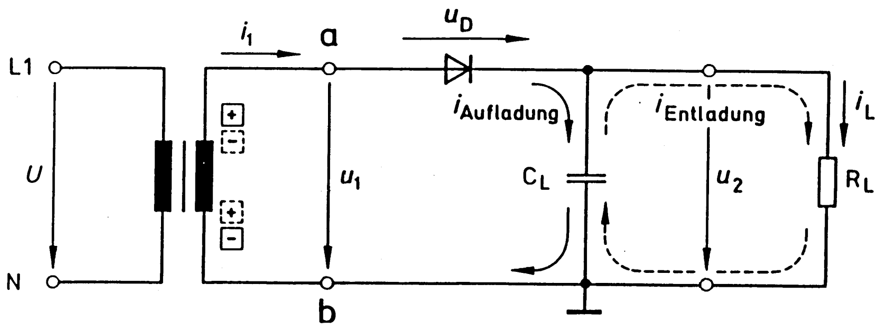
Formelsammlung

$$R_{th\,JU}=\frac{\vartheta_J-\vartheta_U}{P_V}$$ ϑ_J *Temperatur Sperrschicht* ϑ_U *Temperatur Umgebung* $$R_{th\,JU}=R_{th\,JG}+R_{th\,GK}+R_{th\,K}$$

Einweggleichrichter



$C_L=10\,\mu F*[I_L]$

$U_{2-}=\sqrt{2}*U_1-U_{Diode}(\approx 0{,}6\,V \text{ im } Leerlauf)$

$U_{2-}=1{,}2*U_1$ *Belastungsfall*

$I_{FM}\geq 1{,}5....5*J_L$

$U_{RM}=2*\sqrt{2}*U_1(Ungünstigster\ Fall=Leerlauf)$

$U_{RM}=3*\sqrt{2}*U_1(praktisch\ sinnvolle\ Auswahl)$

$Laststrom\ I_{L-}=\frac{U_{2-}}{R_{L\,min}}$

$Trafoübersetzung\ Ü=\frac{U_{Primär}}{U_{Sekundär}}=\frac{230\text{V}}{U_1}$

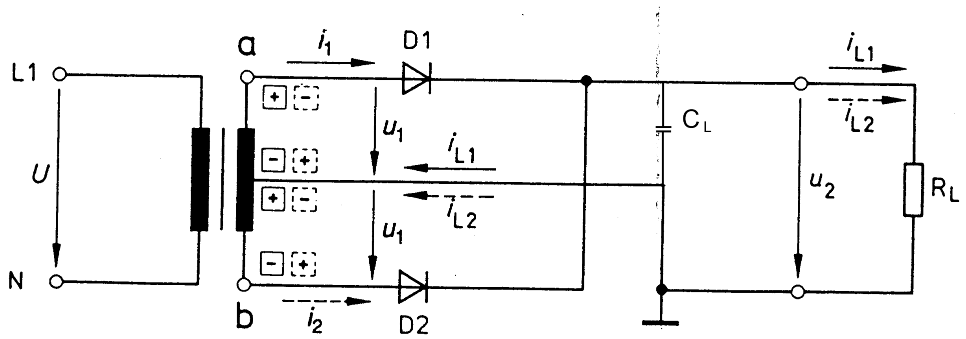
$U_e=2...4\text{x}\ U_a$ $\quad$ *prakt.* 2x

$U_{Breff}=4{,}8*10^{-3}*s*\frac{I_{L-}}{C_L}$

$U_{BrSS}-=14*10^{-3}*s*\frac{I_{L-}}{C_L}$

$W_-=\frac{U_{Breff}}{U_L}-$

Zweipols-Mittelpunkt-Schaltung (M2U)



$U_{2-}=\sqrt{2}*U_1-U_F$

$I_{FM}\geq 0{,}72*I_{L-}$

$U_{RM}\geq 3*\sqrt{2}*U_1$

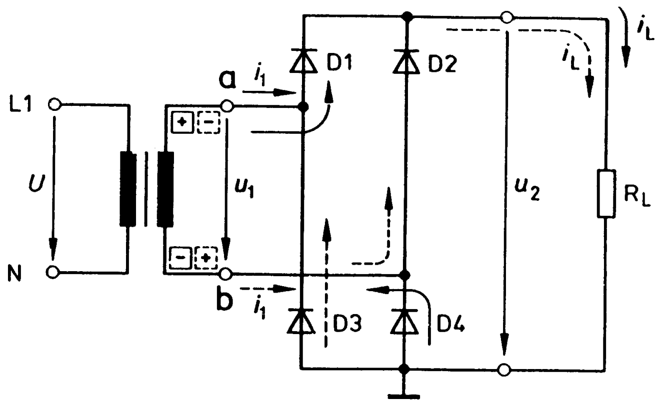
$U_{2-}\approx 1{,}3*U_1$

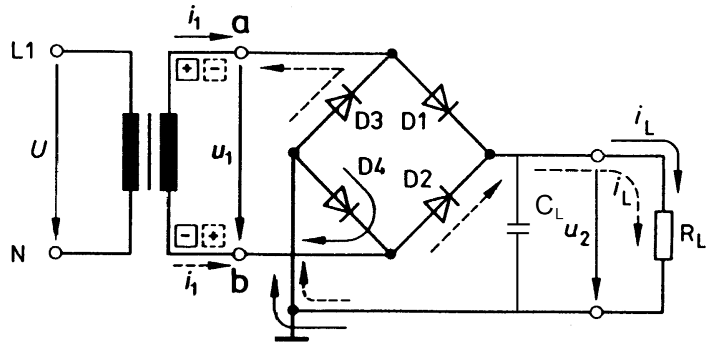
$U_{Breff}=1{,}8*10^{-3}*s*\frac{I_{L-}}{C_L}$

$U_{BrSS}-=7*10^{-3}*s*\frac{I_{L-}}{C_L}$

Brückengleichrichter = „Grätzbrücke“

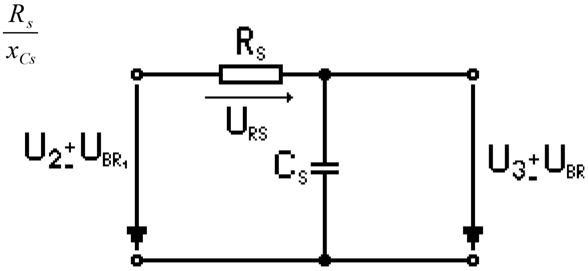
$$U_{2-leer}=\sqrt{2}*U_1-2*U_F$$
$$U_{2-}=1{,}3*U_1$$
$$I_{FM}\geq 0{,}72*I_{L-}(an\,den\,Dioden)$$
$$U_{RM}\geq 1{,}5*\sqrt{2}*U_1(an\,den\,Dioden)$$
$$U_{Breff}=1{,}8*10^{-3}*s*\frac{I_{L-}}{C_L}$$
$$U_{BrSS}=7*10^{-3}*s*\frac{I_{L-}}{C_L}$$





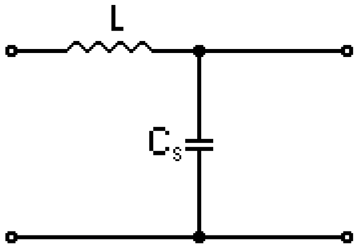
RC-Siebung

$$\frac{U_{Br1}}{\sqrt{R_S^2+x_{Cs}^2}}=\frac{U_{Br2}}{x_{Cs}} \qquad Vorraussetzung: R_s\gg x_{Cs}\rightarrow G\approx\frac{R_s}{x_{Cs}}$$
$$\frac{U_{Br1}}{U_{Br2}}=G-Glättungsfaktor \qquad x_{Cs}=\frac{1}{2\pi*f_{Br}*C_s}$$
$$G=2\pi*f_{Br}*C_s*R_s$$
$$G=\sqrt{(\frac{R_s}{x_{cs}})^2+1} \qquad G\,sinnvoll\,zwischen\,10-20$$
$$U_{Rs}\leq 0{,}1*U_2$$
$$U_{A-}=U_{2-}-U_{Rs} \qquad U_{Rs}=R_s*I_{L-}$$



LC-Siebung

$$G=\frac{x_L}{x_C}-1$$
$$x_L=2\pi*f_{Br}*L_s \qquad x_C=\frac{1}{2\pi*f_{Br}*C_s}$$
$$G=(2\pi*f_{Br})^2*L_s*C_s$$



Zehner-Diode

Fall 1: $U_E=konst.,\ J_L ist\ variabel$

ohne Last $\quad I_L=0 \quad R_V=\frac{U_E-U_Z}{I_Z}$

mit Last $\quad R_V=\frac{U_E-U_Z}{I_Z+I_L} \qquad P_{tot}=I_{Z\,Max}*U_Z$

Fall 3: $U_E\,und\,I_L\,variabel$

$$S-relativer\,Stabilisierungsfaktor$$

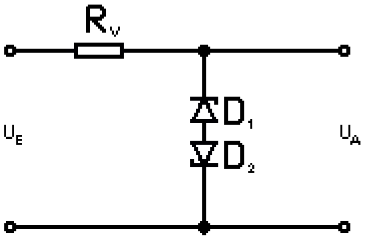
$$I_{Z\,min}=0{,}1*I_{Z\,max} \qquad R_{Vmax}=\frac{U_{E\,min}-U_Z}{I_{Z\,min}+I_{L\,max}} \qquad S=\left(1+\frac{R_V}{r_z}\right)*\frac{U_a}{U_e}$$

$$P_{Rv}=\frac{(U_{E\,max}-U_Z)^2}{R_V} \qquad R_{Vmin}=\frac{U_{E\,max}-U_Z}{I_{Z\,max}+I_{L\,min}} \qquad S_{min}=\left(1+\frac{R_V\,gew.\,min}{r_z}\right)*\frac{U_a}{U_{E\,max}}$$

a) Spannungsgrenzen mit Z-Dioden

$pos.\ HW \quad U_a = U_S + U_{Z2}$

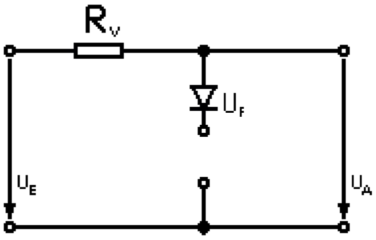
$neg.\ HW \quad U_a = U_S + U_{Z1}$



b) Spannungsbegrenzung mit einer Gegenspannung

$U_a = U_S + U_V$

$U_e > U_S + U_V$

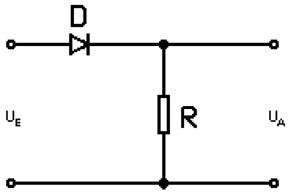


$U_a = U_R$

$U_e = U_{S1} + U_{SL} + U_R$

$U_e < 2 * U_S$

c)

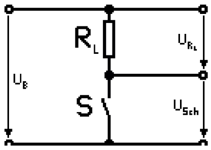


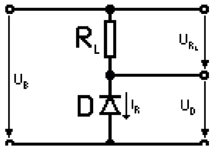
Diode als Schalter

offener Schalter:

$U_B = U_{Schalter}$

$U_{RL} = 0$





$U_{RL} = I_R * R_L$

$U_{Diode} = U_R \approx U_B$

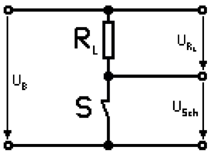
$Gefahr: U_B > U_R$

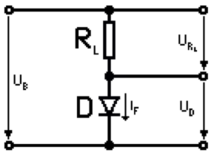
geschlossener Schalter:

$U_B = U_{RL}$

$U_{Schalter} = 0$

$I_{RL}\ zu\ beachten$





$U_{RL} = U_B - U_S$

$U_{Diode} = U_S$

$Gefahr: I_{RL} > I_F$

$Überbelastung\ Diode$

$P_{S\,max} = Schaltleistung\ der\ Diode = U_{RL} * I_{F\,max}$

$U_{RL} = U_B - U_S \qquad I_{F\,max} = \frac{P_{tot}}{U_S} \qquad \rightarrow P_{S\,max} = P_{tot}\left(\frac{U_B}{U_S} - 1\right) \qquad R_{L\,min} = \frac{(U_B - U_S)^2}{P_{S\,max}}$

Kapazitätsdioden

Verlustfaktor $\tan\delta = \frac{r_S}{X_C}$

$X_e = (2\pi f * C_D)^{-1}$

Güte $Q = \frac{1}{\tan\delta} = \frac{X_C}{r_S} = \frac{1}{2\pi f\, C_D r_S}$

Bipolartransistoren

$J_B\uparrow \rightarrow J_C\uparrow \qquad J_B=0 \rightarrow J_C=0$

$\text{Gleichstromverstärkung } B=\frac{J_C}{J_B}$ $\qquad$ $\text{Eingangswiderstand Transistor} \quad r_{BE}=h_{11e}=\frac{\Delta U_{BE}}{\Delta I_{BE}}$

$\text{bei } U_{CE}=\text{konst.}$ $\qquad$ $\text{Ausgangswiderstand Transistor} \quad r_{CE}=h_{22e}=\frac{\Delta I_C}{\Delta U_{CE}}=\frac{1}{r_{CE}}$

$\text{dynamische Gleichstromverstärkung } \beta=h_{21e}=\frac{\Delta I_C}{\Delta I_B}$ $\qquad$ $\text{Steilheit des Transistor} \quad S=y_{21}=\frac{\Delta U_{BE}}{\Delta I_{BE}}$

$P_V=U_{CE}*I_C \; \underbrace{(+U_{BE}*J_B)}_{\text{vernachlässigbar klein}}$

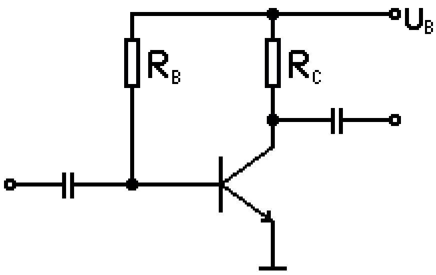
Bestimmung R_C

$U_{CE}\approx\frac{1}{2}U_B \qquad R_C=\frac{U_B-U_{CE(a)}}{J_{C(a)}}$

Erezegen der Basisvorspannung

- durch Basisvorwiderstand

$R_B=\frac{U_B-U_{CE(a)}}{J_{B(a)}}$

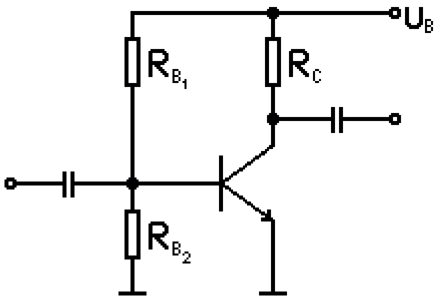


- durch Basisspannungsteiler

$J_q=2\ldots10*J_B$

$R_1=\frac{U_B-U_{BE(a)}}{I_q+I_B}$

$R_2=\frac{U_{BE(a)}}{I_q}$



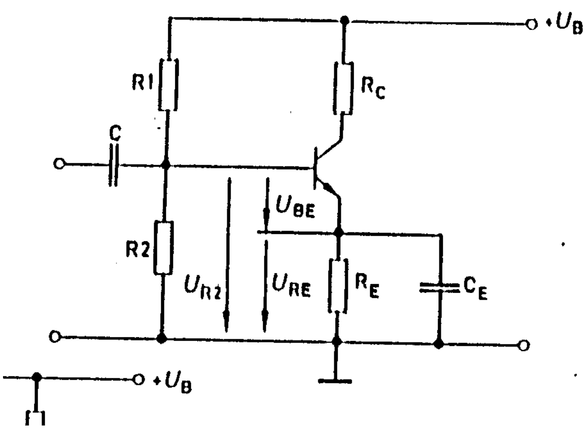
thermische Arbeitspunkstabilisierung

$J_E=J_C+J_B \qquad R_C=\frac{U_B-U_{CE}-U_{BE}}{I_C} \qquad C_E\geq\frac{h_{21e}}{2\pi f_{gu}*(h_{11}e+R_i)}=\frac{\beta}{2\pi f_{gu}*(r_{BE}+R_i)}$ durch Emitter-

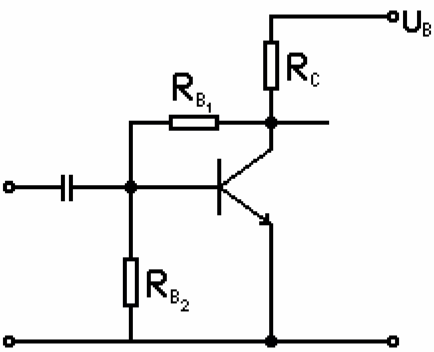
$U_{RE}=R_E*I_E$

Widerstand

$R_1=\frac{U_{CE}-U_{BE(a)}}{I_q+I_B} \qquad R_2=\frac{U_{BE}}{I_q} \qquad R_C=\frac{U_B-U_{CE}}{I_C+I_B+I_q}$ durch Spannungsgegenkopplung



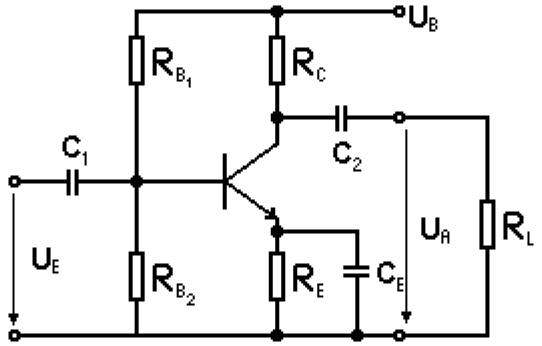
Emitter-Widerstand



Spannungsgegenkopplung

Transistor Grundschaltungen
Emitter-Schaltung

$r_e = R_1 \| R_2 \| r_{BE} \quad (wenn\ R_E\ mit\ C_E\ überbrückt)$
$r_e = R_1 \| R_2 \| (r_{BE} + \beta * R_E) \quad (ohne\ C_E)$



$r_a = R_C \| r_{CE}$

$V_u = \frac{\beta}{r_{BE}} * r_a \quad (ohne\ Last)$

$V_u = \frac{\beta}{r_{BE}} * (r_a \| R_L) \quad (mit\ Last)$

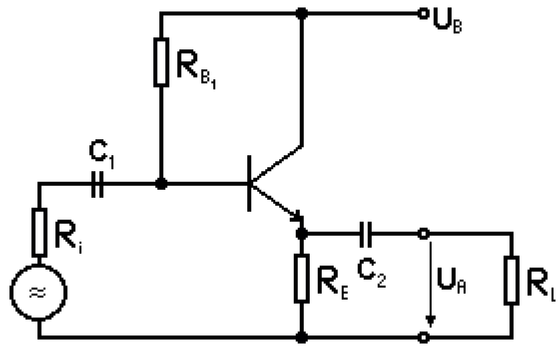
$V_i = \beta * \frac{r_{CE}}{r_{CE} + R_C} \quad (ohne\ Last)$

$V_i = \beta * \frac{r_{CE}}{r_{CE} + (R_C \| R_L)} \quad (mit\ Last)$

$V_p = V_u * V_i \qquad \varphi = 180°$

Kollektor-Schaltung

$r_e = R_1 \| [r_{BE} + \beta (R_E \| r_{CE})] \quad (mit\ Basisvorwiderstand)$
$r_e = R_1 \| R_2 \| [r_{BE} + \beta (R_E \| r_{CE})] \quad (mit\ Basisvorwiderstand)$



$r_a = R_E \| \frac{r_{BE} + R_i}{\beta}$

$V_u = \frac{\beta * R_E}{\beta * R_E + r_{BE}} \quad (ohne\ Last)$

$V_u = \frac{\beta * (R_E \| R_L)}{\beta * (R_E \| R_L) + r_{BE}} \quad (mit\ Last)$

$V_i = \beta * \frac{r_{CE}(1+\beta)}{R_E + r_{CE}} \quad (ohne\ Last)$

$V_i = \beta * \frac{r_{CE}(1+\beta)}{(R_E \| R_L) + r_{CE}} \quad (mit\ Last)$

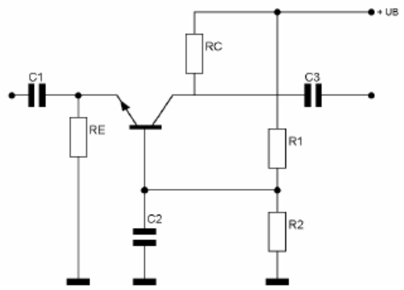
$V_p = V_u * V_i \qquad \varphi = 0°$

$C_1 = \frac{1}{2\pi f_{gu} * (r_e + R_i)}$

$C_2 = \frac{1}{2\pi f_{gu} * (r_a + R_L)}$

Basisschaltung

$r_e = R_E \| \frac{r_{BE}}{\beta}$



$r_a = R_C \| r_{CE}$

$V_u = \frac{\beta}{r_{BE}} * r_a$

$V_i = \frac{\beta}{\beta + 1}$

$V_p = V_u * V_i \qquad \varphi = 0°$

Selektivverstärker

$f_o = \frac{1}{2\pi \sqrt{L*C}} \qquad Q = Güte = \frac{R \| r_{CE}}{X_C} = \frac{R \| r_{CE}}{X_L}$

$X_C = \frac{1}{2\pi f * C} \qquad X_L = 2\pi f * L$

$b_{oL} = \frac{f_0}{Q} = \frac{f_0 * X_C}{R \| r_{CE}} = \frac{f_0 * X_L}{R \| r_{CE}} \qquad V_u = Y_{21}(R \| r_{CE})$

$b_{mL} = \frac{f_0 * X_C}{R \| r_{CE} \| R_L} = \frac{f_0 * X_L}{R \| r_{CE} \| R_L}$

Schaltverstärker

$$Schaltfrequenz\ f_{max} = \frac{1}{t_{ein} + t_{aus}} \qquad R_1 = \frac{U_B - U_{CX}}{I_{BX}} \qquad R_2 = \frac{U_e - U_{BE}}{I_{BX}}$$

Schaltverstärker mit Hilfsspannungen

$$J_{BX} = \frac{ü * U_B}{R_C * B} \qquad U_{IH} \geq R_1 \left(J_{BX} + \frac{U_{BEX} + |U_n|}{R_2} \right) + U_{BEX}$$

$$\frac{R_1 * (U_{BEX} + |U_H|)}{U_{IH} - U_{BEX} - I_{BX} * R_1} \leq R_2 \leq \frac{R_1 (U_{BEY} + |U_H|)}{U_{IL} - U_{BEY}} \qquad R_1 = \frac{(U_{IH} - U_{BEX})(U_{BEY} + U_H) - (U_{BEX} + U_H)(U_{IL} - U_{BEY})}{I_{BX} * (U_{BEY} + U_H)}$$

4. Feldeffekt-Transistoren

$$Vorwärtssteilheit \quad y_{21} = \frac{\Delta I_D}{\Delta U_{GS}} = S \qquad Ausgangsleitwert \quad y_{22} = \frac{\Delta I_D}{\Delta U_{DS}} = \frac{1}{r_{DS}} \qquad P_{tot} = U_{DS} * I_D$$

$$U_{RS} = I_D * R_S \qquad Automatische\ Gate-Spannungs-Erzeugung$$

$$R_1 = \frac{U_B - U_{GS} - U_{RS}}{I_q} \qquad R_2 = \frac{U_{GS} + U_{RS}}{I_q} \qquad Gatespannungserzeuger\ mit\ Gatespannungsteiler$$

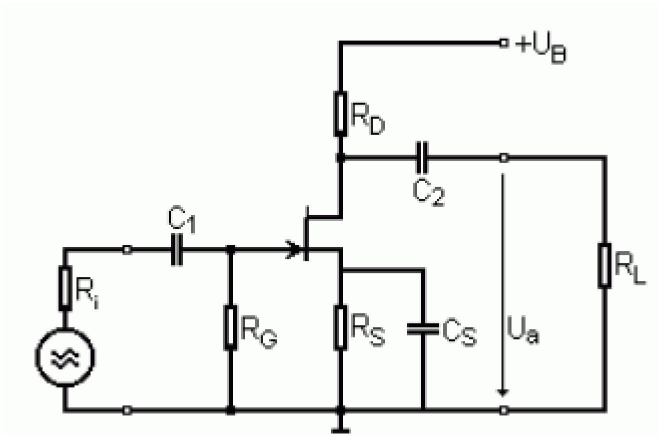
Grundschaltung mit FET's

Source-Schaltung

$$C_S = 0{,}2 * \frac{y_{22}}{f_{gu}} \qquad C_1 = \frac{1}{2\pi f_{gu}(R_i + r_e)} \qquad C_2 = \frac{1}{2\pi f_{gu}(R_L + r_a)} \qquad R_G = \frac{U_{GS} = 0{,}5\,V}{I_{GSS}} \qquad R_{GS} = \frac{-U_{GS}}{-I_{GSS}} \qquad R_S = \frac{U_{GS}}{I_D} = \frac{U_{RS}}{I_D}$$

$$r_a = R_D \| r_{ds} \qquad r_{DS} = \frac{1}{y_{22}} \qquad R_D = \frac{U_B - U_{DS} - U_{GS}}{I_D} = \frac{U_D}{I_D} \qquad r_e = \frac{R_G * R_{GS}}{R_G + R_{GS}} \qquad (oder)\, r_e = R_1 \| R_2 \| R_{GS}\,(für\ Gate\ Sp.\ Teiler)$$

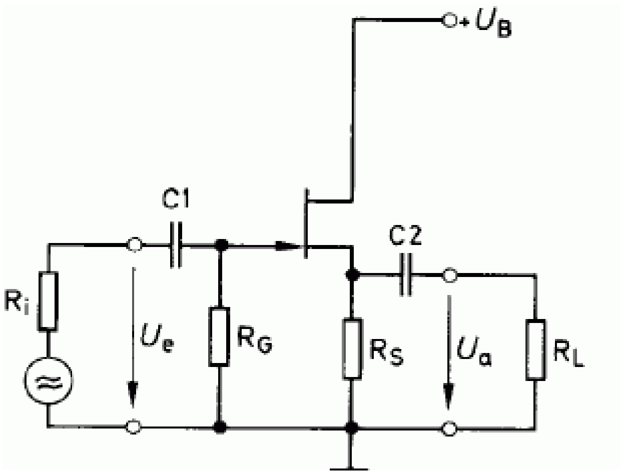
$$V_U = y_{21} * r_a \qquad U_{RG} = -I_{GSS} * R_G \qquad \varphi = 180°$$

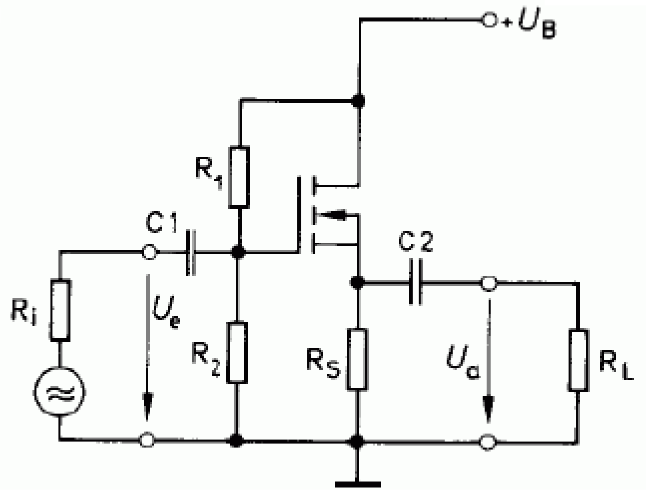


Drain-Schaltung

$$r_e = R_{GS}(1 + y_{21} * R_S) \| R_G \quad bzw.\ bei\ Gate\ Sp-Teiler: r_e = R_{GS}(1 + y_{21} * R_S) \| R_1 \| R_2 \qquad r_a = R_S \| \frac{1}{y_{22}}$$ y_{21}!! nicht y_{22}

$$V_U = \frac{y_{21} * R_S}{1 + y_{21} * R_S} \qquad \varphi = 0° \qquad R_G = \frac{-U_{GS}}{I_{GSS}} \qquad R_S = \frac{U_{RS}}{I_D} \qquad R_{GS} = \frac{-U_{GS}}{-I_{GSS}} \qquad R_1, R_2\ siehe\ 4.\ GS-Erzeuger$$





5. OPV

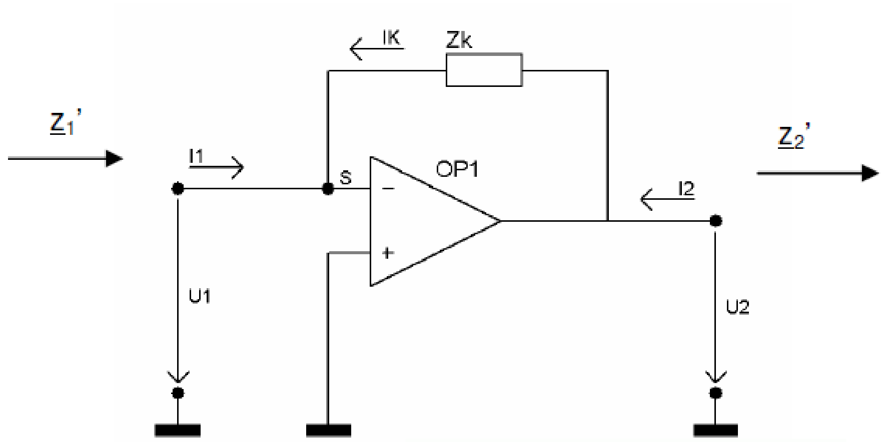
$$V_{ldb} = 20\,lg\frac{U_a}{U_e} \quad \textit{Verstärkung}$$

$$I_1 + I_K = 0 \quad I_K = \frac{U_2 - U_1}{Z_K}$$

$$\underline{Z_1} = \frac{\underline{U_1}}{\underline{I_1}} = \frac{\underline{U_1}}{-\underline{I_K}}$$

$$\underline{Z_1} = \frac{z_K}{-V_0 + 1}$$

$$U_1 = \frac{U_2}{V_0} \quad z_2 = \frac{z_K}{1 + \frac{1}{-V_0}}$$

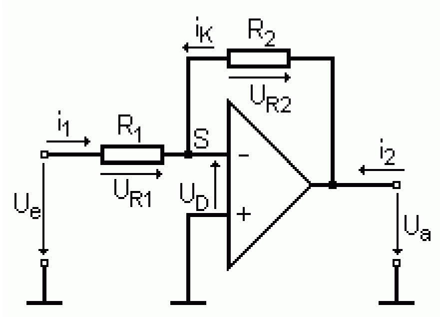


Anwendungen mit Frequenz-Unabhängiger Gegenkopplung

Invertierender Verstärker/Umkehrverstärker

$$r_e = R_1$$

$$r_a{}' = r_a * \frac{V}{V_0} \qquad U_a = -\frac{R_2}{R_1} * U_e \qquad V = -\frac{R_2}{R_1}$$

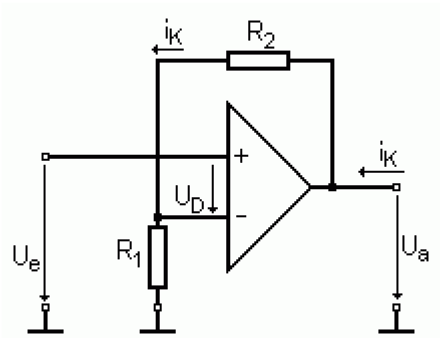


Einfluss der endlichen Verstärkung auf einen realen OPV

$$V = -\frac{V_0 * R_K}{R_K + R_1 * V_0 + R_1}$$

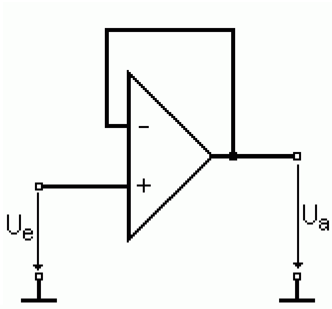
Nicht-Invertierter Verstärker/Elektrometerverstärker

$$V = 1 + \frac{R_K}{R_1} \qquad U_a = \left(1 + \frac{R_K}{R_1}\right) * U_e \qquad R_2 \rightarrow R_K$$



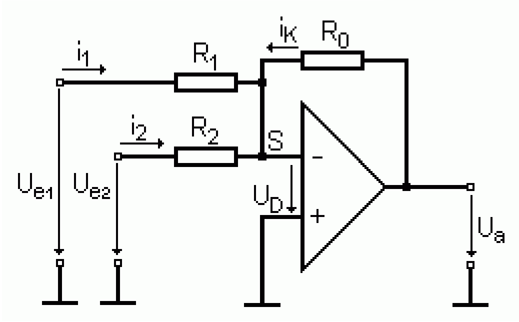
Spannungsfolger

$$U_a = U_e$$
$$V = 1$$



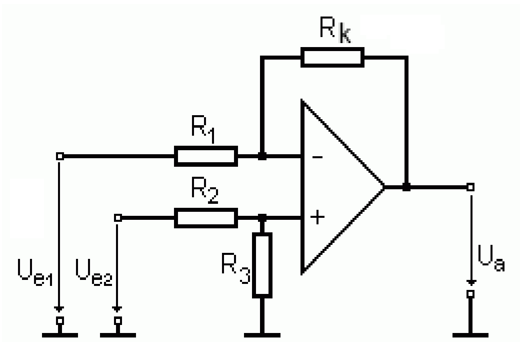
Addierverstärker

$$-U_a = \frac{R_k}{R_1} * U_{e1} + \frac{R_k}{R_2} * U_{e2} \qquad I_1 + I_2 = -I_k$$



Subtrahierer-Verstärker

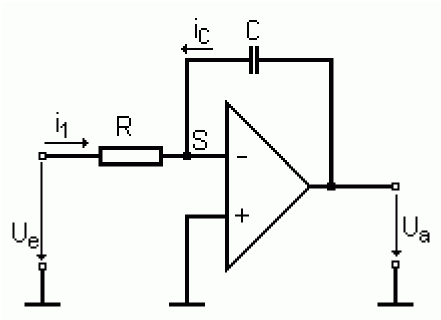
$$-U_a = \frac{R_K}{R_1} * U_{e1} - \left(1 + \frac{R_K}{R_1}\right) * \frac{R_3}{R_2 + R_3} * U_{e2}$$



OPV mit frequenzunabhängiger Gegenkopplung

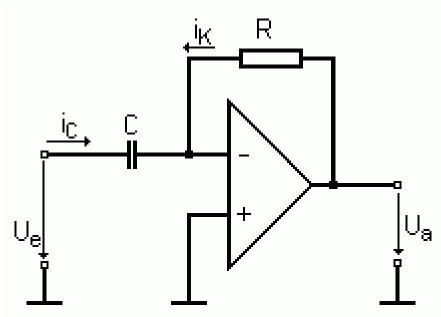
Integrier-Verstärker

$$-U_a = \frac{1}{RC} * \int U_e dt - U_0$$



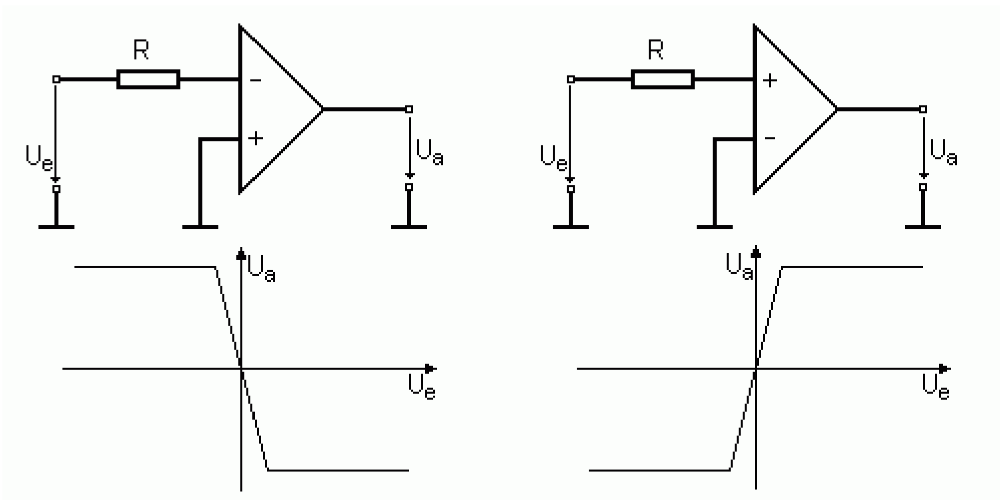
Differenzierer

$$i_C = C * \frac{du_C}{dt} \qquad i_k = \frac{U_a}{R} = -i_c \qquad -U_a = RC * \frac{du_e}{dt}$$



Komparator/Vergleicher

invertierter Komparator / nicht-invertierter Komparator



Schmidtt-Trigger

<u>invertierter SWS</u>

$$U_{ein}=\frac{R_2}{R_1+R_2}*U_{a-}$$

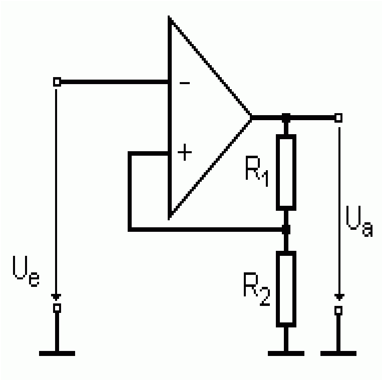
$$U_{aus}=\frac{R_2}{R_1+R_2}*U_{a+}$$

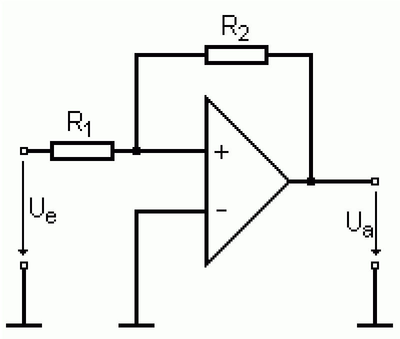
$$U_{Hys}=U_{aus}-U_{ein}$$

<u>nicht-Invertierter SWS</u>

$$U_{ein}=-\frac{R_1}{R_2}*U_{a-}$$

$$U_{aus}=-\frac{R_1}{R_2}*U_{a+}$$

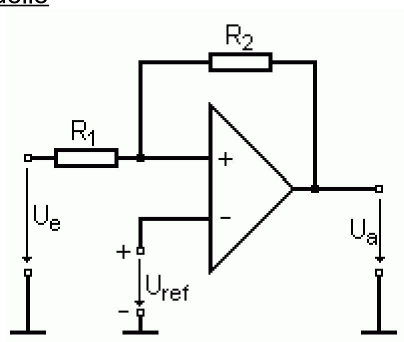




<u>nicht-invertierter SWS mit Referenzspannungsquelle</u>

$$U_{ein}=-\frac{R_1}{R_2}*U_{a\,min}+U_{ref}\left(1+\frac{R_1}{R_2}\right)$$

$$U_{aus}=-\frac{R_1}{R_2}*U_{a\,max}+U_{ref}\left(1+\frac{R_1}{R_2}\right)$$



<u>invertierter SWS mit Referenzspannungsquelle</u>

$$U_{ein}=\frac{R_2}{R_1+R_2}*U_{a\,min}+U_{ref}\left(1-\frac{R_2}{R_1+R_2}\right)$$

$$U_{aus}=\frac{R_2}{R_1+R_2}*U_{a\,max}+U_{ref}\left(1-\frac{R_2}{R_1+R_2}\right)$$