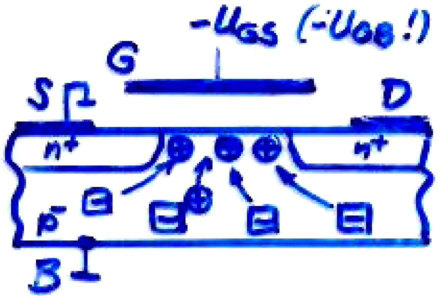
(MOS)

MIS - Leitungsvorgang (n-Kanal)

①

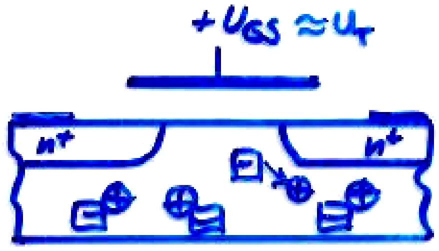


Kanalanreicherung von Defektelektronen

⊕: Defektelektronen
⊟: ortsfeste Akzeptoren

$-U_{GS}$

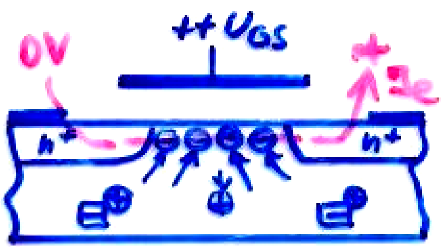
②



Entblößung an beweglichen Ladungsträgern

$0 < U_{GS} < U_T$

③

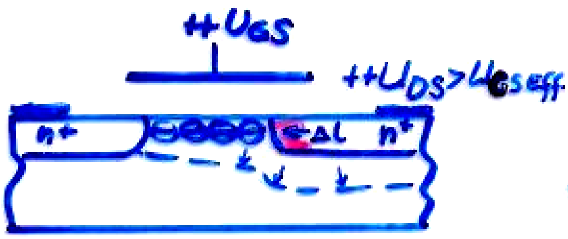


Kanalinversion von entblößten Elektronen

$U_{GS} > U_T$

$U_{GS} - U_T > U_{DS}$

④

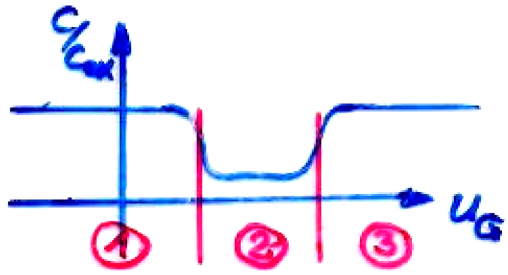


Kanallängenverkürzung ΔL, Aufweitung n^+-RLZ

$U_{GS} > U_T$

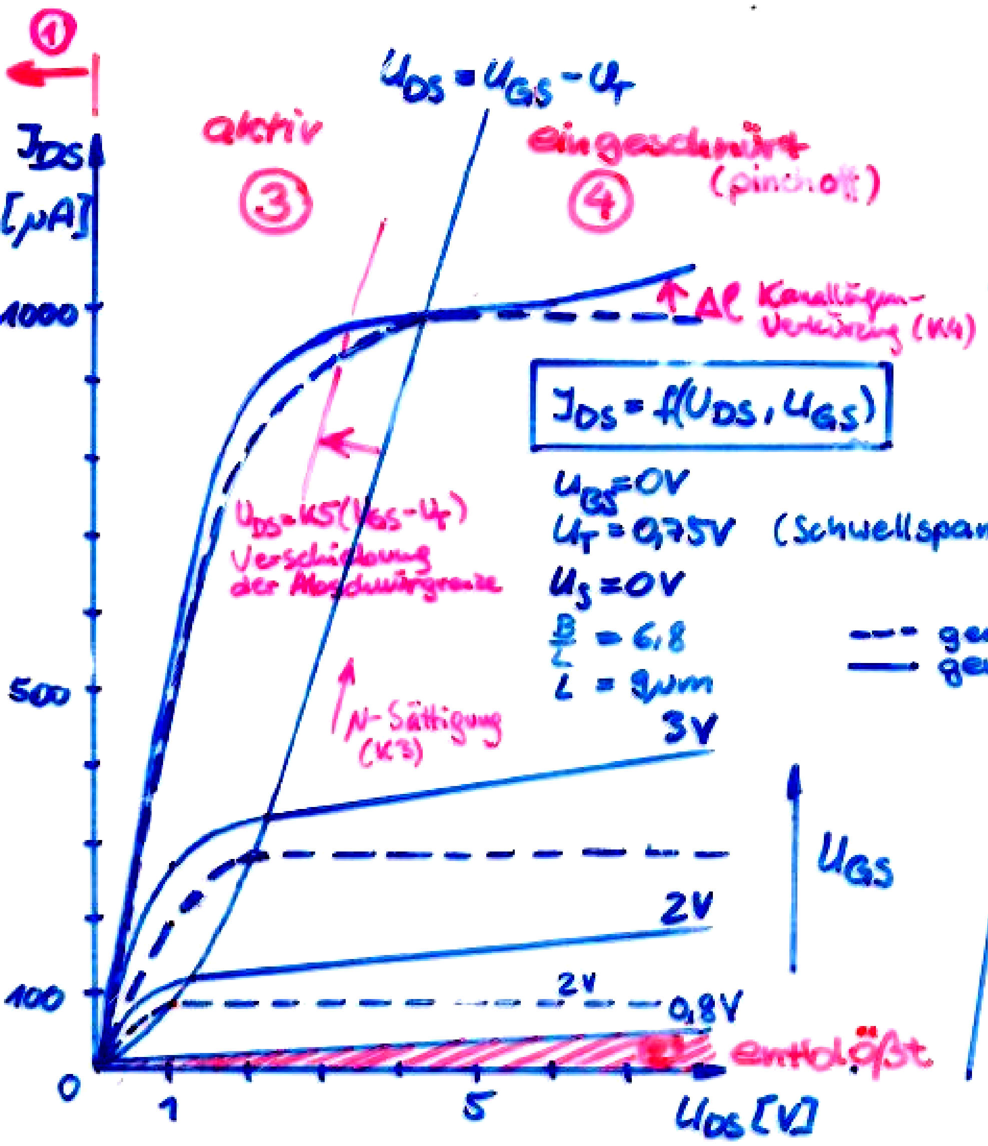
$U_{GS} - U_T < U_{DS}$

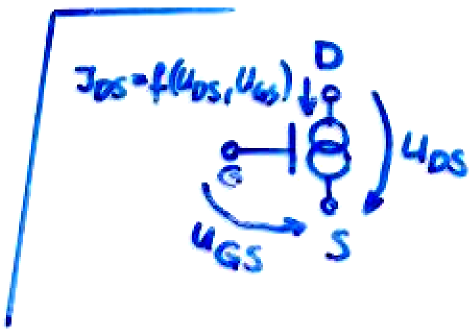
→ spannungsabhängige Gatekapazität:



MOS-Transistorkennl.

(Enhancement, nSGT)





Transistormodell: Kennlinienappr. (vereinfacht, ohne Δl!) E + D !

gesperrt: ①② $0 < U_{GS} < U_T$; $J_{DS}=0$

aktiv: ③ $U_{DS} \le U_{GS}-U_T$

$$J_{DS}=\beta_0 \frac{b}{L}\left((U_{GS}-U_T)U_{DS}-\frac{1}{2}U_{DS}^2\right) \rightarrow J_{DS}\sim \frac{b}{L} f(U_{GS},U_{DS})$$

eingeschnürt: ④ $U_{DS} > U_{GS}-U_T$

$$J_{DS}=\frac{1}{2}\beta_0 \frac{b}{L}(U_{GS}-U_T)^2 \rightarrow J_{DS}\sim \frac{b}{L}\cdot U_{GSE}^2$$

$$\beta_0 = \mu \cdot C''_{ox} = \mu \cdot \frac{\varepsilon_{ox}}{d_{ox}} \approx 12 \ldots 20 \frac{\mu A}{V^2} \text{ (nSGT)}$$

$\uparrow \left[\frac{cm^2}{Vs}\right]$

$U_T = f(U_{BS})$: (Transfergate sG)

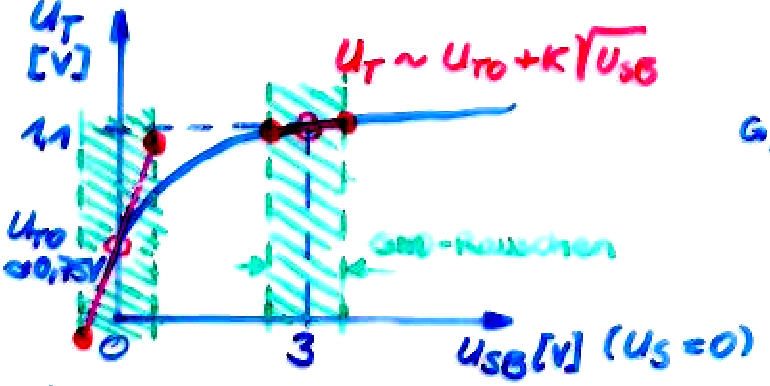
$U_{TD} = \begin{cases} -3{,}5 & (U_{BS} = 0) \\ -3{,}15 & (U_{BS} = -3) \\ -3{,}0 & (U_{BS} = -5) \end{cases}$

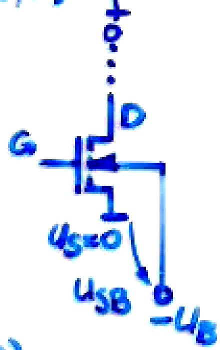
$U_{TE} = \begin{cases} 0{,}75 & (U_{BS} = 0V) \\ 1{,}1 & (U_{BS} = -3V) \\ 1{,}23 & (U_{BS} = -5V) \end{cases}$

$$U_T = U_{T0} + K_1 \left(\sqrt{U_{SB} + 2V_F} - \sqrt{2V_F} \right)$$

U_{T0} : $U_T(U_{BS} = 0)$ (0,75V)
K_1 : Substratrückwirkungskonstante (0,31)
V_F : Fermipotential (0,64V)

Schwellspannungsstabilisierung: (Transfergates, dyn. Speicher etc)





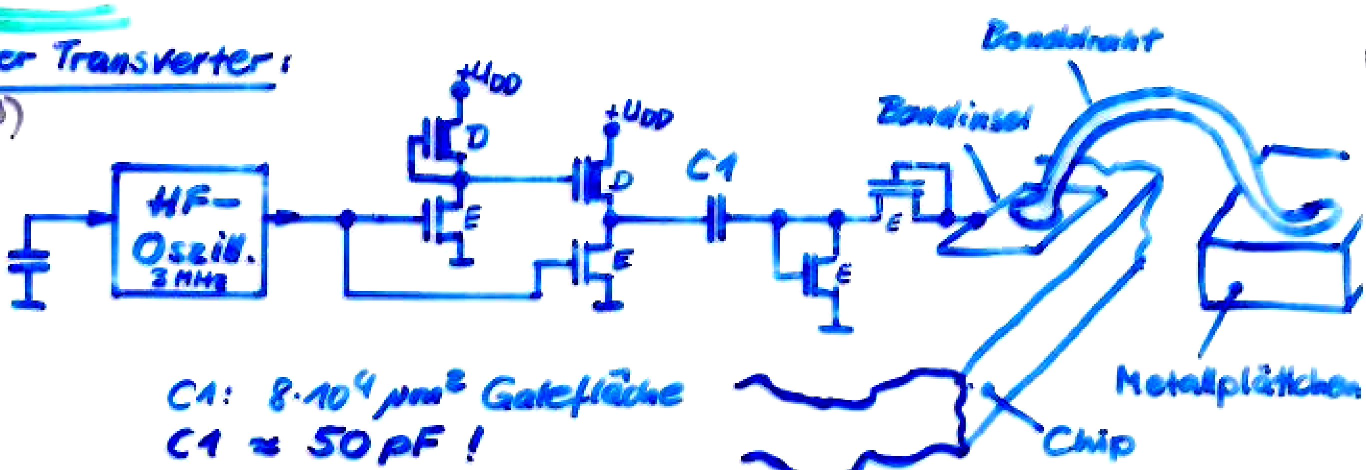
praktisch: (U_{SB} = 3V)

E: $U_{T0E} \approx 0{,}75V$
$U_T \approx 1V$

D: $U_{T0D} \approx -3{,}5V$
$U_T \approx -3V$

Ziel: $\frac{dU_T}{dU_{SB}} \rightarrow$ MIN. + $C_{Sperr} \rightarrow$ MIN. : Verringerung um ca. 30% (!) bei U_{SB} = 3V)

⇒ IC-interner Transverter:
(8279)

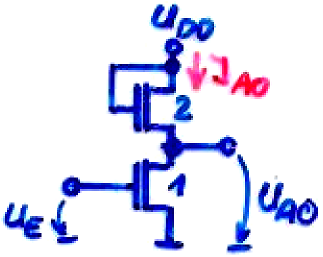


C1: $8 \cdot 10^4 \mu m^2$ Gatefläche
C1 ≈ 50pF !
$\left(C''_{Gate} = 600 \frac{pF}{mm^2} \right)$

$U_{SB} \approx U_{DD} - 2U_{TE} \approx 3V.$

EE - Inverter: statische Dimensionierung:

$\gamma = f(U_{A0}, U_{EH})$



$$\begin{cases} J_{DS2} = \frac{\beta_0}{2} \cdot \frac{b_2}{L_2} (U_{GS2} - U_T)^2 \\ J_{DS1} = \beta_0 \frac{b_1}{L_1} \left((U_{GS1} - U_T) U_{DS1} - \frac{U_{DS1}^2}{2} \right) \end{cases}$$

$U_T = 1{,}1\,V$
$(U_{BS} = -3V)$
$U_{DD} = 5V$
$U_{A0} = 0{,}38\,V$
$\beta_{0E} = 0{,}016 \frac{mA}{V^2}$

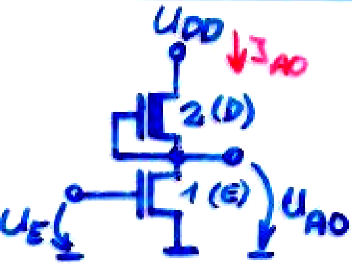
$$\gamma = \frac{\frac{b_1}{L_1}}{\frac{b_2}{L_2}} = \frac{(U_{GS2} - U_T)^2}{2\left((U_{GS1} - U_T) U_{DS1} - \frac{U_{DS1}^2}{2}\right)} \geq 6{,}3$$

Ruhestrom:

$$J_{A0} = \frac{\beta_0}{2} (U_{GS2} - U_{TE})^2 \cdot \frac{b_2}{L_2} = \left(\frac{b}{L}\right)_{Last} \cdot 99{,}1\,\mu A$$

$$\boxed{\begin{array}{l} \text{EE-Inverter:} \\ U_{EH} = U_{DD} = \\ U_T = 1{,}1V \\ U_{A0} = 0{,}38V \\ \gamma \geq 6{,}3 \\ J_{A0} = \left(\frac{b}{L}\right)_L \cdot 100\,\mu A \end{array}}$$

ED - Inverter: statische Dimensionierung:



$$\begin{cases} J_{DS2} = \frac{\beta_{0D}}{2} \cdot \frac{b_2}{L_2} \cdot (\overset{=0}{U_{GS2}} - U_{TD})^2 \\ J_{DS1} = \beta_{0E} \frac{b_1}{L_1} \left((U_{GS1} - U_T) U_{DS1} - \frac{U_{DS1}^2}{2} \right) \end{cases}$$

$U_T = 1{,}1\,V$
$U_{TD} = -3{,}15\,V$
$U_{A0} = 0{,}38\,V$
$\beta_{0D} = 0{,}020 \frac{mA}{V^2}$

$$\gamma = \frac{\frac{b_1}{L_1}}{\frac{b_2}{L_2}} = \frac{\beta_{0D}(-U_{TD}^2)}{\beta_{0E} 2\left((U_{GS1} - U_T) U_{DS1} - \frac{U_{DS1}^2}{2}\right)} \geq 4{,}4$$

Ruhestrom:

$$J_{A0} = \frac{\beta_{0D}}{2} (-U_{TD})^2 \cdot \frac{b_2}{L_2} = \left(\frac{b}{L}\right)_{Last} \cdot 99{,}2\,\mu A$$

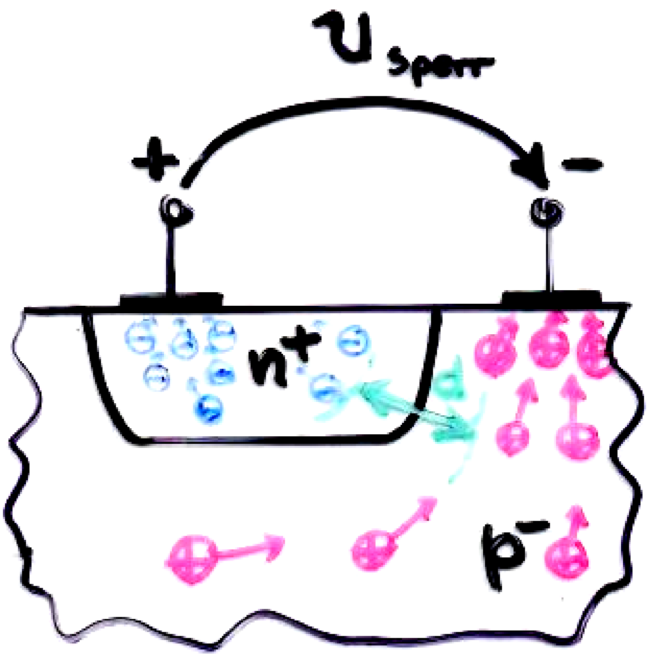
$$\boxed{\begin{array}{l} \text{ED-Inverter:} \\ U_{EH} = U_{DD} = 5V \\ U_T = 1{,}1V \\ U_{A0} = 0{,}38V \\ \gamma \geq 4{,}4 \\ J_{A0} \approx \left(\frac{b}{L}\right)_L \cdot 100\,\mu A \end{array}}$$

$$\Rightarrow \gamma = f(\underbrace{U_{DD}, U_T, \cancel{U_{A0}}}_{\text{für alle Stufen des IC konst.}}, \underbrace{U_{EH}}_{\text{kritisch bei } U_{EH} = U_{DD} - k \cdot U_T})$$

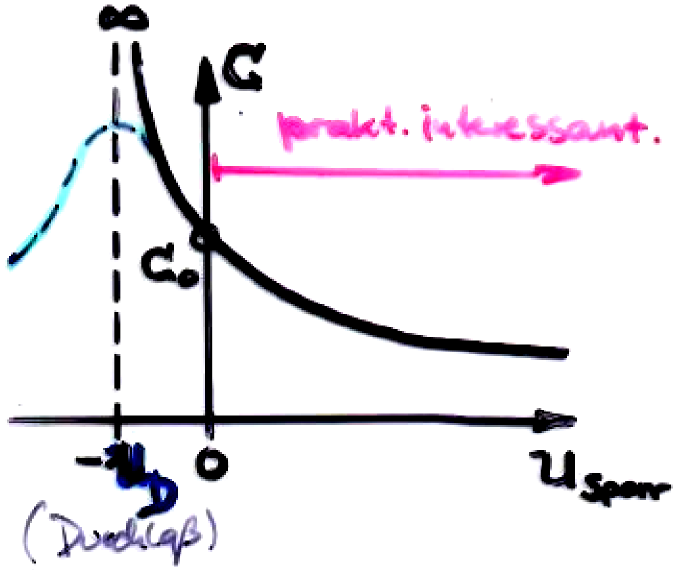
dann: $U_A = f(U_E, \gamma)$-Kennlinie

SPERRSCHICHTKAPAZITÄT

pn-Übergang



$d = f(U_{sperr})$



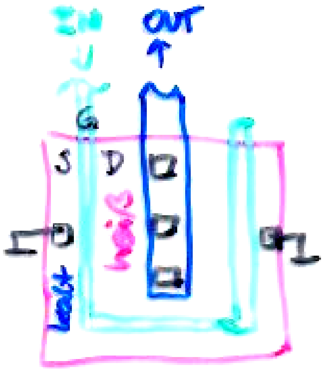
$$C = \frac{C_0}{\sqrt[3..4]{1 + \frac{U_{sperr}}{U_D}}}$$

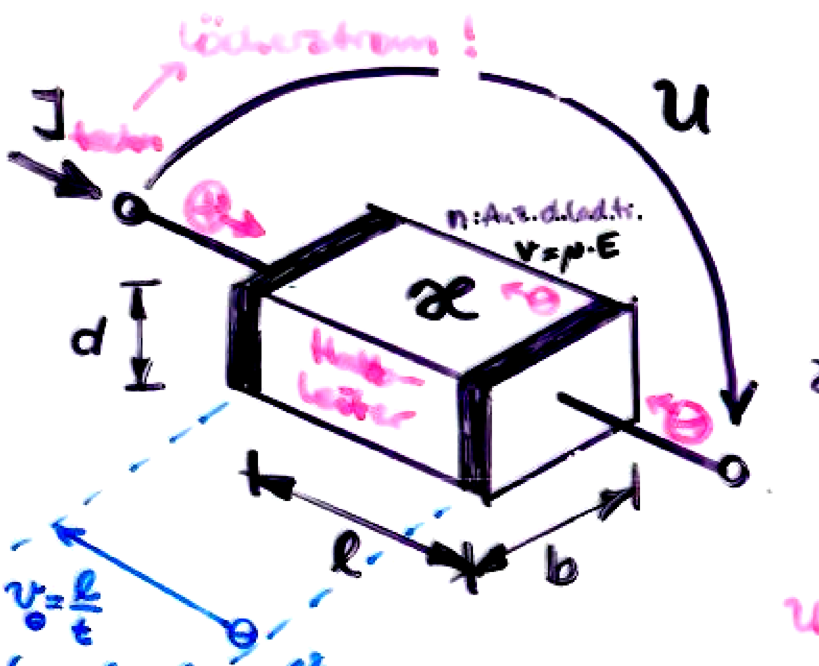
mit:

$C_0 = C'' \cdot A$ (Kanten vernachl.)

→ Randgebiete nicht auf Signalleitungen legen!

↳ Layoutgestaltung bei Padtreibern





$v_0 = \frac{l}{t}$

$t = \frac{l}{v} = \frac{l}{\mu E} = \frac{l^2}{\mu U_{DS}} = \tau$ (Transitzeit) ; $\mu = 270 \frac{cm^2}{Vs}$

$I \sim U$

$I_{DS} = e\mu n d \frac{b}{l} U_{DS}$

$\varkappa = e\mu n$

$n, d = f(U_{GS}, U_{GB})$ (Steuerbar)

$\frac{b}{l}$: Stat. Dimensionierg.

μ_B Si: $30000 \frac{cm^2}{Vs}$

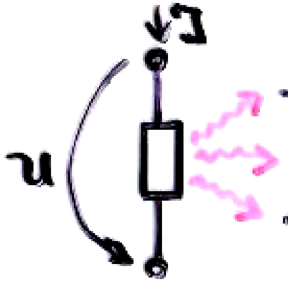
GaInAs: $450000 \frac{cm^2}{Vs}$

$\mu = \frac{v}{E}$ $\left[\frac{m/s}{V/m} = \frac{m^2}{Vs}\right]$

$E = \frac{U}{d}$ $\left[\frac{V}{m}\right]$

Grundglgn:

$R = \frac{U}{I}$ $\left(r = \frac{\Delta U}{\Delta I}\right)$



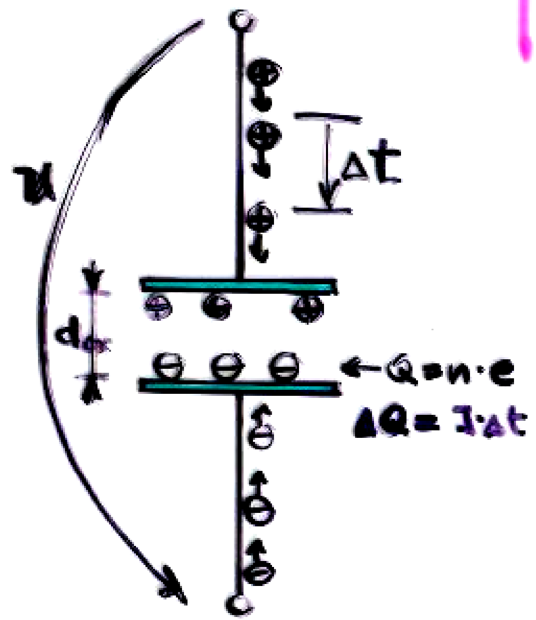
Leistung:
$P = U \cdot I$

$W = P \cdot t$!

Energie: $I = Q \cdot T$

$W = \ldots = U \cdot Q \cdot \ldots t^2$ mit $Q = e$ (Elementarladung) folgt $W = e \cdot U$ (Elektronen-energie)

$n \cdot e$



$$\boxed{\frac{\Delta U}{\Delta t} = \frac{\Delta Q / \Delta t}{C} = \frac{I}{C}}$$

$$\frac{\Delta Q}{\Delta U} = C_{onst} = C$$

$$E = \int Q \, dU = \int C U \, dU$$

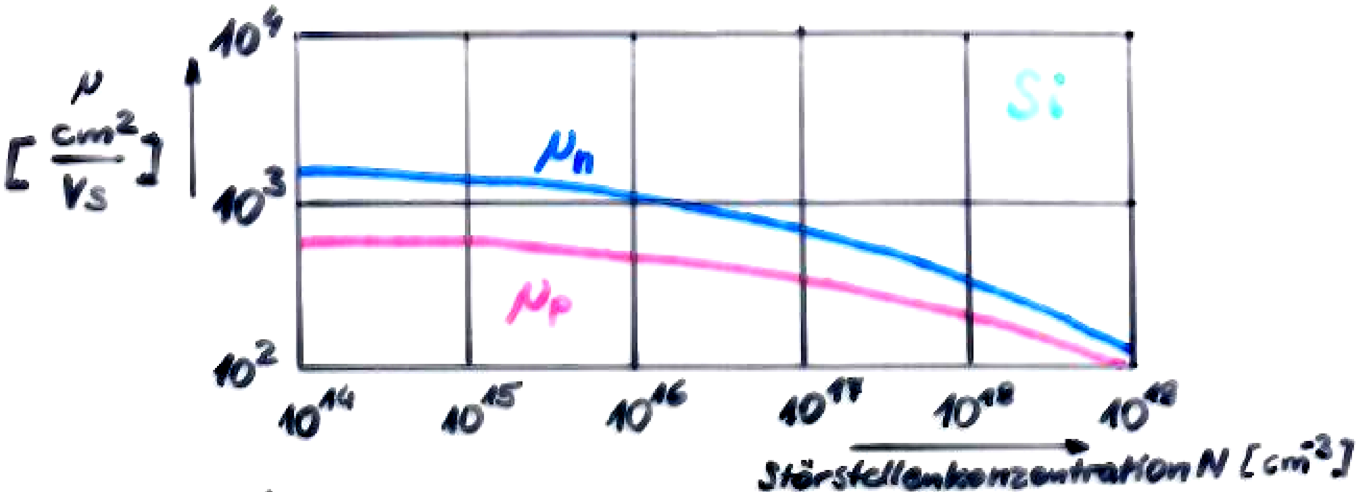
$$\underbrace{C \sim \frac{1}{d_{ox}} \quad C \sim A}$$

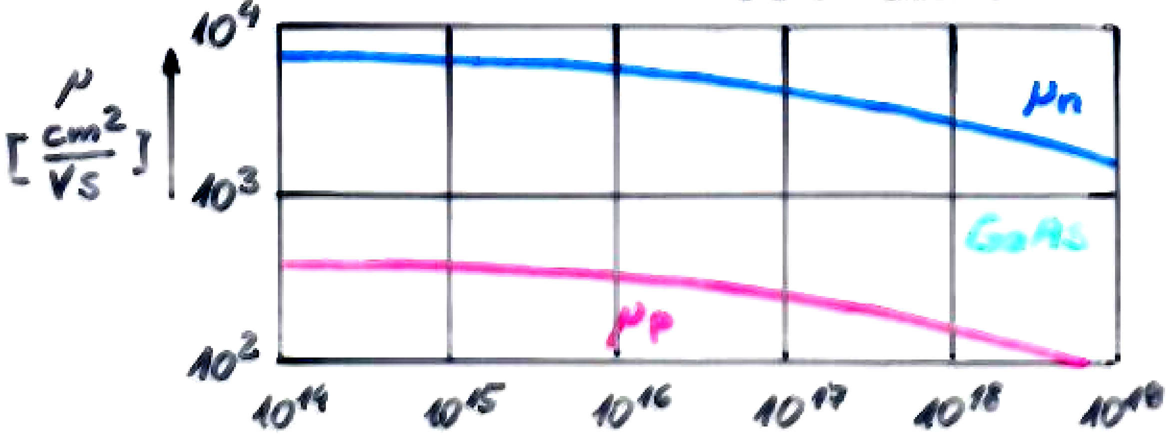
$$C' = \varepsilon_{ox} \frac{A}{d_{ox}}$$

$$C' [pF] = C'' \left[\frac{pF}{mm^2}\right] \cdot A [mm^2]$$

[Quelle: Mösch; "HL-Elektronik-Wissensspeicher" S. 35-36]

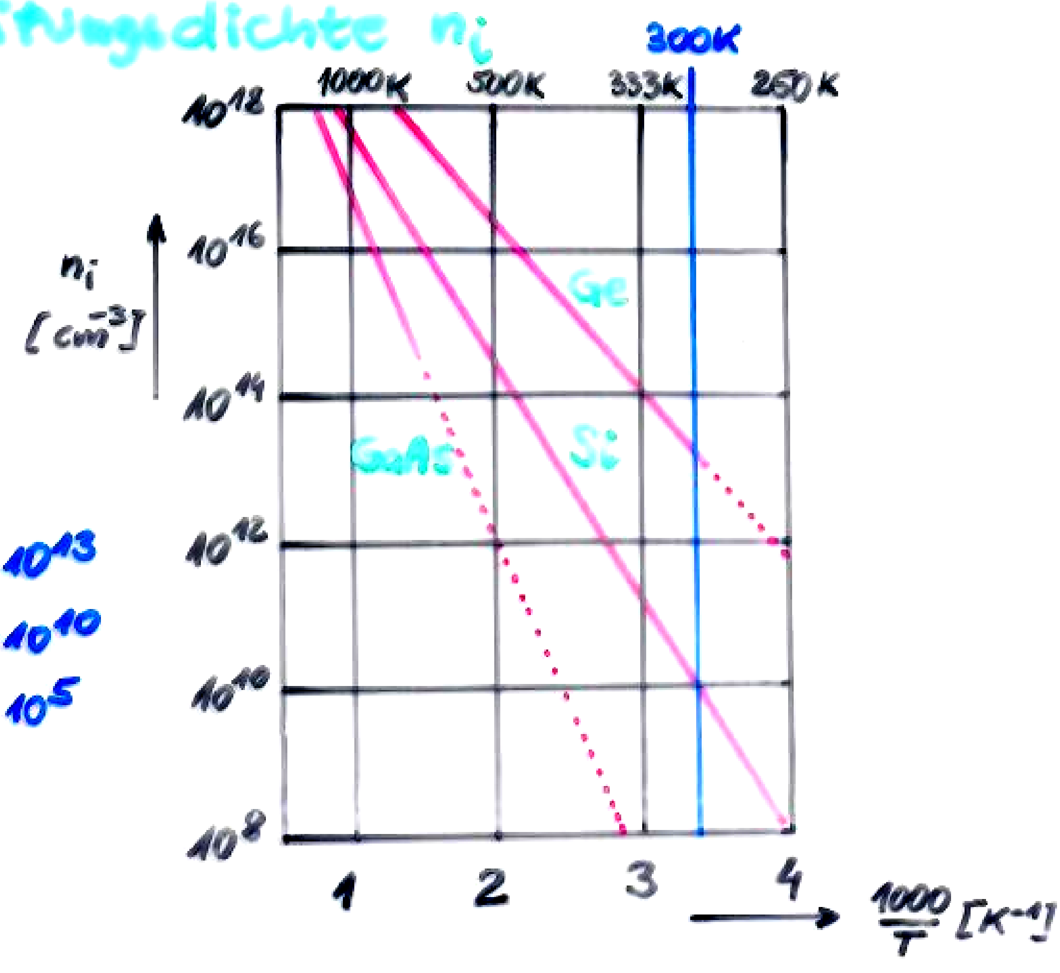
Beweglichkeit μ → R_0





Eigenleitungsdichte n_i

↳ C_{n+p}



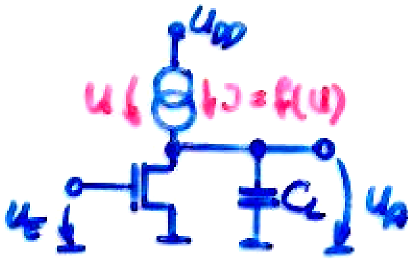
300K:

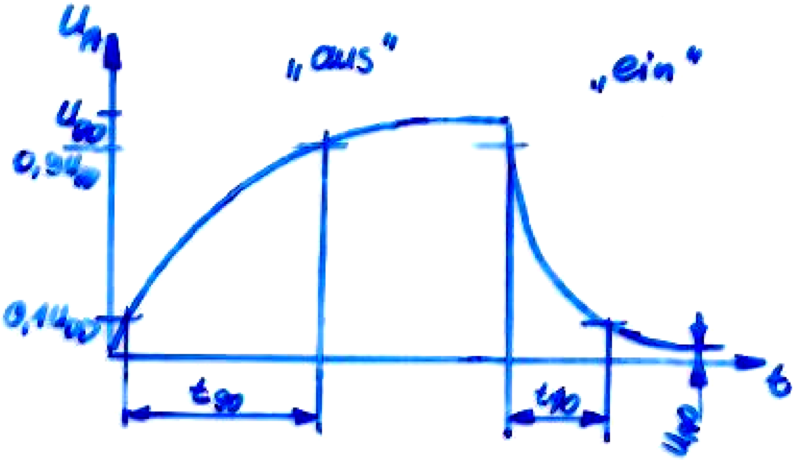
$n_{i\,Ge} = 2 \cdot 10^{13}$

$n_{i\,Si} = 1{,}45 \cdot 10^{10}$

$n_{i\,GaAs} = 5 \cdot 10^{5}$

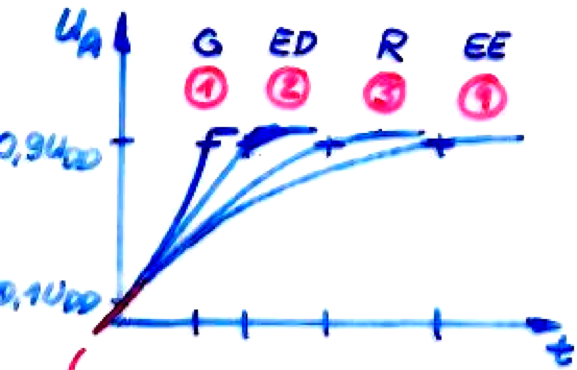
Verzögerungszeiten:





„Einschalten:" $t_{10}/ns \approx 30 \cdot \frac{C_L/pF}{(\frac{b}{l})_{Schalt}}$

„ausschalten:"



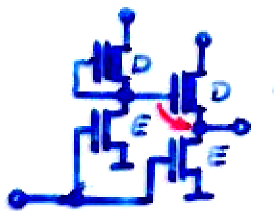
$\frac{dU_A}{dt}\Big|_{t=0} = \frac{(\frac{b}{l})_{Last}}{C_L} \cdot J_{DD}$

unabhängig von ①...④.

① $J \sim \sqrt{U}$ (Gegentakttreiber)

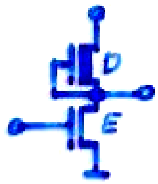
$t_{90}/ns \approx 59 \frac{C_L/pF}{(\frac{b}{l})_{Last}}$

(t_{10} auch kürzer)



② $J \approx$ konst. (Depl. Last)

$t_{90}/ns \approx 65 \frac{C_L/pF}{(\frac{b}{l})_{Last}}$

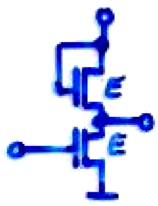


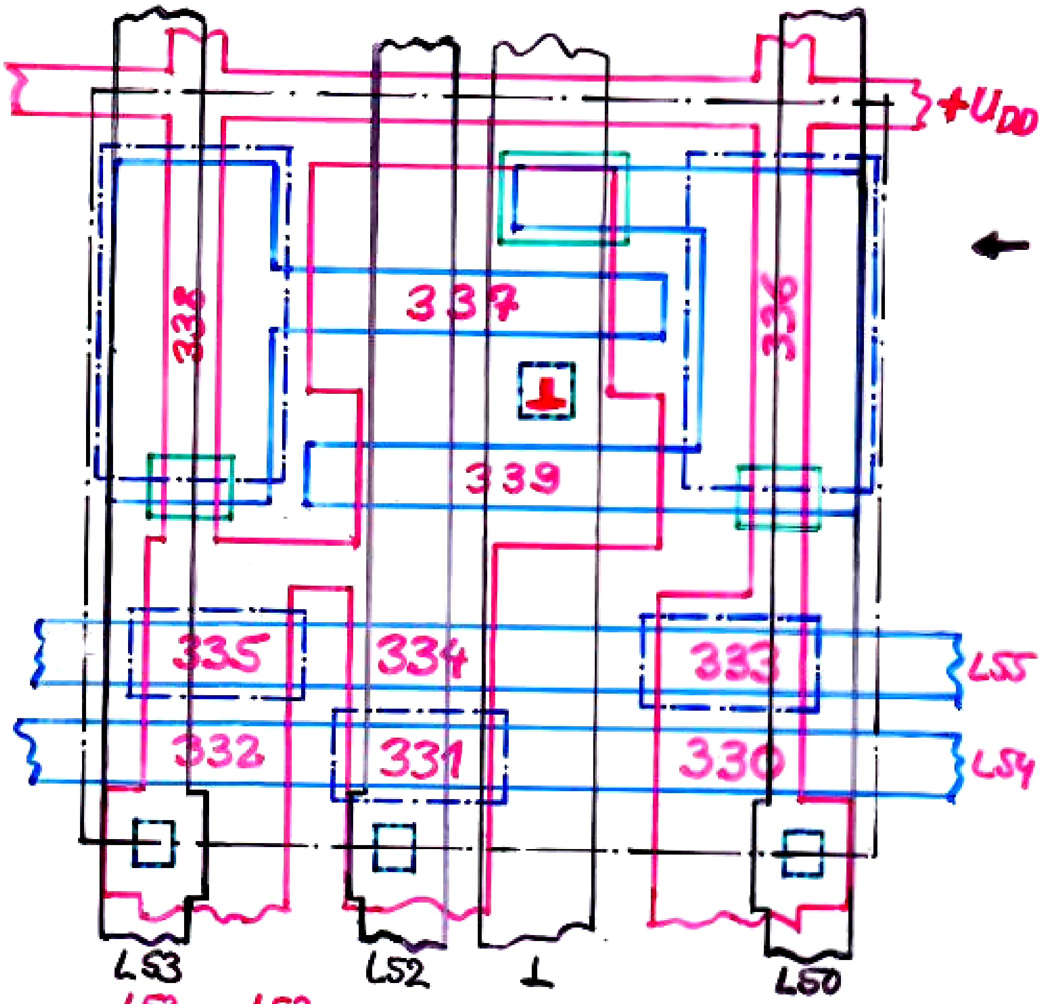
③ $J \sim U$ (ohmsche Last; Enh. Last mit $U_{GS} \gg U_{DD}$)

(praktisch nicht)

④ $J \sim U^2$ (Enhanc. Last)

$t_{90}/ns \approx 280 \frac{C_L/pF}{(\frac{b}{l})_{Last}}$

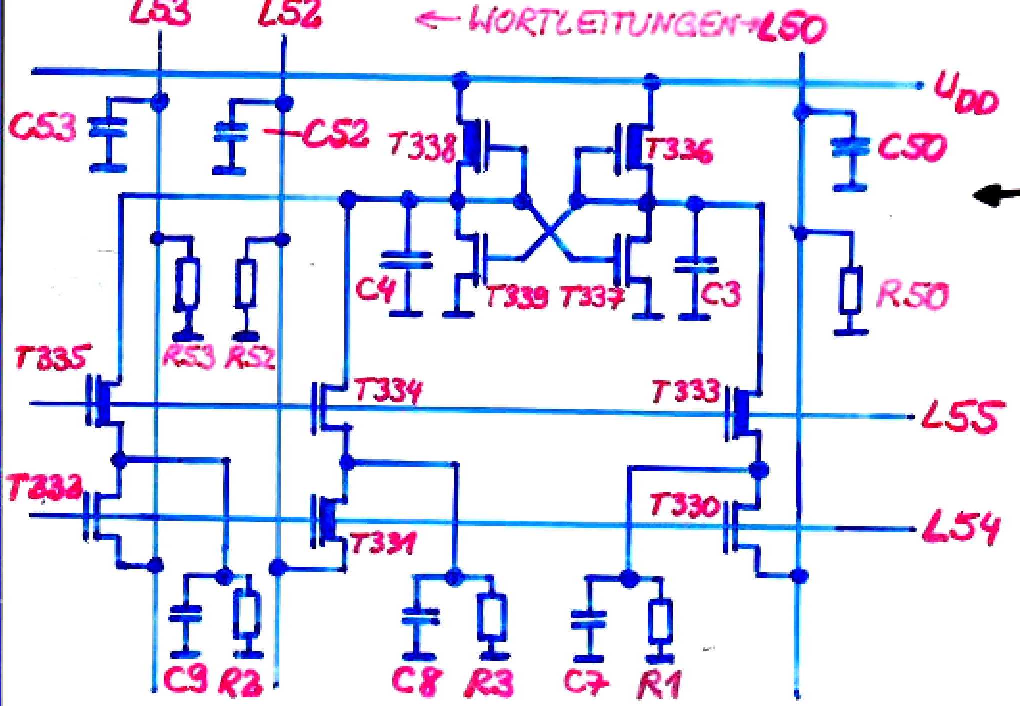




← Layoutentwurf auf Millimeterpapier oder M.-folie
Maßstab 1000 : 1

Tr.	b/L	C	pF
330	4	C3	0,3
331	4	C4	0,34
332	4	C7	0,024
333	4	C8	0,024
334	4	C9	0,024
335	4	C50	0,364 Alu
336	10	C52	
337	10	C53	
338	10		
339	10		

alle R: 10



← Simulationsmodell (NWA) der Speicherzelle

Adr. eingänge

STANDNET-BEISPIEL