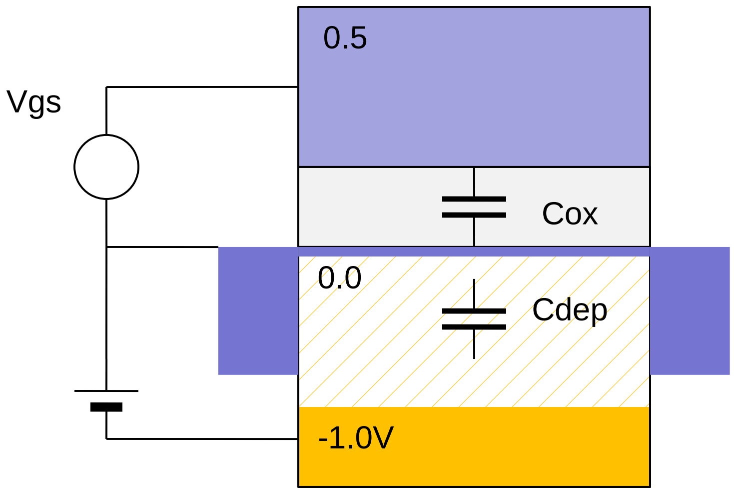


$$g_m = \sqrt{kI_{dssat}(W/L)}$$

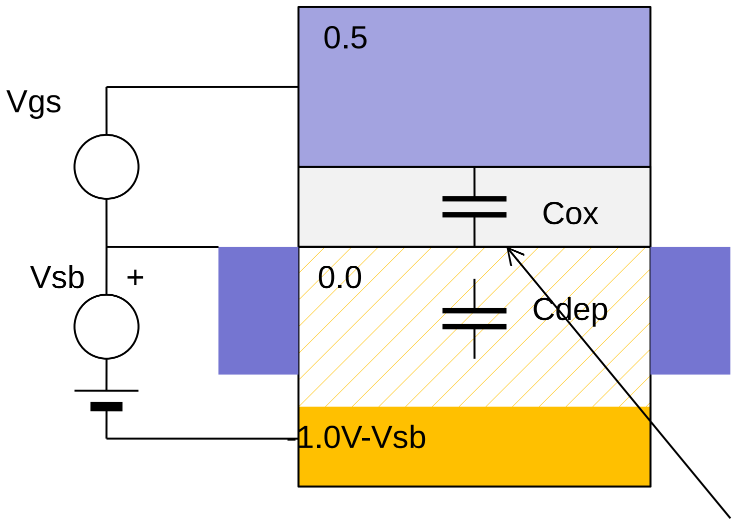


$$g_m = I_{dssat} / nU_T$$

- Transistor

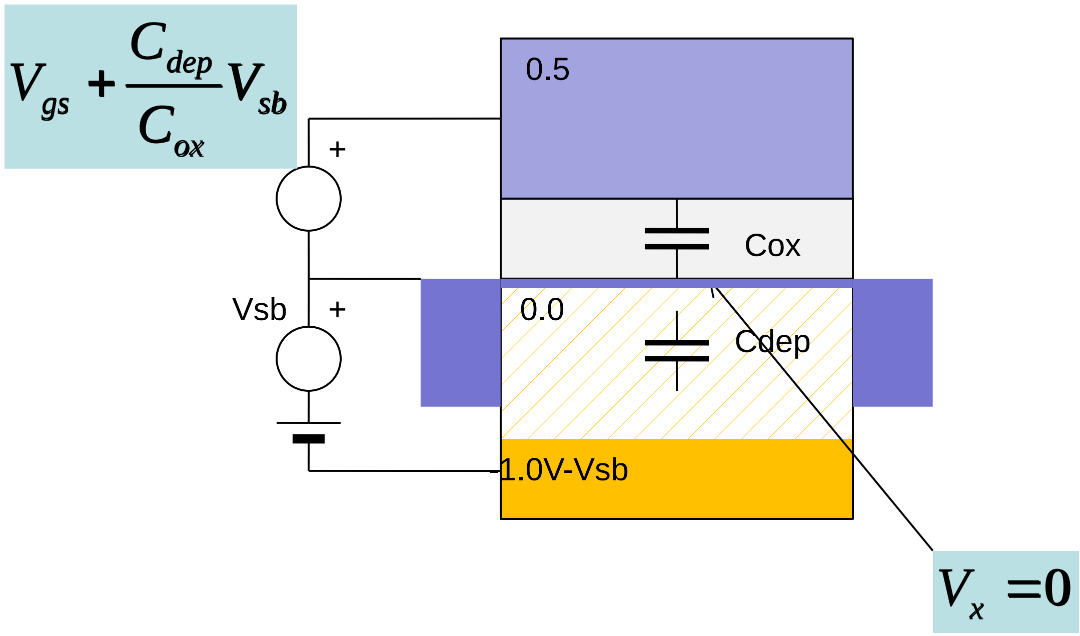


- Transistor



$$V_x = -\frac{C_{dep}}{C_{dep} + C_{ox}} V_{sb}$$

- Transistor

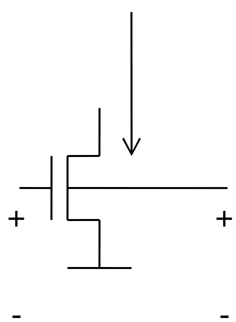


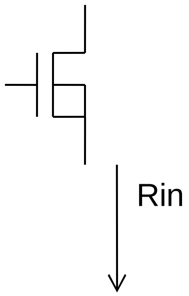
Substrateffekt

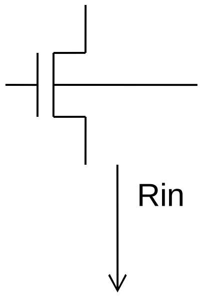
- Transistor

$$I_{dssat} = \frac{1}{2}\mu C'_{ox}\frac{W}{L}(V_{gs} - V_{th0} - 0.5V_{sb})^2$$

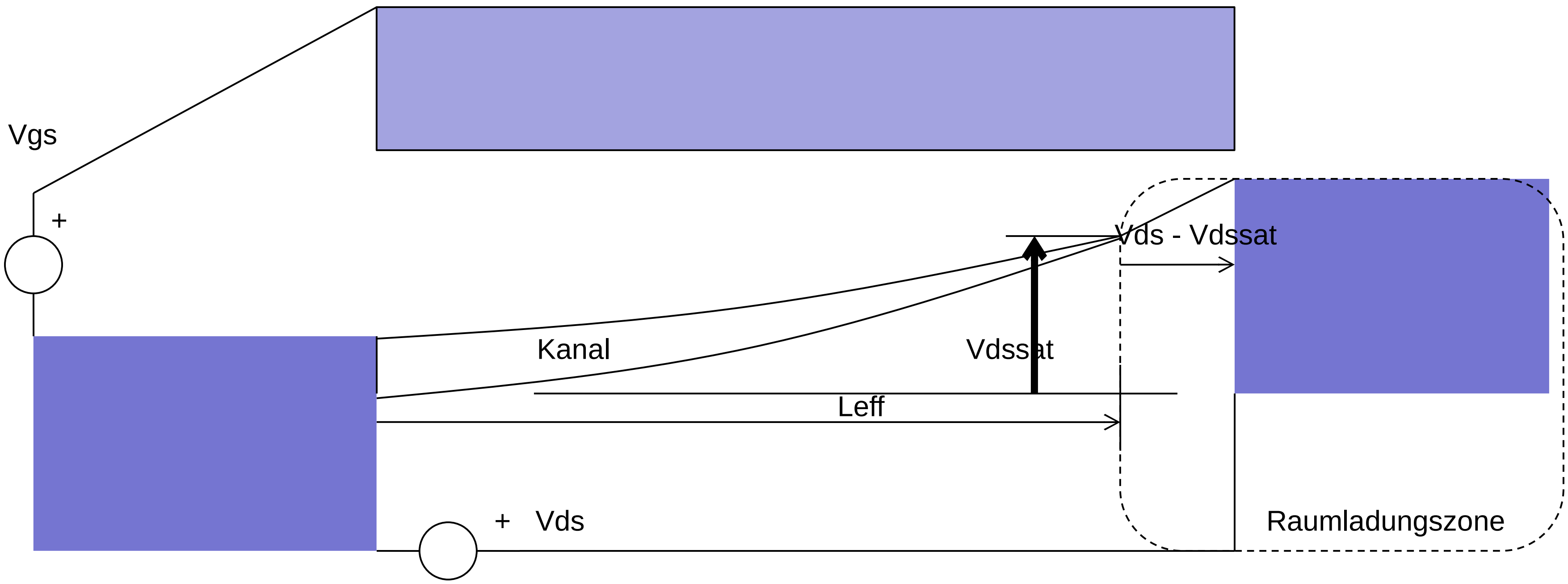
$$I_{dssat} = \frac{1}{2}\mu C'_{ox}\frac{W}{L}(V_{gs} + 0.5V_{sb} - V_{th0})^2$$







- Die Größe der Raumladungszone hängt von der Überspannung Vds – Vdssat



- …

$$I_{dssat} = \frac{1}{2}\mu C'_{ox}\frac{W}{L}(V_{gs} - V_{th})^2$$

$$I_{ds}(V_{ds} - V_{dssat}) = I_{dssat} + \frac{\partial I_{dssat}}{\partial L}\Delta L(V_{ds} - V_{dssat})$$

Reihenentwicklung

$$I_{ds}(V_{ds} - V_{dssat}) = I_{dssat}(1 + \frac{\Delta L}{L})$$

Annahme

$$\Delta L \sim (V_{ds} - V_{dssat}) / E_{sat}$$

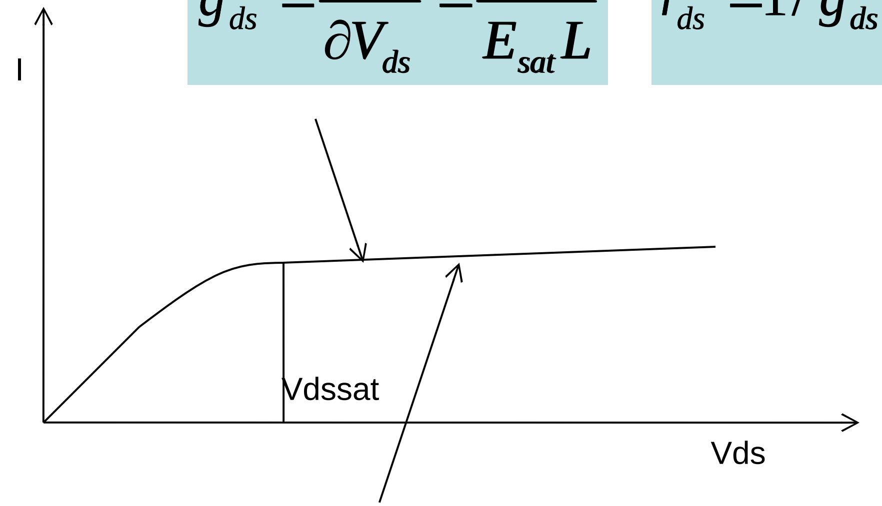
↓

$$I_{ds} = I_{dssat}(1 + (V_{ds} - V_{dssat}) / E_{sat}L)$$

- …

$$g_{ds} = \frac{\partial I_{ds}}{\partial V_{ds}} = \frac{I_{dssat}}{E_{sat} L}$$

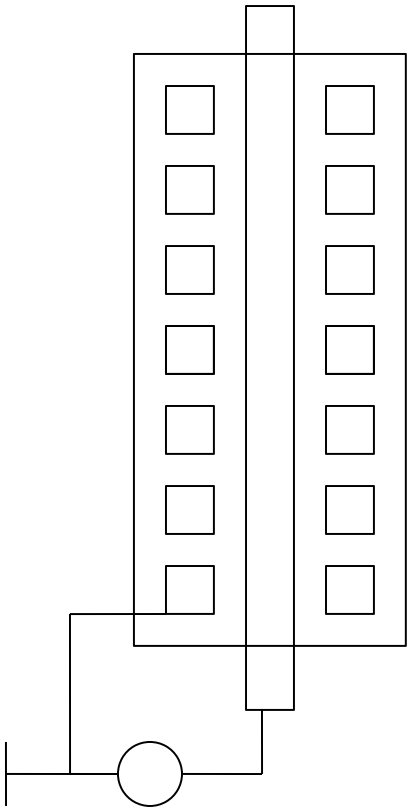
$$r_{ds} = 1/g_{ds} = \frac{E_{sat} L}{I_{dssat}}$$

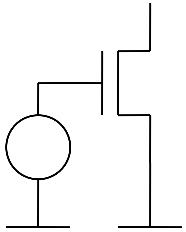


$$I_{ds} = I_{dssat}(1 + (V_{ds} - V_{dssat})/E_{sat} L)$$

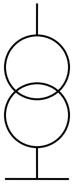
- …

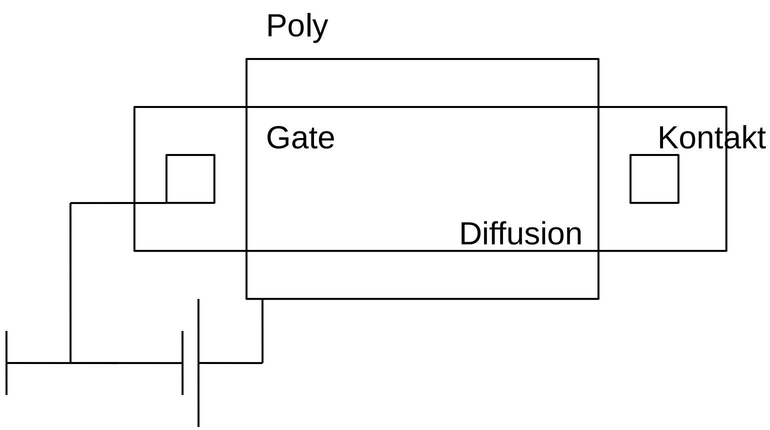
L klein
Schlechte Stromquelle (rds klein)
Guter Verstärker (gm groß)





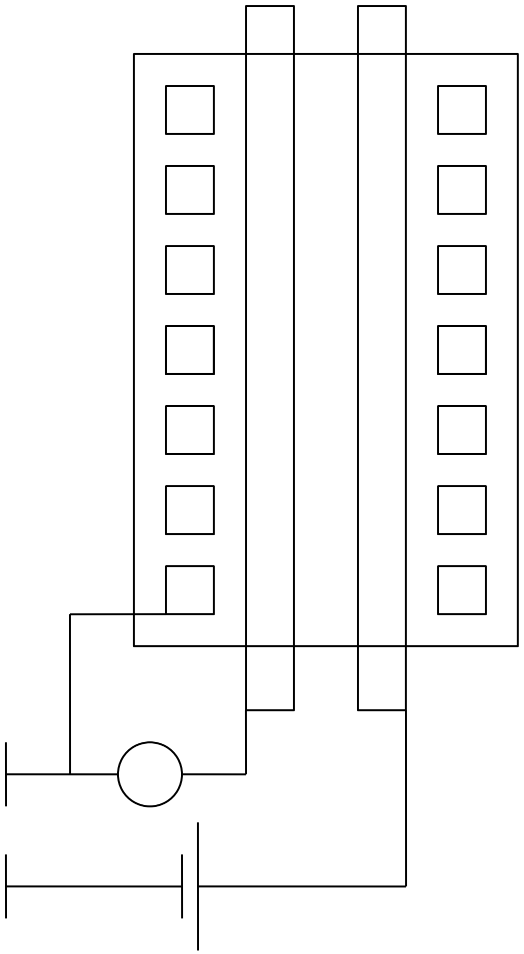
L groß
Gute Stromquelle (rds groß)
Schlechter Verstärker (gm klein)

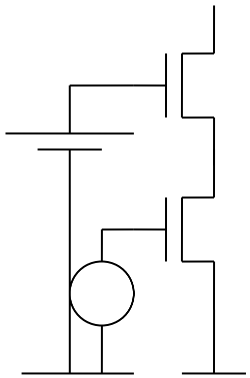




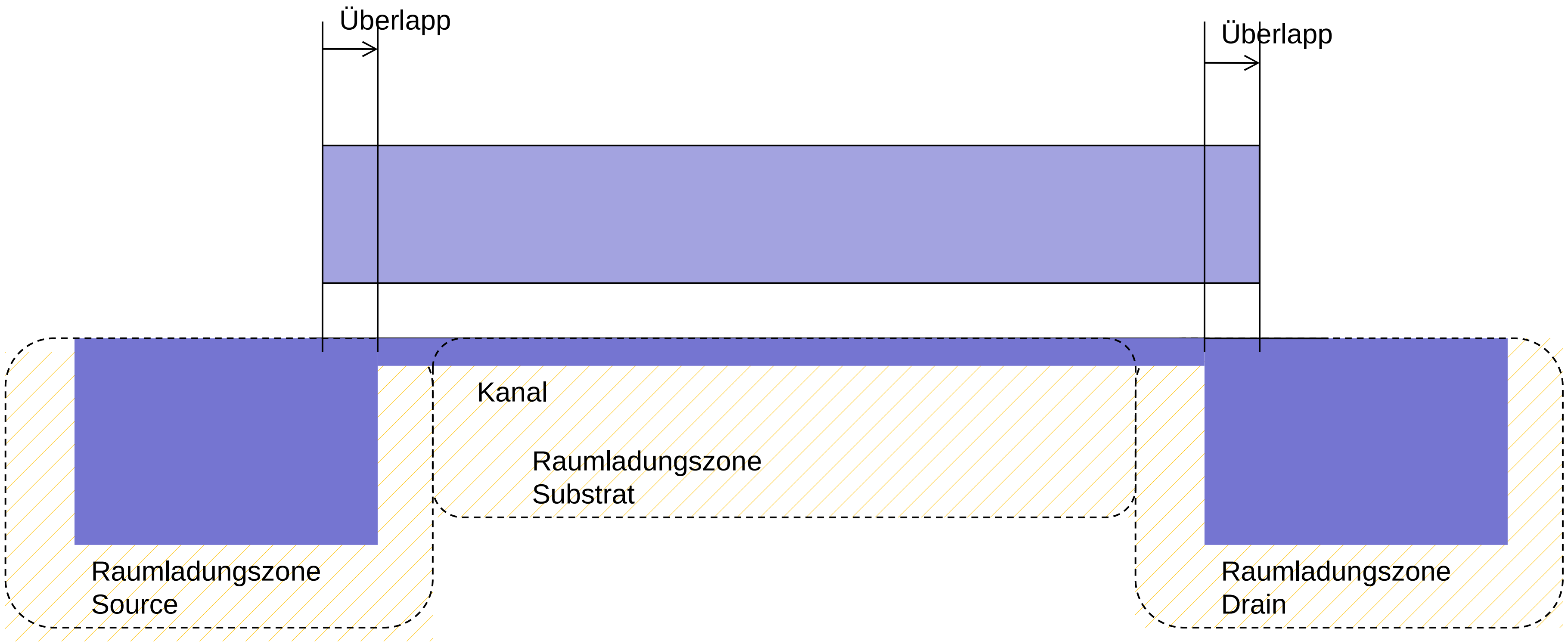
- …

Kaskode (wird später erklärt)
Gute Stromquelle (rout groß)
Guter Verstärker (gm groß)

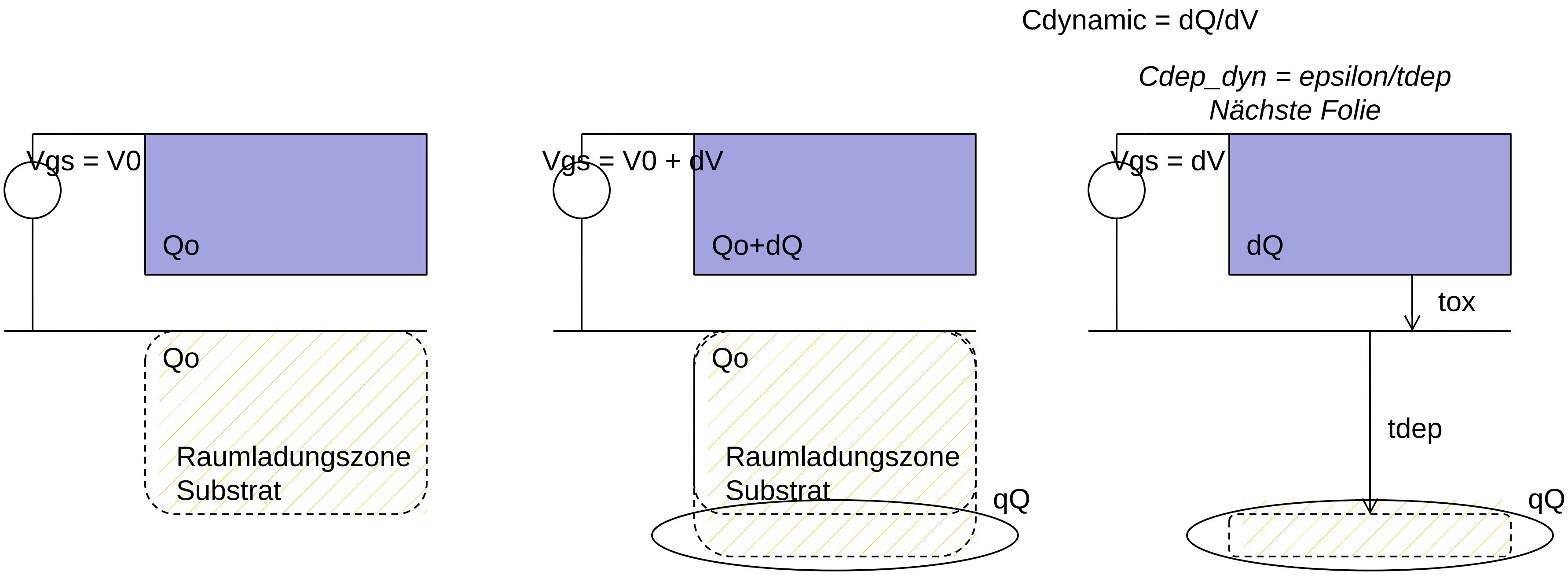




- In der Transistorstruktur haben wir an mehreren Stellen Raumladung



- Dynamische Kapazitäten



- …

$$\frac{dQ}{dV} = C_{dyn}$$

$$C_{dyn} = \frac{\varepsilon}{t}$$

$$Q = const \cdot t$$

$$C_{dyn} = const / Q$$

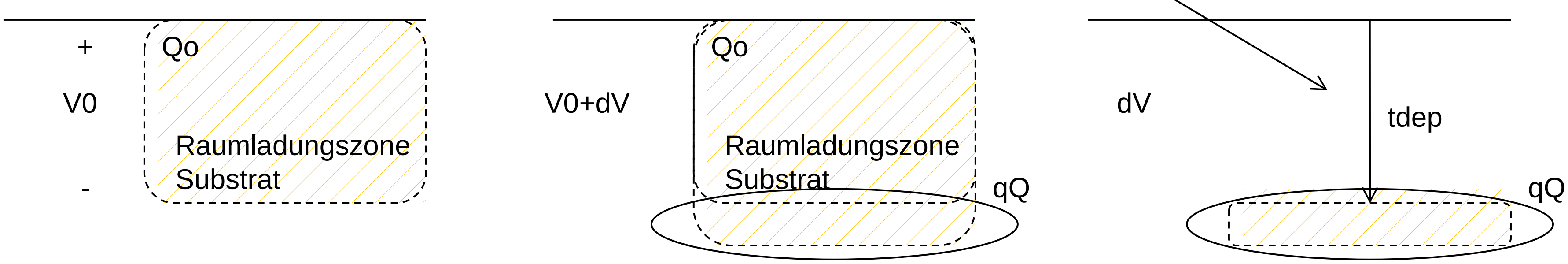
$$\frac{dQ}{dV} = const / Q$$

$$QdQ = const \cdot dV$$

$$\frac{1}{2} Q^2 = const \cdot V$$

$$Q = \sqrt{2 \cdot const \cdot V}$$

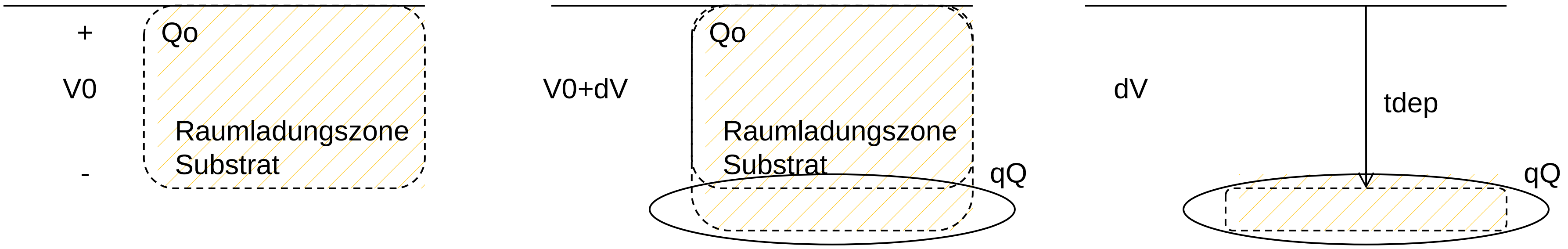
$$C_{dyn} = \frac{dQ}{dV} = \frac{d(\sqrt{2 \cdot const \cdot V})}{dV} = \frac{\sqrt{2 \cdot const \cdot V}}{2\sqrt{V}} = \frac{1}{2} \frac{Q}{V}$$



- Dicke der Raumladungszone und deren Ladung hängen als Quadratwurzel von der Spannung in der Zone V
- Die Ladung der Zone ist durch die Formel 2 * Cdyn * V gegeben
- Man kann näherungsweise Cdyn anstatt normaler Kapazität verwenden
- Wir haben deshalb überall Cdep_dyn verwendet

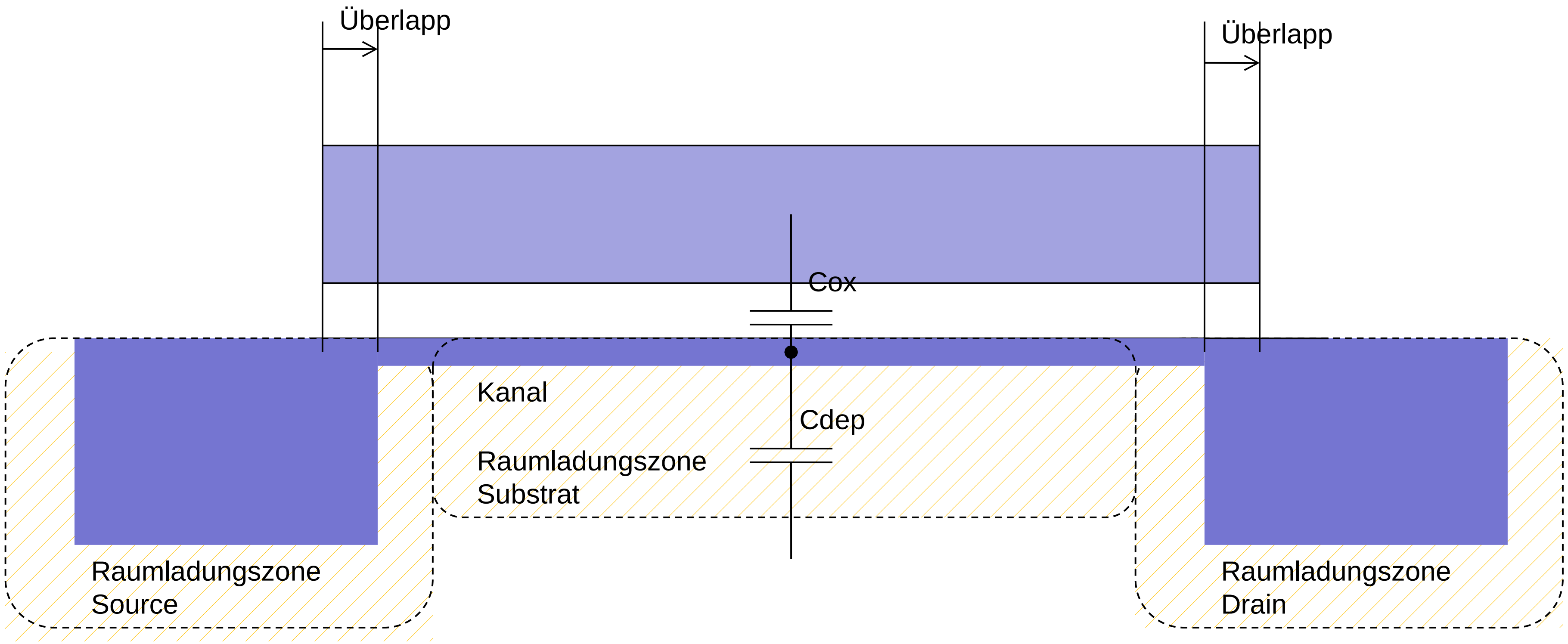
$$Q = \sqrt{2 \cdot const \cdot V}$$

$$2 C_{dyn} V = Q$$



Gate Kapazität

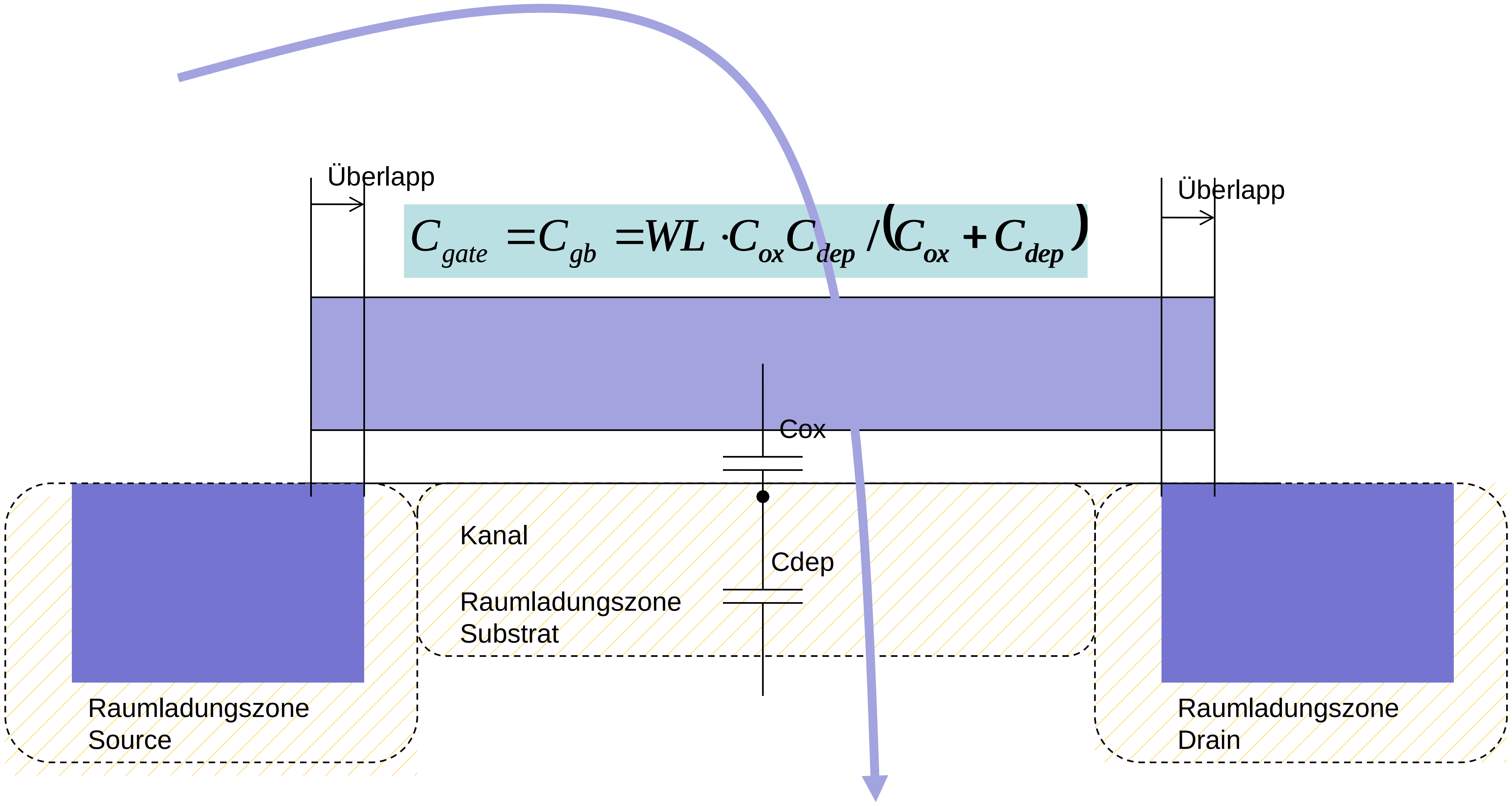
- Oxidkapazität Cox * W * L
- Kapazität der Verarmungszone Cdep * W * L



Gate Kapazität – schwache Inversion

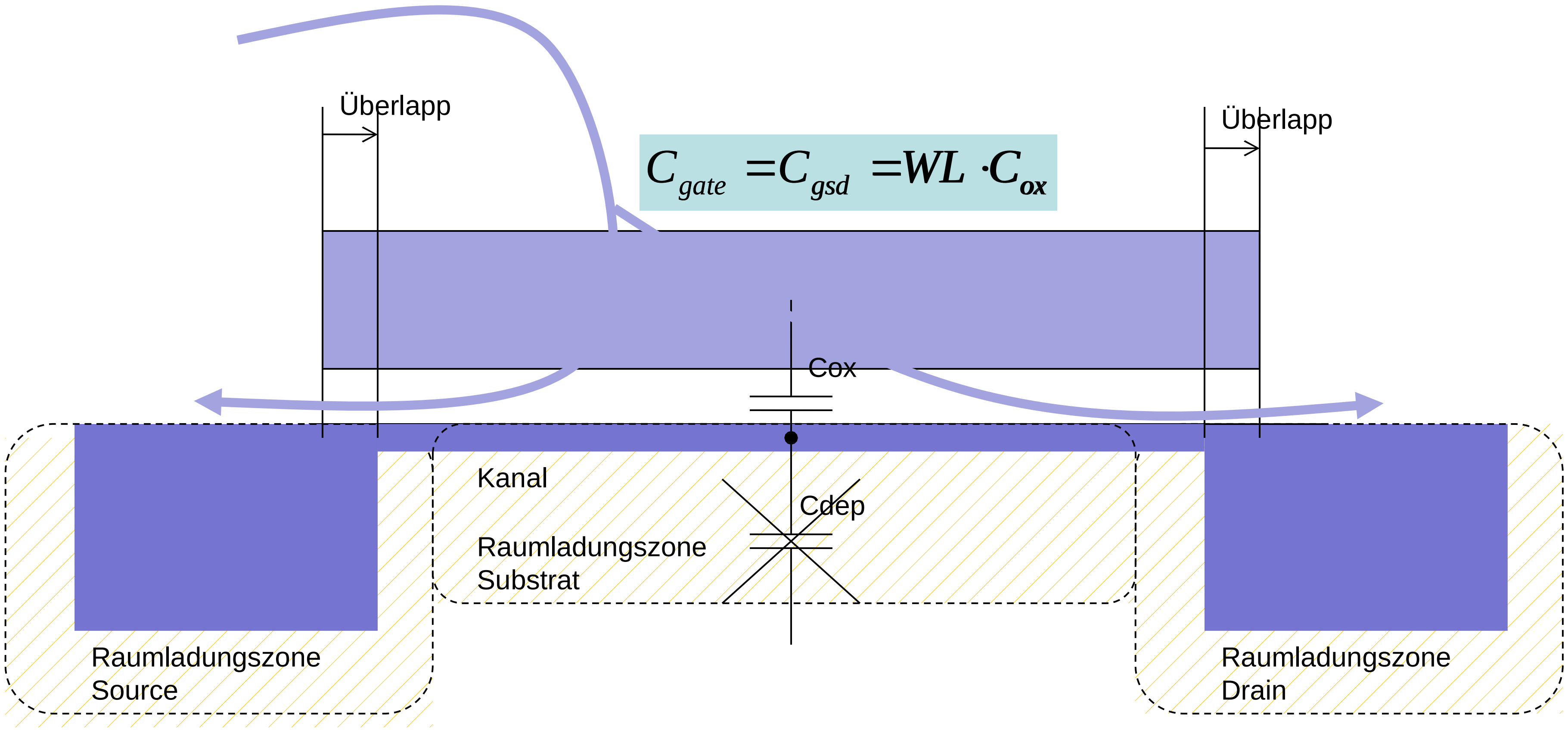
- Die Gate Kapazität ist die Reihenschaltung von Cox und Cdep
- Die Kapazität wirkt zwischen dem Gate und dem Substrat

$$C_{gate} = C_{gb} = WL \cdot C_{ox} C_{dep} / \left(C_{ox} + C_{dep} \right)$$

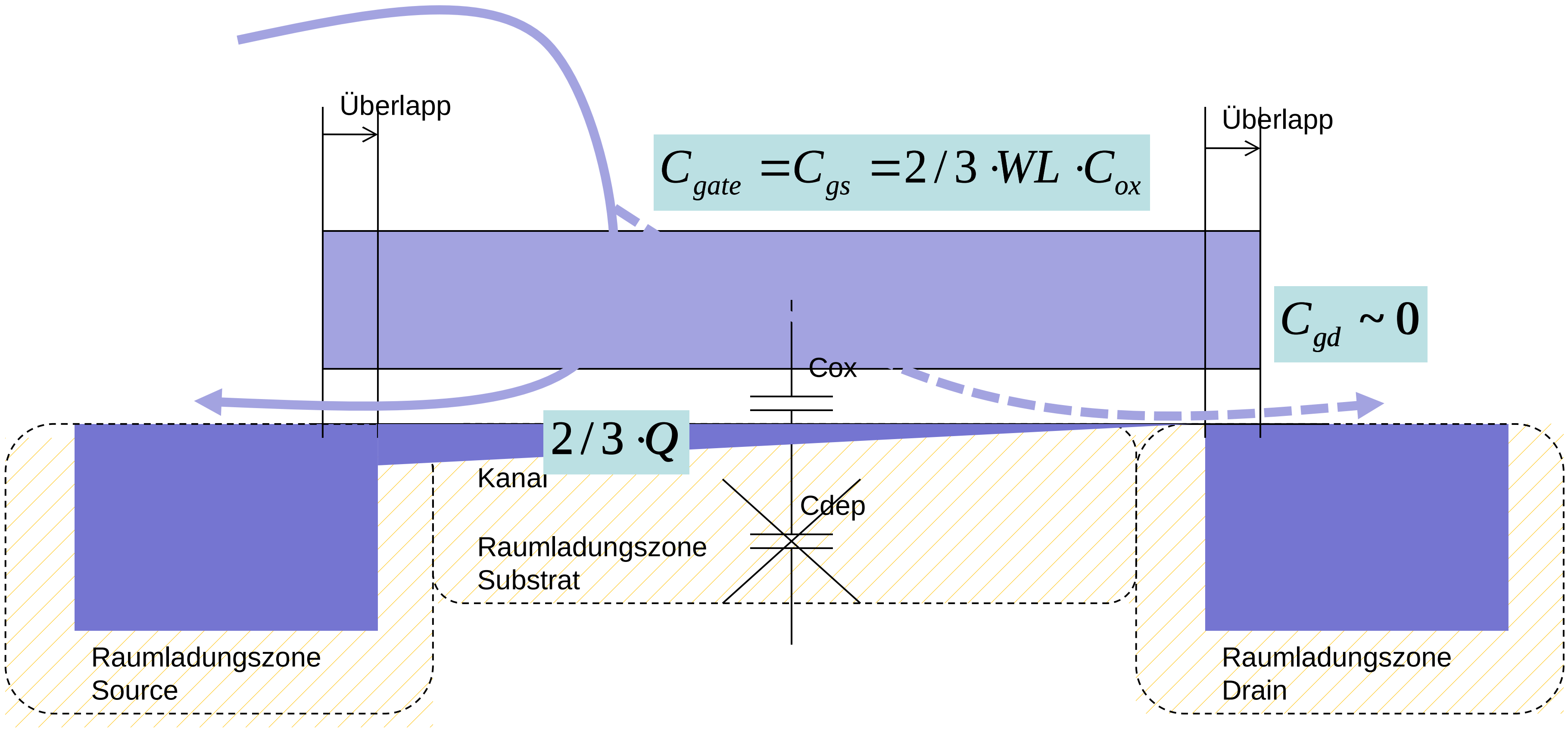


- Die Spannung zwischen den Kontakten von Cdep ist fest
- Die Gate-Kapazität ist also größer als in schwacher Inversion
- Gate-Kapazität wirkt zwischen dem Gate und Source und Drain gleichmäßig

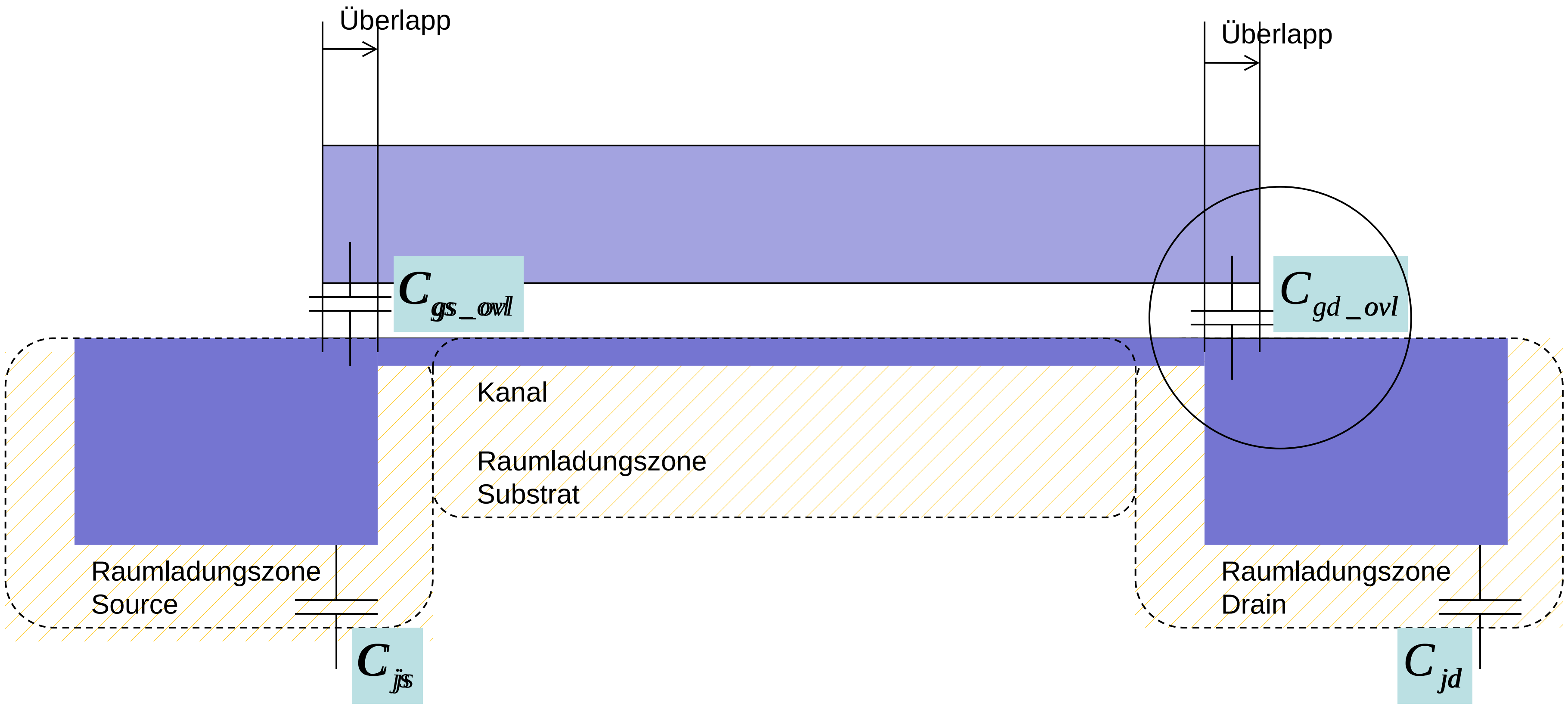
$$C_{gate} = C_{gsd} = WL \cdot C_{ox}$$



- Da der Kanal in Sättigung von Drain abgekoppelt ist, wirkt die Kapazität nur zwischen Gate und Source
- In erster Näherung keine Kapazität zwischen dem Drain und Gate



- PN Übergang Kapazitäten (junction Kapazitäten)
- Überlappkapazitäten Cgs_ovl und Cgd_ovl



Kleinsignalmodell

- …