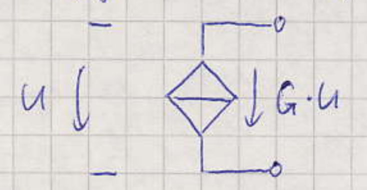
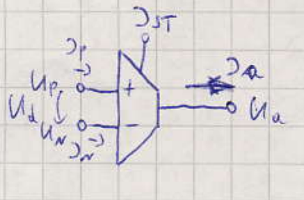
Spannungsgesteuerte Stromquellen

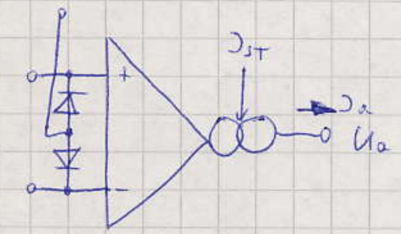


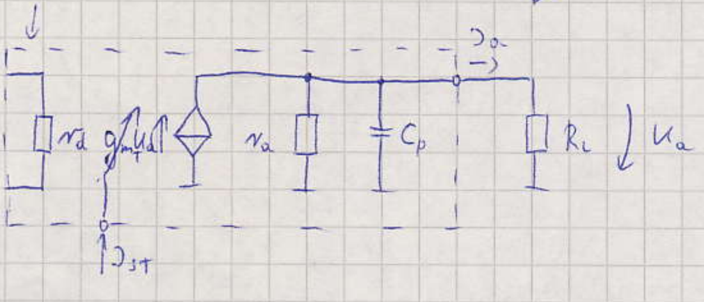
G... Übertragungsleitwert

Transkonduktanzverstärker (OTA)

Symbol, Prinzip



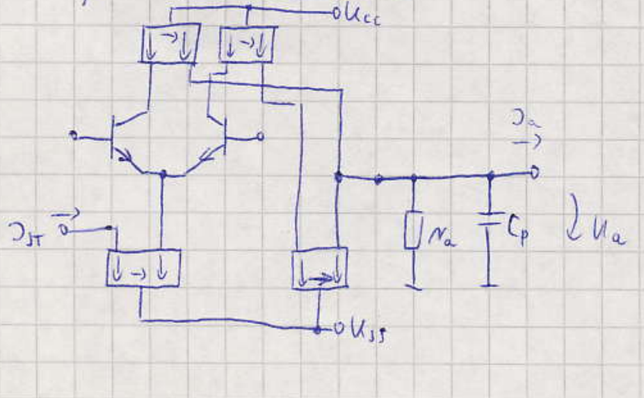




$$\frac{\underline{I}_a}{\underline{U}_d} = \frac{g_{mT}}{1+R_L/r_a} \cdot \frac{1}{1+sC_p(R_L \| r_a)}$$

- Einstellung der Steilheit g_{mT} durch Steuerstrom I_{ST}
- hoher Ausgangswiderstand r_a
- niederfrequenter dominanter Pol bei $\omega = \frac{1}{C_p(r_a \| R_L)}$

prinzipieller Aufbau



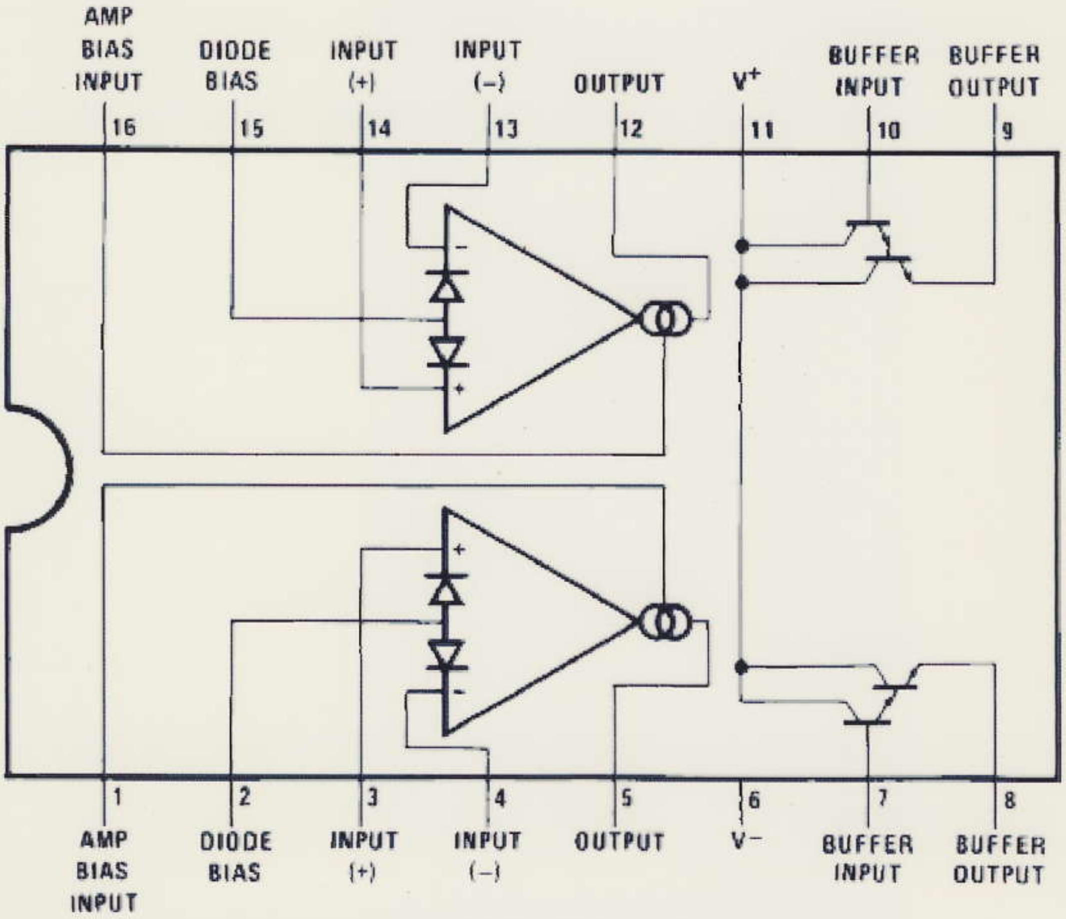
r_a... Ausgangswiderstand der Stromspiegel

C_p... parasitäre Kapazität

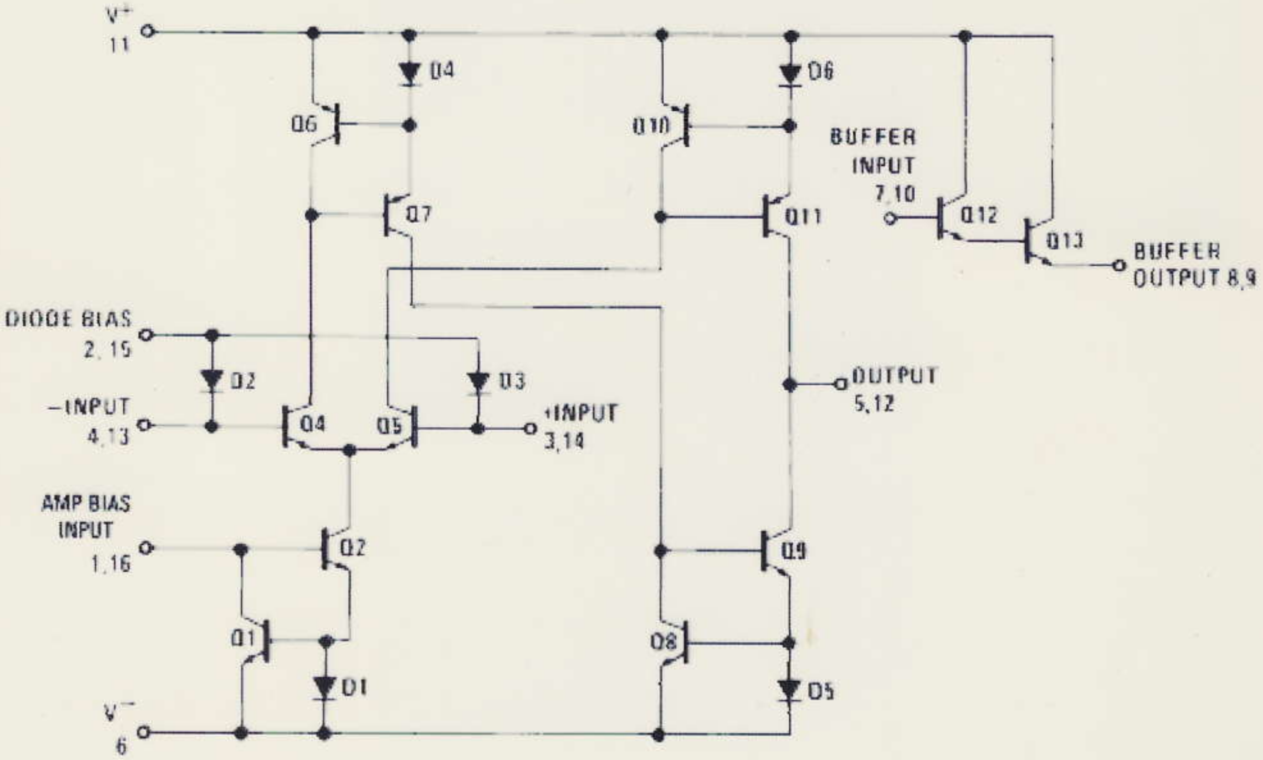
- stark nichtlinear wegen der Differenzstufe am Eingang

$\boxed{\text{Folie LM13700}}$

Pinout LM13700



Innnenschaltung eines Transkonduktanzverstärkers



Kleinsignalverhalten

a) Differenz - Eingangswiderstand r_d

$$r_d = 2 r_{BE} = \frac{2U_T}{I_{DA}} = \frac{4BU_T}{I_{ST}} \sim \frac{1}{I_{ST}} = \frac{K_{rd}}{I_{ST}}$$

b) Steilheit g_{mT}

$$g_{mT} = \frac{i_a}{u_d} = \frac{I_{C1,2}}{U_T} = \frac{I_{ST}}{2U_T} = \frac{I_{ST}}{K_{gm}} \sim I_{ST}$$

c) Ausgangswiderstand r_a

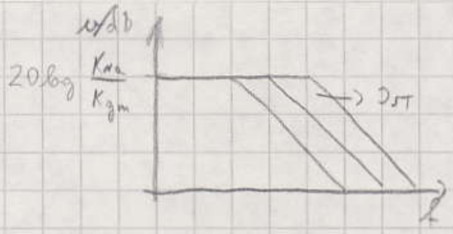
$$r_a = r_{a,SP1} \parallel r_{a,SP2} = \frac{U_{Y,SP1}}{I_{ST}/2} \parallel \frac{U_{Y,SP2}}{I_{ST}/2} = \frac{U_{Y,SP}}{I_{ST}} = \frac{K_{ra}}{I_{ST}} \sim \frac{1}{I_{ST}}$$

d) Leerlaufverstärkung $\underline{v}_e$ (Bei Nutzung als Verstärker, $R_L \to \infty$)

2. Pol an Eingang der SS

$$\underline{v}_e = g_{mT} \frac{r_a}{1+sCr_a} \quad \left(\cdot \frac{1}{1+sT_{\infty 2}} \right)$$

$$\underline{v}_e = \frac{K_{ra}}{K_{gm}} \cdot \frac{1}{1+sC\frac{K_{ra}}{I_{ST}}} \qquad ; \quad T_{\infty 1} \approx \frac{1}{I_{ST}}$$



Folie LM13700 g_{mT}, r_a, r_d

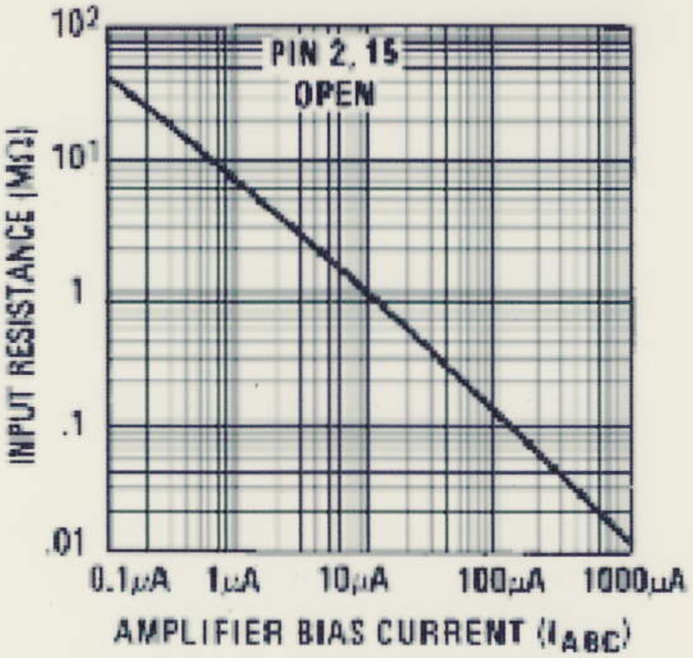
Beispiel LM13700

aus output resistance $\to K_{ra} = I_{ST} \cdot r_a = 1{,}5\,\mathrm{k\Omega \cdot A}$
aus transconductance $\to K_{g_{mT}} = I_{ST} / g_{mT} = 0{,}05\,\mathrm{A/S}$

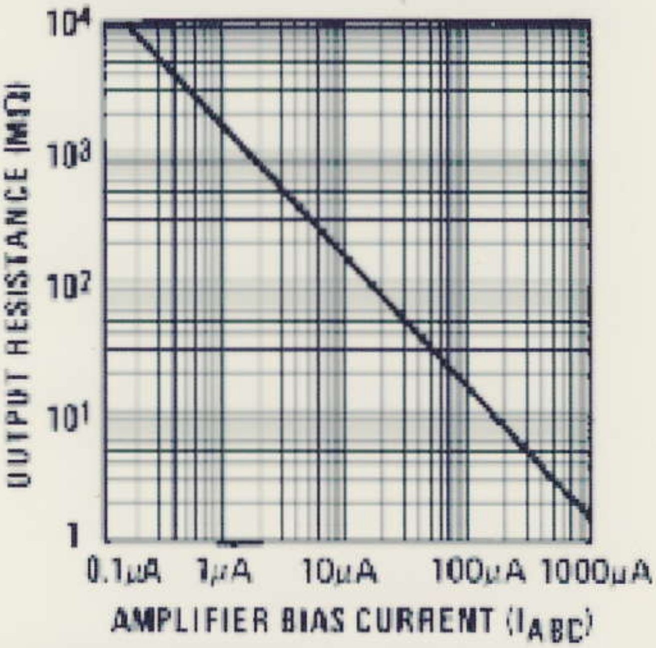
$$v_0 = \frac{K_{ra}}{K_{gm}} = \frac{1500}{0{,}05} = 30000 \mathrel{\hat{=}} 89{,}5\,\mathrm{dB}$$

$C = 5\,\mathrm{pF}$ (Kapazität der Anschlüsse)

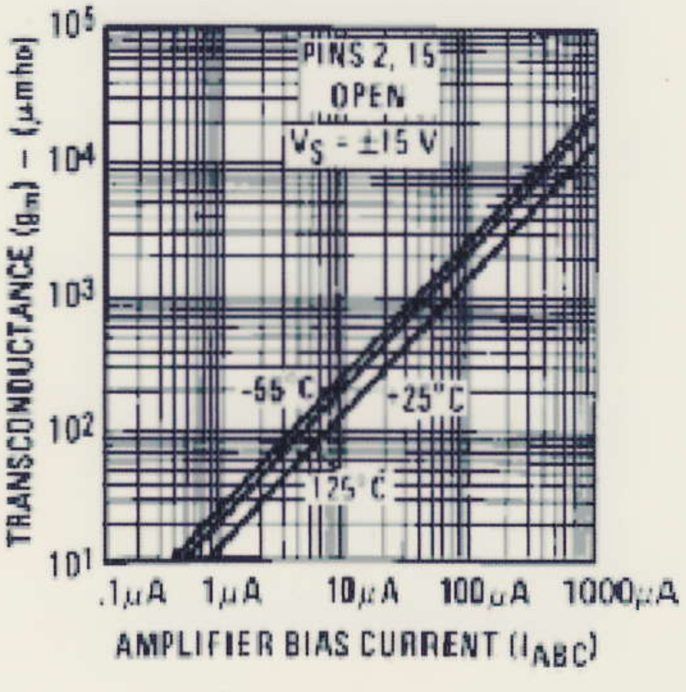
$$\to f_{\infty 1}\Big|_{I_{ST}=0{,}5\,mA} = \frac{\overset{I_{ST}}{0{,}5\,mA}}{2\pi \cdot 5\,pF \cdot \underset{K_{ra}}{1500\,V}} = 10{,}6\,kHz$$



PIN 2, 15
OPEN
INPUT RESISTANCE (MΩ)
10^2
10^1
1
.1
.01
0.1μA
1μA
10μA
100μA
1000μA
AMPLIFIER BIAS CURRENT (I_{ABC})



OUTPUT RESISTANCE (MΩ)
10^4
10^3
10^2
10^1
1
0.1μA
1μA
10μA
100μA
1000μA
AMPLIFIER BIAS CURRENT (I_{ABC})



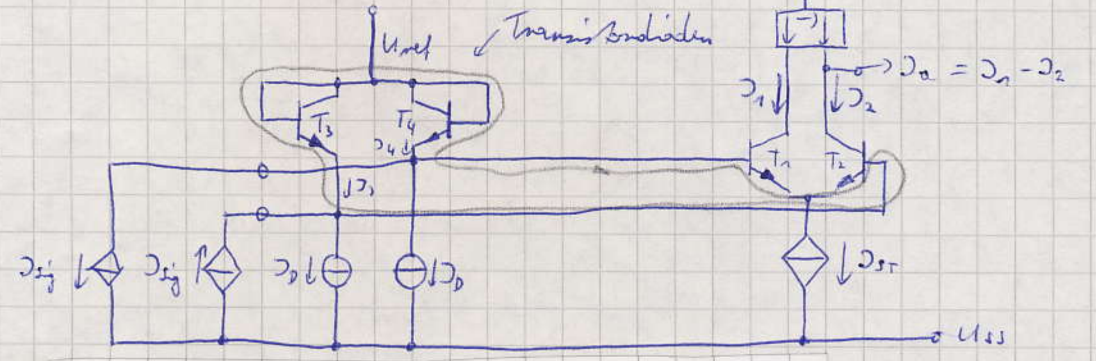
PINS 2, 15
OPEN
V_S = ±15 V
-55°C
-25°C
125°C
TRANSCONDUCTANCE (g_m) – (μmho)
10^5
10^4
10^3
10^2
10^1
.1μA
1μA
10μA
100μA
1000μA
AMPLIFIER BIAS CURRENT (I_{ABC})

Großsignalverhalten

- Transferkennlinie dominant durch Differenzstufe bestimmt

$I_a = I_0 \tanh \frac{U_d}{2U_T}$ → $\boxed{\text{Folie}}$ ne

Linearisierung:



UI-am Transistor: $U_{BE} = U_T \ln\left(\frac{I_C}{I_S}\right)$,

$I_1 + I_2 = I_{ST}$

$I_3 = I_D - I_{sig}$ $\qquad$ $I_4 = I_D + I_{sig}$

$U_{BE4} + U_{BE1} = U_{BE2} + U_{BE3}$ → translineare Maschen, siehe integrierte Analogschaltungen

$\ln \frac{I_4}{I_S} + \ln \frac{I_1}{I_S} = \ln \frac{I_2}{I_S} + \ln \frac{I_3}{I_S}$

$I_4 \cdot I_1 = I_2 \cdot I_3$ $\qquad$ $I_2 = \frac{I_4}{I_3 + I_4} \cdot I_{St} =$

$I_4 (I_{ST} - I_2) = I_2 \cdot I_3$ $\qquad$ → $I_2 = \frac{I_4}{2I_D} \cdot I_{ST}$

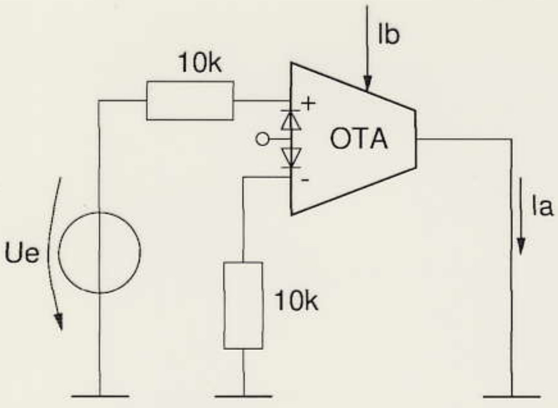
$I_4 I_1 = (I_{ST} - I_1) I_3$ $\qquad$ → $I_1 = \frac{I_3}{2I_D} \cdot I_{ST}$

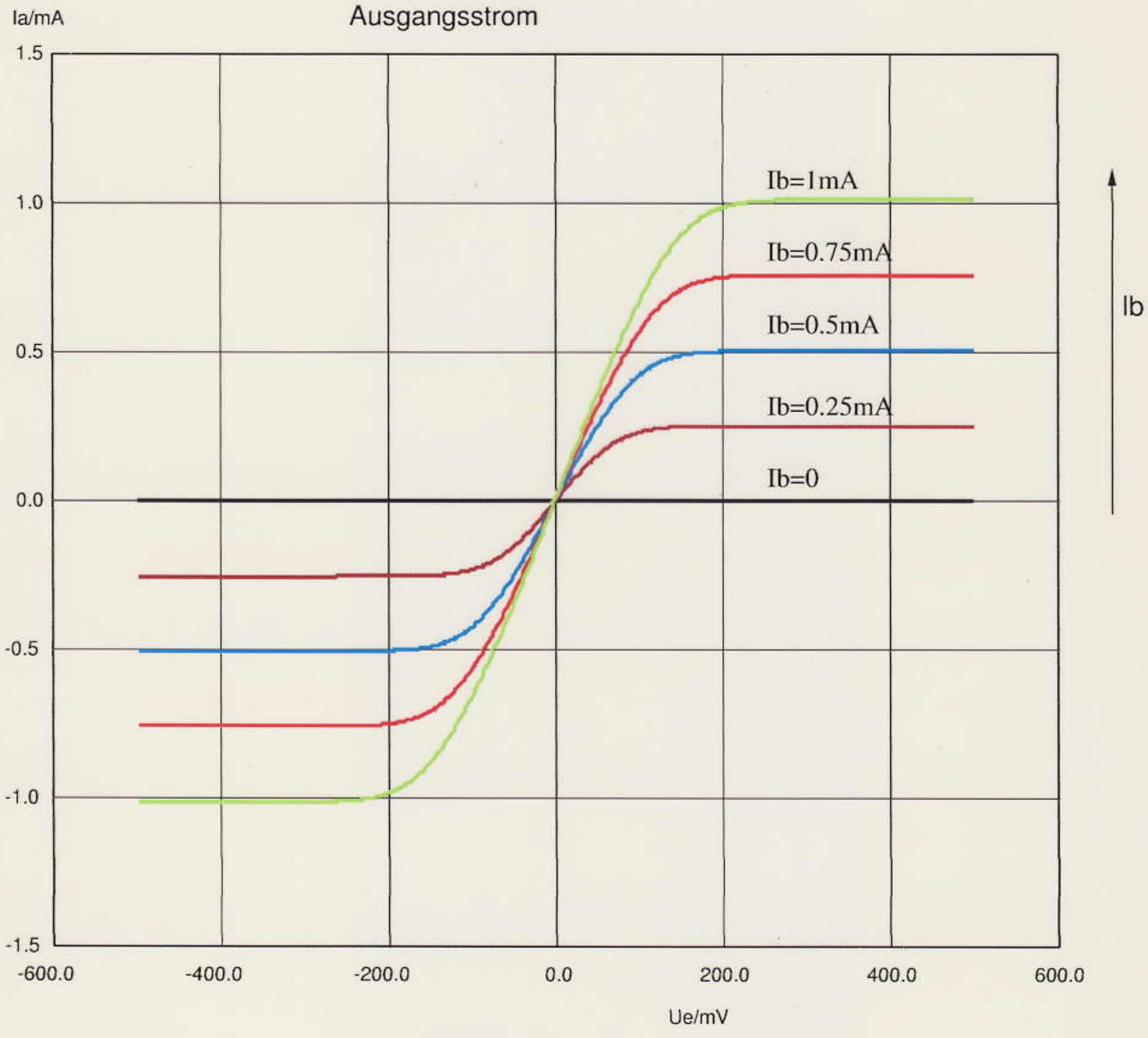
$I_a = I_1 - I_2 = -\overbrace{\frac{I_{ST}}{I_D}}^{v_i'} \cdot I_{sig}$ $\qquad$ $I_a = \frac{I_3 - I_4}{2I_D} \cdot I_{St}$

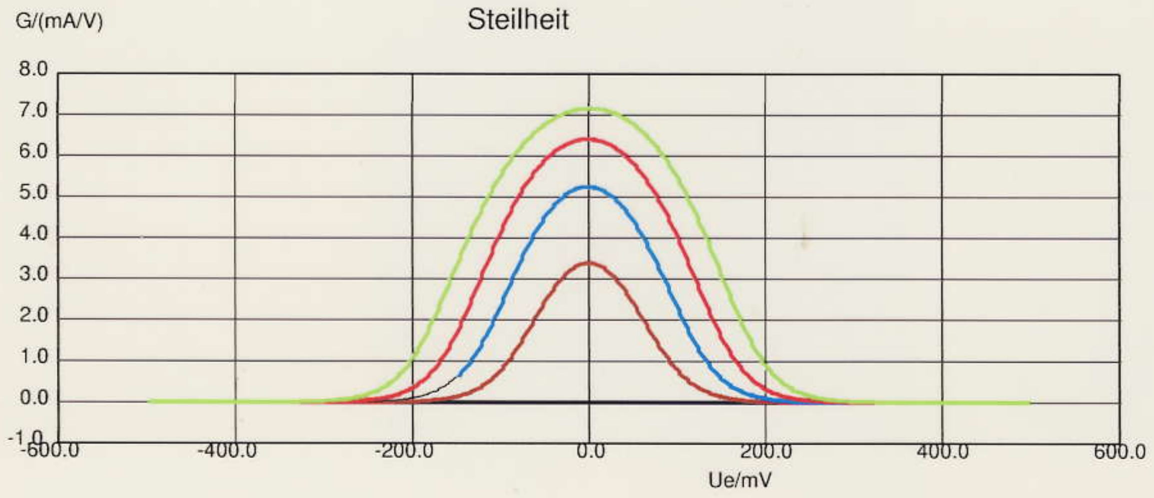
↳ Stromtechnik

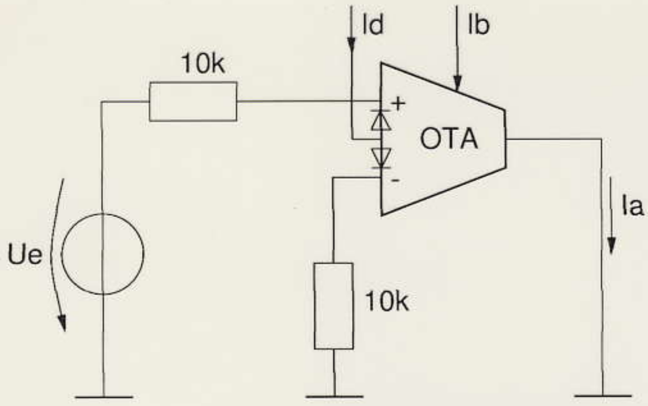
- $I_A \neq f(T)$
- linear für $|I_{sig}| < I_D$ (→ Großsignal!)
- bei Spannungseingang U-I-Wandler erforderlich (im einfachsten Fall, Widerstand)

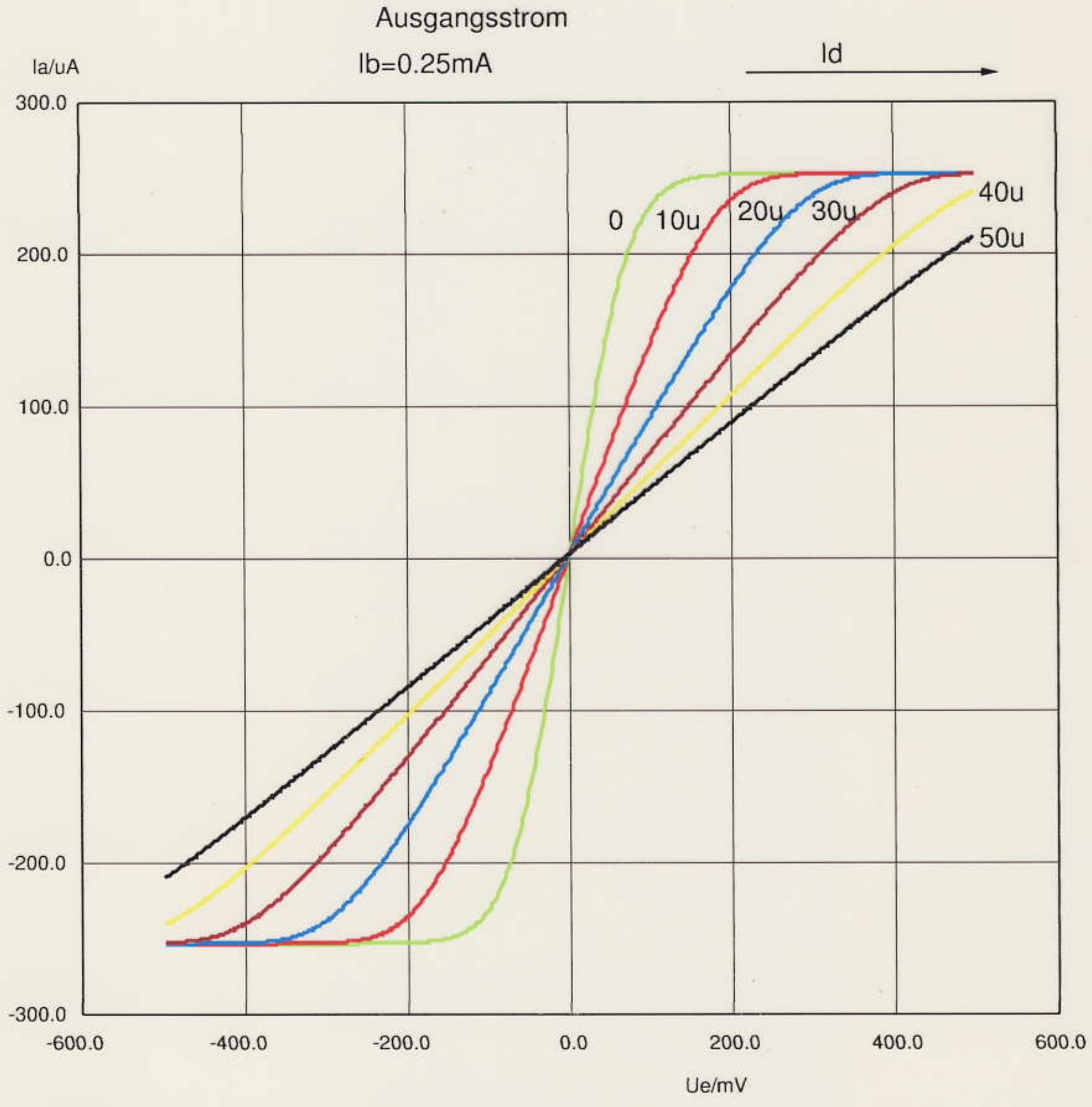
↳ $\boxed{\text{Folie } i_D}$



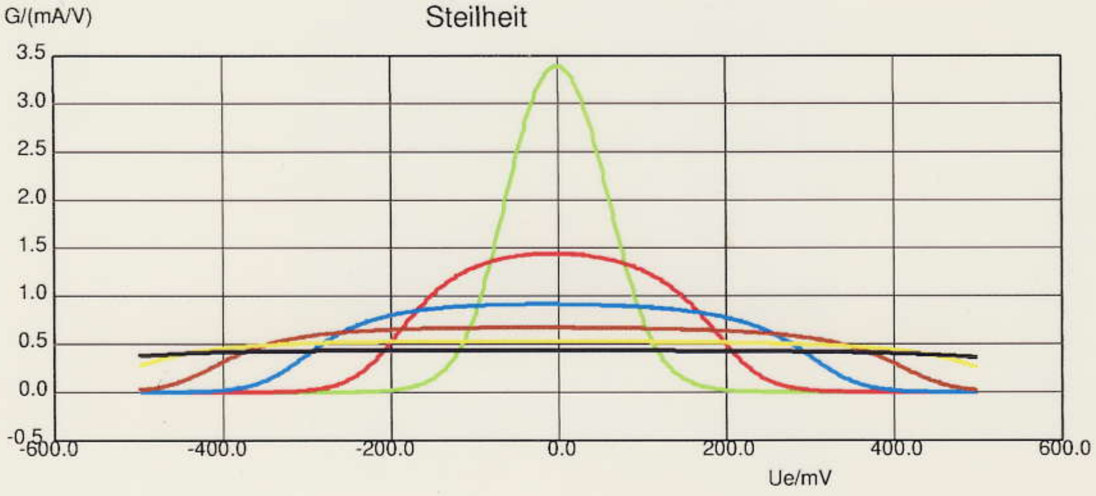

Ausgangsstrom


Steilheit



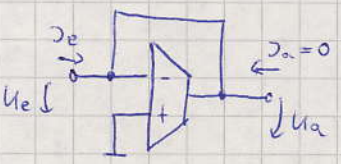

Ausgangsstrom

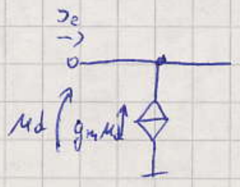
Ib=0.25mA


Steilheit

Anwendungen

a) I-U-Wandler, gesteuerter Widerstand

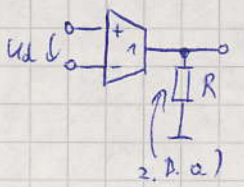




$$I_e = -g_m u_d = g_m U_e \quad \rightarrow U_a = U_e = \frac{1}{g_m} I_e$$

$$R = \frac{U_a}{I_e} = \frac{1}{\overset{\nearrow}{g_m}}$$

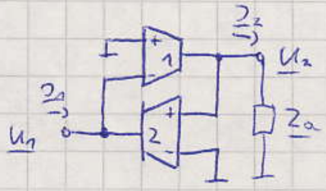
b) Spannungsverstärker



$$U_a = \overset{\nearrow}{g_m} U_d R$$

mit 2. OTA: $U_a = \frac{\overset{\nearrow}{g_{m1}}}{\overset{\nearrow}{g_{m2}}} U_d$
(a))

c) Gyrator

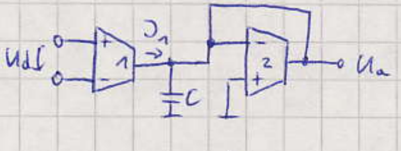


$$\underline{I}_1 = -g_{m2}\underline{U}_2$$

$$\underline{I}_2 = -g_{m1}\underline{U}_1 \quad \rightarrow \underline{U}_2 = -g_{m1}\underline{Z}_a\underline{U}_1$$

$$\underline{Z}_e = \frac{1}{g_{m1}g_{m2}\underline{Z}_a}$$

d) Filter 1. Ordnung



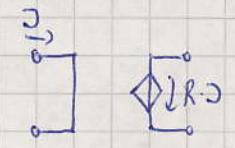
$$\underline{U}_a = \underline{I}_1 \cdot \frac{1}{g_{m2} + sC} = \underline{U}_d \frac{g_{m1}}{g_{m2} + sC}$$

$$\underline{U}_a = \frac{g_{m1}}{g_{m2}} \frac{1}{1 + s\frac{C}{g_{m2}}} \cdot \underline{U}_d \quad , \omega_g = \frac{g_{m2}}{C}$$

→ OTA-C-Filter

24.5.05

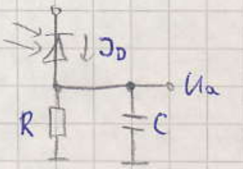
Stromgesteuerte Spannungsquellen



R - Übertragungswiderstand

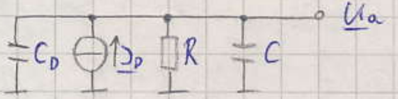
Motivation

Optische Datenübertragung, Empfänger mit Fotodiode



- sehr kleiner J_D, ≈ 10 µA/lx

KS-ESB

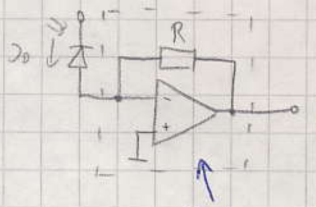


$$\omega_g = \frac{1}{R(C+C_D)} = \frac{J_{DA}}{U_{aA}(C+C_D)}$$

Bsp. $J_{DA} = 10\mu A$, $U_{aA} = 1V$, $C = 15pF$, $C_D = 10pF$

$\to f_g = 64\,kHz$

↳ Problem: Umladestrom der Kapazitäten
Abhilfe: U_a = konst., J_a ist Signal

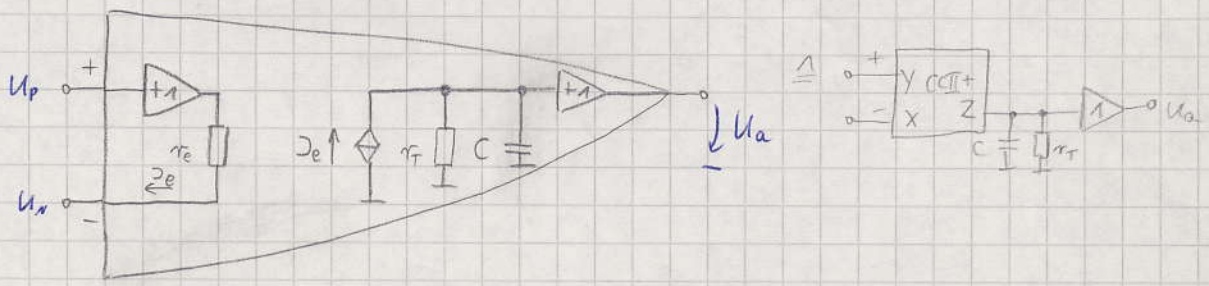


$U_a = -J_D \cdot R$, U_D = konst.

Transimpedanzverstärker (TIA)

Transimpedanzverstärker

Modell



$$\underline{U_a} = \frac{r_T}{1+sCr_T} \cdot \underline{J_E}$$

r_T: Transimpedanz (sehr hoch, z.B. 200 MΩ)

$$\underline{J_E} = \frac{U_P - U_N}{r_e} = \frac{U_d}{r_e}$$

r_e: Eingangsimpedanz (sehr klein, 50 Ω)