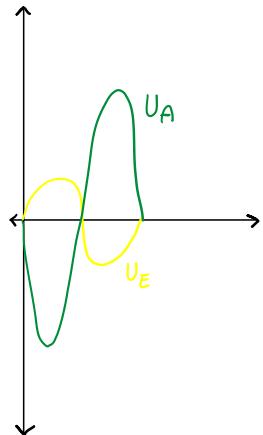
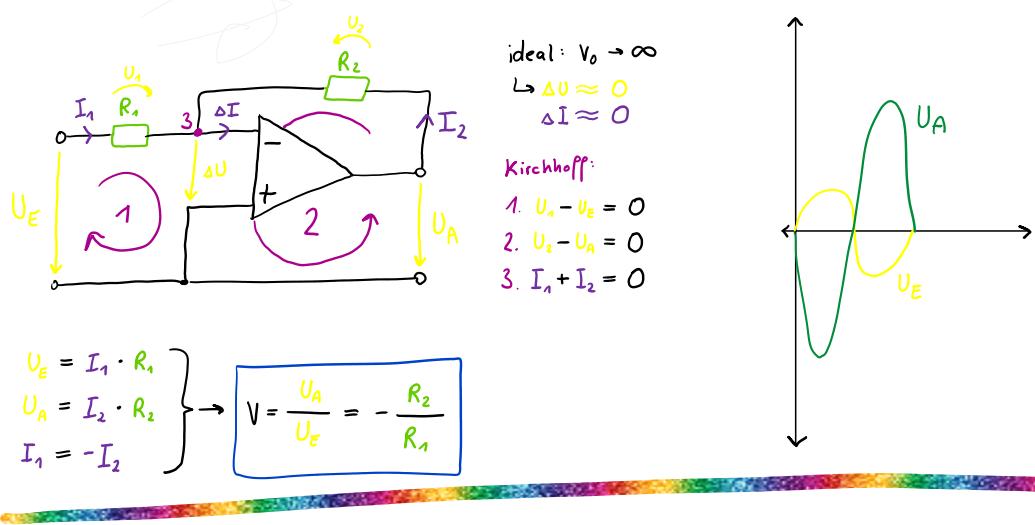
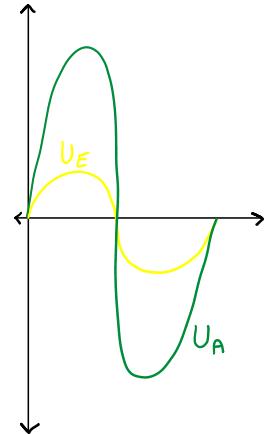
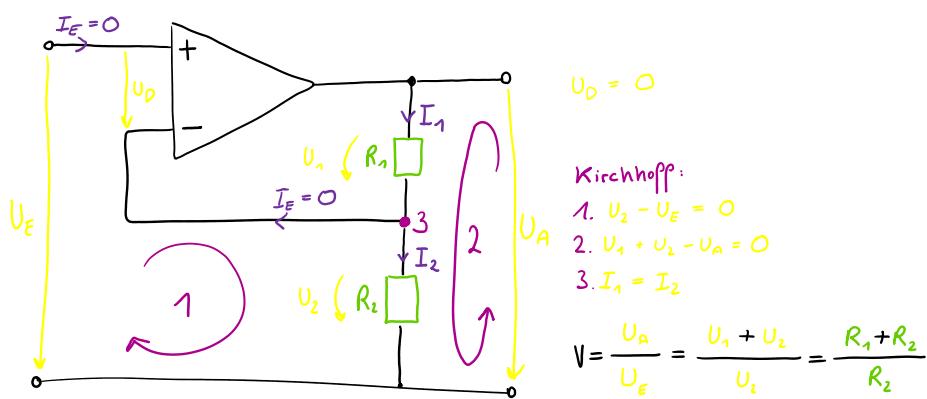


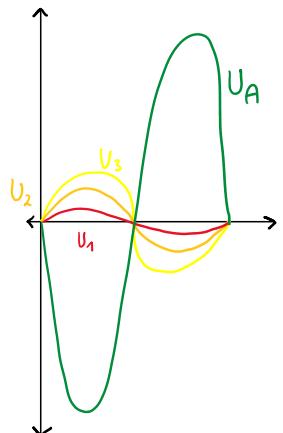
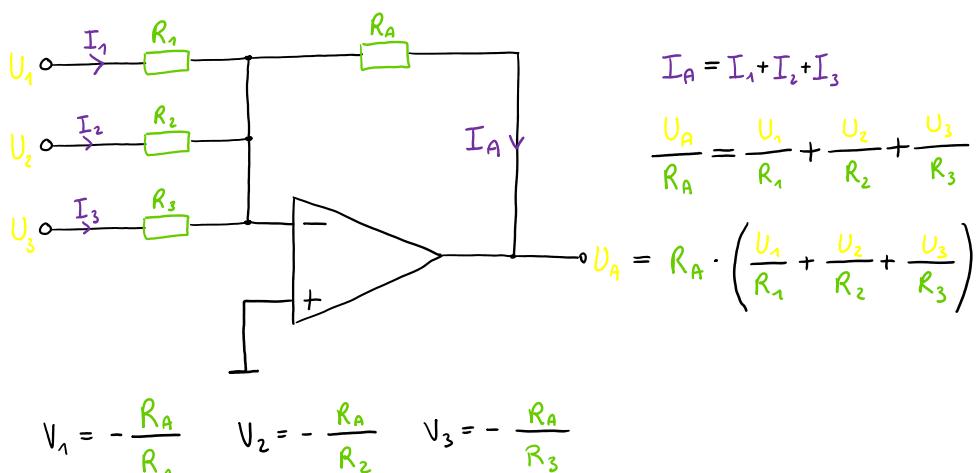
Invertierender Verstärker



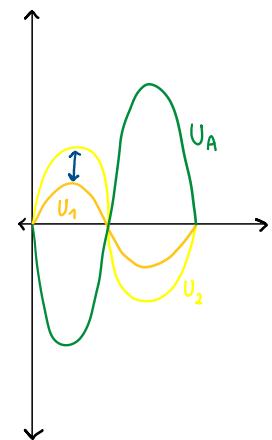
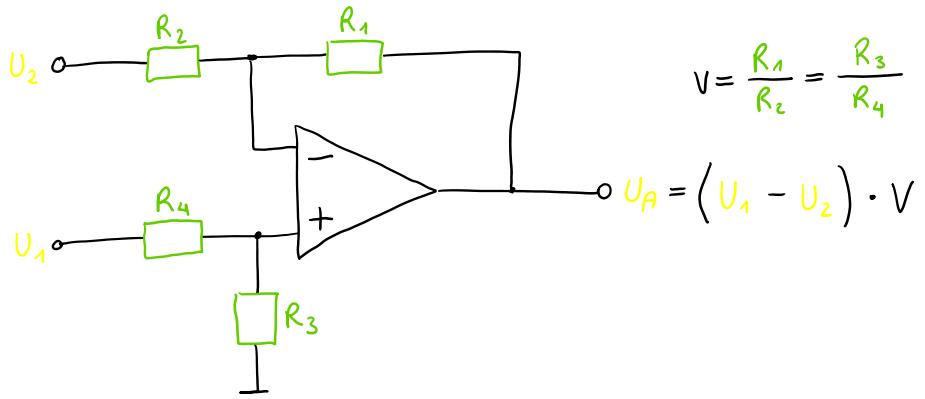
Nicht invertierender Verstärker



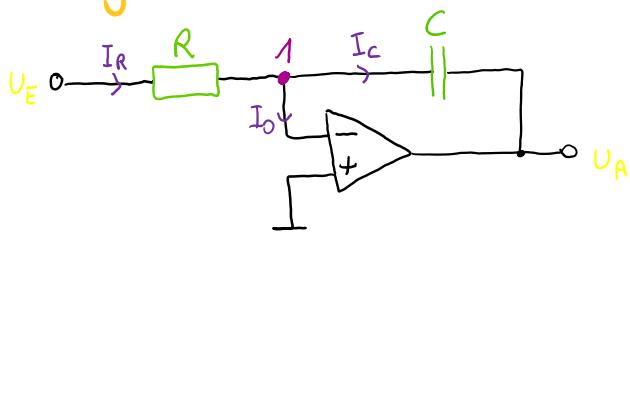
Summierender Verstärker



Differenzial Verstärker



Integrator



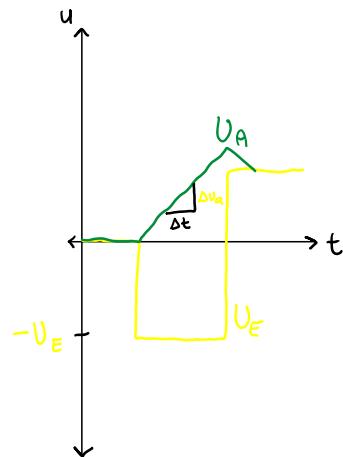
$$I: I_R = I_C$$

$$I_R = I \cdot \Delta t = -C \cdot \Delta u_a$$

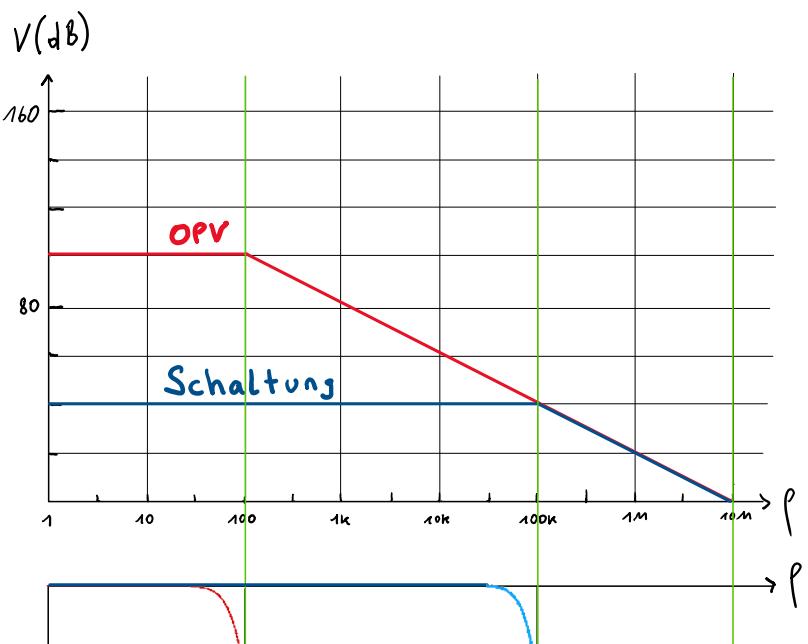
$$\frac{U_E}{R} \cdot \Delta t = -C \cdot \Delta u_a$$

$$\Delta u_a = -\frac{U_E}{R \cdot C} \cdot \Delta t$$

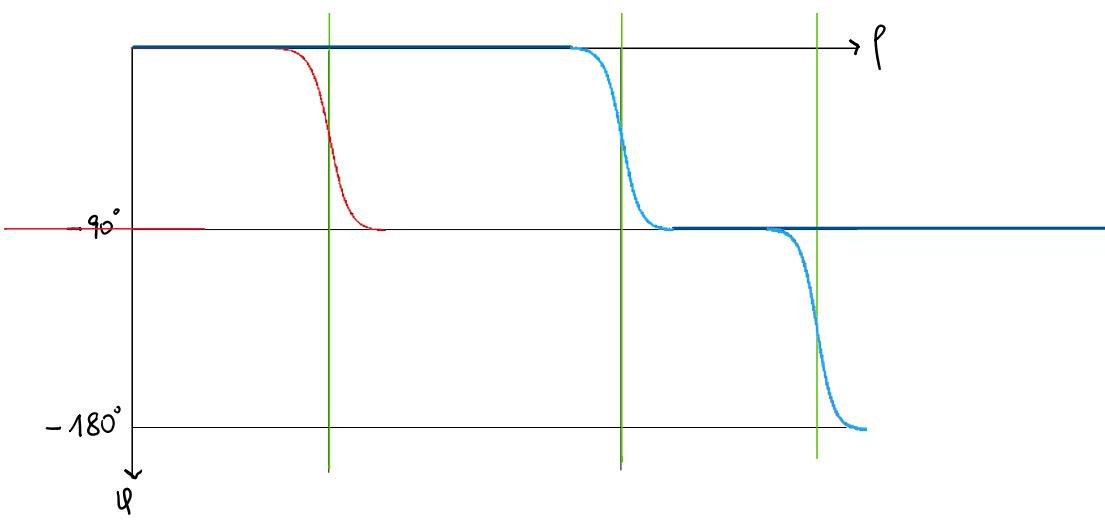
$$\Delta u_a = -\frac{U_E}{\zeta} \cdot \Delta t$$



Bodediagramm

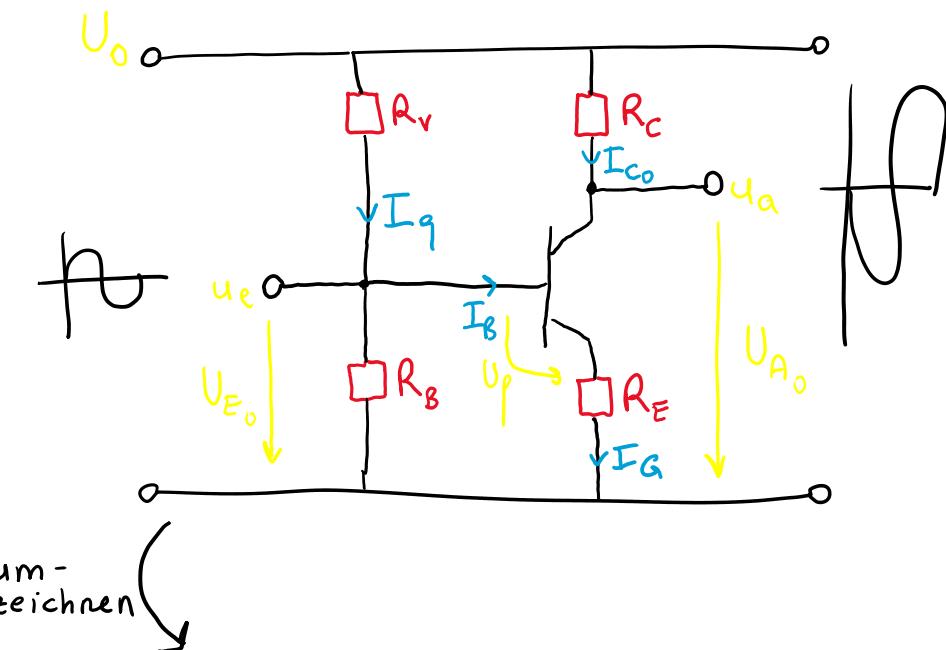


Schaltung



Transistor

Montag, 12. April 2021 14:10



$$I_B \approx 0 \text{ mA}$$

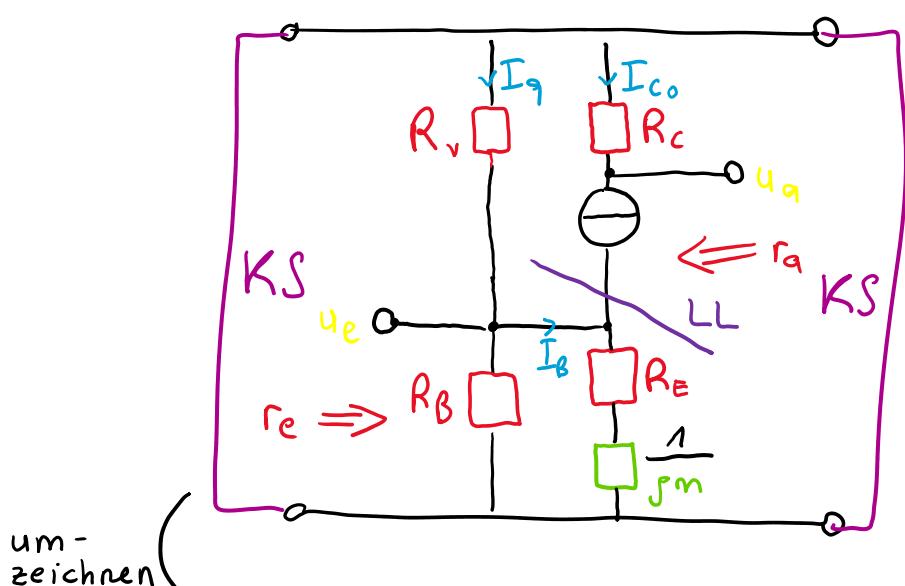
$$I_{C_0} = \beta \times I_B$$

$$R_V = \frac{U_O - U_{E_0}}{I_q}$$

$$R_B = \frac{U_{E_0}}{I_q}$$

$$R_C = \frac{U_O - U_{A_0}}{I_{C_0}}$$

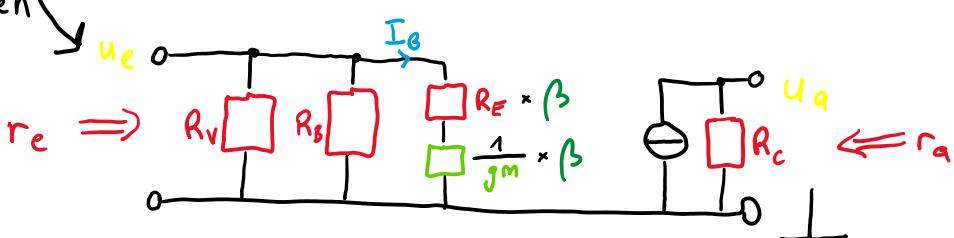
$$R_E = \frac{U_{A_0} - U_p}{I_G}$$



Kurzschluss & Leerlauf

$$g_m = \frac{I_{C_0}}{U_T}$$

$$U_T = 25 \text{ mV}$$



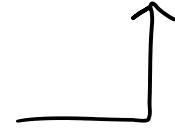
$$r_a = R_C$$

$$r_e = \frac{1}{\frac{1}{R_V} + \frac{1}{R_B} + \frac{1}{(R_E + \frac{1}{g_m}) \times \beta}}$$

$$V = \frac{U_A}{1} = \frac{-R_C \times I_C}{1 + \frac{1}{1 + R_E}} = -\frac{R_C}{1 + R_E}$$

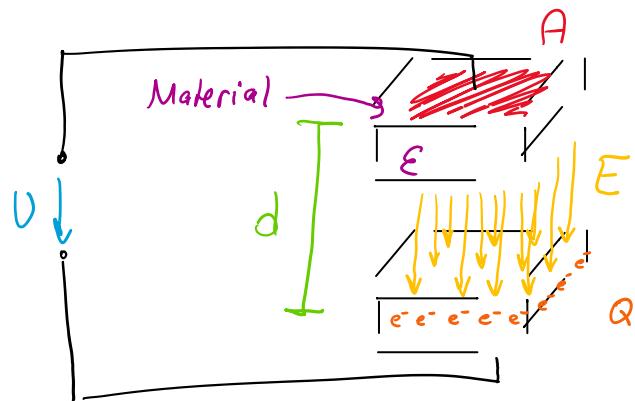
$$V = \frac{U_A}{U_E} = \frac{-K_C \times L_C}{\left(\frac{1}{g_m} + R_E\right) \times \beta \times I_B} = -\frac{R_C}{\frac{1}{g_m} + R_E}$$

\downarrow
 $I_C = \beta \times I_B$
 \downarrow
 kürzt sich weg!



Plattenkondensator

Sonntag, 21. Februar 2021 13:26



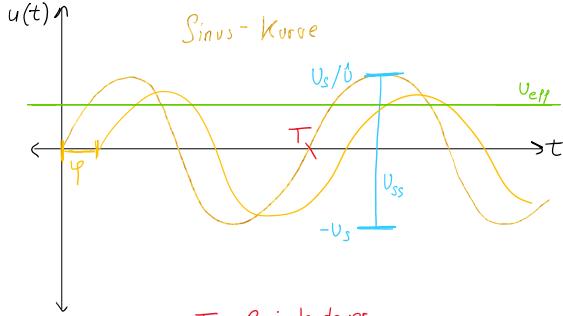
- U ... Spannung [V]
- A ... Fläche [m^2]
- d ... Abstand [m]
- ϵ ... Dielektrikum [$\frac{F}{N}$]
- C ... Kapazität [F]
- Q ... Ladung [C]
- E ... elektrisches Feld [$\frac{V}{m}$]

$$\rightarrow E = \frac{U}{d}$$

$$\rightarrow \epsilon = \epsilon_0 \times \epsilon_r$$

$$\rightarrow Q = C \times U$$

$$\rightarrow C = \frac{\epsilon \times A}{d}$$



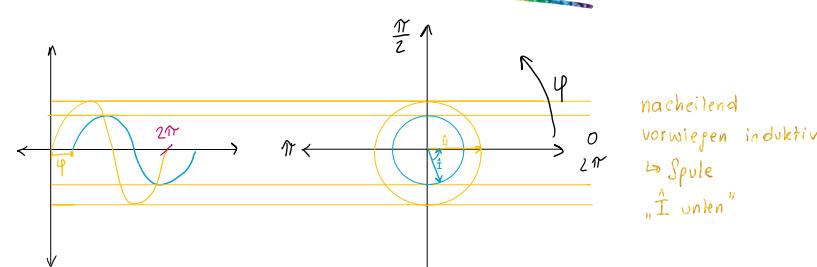
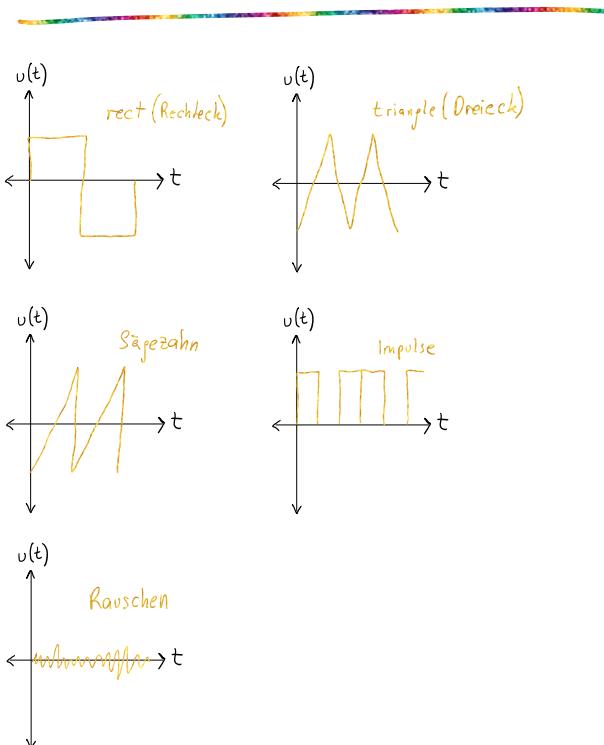
$$|\bar{U}| = \frac{1}{T} \sum |u| \cdot dt$$

$$U_{eff} = \sqrt{\frac{1}{T} \sum u^2 \cdot dt}$$

... Gleichr

... Effekt

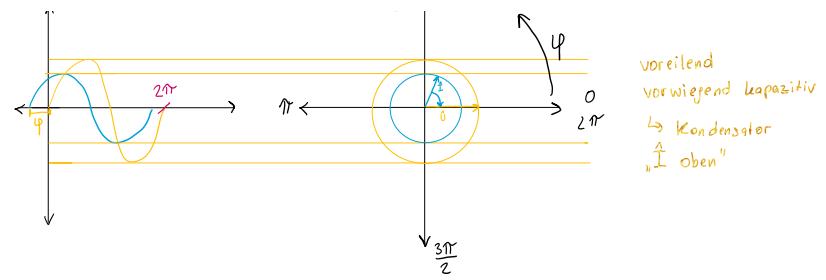
Effektivwert liegt meist wenig über



ichtwert

wert

r Gleichrichtwert



voreilend
 vorwiegend kapazitiv
 ↳ Kondensator
 „I oben“

Tiefpass

Sonntag, 21. Februar 2021 11:43

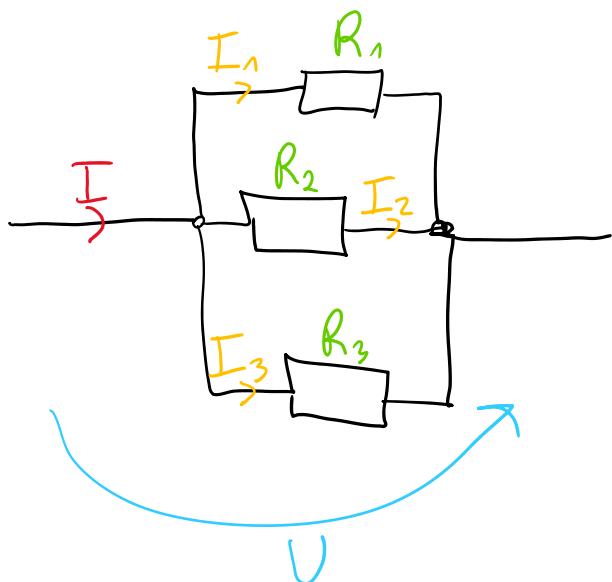
$$U_c = U \times \left(1 - e^{-\frac{t}{\tau}} \right)$$

$$U_c = U_c \times e^{-\frac{t}{\tau}}$$

Strom- und Spannungsteiler

Sonntag, 21. Februar 2021 12:29

Stromteiler

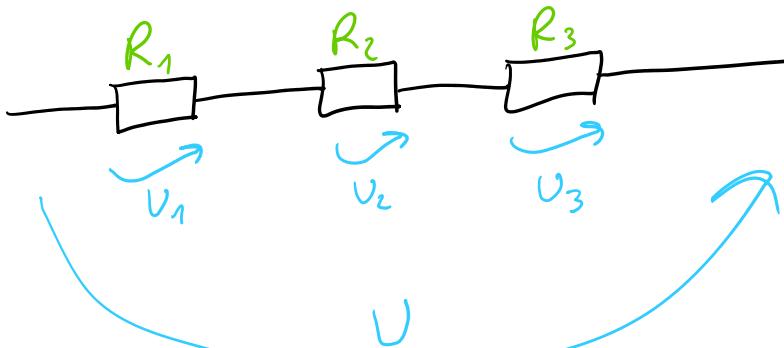


$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

$$\frac{I_2}{I_3} = \frac{R_3}{R_2}$$

$$\frac{I_1}{I} = \frac{R_{1||2||3}}{R_1}$$

Spannungsteiler



$$\frac{U_1}{U_2} = \frac{R_1}{R_2}$$

$$\frac{U_1}{U} = \frac{R_1}{R_{123}}$$

Ohm'sches Gesetz

Sonntag, 21. Februar 2021 11:48

$$U = R \times I$$

U ... Spannung

$$P = U \times I$$

R ... Widerstand

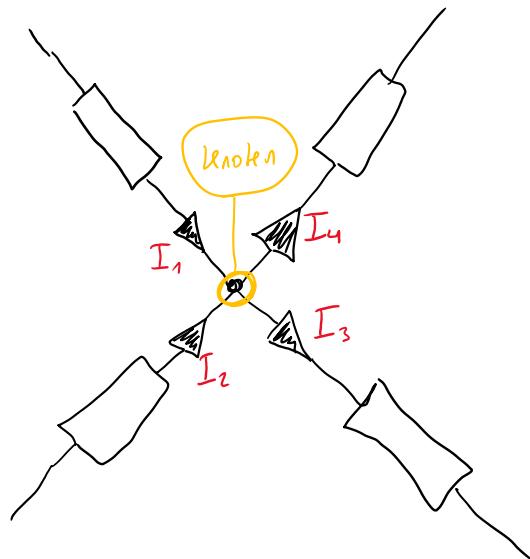
$$W = P \times t$$

I ... Stromstärke

P ... Leistung

W ... Energie

1. Kirchhoffsches Gesetz (Knotenregel)

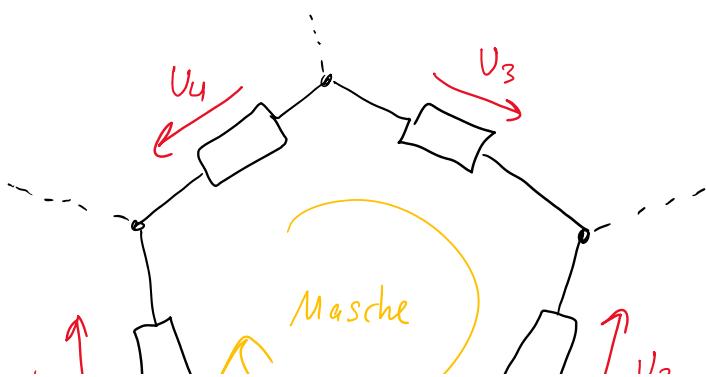


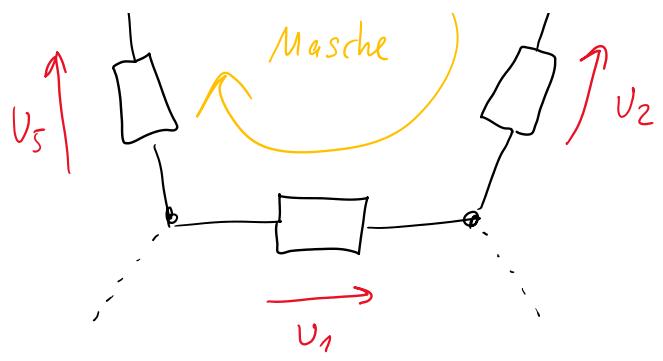
$$I_1 + I_2 - I_3 - I_4 = 0$$

allg.:
$$\sum_{i=1}^N I_i = 0$$

N... Anzahl der Leiter im Knotenpunkt

2. Kirchhoffsches Gesetz (Maschenregel)





$$-U_1 - U_2 + U_3 - U_4 + U_5 = 0$$

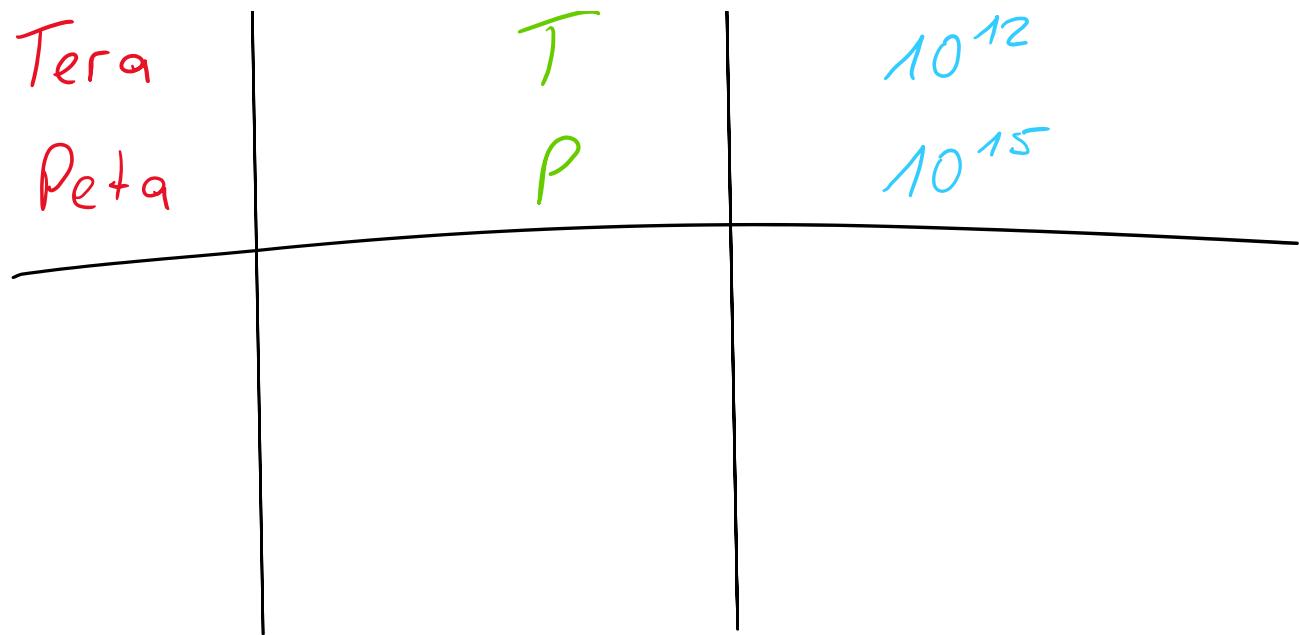
allg.:
$$\sum_{i=1}^N U_i = 0$$

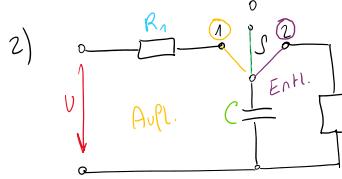
N... Anzahl der Leiter im Knotenpunkt

Vorsätze der Einheiten

Sonntag, 21. Februar 2021 11:59

Name	Zeichen	Faktor
Dezi	d	10^{-1}
Zenti	c	10^{-2}
Milli	m	10^{-3}
Mikro	μ	10^{-6}
Nano	n	10^{-9}
Piko	p	10^{-12}
Femto	f	10^{-15}
<hr/>		
Deka	d _a	10
Hekto	h	10^2
Kilo	k	10^3
Mega	M	10^6
Giga	G	10^9
Tera	T	10^{12}

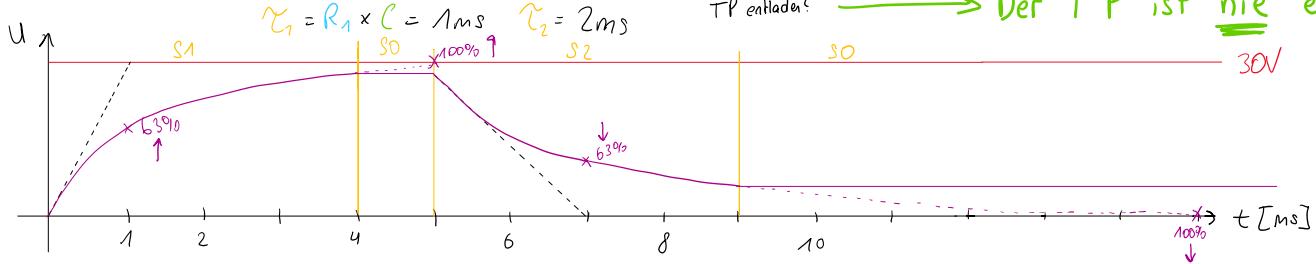




gep: $R_1 = 100\text{k}$
 $C = 10\text{nF}$
 $R_2 = 200\text{k}$
 $U = 30V$

ges: $U_C (1, 2, 3, 4, 5, 7, 9, 10\text{ms}) \checkmark$
 Skizze $S_1: 0-4\text{ms}$
 $S_2: 4-5\text{ms}$
 $S_3: 5-9\text{ms}$
 $S_4: > 9\text{ms} \checkmark$

TP entladen? \rightarrow Der TP ist nie entladen! $30V$



$$U_C = U \times \left(1 - e^{-\frac{t}{\tau_1}}\right)$$

$$1\text{ms} \quad U_C = 30 \times \left(1 - e^{-\frac{1}{1}}\right)$$

$$\underline{\underline{U_C = 18,9636V}}$$

$$U_C = U_C \times e^{-\frac{t}{\tau_1}}$$

$$7\text{ms} \quad 5\text{ms} \quad 2 \quad (7-5=2)$$

$$U_C = 29,4504 \times e^{-\frac{2}{2}}$$

$$\underline{\underline{U_C = 0,8893V}}$$

Startpunkt
10,834V

$$U_C = U \times \left(1 - e^{-\frac{t}{\tau_1}}\right)$$

$$2\text{ms} \quad U_C = 30 \times \left(1 - e^{-\frac{2}{1}}\right)$$

$$\underline{\underline{U_C = 25,9399V}}$$

$$U_C = U_C \times e^{-\frac{t}{\tau_1}}$$

$$9\text{ms} \quad 5\text{ms} \quad 4 \quad (9-5=4)$$

$$U_C = 29,4504 \times e^{-\frac{4}{2}}$$

$$\underline{\underline{U_C = 0,3272V}}$$

3,985...V

$$U_C = U_C = \underline{\underline{0,3272V}}$$

$$10\text{ms} \quad 9\text{ms}$$

$$U_C = U \times \left(1 - e^{-\frac{t}{\tau_1}}\right)$$

$$3\text{ms} \quad U_C = 30 \times \left(1 - e^{-\frac{3}{1}}\right)$$

$$\underline{\underline{U_C = 28,5064V}}$$

$$U_C = U \times \left(1 - e^{-\frac{t}{\tau_1}}\right)$$

$$4\text{ms} \quad U_C = 30 \times \left(1 - e^{-\frac{4}{1}}\right)$$

$$\underline{\underline{U_C = 29,4504V}}$$

$$U_C = U_C = \underline{\underline{29,4504V}}$$

\downarrow
 5ms

\downarrow
 4ms

3) a) Wie lange dauert die Entladzeit eines RC-TP?

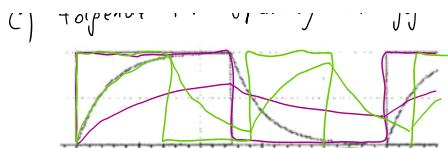
5 τ \rightarrow Merkregel!

b) Was ist τ und wie berechnet man es?

$$\tau \text{ „Tau“} = \text{griechischer Buchstabe} \rightarrow R \times C$$

c) Folgende TP-Spannung ist gep.:





Wie verändern sich die Signale, wenn ich C verkleinere und warum?
! rosa einzeichnet!

Wenn sich C verkleinert, dann verkleinert sich

\sim proportional mit.

\hookrightarrow der RC-TP lädt langsamer auf/entlädt langsamer.

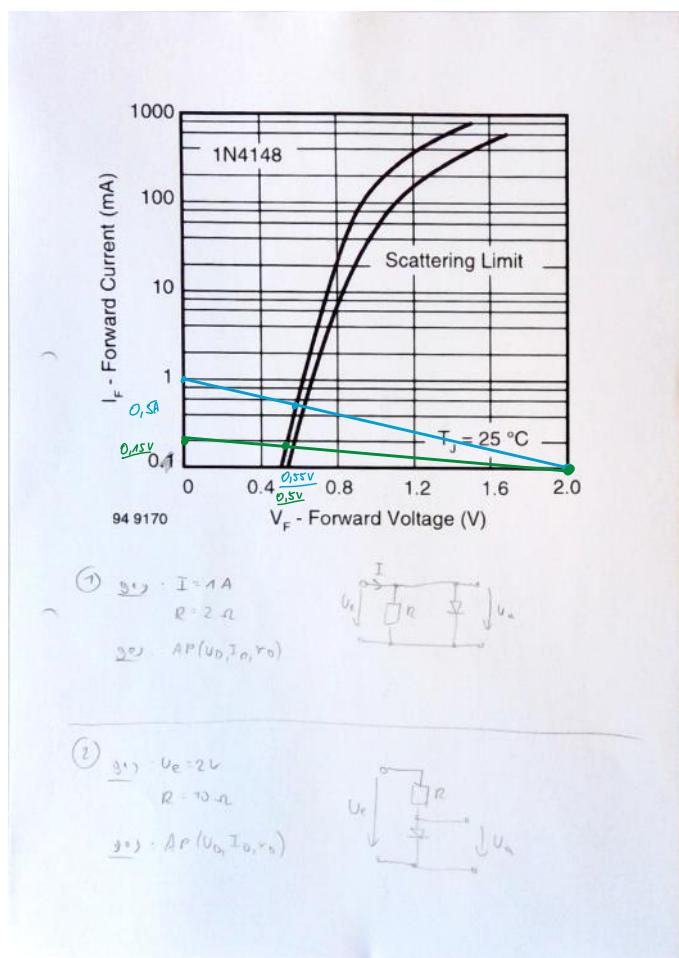
\hookrightarrow das Signal wird schmäler

Wie verändern sich die Signale, wenn ich f vergrößere und warum?

! GRÜN einzeichnet!

Wenn man f vergrößert, verkleinert man T (Periodendauer).

\hookrightarrow Wenn sich T verkleinert, schrumpft das Signal auf der X-Achse (t).



$$1) U_E = U_A = U_R = U_D$$

$$I = I_R + I_D$$

$$U_R = R \cdot I_R$$

$$I = \frac{U_D}{R} + I_D$$

$$U_D = 0$$

$$\hookrightarrow I_D = 1A$$

$$I_D = 0$$

$$\hookrightarrow U_D = 2V$$

$$U_{D_{AP}} = 0,55V$$

$$\underline{\underline{I_{D_{AP}} = 0,5A}}$$

$$r_{D_{AP}} = 1,1\Omega$$

$$2) I_E = I_D$$

$$U_R = R \cdot I_E$$

$$U_A = U_D$$

$$U_E = U_R + U_A$$

$$U_D = U_E - R \cdot I_D$$

$$U_D = 0$$

$$\hookrightarrow I_D = \frac{U_E}{R} = 0,2A$$

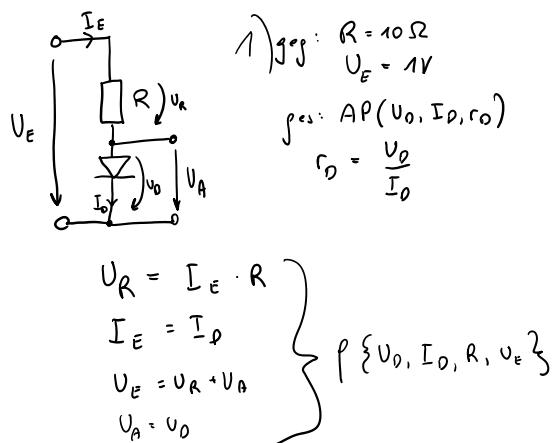
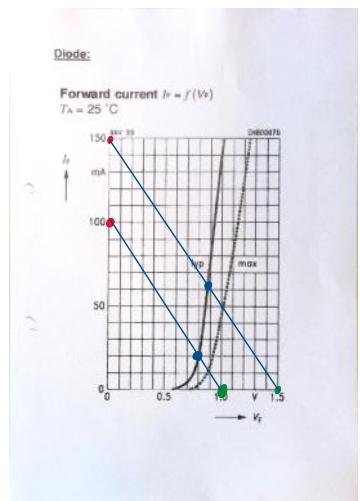
$$I_D = 0$$

$$\hookrightarrow U_D = 2V$$

$$U_{D_{AP}} = 0,5V$$

$$\underline{\underline{I_{D_{AP}} = 0,15A}}$$

$$r_{D_{AP}} = 3,3\Omega$$



$$\boxed{I_{DAP} = 20mA}$$

$$\boxed{U_{DAP} = 0,8V}$$

$$\boxed{r_{DAP} = 40\Omega}$$

2) Änderung: $U_E = 1,5V$

$$I_D = 0$$

$$\hookrightarrow U_D = 1,5V$$

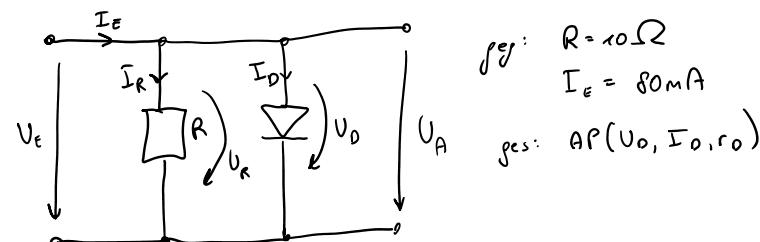
$$U_D = 0$$

$$\hookrightarrow I_D = 150mA$$

$$\boxed{U_{DAP} = 0,89V}$$

$$\boxed{I_{DAP} = 60mA}$$

$$\boxed{r_{DAP} = 14,8\Omega}$$



ges: $R = 10\Omega$
 $I_E = 80mA$

ges: $A_P(U_0, I_D, r_0)$

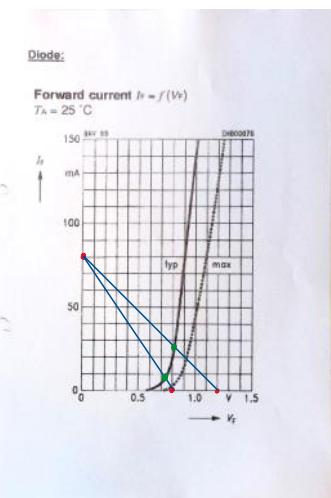
$$I_E = I_R + I_D$$

$$U_E = U_R = U_A = U_0$$

$$U_R = R \cdot I_R$$

(weil parallel)

$$\boxed{I_E = \frac{U_0}{R} + I_D}$$



$$U_D = 0$$

$$\hookrightarrow I_D = 80mA$$

$$I_D = 0$$

$$\hookrightarrow U_D = 0,8V$$

$$\boxed{U_{DAP} = 0,72V}$$

$$\boxed{I_{DAP} = 7mA}$$

$$\boxed{r_{DAP} = 102,85\Omega}$$

$$\text{ges} : R = 15 \Omega$$
$$I_E = 80 \text{ mA}$$

$$I_D = 0$$

$$\hookrightarrow U_D = 1,2 \text{ V}$$

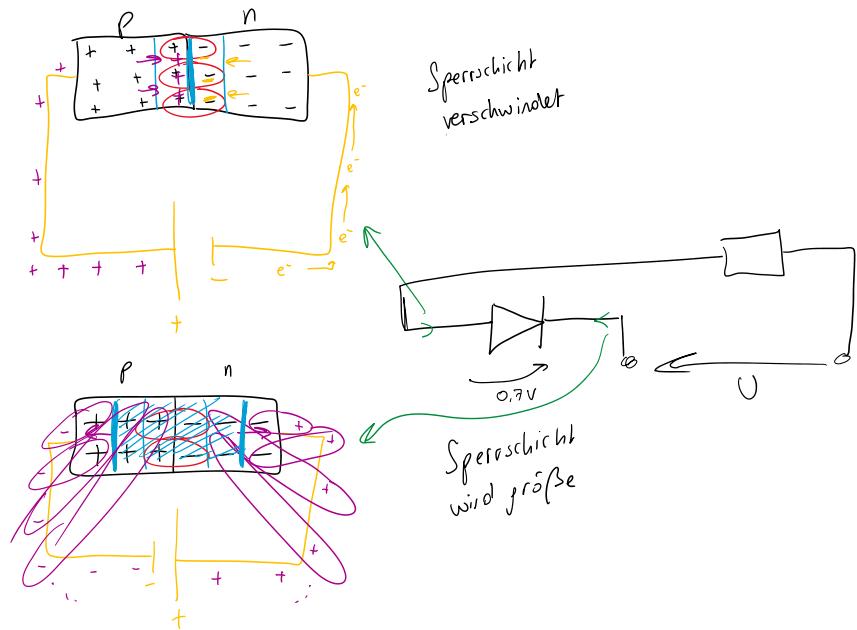
$$U_D = 0$$

$$\hookrightarrow I_D = 80 \text{ mA}$$

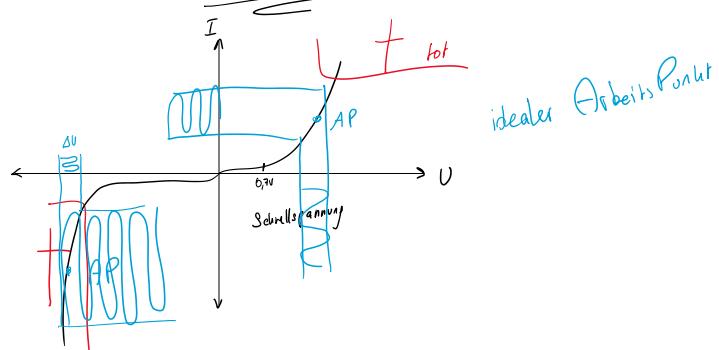
$$I_{D_{AP}} = 25 \text{ mA}$$

$$\overline{U_{D_{AP}}} = 0,81 \text{ mA}$$

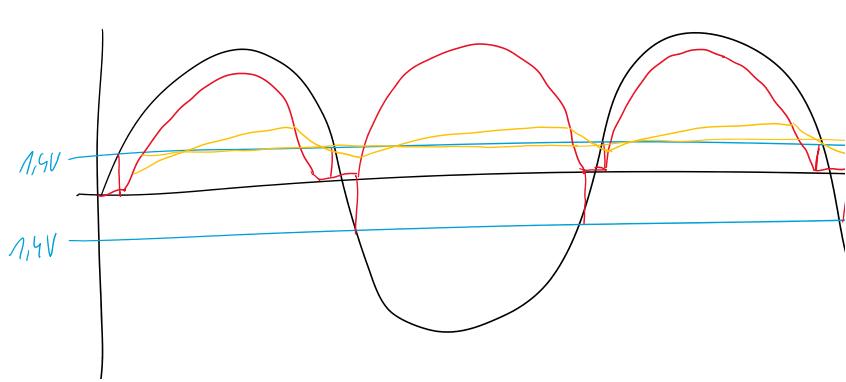
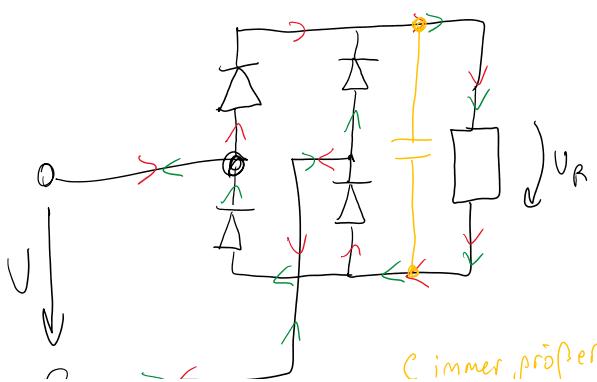
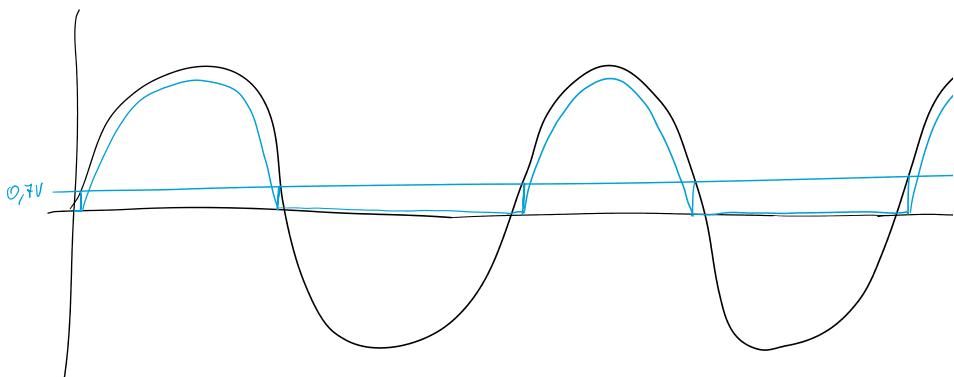
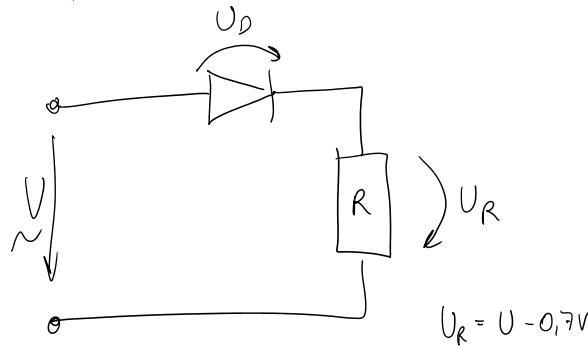
$$r_{D_{AP}} \sim 32,4 \Omega$$

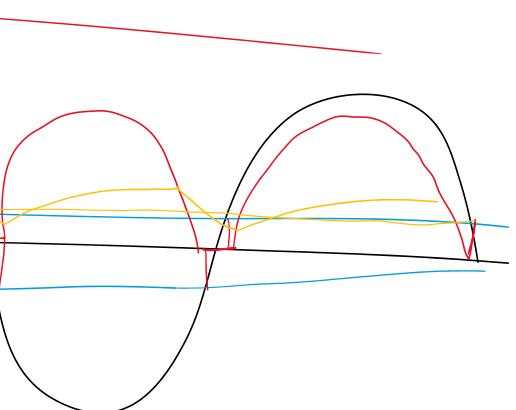
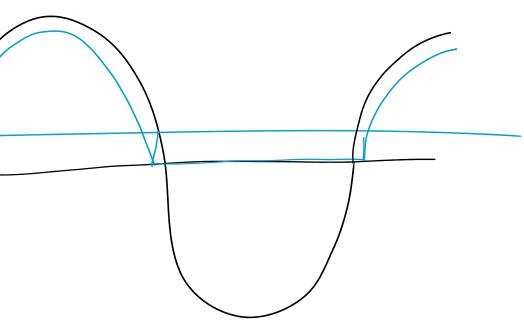


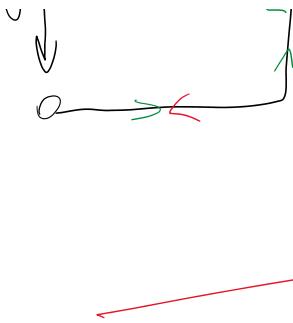
Kennlinie



idealer Arbeitspunkt







C immer propter
↳ Kurve immer flacher

Datenblatt



VISHAY www.vishay.com IN4148 Vishay Semiconductors

Small Signal Fast Switching Diodes

FEATURES

- Small signal肖特基二极管
- Electrolytic equivalent diode: 1N4148 - 1N914
- Max. reverse voltage: 100V
- Max. reverse current: 100mA
- For definitions of compliance please see [www.vishay.com/docid/3022](#)

APPLICATIONS

- External fast switching

MECHANICAL DATA

Case: DO-35
Weight: 0.05 g
Cathode lead color: black
Packaging: 1000 pieces per 13" reel, 500 pieces per 13" reel tape, 100Kcassette
TAS10K per strip pack, 50 pieces per tape, 500Kcassette

PARTS TABLE

PART	ORDERING CODE	TYPE MARKING	INTERNAL CONDITION/TEST	REMARKS
IN4148	1N4148 TAP or IN4148 T1	VA148	Single-diode	Tape and reflowpack

ABSOLUTE MAXIMUM RATINGS [$T_{J\max} = 25^\circ\text{C}$, unless otherwise specified]

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Forward reverse voltage	$V_F = 100\text{ V}$	V_F	100	V
Reverse current	$V_R = 100\text{ V}$	I_R	100	µA
Peak forward current	$t = 1\text{ \mu s}$	I_{FW}	1000	mA
Forward continuous current	$T_J = 25^\circ\text{C}$	I_F	100	mA
Repetitive peak current	$T_J = 40^\circ\text{C}, T_F = 40^\circ\text{C}$	I_{FW}	400	mA
Power dissipation	$T_J = 40^\circ\text{C}, T_F = 35^\circ\text{C}$	P_D	100	mW

THERMAL CHARACTERISTICS [$T_{J\max} = 25^\circ\text{C}$, unless otherwise specified]

PARAMETER	TEST CONDITION	SYMBOL	VALUE	UNIT
Thermal resistance junction to ambient	$t = 1\text{ \mu s}, T_c = \text{constant}$	θ_{JA}	1.25	°C/W
Ambient temperature		T_A	-55 to +150	°C
Storage temperature range		T_S	-55 to +150	°C

Rev. 1.3, Rev. 1.2
1 Document Number: 8902
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VISHAY www.vishay.com IN4148 Vishay Semiconductors

ELECTRICAL CHARACTERISTICS [$T_{J\max} = 25^\circ\text{C}$, unless otherwise specified]

PARAMETER	TEST CONDITION	SYMBOL	MIN.	MAX.	UNIT
Forward voltage	$I_F = 10\text{ mA}$	V_F	0.7	0.9	V
Forward current	$V_F = 0.7\text{ V}, T_J = 100^\circ\text{C}$	I_F	50	100	µA
Reverse current	$V_R = 100\text{ V}$	I_R	5	10	µA
Breakdown voltage	$I_R = 100\text{ \mu A}, I_F = 0.01\text{ mA}$	V_{BR}	100		V
Diode capacitance	$I_F = 0.01\text{ mA} + 1\text{ mA}$	C_D	4	10	pF
Rectification efficiency	$V_F = 2.7\text{ V}, I_F = 100\text{ mA}$	η_F	40	50	%
Reverse recovery time	$I_F = 10\text{ mA}, V_R = 0\text{ V}$	t_{RR}	0	10	ns
Reverse recovery time	$I_F = 10\text{ mA}, V_R = 0\text{ V}$	t_{RR}	4	10	ns

TYPICAL CHARACTERISTICS [$T_{J\max} = 25^\circ\text{C}$, unless otherwise specified]

Fig. 1 - Forward Voltage vs. Junction Temperature
Fig. 2 - Reverse Current vs. Reverse Voltage
Fig. 3 - Forward Current vs. Forward Voltage

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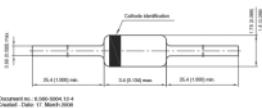


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1N4148

Vishay Semiconductors

PACKAGE DIMENSIONS in millimeters (inches) D0-36_02

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Date: 11. March 2008
Ver.: 1.0Rev. 1.0, MSL4-17 Document Number: 41602
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Part No.: 0-004-02 Document Number: 41600

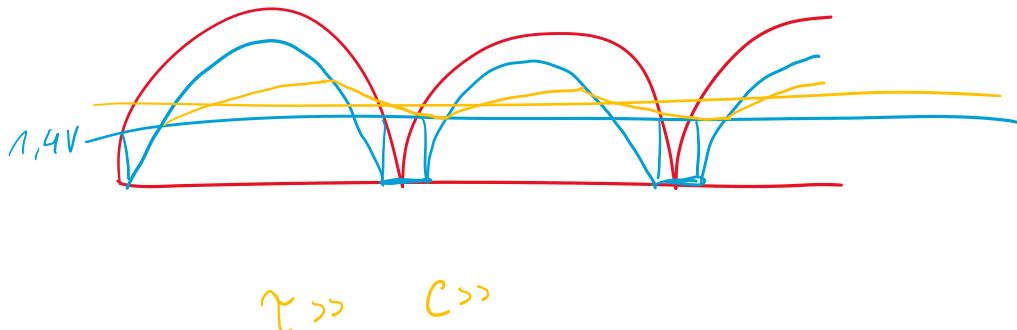
3

Document Number: 41600

Halbleiter

leiten bei bestimmten Temperaturen; bei manchen nicht
hohe Temperatur: gute Leitfähigkeit

Wechselspannung \rightarrow Gleichspannung



$$\tau \gg C \gg$$



Elektrotechnik und Elektronik für Informationstechnologie2 (SYTE2)

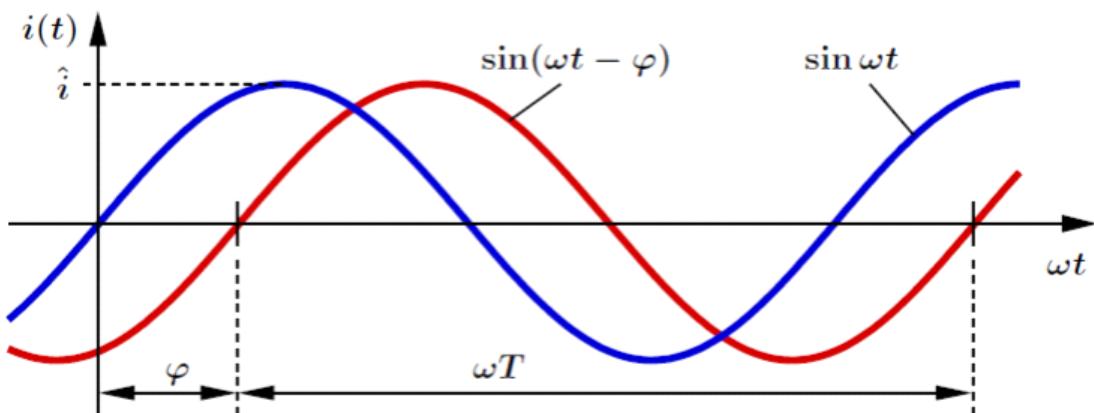
Skriptum zur Vorlesung/Übung
der Schulstufe 2

HTBL Krems/Informationstechnologie
DI Dr. Sabine Strohmayer

Überblick SYTE2

- Wechselspannungstechnik
- Wechselspannungsmesstechnik
- Halbleitertechnologie
- Grundschaltungen
- Digitaltechnik

Wechselstrom



$i(t)$	Augenblickswert des Stromes
\hat{i}	Spitzenwert des Stromes
T	Periodendauer
$f = 1/T$	Frequenz, [f] = Hz = Hertz
$\omega = 2\pi f$	Kreisfrequenz
φ	Phasenverschiebung

Effektivwert



Der Effektivwert I eines periodischen Wechselstromes $i(t)$ entspricht der Stärke eines äquivalenten Gleichstromes, der in einem Widerstand R die gleiche Leistung wie der Wechselstrom im zeitlichen Mittel umsetzt.

$$I^2 \cdot R = R \cdot \frac{1}{T} \int_0^T i^2(t) dt \quad \rightarrow$$

$$I = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt}$$

analog für Wechselspannungen:

$$U = \sqrt{\frac{1}{T} \int_0^T u^2(t) dt}$$

Bei **sinusförmigen Wechselgrößen** gilt:

$$I = \frac{\hat{i}}{\sqrt{2}}, \quad U = \frac{\hat{u}}{\sqrt{2}}$$

Gleichrichtwert



Der Gleichrichtwert $\overline{|i|}$ eines periodischen Wechselstromes $i(t)$ ist der arithmetische Mittelwert des Betrages der Zeitfunktion.



$$\text{Gleichrichtwert} \quad \overline{|i|} = \frac{1}{T} \int_0^T |i(t)| \, dt$$

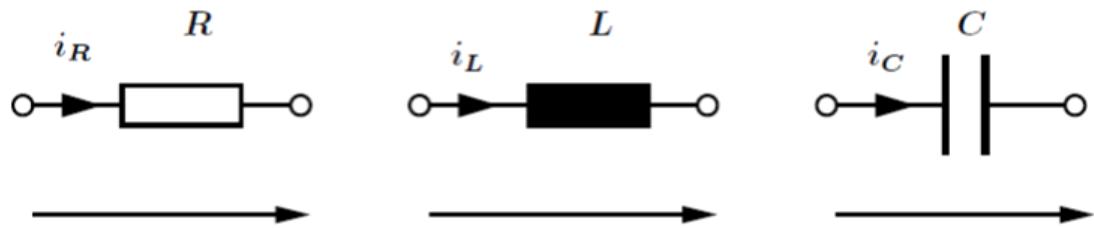
Die Definition gilt wieder völlig analog für Wechselspannungen.

Bei **sinusförmigen Wechselgrößen** ergibt sich:

$$\overline{|i|} = \frac{2}{\pi} \hat{i} = 0.637 \hat{i} = \frac{2\sqrt{2}}{\pi} \cdot I = 0.9 I \quad \text{bzw.} \quad \overline{|u|} = 0.9 U$$

Zweipole der Wechselstromtechnik

Wechselstromnetzwerke enthalten i.a. Ohmsche Widerstände (R), Induktivitäten (L) und Kapazitäten (C):



$$u_R = i_R R$$

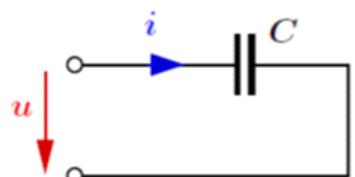
$$u_L = L \frac{di_L}{dt}$$

$$u_C = \frac{1}{C} \int i_C dt$$



Liegt eine sinusförmige Spannung an einem **linearen** Bauelement an, so ist der Strom durch das Bauelement ebenfalls sinusförmig und weist eine Phasenverschiebung gegenüber der Spannung auf, wenn das Bauelement induktive oder kapazitive Elemente enthält.

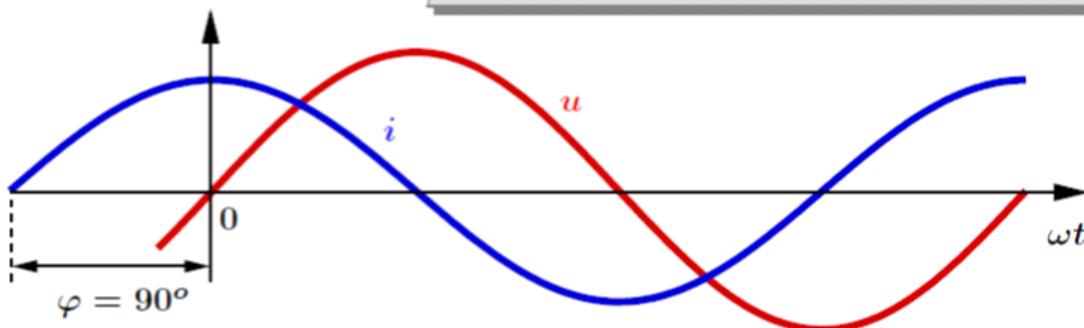
Wechselstrom am Kondensator



$$u(t) = \sqrt{2} U \sin \omega t$$

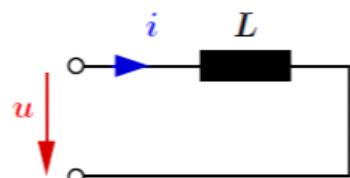
$$i(t) = \sqrt{2} I \sin(\omega t + \pi/2)$$

$$\frac{U}{I} = X_C \quad , \quad X_C = \frac{1}{\omega C}$$
 kapazitiver Widerstand



An einem Kondensator eilt der Strom der Spannung um den Phasenwinkel $\varphi = 90^\circ$ voraus.

Wechselstrom an der Spule

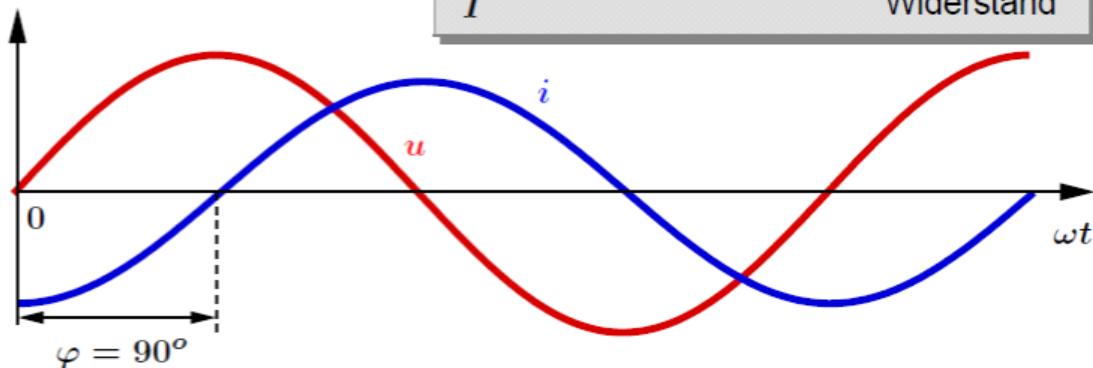


$$u(t) = \sqrt{2} U \sin \omega t$$

$$i(t) = \sqrt{2} I \sin(\omega t - \pi/2)$$

$$\frac{U}{I} = X_L \quad , \quad X_L = \omega L$$

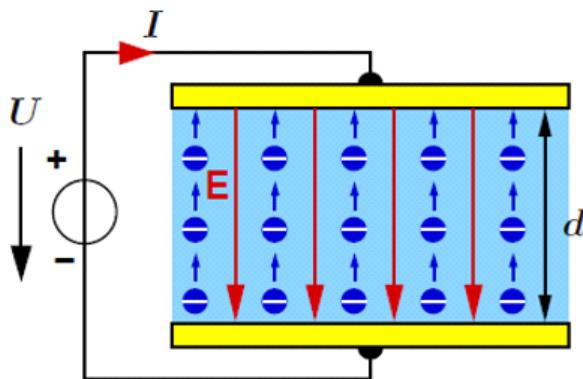
induktiver
Widerstand



An einer Spule hinkt der Strom der Spannung um den Phasenwinkel $\varphi = 90^\circ$ hinterher.

Plattenkondensator/elektr. Feld

Wir betrachten 2 gut leitende Platten mit Abstand d , zwischen denen sich ein schlecht leitendes Material befindet:

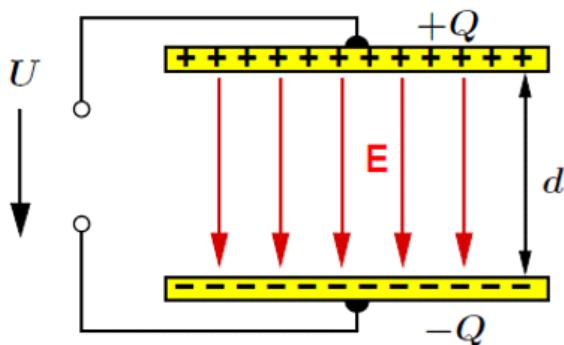


$$E = \frac{U}{d} \quad , \quad [E] = \text{V/m}$$

Dieses Feld bleibt auch dann erhalten, wenn wir den Widerstand des Materials zwischen den Platten weiter erhöhen, bis schließlich gar kein Strom mehr fließt. Es wird durch die positiven und negativen Ladungen, die sich auf den Platten ansammeln, aufgebaut.

Plattenkondensator

Die Spannungsquelle kann entfernt werden, aber das elektrische Feld und damit die Spannung zwischen den Platten bleibt erhalten.



Die beiden Platten stellen also einen Energiespeicher dar. Man spricht von einem **Kondensator**.

Messungen zeigen, daß die Ladung Q auf den Platten der Spannung proportional ist, $Q \sim U$:

$$Q = C \cdot U \quad , \quad C = \text{Kapazität} \quad , \quad [C] = \text{As/V} = \text{F (Farad)}$$

Plattenkondensator

Unter der Annahme eines homogenen Feldes zwischen den Platten ergibt sich beim Plattenkondensator eine zur Plattenfläche A direkt und zum Plattenabstand d umgekehrt proportionale Kapazität:

$$C = \varepsilon \frac{A}{d} \quad , \quad \varepsilon = \text{Dielektrizitätskonstante}$$

Die Dielektrizitätskonstante ε ist eine Materialkonstante:

$$\varepsilon = \varepsilon_0 \cdot \varepsilon_r$$

$$\varepsilon_0 = 8.85 \cdot 10^{-12} \frac{\text{As}}{\text{Vm}}$$

ε_r = relative Dielektrizitätskonstante

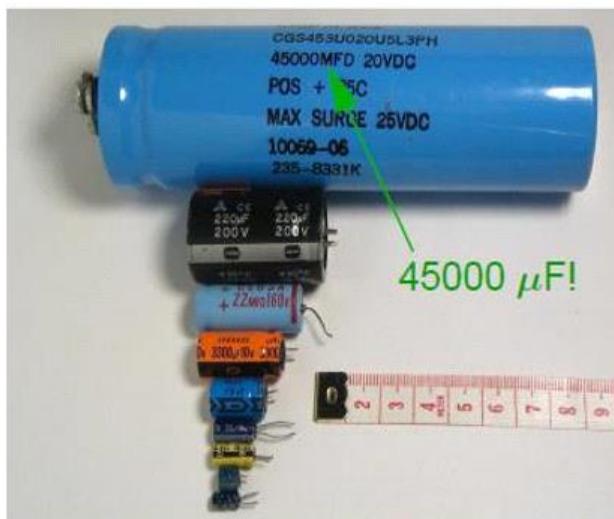
Material	ε_r
Luft	1.0006
Glas	5-7
dest. Wasser	80

Ü-Bsp:

- Plattenkondensator

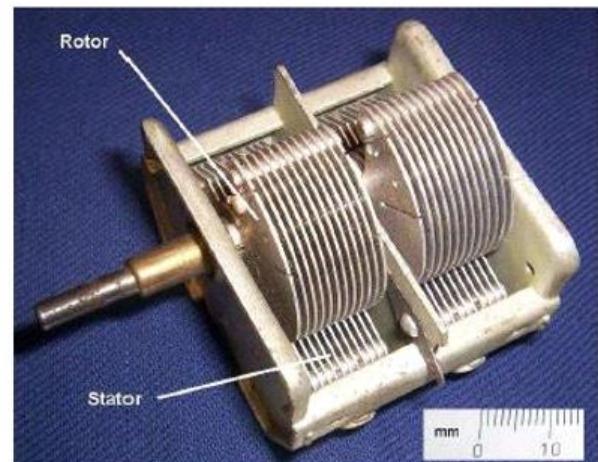
Bauformen von Kondensatoren

Festkondensatoren: z.B. Metallpapier- (MP, selbstheilend bei Durchschlag, 0.1-50 μF), Keramikkondensatoren (0.5 pF-100 nF), ...



Elektrolytkondensator

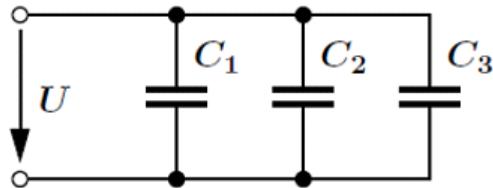
(hohe Kapazität, Polung beachten!)



Drehkondensator

(variable Kapazität bis ca. 250 pF)

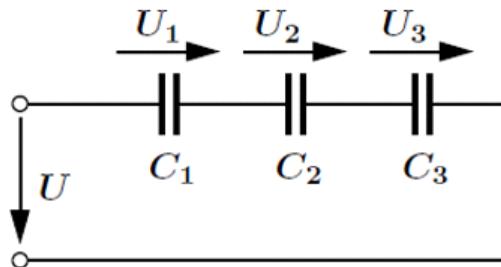
Parallel-/Reihenschaltung



Parallelschaltung

$$C_{ges} = C_1 + C_2 + C_3 + \dots$$

$$Q_{ges} = U \underbrace{(C_1 + C_2 + C_3)}_{C_{ges}}$$



Reihenschaltung

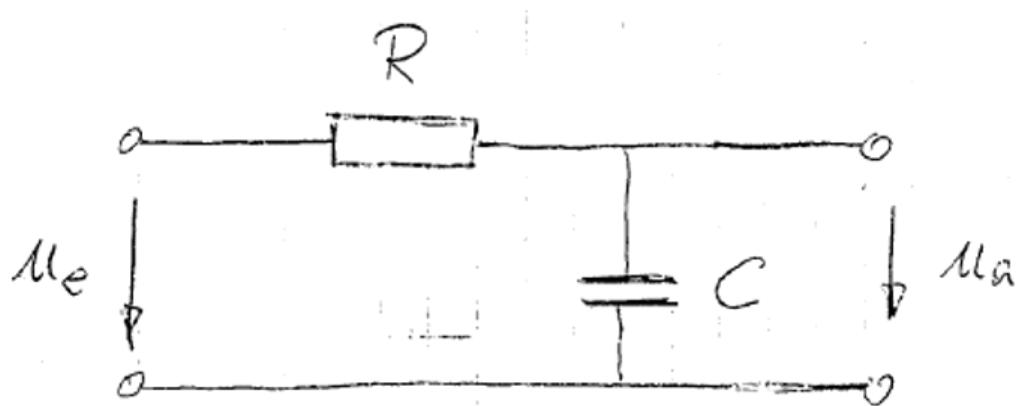
$$\frac{1}{C_{ges}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

$$U = Q \underbrace{\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right)}_{1/C_{ges}}$$

Ü-Bsp:

- Kondensator: seriell/parallel

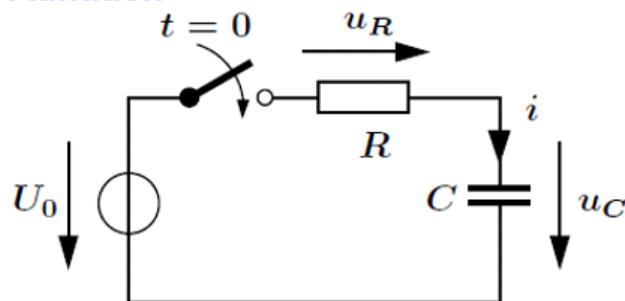
RC-Tiefpass



- Anwendung bei Signalleitungen, Leiterplatten, analoge Schaltungen,...
- Zeitkonstante $\tau = RC$

Auf-/Entladevorgang

Aufladen



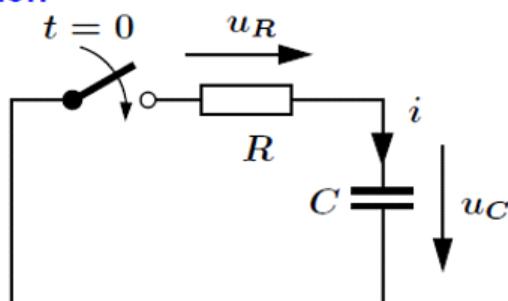
$$t \geq 0 \quad U_0 = u_R + u_C$$

$$u_R = iR \quad , \quad i = C \frac{du_C}{dt}$$

$$\rightarrow U_0 = RC \frac{du_C}{dt} + u_C$$

$$\rightarrow u_C = U_0 (1 - e^{-t/\tau})$$

Entladen



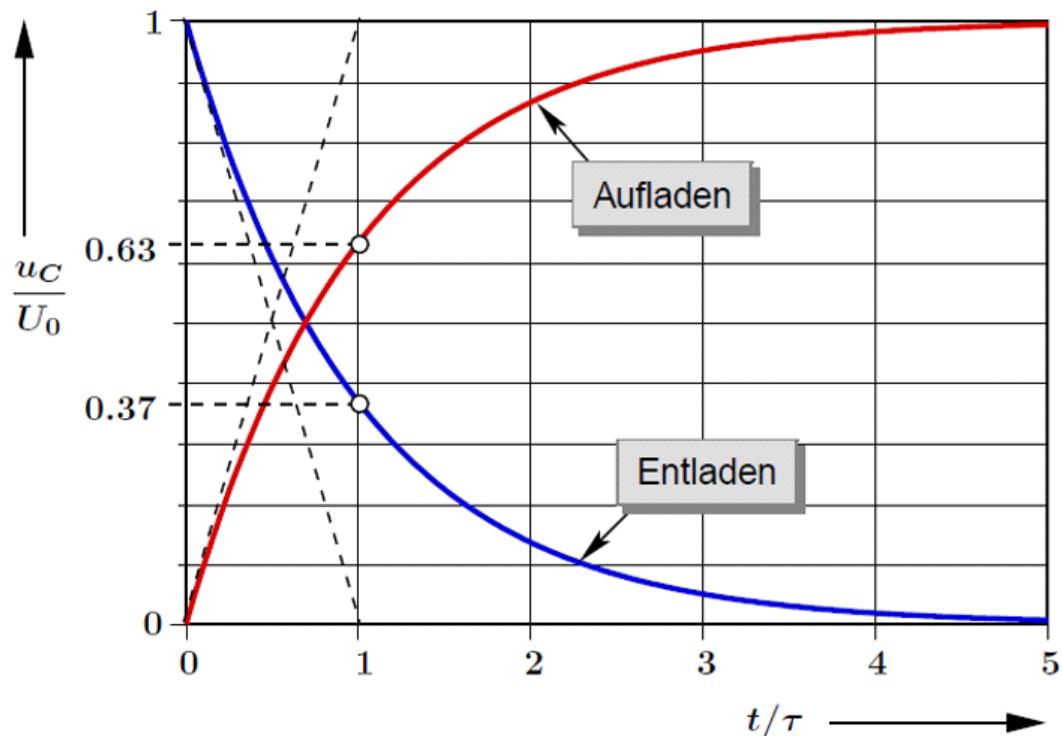
$$t \geq 0 \quad 0 = u_R + u_C$$

$$\rightarrow 0 = RC \frac{du_C}{dt} + u_C$$

$$\rightarrow u_C = U_0 e^{-t/\tau}$$

$$\text{Zeitkonstante} \quad \tau = R \cdot C$$

Auf-/Entladevorgang



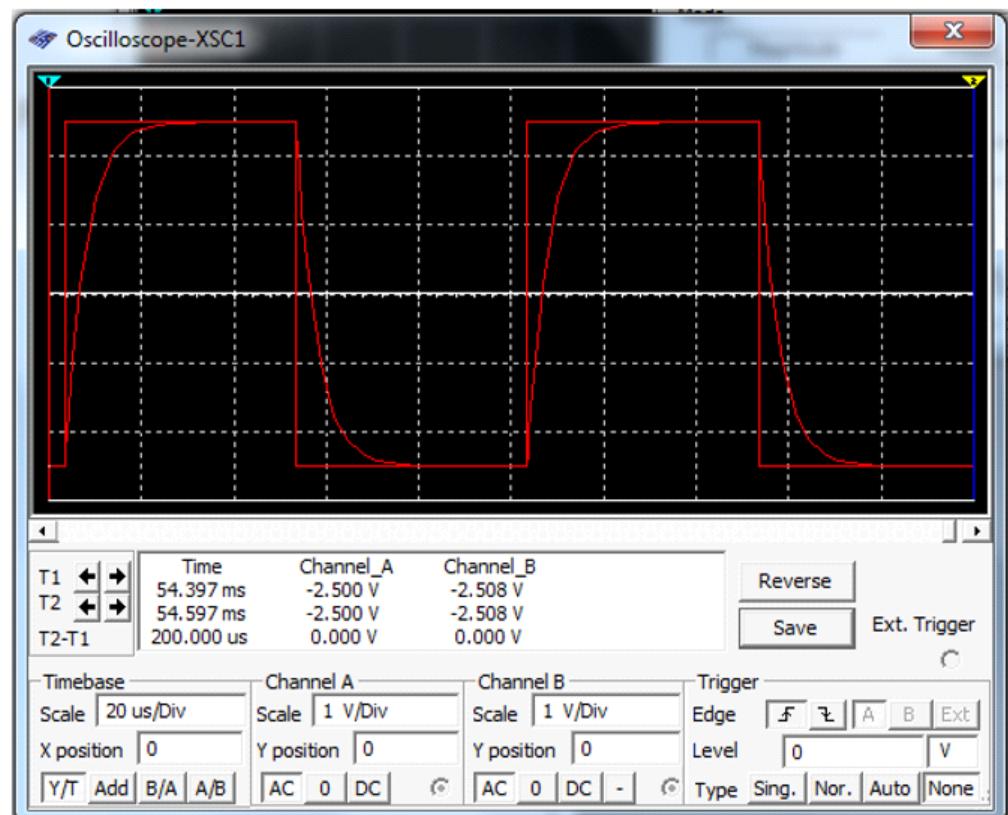
Rechtecksignal an TP

$R=2,2k\ \Omega$

$C=2nF$

$f=10kHz$

$\hat{U}_e=5V$



Ü-Bsp:

- RC-TP

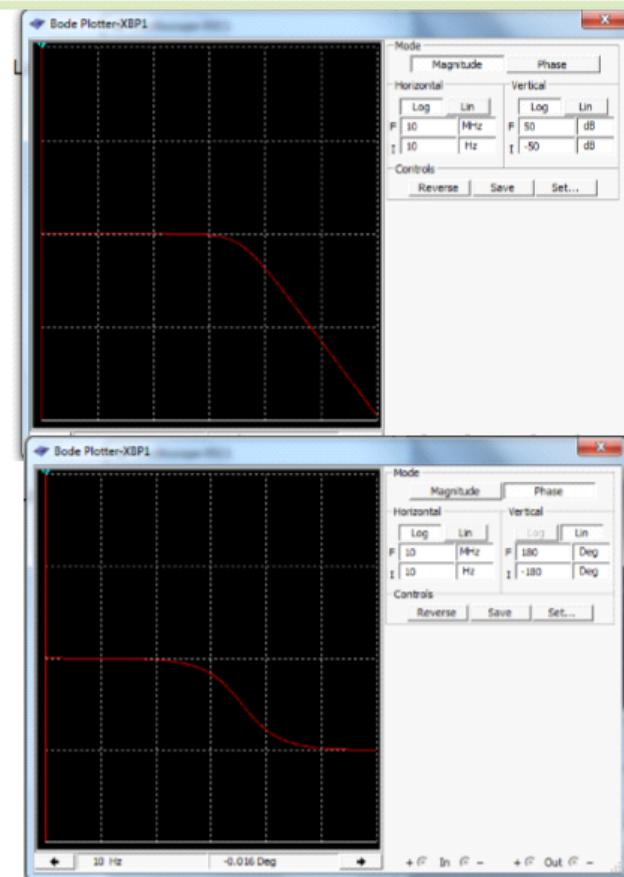
Bodediagramm

$R=2,2k\ \Omega$

$C=2nF$

$f=1kHz$

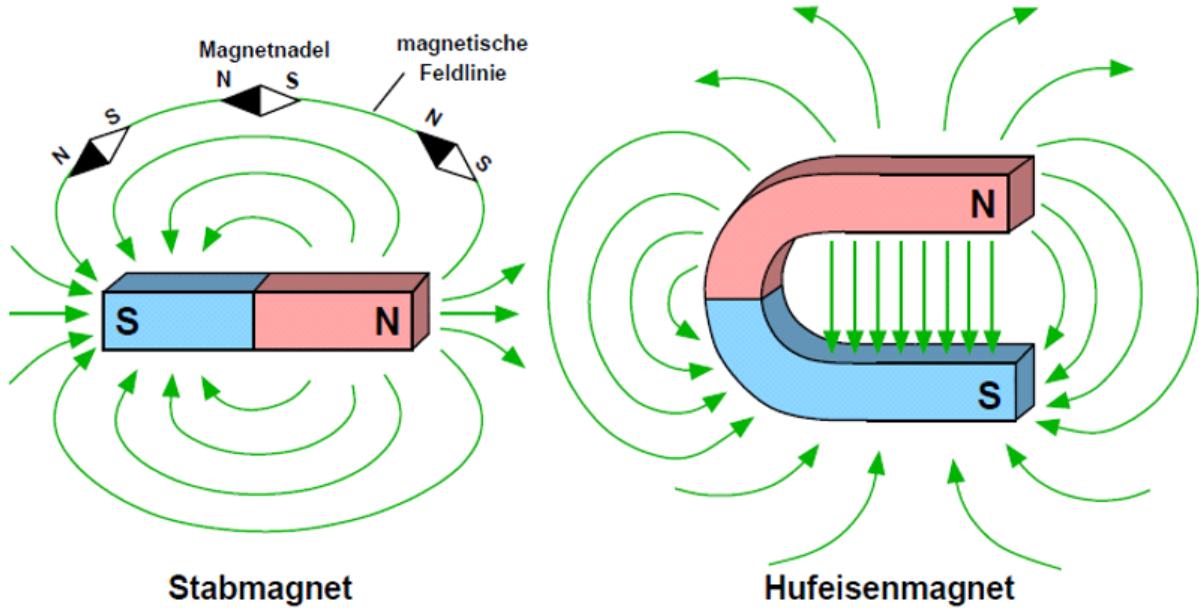
$\hat{U}_e=1V, \sin$



Magnetisches Feld

Magnetische Felder können durch Permanentmagneten oder durch stromdurchflossene Leiter hervorgerufen werden.

Permanentmagnet



Magnetisches Feld

- Materialien reagieren auf magnetische Felder durch die Ausrichtung der atomaren Elementarmagnete → **Magnetisierung**.
- Die damit einhergehende veränderte magnetische Wirkung wird durch eine neue Feldgröße, die **magnetische Flußdichte B** (auch **magnetische Induktion**) und eine Materialkonstante μ beschrieben:

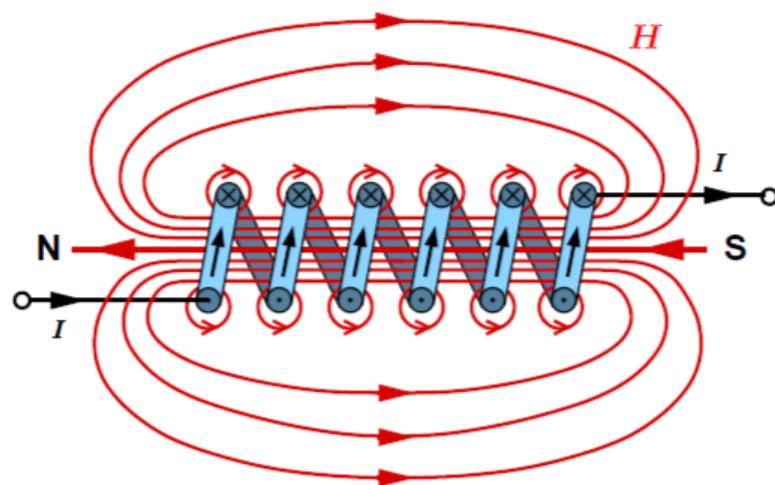
$$B = \mu H = \mu_0 \mu_r H \quad , \quad [B] = \frac{\text{Vs}}{\text{m}^2} \quad , \quad \mu_0 = 4\pi \cdot 10^{-7} \frac{\text{Vs}}{\text{Am}}$$

$\mu_r = \text{relative Permeabilitätskonstante}$

diamagnetische Stoffe	$\mu_r < 1$	z.B. Kupfer
paramagnetische Stoffe	$\mu_r > 1$	z.B. Aluminium
ferromagnetische Stoffe	$\mu_r \gg 1$	Eisen, Kobalt, Nickel

- In der Elektrotechnik spielen nur die ferromagnetischen Stoffe eine bedeutende Rolle. Für alle anderen kann von $\mu_r \approx 1$ ausgegangen werden.

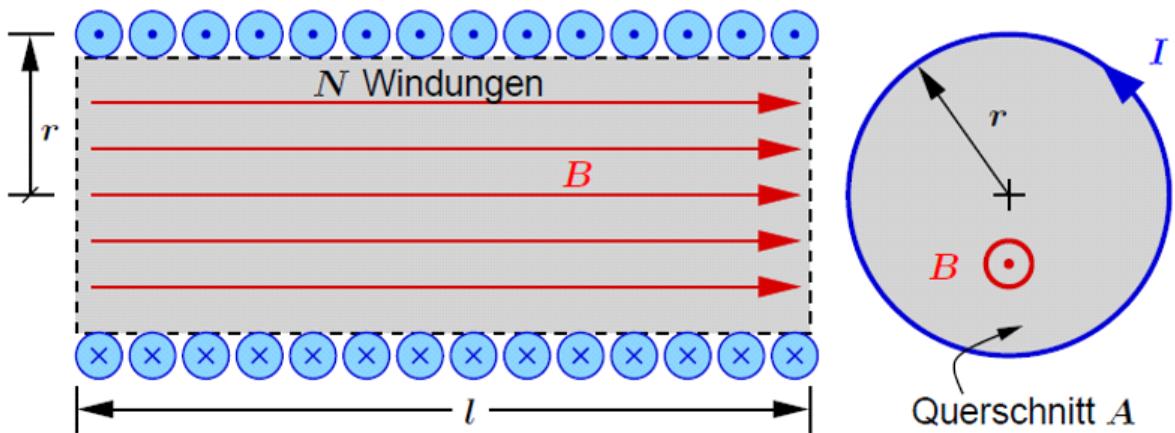
Magnetisches Feld einer Spule



Bei einer langen Spule mit vielen (N) Windungen ist das Magnetfeld innerhalb der Spule annähernd homogen und außerhalb vernachlässigbar:

$$H \cdot l = \text{Durchflutung } \Theta = N \cdot I \quad \rightarrow \quad H = \frac{NI}{l}$$

Selbstinduktivität einer Spule



Die **Selbstinduktivität** einer Spule ist die Proportionalitätskonstante zwischen dem verketteten magnetischen Fluß $N\Phi$ und dem Strom I :

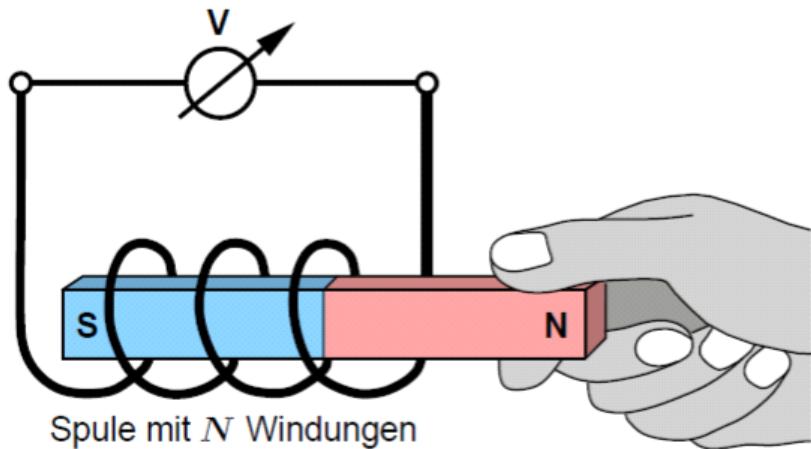
$$L = \frac{N\Phi}{I} \quad , \quad [L] = \frac{\text{Vs}}{\text{A}} = \text{H (Henry)}$$

$$L = \mu N^2 \frac{A}{l}$$

für die lange Spule

Induktionsgesetz

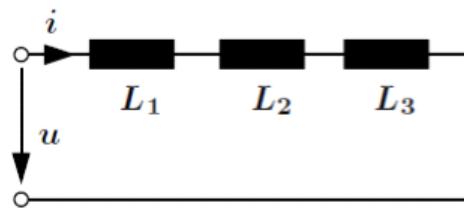
Faraday hat um 1831 ähnliche Versuche folgender Art durchgeführt:



Er fand heraus, daß die induzierte Klemmenspannung an der Spule proportional zur zeitlichen Änderung des mit der Spule verbundenen magnetischen Flusses ist:

$$\text{Induktionsgesetz} \quad u(t) = N \cdot \frac{d\Phi}{dt}$$

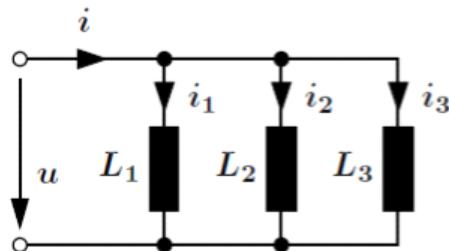
Reihen-/Parallelschaltung



Reihenschaltung

$$L_{ges} = L_1 + L_2 + L_3 + \dots$$

$$u = \underbrace{(L_1 + L_2 + L_3)}_{L_{ges}} \frac{di}{dt}$$



Parallelschaltung

$$\frac{1}{L_{ges}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots$$

$$\frac{di}{dt} = u \underbrace{\left(\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} \right)}_{1/L_{ges}}$$

Ü-Bsp:

- L parallel/seriell

Halbleitermaterialien

Ausschnitt aus dem Periodensystem der Elemente:

	II	III	IV	V	VI
2	9,0 Be 4	10,8 B 5	12,0 C 6	14,0 N 7	16,0 O 8
3	24,3 Mg 12	27,0 Al 13	28,1 Si 14	31,0 P 15	32,1 S 16
4	40,1 Ca 20	69,7 Ga 31	72,6 Ge 32	74,9 As 33	79,0 Se 34
5	87,6 Sr 38	114,8 In 49	118,7 Sn 50	121,8 Sb 51	127,6 Te 52
6	137,3 Ba 56	204,4 Tl 81	207,2 Pb 82	209,0 Bi 83	209 Po 84

Spez. Widerstand von Silizium bei 20° C:

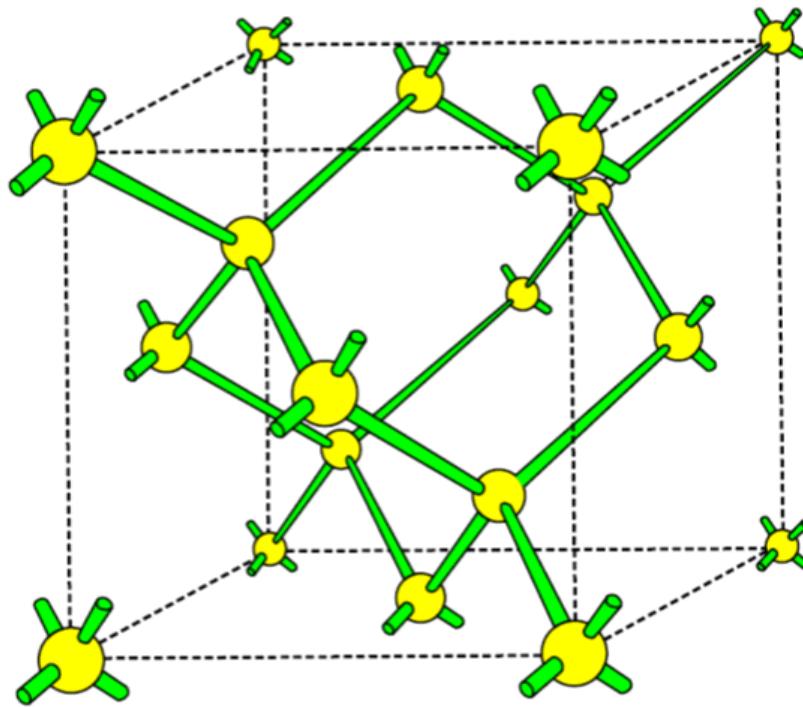
$$\rho_{\text{Si}} \approx 625 \Omega \text{m}$$

Stark temperaturabh.!
($T \uparrow \rightarrow \rho \downarrow$)

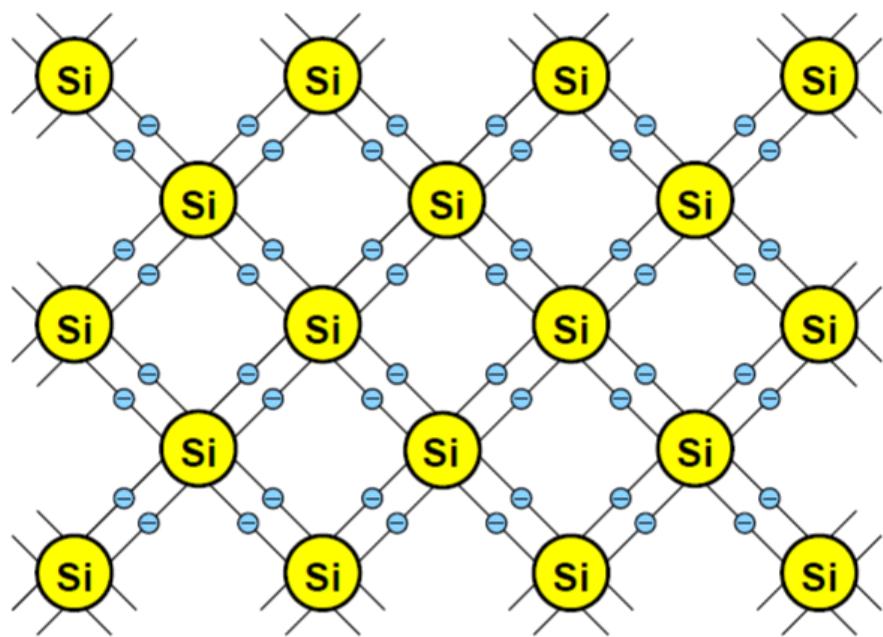
Zum Vergleich Kupfer:

$$\rho_{\text{Cu}} \approx 1.8 \cdot 10^{-8} \Omega \text{m}$$

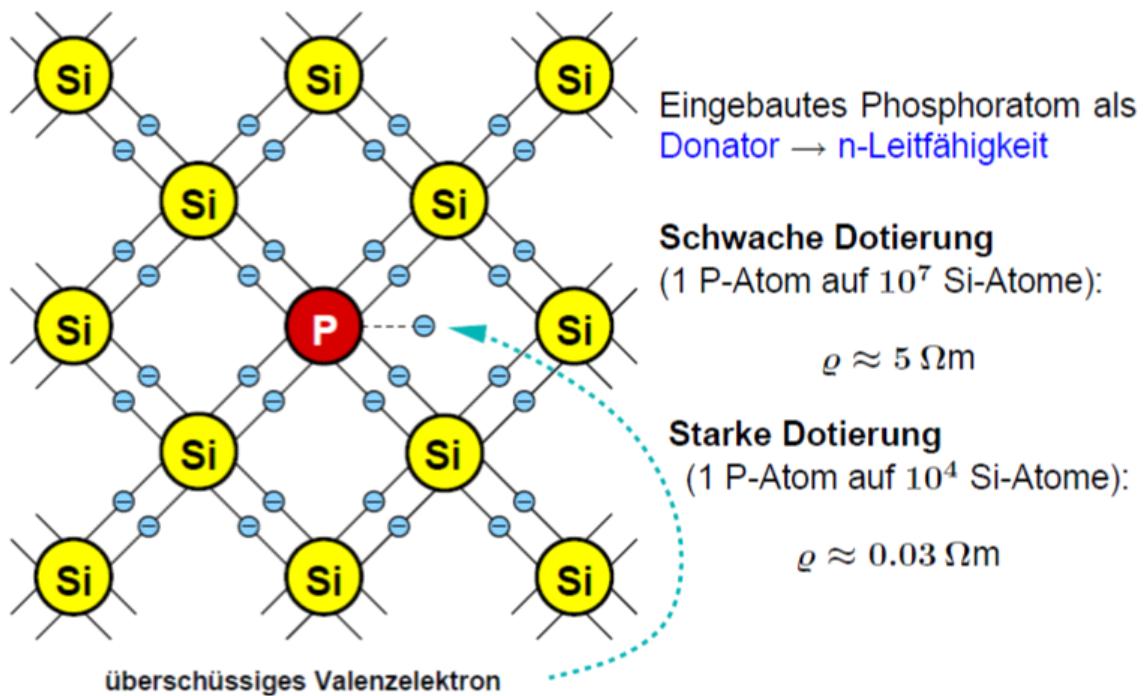
Si-Kristall



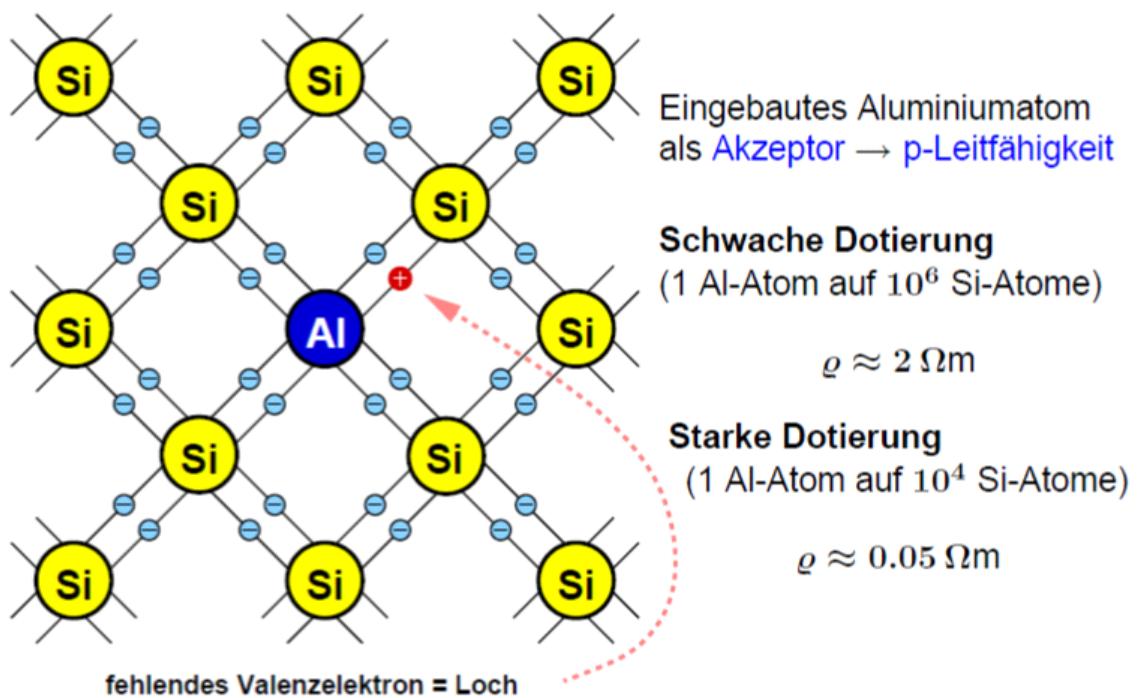
Si-Kristall



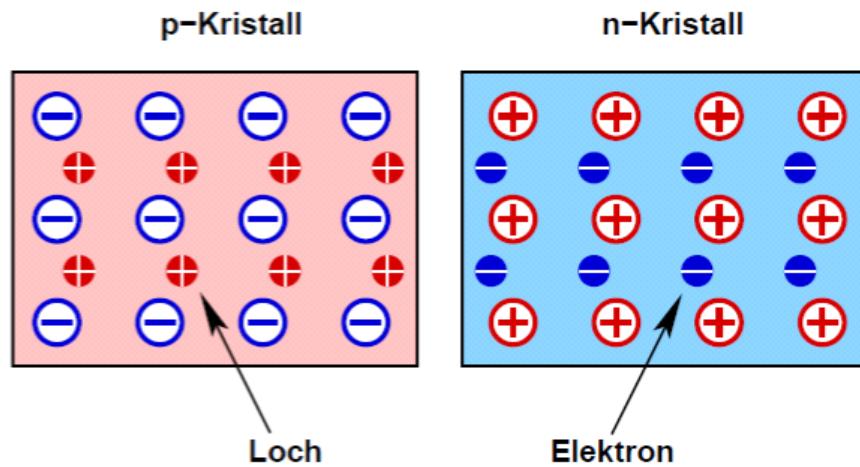
Dotierung mit Phosphor



Dotierung mit Aluminium

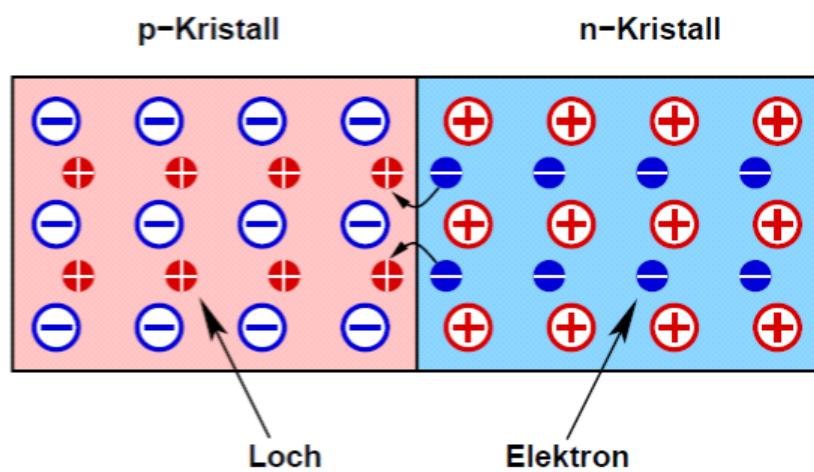


pn-Übergang



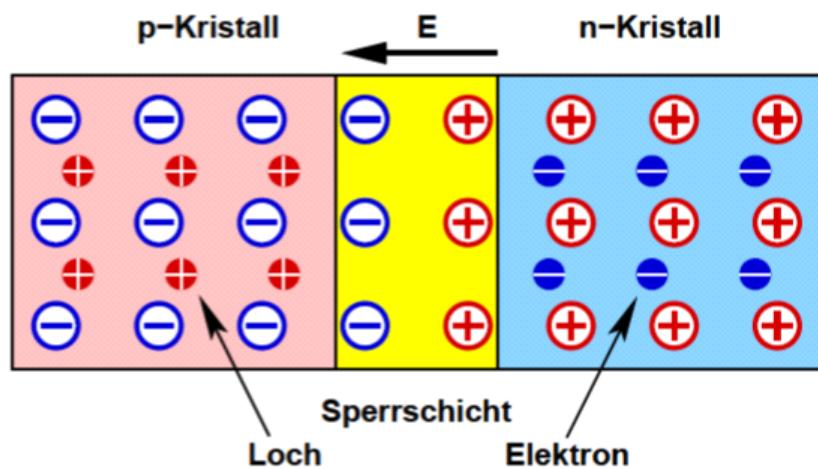
Als **pn-Übergang** bezeichnet man ein Gebiet, in dem ein p-leitendes Material und ein n-leitendes Material aneinandergrenzen. Dabei verändert sich das physikalische Verhalten bei Berührung der beiden Materialien ganz erheblich. Es entsteht eine Halbleiterdiode.

pn-Übergang ohne Spannung



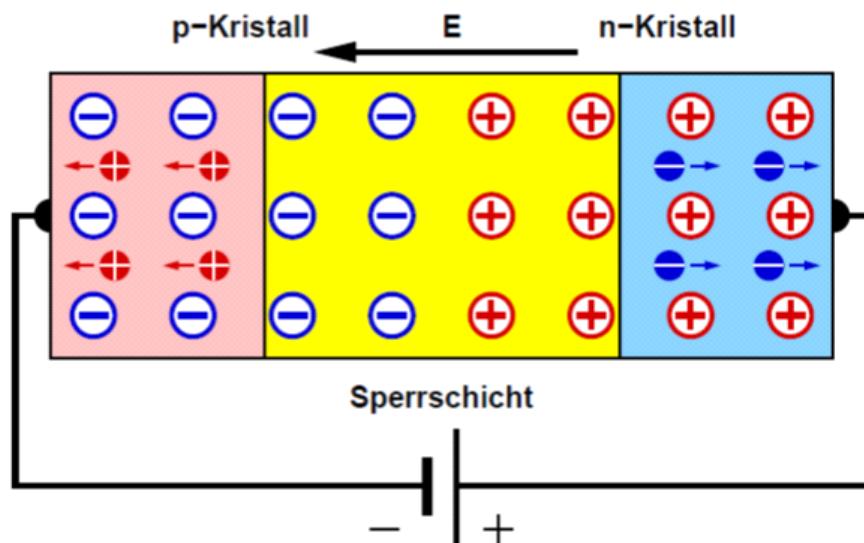
Bei Berührung beider Materialien **diffundieren** Elektronen aus dem n-Gebiet in das p-Gebiet und **rekombinieren** dort mit Löchern. Umgekehrt diffundieren aus dem p-Gebiet Löcher in das n-Gebiet und rekombinieren dort mit freien Elektronen.

pn-Übergang ohne Spannung



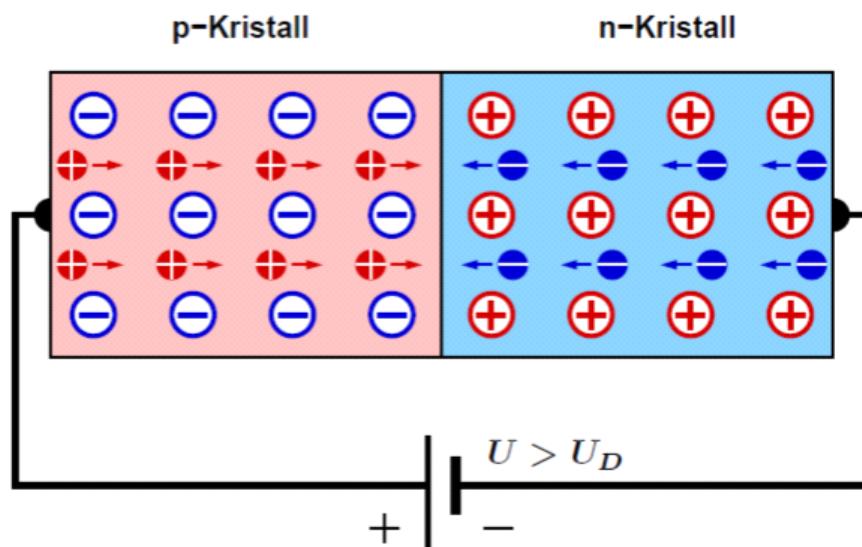
Durch die Diffusion freier Ladungsträger verbleiben im n-Gebiet positive Donator-Ionen und im p-Gebiet negative Akzeptor-Ionen. Das elektrische Feld dieser Ionen wirkt dem Diffusionsprozeß entgegen. Im Gleichgewicht bildet sich eine **Sperrsicht** aus, über der die **Diffusionsspannung U_D** abfällt ($U_D \approx 0.5 \dots 0.8 \text{ V}$ bei Silizium).

pn-Übergang mit Spannung



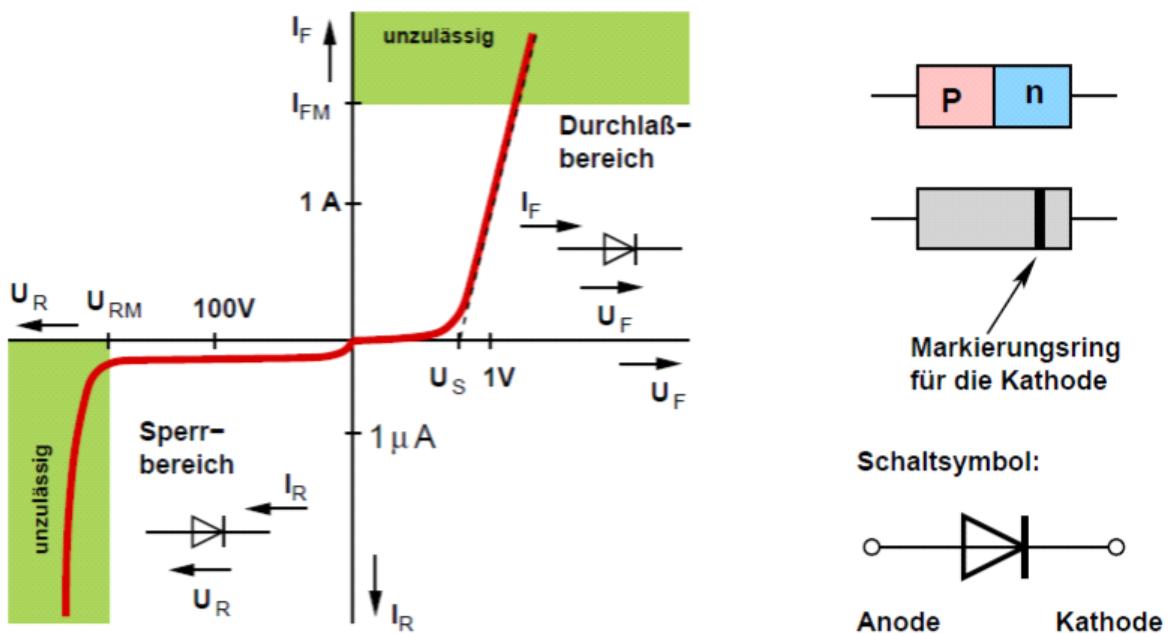
Durch Anlegen einer **äußereren Spannung in Sperr-Richtung** (Pluspol an n, Minuspol an p) wird das Feld in der Sperrsicht verstärkt → die Sperrsicht vergrößert sich → der pn-Übergang sperrt!

pn-Übergang mit Spannung

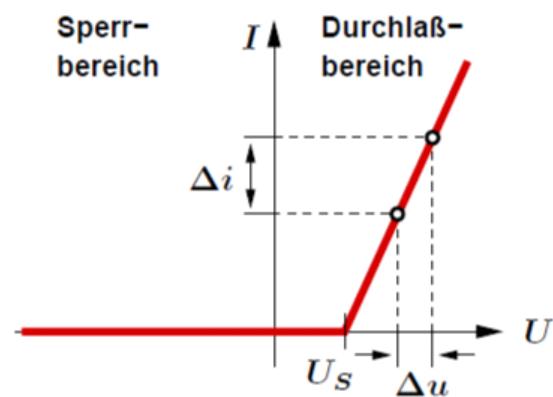


Durch Anlegen einer äußeren Spannung in Durchlaß-Richtung (Pluspol an p, Minuspol an n) wird die Sperrsicht von Ladungsträgern überschwemmt → die Sperrsicht verschwindet für $U > U_D \rightarrow$ Stromfluß!

Diodenkennlinie



Diodenkennlinie



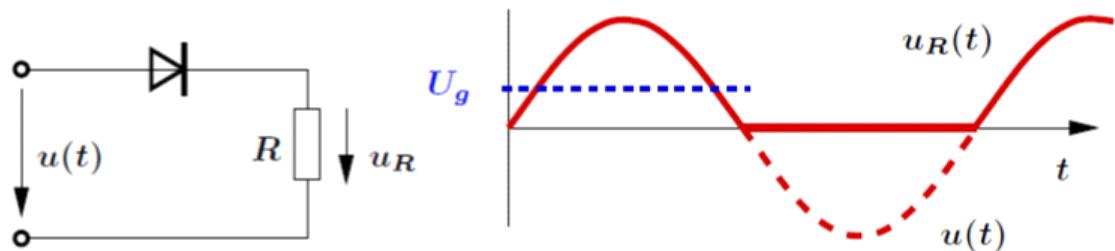
Schwellspannung $U_S \approx 0.8 \text{ V}$

Differentieller Widerstand:

$$r_D = \frac{\Delta u}{\Delta i}$$

Einwegschaltung

Gleichrichtung einer Wechselspannung mit Hilfe einer Diode (als ideal angenommen):

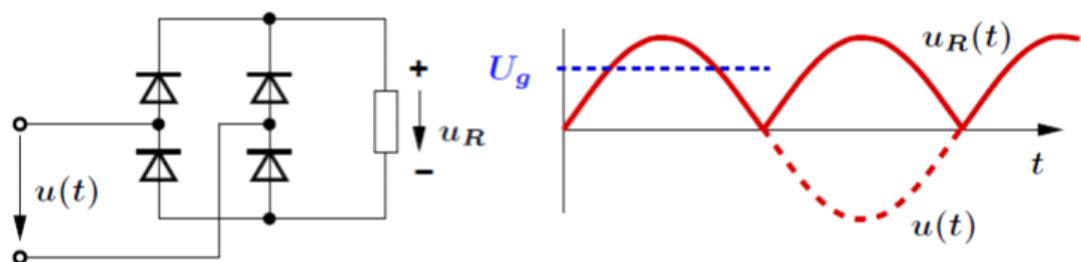


Mittelwert von $u_R(t)$: $U_g = 0.45 \cdot U$

U : Effektivwert der Wechselspannung

Zweiwegbrückenschaltung

Gleichrichtung einer Wechselspannung mit Hilfe einer Diodenbrückenschaltung (Dioden als ideal angenommen):

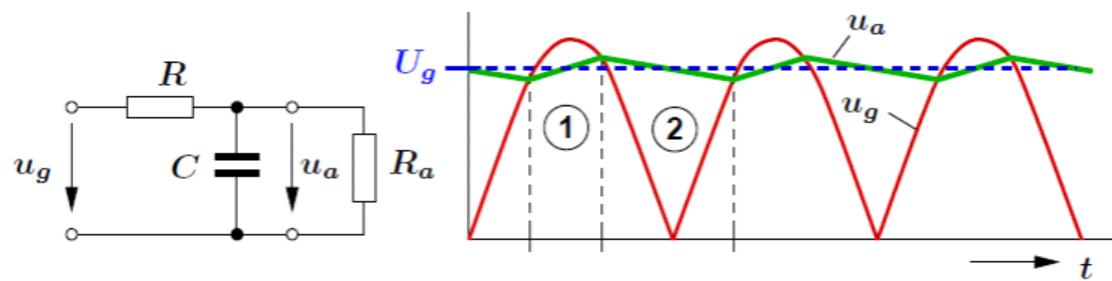


Mittelwert von $u_R(t)$: $U_g = 0.9 \cdot U$

U : Effektivwert der Wechselspannung

Zweiwegschaltung mit Glättungskondensator

Mit einem **Tiefpaß** lässt sich die Spannung am Ausgang der Zweiwegbrückenschaltung glätten:



- ① Kondensator wird aufgeladen
- ② Entladenvorgang

Dioden für spezielle Anwendungen

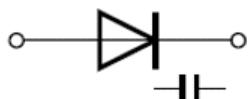
Für Halbleiterdioden existieren neben dem Einsatz als Gleichrichterbauteil zahlreiche weitere Spezialanwendungen:

- Zenerdiode



Wird in Sperr-Richtung betrieben. Ist so konstruiert, daß sie beim Überschreiten der Durchbruchspannung nicht zerstört wird. Die sog. Zenerspannung, bei der der Durchbruch stattfindet, liegt bei 4.5 . . . 30 V. Anwendung: [Spannungsstabilisierung](#).

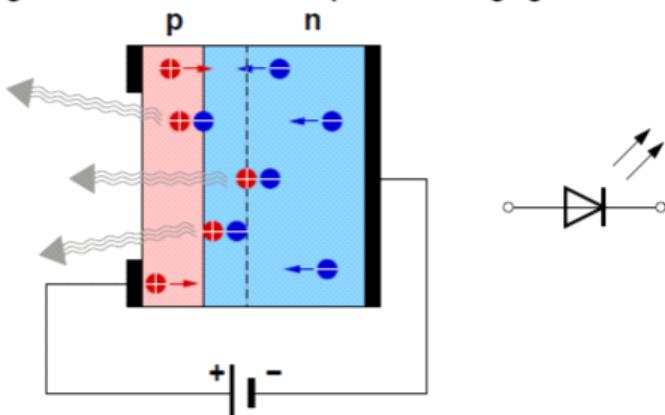
- Kapazitätsdiode



Wird in Sperr-Richtung aber unterhalb des Durchbruchs betrieben. Durch Änderung der Spannung ändert sich die Breite der Sperrschicht und damit die Kapazität des pn-Übergangs. Anwendung: [Abstimmung von Schwingkreisen](#).

LED

Durch Rekombination von freien Elektronen und Löchern am pn-Übergang einer in Durchlaßrichtung betriebenen Diode wird die frei werdende Energie in Form von Lichtquanten abgegeben.



Die Kristallart und Dotierung bestimmen die Farbe des Lichtes.

GaAs

→ infrarot

GaAsP

→ rot bis gelb

GaP mit Zink u. Sauerstoffdotierung

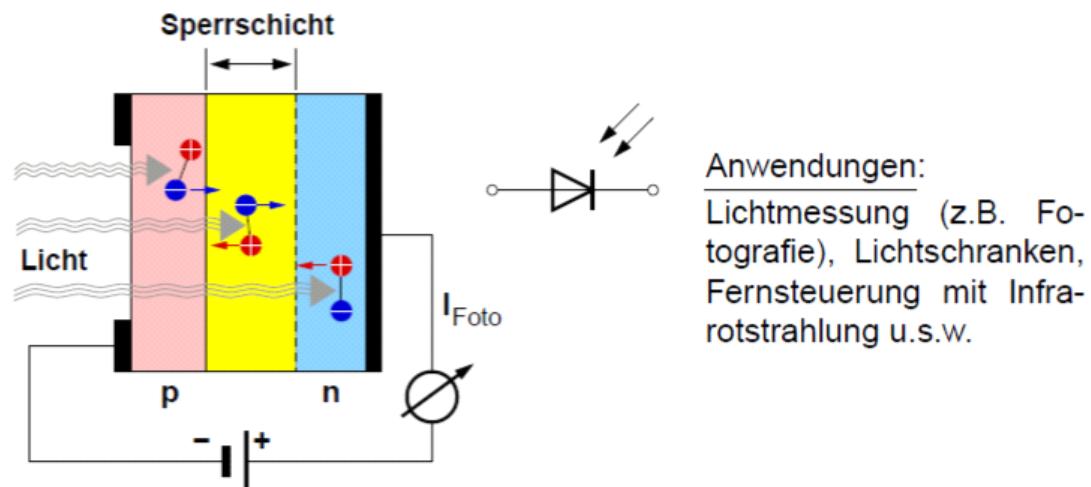
→ rot

GaP mit Stickstoffdotierung

→ grün und gelb

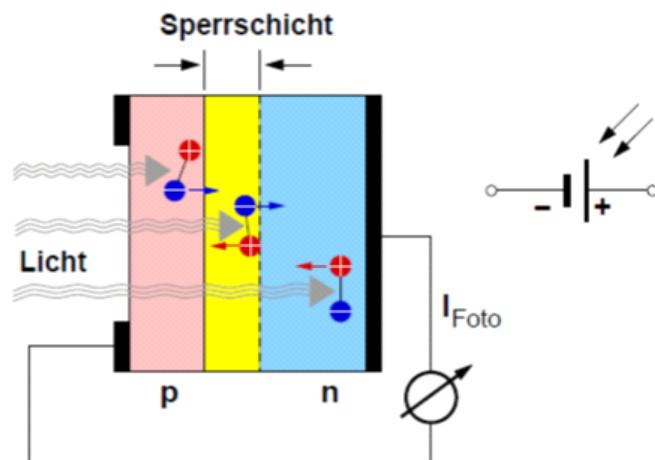
Fotodiode

Einfallendes Licht löst Elektronen aus der Gitterbindung → zusätzliche freie Elektronen und Löcher, die zur Sperrsicht wandern und den Sperrstrom (=Fotostrom) eines in Sperr-Richtung betriebenen pn-Übergangs proportional zur Lichtintensität erhöhen:



Fotoelement

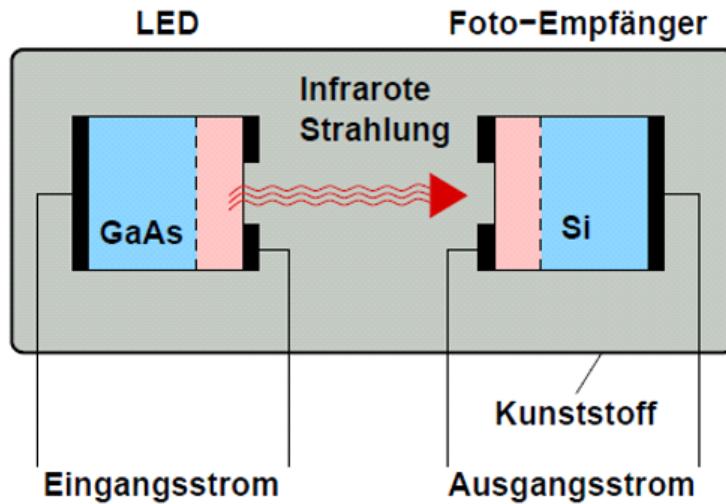
Arbeitet im Gegensatz zur Fotodiode ohne äußere Spannung. Durch Lichteinfall erzeugte Elektronen und Löcher werden durch das innere Feld der Sperrsicht getrennt → Fotostrom



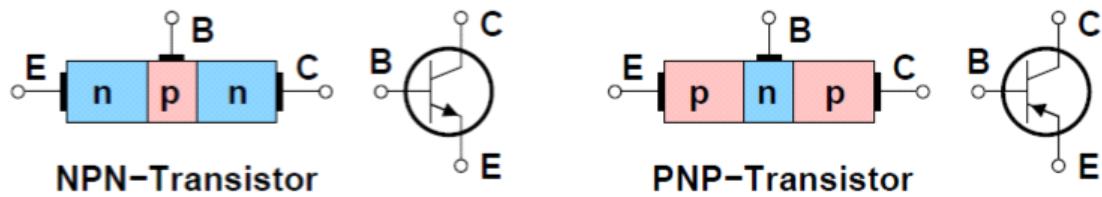
Solarzelle=Silizium-Fotoelement. (4 cm^2 liefern etwa 60 mW)
Erzeugung elektrischer Energie mit einem Wirkungsgrad von nahe 20% .

Optokoppler

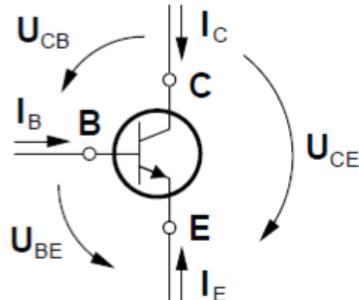
Wie beim Relais (nur ohne mechanische Abnutzung) lässt sich mit Hilfe eines Optokopplers eine galvanische Trennung zweier Stromkreise erreichen:



BipTransistor

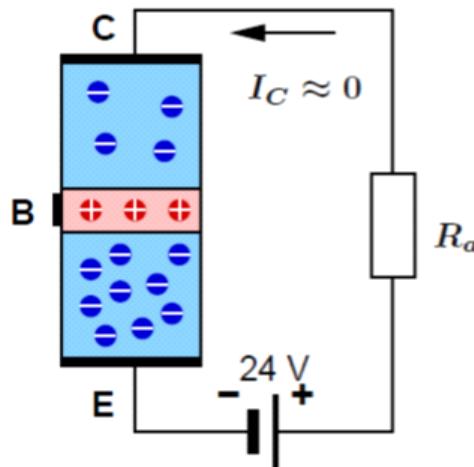


B Basis
E Emitter
C Kollektor

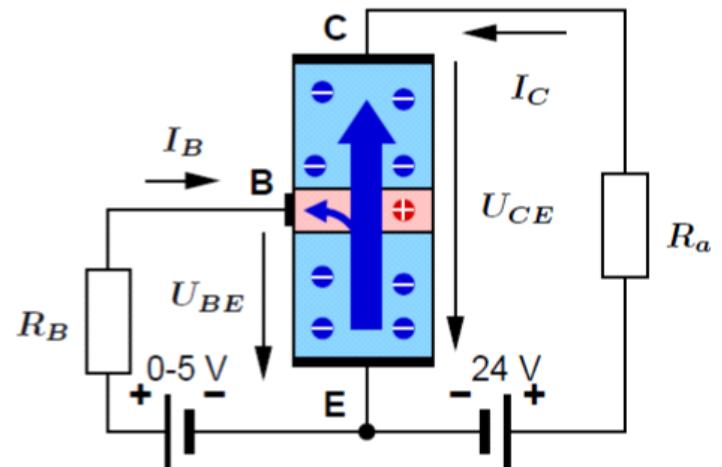


Die folgenden Betrachtungen beschränken sich auf NPN-Transistoren. Bei PNP-Transistoren sind lediglich die Vorzeichen sämtlicher Ströme und Spannungen umzukehren.

BipTransistor-Funktionsprinzip



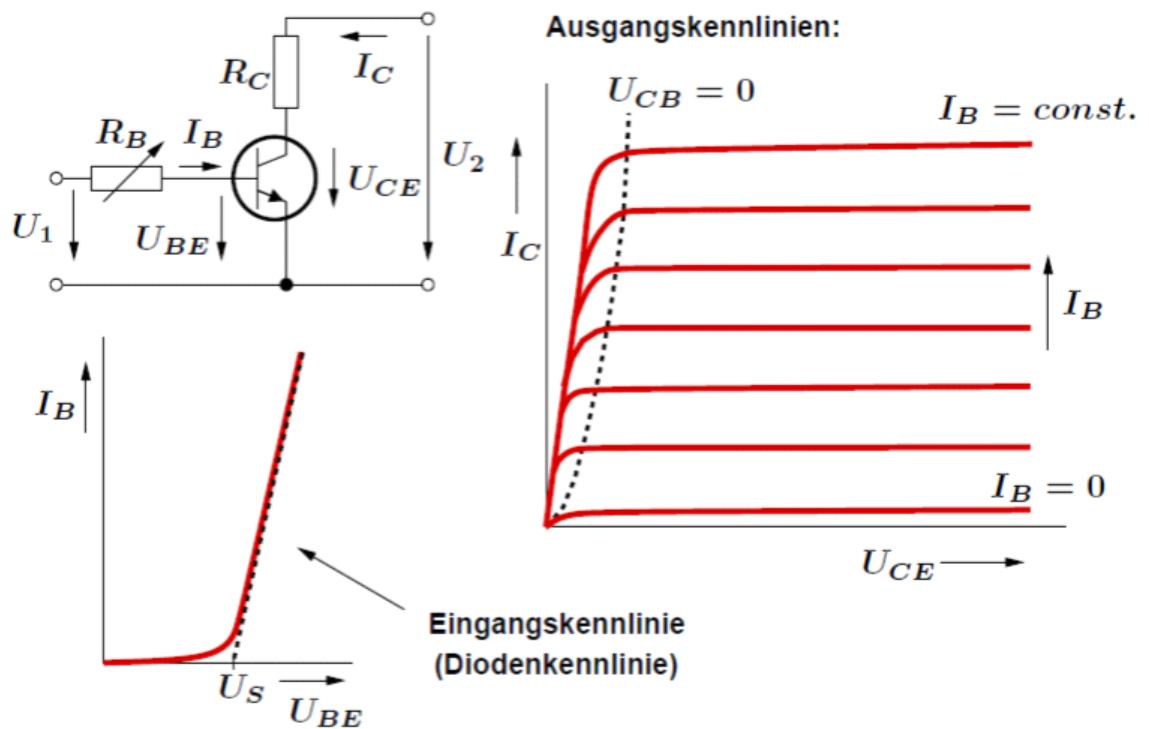
Transistor mit $I_B = 0$



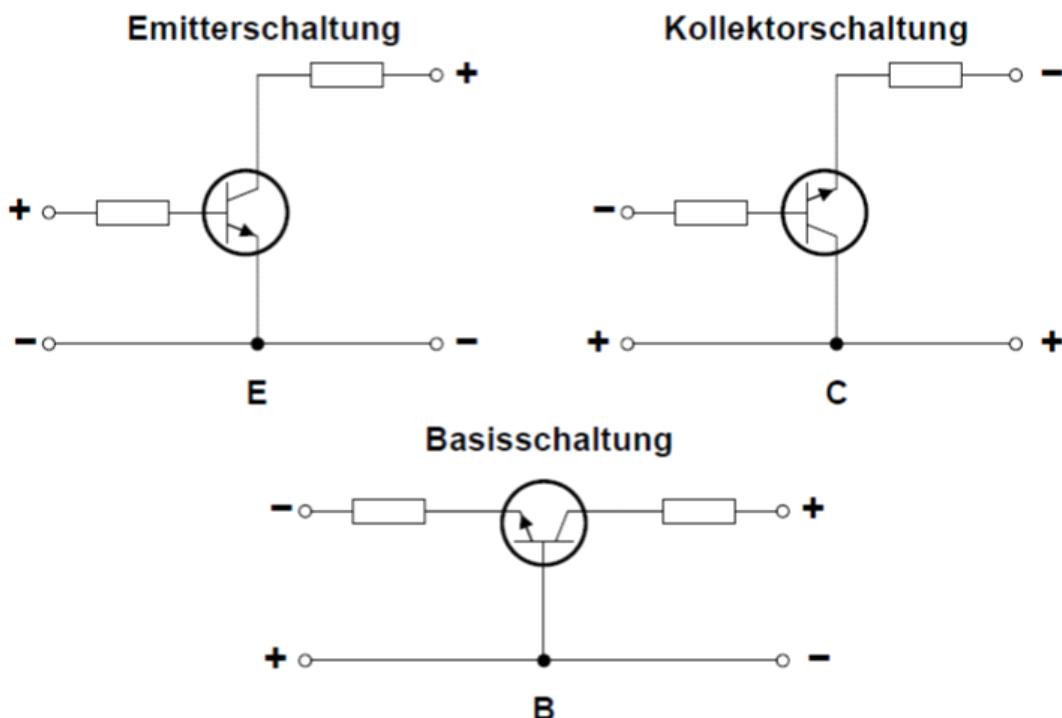
Transistor mit $I_B > 0$

$I_B > 0 \rightarrow$ Basis-Emitter-Diode durchlässig \rightarrow ca. 99% der Elektronen "rutschen" dabei vom Emitter zum Kollektor durch, der kleine Rest bleibt in der dünnen Basis hängen und fließt über R_B ab \rightarrow ein kleiner Strom I_B bewirkt einen hohen Ausgangsstrom I_C .

BipTransistor-Kennlinien

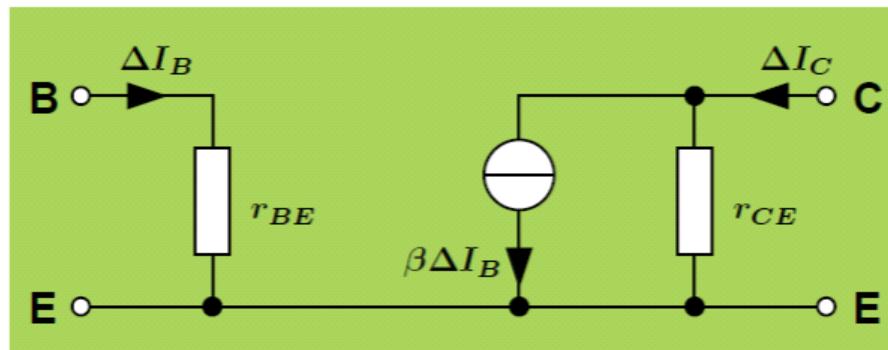


Transistorgrundschaltungen



ESB des BipT

Unter der Voraussetzung, daß die Eingangskennlinie eines bipolaren Transistors $I_B = f(U_{BE})$ unabhängig von der Kollektoremitterspannung U_{CE} ist, läßt sich bei niedrigen Frequenzen und für $\Delta I_B \ll I_B$, $\Delta I_C \ll I_C$ ein einfaches Wechselstromersatzschaltbild angeben:

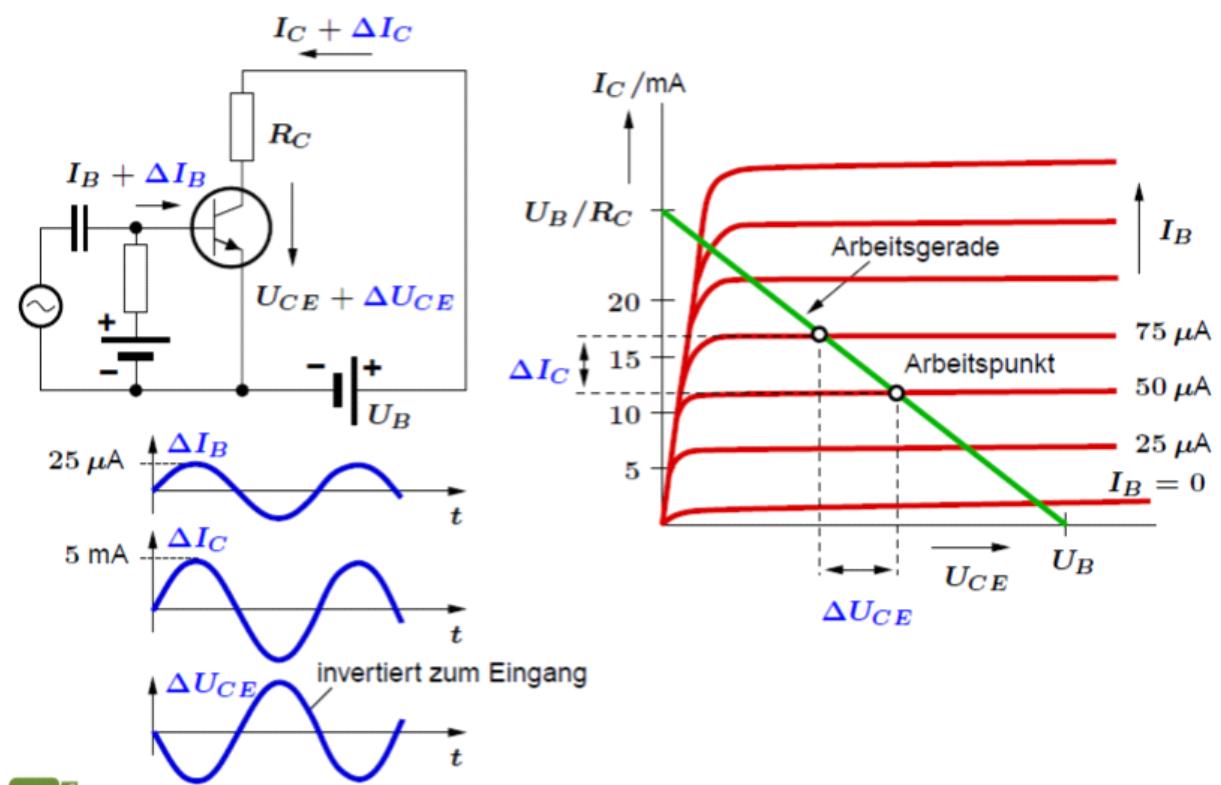


Wechselstromverstärkung: $\beta = \Delta I_C / \Delta I_B \Big|_{\text{Arbeitspunkt}}$

differentieller Eingangswiderstand: $r_{BE} = \Delta U_{BE} / \Delta I_B \Big|_{\text{Arbeitspunkt}}$

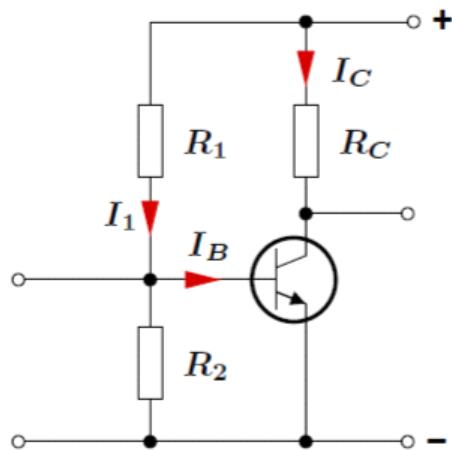
differentieller Ausgangswiderstand: $r_{CE} = \Delta U_{CE} / \Delta I_C \Big|_{\text{Arbeitspunkt}}$

BipTransistor als Verstärker



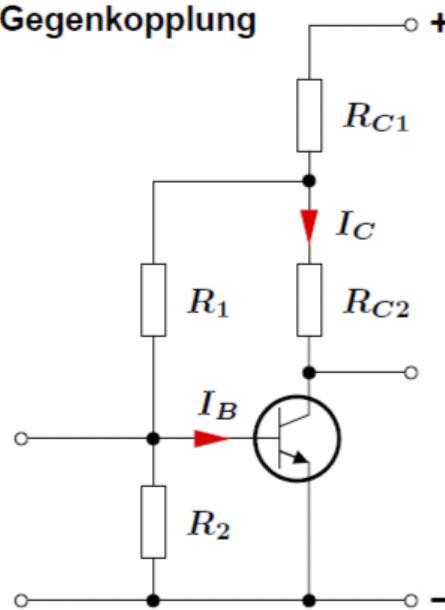
Einstellen des Arbeitspunktes

Basisspannungsteiler



$$I_1 > 10 I_B$$

Gegenkopplung

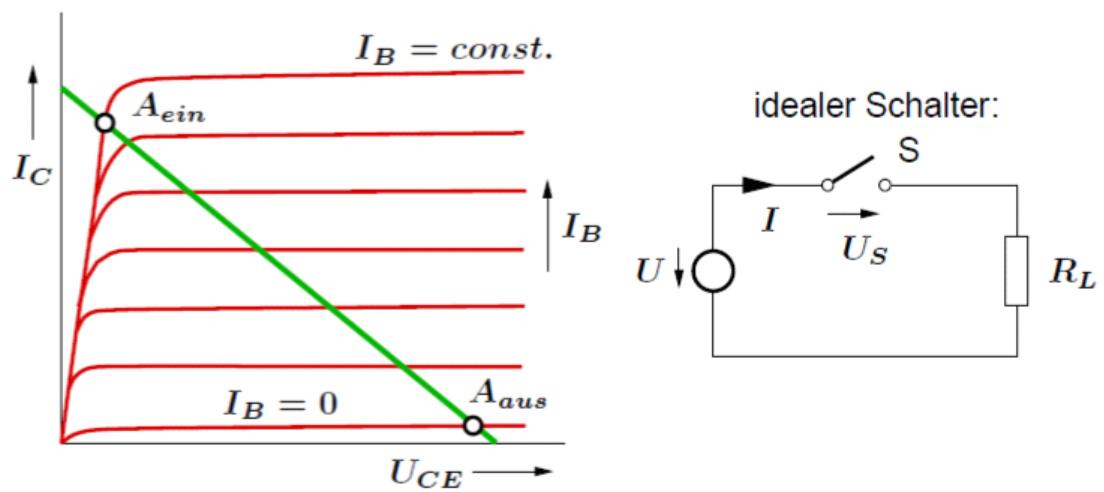


$$T \uparrow \rightarrow I_B \uparrow \rightarrow I_C \uparrow \rightarrow U_{R_{C1}} \uparrow \rightarrow I_B \downarrow$$

Ü-Bsp:

- Transistor Arbeitspunkteinstellung

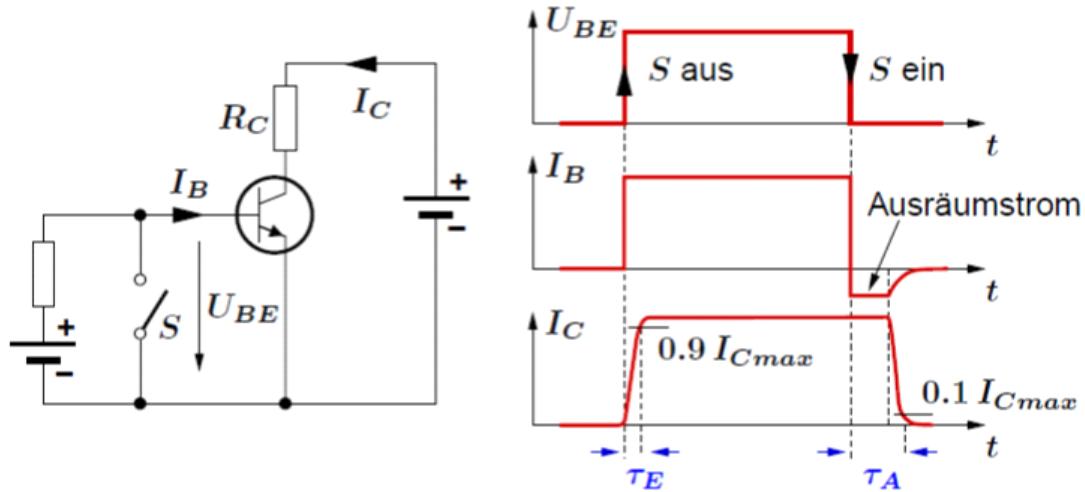
BipTransistor als Schalter



$U_{CE} \neq 0$ für A_{ein}
 $I_C \neq 0$ für A_{aus}

S geschlossen → $U_S = 0$
 S offen → $I = 0$

Schaltzeiten beim Transistor-Schalter



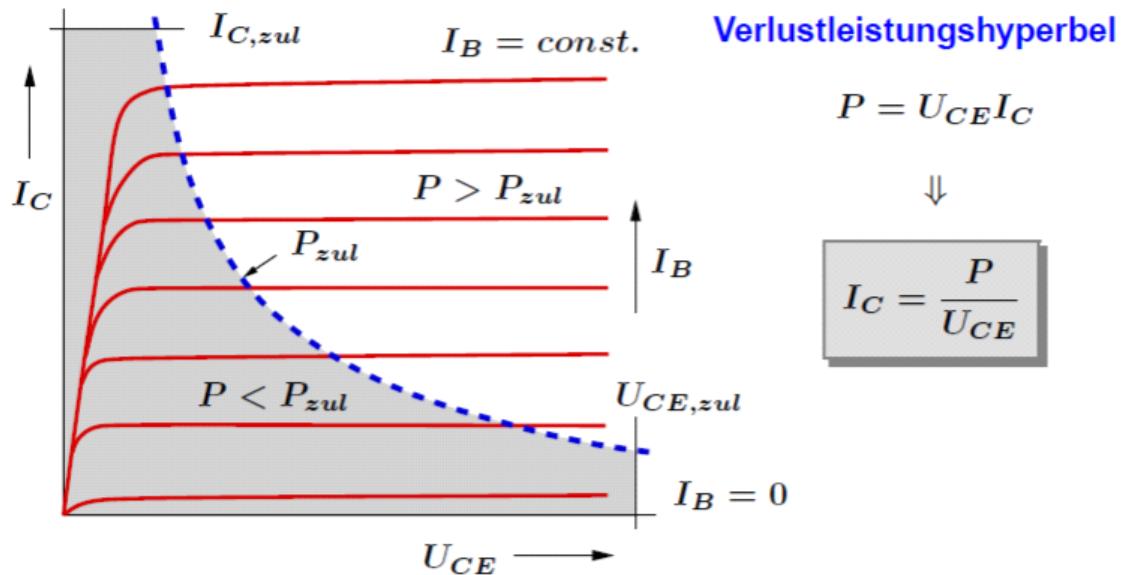
Verzögerungszeiten:

τ_E : Einschaltzeit bis zum Erreichen von $0.9 I_{Cmax}$

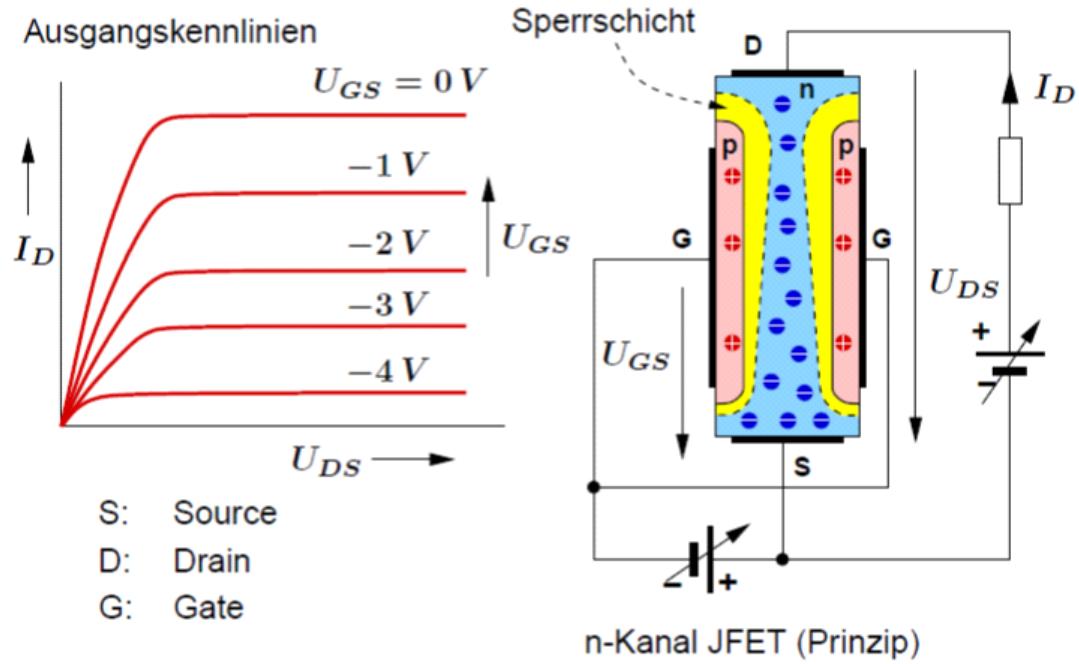
τ_A : Ausschaltzeit bis zum Absinken auf $0.1 I_{Cmax}$

Belastbarkeit

begrenzt durch zulässigen Kollektorstrom bei A_{ein} , zulässige Kollektoremitterspannung bei A_{aus} und zulässige Verlustleistung.

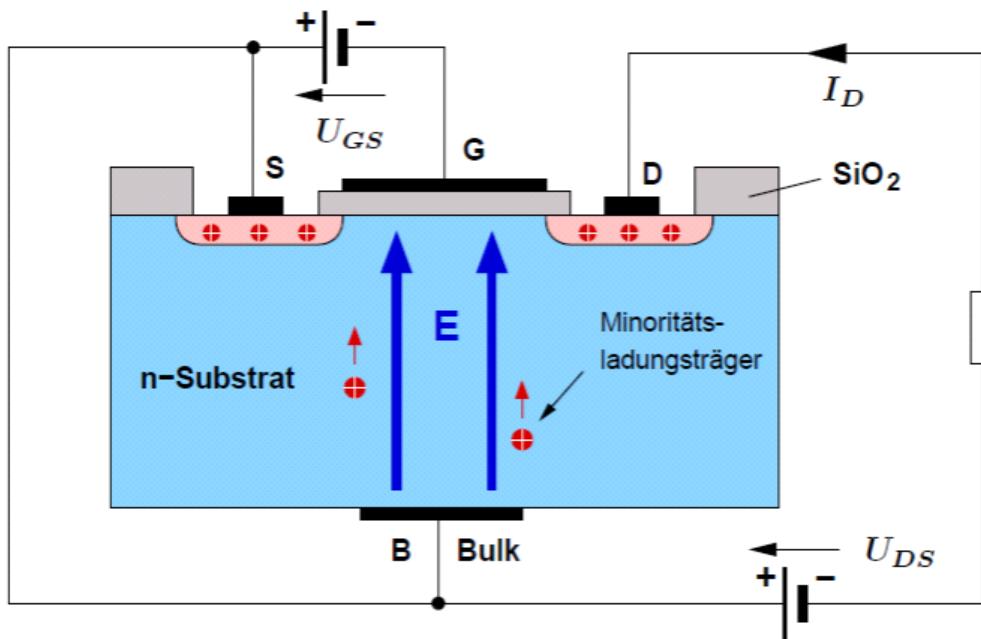


JFET



Warum wird die Sperrsicht in Richtung Drain breiter?

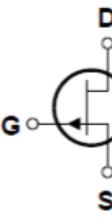
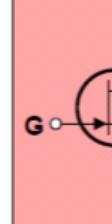
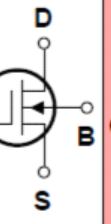
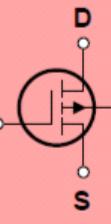
MOSFET



Minoritätsladungsträger bilden für $U_{GS} < 0$ unter dem Gate einen dünnen, p-leitenden Kanal $\rightarrow I_D \neq 0$

Schaltzeichen FET

Bisher wurde der n-Kanal JFET sowie der selbstsperrende p-Kanal MOSFET behandelt. Daneben gibt es noch weitere übliche Bauformen:

JFET		MOSFET			
p-Kanal	n-Kanal	Verarmungstyp (selbstleitend)		Anreicherungstyp (selbstsperrend)	
p-Kanal	n-Kanal	p-Kanal	n-Kanal	p-Kanal	n-Kanal
					

Bitte für später (CMOS-NAND-Gatter) einprägen:

- selbstsperrender p-Kanal MOSFET benötigt negative Spannung zwischen Gate und Source für geöffneten Drain-Source-Kanal.
- selbstsperrender n-Kanal MOSFET benötigt positive Spannung zwischen Gate und Source für geöffneten Drain-Source-Kanal.

Digitale Schaltungen

- Ein analoges Signal verändert sich kontinuierlich. Um analoge Signale mit einem Computer zu verarbeiten, werden sie mit Hilfe eines ADU (Analog-Digital-Umsetzer) digitalisiert, d.h. zeitlich und amplitudenmäßig quantisiert.
- In digitalen Schaltungen treten nur 2 binäre Zustände auf:
 - H = High = hoher Spannungspiegel
 - L = Low = niedriger Spannungspiegel
- Den binären Zuständen werden logische Zustände zugeordnet. Bei positiver Logik gilt $0=L$ und $1=H$.
- Ein binärer Zustand ist die kleinste Informationsmenge in einer digitalen Schaltung. Als kleinste Informationseinheit bezeichnet man das Bit (Binary Digit), dessen Wert (0 oder 1) den Zustand angibt.
- Um mehr als 2 verschiedene Amplitudenwerte eines abgetasteten Signals darstellen zu können, müssen mehrere Bits zu einem Wort zusammengefaßt werden.

Digitale Schaltungen

2 Bit-Wort → $2^2 = 4$ Zustände (00, 01, 10, 11)

3 Bit-Wort → $2^3 = 8$ Zustände

4 Bit-Wort → $2^4 = 16$ Zustände

:

8 Bit-Wort → $2^8 = 256$ Zustände

:

16 Bit-Wort → $2^{16} = 65.536$ Zustände

1 Byte = 8 Bit

1 KibiByte (KiB) = 2^{10} Byte = 1.024 Byte

1 MebiByte (MiB) = 2^{20} Byte = 1.048.576 Byte

1 GibiByte (GiB) = 2^{30} Byte = 1.073.741.824 Byte

1 TebiByte (TiB) = 2^{40} Byte = 1.099.511.627.776 Byte

Digitale Schaltungen

Ein Schaltnetz ist ein Netz aus elementaren logischen Schaltgliedern, so genannten **Gattern**. Es bestimmt den logischen Ausgangszustand Y in Abhängigkeit von einem oder mehreren binären Eingangssignalen.



Die Funktion des Schaltnetzes geht aus der [Wahrheitstabelle](#) hervor, die theoretisch mit Hilfe der [Boolschen Algebra](#) analysiert wird.

Ziel der Analyse ist die Realisierung des Schaltnetzes aus elementaren Logikgattern.

Logische Grundverknüpfungen

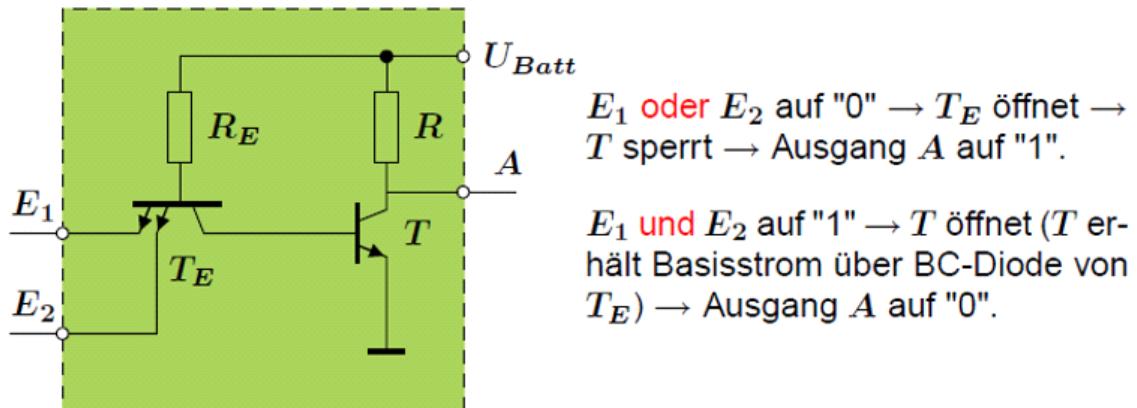
		DIN	US-Norm	veraltet																
Konjunktion AND	$Y = A \wedge B$	A —>  —> Y	A —>  —> Y	A —>  —> Y	<table border="1"> <thead> <tr> <th>A</th><th>B</th><th>Y</th></tr> </thead> <tbody> <tr><td>0</td><td>0</td><td>0</td></tr> <tr><td>0</td><td>1</td><td>0</td></tr> <tr><td>1</td><td>0</td><td>0</td></tr> <tr><td>1</td><td>1</td><td>1</td></tr> </tbody> </table>	A	B	Y	0	0	0	0	1	0	1	0	0	1	1	1
A	B	Y																		
0	0	0																		
0	1	0																		
1	0	0																		
1	1	1																		
Disjunktion OR	$Y = A \vee B$	A —>  —> Y	A —>  —> Y	A —>  —> Y	<table border="1"> <thead> <tr> <th>A</th><th>B</th><th>Y</th></tr> </thead> <tbody> <tr><td>0</td><td>0</td><td>0</td></tr> <tr><td>0</td><td>1</td><td>1</td></tr> <tr><td>1</td><td>0</td><td>1</td></tr> <tr><td>1</td><td>1</td><td>1</td></tr> </tbody> </table>	A	B	Y	0	0	0	0	1	1	1	0	1	1	1	1
A	B	Y																		
0	0	0																		
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1	1	1																		
Negation NOT	$Y = \overline{A}$	A —>  —> Y	A —>  —> Y	A —>  —> Y	<table border="1"> <thead> <tr> <th>A</th><th>Y</th></tr> </thead> <tbody> <tr><td>0</td><td>1</td></tr> <tr><td>1</td><td>0</td></tr> </tbody> </table>	A	Y	0	1	1	0									
A	Y																			
0	1																			
1	0																			
NAND	$Y = \overline{A \wedge B}$	A —>  —> Y	A —>  —> Y	A —>  —> Y	<table border="1"> <thead> <tr> <th>A</th><th>B</th><th>Y</th></tr> </thead> <tbody> <tr><td>0</td><td>0</td><td>1</td></tr> <tr><td>0</td><td>1</td><td>1</td></tr> <tr><td>1</td><td>0</td><td>1</td></tr> <tr><td>1</td><td>1</td><td>0</td></tr> </tbody> </table>	A	B	Y	0	0	1	0	1	1	1	0	1	1	1	0
A	B	Y																		
0	0	1																		
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1	1	0																		
NOR	$Y = \overline{A \vee B}$	A —>  —> Y	A —>  —> Y	A —>  —> Y	<table border="1"> <thead> <tr> <th>A</th><th>B</th><th>Y</th></tr> </thead> <tbody> <tr><td>0</td><td>0</td><td>1</td></tr> <tr><td>0</td><td>1</td><td>0</td></tr> <tr><td>1</td><td>0</td><td>0</td></tr> <tr><td>1</td><td>1</td><td>0</td></tr> </tbody> </table>	A	B	Y	0	0	1	0	1	0	1	0	0	1	1	0
A	B	Y																		
0	0	1																		
0	1	0																		
1	0	0																		
1	1	0																		

Boolsche Algebra

Kommutativ- gesetz	$X_1 \wedge X_2 = X_2 \wedge X_1$	$X_1 \vee X_2 = X_2 \vee X_1$
Assoziativ- gesetz	$\begin{aligned} X_1 \wedge X_2 \wedge X_3 &= \\ &= X_1 \wedge (X_2 \wedge X_3) \\ &= (X_1 \wedge X_2) \wedge X_3 \\ &= (X_1 \wedge X_3) \wedge X_2 \end{aligned}$	$\begin{aligned} X_1 \vee X_2 \vee X_3 &= \\ &= X_1 \vee (X_2 \vee X_3) \\ &= (X_1 \vee X_2) \vee X_3 \\ &= (X_1 \vee X_3) \vee X_2 \end{aligned}$
Distributiv- gesetz	$\begin{aligned} X_1 \wedge (X_2 \vee X_3) &= (X_1 \wedge X_2) \vee (X_1 \wedge X_3) \\ X_1 \vee (X_2 \wedge X_3) &= (X_1 \vee X_2) \wedge (X_1 \vee X_3) \end{aligned}$	
Gesetze von De Morgan	$\overline{X_1 \wedge X_2} = \overline{X_1} \vee \overline{X_2}$	$\overline{X_1 \vee X_2} = \overline{X_1} \wedge \overline{X_2}$
Spezielle Verknüpfungen	$\begin{aligned} X \wedge X &= X \\ X \wedge \overline{X} &= 0 \\ X \wedge 1 &= X \\ X \wedge 0 &= 0 \end{aligned}$	$\begin{aligned} X \vee X &= X \\ X \vee \overline{X} &= 1 \\ X \vee 1 &= 1 \\ X \vee 0 &= X \end{aligned}$
	$X_1 \wedge (X_1 \vee X_2) = X_1$	$X_1 \vee (X_1 \wedge X_2) = X_1$

Transistor-Transistor-Logik (TTL)

Bipolare integrierte Schaltung mit **Multiemittertransistoren**. Versorgungsspannung 5 V.

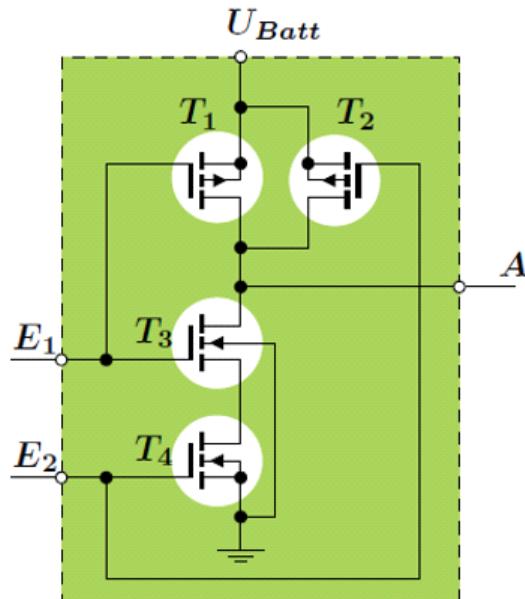


$$U_E < 0.4 \text{ V} \rightarrow \text{Low, logisch "0"} \quad , \quad U_E > 2.4 \text{ V} \rightarrow \text{High, logisch "1"} \quad , \quad \text{Störabstand } 0.4 \text{ V}$$

Unbeschaltete Eingänge wirken so, als lägen sie auf logisch "1"!

CMOS

CMOS=Complementary MOS: Verwendung von n-Kanal und p-Kanal MOSFET's (Anreicherungstypen)



$T_1, T_2 \rightarrow$ p-Kanal MOSFET (brauchen neg. Spg. zwischen G und S für geöffneten S-D-Kanal)

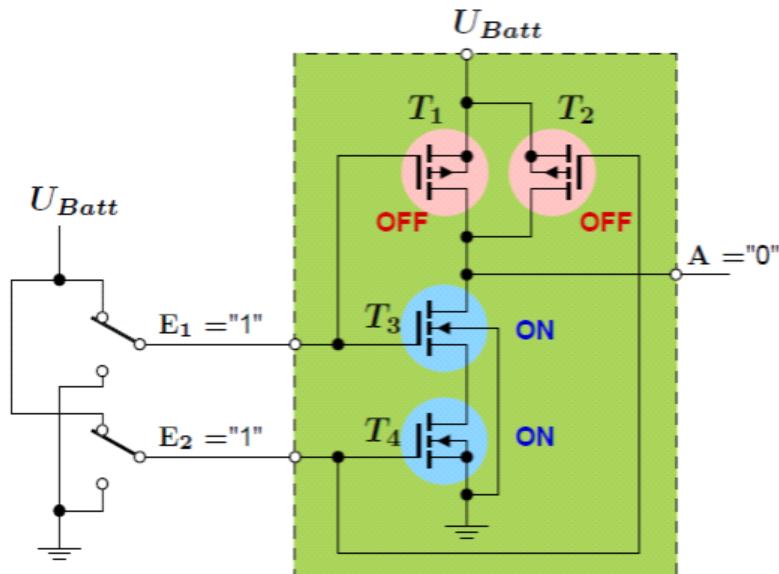
$T_3, T_4 \rightarrow$ n-Kanal MOSFET (brauchen pos. Spg. zwischen G und S für geöffneten S-D-Kanal)

Ausgang liegt auf "0", wenn T_3 und T_4 leiten und er liegt auf "1" wenn entweder T_1 oder T_2 leitet.

Es werden keine Widerstände benötigt!

CMOS-NAND-Gatter

Veranschaulichung der Schaltfunktion:



Wahrheitstabelle:

E_1	E_2	A
0	0	1
0	1	1
1	0	1
1	1	0

TTL/CMOS

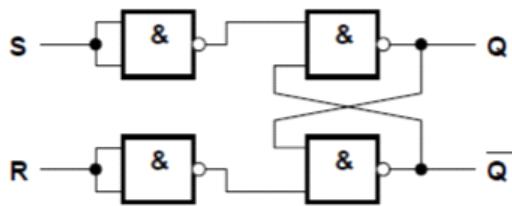
TTL

- Signallaufzeit ~ 10 ns
(3 ns bei Schottky-TTL)
- Verlustleistung ~ 10 mW
(1 mW bei Low-Power-TTL)

CMOS

- höhere Integrationsdichte
- höhere Schaltzeiten ~ 35 ns
(Grund: Aufladen der Gatekapazität!)
- geringe Verlustleistung und Stromaufnahme,
10 nW im Ruhezustand,
beim Schalten abhängig von der Taktfrequenz

RS Flip-Flop



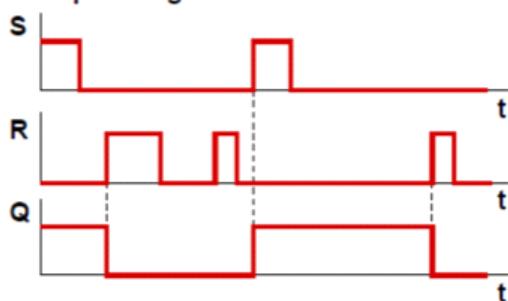
S: set R: reset

Wahrheitstabelle:

R	S	Q	Zustand
0	0	X	speichern
0	1	1	setzen
1	0	0	rücksetzen
1	1	X	verboten

voriger Zustand bleibt erhalten!

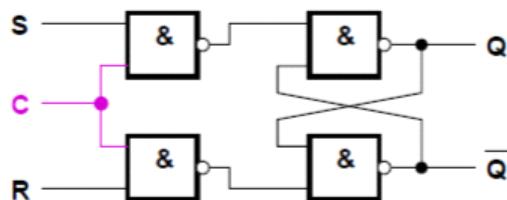
Impulsdiagramm:



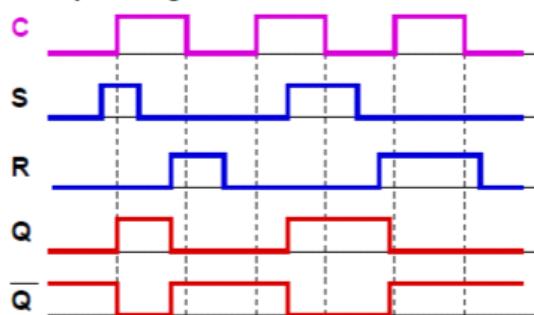
Kurzzeitige Impulse am Eingang lassen das Flipflop zwischen den beiden stabilen Ausgangszuständen $Q = 0$ und $Q = 1$ hin- und herschalten (flip... flop... flip... flop...)

Taktgesteuertes RS Flip-Flop

Logische Schaltungen werden häufig von einem periodischen Taktsignal gesteuert (**clock C**):



Impulsdiagramm:



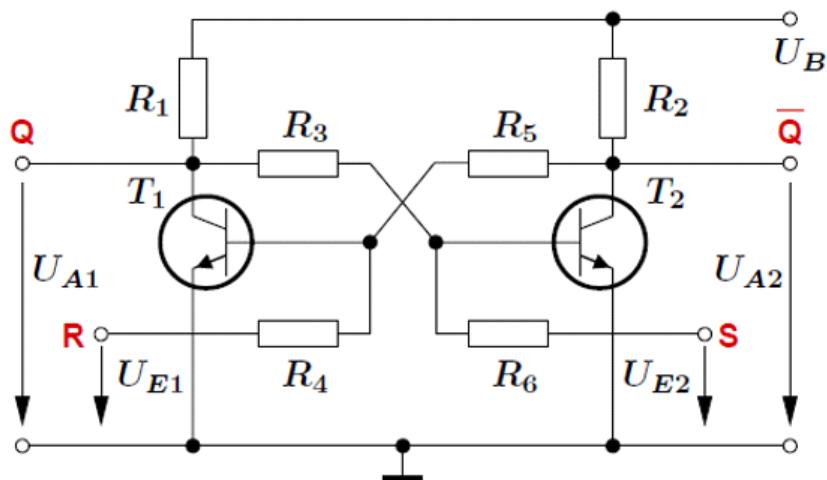
Zustandsgesteuertes Flipflop:

Die am Eingang anliegenden Signale R und S werden erst ausgewertet, wenn das Taktsignal C=1 anliegt.

Flankengesteuertes Flipflop:

Die Auswertung erfolgt z.B. bei der ansteigenden Taktflanke, dh. beim Übergang C=0 → C=1.

RS Flip-Flop mit 2 Transistoren



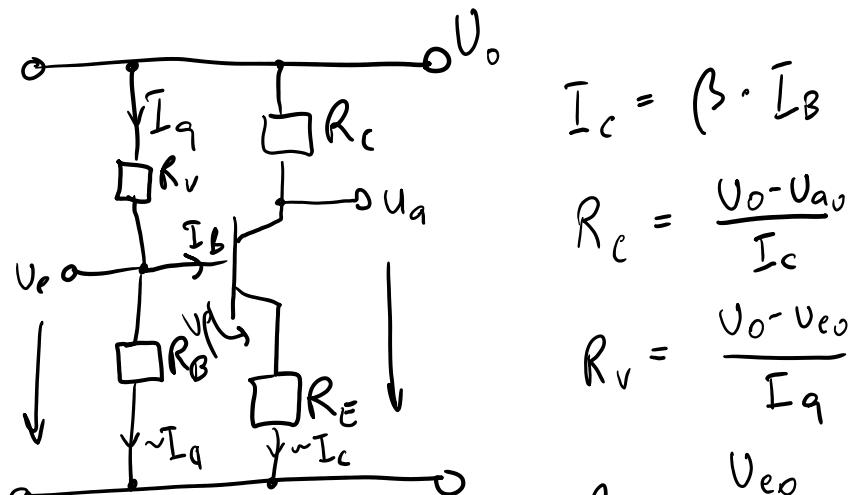
Setzen: $S=1, R=0 \rightarrow T_2$ leitet, T_1 sperrt $\rightarrow Q=1$

Speichern: $S=0, R=0 \rightarrow$ wegen Rückkopplung über R_3 bleibt T_2 leitend und damit T_1 sperrend, d.h. $Q=1$ bleibt erhalten.

Rücksetzen: $S=0, R=1 \rightarrow T_1$ leitet, T_2 sperrt $\rightarrow Q=0$

Emitterschaltung

Montag, 17. Mai 2021 14:01



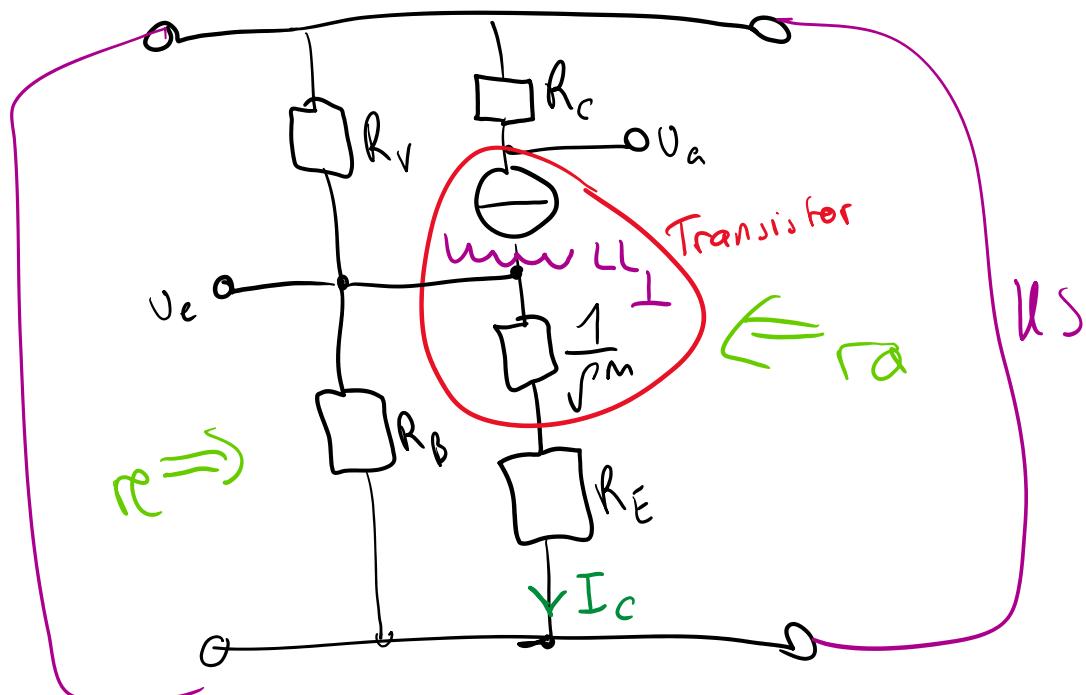
$$I_c = \beta \cdot I_B$$

$$R_c = \frac{U_o - U_{ao}}{I_c}$$

$$R_v = \frac{U_o - U_{eo}}{\sim I_B}$$

$$R_B = \frac{U_{eo}}{\sim I_B}$$

$$R_E = \frac{U_{co} - U_f}{I_c}$$



$$\frac{1}{\rho_m} = \frac{U_T}{I_c}$$

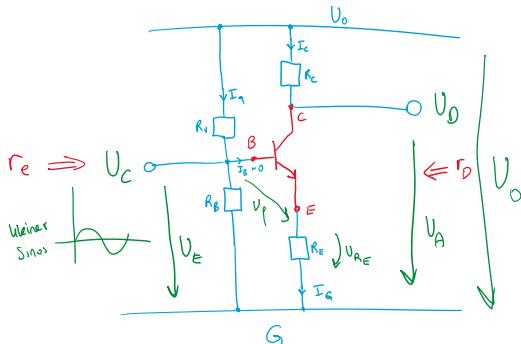
$$r_e = R_v \parallel R_B \parallel \left(R_E + \frac{1}{\rho_m} \right) \cdot \beta$$

$$r_a = R_c$$

$$V = \frac{U_a}{U_e} = \frac{-R_c \cdot I_c}{\left(\frac{1}{\rho_m} + R_E\right) \cdot \beta \cdot I_B}$$

Rechnen

Montag, 12. April 2021 14:06

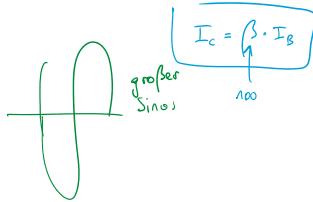


$$R_C = \frac{U_C}{I_C} = \frac{U_o - U_{A_o}}{I_C} = 0,6k\Omega$$

$$R_E = \frac{U_{RE}}{I_E} = \frac{U_{E_o} - U_P}{I_E} = 240\Omega$$

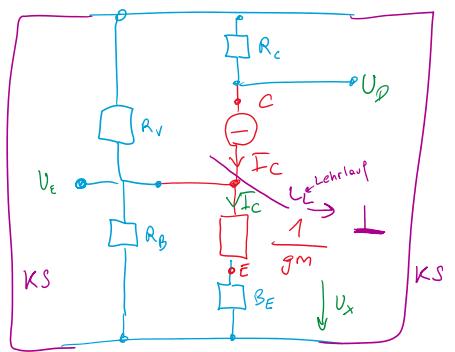
$$R_v = \frac{U_v}{I_q} = \frac{U_o - U_{E_o}}{I_q} = 7k\Omega$$

$$R_B = \frac{U_{E_o}}{I_q} = 3k\Omega$$



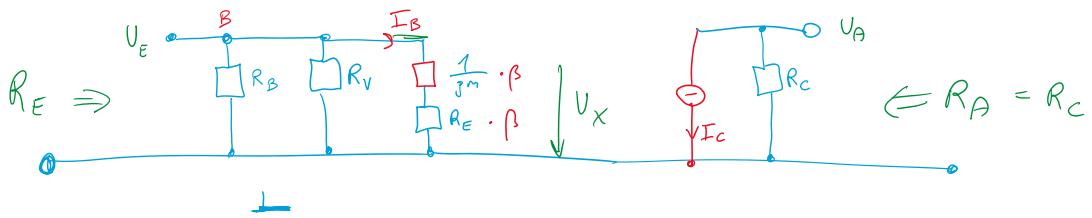
$$g_m = \frac{I_c}{U_+}$$

$$U_+ = 25mV$$



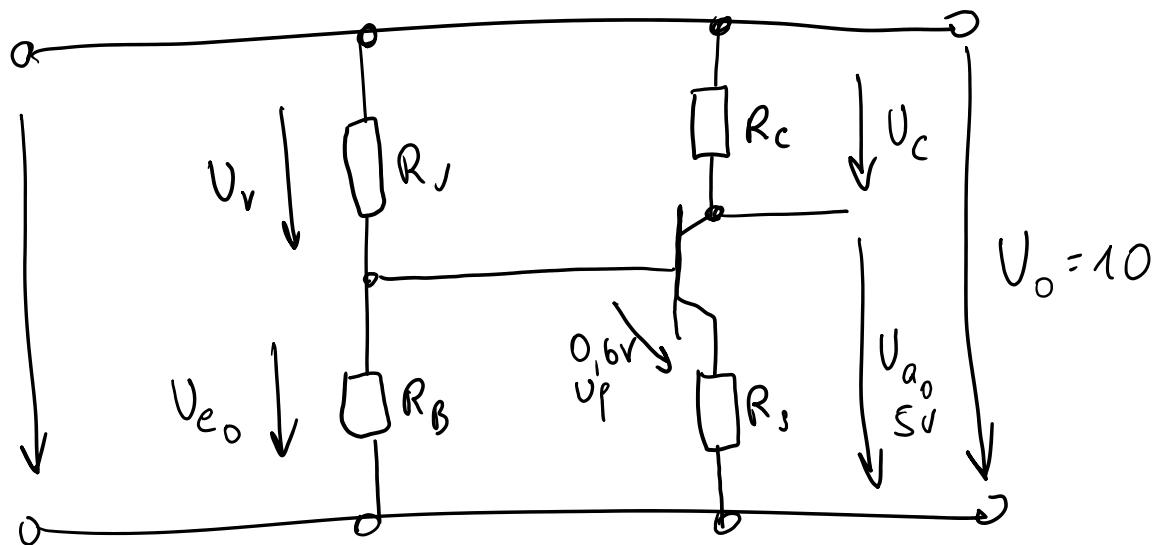
$$U_X = \left(R_E + \frac{1}{g_m} \right) \circ I_C$$

$$= \left(R_E + \frac{1}{g_m} \right) \circ \beta \circ I_B$$



$$R_E = R_B \parallel R_V \parallel \left(\frac{1}{g_m} + R_E \right) \cdot \beta = 1,9 k\Omega$$

$$V = \frac{U_A}{U_E} = \frac{-R_C \cdot I_C}{\left(\frac{1}{g_m} + R_E \right) \cdot \beta \cdot I_B} = -2,5$$

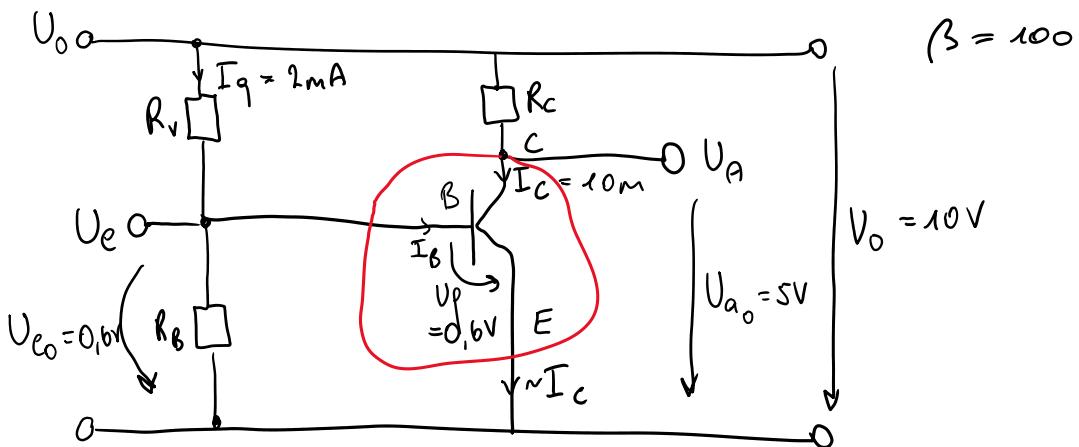


$$R_C = \frac{U_c}{I_{C_0}} = \frac{U_o - U_{A_0}}{I_{C_0}} = \underline{500 \Omega}$$

$$R_S = \frac{U_s}{I_{C_0}} = \frac{U_{e_0} - U_p}{I_{C_0}} = \underline{340 \Omega}$$

$$R_V = \frac{U_V}{I_q} = \frac{U_o - U_{e_0}}{I_q} = \underline{3k \Omega}$$

$$R_B = \frac{U_{e0}}{I_q} = \underline{2k\Omega}$$



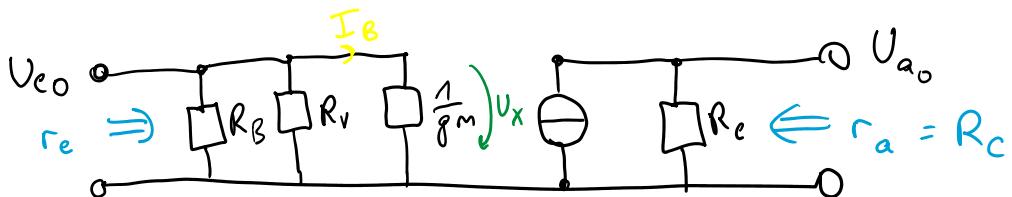
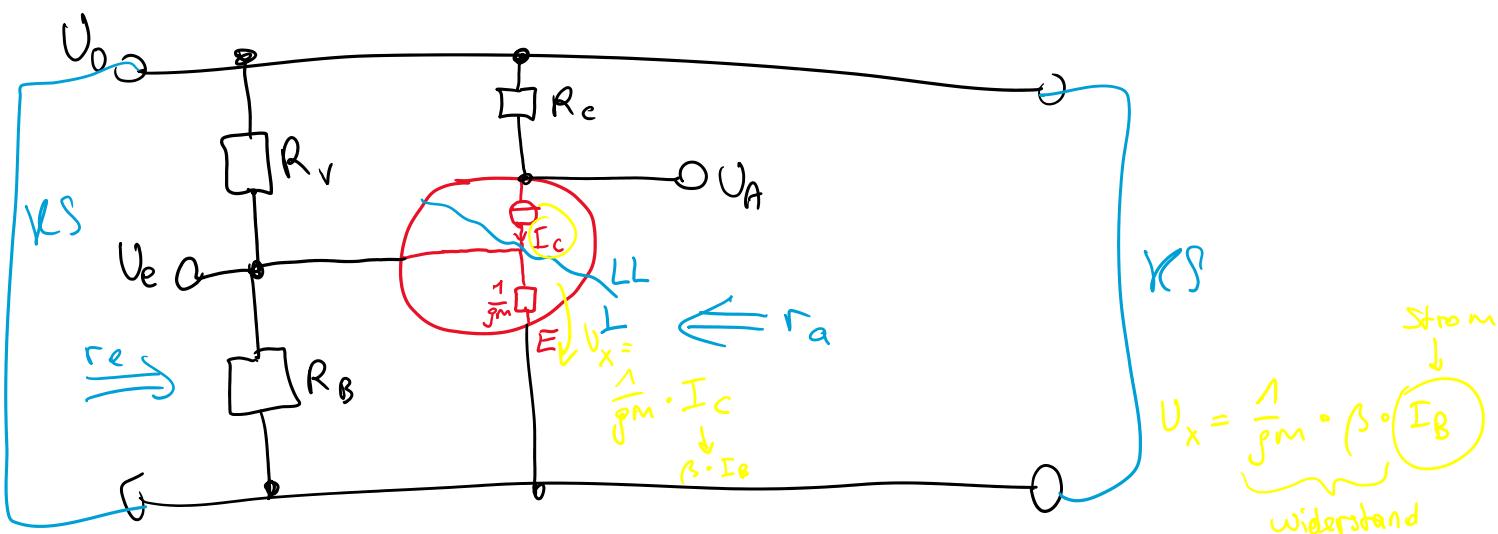
⇒ Arbeitspunkt einstellung

$$R_v = \frac{U_{RV}}{I_q} = \frac{U_o - U_P}{I_q} = \frac{10 - 0,6}{2} = \underline{4,7\text{k}\Omega}$$

$$R_B = \frac{U_P}{I_q} = \frac{0,6}{2} = \underline{300\Omega}$$

$$R_c = \frac{U_o - U_{a_0}}{I_c} = \frac{5}{10} = \underline{500\Omega}$$

$$r_e, r_a = ?$$



$$r_e = R_B \parallel R_V \parallel \frac{\beta}{g_m} =$$

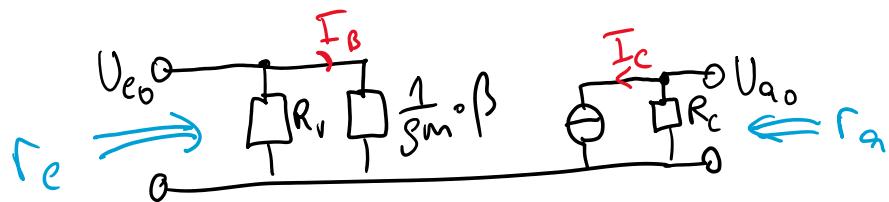
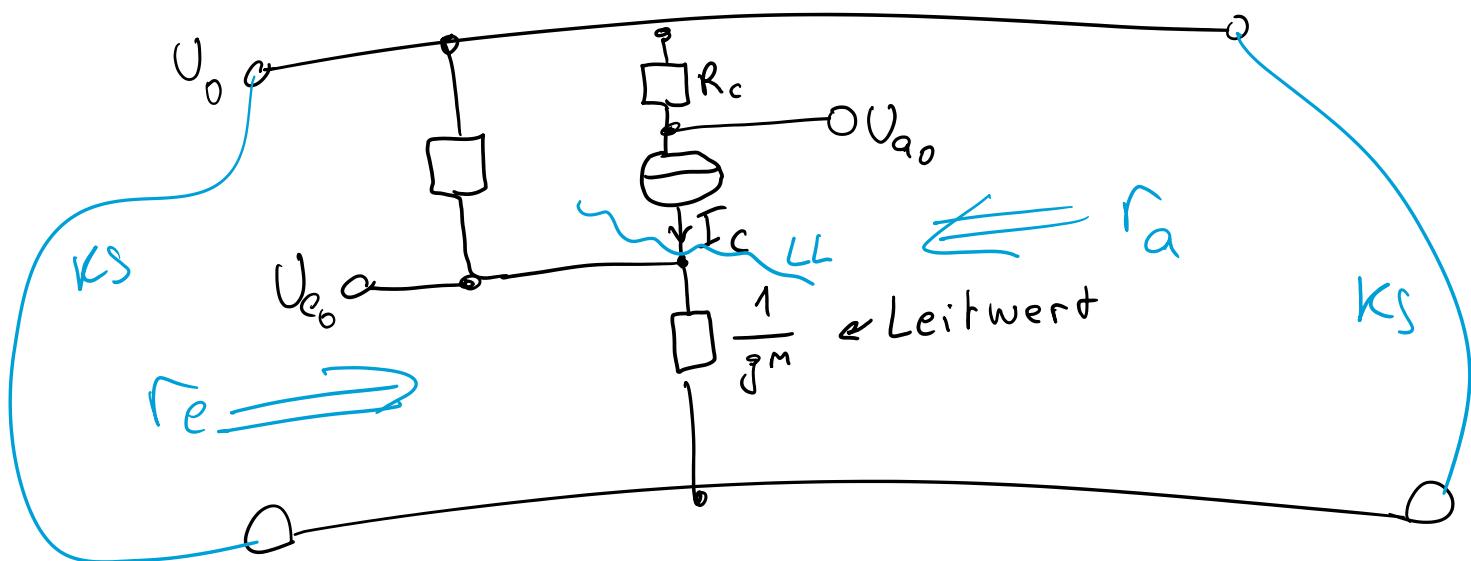
$$\frac{1}{r_e} = \frac{1}{R_B} + \frac{1}{R_V} + \frac{1}{\frac{\beta}{g_m}} = \frac{1}{4.7k} + \frac{1}{300} + \frac{1}{\frac{100}{0.4}} = 132,518 \Omega$$

$$V = \frac{U_a}{I_c} = \frac{-R_C \cdot I_C}{\frac{1}{g_m} \cdot \beta \cdot I_B}$$

$$V = -R_C \cdot g_m = \underline{\underline{-200}}$$

$$R_C = \frac{U_o - U_{a_0}}{I_{C_0}} = \underline{\underline{500 \Omega}}$$

$$R_V = \frac{U_o - U_P}{I_B} = \underline{\underline{94 k\Omega}}$$

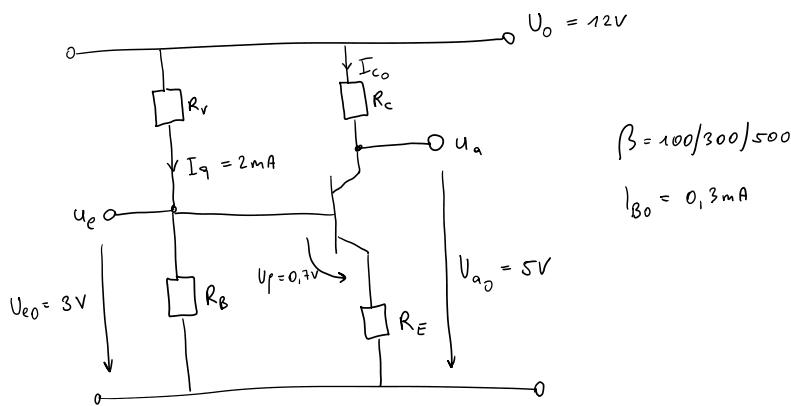


$$r_e = R_v \parallel \frac{1}{g_m \cdot \beta} = 249,34 \Omega \quad r_a = R_c = 500 \Omega$$

$\approx 250 \Omega$

$$\underline{\underline{V_u}} = \frac{U_a}{U_e} = \frac{-R_c \cdot I_c}{\frac{1}{g_m \cdot \beta} \cdot I_B} = -R_c \cdot g_m = \underline{\underline{-200}}$$

1)



$$\beta = 100:$$

$$I_{C_0} = \beta \cdot I_B = \underline{\underline{30mA}}$$

$$R_V = \frac{U_V}{I_B} = \frac{U_o - U_{e0}}{I_B} = \frac{12 - 3}{2m} = \underline{\underline{4.5k}}$$

$$R_B = \frac{U_{e0}}{I_B} = \underline{\underline{1.5k}}$$

$$R_C = \frac{U_C}{I_{C_0}} = \frac{U_o - U_{a0}}{I_{C_0}} = \frac{12 - 5}{30m} = \underline{\underline{233\Omega}}$$

$$R_E = \frac{U_E}{I_B} = \frac{U_{a0} - U_f}{I_{C_0}} = \frac{5 - 0.7}{30m} = \underline{\underline{143\Omega}}$$

$$\beta = 300:$$

$$I_{C_0} = \underline{\underline{90mA}}$$

$$R_C = \underline{\underline{77\Omega}}$$

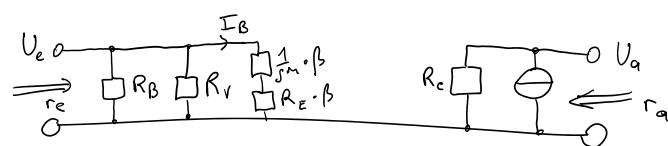
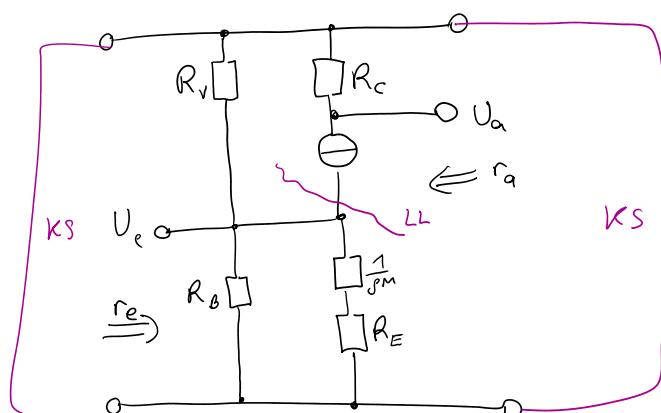
$$R_E = \underline{\underline{47\Omega}}$$

$$\beta = 500:$$

$$I_{C_0} = \underline{\underline{150mA}}$$

$$R_C = \underline{\underline{46\Omega}}$$

$$R_E = \underline{\underline{28\Omega}}$$



$$r_a = R_C = \underline{\underline{233\Omega}}$$

$$r_e = R_B || R_V || \left(\frac{1}{\beta m} + R_E \right) \cdot \beta$$

$$r_e = \frac{1}{\frac{1}{R_B} + \frac{1}{R_V} + \frac{1}{\frac{1}{\beta m} + R_E}}$$

$$r_a = \underline{\underline{77\Omega}}$$

$$r_a = \underline{\underline{46\Omega}}$$

$$r_e = \frac{1}{\frac{1}{R_B} + \frac{1}{R_V} + \frac{1}{(\frac{1}{j_m} + R_E) \cdot \beta}}$$

$$r_e = \frac{1}{\frac{1}{1,5k} + \frac{1}{4,5k} + \frac{1}{(\frac{1}{7,2} + 1438k) \cdot 100}}$$

$$r_e = \underline{\underline{1,043 \text{ k}}}$$

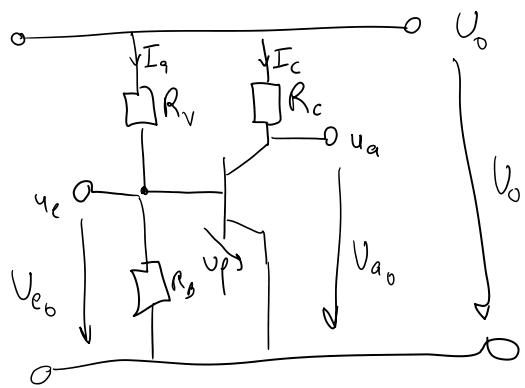
$$r_e = \underline{\underline{1,043 \text{ k}}}$$

$$r_e = \underline{\underline{1,043 \text{ k}}}$$

$$V = \frac{U_a}{U_c} = \frac{-R_C \cdot I_{C_0}}{(\frac{1}{j_m} + R_E) \cdot \beta \cdot I_B} = \frac{-233}{\underline{\underline{7,2 + 143}}} = \underline{\underline{-1,618...}}$$

$$V = \underline{\underline{-1,618...}}$$

$$V = \underline{\underline{-1,618...}}$$



$$\beta = 200 :$$

$$R_V = \frac{U_V}{I_Q} = \frac{U_0 - U_{e0}}{I_Q} = \underline{4,7 \text{ k}}$$

$$R_B = \frac{U_B}{I_Q} = \frac{U_T}{I_Q} = \underline{233 \Omega}$$

$$R_C = \frac{U_0 - U_{a0}}{I_{C0}} = \underline{615 \Omega}$$

$$\beta = 400 :$$

gleich

gleich

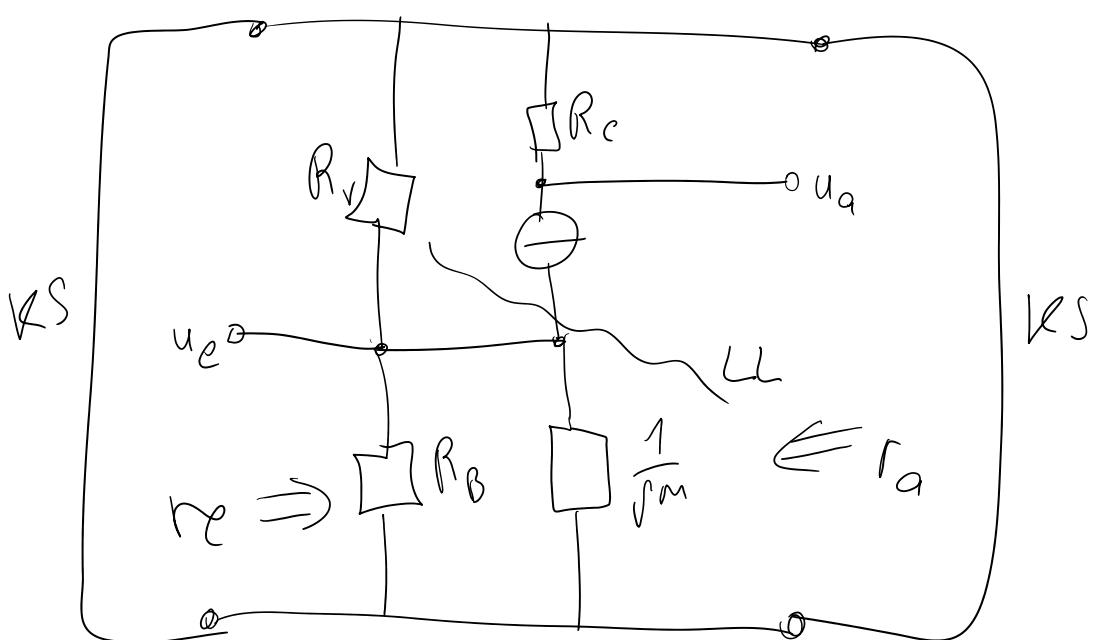
gleich

$$\beta = 600 :$$

gleich

gleich

gleich



$$r_e \Rightarrow R_V, R_B, \frac{1}{g_m} \cdot \beta$$

$$U_a \quad R_C \leftarrow r_a$$

$$r_e \Rightarrow \frac{1}{R_V + R_B + \frac{1}{j\omega} + 1} \quad \leftarrow r_a$$

$$r_a = R_C$$

$$r_e = R_V \parallel R_B \parallel \frac{1}{j\omega} \cdot \beta$$

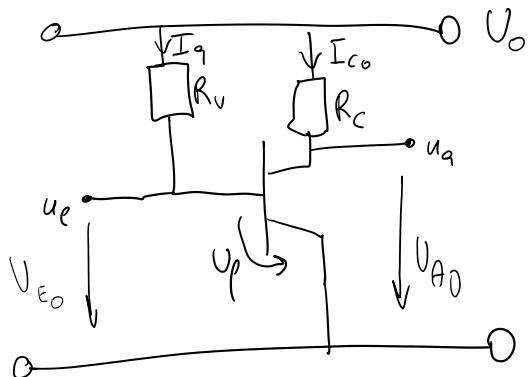
$$r_c = \frac{1}{\frac{1}{R_V} + \frac{1}{R_B} + \frac{j\omega}{\beta}}$$

$$\underline{r_e = 140,934 \dots \Omega}$$

gleich gleich

$$\underline{172,5 \Omega} \quad \underline{186 \Omega}$$

$$V = \frac{U_A}{U_E} = \frac{-R_C \cdot I_C}{\left(\frac{1}{j\omega}\right) \cdot (\beta \cdot I_B)} = \underline{\underline{-320}}$$



$$I_{C0} = I_q \cdot 100$$

$\beta = 100:$

$$R_V = \frac{U_0 - U_P}{I_q} = \frac{9 - 0,7}{1m} = \underline{\underline{8,3k}}$$

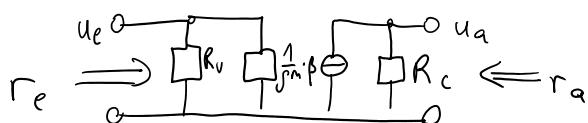
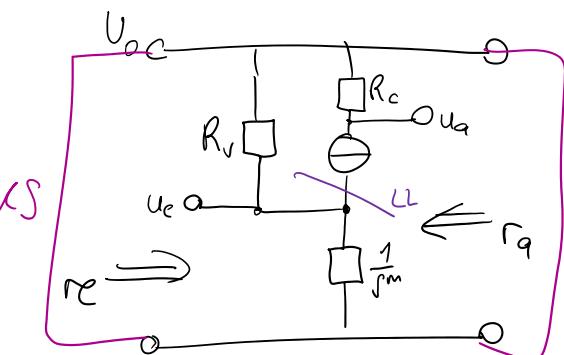
$$R_C = \frac{U_0 - U_{A0}}{I_{C0}} = \frac{9 - 5}{100m} = \underline{\underline{40\Omega}}$$

$\beta = 300:$

$$\underline{\underline{8,3k}}$$

$\beta = 500:$

$$\underline{\underline{8,3k}}$$



$$r_a = R_C = \underline{\underline{40\Omega}}$$

$$r_e = \frac{1}{R_V + \frac{1}{j\mu m \beta}} = \underline{\underline{24,92\Omega}}$$

$$\underline{\underline{13,3\Omega}}$$

$$\underline{\underline{8\Omega}}$$

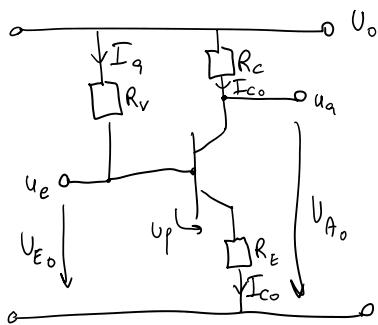
$$\underline{\underline{24,92\Omega}}$$

$$\underline{\underline{24,92\Omega}}$$

$$V = \frac{U_A}{U_E} = -\frac{-R_C}{\frac{1}{j\mu m}} = -R_C \cdot j\mu m = \underline{\underline{-160}}$$

$$\underline{\underline{-160}}$$

$$\underline{\underline{-160}}$$



$$\beta = 400 :$$

$$R_V = \frac{U_0 - U_{E0}}{I_Q} = \frac{16 - 7}{0,5 \text{ m}} = \underline{\underline{18 \Omega}}$$

$$\underline{\underline{18 \Omega}}$$

$$\beta = 600 :$$

$$\underline{\underline{18 \Omega}}$$

$$R_C = \frac{U_0 - U_{A0}}{I_{Co}} = \frac{16 - 5}{100 \text{ m}} = \underline{\underline{110 \Omega}}$$

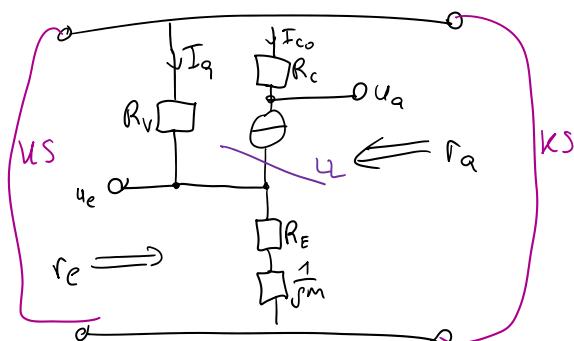
$$\underline{\underline{55 \Omega}}$$

$$\underline{\underline{36,6 \Omega}}$$

$$R_E = \frac{U_{E0} - U_P}{I_{Co}} = \frac{7 - 0,7}{100 \text{ m}} = \underline{\underline{63 \Omega}}$$

$$\underline{\underline{31,5 \Omega}}$$

$$\underline{\underline{21 \Omega}}$$



$$r_e \xrightarrow{u_e 0} R_V + \frac{R_E \cdot \beta}{\beta m \cdot \beta}$$

$$\xrightarrow{u_a 0} R_C \leftarrow r_a$$

$$r_a = R_C = \underline{\underline{110 \Omega}}$$

$$\underline{\underline{55 \Omega}}$$

$$\underline{\underline{36,6 \Omega}}$$

$$r_e = \frac{1}{R_V} + \frac{1}{(R_E + \frac{1}{\beta m}) \cdot \beta} = \underline{\underline{7,41 \text{ k}}} \quad \underline{\underline{7,41 \text{ k}}} \quad \underline{\underline{7,41 \text{ k}}}$$

$$V = \frac{U_A}{U_E} = \frac{-R_C}{\frac{1}{\beta m} + R_E} = \underline{\underline{-1,746}}$$

$$\underline{\underline{-1,746}}$$

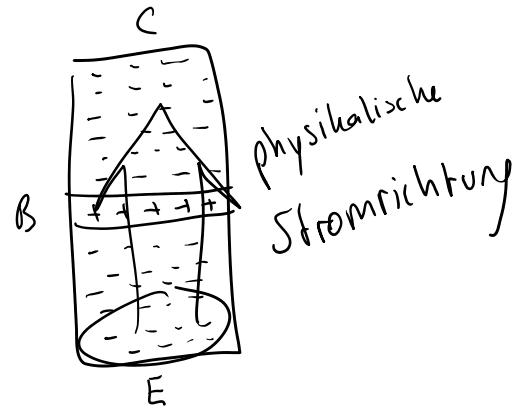
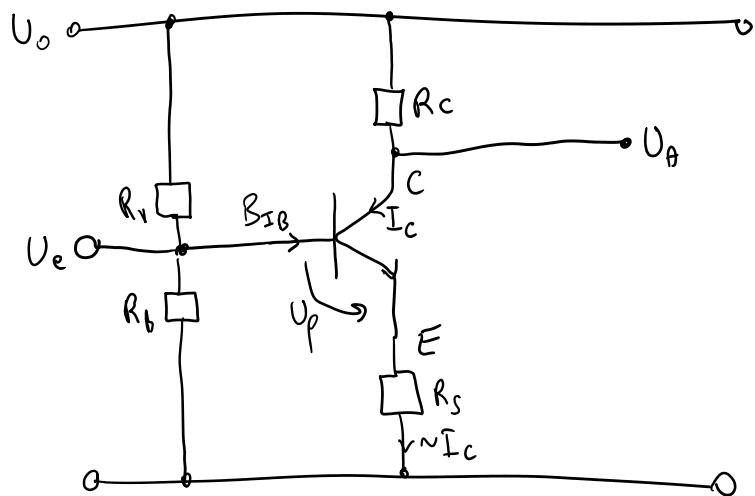
$$\underline{\underline{-1,746}}$$

= Verstärker

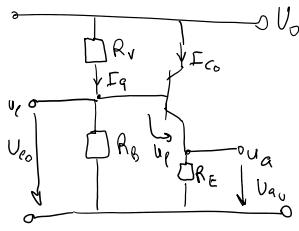
Gatter werden mit Transistoren aufgebaut



NAND-Gatter / AND-Gatter



6)



$$\text{ges: } U_O = 11V$$

$$U_P = 0,7V$$

$$U_{EO} = 7V$$

$$I_Q = 3mA$$

$$I_{CO} = 10mA$$

$$U_T = 25mV$$

$$\beta = 200/400/600$$

$$R_V = \frac{U_O - U_{EO}}{I_Q} = \underline{1,3k}$$

$$R_B = \frac{U_{EO}}{I_Q} = \underline{2,3k}$$

$$R_E = \frac{U_{EO}}{I_{CO}} = \frac{U_{EO} - U_T}{I_{CO}} = \underline{630\Omega}$$

$$\text{ges: } R_V, R_B, R_E, r_e, r_a, V$$

$$r_e = R_V \parallel R_B \parallel \left(R_E + \frac{1}{\beta m} \right) \circ \beta$$

$$r_e = \frac{1}{\frac{1}{R_V} + \frac{1}{R_B} + \frac{1}{(R_E + \frac{1}{\beta m}) \cdot \beta}} = \underline{842,654\dots} \quad \underline{845,470\dots} \quad \underline{846,413\dots}$$

$$r_a = R_E \parallel \left[\frac{1}{\beta m} + \frac{R_V \parallel R_B}{\beta} \right]$$

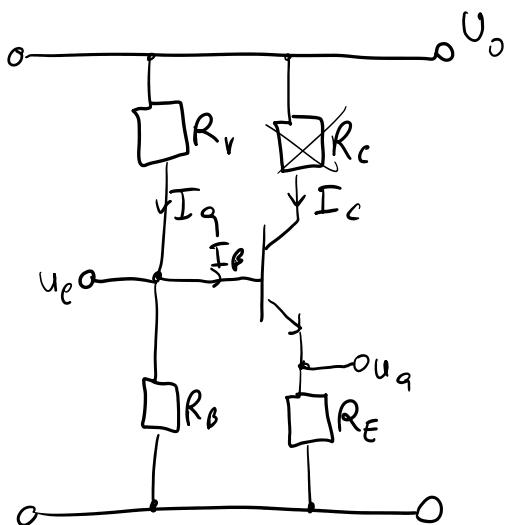
1

$$r_a = \frac{\frac{1}{R_E} + \frac{1}{\frac{1}{\beta m} + \frac{1}{\frac{1}{R_V} + \frac{1}{R_B}}}}{\beta} = \underline{6,670\dots} \quad \underline{4,587\dots}$$

3,889...

Rechnen

Montag, 17. Mai 2021 14:12



$$U_P = 0,6 \text{ V}$$

ges.: R_V, R_B, R_E

$$U_T = 25 \text{ mV}$$

$$\beta = 200$$

$$U_O = 20 \text{ V}$$

$$I_{C_0} = 10 \text{ mA}$$

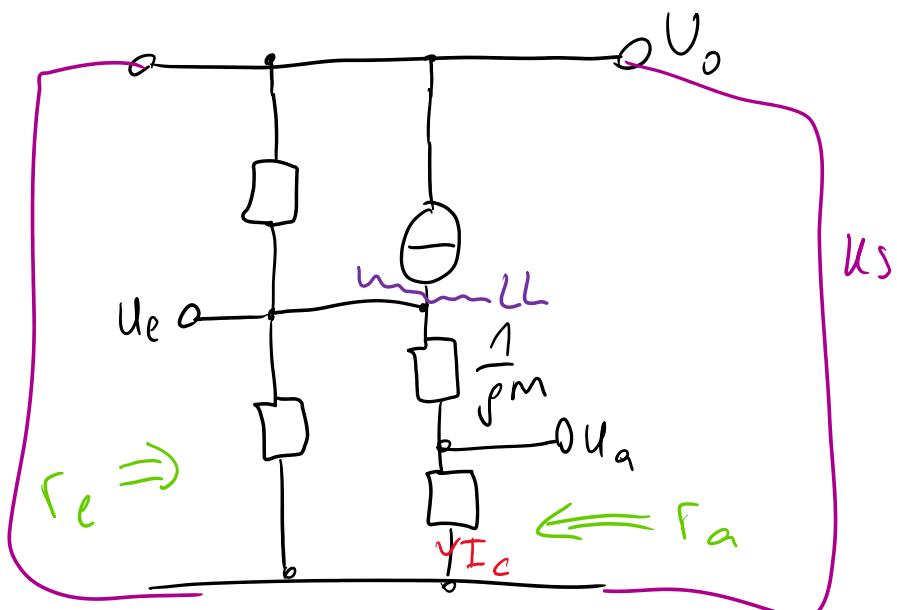
$$I_Q = 2 \text{ mA}$$

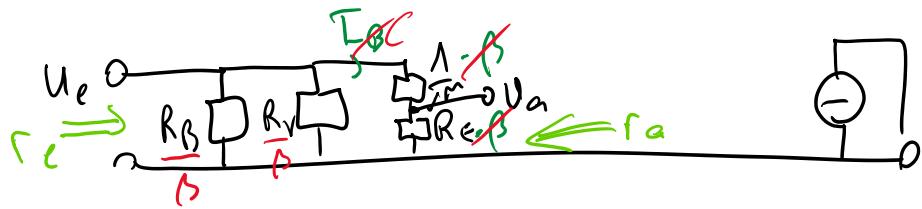
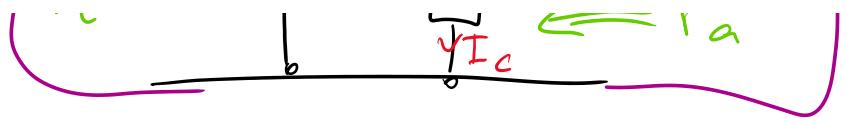
$$U_{a_0} = 8 \text{ V}$$

$$R_V = \frac{U_O - U_P - U_{a_0}}{I_Q} = \underline{5,7 \text{ k}\Omega}$$

$$R_B = \frac{U_P + U_{a_0}}{I_Q} = \underline{4,3 \text{ k}\Omega}$$

$$R_E = \frac{U_{a_0}}{I_C} = \underline{800 \Omega}$$



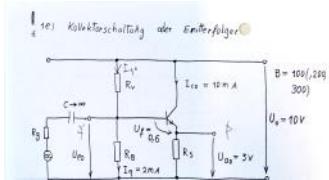


$$r_e = r_B \parallel R_V \parallel \left(\frac{1}{\beta} + R_E \right) \cdot \beta = 2,4 \text{ k}\Omega$$

$$r_a = R_E \parallel \left[\frac{1}{\beta} + \frac{R_V \parallel R_B}{\beta} \right] = 14,4 \text{ }\Omega$$

$$V = \frac{U_a}{U_e} = \frac{R_E \cdot I_C}{\left(\frac{1}{\beta} + R_E \right) \cdot I_C}$$

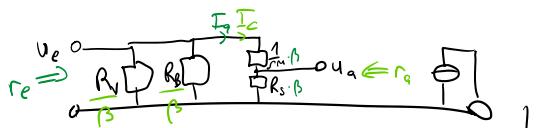
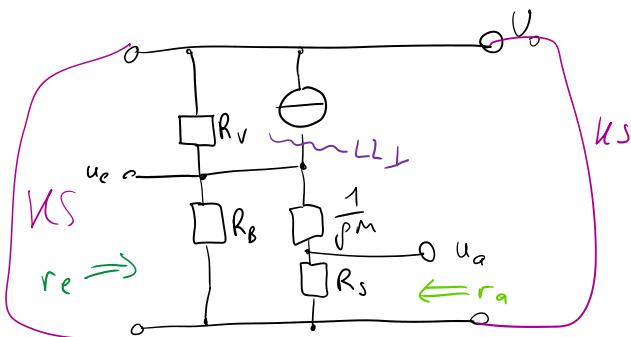
$$\approx \frac{R_E}{R_E} = 1$$



$$R_V = \frac{U_o - U_F - U_{ao}}{I_q} = \frac{10 - 0,6 - 3}{2 \text{ mA}} = \underline{3,2 \text{ k}\Omega}$$

$$R_B = \frac{U_F + U_{ao}}{I_q} = \underline{1,8 \text{ k}\Omega}$$

$$R_S = \frac{U_{ao}}{I_C} = \underline{300 \Omega}$$



$$r_e = R_V \parallel R_B \parallel \left(\frac{1}{\beta_m} + R_S \right) \cdot \beta$$

$$r_e = \frac{1}{\frac{1}{R_V} + \frac{1}{R_B} + \left(\frac{1}{\beta_m} + R_S \right) \cdot \beta} = \underline{1,109 \text{ k}\Omega}$$

$$\beta = 200 :$$

$$\beta = 300 :$$

$$\underline{1,130 \text{ k}\Omega}$$

$$\underline{1,137 \text{ k}\Omega}$$

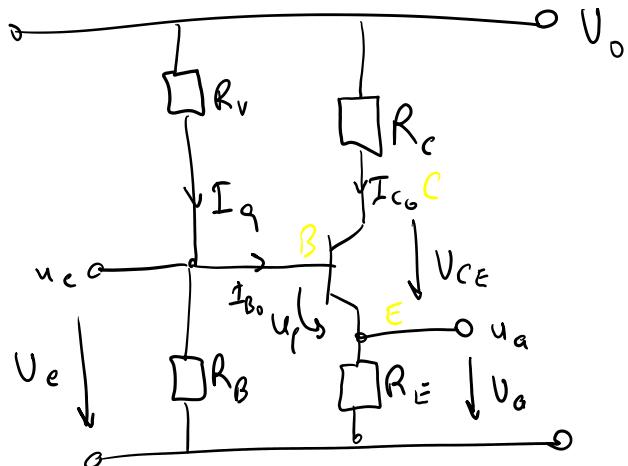
$$r_a = R_S \parallel \left[\frac{1}{\beta_m} + \frac{R_B \parallel R_V}{\beta} \right] =$$

$$r_a = \frac{1}{\frac{1}{R_S} + \frac{1}{\frac{1}{\beta_m} + \frac{1}{R_B + R_V}}} = \underline{13,39 \Omega}$$

$$\underline{8,038 \Omega}$$

$$\underline{6,208 \Omega}$$

$$\underline{V = 1}$$



$$\text{geg: } U_o = 10V \\ U_p = 0,7V$$

$$U_{q_0} = 6V$$

$$I_q = 2mA$$

$$I_{B_0} = 0,1mA$$

$$U_{C_E} = 2V$$

$$U_T = 25mV$$

$$\beta = 500 / 300 / 100$$

$$\text{ges: } R_V, R_B, R_E, R_C$$

$$r_e, r_q$$

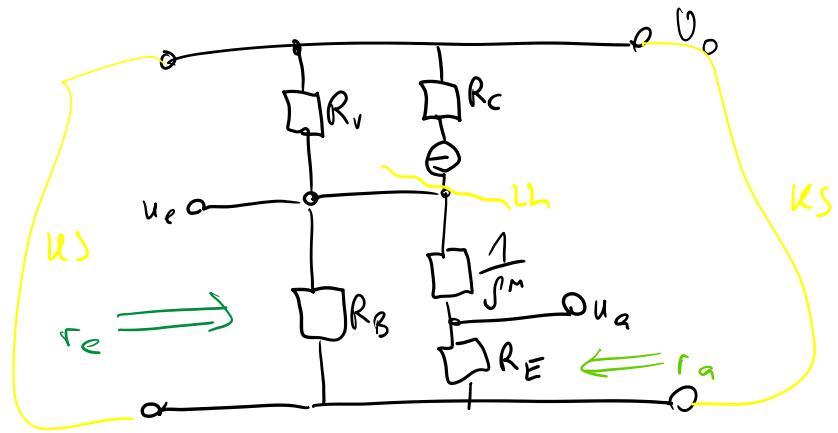
$$V \approx 1$$

$$R_V = \frac{U_o - U_{q_0} - U_I}{I_q} = \underline{1,65k\Omega}$$

$$R_B = \frac{U_{C_0}}{I_q} = \underline{3,35k\Omega}$$

$$R_C = \frac{U_o - U_{CE} - U_{q_0}}{I_{B_0} \cdot \beta} = \underline{40\Omega} \quad \underline{66,6\Omega} \quad \underline{200\Omega}$$

$$R_E = \frac{U_{q_0}}{I_{B_0} \cdot \beta} = \underline{120\Omega} \quad \underline{200\Omega} \quad \underline{600\Omega}$$



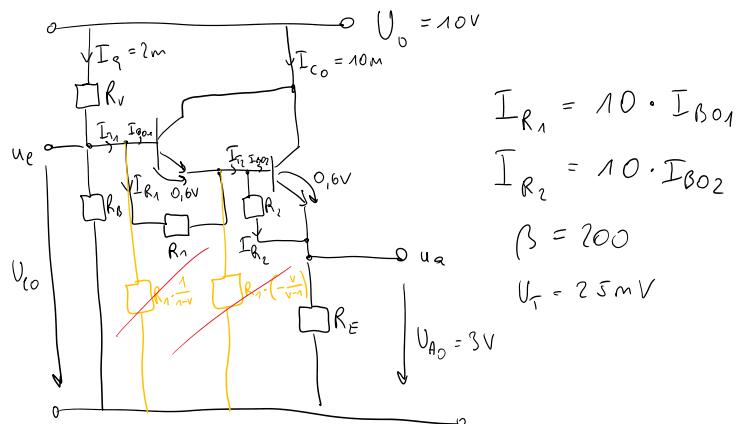
$$r_e = R_v \parallel R_B \parallel \frac{1}{\beta_m} + R_E$$

$$r_e = \frac{1}{\frac{1}{R_v} + \frac{1}{R_B} + \frac{1}{(\frac{1}{\beta_m} + R_E) \cdot \beta}} = \frac{1,085 \text{ k}\Omega}{1,085 \text{ k}\Omega}$$

$$r_a = R_E \parallel \left(\frac{1}{\beta_m} + R_B \cdot \beta \right) \parallel R_v \cdot \beta$$

$$r_a = \frac{1}{\frac{1}{R_E} + \frac{1}{\frac{1}{\beta_m} + \frac{1}{R_v \cdot \beta + R_B \cdot \beta}}} = \frac{2,6 \text{ }\Omega}{4,41 \dots \Omega} \quad \underline{13,25 \dots \Omega}$$

V ≈ 1



$$R_V = \frac{U_0 - U_{A0} - 2 \cdot 0,6}{I_Q} = 2,9 \text{ k}$$

$$R_B = \frac{U_{A0} + 2 \cdot 0,6}{I_Q} = 2,1 \text{ k}$$

$$R_1 = \frac{0,6}{0,0000275} = 21,8 \text{ k}$$

$$R_2 = \frac{0,6}{0,0005} = 1,2 \text{ k}$$

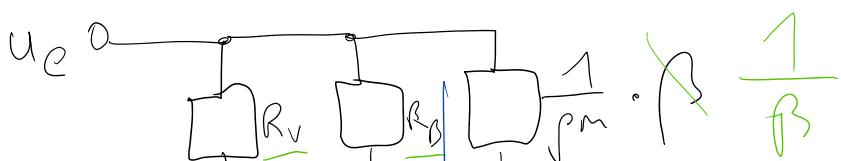
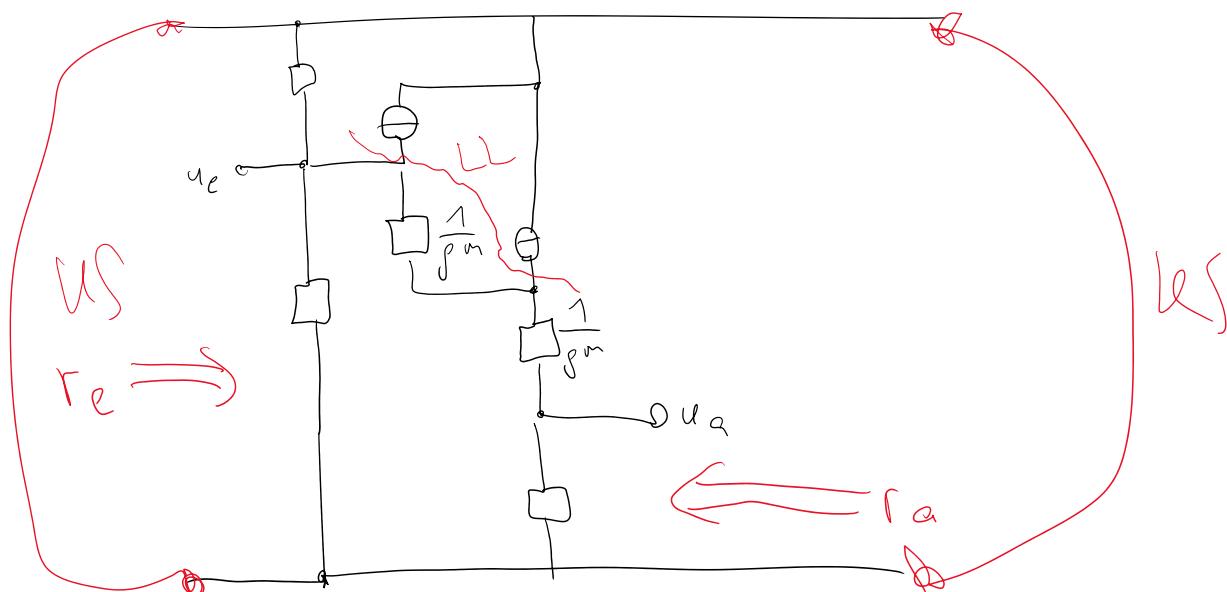
$$R_E = \frac{U_{A0}}{I_{CQ}} = 300 \Omega$$

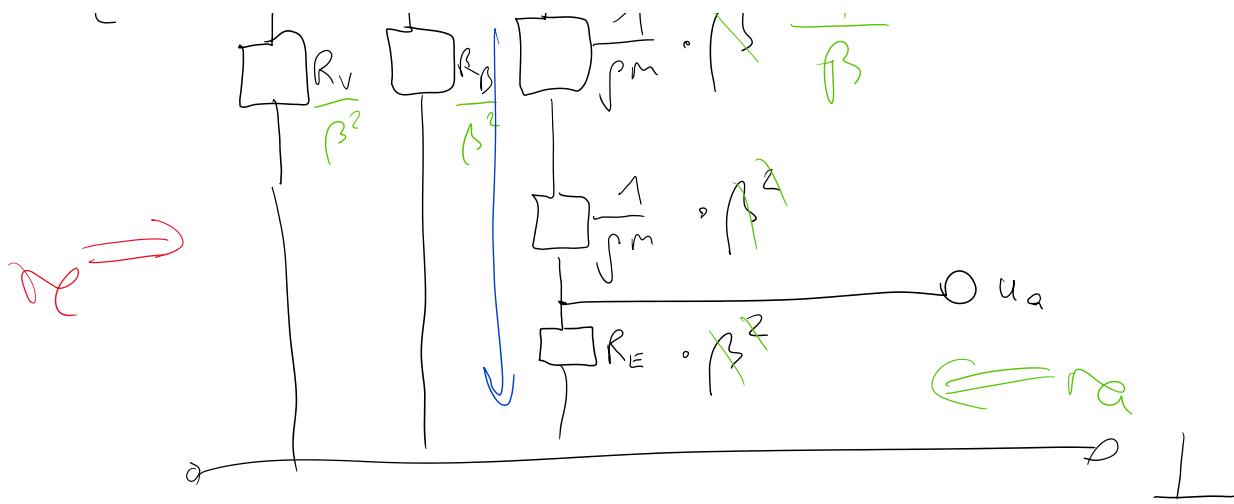
$$I_{B02} = 50 \mu\text{A} \rightarrow I_{R2} = 0,5 \text{ mA}$$

$$I_{T2} = I_{B02} + I_{R2} = 550 \mu\text{A}$$

$$I_{B01} = 2,75 \mu\text{A} \rightarrow I_{R1} = 27,5 \text{ mA}$$

$$I_{T1} = 30,25 \mu\text{A}$$





$$r_e = R_V \parallel R_B \parallel \left[\left(\frac{1}{\beta m} + R_E \right) \cdot \beta + \frac{1}{\beta m} \right] \cdot \beta$$

$$r_e = \frac{1}{R_V} + \frac{1}{R_B} + \frac{1}{\left(\left(\frac{1}{\beta m} + R_E \right) \cdot \beta + \frac{1}{\beta m} \right) \cdot \beta}$$

$$r_a = R_E \parallel \left[\frac{1}{\beta m_2} + \frac{1}{\beta} \cdot \left(\frac{1}{\beta m_1} + \frac{R_V \parallel R_B}{\beta} \right) \right]$$

$$r_a = \frac{1}{R_E} + \frac{1}{\frac{1}{\beta m_2} + \frac{1}{\beta} \cdot \left(\frac{1}{\beta m_1} + \frac{1}{R_V + R_B} \right)}$$

= 1,217 6

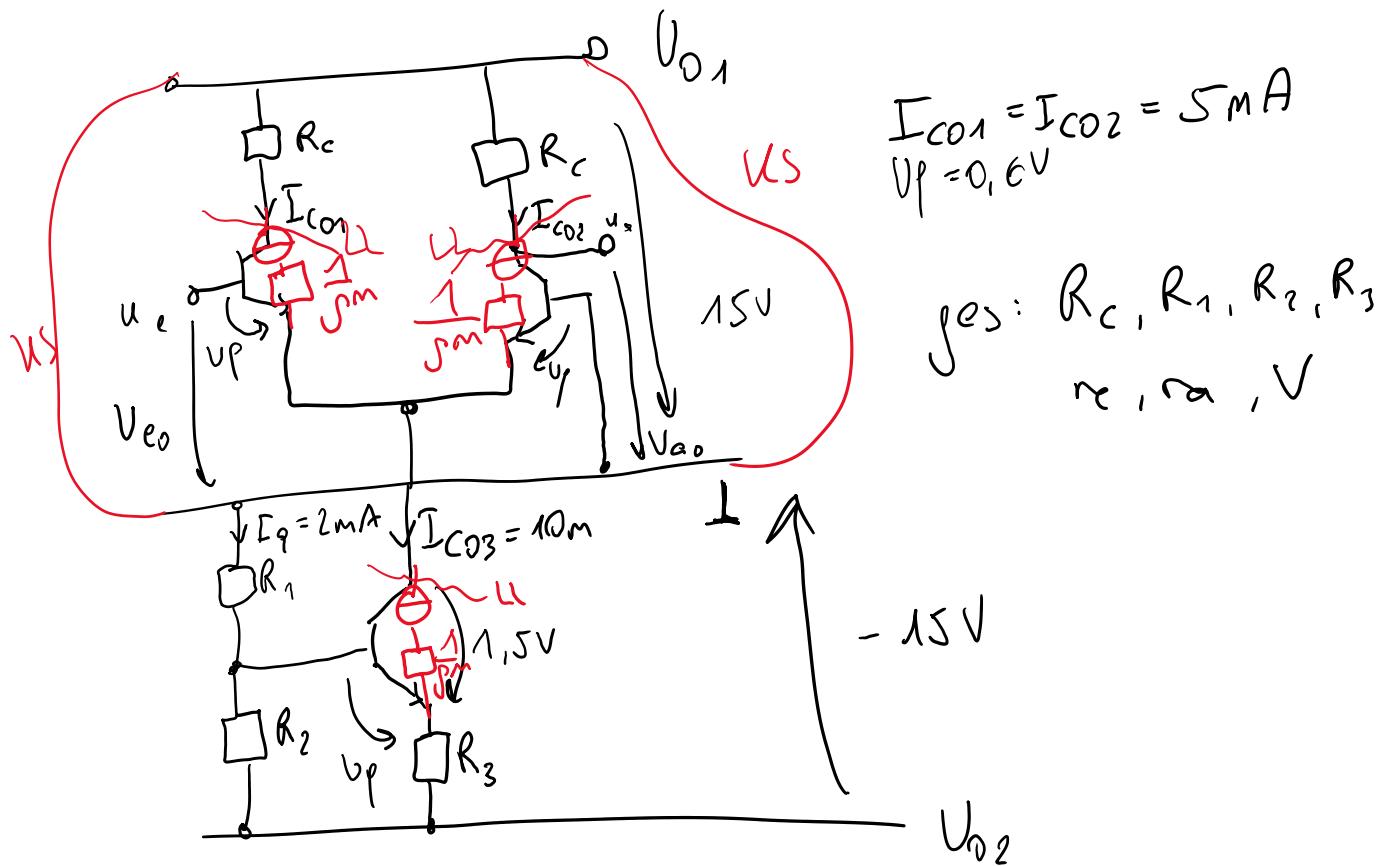
= 2,732 . . . 8

1
23

$$\frac{1}{\int_{\rho_m_2}^{\rho_m_1}} + \frac{1}{\beta} \cdot \left(\frac{1}{\int_{\rho_m_1}^{\rho_m_2}} + \frac{K_V}{\beta} \right)$$

$$V = \frac{u_q}{u_e} = \frac{R_E}{R_E + \frac{1}{\int_{\rho_m_2}^{\rho_m_1}} + \frac{1}{\int_{\rho_m_1}^{\rho_m_2}} \cdot \frac{1}{\beta}} = 1$$

β)

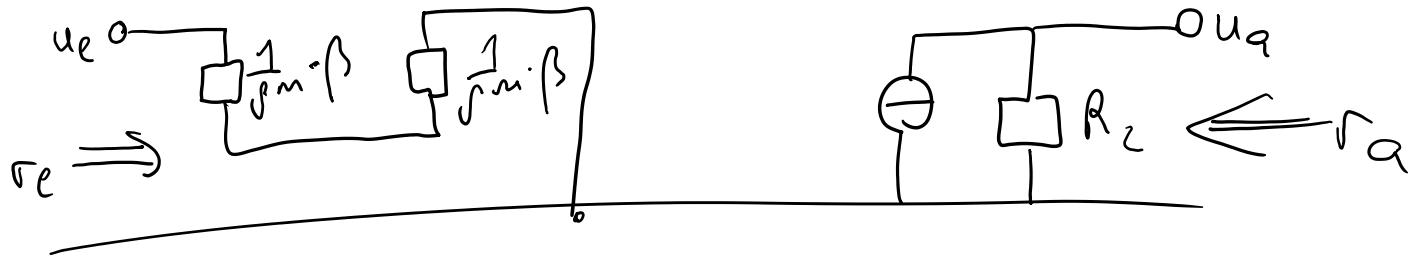


$$R_C = \frac{U_{O1} - U_{Q2}}{I_{CO2}} = 1,5 \text{ k}\Omega$$

$$R_3 = \frac{-1,5 - V_P + 15}{I_{CO3}} = 1,3 \text{ k}\Omega$$

$$R_2 = \frac{V_P + U_3}{I_g} = 6,75 \text{ k}\Omega$$

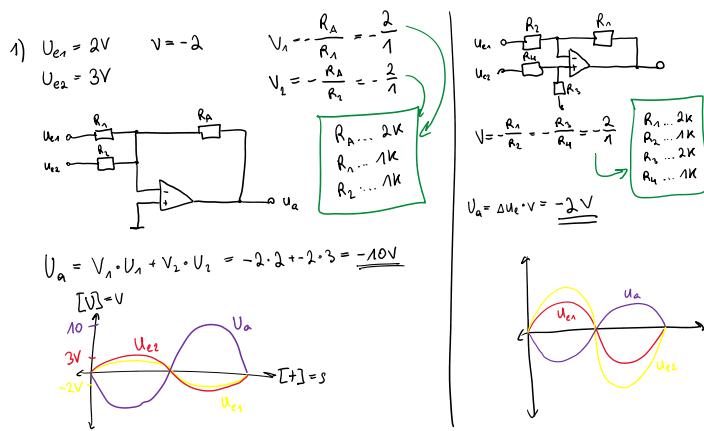
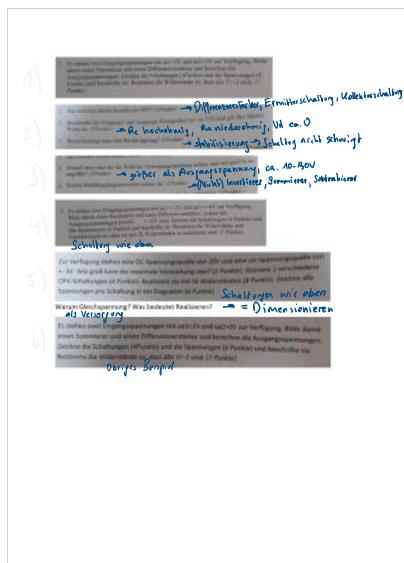
$$R_1 = \frac{15 - V_P - U_3}{I_g} = 750 \Omega$$



$$r_e = \frac{1}{j f_m} \cdot \beta + \frac{1}{j f_m} \cdot \beta - 1k \quad \underline{\underline{=}}$$

$$r_a = R_c$$

$$\sqrt{\frac{u_a}{u_e}} = \frac{-R_c}{\frac{j f_m}{2}} = \frac{R_c \cdot j f_m}{2} = \underline{\underline{-150}}$$



SYTE 3.1. Test				
Name: [REDACTED]				
0-10	11-13	14-16	17-18	19-20
Nicht Genügend	Genügend	Befriedigend	Gut	Sehr Gut

1. Ihr habt ein geheimes Sin-Signal mit 10V Spitzennwert entdeckt und wollt es weiter analysieren. Deshalb müsst ihr es auf 10V Spitzennwert verstärken und einen geeigneten Verstärker bestellt. Ihr bekommt einen OPV mit $f_1=10Hz$, $f_2=100MHz$, ein Säckerl mit $4K$ Widerständen und eine DC-Spannungsquelle, die bis 15V Gleichspannung erzeugt.

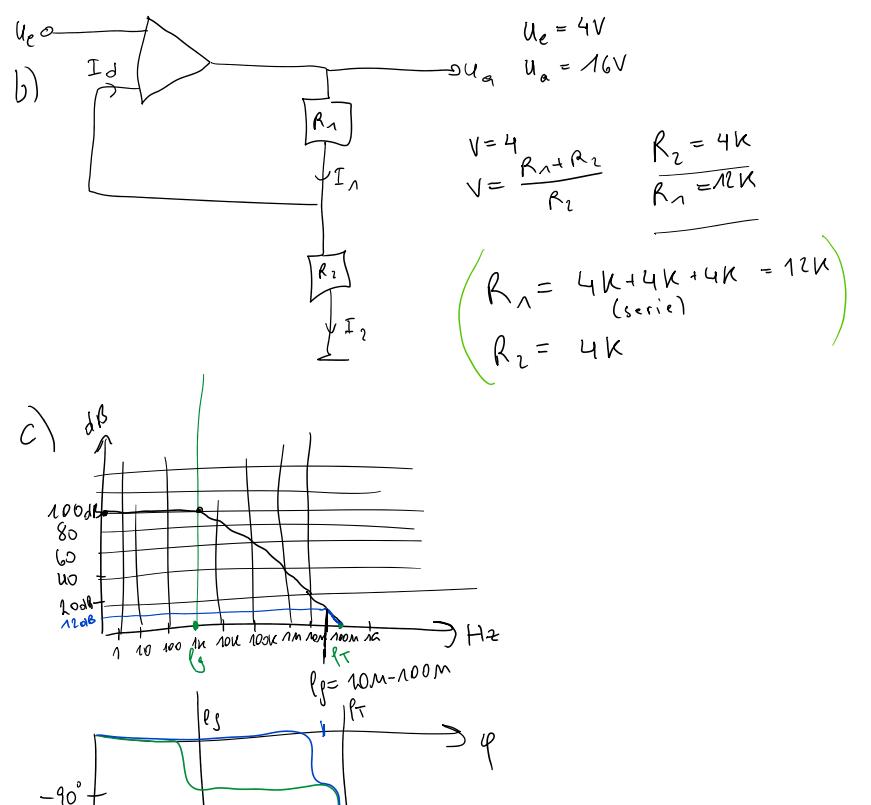
- Welche Verstärkungswahlung darf? (1P)
- Zeichne deine Schaltung (1P), dimensioniere sie (1P) und zeichne alle zu messenden Spannungskurven (1P).
- Stelle auch den Frequenzgang von OPV und Schaltung im Blockdiagramm dar (4P). Die Verstärkung der Schaltung entspricht 12 dB.
- Wie groß ist die Grenzfrequenz der Schaltung? (1P)
- Liefert die Schaltung das gewünschte Ergebnis? (1P)

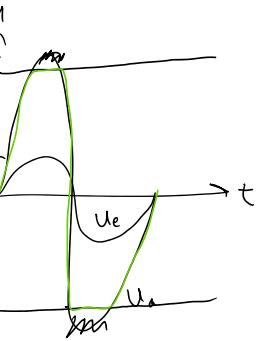
2. Berechne einen Differenzverstärker mit folgenden Eingangsspannungen: $U_1=1V$, $U_2=2V$, und den dazu gehörigen Widerständen: $R_1=R_3=6K$, $R_2=R_4=3K$.

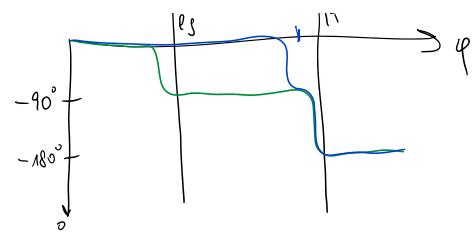
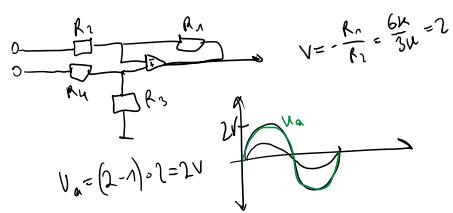
Zeichne die Schaltung des Verstärkers (1P) und berechne die Verstärkung (1P).

Wie groß muss die Versorgungsspannung Vcc mindestens sein? (1P)

Stelle alle Spannungen in einem Diagramm dar. (5P)







SYTE Test, am 16.12.2021

Donnerstag, 6. Januar 2022 15:02

ZoP

SYTE 3	1. Test	Datum: 16.12.2021			
Klasse: 3AHIT	Name: Felix Schneider				
Punkte	0-10	11-13	14-16	17-18	19-20
Note	Nicht genugend	Gentigend	Befriedigend	Gut	Sehr Gut

1. Ihr habt ein Signal mit 3V Spitzenwert und wollt es ums 5-fache verstärken. Ihr findet einen OPV mit $V_{OPV} = 100\text{dB}$ und $f_{SCH} = 100\text{MHz}$, ein Sackerl mit 5 Ohm Widerständen und eine DC-Spannungsquelle die bis 15V Gleichspannung erzeugt.
Wähle einen invertierenden Verstärker.

Zeichne die Schaltung (2P), berechne U_a , R_1 und R_2 (6P) und zeichne alle zu messenden Spannungskurven (4P) in einem Zeitdiagramm.
Stelle den Frequenzgang von OPV und Schaltung im Bode-Diagramm dar (6P). Wie groß ist die Verstärkung der Schaltung, wenn die $f_{SCH} = 10\text{MHz}$ ist (2P). 20dB

$$U_a = -V \cdot U_e = -5 \cdot 3V = -15V$$

$$-5 = V = -\frac{R_2}{R_1} = -\frac{5K + 5K + 5K + 5K + 5K}{5K}$$

$$\frac{R_2}{R_1} = \frac{5K + 5K + 5K + 5K + 5K}{5K} = \frac{25K}{5K} = 5$$

$$V = \frac{U_a}{U_e}$$

$$V = -\frac{R_2}{R_1}$$

Time-domain plot showing input voltage U_e and output voltage U_a over time t . The input U_e has a peak of 3V. The output U_a has a peak of 15V. A DC voltage $DC(V_{CC})$ is also indicated.

Frequency response plots:

- Top plot: Frequency f (Hz) vs. Gain V (dB). The OPV curve starts at 100 dB. The circuit curve starts at 20 dB. The corner frequency is marked as 10MHz .
- Middle plot: Frequency f (Hz) vs. Phase ϕ . The OPV curve has a phase shift of -180° . The circuit curve has a phase shift of -90° .
- Bottom plot: Frequency f (Hz) vs. Power P (Hz).

SYTE Test, am 24.03.2022

Freitag, 20. Mai 2022 12:23

SYTE 3	3.Test	Datum: 24.03.2022			
Klasse: 3AHIT		Name: Felix Schneider			
Punkte	0-15	16-19	20-23	24-27	28-30
Note	Nicht genügend	Gut	Befriedigend	Gut	Sehr Gut

30P

1. Wie erfolgt die Digitalisierung bei den beiden DACs: R/2ⁿR und R/2R?
 Zeichne die Schaltungen, erkläre das Prinzip und die jeweiligen Vor- und Nachteile: (8 Punkte) (8P)

2. *Welche unterschiedlichen ADCs kennst du? Zähle mindestens 4 auf und beschreibe die Unterschiede zueinander. (8 Punkte) (8P)

*Welchen würdest du wählen und warum. Stelle die Vor- und Nachteile gegenüber. Zeichne seine Schaltung und skizziere die Konvertierung von 4V in eine binäre Zahl anhand der Schaltung und der Spannungskurven.: (8 Punkte) (8P)

*Zeichne die Schaltung des schnellsten ADCs und erkläre sie am Bsp. einer beliebigen zweistelligen binären Zahl. (6 Punkte) (6P)

allgemein Prinzip:
 die Widerstände verdeckeln sich immer, dadurch kann man
 binäre Zahlen darstellen, weil sich die Stellen dort auch voneinander

1. R/2ⁿR: MSB

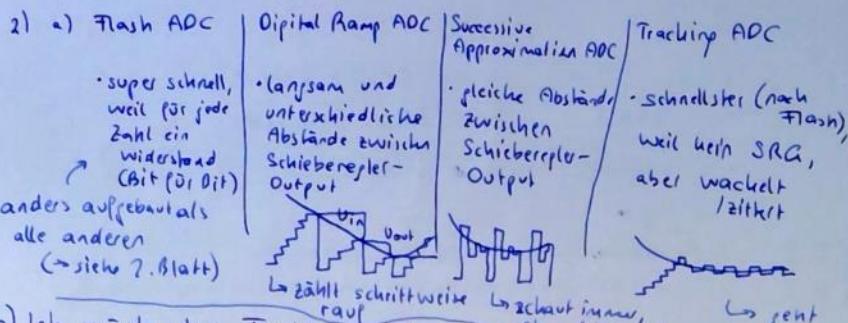
$$U_a = -800 \Omega \cdot \left(\frac{U_1}{4\kappa} + \frac{U_2}{2\kappa} + \frac{U_3}{\kappa} \right)$$

Über die Widerstände kann man die analoge Zahl mit obiger Formel ausrechnen.
 MSB ... Most Significant Bit
 LSD ... Least Significant Bit

R/2R:

R/2ⁿR: VT: • einfach verständlich
 • leicht rechenbar NT: • teuer (viele oder wenige Toleranzen)
 • weil viele Widerstände
 • Tolerant

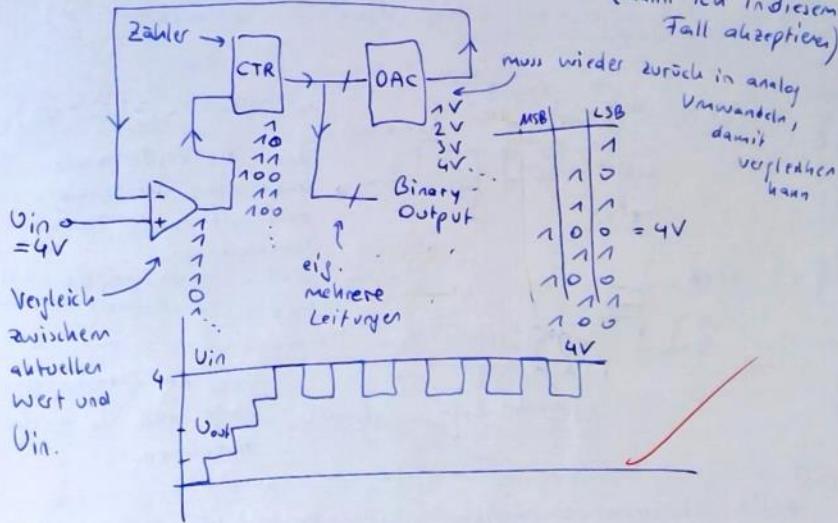
R/2R: VT: • billig, wenige Widerstände
 • nicht so tolerant abhängig
 • fehlt über Spannung NT: • schwer zu verstehen
 • rechnen schwieriger
 • komplex



b) Ich würde den Tracking ADC wählen, weil:

VT: super schnell (Nice)
 NT: zittert, wackelt

\leftarrow ist mir aber egal, weshalb ich den wähle (kann ich in diesem Fall akzeptieren)

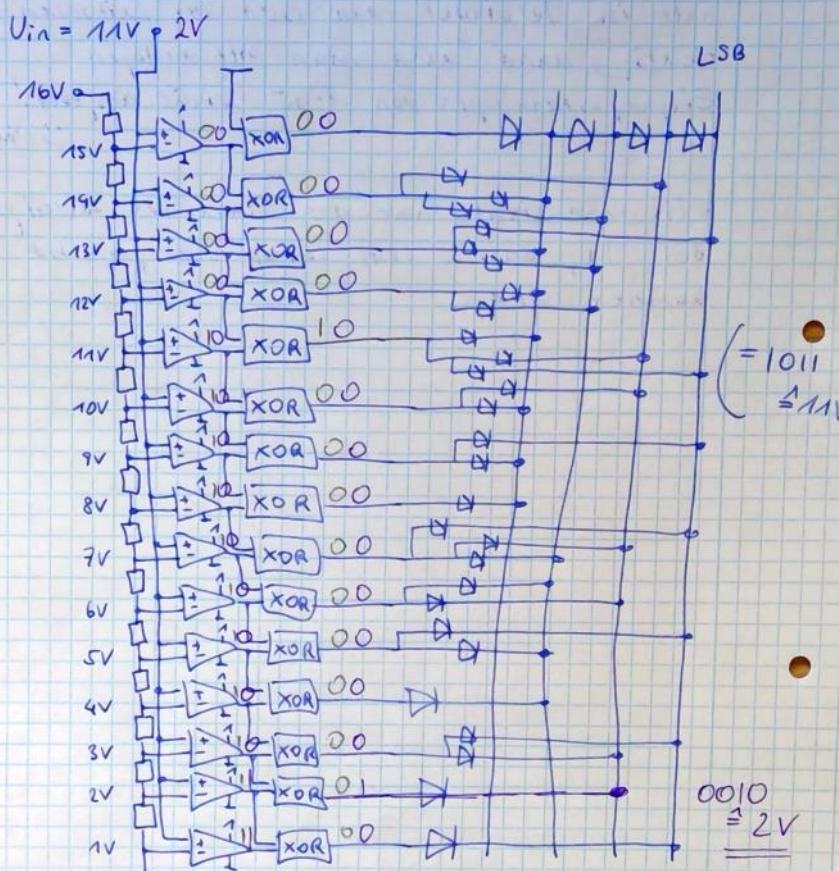


Das Most Significant Bit heißt so, weil es die größte Differenz entscheidet.

Beispiel: $0000 \leftrightarrow 1000$ $0000 \leftrightarrow 0001 \leftarrow$ LSB

MSB

2)c) schnellster ADC = Flash ADC



Zuerst vergleicht der Flash ADC die Eingangsspannung mit all den möglichen Spannungen (1-15). Alle Werte, die oder sie liegen kleiner sind, als die Eingangsspannung geben Strom weiter (1), alle größeren Werte 0. Durch die XOR-Gatter, geht nur die Leitung Strom weiter, wo unterschiedliche Eingänge sind →

• was genau da ist, so proß die Eingangsspannung
holt ist. Verbindet man nun die Leitungen
richtig, dann kann man alle analogen
Eingangsspannungen von 1-15 binär ausgeben!
Ü Nice!

Wie man sieht, hat der Flash ADC allerdings
den NT, dass er sehr schnell sehr proß und
komplex wird..





Grundlagen der Elektrotechnik und Elektronik3 (SYTE3)

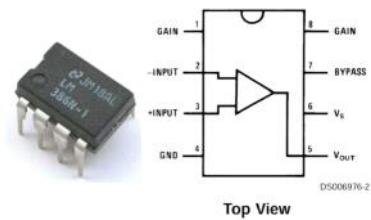
Skriptum zur Vorlesung/Übung
der Schulstufe 3

HTBL Krems/Informationstechnologie
DI Dr. Sabine Strohmayer

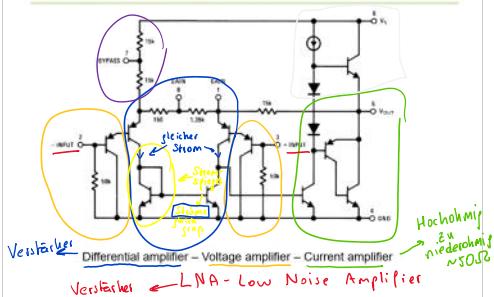
Outlook SYTE3

- Operational amplifier
- Converter AD/DA
- Measurements of non electrical quantities
- EMC

Integrated Operational Amplifier

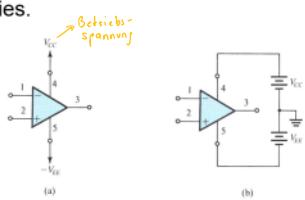


Integrated Operational Amplifier



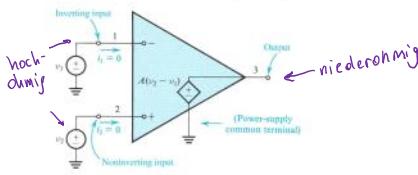
Operational Amplifier

The op amp shown connected to dc power supplies.



Ideal Operational Amplifier

- The gain is ideally infinite (Open loop configuration)
- We will use other components to apply feedback to close the loop around the op-amp

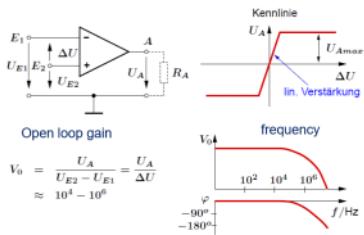


Operational Amplifier

Typical ranges for op amp parameters.

Parameter	Typical range	Ideal values
Open-loop gain, A	10^5 to 10^8	∞
Input resistance, R_i	10^5 to $10^{13} \Omega$	0Ω
Output resistance, R_o	10 to 100 Ω	0Ω
Supply voltage, V_{CC}	5 to 24 V	

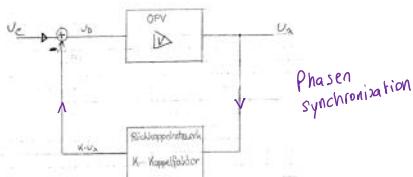
Integrated Operational Amplifier



introduction, motivation (5min)

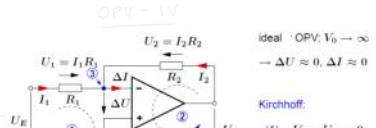
<http://www.youtube.com/watch?v=TQB1VILBqJE&feature=related>

Feedback Operational Amplifier



Inverting Amplifier

Invertierender Verstärker

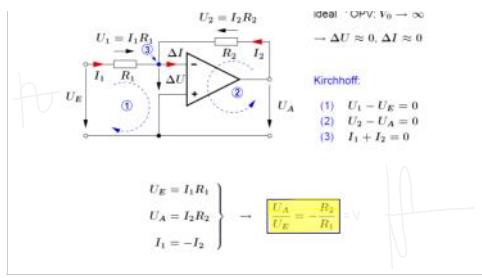


Invertierende Verstärker

Berechne die fehlenden Größen:

$$\frac{U_A}{U_E} = -\frac{R_2}{R_1} = V \quad \frac{U_E}{U_A} = -\frac{R_1}{R_2} = \frac{1}{V}$$

R2	30k	20k	40k	4.1k	4k	8k	20k
R1	10k	5k	6k	7k	2k	4k	10k
Ua	-15	-8	-15	18	-6	-8	-10

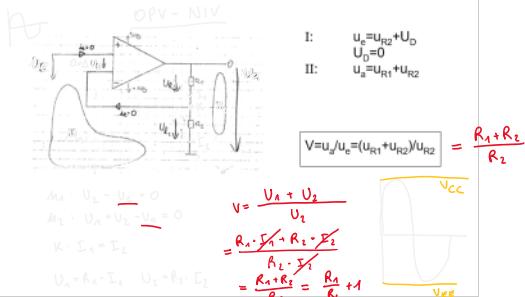


R1	10k	5k	8k	7k	2k	4k	10k
Ua	-15	-8	-15	18	-6	-8	-10
Ue	5	2	3	-3	3	4	5
v	-3	-4	-5	-6	-2	-2	-2

Inverting Amplifier

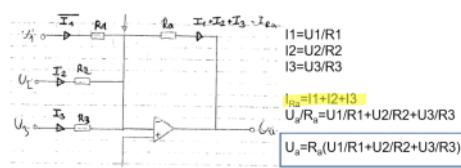
- Negative feedback
- Closed-loop gain depends entirely on passive components and is independent of the op amp.
- Engineer can make the closed-loop gain as accurate as he wants as long as the passive components are accurate.

Non Inverting Amplifier



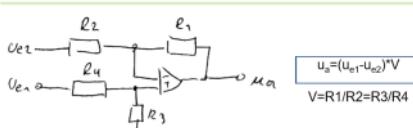
Nicht invertierende Verstärker berechnen die fehlenden Größen							
R1	8k	6k	40k	100k	24k	48k	16k
R2	2k	3k	2k	50k	4k	24k	4k
Ua	20	45	42	21	18	15	15
Ue	4	5	2	7	6	5	3
v	5	3	21	3	3	5	3

Summing Amplifier



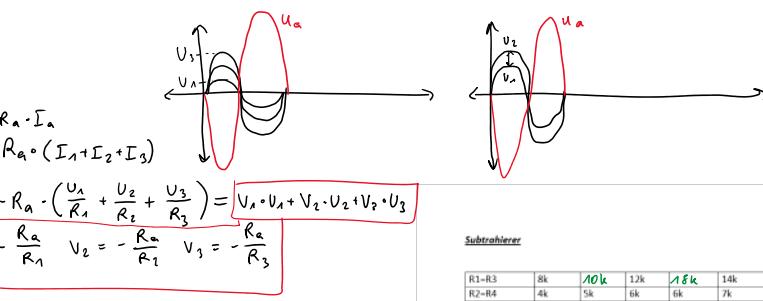
The inverting summer is the basic op amp circuit that is used to sum two or more signal voltages, to sum a dc voltage with a signal voltage, etc.

Differential Amplifier



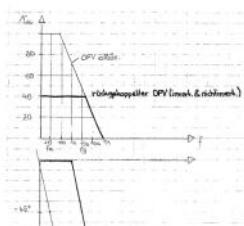
A differential amplifier or diff amp is an amplifier which has two inputs and one output. When a signal is applied to one input, the diff amp operates as a non-inverting amplifier. When a signal is applied to the other input, it acts as an inverting amplifier.

To avoid offset: $R_1=R_3$ und $R_2=R_4$.

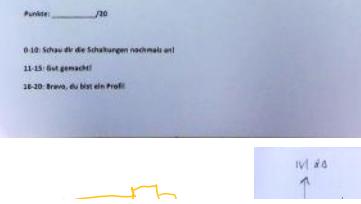
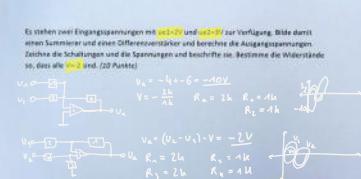


R1=R3	8k	10k	12k	18k	14k
R2=R4	4k	5k	6k	10k	8k
-Ua	6	8	10	6	8
-V	2	2	2	2	2
ΔUo=Uo-U	3	4	5	2	4
Uo2					

Bode Diagramm



R1	4k	5k	3k	2k	1k
R2	2k	5k	3k	2k	1k
R3	2k	3k	3k	2k	1k
R4	2k	3k	2k	3k	1k
U1	8	2	4	2	1
U2	6	10	5	12	2
U3	10	8	6	3	1
-Ua	24	20	12	12	1
V1	0.5	1	4	7	3
V2	2.0	3/5	4/5	1/5	3
V3	1	1/4	4/3	1/3	1



SVTE:
SMÜ: OPV
Zur Verfügung stehen verschiedene Doppelpoleinstellungen, die eine Ausgangsspannung von +/- 10 V ergeben. Berechne die Schaltung und die Widerstände so, dass die mit einer Eingangsspannung von jeweils +/- 20 mV auskommt. Zeichne die Ein- und Ausgangsspannungen in ein Diagramm. Wie groß muss sich die Betriebsspannung mindestens wählen und warum? (20 Punkte)

SVTE:
SMÜ: OPV
Zur Verfügung stehen verschiedene Doppelpoleinstellungen, die eine Ausgangsspannung von +/- 10 V ergeben. Berechne die Schaltung und die Widerstände so, dass die mit einer Eingangsspannung von jeweils +/- 20 mV auskommt. Zeichne die Ein- und Ausgangsspannungen in ein Diagramm. Wie groß muss sich die Betriebsspannung mindestens wählen und warum? (20 Punkte)

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SMÜ: OPV
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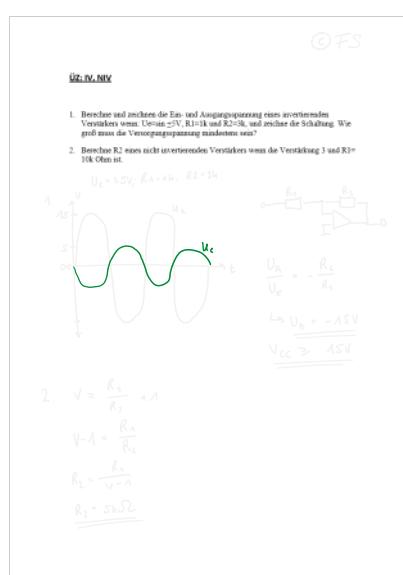
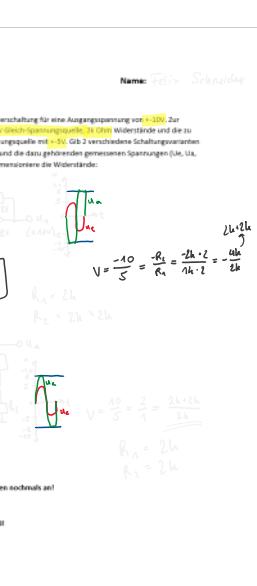
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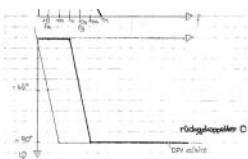
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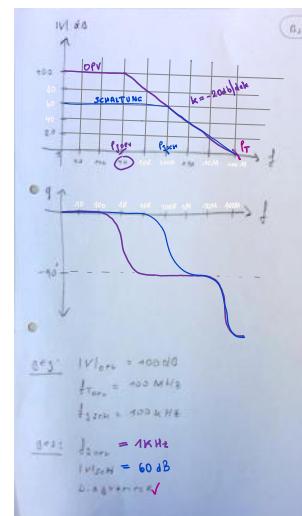
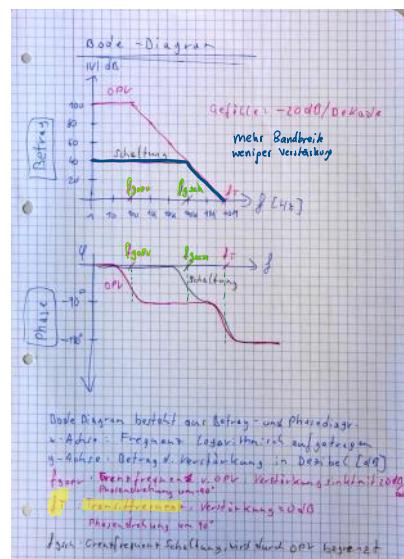
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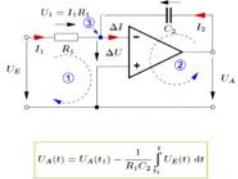




Bode Diagramm

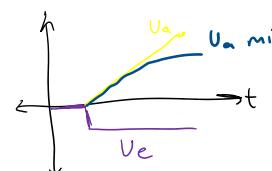
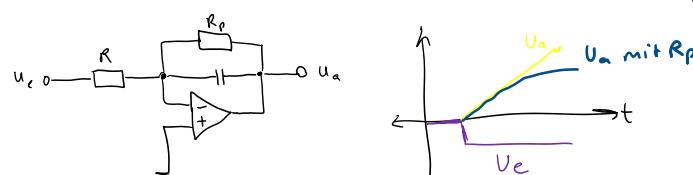
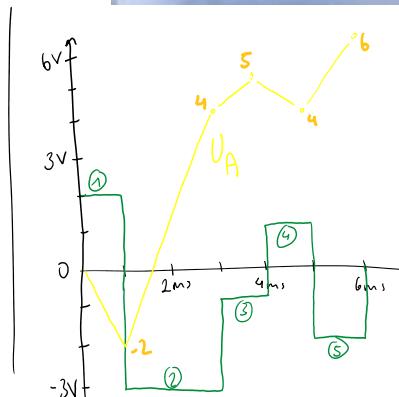
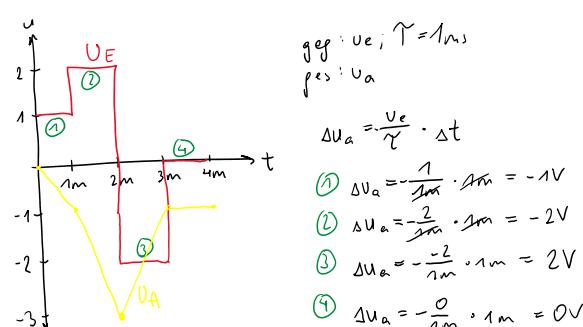
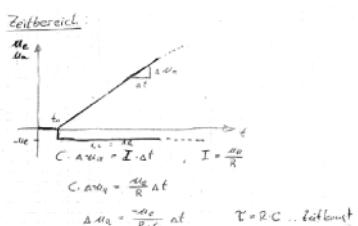


Integrator



If a capacitor is used as the feedback element in the inverting amplifier, the result is an integrator. An intuitive grasp of the integrator action may be obtained from the statement under the section, "Current Output," that current through the feedback loop charges the capacitor and is stored there as a voltage from the output to ground. This is a voltage input current integrator.

Integrator

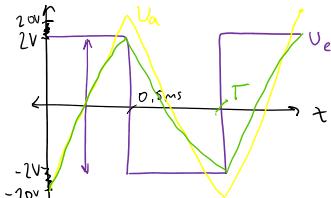


$$\text{geg: } f = 1 \text{ kHz} \quad \rightarrow \underline{T = 1 \text{ ms}}$$

$$R = 10k \quad C = 5 \text{ nF}$$

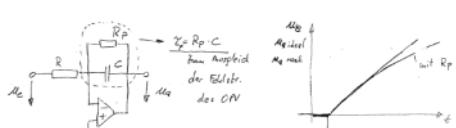
$$\Delta U_A = -\frac{U_E}{R \cdot C} \cdot \Delta t$$

$$\Delta U_A = -\frac{4V}{10k \cdot 5nF} \cdot 0.5m = \underline{\underline{40V}}$$



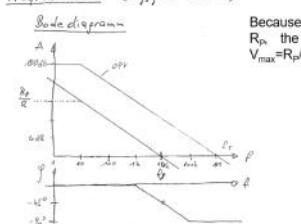
Integrator

Problems:
In order to prevent integrator saturation due to infinite dc gain, parallel feedback resistance is included.
Result: non linearity

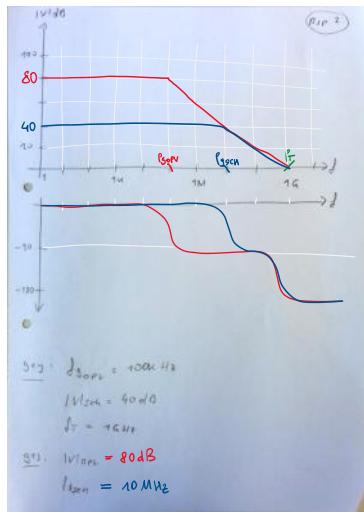


Integrator

Frequenzbereich (Empirical noise η)



Because of the resistance R_p , the max. Gain is $V_{max} = R_p / R$.

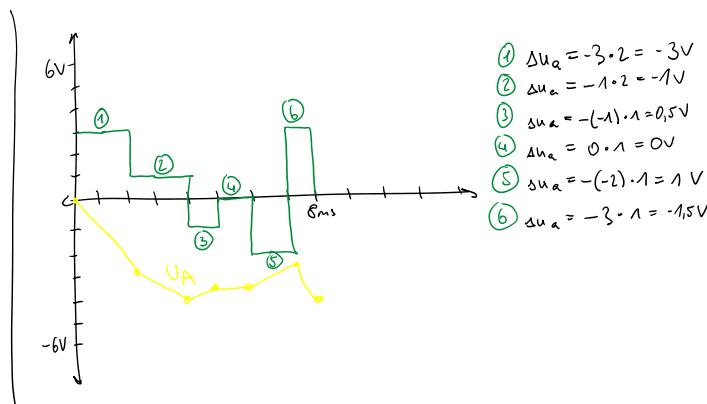


$\rho_{cf}: V_C; T=1 \text{ ms}$

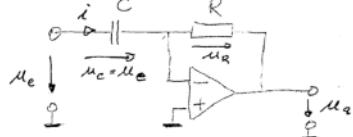
$\rho_{cs}: u_a$

$$\Delta u_a = -\frac{u_c}{T} \cdot \Delta t$$

- (1) $\Delta u_a = -\frac{2}{1 \text{ ms}} \cdot 1 \text{ ms} = -2 \text{ V}$
- (2) $\Delta u_a = -\frac{-3}{1 \text{ ms}} \cdot 2 \text{ ms} = 6 \text{ V}$
- (3) $\Delta u_a = -\frac{-1}{1 \text{ ms}} \cdot 1 \text{ ms} = 1 \text{ V}$
- (4) $\Delta u_a = -1 \text{ V}$
- (5) $\Delta u_a = -\frac{-2}{1 \text{ ms}} \cdot 1 \text{ ms} = 2 \text{ V}$



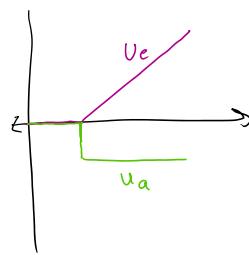
Differentiator



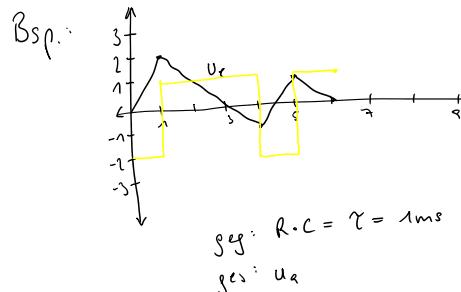
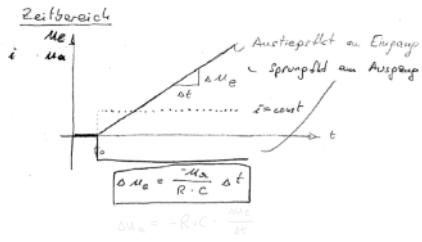
Using a capacitor as the input element to the inverting amplifier, yields a differentiator circuit..

$$\Delta u_c = -\frac{u_a}{R \cdot C} \cdot \Delta t$$

$$u_a = -\frac{R \cdot C}{\Delta t} \cdot \Delta u_c$$



Differentiator



$$u_a = -\frac{\gamma}{\Delta t} \cdot u_e$$

$$u_a = -\frac{1 \text{ m}}{1 \text{ m}} \cdot 2 = -2 \text{ V}$$

$$u_a = -\frac{1 \text{ m}}{3 \text{ m}} \cdot (-2) = 1 \text{ V}$$

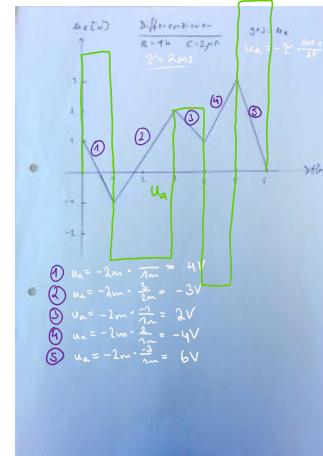
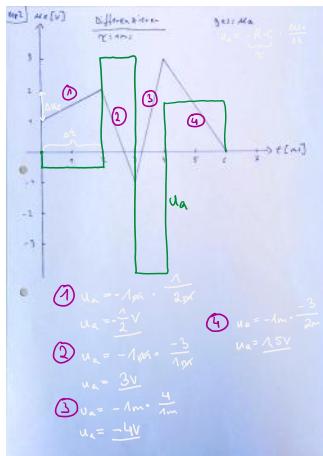
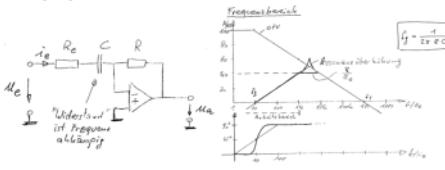
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$$u_a = -\frac{1 \text{ m}}{1 \text{ m}} \cdot (-2) = 1 \text{ V}$$

Differentiator

Probleme:

Bei Eingangssignalen mit hohen Frequenzanteilen wird beim einfachen Differenzierer der Widerstand des C sehr klein, sodaß ein hoher Strom durch den Eingangskreis fließt. Dieser belastet die Spannungsquelle. Um die Belastung der Spannungsquelle zu begrenzen, wird ein R_0 in Serie hinzugefügt.



Bsp. Diff + Int
 JG: Diff. $R = 1 \text{ k}$ $C = 5 \mu\text{F}$ Int. $R = 10 \text{ k}$ $C = ?$ $u_e = \pm 15 \text{ V}$
 Distanz $\Delta t = 2 \text{ ms}$ $f = 100 \text{ Hz}$
 ges: Schaltung, Spannungsverlauf, C

Diffintegrierer:

$$u_a = -R \cdot C \cdot \frac{u_e}{\Delta t}$$

$$u_a = 1 \text{ k} \cdot 5 \mu\text{F} \cdot \frac{10}{2 \text{ ms}} = 10 \text{ V}$$

$$\Delta u_a = \frac{u_a}{RC} \cdot \Delta t$$

$$30 = \frac{10}{10 \text{ k} \cdot 5 \mu\text{F}} \cdot 5 \text{ ms}$$

$$C = \frac{5 \mu\text{F}}{30000 \text{ ms}} = \frac{1}{6} \mu\text{F}$$

Introduction1 voltage follower

http://www.youtube.com/watch?v=Q3RMFpGGcZM&feature=player_detailpage
<http://www.youtube.com/watch?v=zYMKASTSO8>

Voltage Follower

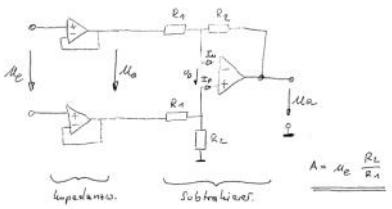
Impedanzumwandler



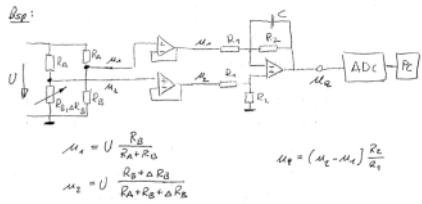
Because the output node is connected directly to the inverting input instead of through a voltage divider, the circuit is said to have 100% feedback. Because $v_+ = v_-$, it follows that $v_0 = v_i$. Therefore, the circuit has unity voltage gain. The voltage follower is often used to isolate a low resistance load from a high output resistance source. That is, the voltage follower supplies the current to drive the load while drawing no current from the input circuit.

—
○

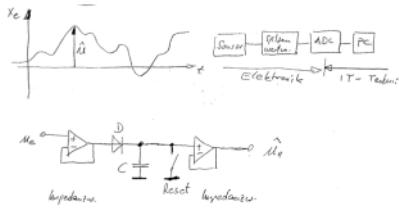
Voltage Follower



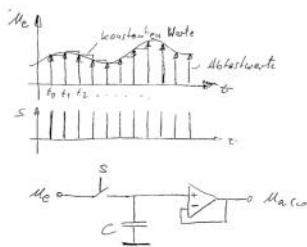
Voltage Follower



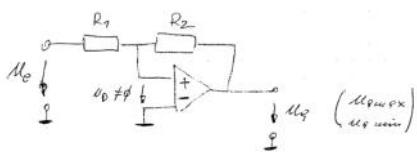
Peakdetector



Sampling Detector

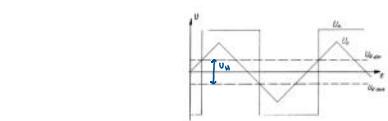
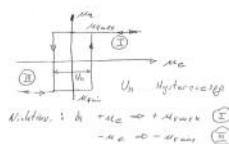


Non Inverting Schmitt-Trigger

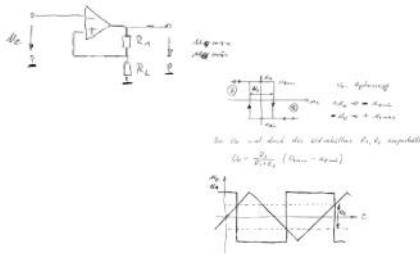


Positive feedback is often used with comparator circuits. The feedback is applied from the output to the non-inverting input of the op amp. This is in contrast to the circuits covered in the preceding sections of this chapter where feedback is applied to the inverting input.

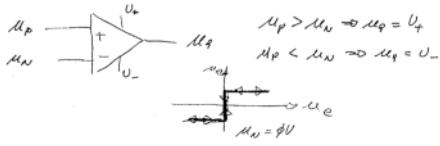
Non Inverting Schmitt-Trigger



Inverting Schmitt-Trigger



Comparator



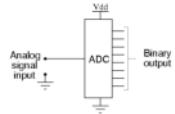


Chapter 13 DIGITAL ANALOG CONVERSION

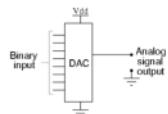
Introduction

Connecting digital circuitry to sensor devices is simple if the sensor devices are inherently digital (e.g., digital Hall sensors). However, when analog sensors are used, the connection becomes more complex. What is needed is a way to electronically translate analog signals into digital (binary) quantities, and this is what a digital-to-analog converter, or ADC, performs the former task while a digital-to-analog converter, or DAC, performs the latter.

An ADC inputs an analog electrical signal such as voltage or current and outputs a binary number. In block diagram form, it can be represented as such:

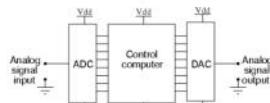


A DAC, on the other hand, inputs a binary number and outputs an analog voltage or current signal. In block diagram form, it looks like this:



Together, they are often used in digital systems to provide complete interface with analog sensors and output devices for control systems such as those used in automotive engine controls.

Digital control system with analog I/O

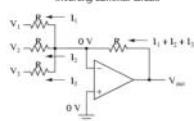


It is much easier to convert a digital signal into an analog signal than it is to do the reverse. Therefore, we will begin with DAC circuitry and then move to ADC circuitry.

The R/2ⁿR DAC

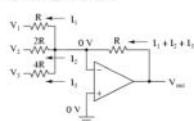
This DAC circuit, otherwise known as the binary-weighted-input DAC, is a variation on the inverting summer op-amp circuit. You recall, the classic inverting summer circuit is an operational amplifier using negative feedback for controlled gain with several voltage inputs and one voltage output. The output voltage is the inverted (opposite polarity) sum of all input voltages.

Inverting summer circuit

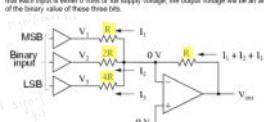


$$V_{out} = -(V_1 + V_2 + V_3)$$

For a simple inverting summer circuit, all resistors must be equal value. If any of the input resistors were different, the analog output would be different depending on which input had the higher voltage. This would not be a true sum. Let's consider, however, intentionally setting the input resistor values at different values. Suppose we set the input resistor values at multiples of two: R, 2R, and 4R, instead of all the same value R.



Starting from V₁ and going through V₃, this would give each input voltage exactly half the effect on the output as the voltage before it. In other words, input voltage V₃ has a 1/1 effect on the output voltage (given a 4R resistor), V₂ has a 1/2 effect, and V₁ has a 1/4 effect. This is equivalent to a ratio of 1/4, 1/2, and 1/1. These ratios are were not arbitrarily chosen; they are the same ratios corresponding to the binary weight of each bit in a digital system. If we drive the inputs of this circuit with digital pulses to turn each input on either 0 volts or M supply voltage, the output voltage will be an analog representation of the binary value of these three bits.



If we chart the output voltages for all eight combinations of binary bits (000 through 111) input to this circuit, we will get the following progression of voltages:

Binary | Output voltage |

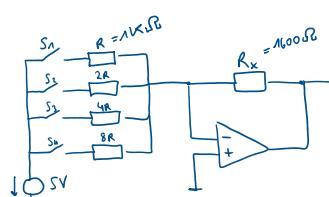
| 000 | 0.00 V |

| 001 | -1.25 V |

| 010 | -2.50 V |

| 011 | -3.75 V |

| 100 | -5.00 V |

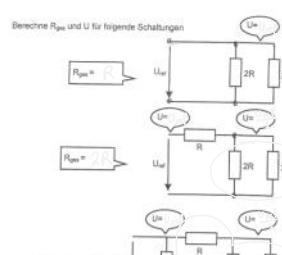


$$U_a = \left(\frac{R_x}{R} \cdot U_1 + \frac{R_x}{2R} \cdot U_2 + \frac{R_x}{4R} \cdot U_3 + \frac{R_x}{8R} \cdot U_4 \right)$$

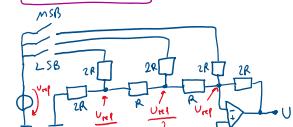
$$U_a = -\frac{R_x}{R} \cdot \left(U_1 + \frac{U_2}{2} + \frac{U_3}{4} + \frac{U_4}{8} \right)$$

$$U_a = -1600m \cdot \left(U_1 + \frac{U_2}{2} + \frac{U_3}{4} + \frac{U_4}{8} \right)$$

	MSB	-	-	LSB	- U _a
0	0	0	0	0	0
0	0	0	0	1	1
0	0	0	1	0	(-1,6 · $\frac{5}{8}$)
0	0	1	0	1	2
0	1	0	0	0	(-1,6 · $\frac{5}{4}$)
0	1	0	1	1	3
0	1	0	0	0	4
0	1	0	1	1	5
0	1	1	0	1	6
0	1	1	1	1	7
1	0	0	0	0	8
1	0	0	0	1	9
1	0	1	0	1	10
1	0	1	1	1	11
1	1	0	0	0	12
1	1	0	1	0	13
1	1	1	1	0	14
1	1	1	1	1	15

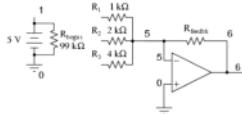
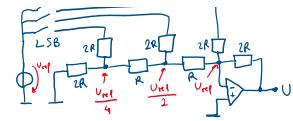
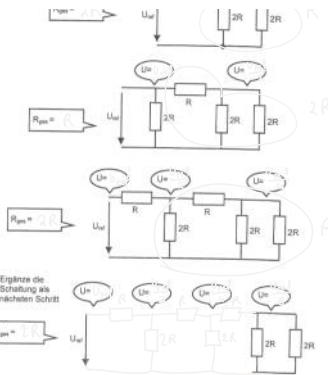


R/2ⁿ-DAC



010	-2.50 V
011	-3.75 V
100	-5.00 V
101	-6.25 V
110	-7.50 V
111	-8.75 V

Note that with each step in the binary count sequence, there results a 1.25 volt change in the output. This circuit is very easy to simulate using SPICE. In the following simulation, I set up the DAC circuit with a binary input of "010" (note the first node is connected to resistors R_1 , R_2 , and R_3 ; a node number of "1" connects it to the bottom of a 5 volt battery; and a node number of "0" connects node 6 to ground). The output voltage appears on node 6 in the simulation.



binary-weighted dac:

```
v1 1 0 dc 5
rheqa 1 0 50k
r1 1 5 1k
r2 1 5 2k
r3 1 5 4k
rfeedback 5 6 1k
e1 6 0 0 0 999k
and
```

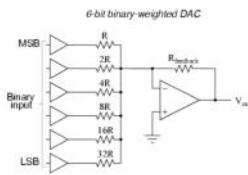
node voltage node voltage node voltage
(1) 5.0000 (5) 0.0000 (6) -7.5000

We can adjust resistor values in the circuit to obtain output voltages directly corresponding to the binary input. For example, by making the feedback resistor 100 Ω instead of 1 kΩ, the DAC will output -1 volt for the binary input 001, -4 volts for the binary input 100, -7 volts for the binary input 111, and so on.

(with feedback resistor set at 100 ohms)

Binary Output voltage
000 0.00 V
001 -1.00 V
010 -2.00 V
011 -3.00 V
100 -4.00 V
101 -5.00 V
110 -6.00 V
111 -7.00 V

If we wish to expand the resolution of this DAC (add more bits to the input), all we need to do is add more input resistors, holding to the same power of two sequence of values.

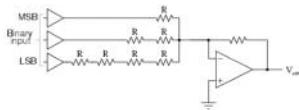


It should be noted that if logic gates meet output exactly the same voltage when in the "high" state. If resistor values are not identical, then the output voltage will be different. This means that the output of the DAC will be adversely affected. Likewise, all "low" voltage levels should be identical between gates. Ideally 0.00 volts exactly. It is recommended that CMOS output gates are used, and that individual resistor values are chosen so as to minimize the amount of current each gate has to source or sink.

The R/2R DAC

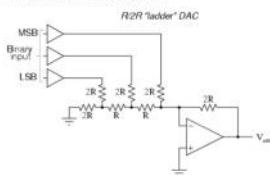
An alternative to the binary-weighted-input DAC is the so-called R/2R DAC, which uses fewer unique resistor values. A disadvantage of the former DAC design was its requirement of seven different precise logic-level inputs. The R/2R DAC design can be simplified if there are fewer different resistor values to purchase, stock, and sort prior to assembly.

Of course, we could take our last DAC circuit and modify it to use a single input resistance value, by connecting multiple resistors together in series.



Unfortunately, this approach merely substitutes one type of complexity for another: volume of components over diversity of component values. There is, however, a more efficient design methodology.

By constructing a different kind of resistor network on the input of our running circuit, we can achieve the same kind of binary weighting with a smaller number of resistor values, and with only a modest increase in resistor count. This "wonder network" looks like this:



Mathematically analyzing this ladder network is a bit more complex than for the previous circuit, where each input had a unique voltage level. However, in order to keep things simple, and in pursuing the goals of this circuit type, we may opt to use Thévenin's theorem for each binary input (remember to consider the effects of the virtual ground), and/or use a simulation program like SPICE to determine circuit response. Either way, you should obtain the following table of outputs:

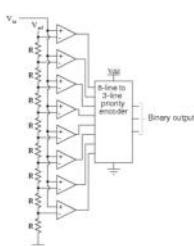
| Binary | Output voltage |

000	0.00 V
001	-1.25 V
010	-2.50 V
011	-3.75 V
100	-5.00 V
101	-6.25 V
110	-7.50 V
111	-8.75 V

As was the case with the binary-weighted DAC design, we can modify the value of the feedback resistor to change the "resolution" of our digital-to-analog converter. If we set the MSB to a "high" voltage level and 0 bits to a "low" voltage level, we can obtain an analog output directly corresponding to the binary input (011 = -3 volts, 101 = -5 volts, 111 = -7 volts, etc.) by using a feedback resistance with a value of 1.6K instead of 2K.

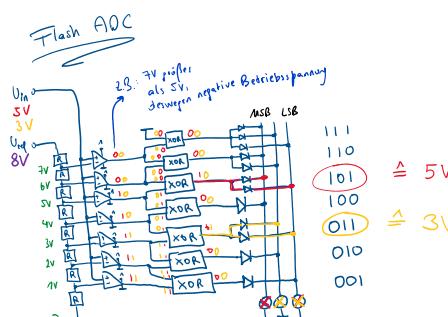
Flash ADC

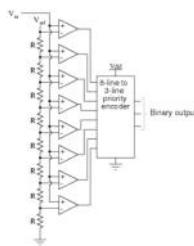
A flash (parallel) ADC converts the input to the simplest to understand. It consists of a series of comparators, each one comparing the input signal to a unique reference voltage. The comparator outputs connect to the inputs of a priority encoder circuit, which then produces a binary output. The following illustration shows a 3-bit flash ADC circuit.



V_{ref} is a stable reference voltage provided by a precision voltage regulator as part of the converter circuit. As the input voltage increases, the output of the ladder will eventually reach the reference voltage. The comparator outputs will sequentially saturate to a high state. The priority encoder generates a binary number based on the highest-order active input, ignoring all other active inputs.

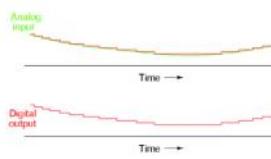
When operated, the flash ADC produces an output that looks something like this:



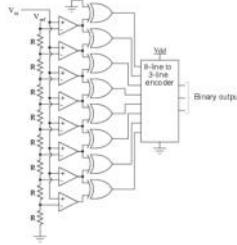


V_{ref} is a stable reference voltage provided by a precision voltage regulator as part of the converter circuit. In this design, the reference voltage is set by a resistor ladder network. As each successive comparator's output goes high, the priority encoder generates a binary number based on the highest-order active input, ignoring all other active inputs.

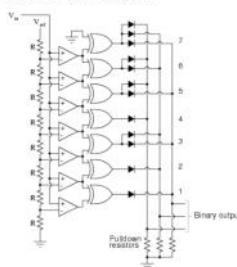
When operated, the flash ADC produces an output that looks something like this:



For this particular application, a regular priority encoder with all its inherent complexity isn't necessary. Due to the nature of the sequential comparator output states (each comparator saturating "high" in sequence from lowest to highest), the same "highest-order-input-selector" effect may be realized through a bank of discrete CMOS gates, allowing the use of a simpler, non-priority encoder.



And, of course, the encoder circuit itself can be made from a matrix of diodes, demonstrating just how simply this converter design may be constructed.



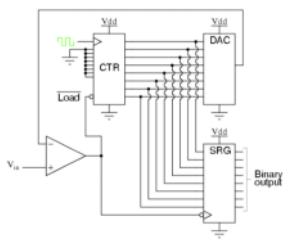
Not only is the flash converter the simplest in terms of operational theory, but it is the most efficient of the ADC technologies in terms of speed, being limited only in comparator and gate propagation delays. Likewise, it is the most expensive. A single 8-bit flash converter requires 256 comparators. A 4-bit flash ADC requires eight comparators. A four-bit version would require 16 comparators. With each additional output bit, the number of comparators required doubles. While this may seem like a disadvantage, it must be considered the minimum necessary for any practical ADC (256 comparators needed), the flash methodology quickly shows its weakness.

An additional advantage of the flash converter, often overlooked, is the ability for it to produce a non-linear response. With respect to the reference voltage divider network, each successive binary count requires the same amount of analog signal increase, providing a proportional response. For specific applications, however, this is not the desired behavior. By adding a feedback loop to the flash converter, the ADC can create a nonlinear response to the analog input signal. No other ADC design is able to grant this signal-conditioning behavior with just a few component value changes.

Digital ramp ADC

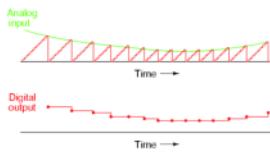
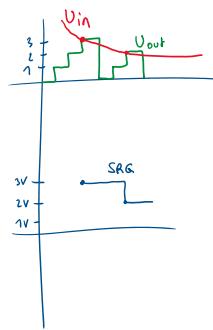
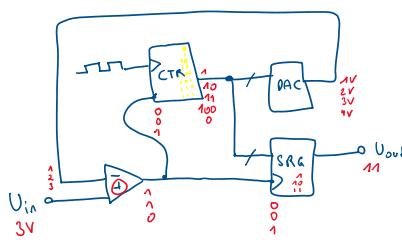
Also known as the staircase-ramp, or simply counter A/D converter, this is also fairly easy to understand.

The basic idea is to connect the output of a free-running binary counter to the input of a DAC. Then compare the analog output of the DAC with the analog input signal to be digitized and use the comparator's output to tell the counter when to stop counting and reset. The following schematic shows the basic idea:

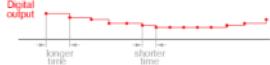


As the counter counts up with each clock pulse, the DAC outputs a slightly higher (more positive) voltage. This voltage is compared against the input voltage by the comparator. If the input voltage is higher than the DAC's output, the comparator's output will be high, telling the counter to continue counting normally. Eventually, though, the DAC output will exceed the input voltage, causing the comparator's output to go low. When this happens, the SRG's output goes low, telling the CTR to stop counting. This will cause the shift register to "load" whatever binary count is being output by the counter, thus updating the ADC's digital output. The SRG will receive a low signal on the active-low LOAD input, causing it to reset to 00000000 on the next clock.

The effect of the circuit is to produce a DAC output that ramps up to whatever level the analog input signal is at, output the binary number corresponding to that level, and start over again. Plotted over time, it looks like this:



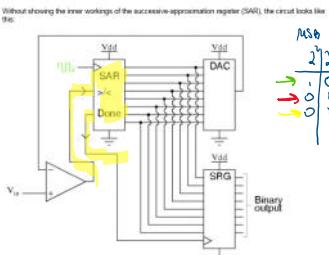
Note how the time between updates (new digital output values) changes depending on how high the input voltage is. For low signal levels, the updates are rather far apart. For higher signal levels, they are spaced further apart in time.



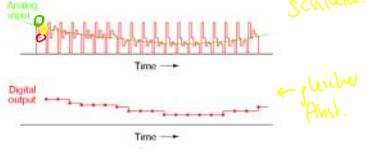
For many ADC applications, this variation in update frequency (sample times) would not be acceptable. That, and the fact that the circuit's need to count all the way from 0 at the beginning of each count cycle makes for relatively slow sampling of the analog signal, places the digital-ramp ADC at a disadvantage to other counter strategies.

Successive approximation ADC

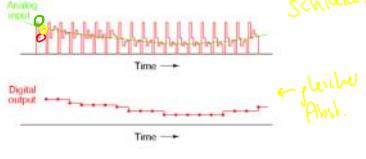
One method of addressing the digital ramp ADC's shortcomings is the so-called successive-approximation ADC (SAR). This ADC uses a special digital circuit known as a successive-approximation register. Instead of counting up in binary sequence, this register counts by trying out values of bits until it finds the right one. The SAR's output is compared with the analog input. Then, if the result is too high, the register monitors the comparator's output to see if the binary count is less than or greater than the analog signal input, adjusting the bit values accordingly. The way the register works is to start with the most significant bit (MSB) and work down to the least significant bit (LSB). Different values of bits are tried from MSB to LSB to get a binary number that equals the original decimal number. The advantage to this counting strategy is much faster results; the DAC output converges on the analog signal input in much fewer stages than with the 1-bit-1-bit count sequence of a regular counter.



Without showing the inner workings of the successive-approximation register (SAR), the circuit looks like this:



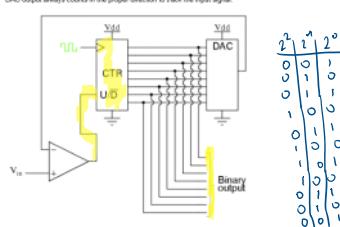
It should be noted that the SAR is technically capable of outputting the binary number in serial (one bit at a time) format, thus allowing for even faster shift register. Plotted over time, the operation of a successive-approximation-ADC looks like this:



Note how the updates for this ADC occur at regular intervals, unlike the digital ramp ADC circuit.

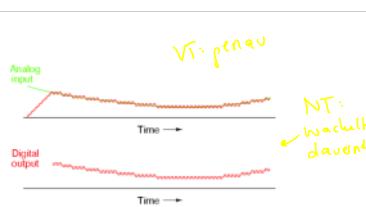
Tracking ADC

A third variation on the counter-DAC-based converter theme is, in my estimation, the most elegant: instead of a regular “up” counter driving the DAC, this circuit uses an up/down counter. The counter is continually clocked, and the up/down control line is driven by the output of the comparator. So, when the analog input voltage is higher than the DAC's output, the up/down line goes high, and the DAC output exceeds the analog input, the counter switches into the “count down” mode. Either way, the DAC output always counts in the proper direction to track the input signal.



Notice how no shift register is needed to buffer the binary count at the end of a cycle. Since the counter is updated continuously tracking the input (rather than counting the input and then resetting back to zero), the binary output is logically updated with every clock pulse.

An advantage of this converter circuit is speed, since the counter never has to reset. Note the behavior of this circuit:



Note the much faster update time than any of the other “counting” ADC circuits. Also note how at the very beginning of the plot where the counter had to “catch up” with the analog signal, the rate of change for the output was identical to that of the first counting ADC. Also, with no shift register in this circuit, the binary output is logically updated with every clock pulse, making it more accurate overall. It also cuts the cost and increases the speed of the converter compared to the standard counter and successive approximation ADC circuits.

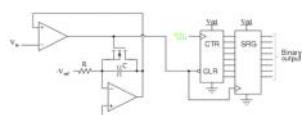
Perhaps the greatest drawback to this design is the fact that the binary output is never stable. It always switches between counts with every clock pulse, even with a perfectly stable analog input signal. That makes it difficult to interface with digital logic, but it is possible if care is taken in the digital system.

That tendency can be overcome, though, through the use of a shift register. For example, the counter's output may be latched through a parallel-interfaced-out shift register only when the output changes by two or more steps. Building a circuit to detect two or more successive counts in the same direction takes a little ingenuity, but is worth the effort.

Slope (integrating) ADC

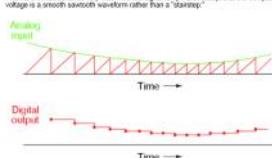
So far, we've only been able to escape the sheer volume of components in the flash converter by using a DAC as part of the ADC circuitry. However, this is not our only option. It is possible to avoid using a DAC if we substitute an analog ramping circuit and a digital counter with precise timing.

The basic idea behind the so-called single-slope, or integrating ADC, instead of using a DAC with a ramped output, we use an op-amp circuit called an integrator to generate a sawtooth waveform which it compares against the input signal. The number of samples will increase until the output voltage exceeds the input signal voltage level is measured by means of a digital counter clocked with a precise frequency square wave (usually from a crystal oscillator). The basic schematic diagram is shown here.



The IGBT capacitor-discharging transistor scheme shown here is a bit complicated. In reality, a timing circuit timed with the clock signal would most likely have to be connected to the IGBT gate to ensure full discharge of the capacitor when the comparator's output goes high. The basic idea, however, is that the capacitor is charged up to the input voltage level. When the comparator's output goes high, the integrator is allowed to charge the capacitor in a linear fashion. Meanwhile, the counter is counting up at a rate determined by the clock frequency. The time it takes for the capacitor to charge up to the input voltage level is the input conversion time. R and C, when the capacitor reaches that voltage level, the comparator output goes high, loading the counter with the current value. This causes the integrator to switch to a low state, discharging the capacitor's high output, discharging the capacitor back to zero volts. When the integrator output voltage falls to zero, the counter switches back to a low state, clearing the counter and enabling the integrator to charge up voltage again.

This ADC circuit behaves very much like the digital ramp ADC, except that the comparator reference voltage is a smooth sawtooth waveform rather than a “stamp.”



The single-slope ADC suffers all the disadvantages of the digital ramp ADC, with the added drawback of calibration drift. The accurate correspondence of this ADC's output with its input is dependent on the values of the resistors and capacitors used in the integrator and the clocking circuit (the SRG). With the digital ramp ADC, the clock frequency had no effect on conversion accuracy, only on update time. In this circuit, since the rate of integration and the rate of count are independent of each other,

variation between the two is inevitable as it ages, and will result in a loss of accuracy. The only good thing to say about this circuit is that it avoids the use of a DAC, which reduces circuit complexity.

An answer to this calibration drift-dilemma is found in a design variation called the dual-slope converter. In the dual-slope converter, the analog input voltage is converted to a digital output by first being integrated down and then up, rather than being reset to 0 volts at the end of every cycle. In one direction of ramping, the integrator is driven by the positive analog input signal producing a negative, variable rate of output voltage. This output voltage is then compared to a fixed reference voltage, and the time required to reach the reference clock. Then, in the other direction, with a fixed reference voltage producing a fixed rate of output voltage, the integrator is driven by the negative output of the first stage. This second stage continues until the integrator's output reaches the same voltage as it was when it started the fixed-time portion of the cycle. The amount of time it takes for the integrator's capacitor to discharge back to its initial output voltage is an integer multiple of the period of the reference clock.

The dual-slope method can be thought of analogously in terms of a rotary spring such as that used in a mechanical clock mechanism. Imagine we were building a mechanism to measure the rotary speed of a shaft. That shaft would be our "analog input" signal, and the output of the system would be the digital output. We could have a "spooling up" phase where the shaft turns clockwise, and a "spooling down" phase where the shaft turns counter-clockwise. The spring is then turned, or "wound up", by the rotating shaft (input signal) for a fixed amount of time. This places the spring in a certain amount of tension proportional to the angle of rotation. After that, the spring is uncoupled from the shaft and allowed to turn counter-clockwise (output signal) until the spring has wound back down to its original state. The amount of time it takes for the spring to unwind at that fixed rate will be directly proportional to the speed at which it was wound (input signal magnitude) during the fixed-time portion of the cycle.

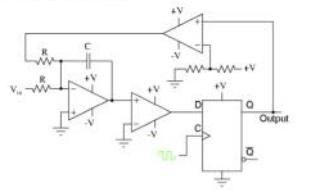
This technique of analog-to-digital conversion escapes the calibration-drift problem of the single-slope ADC. However, it does introduce a new problem: the clock speed error. If the clock frequency were to change during the entire "winding" and "unwinding" cycle portions, if the counter's clock speed were to suddenly increase or decrease, then when the analog signal "winds up" (winds up is a loose term accustomed to the integrator), but it would mean that the analog signal would have a longer period of time when the integrator was allowed to "unwind" at a fixed rate. The proportion that the counter is allowed to run faster or slower than its intended rate will affect the output of the digital converter before the clock speed change. Thus, the clock speed error would cancel itself out and the digital output would be accurate.

Another important advantage of this method is that the output signal becomes averaged as it drives the integrator during the fixed-time portion of the cycle. Any changes in the analog signal during that period of time have a cumulative effect on the digital output at the end of that cycle. Other ADC strategies merely "average" the signal over a period of time, but do so in a much more physical way. For example, a sigma-delta converter (which contains significant levels of spurious voltage noise/spikelets), one of the other ADC converter technologies may occasionally convert a spike or dip because it samples the signal repeatedly at a single point in time. A-D converters using the dual-slope method, however, sample the signal over a much longer time period, thus providing an output with greater noise immunity. Dual-slope ADCs are used in applications demanding high accuracy.

Delta-Sigma ($\Delta\Sigma$) ADC

One of the more advanced ADC technologies is the so-called delta-sigma, or $\Delta\Sigma$ (using the proper Greek letter notation to indicate the physical meaning of the symbol). The $\Delta\Sigma$ converter is a type of ADC that performs a digital-to-analog conversion by summing the digital terms together. The capital letter sigma (Σ) represents summation: the adding of multiple terms together. Sometimes this converter is referred to by the same Greek letters in reverse order: sigma-delta, or $\Delta\Sigma$.

In a $\Delta\Sigma$ converter, the analog input voltage signal is connected to the input of an integrator, producing a voltage rate-of-change, or slope, at the output corresponding to input magnitude. This ramping voltage is then compared against a potential (2 volts) by a comparator. The comparator acts as a sort of 1-bit ADC, outputting a bit of either "high" or "low" to indicate the polarity of the output of the integrator. The final comparator is necessary to convert the single polarity (V or SV logic level) output of the flip-flop into a standard logic level output.

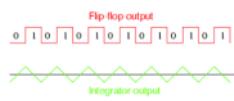


The leftmost op-amp is the (summing) integrator. The next op-amp, the integrator feeds into the comparator. The comparator is a D flip-flop, which has the compare output of every clock pulse sending either "high" or "low" to the D input of the D flip-flop. The final comparator is necessary to convert the single polarity (V or SV logic level) output of the flip-flop into a standard logic level output.

If the integrator output is positive, the first comparator will output a "high" signal to the D input of the D flip-flop. At the next clock pulse, the "high" signal will be output from the Q line into the noninverting input of the first comparator. This first comparator, seeing an input voltage greater than the threshold voltage of 1.5V, will output a "low" signal to the D input of the D flip-flop. This "low" signal will be output from the Q line into the noninverting input of the first comparator. This "low" signal needs to drive the integrator output in a negative direction. If that output voltage ever became negative, the first comparator would output a "high" signal to the D input of the D flip-flop. The top of the integrator to drive it in a positive direction. This is the delta-sigma concept in action: the first comparator senses a difference (D) between the integrator output and zero volts. The integrator sums (Σ) the compensation voltage to the integrator output.

Finally, this results in a serial stream of bits output by the flip-flop. If the analog input is zero volts, the integrator will have no tendency to ramp either positive or negative, except in response to the feedback voltage. In this scenario, the flip-flop output will continually oscillate between "high" and "low," as the feedback system "bounces" back and forth, trying to maintain the integrator output at zero volts.

$\Delta\Sigma$ converter operation with 0 volt analog input



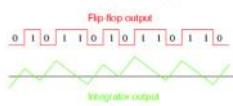
If, however, we apply a negative analog input voltage, the integrator will have a tendency to ramp its output in a positive direction. Feedback can only add to the integrator's ramping by a fixed voltage over a fixed time, and so the bit stream output by the flip-flop will not quite be the same.

$\Delta\Sigma$ converter operation with small negative analog input



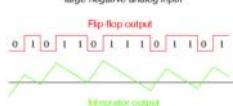
By applying a larger (negative) analog input signal to the integrator, we force its output to ramp more steeply in the positive direction. Thus, the feedback system has to output more 1's than before to bring the integrator output back to zero volts.

$\Delta\Sigma$ converter operation with medium negative analog input



As the analog input signal increases in magnitude, so does the occurrence of 1's in the digital output of the flip-flop.

$\Delta\Sigma$ converter operation with large negative analog input



A parallel binary output is obtained from this circuit by averaging the serial streams of bits together. For example, a counter circuit could be designed to collect the total number of 1's output by the flip-flop in a given time interval. This count would then be indicative of the analog input voltage.

Variations on this theme exist, employing multiple integrator stages and/or comparator circuits outputting more than one bit per sample. In this case, the number of bits per sample is increased, which corresponds to when multiple samples of an analog signal are taken by an ADC (in this case, a 1-bit ADC), and those digitized samples are averaged. The end result is an effective increase in the number of bits resolved from the original signal. A low-sampling-rate, multi-bit sampled 1-bit ADC can do the same job as an 8-MHz ADC with one-time sampling, albeit at a slower rate.

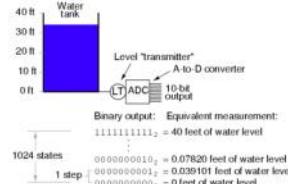
Practical considerations of ADC circuits

Perhaps the most important consideration of an ADC is its resolution. Resolution is the number of binary bits output by the converter. Because ADC circuits take in an analog signal, which is continuously

variable, and resolve it into one of many discrete steps, it is important to know how many of these steps there are in total.

For example, an ADC with a 10-bit output can represent up to $1024\ 2^9$ unique conditions of signal measurement. Over the range of measurement from 0% to 100%, these will be exactly 1024 unique binary states, ranging from 0000000000 to 1111111111, inclusive. An 11-bit ADC will have twice as many states as its output, or 2^{11} , representing twice as many unique conditions of signal measurement between 0% and 100%.

Resolution is very important in data acquisition systems. Circuits designed to interpret and record physical measurements often require a high degree of resolution. For example, consider a water level monitoring system for a storage tank using an instrument with a 10-bit ADC. 0 feet of water in the tank corresponds to 0% of measurement, while 40 feet of water in the tank corresponds to 100% of measurement. Because the ADC is 10 bits, it has 1024 unique states, ranging from 0000000000 to 1111111111, inclusive. To determine how much physical water level will be represented in each step of the ADC, we need to divide the total range of measurement by the number of discrete steps. Doing this, we obtain a figure of 0.039161 feet per step. This equates to 0.45021 inches per step, a little less than half an inch of water level represented for every binary count.



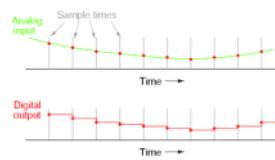
The step value of 0.039161 foot (0.45021 inches) represents the smallest amount of tank-level change detectable by the instrument. Admittedly, this is a small amount, less than 2% of the overall measurable span of 40 feet. However, for some applications it may not be fine enough. Suppose we needed to detect changes in water level as small as 0.039161 feet. To do this, we would need to achieve this degree of resolution and still maintain a measurement span of 40 feet, we would need an instrument with at least 13 bits of resolution.

To determine how many ADC bits are necessary, we need to first determine how many 1/10 inch steps there are in 40 feet. The answer to this is 40(10.142), or 400 1/10 inch steps in 40 feet. Thus, we need enough bits to provide at least 4000 discrete steps in a binary counting sequence. 10 bits gave us 1023

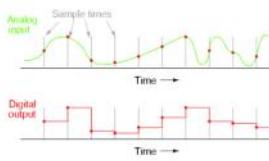
steps, and we know this by calculating $2^{10} = 1024$ and then subtracting one. Following the same mathematical procedure, $2^{11} = 2048$, $2^{12} = 4096$, and $2^{13} = 8192$. 12 bits falls shy of the amount needed for 4000 steps, while 13 bits is more than enough. Therefore, we need an instrument with at least 13 bits of resolution.

Another important consideration of ADC circuits is its sample frequency, or conversion rate. This is simply the number of times per second the converter outputs a new binary number, like resolution. This consideration is linked to the specific application of the ADC. If the converter is being used to measure slow-changing signals, such as a water level, then a slow conversion rate is acceptable, and the converter will still perform adequately. Conversely, if it is being used to digitize an audio frequency signal cycling at several thousand times per second, the converter needs to be considerably faster.

Consider the following illustration of ADC conversion rate versus signal type, typical of a successive approximation ADC with regular sample intervals:



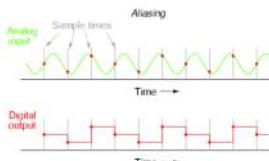
Here, for this slow-changing signal, the sample rate is more than adequate to capture its general trend. But consider this example with the same sample time:



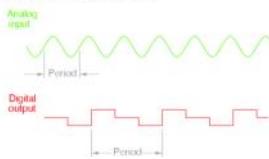
When the sample period is too long (too slow), substantial details of the analog signal will be missed. Notice how, especially in the later portions of the analog signal, the digital output clearly fails to reproduce the true shape. Even in the first section of the analog waveform, the digital reproduction deviates noticeably from the original.

It is imperative that an ADC's sample time is fast enough to capture essential changes in the analog waveform. In data acquisition terminology, the highest-frequency waveform an ADC can theoretically capture is the so-called **Nyquist Frequency**, equal to one-half of the ADC's sample frequency. Therefore, if an ADC has a sample frequency of 2000 Hz, the highest-frequency waveform it can successfully measure will be the Nyquist frequency of 1000 Hz.

If an ADC is subjected to an analog input signal whose frequency exceeds the Nyquist frequency for that ADC, the converter will output a digitized signal of falsely low frequency. This phenomenon is known as **aliasing**. Observe the following illustration to see how aliasing occurs.



Note how the period of the output waveform is much longer (slower) than that of the input waveform, and how the two waveform shapes aren't even similar:



It should be understood that the Nyquist frequency is an absolute maximum frequency limit for an ADC, and it does not represent the minimum practical limit. In fact, most ADCs can actually receive any frequency greater than one-half its one-half of its sample frequency.

A practical means of preventing aliasing is to place a low-pass filter before the input of the ADC, to block any signal frequencies greater than the practical limit. This way, the ADC circuitry will be prevented from seeing any excessive frequencies and thus will not try to digitize them. It is generally considered better that these frequencies go unmeasured than to have them be "distorted" and appear in the output as false signals.

Yet another measure of ADC performance is something called step recovery. This is a measure of how quickly an ADC can change its output state after a large input voltage step. In tracking converter technologies especially, step recovery is a serious limitation. One example is the tracking converter, which has a typically fast update period but a disproportionately slow step recovery.

An ideal ADC has a great many bits for very fine resolution, samples at lightning-fast speeds, and recovers from large input voltage steps in a matter of nanoseconds. In reality, the performance of these traits may be improved through additional circuit complexity, either in terms of increased component count and/or special circuit designs made to run at higher clock speeds. Different ADC technologies, though, have different strengths. Here is a summary of them, listed from best to worst:

Resolution/complexity ratios:
Single-slope integrating, dual-slope integrating, counter, tracking, successive approximation, flash.

Speed:

Flash, tracking, successive approximation, single-slope integrating & counter, dual-slope integrating.

Step recovery:

Flash, successive approximation, single-slope integrating & counter, dual-slope integrating, tracking.

Please bear in mind that the rankings of these different ADC technologies depend on other factors. For instance, how an ADC rates on step recovery depends on the nature of the step change. A tracking ADC is usually faster at recovering from a high-to-low step change than from a low-to-high step change. High-to-low step change quicker than a low-to-high step change. Successive approximation ADCs are already equally fast at resolving any analog signal, but a tracking ADC will consistently beat a successive approximation ADC at step recovery. Tracking converters are often referred to as "oversampling" or "oversampled" integrating converters as having a greater resolution/complexity ratio than counter converters, but this assumes that precision analog integrator circuits are less expensive to design and manufacture than successive approximation counter-based converters. Others may not agree with this assumption.

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Schulstufe 3

**Part: Measurements of non-electrical
quantities**

DI Dr. Sabine Strohmayer

HTBL Krems – Informationstechnologie

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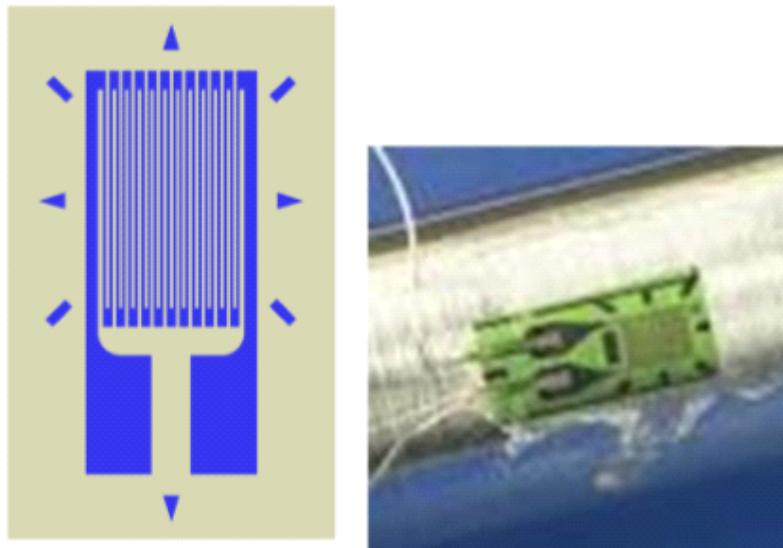
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1. Strain gauge



Typical foil strain gauge. The gauge is far more sensitive to strain in the vertical direction than in the horizontal direction. The markings outside the active area help to align the gauge during installation.

A **strain gauge** (also **strain gage**) is a device used to measure the [strain](#) of an object. Invented by [Edward E. Simmons](#) and [Arthur C. Ruge](#) in 1938, the most common type of strain gauge consists of an [insulating](#) flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive, such as [cyanoacrylate](#).^[1] As the object is deformed, the foil is deformed, causing its [electrical resistance](#) to change. This resistance change, usually measured using a [Wheatstone bridge](#), is related to the strain by the quantity known as the [gauge factor](#).

Physical operation

A strain gauge takes advantage of the physical property of [electrical conductance](#) and its dependence on the conductor's geometry. When an [electrical conductor](#) is stretched within the limits of its [elasticity](#) such that it does not break or permanently deform, it will become narrower and longer, changes that increase its electrical resistance end-to-end. Conversely, when a conductor is compressed such that it does not buckle, it will broaden and shorten,

changes that decrease its electrical resistance end-to-end. From the measured [electrical resistance](#) of the strain gauge, the amount of applied [stress](#) may be inferred. A typical strain gauge arranges a long, thin conductive strip in a zig-zag pattern of parallel lines such that a small amount of stress in the direction of the orientation of the parallel lines results in a multiplicatively larger [strain](#) over the effective length of the conductor—and hence a multiplicatively larger change in resistance—than would be observed with a single straight-line conductive wire. Strain gauges measure only local deformations and can be manufactured small enough to allow a "finite element" like analysis of the stresses to which the specimen is subject. This can be positively used in fatigue studies of materials.

Gauge factor

The [gauge factor](#) GF is defined as:

$$GF = \frac{\Delta R/R_G}{\epsilon}$$

where

ΔR is the change in resistance caused by strain,
 R_G is the resistance of the undeformed gauge, and
 ϵ is strain.

For metallic foil gauges, the gauge factor is usually a little over 2.^[2] For a single active gauge and three dummy resistors, the output v from the bridge is:

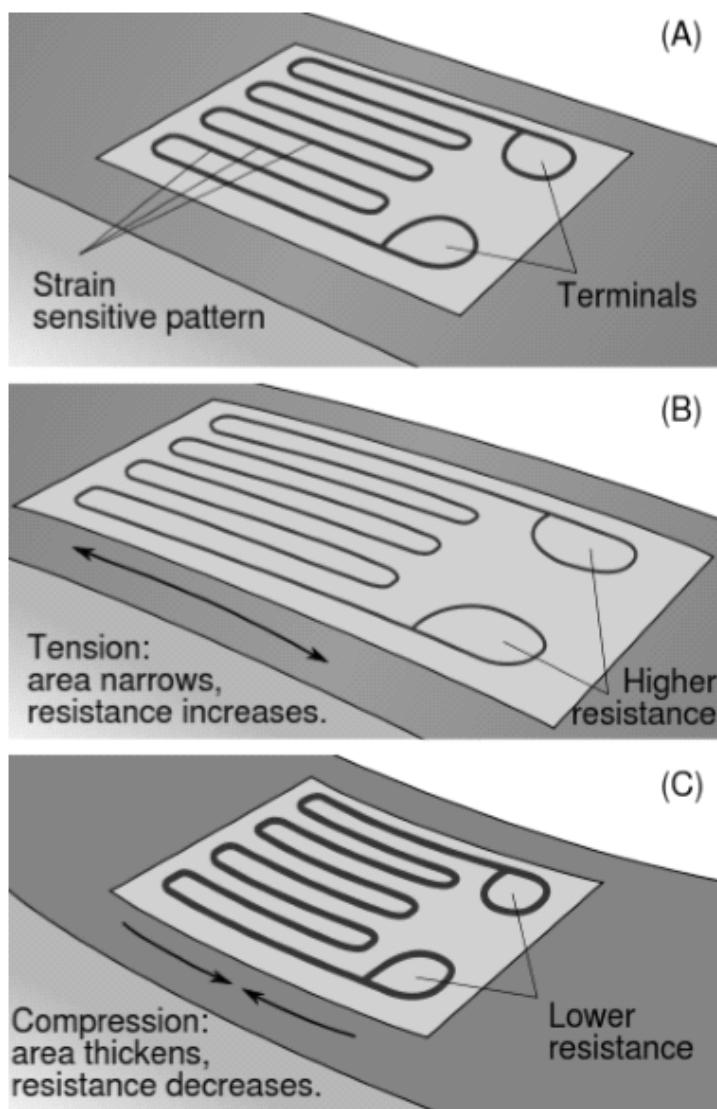
$$v = \frac{BV \cdot GF \cdot \epsilon}{4}$$

where

BV is the bridge excitation voltage.

Foil gauges typically have active areas of about 2–10 mm² in size. With careful installation, the correct gauge, and the correct [adhesive](#), strains up to at least 10% can be measured.

Gauges in practice



Visualization of the working concept behind the strain gauge on a [beam](#) under exaggerated bending.

An excitation voltage is applied to input leads of the gauge network, and a voltage reading is taken from the output leads. Typical input voltages are 5 V or 12 V and typical output readings are in millivolts.

Foil strain gauges are used in many situations. Different applications place different requirements on the gauge. In most cases the orientation of the strain gauge is significant.

Gauges attached to a [load cell](#) would normally be expected to remain stable over a period of years, if not decades; while those used to measure response in a dynamic experiment may only need to remain attached to the object for a few days, be energized for less than an hour, and operate for less than a second.

Strain gauges are attached to the substrate with a special glue. The type of glue depends on the required lifetime of the measurement system. For short term measurements (up to some weeks) cyanoacrylic glue is appropriate, for long lasting installation epoxy glue is required. Usually epoxy glue requires high temperature curing (at about 80-100°C). The preparation of the surface where the strain gauge is to be glued is of the utmost importance. The surface must be smoothed (e.g. with very fine sand paper), deoiled with solvents, the solvent traces must then be removed and the strain gauge must be glued immediately after this to avoid oxidation or pollution of the prepared area. If these steps are not followed the strain gauge binding to the surface may be unreliable and unpredictable measurement errors may be generated.

Strain gauge based technology is utilized commonly in the manufacture of [pressure sensors](#). The gauges used in pressure sensors themselves are commonly made from silicon, polysilicon, metal film, thick film, and bonded foil.

Variations in temperature

Variations in temperature will cause a multitude of effects. The object will change in size by thermal expansion, which will be detected as a strain by the gauge. Resistance of the gauge will change, and resistance of the connecting wires will change.

Most strain gauges are made from a [constantan](#) alloy.^[3] Various constantan alloys and Karma alloys have been designed so that the temperature effects on the resistance of the strain gauge itself cancel out the resistance change of the gauge due to the thermal expansion of the object under test. Because different materials have different amounts of thermal expansion, self-temperature compensation (STC) requires selecting a particular alloy matched to the material of the object under test.

Strain gauges that are not self-temperature-compensated (such as isoelastic alloy) can be temperature compensated by use of the dummy gauge technique. A dummy gauge (identical to the active strain gauge) is installed on an unstrained sample of the same material as the test specimen. The sample with the dummy gauge is placed in thermal contact with the test specimen, adjacent to the active gauge. The dummy gauge is wired into a [Wheatstone bridge](#) on an adjacent arm to the active gauge so that the temperature effects on the active and dummy gauges cancel each other.^[4] ([Murphy's Law](#) was originally coined in response to a set of gauges being incorrectly wired into a Wheatstone bridge.^[5])

Temperature effects on the lead wires can be cancelled by using a "3-wire bridge" or a "4-wire ohm circuit"^[6] (also called a "4-wire [Kelvin connection](#)").

In any case it is a good engineering practice to keep the Wheatstone bridge voltage drive low enough to avoid the self heating of the strain gauge. The self heating of the strain gauge depends on its mechanical characteristic (large strain gauges are less prone to self heating). Low voltage drive levels of the bridge reduce the sensitivity of the overall system.

Errors and compensation

Zero Offset - If the impedance of the four gauge arms are not exactly the same after bonding the gauge to the force collector, there will be a zero offset which can be compensated by introducing a parallel resistor to one or more of the gauge arms.

Temperature coefficient of Gauge Factor (TCGF) - This is the change of sensitivity of the device to strain with change in temperature. This is generally compensated for by the introduction of a fixed resistance in the input leg, whereby the effective supplied voltage will increase with temperature, compensating for the decrease in sensitivity with temperature.

Zero Shift with temperature - If the TCGF of each gauge is not the same, there will be a zero shift with temperature. This is also caused by anomalies in the force collector. This is usually compensated for with one or more resistors strategically placed in the compensation network.

Linearity - This is an error whereby the sensitivity changes across the pressure range. This is commonly a function of the force collection thickness selection for the intended pressure and/or the quality of the bonding.

Hysteresis - This is an error of return to zero after pressure excursion.

Repeatability - This error is sometimes tied-in with hysteresis but is across the pressure range.

EMI induced errors - As strain gauges output voltage is in the mV range, even uV if the Wheatstone bridge voltage drive is kept low to avoid self heating of the element, special care must be taken in output signal amplification to avoid amplifying also the superimposed noise. A solution which is frequently adopted is to use "carrier frequency" amplifiers which convert the voltage variation into a frequency variation (as in VCOs) and have a narrow bandwidth thus reducing out of band EMI.

Overloading - If a strain gauge is loaded beyond its design limit (measured in microstrains) its performance degrades and can not be recovered. Normally good engineering practice suggests not to stress strain gauges beyond +/-3000 microstrains.

Humidity - If the wires connecting the strain gauge to the signal conditioner are not protected against humidity (bare wire) a parasitic resistance creates between the wires and the substrate

to which the strain gauge is glued, or between the two wires themselves. This resistance introduces an error which is proportional to the resistance of the strain gauge. For this reason low resistance strain gauges (120 ohm) are less prone to this type of error. To avoid this error it is sufficient to protect the strain gauges wires with insulating enamel (e.g., epoxy or polyurethane type). Strain gauges with unprotected wires may be used only in a dry laboratory environment but not in an industrial one.

Other gauge types

For measurements of small strain, [semiconductor](#) strain gauges, so called [piezoresistors](#), are often preferred over foil gauges. A [semiconductor gauge](#) usually has a larger gauge factor than a foil gauge. Semiconductor gauges tend to be more expensive, more sensitive to temperature changes, and are more fragile than foil gauges.

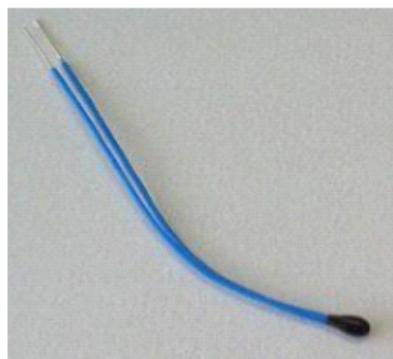
In biological measurements, especially [blood flow](#) / tissue swelling, a variant called **mercury-in-rubber strain gauge** is used. This kind of strain gauge consists of a small amount of liquid mercury enclosed in a small rubber tube, which is applied around e.g., a toe or leg. Swelling of the body part results in stretching of the tube, making it both longer and thinner, which increases electrical resistance.

[Fiber optic sensing](#) can be employed to measure strain along an [optical fiber](#). Measurements can be distributed along the fiber, or taken at predetermined points on the fiber. The 2010 [America's Cup](#) boats [Alinghi 5](#) and [USA-17](#) both employ embedded sensors of this type [1].

Capacitive strain gauges use a [variable capacitor](#) to indicate the level of mechanical deformation.

Vibrating wire strain gauges are used in Geotechnical and Civil Engineering applications. The gauge consists of a vibrating, tensioned wire. The strain is calculated by measuring the resonant frequency of the wire (an increase in tension increases the resonant frequency).

2.Thermistor

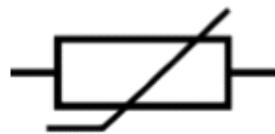


Negative temperature coefficient (NTC) thermistor, bead type, insulated wires

A **thermistor** is a type of [resistor](#) whose [resistance](#) varies significantly with [temperature](#), more so than in standard resistors. The word is a [portmanteau](#) of [thermal](#) and [resistor](#). Thermistors are widely used as inrush [current](#) limiters, temperature [sensors](#), self-resetting overcurrent protectors, and self-regulating [heating elements](#).

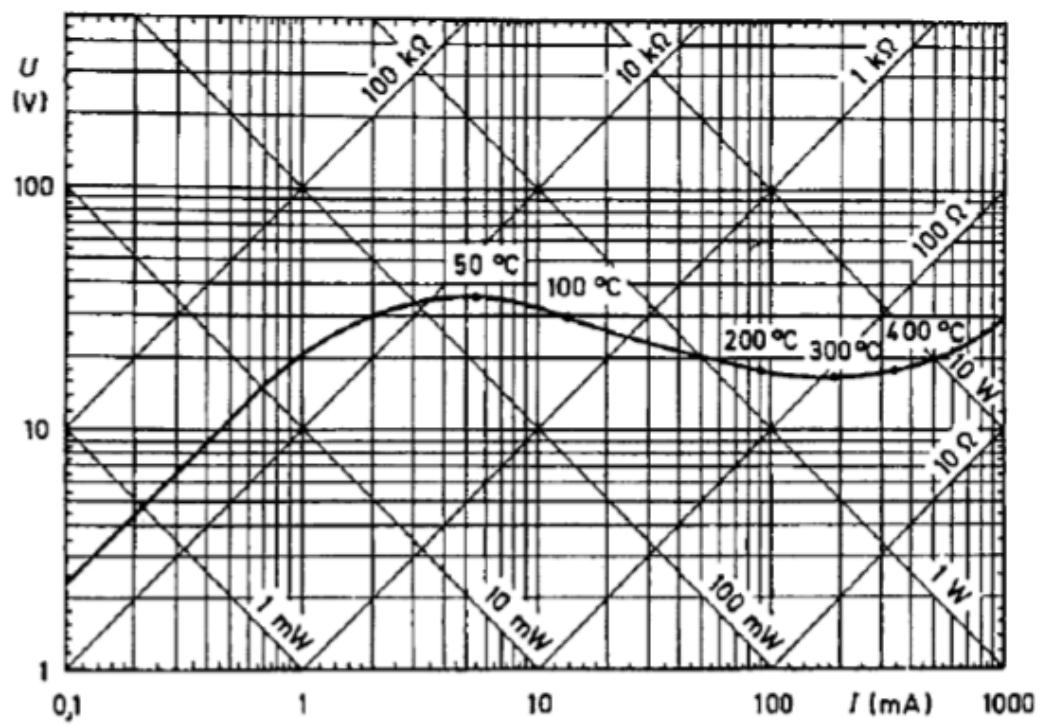
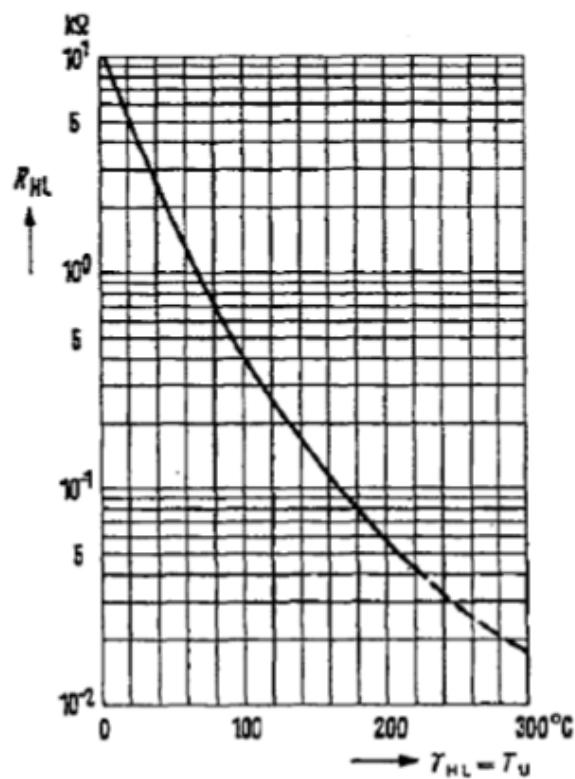
Thermistors differ from [resistance temperature detectors](#) (RTD) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The temperature response is also different; RTDs are useful over larger temperature ranges, while thermistors typically achieve a higher precision within a limited temperature range, typically $-90\text{ }^{\circ}\text{C}$ to $130\text{ }^{\circ}\text{C}$.

Basic operation

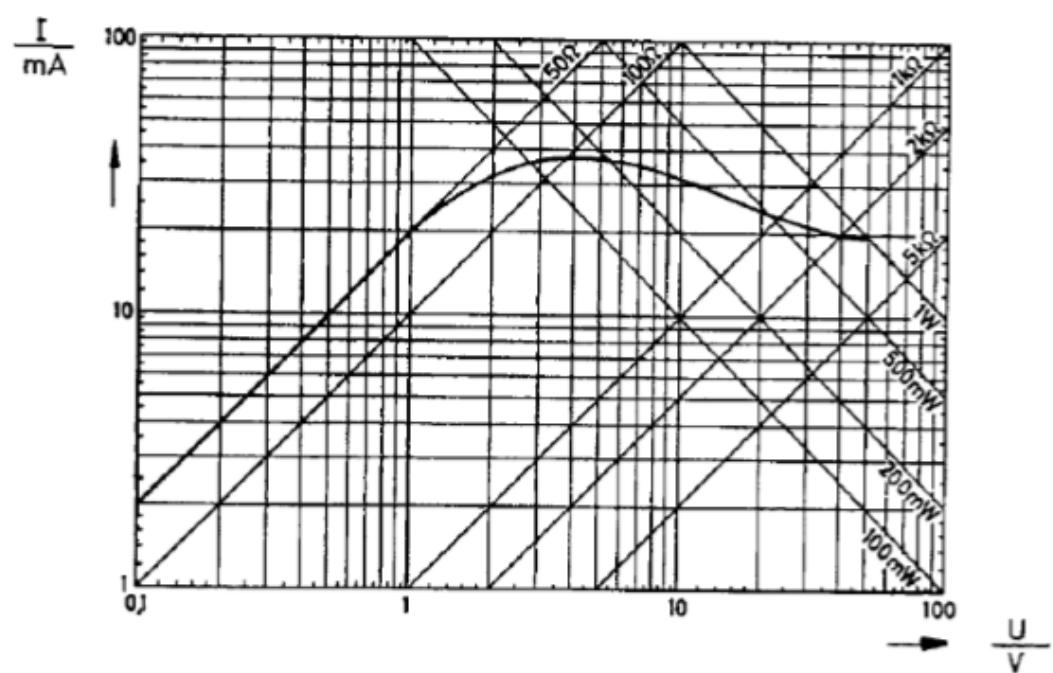
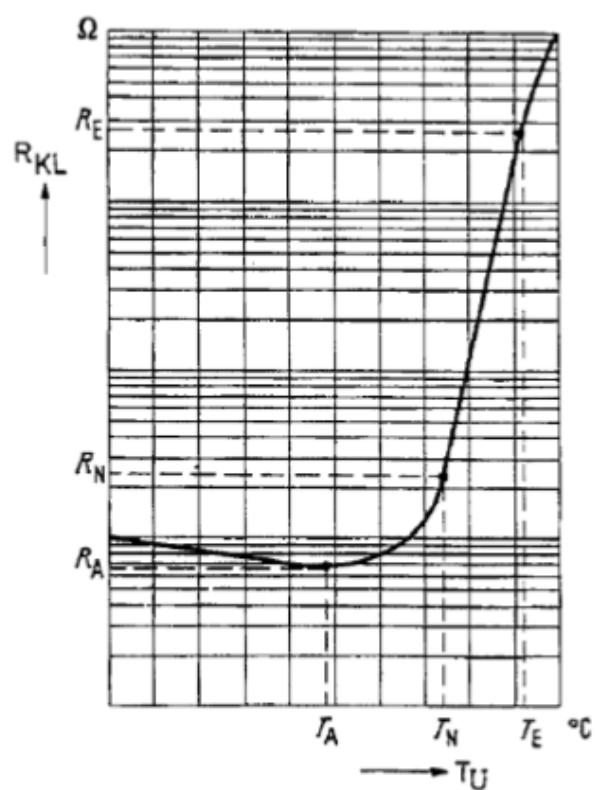


Thermistor symbol

Characteristics of NTC



Characteristics of PTC



Assuming, as a first-order approximation, that the relationship between resistance and temperature is [linear](#), then:

$$\Delta R = k\Delta T$$

where

ΔR = change in resistance

ΔT = change in temperature

k = first-order temperature coefficient of resistance

Thermistors can be classified into two types, depending on the sign of k . If k is [positive](#), the resistance increases with increasing temperature, and the device is called a [positive temperature coefficient](#) (PTC) thermistor, or **posistor**. If k is negative, the resistance decreases with increasing temperature, and the device is called a [negative temperature coefficient](#) (NTC) thermistor. Resistors that are not thermistors are designed to have a k as close to zero as possible, so that their resistance remains nearly constant over a wide temperature range.

Instead of the temperature coefficient k , sometimes the *temperature coefficient of resistance* α_T (alpha sub T) is used. It is defined as^[2]

$$\alpha_T = \frac{1}{R(T)} \frac{dR}{dT}.$$

This α_T coefficient should not be confused with the a parameter below.

In practice, the linear approximation (above) works only over a small temperature range. For accurate temperature measurements, the resistance/temperature curve of the device must be described in more detail.

Most PTC thermistors are of the "switching" type, which means that their resistance rises suddenly at a certain critical temperature. The devices are made of a doped polycrystalline [ceramic](#) containing [barium titanate](#) ($BaTiO_3$) and other compounds. The [dielectric constant](#) of this [ferroelectric](#) material varies with temperature. Below the [Curie point](#) temperature, the high [dielectric constant](#) prevents the formation of potential barriers between the crystal grains, leading to a low resistance. In this region the device has a small negative temperature coefficient. At the Curie point temperature, the dielectric constant drops sufficiently to allow the formation of potential barriers at the grain boundaries, and the resistance increases sharply. At even higher temperatures, the material reverts to NTC behaviour. The equations

used for modeling this behaviour were derived by W. Heywang and G. H. Jonker in the 1960s.

Another type of PTC thermistor is the [polymer](#) PTC, which is sold under brand names such as "[Polyswitch](#)" "Semifuse", and "Multifuse". This consists of a slice of plastic with [carbon](#) grains embedded in it. When the [plastic](#) is cool, the carbon grains are all in contact with each other, forming a [conductive](#) path through the device. When the plastic heats up, it expands, forcing the carbon grains apart, and causing the resistance of the device to rise rapidly. Like the BaTiO₃ thermistor, this device has a highly nonlinear resistance/temperature response and is used for switching, not for proportional temperature measurement.

Yet another type of thermistor is a [silistor](#), a thermally sensitive silicon resistor. Silistors are similarly constructed and operate on the same principles as other thermistors, but employ silicon as the semiconductive component material.

Self-heating effects

When a current flows through a thermistor, it will generate heat which will raise the temperature of the thermistor above that of its environment. If the thermistor is being used to measure the temperature of the environment, this electrical heating may introduce a significant error if a correction is not made. Alternatively, this effect itself can be exploited. It can, for example, make a sensitive air-flow device employed in a [sailplane](#) rate-of-climb instrument, the electronic [variometer](#), or serve as a [timer](#) for a [relay](#) as was formerly done in [telephone exchanges](#).

The electrical power input to the thermistor is just:

$$P_E = IV$$

where I is current and V is the voltage drop across the thermistor. This power is converted to heat, and this heat energy is transferred to the surrounding environment. The rate of transfer is well described by [Newton's law of cooling](#):

$$P_T = K(T(R) - T_0)$$

where $T(R)$ is the temperature of the thermistor as a function of its resistance R , T_0 is the temperature of the surroundings, and K is the **dissipation constant**, usually expressed in units of milliwatts per degree Celsius. At equilibrium, the two rates must be equal.

$$P_E = P_T$$

The current and voltage across the thermistor will depend on the particular circuit configuration. As a simple example, if the voltage across the thermistor is held fixed, then by [Ohm's Law](#) we have $I = V/R$ and the equilibrium equation can be solved for the ambient temperature as a function of the measured resistance of the thermistor:

$$T_0 = T(R) - \frac{V^2}{KR}$$

The dissipation constant is a measure of the thermal connection of the thermistor to its surroundings. It is generally given for the thermistor in still air, and in well-stirred oil. Typical values for a small glass bead thermistor are 1.5 mW/°C in still air and 6.0 mW/°C in stirred oil. If the temperature of the environment is known beforehand, then a thermistor may be used to measure the value of the dissipation constant. For example, the thermistor may be used as a flow rate sensor, since the dissipation constant increases with the rate of flow of a fluid past the thermistor.

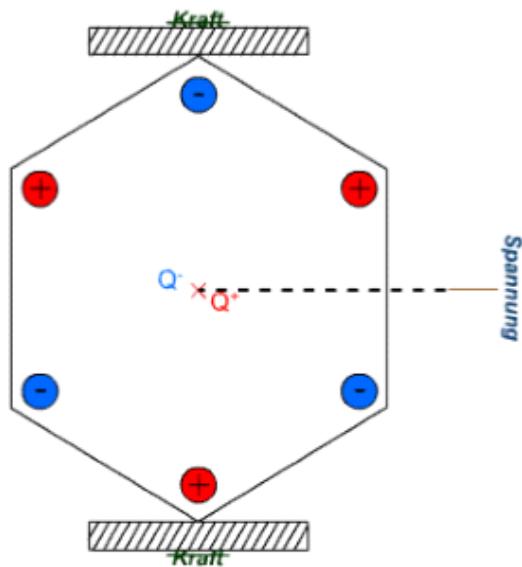
The power dissipated in a thermistor is typically maintained at a very low level to ensure insignificant temperature measurement error due to self heating. However, some thermistor applications depend upon significant "self heating" to raise the body temperature of the thermistor well above the ambient temperature so the sensor then detects even subtle changes in the thermal conductivity of the environment. Some of these applications include liquid level detection, liquid flow measurement and air flow measurement.^[4]

Applications

- PTC thermistors can be used as current-limiting devices for circuit protection, as replacements for fuses. Current through the device causes a small amount of resistive heating. If the current is large enough to generate more heat than the device can lose to its surroundings, the device heats up, causing its resistance to increase, and therefore causing even more heating. This creates a self-reinforcing effect that drives the resistance upwards, reducing the current and voltage available to the device.
- PTC thermistors were used as timers in the [degaussing coil](#) circuit of most CRT displays. When the display unit is initially switched on, current flows through the thermistor and degaussing coil. The coil and thermistor are intentionally sized so that the current flow will heat the thermistor to the point that the degaussing coil shuts off in under a second. For effective degaussing, it is necessary that the magnitude of the alternating magnetic field produced by the degaussing coil decreases smoothly and continuously, rather than sharply switching off or decreasing in steps; the PTC thermistor accomplishes this naturally as it heats up. A degaussing circuit using a PTC thermistor is simple, reliable (for its simplicity), and inexpensive.

- NTC thermistors are used as [resistance thermometers](#) in low-temperature measurements of the order of 10 K.
- NTC thermistors can be used as inrush-current limiting devices in power supply circuits. They present a higher resistance initially which prevents large currents from flowing at turn-on, and then heat up and become much lower resistance to allow higher current flow during normal operation. These thermistors are usually much larger than measuring type thermistors, and are purposely designed for this application.
- NTC thermistors are regularly used in automotive applications. For example, they monitor things like coolant temperature and/or oil temperature inside the engine and provide data to the ECU and, indirectly, to the dashboard.
- NTC thermistors can be also used to monitor the temperature of an incubator.
- Thermistors are also commonly used in modern [digital thermostats](#) and to monitor the temperature of battery packs while charging.
- Thermistors are also used in the hot ends of 3d printers, they produce heat and keep a constant temperature for melting the plastic filament.
- NTC Thermistors are used in the Food Handling and Processing industry, especially for food storage systems and food preparation. Maintaining the correct temperature is critical to prevent food borne illness.
- NTC Thermistors are used throughout the Consumer Appliance industry for measuring temperature. Toasters, coffee makers, refrigerators, freezers, hair dryers, etc. all rely on thermistors for proper temperature control

3.Piezoelectricity



Direct Piezoelectric Effect: by mechanical pressure shifts the positive ($Q +$) and negative charge center ($Q -$). This results in a [dipole](#), or a [voltage](#) of the element.

Piezoelectricity describes the change of the electric [polarization](#), and thus the occurrence of an electrical voltage is applied to solids when they elastically deformed (*direct piezoelectric effect*). Conversely deform materials when an electrical voltage (*an inverse piezoelectric effect*).

Principle

By the directional deformation of a piezoelectric material is microscopic form [dipoles](#) within the [unit cells](#) (shift of [charge](#) - [focus](#)). The summation over the associated electric field in each unit cell of the crystal leads to a macroscopically measurable [electrical voltage](#). *looking* deformation means that the pressure applied by all sides to the test works, but for example, only from the opposite sides. Conversely, by applying an electrical voltage, a deformation of the [crystal](#) (or the component of [piezoelectric ceramic](#)) can be achieved.

Like any other solids, can also piezoelectric body perform mechanical vibrations. Piezoelectrics in these vibrations can be excited electrically, and in turn cause an electrical voltage. The frequency of oscillation is from the [speed of sound](#) (a material constant) and the dimensions of the piezoelectric body dependent. With a suitable mounting these are [natural frequencies](#) hardly affected by environmental influences, which piezoelectric devices such as [quartz crystals](#) very well suited for use in precision [oscillators](#) are suitable (eg [quartz](#)).

Piezoelectric materials

Basics

The piezoelectric effect can be explained by the first change in the geometry. This is the piezoelectric resistive effect. Stretched, thus longer and thinner, a wire has a higher resistance. For metals, the piezoelectric effect is based solely on the change in the geometry. Furthermore, all are non-conductive [ferroelectric](#) materials or materials with a permanent electric dipole also piezoelectric, such as [barium titanate](#) and [lead zirconate titanate](#) (PZT). However, only a part of piezoelectrics behaves ferroelectric.

In crystals, the crystal symmetry is another criterion for the occurrence of piezoelectricity. The piezoelectric polarization does not occur, when the crystal has a center of inversion. For all 21 non-centrosymmetric [point groups](#) can piezoelectricity occur, except for the cubic point group $432nd$. In other words, a unit cell may no center of symmetry (= a point at which a point mirroring the crystal transferred into itself) have.

The best known material with piezoelectric properties, [quartz](#) (SiO_2). Quartz crystals have the non-centrosymmetric point assembly 32 . Each Si atom is located in the center of a [tetrahedron](#) of four oxygen atoms. One in the direction of base-to-peak (Crystallographic direction: [111]) acting force deforms now this tetrahedron such that the compressed tetrahedra are electrically polarized and so on the surfaces of the crystal (in the [111] direction), a net voltage occurs.

Technically used materials that exhibit a stronger effect than quartz piezo guide, often of the [perovskite](#) structure from, for example: barium titanate (BaTiO_3). The [cubic](#) perovskite modification itself has $m3m$ the centrosymmetric point group, and is thus non-piezoelectric, the material can, however, below a critical temperature - the piezoelectric [Curie temperature](#) T_c - (pass into a non-centrosymmetric perovskite structure rhombohedral / tetragonal, see [lead zirconate titanate](#)). It then shows a [spontaneous polarization](#), and has ferroelectric properties.

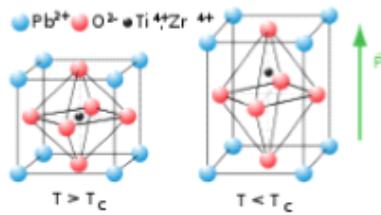
Piezoelectric crystals

- The main piezoelectric quartz crystal is, more precisely up to 573°C stable trigonal crystal structure α -quartz. The most important application are oscillating crystals.
- [Lithium](#) has increased compared to quartz piezoelectric constants and for piezoelectric filters and [SAW devices](#) (English: *surface acoustic wave*, [surface acoustic wave](#)) is used.
- [Gallium](#) is only since the 1990s, available as piezoelectric. This material is similar to the crystal, but has higher piezoelectric constants and better temperature stability. It is stable up to 900°C .

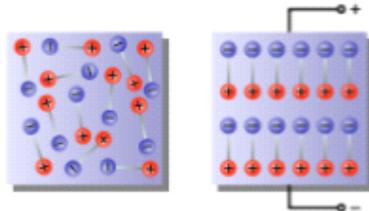
Further piezo-electric crystals are [berlinite](#), minerals of [Turmalinengruppe](#), [Rochelle salt](#) and all [ferroelectrics](#) such as barium titanate (BTO), or lead zirconate titanate (PZT). BTO and PZT but are usually not used as single crystals, but in polycrystalline form (ceramics).

Against piezoelectric crystals piezoelectric ceramics such as PZT have the advantage of substantially higher piezoelectric coefficients. Advantages of the crystals of quartz, gallium and [lithium](#), higher thermal stability, lower losses, a substantially lower [hysteresis](#) and it hardly creep (ie delayed deformation) after changing the voltage applied.

Piezoelectric ceramics



☞ Perovskite [unit cell](#) of piezoceramics. Below the Curie temperature is formed from a dipole.



☞ Memorize a polarization direction by the alignment of the dipoles in an electric field

Industrially produced [piezo elements](#) are mostly [ceramics](#). These ceramics are made from [synthetic](#), [inorganic](#), [ferroelectric](#) and [polycrystalline](#) ceramic materials made. Typical base materials for high-voltage actuators are modified lead zirconate titanate (PZT), and for low-voltage actuators [lead magnesium niobate](#) (PMN).

The composite of the PZT ceramics (Pb, O, Ti / Zr) crystallizes in the perovskite crystal structure, below Curie temperature of the piezoelectric is formed by distortions of the ideal perovskite structure has a [dipole moment](#) of. Of ceramic piezoelectric elements, the internal dipoles after [sintering process](#) still disordered, which is why there is no show piezoelectric properties. The [Weiss' domains](#) or domains have a random spatial orientation and balance each other. Significant measurable piezoelectric property can be only by an external [DC electric field](#) impress (some 10^6 V / m), while the material to just below the [Curie temperature](#) is heated and cooled. The impressed orientation then remains for the most part obtained ([remanent polarization](#)) and is referred to as *direction of polarization*.

The rotation of the white 'domains' by the polarization leads to a slight distortion of the material and a macroscopic length increase in polarization direction.

Other piezoelectric materials

As an active sensor materials increasingly are [piezoelectric thin films](#) used. With the help of semiconductor technology, it is possible to deposit these active piezoelectric thin films on silicon. These are mostly [zinc oxide](#) (ZnO) or [aluminum nitride](#) (AlN).

The plastic [polyvinylidene fluoride](#) (PVDF) can be - like piezoelectric ceramics - polarize and then piezoelectric. Applications include, for example, [hydrophones](#).

Applications

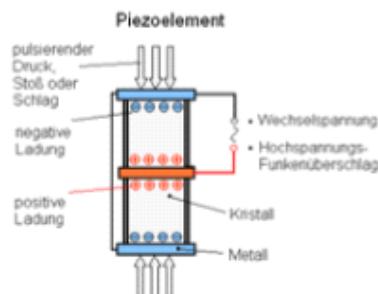
Today, piezoelectric devices are used in many industries: industrial and manufacturing, automotive, medical, telecommunications, etc. In 2010, the global market for piezoelectric devices achieved a turnover of around 14.8 billion U.S. dollars. [2]

Generally, the applications can be divided into three areas:

1. [Sensors](#)
2. [Actuators](#)
3. [Electrical Components](#)

Sensors

The appearance of the piezoelectric charge in the case of mechanical deformation [force, pressure and acceleration sensors](#) used. The resulting charge can with a [charge amplifier](#) in a voltage with a low [source impedance](#) can be converted. For the other option, with this charge charge a capacitor and measure the voltage with a possible high-impedance voltmeter, inadequate insulation resistance, for example, moisture falsify the result and prevent the registration slow deformations.



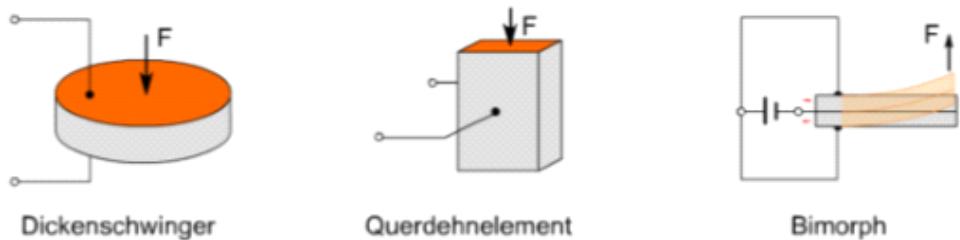
Piezoelectric element for the conversion of mechanical pressure to electrical voltage.

- In music, piezo elements as [pickups](#) used for acoustic instruments, mainly for [string instruments](#) such as [guitar](#), [violin](#) or [mandolin](#). The dynamic deformation of the instrument (vibration of the sound source) is converted into a low [AC voltage](#) is converted, which is then [electrically amplified](#) is.
- With piezoelectric acceleration sensors or transducers, it is in a mechanical deformation (compression or shear) by the acceleration to a charge separation and thus to a tapped charge (or voltage) to the vapor-deposited electrode.
- When quartz crystals, the influence of various factors on the resonance frequency, are exploited in surface acoustic wave components of the influence on the delay time. An important application is the measurement of the force applied to the crystal mass, for example in industrial coating method for the determination of the layer thickness. It can also be the temperature dependence of the oscillation frequency can be measured and such quartz thermometer but are no longer on the market.

actuators

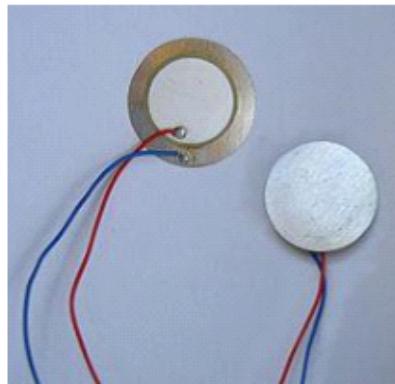
Piezo actuators can be made between two different criteria: by mode (quasi-static or resonant mode) or by the direction of the effect used. Since the transverse and longitudinal effect occur simultaneously, is distinguished according to the used effect.

From the distinction transversal (cross-effect) and Longitudinal (longitudinal effect) results in three different basic elements for piezoelectric actuators: the thickness vibrator, and as the Querdehnelement special design of the U-tube (bimorph). This is a combination of two Querdehnelementen. An opposite control of the elements in this case causes a bending of the actuator, which is why he gets a separate designation.



☞ Piezoaktorische basic elements

Over the cross and longitudinal effect addition, the piezoelectric perpendicular by applying the electric field to the polarization direction, a shearing experienced. But this effect is usually only in acoustic transducers and accelerometers used.



☞ [Piezo Buzzer](#) , [English Buzzer](#)

In the category of quasistatic operation also covers actuators which operate in the kHz range, as long as the case of resonance does not occur. The high accuracy and wide dynamic predestine the piezoelectric actuator for positioning and active vibration control. Through the use of stacked piezoelectric elements or lever can be extended to the relatively short travel ranges of $\Delta l / l = 10^{-3}$. Limiting the adjustment paths contribute the dielectric strength of the material, the high operating voltage and the current in a saturation characteristic of the material. Typical changes in length are at low voltage elements at 0.1 microns, in high-voltage components at about 1 micron. If larger travel ranges are handled, offers itself to the resonant mode.

In the resonant operation of the rotor of the motor is from the piezo by a [traveling wave](#) driven. Additionally, the mass inertia of the rotor is used to produce a continuous movement. Thus possible to meet larger adjustment paths, such as in a [lens \(optics\)](#).

As examples of the use of quasi-static piezoelectric actuators are: [Braille](#) for the blind, which is pushed up by applying a voltage to the blind tactile pins, which is implemented on the PC monitor in tactile Braille text characters.

Classic examples of this form of operation should ink printer (german *drop on demand*, for example, by [Epson](#)) and [piezo speaker](#) be, in which the [sound waves](#) are generated by an audio-frequency alternating voltage. Even diesel injection systems work with piezoelectric actuators (multilayer ceramic components with precious metal internal electrodes) and have the [common rail technology](#) improved. Here, the injection of diesel via valves is partially replaced. Since 2005, when are [pump-nozzle system](#) used piezoelectric actuators. Industrial companies who manufacture these actuators in large numbers, the company [Epcos](#) and [Bosch](#).

The polarization of the piezoelectric element defines the spatial directions fixed in the piezoelectric element. Hence the anisotropic piezoelectric charge constants are predetermined. Typically have: $d = -0.5 \cdot d_{\text{longitudinally transversely}}$. For two-or three-dimensional movements, several piezo elements are combined so that they act in different directions.

Electrical Components

In these applications, a mechanical vibration of a piezoelectric solid body is electrically excited and then electrically detected. There is a fundamental distinction between two types:

- Volume resonators, where substantially all the piezoelectric element vibrates. The main representatives are [quartz crystals](#) and ceramic filters.
- SAW devices based on [surface acoustic waves](#) (german *surface acoustic wave*, SAW). Examples are [SAW filters](#) and delay lines.

As a component is the [piezoelectric transformer](#) used as a form of the [resonant transformer](#) for generating the high voltage in the range of the [inverter](#). He used to supply [tubes](#) (CCFL) as a backlight for [TFT displays](#) are used.

Other applications

The piezoelectric effect is used in [piezoelectric lighters](#), here in a piezo igniter is a sudden large pressure (Hammer) used to produce a short-term high electric voltage. The [spark discharge](#) will then ignite the gas flame. Impact detonator, such as in the warheads of anti-tank weapons (bazooka / [RPG-7](#)), [piezoelectric microphones](#) (crystal microphones), [piezo speakers](#) in headphones, piezo sirens or - [Summer](#) are other uses.

A number of micromechanical sensors makes itself piezoelectricity advantage, such as [accelerometers](#), [angular rate - pressure](#) - and [force sensors](#) and ultrasonic sensors, micro balances and [knock sensors](#) in the car.

Also, some micromechanical [actuators](#) based on piezoelectricity: [Piezo Motors](#) (Squiggler), [ultrasonic motors](#), eg for the [lens autofocusing](#) or [watches drives](#), in the field of micro-and

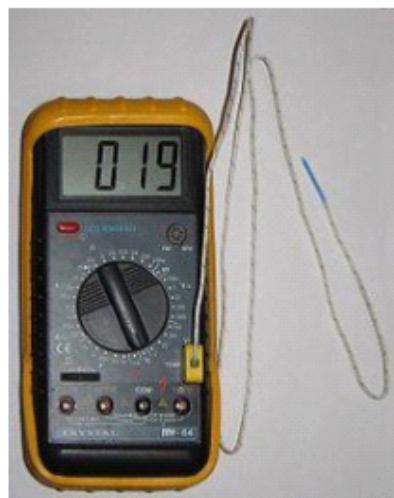
nanopositioning systems are scanning tunneling microscope, scanning electron microscope and atomic force microscope piezoelectrically driven systems. In valve technology are injectors of cars (production start 2000 for diesel engines), proportional pressure regulator and pressure heads of inkjet printers to mention.

Pickups, electro-acoustic delay lines, such as in older PAL- or SECAM color television sets, powered wireless technology (switch) and optical modulators are also piezoelectric devices.

Feeding uses many of the components mentioned.

<http://www.youtube.com/watch?v=Jglork3SDck>

4.Thermocouple



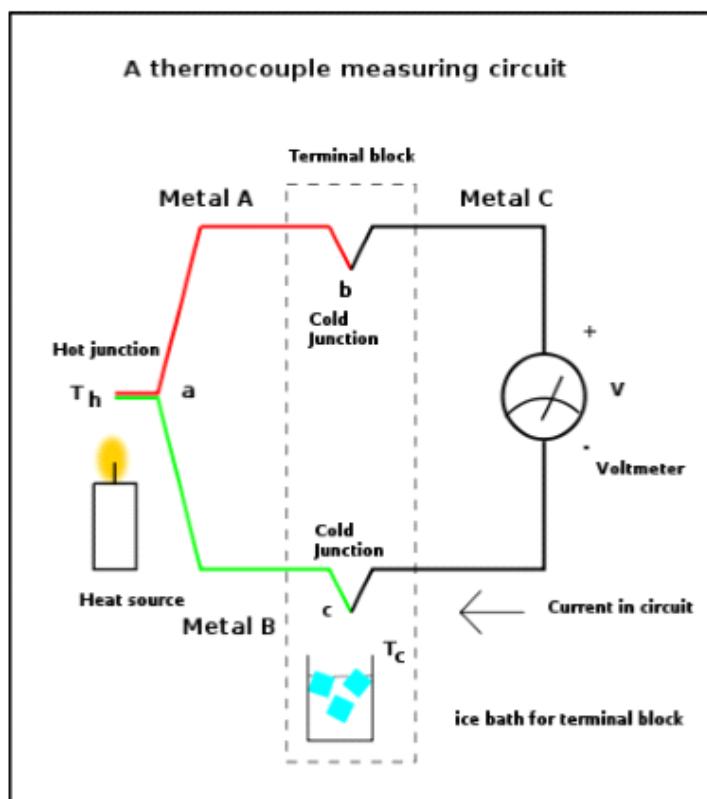
Thermocouple connected to a [multimeter](#) displaying room temperature in [°C](#).

A **thermocouple** consists of two conductors of different materials (usually metal alloys) that produce a [voltage](#) in the vicinity of the point where the two conductors are in contact. The voltage produced is dependent on, but not necessarily proportional to, the difference of temperature of the junction to other parts of those conductors. Thermocouples are a widely used type of [temperature sensor](#) for measurement and control^[1] and can also be used to convert a temperature [gradient](#) into electricity. They are inexpensive,^[2] interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree [Celsius](#) (C) can be difficult to achieve.^[3]

Any junction of dissimilar metals will produce an electric potential related to temperature. Thermocouples for practical measurement of temperature are junctions of specific [alloys](#) which have a predictable and repeatable relationship between temperature and voltage. Different alloys are used for different temperature ranges. Properties such as resistance to corrosion may also be important when choosing a type of thermocouple. Where the measurement point is far from the measuring instrument, the intermediate connection can be made by extension wires which are less costly than the materials used to make the sensor. Thermocouples are usually standardized against a reference temperature of 0 degrees Celsius; practical instruments use electronic methods of cold-junction compensation to adjust for varying temperature at the instrument terminals. Electronic instruments can also compensate

for the varying characteristics of the thermocouple, and so improve the precision and accuracy of measurements.

Thermocouples are widely used in science and industry; applications include temperature measurement for [kilns](#), [gas turbine](#) exhaust, [diesel](#) engines, and other industrial processes.



A thermocouple measuring circuit with a heat source, cold junction and a measuring instrument.

Principle of operation

In 1821, the [German–Estonian](#) physicist [Thomas Johann Seebeck](#) discovered that when any conductor is subjected to a thermal gradient, it will generate a voltage. This is now known as the [thermoelectric effect](#) or Seebeck effect. Any attempt to measure this voltage necessarily involves connecting another conductor to the "hot" end. This additional conductor will then also experience the temperature gradient, and develop a voltage of its own which will oppose the original. Fortunately, the magnitude of the effect depends on the metal in use. Using a

dissimilar metal to complete the circuit creates a circuit in which the two legs generate different voltages, leaving a small difference in voltage available for measurement. That difference increases with temperature, and is between 1 and 70 microvolts per degree Celsius ($\mu\text{V}/^\circ\text{C}$) for standard metal combinations.

The voltage is not generated at the junction of the two metals of the thermocouple but rather along that portion of the length of the two dissimilar metals that is subjected to a temperature gradient. Because both lengths of dissimilar metals experience the same temperature gradient, the end result is a measurement of the difference in temperature between the thermocouple junction and the reference junction.

Laws for thermocouple circuits

The properties of thermoelectric junctions with varying temperatures and compositions can be summarized in three laws describing the behaviour of thermocouple circuits.

Homogeneous material

A thermoelectric current cannot be sustained in a circuit of a single homogeneous material by the application of heat alone, regardless of how it might vary in cross section. In other words, temperature changes in the wiring between the input and output do not affect the output voltage, provided all wires are made of the same materials as the thermocouple. No current flows in the circuit made of a single metal by the application of heat alone. [\[citation needed\]](#)

Intermediate materials

The algebraic sum of the thermoelectric [EMFs](#) in a circuit composed of any number of dissimilar materials is zero if all of the junctions are at a uniform temperature. So If a third metal is inserted in either wire and if the two new junctions are at the same temperature, there will be no net voltage generated by the new metal. [\[citation needed\]](#)

Successive or intermediate temperatures

If two dissimilar homogeneous materials produce thermal EMF1 when the junctions are at T1 and T2 and produce thermal EMF2 when the junctions are at T2 and T3, the EMF generated when the junctions are at T1 and T3 will be EMF1 + EMF2, provided $T_1 < T_2 < T_3$. [\[citation needed\]](#)

Practical use

Voltage–temperature relationship

For typical metals used in thermocouples, the output voltage increases almost linearly with the temperature difference (ΔT) over a bounded range of temperatures. For precise measurements or measurements outside of the linear temperature range, non-linearity must be corrected. The [nonlinear](#) relationship between the temperature difference (ΔT) and the output voltage (a few mV) of a thermocouple can be approximated by a polynomial:

$$\Delta T = \sum_{n=0}^N a_n v^n$$

The coefficients a_n are given for n from 0 to between 5 and 13 depending upon the metals. In some cases better accuracy is obtained with additional non-polynomial terms.^[4] A database of voltage as a function of temperature, and coefficients for computation of temperature from voltage and vice-versa for many types of thermocouple is available online.^[4]

In modern equipment the equation is usually implemented in a digital controller or stored in a look-up table;^[5] older devices use analog circuits.

Piece-wise linear approximations are an alternative to polynomial corrections.^[6]

Cold junction compensation

Thermocouples measure the temperature difference between two points, not absolute temperature. To measure a single temperature one of the junctions—normally the cold junction—is maintained at a known reference temperature, and the other junction is at the temperature to be sensed.

Having a junction of known temperature, while useful for laboratory calibration, is not convenient for most measurement and control applications. Instead, they incorporate an artificial cold junction using a thermally sensitive device such as a [thermistor](#) or [diode](#) to measure the temperature of the input connections at the instrument, with special care being taken to minimize any temperature gradient between terminals. Hence, the voltage from a known cold junction can be simulated, and the appropriate correction applied. This is known as cold junction compensation. Some integrated circuits are designed for cold junction temperature compensation for specific thermocouple types.

Grades

Thermocouple wire is available in several different metallurgical formulations per type, typically, in decreasing levels of accuracy and cost: special limits of error, standard, and extension grades.

Extension grade wires made of the same metals as a higher-grade thermocouple are used to connect it to a measuring instrument some distance away without introducing additional junctions between dissimilar materials which would generate unwanted voltages; the connections to the extension wires, being of like metals, do not generate a voltage.

In the case of platinum thermocouples, extension wire is a copper alloy, since it would be prohibitively expensive to use platinum for extension wires. The extension wire is specified to have a very similar thermal coefficient of [EMF](#) to the thermocouple, but only over a narrow range of temperatures; this reduces the cost significantly.

The temperature-measuring instrument must have high input impedance to prevent any significant current draw from the thermocouple, to prevent a resistive voltage drop across the wire. Changes in metallurgy along the length of the thermocouple (such as termination strips or changes in thermocouple type wire) will introduce another thermocouple junction which affects measurement accuracy.

Applications

Thermocouples are suitable for measuring over a large temperature range, up to 2300 °C. They are less suitable for applications where smaller temperature differences need to be measured with high accuracy, for example the range 0–100 °C with 0.1 °C accuracy. For such applications [thermistors](#), [silicon bandgap temperature sensors](#) and [resistance temperature detectors](#) are more suitable. Applications include temperature measurement for [kilns](#), [gas turbine](#) exhaust, [diesel](#) engines, and other industrial processes.

Steel industry

Type B, S, R and K thermocouples are used extensively in the [steel](#) and [iron](#) industries to monitor temperatures and chemistry throughout the steel making process. Disposable, immersible, type S thermocouples are regularly used in the [electric arc furnace](#) process to accurately measure the temperature of steel before tapping. The cooling curve of a small steel sample can be analyzed and used to estimate the carbon content of molten steel.

Heating appliance safety

Many [gas](#)-fed heating appliances such as [ovens](#) and [water heaters](#) make use of a [pilot flame](#) to ignite the main gas burner when required. If it goes out, gas may be released, which is a fire risk and a health hazard. To prevent this, some appliances use a thermocouple in a [fail-safe](#) circuit to sense when the pilot light is burning. The tip of the thermocouple is placed in the pilot flame, generating a voltage which operates the supply valve which feeds gas to the pilot. So long as the pilot flame remains lit, the thermocouple remains hot, and the pilot gas valve is held open. If the pilot light goes out, the thermocouple temperature falls, causing the voltage across the thermocouple to drop and the valve to close. Some combined main burner and pilot gas valves (mainly by Honeywell) reduce the power demand to within the range of a single universal thermocouple heated by a pilot (25mV open circuit falling by half with the coil connected to 10~12mV @ 0.2~0.25A typically) by sizing the coil to be able to hold the valve open against a light spring, only after the initial turning-on force is provided by the user pressing and holding a knob to compress the spring during first lighting. These systems are identifiable by the 'press and hold for x minutes' in the pilot lighting instructions. (The holding current requirement of such a valve is much less than a bigger solenoid designed for pulling the valve in from closed would require.) Special test sets are made to confirm the valve let-go and holding currents as an ordinary milliammeter cannot be used as it introduces more resistance than the gas valve coil. Apart from testing the open circuit voltage of the thermocouple, and the near short-circuit DC continuity through the thermocouple gas valve coil, the easiest non-specialist test is substitution of a known good gas valve.

Some systems, known as millivolt control systems, extend the thermocouple concept to both open and close the main gas valve as well. Not only does the voltage created by the pilot thermocouple activate the pilot gas valve, it is also routed through a [thermostat](#) to power the main gas valve as well. Here, a larger voltage is needed than in a pilot flame safety system described above, and a [thermopile](#) is used rather than a single thermocouple. Such a system requires no external source of electricity for its operation and so can operate during a power failure, provided all the related system components allow for this. Note that this excludes common [forced air furnaces](#) because external power is required to operate the blower motor, but this feature is especially useful for un-powered convection heaters. A similar gas shut-off safety mechanism using a thermocouple is sometimes employed to ensure that the main burner ignites within a certain time period, shutting off the main burner gas supply valve should that not happen.

Out of concern for energy wasted by the standing pilot, designers of many newer appliances have switched to an electronically controlled pilot-less ignition, also called intermittent ignition. With no standing pilot flame, there is no risk of gas buildup should the flame go out, so these appliances do not need thermocouple-based pilot safety switches. As these designs lose the benefit of operation without a continuous source of electricity, standing pilots are still

used in some appliances. The exception is later model instantaneous (aka "tankless") water heaters that use the flow of water to generate the current required to ignite the gas burner, in conjunction with a thermocouple as a safety cut-off device in the event the gas fails to ignite, or the flame is extinguished.

Thermopile radiation sensors

Thermopiles are used for measuring the intensity of incident radiation, typically visible or infrared light, which heats the hot junctions, while the cold junctions are on a heat sink. It is possible to measure radiative [intensities](#) of only a few $\mu\text{W}/\text{cm}^2$ with commercially available thermopile sensors. For example, some [laser power](#) meters are based on such sensors.

Manufacturing

Thermocouples can generally be used in the testing of prototype electrical and mechanical apparatus. For example, [switchgear](#) under test for its current carrying capacity may have thermocouples installed and monitored during a heat run test, to confirm that the temperature rise at rated current does not exceed designed limits.

Power production

A thermocouple can produce current to drive some processes directly, without the need for extra circuitry and power sources. For example, the power from a thermocouple can activate a valve when a temperature difference arises. The [electrical energy](#) generated by a thermocouple is converted from the [heat](#) which must be supplied to the hot side to maintain the electric potential. A continuous transfer of heat is necessary because the current flowing through the thermocouple tends to cause the hot side to cool down and the cold side to heat up (the [Peltier effect](#)).

Thermocouples can be connected in series to form a [thermopile](#), where all the hot junctions are exposed to a higher temperature and all the cold junctions to a lower temperature. The output is the sum of the voltages across the individual junctions, giving larger voltage and power output. In a [radioisotope thermoelectric generator](#), the [radioactive decay](#) of [transuranic elements](#) as a heat source has been used to power spacecraft on missions too far from the Sun to use solar power.

Thermopiles heated by [kerosene lamps](#) were used to run [batteryless radio](#) receivers in isolated areas.^[10] There are commercially produced lanterns that use the heat from a candle to run several light-emitting diodes, and thermoelectrically-powered fans to improve air circulation and heat distribution in [wood stoves](#).

Thermoelectric cooling

The Peltier effect can be used for cooling, in the reverse process to a thermoelectric generator. Instead of generating electric power, the thermocouple consumes it, working as a [heat pump](#).

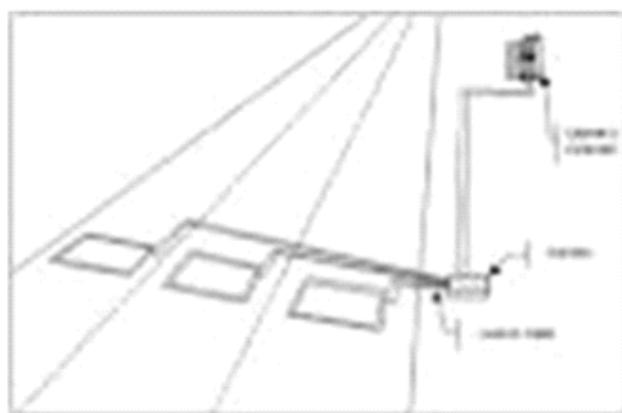
Process plants

Chemical production and petroleum refineries will usually employ computers for logging and limit testing the many temperatures associated with a process, typically numbering in the hundreds. For such cases a number of thermocouple leads will be brought to a common reference block (a large block of copper) containing the second thermocouple of each circuit. The temperature of the block is in turn measured by a [thermistor](#). Simple computations are used to determine the temperature at each measured location.

5. Induction loop

An **induction loop** is an [electromagnetic](#) communication or detection system, which uses a moving [magnet](#) to [induce](#) an [electrical current](#) in a nearby wire. Induction loops are used for transmission and reception of communication signals, or for detection of metal objects in metal detectors or vehicle presence indicators. A common modern use for induction loops is to provide hearing assistance to hearing-aid users.

Implementation



An example of the Inductance loop installed in the road for cars and bikes

The "[aerial](#)" system of an induction loop installation can consist of one or more loops of a conductive element.

In industrial applications this might be a large single- or multi-turn, loop, or a complex multi-lobed, phase coincident sub-loop design, most effectively mounted above the required reception area in industrial applications.

An [audio induction loop](#) might have one or more loops sometimes with a phase shift between them, and either near to or around the area in which a hearing aid user would be present. Many different configurations can be used depending on the application.^[1]

Such an induction loop receiver is classically a very small iron-cored inductor ([telecoil](#)), although [Rediffusion](#) demonstrated a prototype [Hall-Effect](#) system in its PLL FM system.

The system commonly uses an analogue power amplifier matched to the low impedance of the transmission loop. The transmission is normally direct rather than superimposed or modulated upon a carrier, though multi-channel systems have been implemented using modulation.

Vehicle detection

Vehicle detection loops are used to detect vehicles passing or arriving at a certain point, for instance approaching a [traffic light](#), and in motorway traffic management. An insulated, electrically conducting loop is installed in the pavement. The electronics unit transmits energy into the wire loops at frequencies between 10 kHz to 200 kHz, depending on the model. The inductive-loop system behaves as a tuned electrical circuit in which the loop wire and lead-in cable are the inductive elements. When a vehicle passes over the loop or is stopped within the loop, the vehicle induces [eddy currents](#) in the wire loops, which decrease their inductance. The decreased [inductance](#) actuates the electronics unit output relay or solid-state optically isolated output, which sends a pulse to the traffic signal controller signifying the passage or presence of a vehicle^[2]. Parking structures for automobiles may have [Parking Guidance and Information](#) systems. Railways may use an induction loop to detect the passage of trains past a given point, as an electronic [treadle](#).

Other uses

A different sort of "induction loop" is applied to [metal detectors](#), where a large coil, which forms part of a resonant circuit, is effectively "detuned" by the coil's proximity to a conductive object. The detected object may be metallic (metal and cable detection) or conductive/capacitive ([stud](#)/cavity detection). Other configurations of this equipment use two or more receiving coils, and the detected object modifies the inductive coupling or alters the phase angle of the voltage induced in the receiving coils relative to the oscillator coil.

An increasingly common application is for providing [hearing aid](#)-compatible "assistive listening" [telecoil](#). In this application a loop or series of loops is used to provide an audio frequency oscillating magnetic field in an area where a hearing aid user may be present. Many hearing aids contain a telecoil which allows the user to receive and hear the magnetic field and remove the normal audio signal provided from the hearing aid microphone^[3] site. These loops are often referred to as a hearing loop or [audio induction loop](#).

6.Capacitive sensing

This article is about the sensing technology used in human interfaces. For the device used in distance measurements, see [Capacitive displacement sensor](#).

In [electrical engineering](#), **capacitive sensing** is a technology based on [capacitive coupling](#) which takes human [body capacitance](#) as input.

Capacitive sensing is used in many different types of sensors, including those to detect and measure proximity, [position or displacement](#), [humidity](#), fluid level, and [acceleration](#). Capacitive sensing as a [human interface device](#) (HID) technology, for example to replace the [computer mouse](#), is growing increasingly popular.

Capacitive touch sensors are used in many devices such as laptop trackpads, [digital audio players](#), [computer displays](#), [mobile phones](#), [mobile devices](#), [tablets](#) and others. More and more design engineers are selecting capacitive sensors for their versatility, reliability and robustness, unique human-device interface and cost reduction over mechanical switches.

Capacitive sensors detect anything that is conductive or has a [dielectric](#) different than that of air. While capacitive sensing applications can replace mechanical buttons with capacitive alternatives, other technologies such as [multi-touch](#) and gesture-based [touchscreens](#) are also premised on capacitive sensing.

Design

Capacitive sensors are constructed from many different media, such as copper, [Indium tin oxide](#) (ITO) and printed ink. Copper capacitive sensors can be implemented on standard [FR4](#) PCBs as well as on flexible material. ITO allows the capacitive sensor to be up to 90% transparent (for one layer solutions, such as touch phone screens). Size and spacing of the capacitive sensor are both very important to the sensor's performance. In addition to the size of the sensor, and its spacing relative to the [ground plane](#), the type of ground plane used is very important. Since the [parasitic capacitance](#) of the sensor is related to the [electric field](#)'s (e-field) path to ground, it is important to choose a ground plane that limits the concentration of e-field lines with no conductive object present.

Designing a capacitance sensing system requires first picking the type of sensing material (FR4, Flex, ITO, etc.). One also needs to understand the environment the device will operate

in, such as the full [operating temperature](#) range, what radio frequencies are present and how the user will interact with the interface.

There are two types of capacitive sensing system: mutual capacitance,^[3] where the object (finger, conductive stylus) alters the mutual coupling between row and column electrodes, which are scanned sequentially,^[4] and self- or absolute capacitance where the object (such as a finger) loads the sensor or increases the parasitic capacitance to ground. In both cases, the difference of a preceding absolute position from the present absolute position yields the relative motion of the object or finger during that time. The technologies are elaborated in the following section.

Surface capacitance

In this basic technology, only one side of the insulator is coated with conductive material. A small [voltage](#) is applied to this layer, resulting in a uniform electrostatic field.^[5] When a [conductor](#), such as a human finger, touches the uncoated surface, a [capacitor](#) is dynamically formed. Due to the sheet resistance of the surface, each corner is measured to have a different effective capacitance.^[citation needed] The sensor's [controller](#) can determine the location of the touch indirectly from the change in the [capacitance](#) as measured from the four corners of the panel: the larger the change in capacitance, the closer the touch is to that corner. With no moving parts, it is moderately durable, but has low resolution, is prone to false signals from parasitic [capacitive coupling](#), and needs [calibration](#) during manufacture. Therefore, it is most often used in simple applications such as industrial controls and [interactive kiosks](#).^[6]

Projected capacitance

Projected capacitive touch (PCT) technology is a capacitive technology which allows more accurate and flexible operation, by [etching](#) the conductive layer. An [X-Y grid](#) is formed either by etching one layer to form a grid pattern of [electrodes](#), or by etching two separate, perpendicular layers of conductive material with parallel lines or tracks to form the grid; comparable to the [pixel](#) grid found in many [liquid crystal displays](#) (LCD).^[7]

The greater resolution of PCT allows operation with no direct contact, such that the conducting layers can be coated with further protective insulating layers, and operate even under screen protectors, or behind weather and vandal-proof glass. Due to the top layer of a PCT being glass, PCT is a more robust solution versus resistive touch technology. Depending on the implementation, an active or passive stylus can be used instead of or in addition to a finger. This is common with [point of sale](#) devices that require signature capture. Gloved fingers may or may not be sensed, depending on the implementation and gain settings. Conductive smudges and similar interference on the panel surface can interfere with the

performance. Such conductive smudges come mostly from sticky or sweaty finger tips, especially in high humidity environments. Collected dust, which adheres to the screen due to the moisture from fingertips can also be a problem. There are two types of PCT: self capacitance, and mutual capacitance.

Mutual capacitive sensors have a [capacitor](#) at each intersection of each row and each column. A 12-by-16 array, for example, would have 192 independent capacitors. A [voltage](#) is applied to the rows or columns. Bringing a finger or conductive stylus near the surface of the sensor changes the local electric field which reduces the mutual capacitance. The capacitance change at every individual point on the grid can be measured to accurately determine the touch location by measuring the voltage in the other axis. Mutual capacitance allows [multi-touch](#) operation where multiple fingers, palms or styli can be accurately tracked at the same time.

Self-capacitance sensors can have the same X-Y grid as mutual capacitance sensors, but the columns and rows operate independently. With self-capacitance, current senses the capacitive load of a finger on each column or row. This produces a stronger signal than mutual capacitance sensing, but it is unable to resolve accurately more than one finger, which results in "ghosting", or misplaced location sensing

Circuit design

Capacitance is typically measured indirectly, by using it to control the frequency of an oscillator, or to vary the level of coupling (or attenuation) of an AC signal.

The design of a simple capacitance meter is often based on a [relaxation oscillator](#). The capacitance to be sensed forms a portion of the oscillator's [RC circuit](#) or [LC circuit](#). Basically the technique works by charging the unknown capacitance with a known current. (The equation of state for a capacitor is $i = C \frac{dv}{dt}$. This means that the capacitance equals the current divided by the rate of change of voltage across the capacitor.) The capacitance can be calculated by measuring the charging time required to reach the threshold voltage (of the relaxation oscillator), or equivalently, by measuring the oscillator's frequency. Both of these are proportional to the RC (or LC) [time constant](#) of the oscillator circuit.

The primary source of error in capacitance measurements is stray capacitance, which if not guarded against, may fluctuate between roughly 10 pF and 10 nF. The stray capacitance can be held relatively constant by shielding the (high impedance) capacitance signal and then connecting the shield to (a low impedance) ground reference. Also, to minimize the unwanted effects of stray capacitance, it is good practice to locate the sensing electronics as near the sensor electrodes as possible.

Another measurement technique is to apply a fixed-frequency AC-voltage signal across a capacitive divider. This consists of two capacitors in series, one of a known value and the other of an unknown value. An output signal is then taken from across one of the capacitors. The value of the unknown capacitor can be found from the ratio of capacitances, which equals the ratio of the output/input signal amplitudes, as could be measured by an AC voltmeter. More accurate instruments may use a capacitance bridge configuration, similar to a [wheatstone bridge](#).^[8] The capacitance bridge helps to compensate for any variability that may exist in the applied signal.

Comparison with other touchscreen technologies

Since capacitive screens respond to only materials which are conductive (human finger used most commonly), they can be cleaned with cloths with no accidental command input. Capacitive touchscreens are more responsive than [resistive touchscreens](#).^[9]

A standard stylus cannot be used for capacitive sensing unless it is tipped with some form of conductive material, such as anti-static conductive foam.^[10] However, capacitive styli—different from standard [styli](#)—can be used as well as finger input on capacitive screens. Capacitive touchscreens are more expensive to manufacture and offer a significantly lesser degree of accuracy than [resistive touchscreens](#).^[9] Some cannot be used with gloves, and can fail to sense correctly with even a small amount of water on the screen.

Power supplies with high electronic [noise](#) can reduce accuracy.

Styli



Capacitive styli

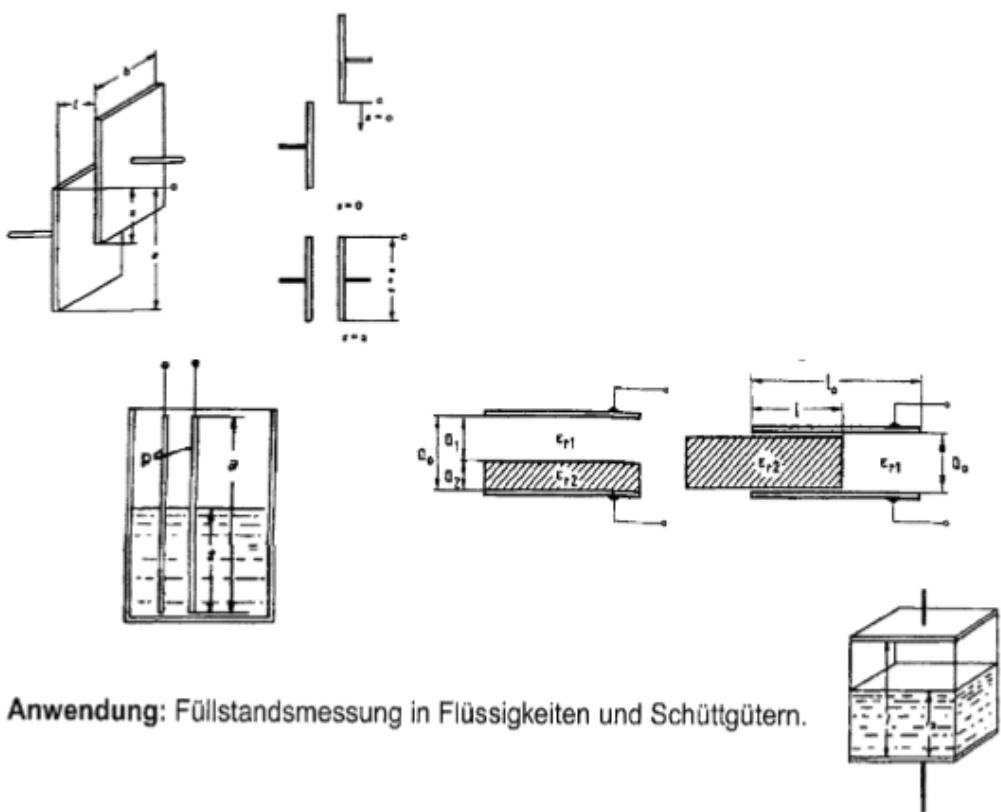
A [stylus](#) designed for resistive touchscreens will not register on capacitive sensors. Styli that work on capacitive touchscreens primarily designed for fingers are required to simulate the difference in dielectric offered by a human digit.^[11]

According to a report by ABI Research, styli are especially needed in China for handwriting recognition because of the [nature of its writing system](#).^[12]

[HTC](#) patented a capacitive stylus in 2009. The design features a magnetic tip which is smaller and therefore more precise than the human finger.

7. Capacitive displacement sensor

Capacitive displacement sensors "are non-contact devices capable of high-resolution measurement of the position and/or change of position of any conductive target".^[1] They are also able to measure the thickness or density of non-conductive materials.^[2] Capacitive displacement sensors are used in a wide variety of applications including semiconductor processing, assembly of precision equipment such as disk drives, precision thickness measurements, machine tool metrology and assembly line testing. These types of sensors can be found in machining and manufacturing facilities around the world.



Anwendung: Füllstandsmessung in Flüssigkeiten und Schüttgütern.

Basic capacitive theory

Capacitance is an electrical property which is created by applying an electrical charge to two conductive objects with a gap between them. This property is most commonly illustrated using the example of two parallel conductive plates with a gap between them and a charge applied to them. In this situation, the Capacitance can be expressed by the equation:

$$C = \frac{\epsilon_0 K A}{d}$$

Where C is the capacitance, ϵ_0 is the [permittivity of free space](#) constant, K is the [dielectric constant](#) of the material in the gap, A is the area of the plates, and d is the distance between the plates.

There are two general types of capacitive displacement sensing systems. One type is used to measure thicknesses of conductive materials. The other type measures thicknesses of non conductive materials or the level a fluid.

A capacitive sensing system for conductive materials uses a model similar to the one described above, but in place of one of the conductive plates, is the [sensor](#), and in place of the other, is the conductive target to be measured. Since the area of the probe and target remain constant, and the [dielectric](#) of the material in the gap (usually air) also remains constant, "any change in capacitance is a result of a change in the distance between the probe and the target."
Therefore, the equation above can be simplified to:

$$C \propto \frac{1}{d}$$

Where \propto indicates a proportional relationship. Due to this proportional relationship, a capacitive sensing system is able to measure changes in capacitance and translate these changes into distance measurements.

The operation of the sensor for measuring thickness of non-conductive materials can be thought of as two capacitors in series, with each having a different dielectric (and dielectric constant). The sum of the thicknesses of the two dielectric materials remains constant but the thickness of each can vary. The thickness of the material to be measured displaces the other dielectric. The gap is often an air gap, (dielectric constant = 1) and the material has a higher dielectric. As the material gets thicker, the capacitance increases and is sensed by the system.

A sensor for measuring fluid levels works as two capacitors in parallel with constant total area. Again the difference in the dielectric constant of the fluid and the dielectric constant of air results in detectable changes in the capacitance between the conductive probes or plates.

Applications

Precision positioning

One of the more common applications of capacitive sensors is for precision positioning. Capacitive displacement sensors can be used to measure the position of objects down to the [nanometer](#) level. This type of precise positioning is used in the semiconductor industry where

[silicon wafers](#) need to be positioned for exposure. Capacitive sensors are also used to pre-focus the [electron microscopes](#) used in testing and examining the wafers.

Disc drive industry

In the disc drive industry, capacitive displacement sensors are used to measure the runout (a measure of how much the axis of rotation deviates from an ideal fixed line) of disc drive [spindles](#). By knowing the exact runout of these spindles, disc drive manufacturers are able to determine the maximum amount of data that can be placed onto the drives. Capacitive sensors are also used to ensure that disc drive platters are [orthogonal](#) to the spindle before data is written to them.

Precision thickness measurements

Capacitive displacement sensors can be used to make very precise [thickness](#) measurements. Capacitive displacement sensors operate by measuring changes in position. If the position of a reference part of known thickness is measured, other parts can be subsequently measured and the differences in position can be used to determine the thickness of these parts.^[5] In order for this to be effective using a single probe, the parts must be completely flat and measured on a perfectly flat surface. If the part to be measured has any [curvature](#) or [deformity](#), or simply does not rest firmly against the flat surface, the distance between the part to be measured and the surface it is placed upon will be erroneously included in the thickness measurement. This error can be eliminated by using two capacitive sensors to measure a single part. Capacitive sensors are placed on either side of the part to be measured. By measuring the parts from both sides, curvature and deformities are taken into account in the [measurement](#) and their effects are not included in the thickness readings.

The thickness of plastic materials can be measured with the material placed between two electrodes a set distance apart. These form a type of capacitor. The plastic when placed between the electrodes acts as a dielectric and displaces air (which has [dielectric constant](#) of 1, different than the plastic). Consequently the capacitance between the electrodes changes. The capacitance changes can then be measured and correlated with the material's thickness.^[6]

Capacitive sensors circuits can be constructed that are able to detect changes in capacitance on the order of a 10^{-5} [picofarads](#) (10 attofarads).^[7]

Non-conductive targets

While capacitive displacement sensors are most often used to sense changes in position of conductive targets, they can also be used to sense the thickness and/or density of non-conductive targets as well.^[4] A non-conductive object placed in between the probe and

conductive target will have a different dielectric constant than the air in the gap and will therefore change the Capacitance between probe and target. (See the first equation above) By analyzing this change in capacitance, the thickness and density of the non-conductor can be determined.

Machine tool metrology

Capacitive displacement sensors are often used in metrology applications. In many cases, sensors are used “to measure shape errors in the part being produced. But they also can measure the errors arising in the equipment used to manufacture the part, a practice known as machine tool metrology”.^[8] In many cases, the sensors are used to analyze and optimize the rotation of spindles in various machine tools, examples include [surface grinders](#), [lathes](#), [milling machines](#), and [air bearing](#) spindles.^[9] By measuring errors in the machines themselves, rather than simply measuring errors in the final products, problems can be dealt with and fixed earlier in the manufacturing process.

Assembly line testing

Capacitive displacement sensors are often used in assembly line testing. Sometimes they are used to test assembled parts for [uniformity](#), thickness or other design features. At other times, they are used to simply look for the presence or absence of a certain component, such as [glue](#).^[10] Using capacitive sensors to test assembly line parts can help to prevent quality concerns further along in the production process.

8.Flow measurement

Flow measurement is the quantification of bulk [fluid](#) movement. Flow can be measured in a variety of ways. Positive-displacement flow meters accumulate a fixed volume of fluid and then count the number of times the volume is filled to measure flow. Other flow measurement methods rely on forces produced by the flowing stream as it overcomes a known constriction, to indirectly calculate flow. Flow may be measured by measuring the velocity of fluid over a known area.

Units of measurement

Both gas and liquid flow can be measured in [volumetric](#) or [mass flow rates](#), such as liters per second or kilograms per second. These measurements can be converted between one another if the material's [density](#) is known. The density for a liquid is almost independent of the liquid conditions; however, this is not the case for gas, the density of which depends greatly upon pressure, temperature and to a lesser extent, the gas composition.

When gases or liquids are transferred for their energy content, such as the sale of [natural gas](#), the flow rate may also be expressed in terms of energy flow, such as GJ/hour or BTU/day. The energy flow rate is the volume flow rate multiplied by the energy content per unit volume or mass flow rate multiplied by the energy content per unit mass. Where accurate energy comes to the time of the legit flow rate is desired, most flow meters will be used to calculate the volume or mass flow rate which is then adjusted to the energy flow rate by the use of a [flow computer](#).

In engineering contexts, the [volumetric](#) flow rate is usually given the symbol Q , and the [mass](#) flow rate, the symbol \dot{m} .

Gas

Gases are compressible and change volume when placed under pressure, are heated or are cooled. A volume of gas under one set of pressure and temperature conditions is not equivalent to the same gas under different conditions. References will be made to "actual" flow rate through a meter and "standard" or "base" flow rate through a meter with units such as *acm/h* (actual cubic meters per hour), *kscm/h* (kilo standard cubic meters per hour), **LFM** (linear feet per minute), or *MSCFD* (thousands of standard cubic feet per day).

Gas *mass* flow rate can be directly measured, independent of pressure and temperature effects, with [thermal mass flow meters](#), Coriolis [mass flow meters](#), or [mass flow controllers](#).

Liquid

For liquids, various units are used depending upon the application and industry, but might include gallons (U.S. liquid or imperial) per minute, liters per second, [bushels](#) per minute or, when describing river flows, cumecs (cubic metres per second) or acre-feet per day. In oceanography a common unit to measure volume transport (volume of water transported by a current for example) is a [sverdrup](#) (Sv) equivalent to $10^6 \text{ m}^3 / \text{s}$.

Mechanical flow meters

A bucket and a stopwatch is an analogy for the operation of a [positive displacement meter](#). The stopwatch is started when the flow starts, and stopped when the bucket reaches its limit. The volume divided by the time gives the flow rate. For continuous measurements, we need a system of continually filling and emptying buckets to divide the flow without letting it out of the pipe. These continuously forming and collapsing volumetric displacements may take the form of pistons reciprocating in cylinders, gear teeth mating against the internal wall of a meter or through a progressive cavity created by rotating oval gears or a helical screw.

[Piston meter/Rotary piston](#)

Because they are used for domestic water measurement, [piston](#) meters, also known as rotary piston or semi-positive displacement meters, are the most common flow measurement devices in the UK and are used for almost all meter sizes up to and including 40 mm (1½"). The piston meter operates on the principle of a piston rotating within a chamber of known volume. For each rotation, an amount of water passes through the piston chamber. Through a [gear mechanism](#) and, sometimes, a [magnetic](#) drive, a needle dial and [odometer](#) type display are advanced.

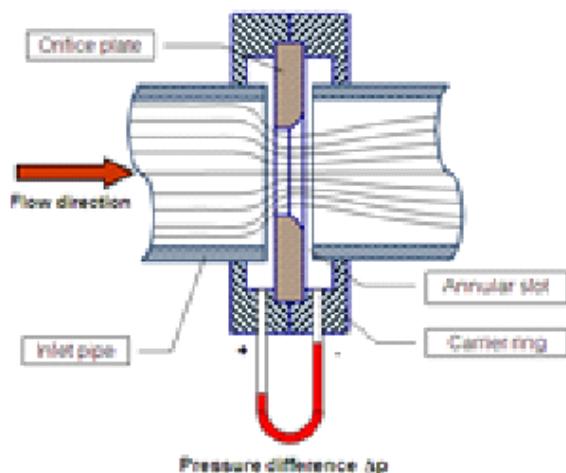
Pressure-based meters

There are several types of flow meter that rely on [Bernoulli's principle](#), either by measuring the differential pressure within a constriction, or by measuring [static](#) and [stagnation pressures](#) to derive the [dynamic pressure](#).

Venturi meter

A [Venturi](#) meter constricts the flow in some fashion, and [pressure sensors](#) measure the differential pressure before and within the constriction. This method is widely used to

measure flow rate in the transmission of gas through [pipelines](#), and has been used since [Roman Empire](#) times. The [coefficient of discharge](#) of Venturi meter ranges from 0.93 to 0.97.



ISO 5167 Orifice Plate

Optical flow meters

Optical flow meters use light to determine flow rate. Small particles which accompany natural and industrial gases pass through two laser beams focused a short distance apart in the flow path. in a pipe by illuminating optics. Laser light is scattered when a particle crosses the first beam. The detecting optics collects scattered light on a photodetector, which then generates a pulse signal. As the same particle crosses the second beam, the detecting optics collect scattered light on a second photodetector, which converts the incoming light into a second electrical pulse. By measuring the time interval between these pulses, the gas velocity is calculated as $V = D/t$ where D is the distance between the laser beams and t is the time interval.

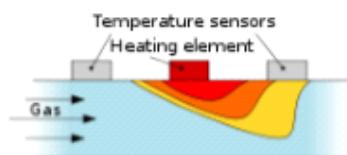
Laser-based optical flow meters measure the actual speed of particles, a property which is not dependent on thermal conductivity of gases, variations in gas flow or composition of gases. The operating principle enables optical laser technology to deliver highly accurate flow data, even in challenging environments which may include high temperature, low flow rates, high pressure, high humidity, pipe vibration and acoustic noise.

Optical flow meters are very stable with no moving parts and deliver a highly repeatable measurement over the life of the product. Because distance between the two laser sheets does not change, optical flow meters do not require periodic calibration after their initial

commissioning. Optical flow meters require only one installation point, instead of the two installation points typically required by other types of meters. A single installation point is simpler, requires less maintenance and is less prone to errors.

Commercially available optical flow meters are capable of measuring flow from 0.1 m/s to faster than 100 m/s (1000:1 turn down ratio) and have been demonstrated to be effective for the measurement of flare gases from oil wells and refineries, a contributor to atmospheric pollution.^[6]

Thermal mass flow meters



Temperature at the sensors varies depending upon the mass flow

Thermal mass flow meters generally use combinations of heated elements and temperature sensors to measure the difference between static and flowing heat transfer to a [fluid](#) and infer its flow with a knowledge of the fluid's [specific heat](#) and density. The fluid temperature is also measured and compensated for. If the density and [specific heat](#) characteristics of the [fluid](#) are constant, the meter can provide a direct mass flow readout, and does not need any additional pressure temperature compensation over their specified range.

Technological progress has allowed the manufacture of thermal mass flow meters on a microscopic scale as [MEMS sensors](#); these flow devices can be used to measure flow rates in the range of nanolitres or microlitres per minute.

[Thermal mass flow meter](#) (also called thermal dispersion flowmeter) technology is used for compressed air, nitrogen, helium, argon, oxygen, and natural gas. In fact, most gases can be measured as long as they are fairly clean and non-corrosive. For more aggressive gases, the meter may be made out of special alloys (e.g. [Hastelloy](#)), and pre-drying the gas also helps to minimize corrosion.

Today, thermal mass flow meters are used to measure the flow of gases in a growing range of applications, such as chemical reactions or thermal transfer applications that are difficult for other flow metering technologies. This is because thermal mass flow meters monitor

variations in one or more of the thermal characteristics (temperature, thermal conductivity, and/or specific heat) of gaseous media to define the mass flow rate.

Electromagnetic, ultrasonic and coriolis flow meters



A magnetic flow meter at the [Tetley's Brewery](#) in [Leeds, West Yorkshire](#).

Modern innovations in the measurement of flow rate incorporate electronic devices that can correct for varying pressure and temperature (i.e. density) conditions, non-linearities, and for the characteristics of the fluid.

Magnetic flow meters



Industrial magnetic flowmeter

[Magnetic flow meters](#), often called "mag meter"s or "electromag"s, use a [magnetic field](#) applied to the metering tube, which results in a potential difference proportional to the flow velocity perpendicular to the [flux](#) lines. The potential difference is sensed by electrodes aligned perpendicular to the flow and the applied magnetic field. The physical principle at work is [Faraday's law of electromagnetic induction](#). The magnetic flow meter requires a conducting fluid and a nonconducting pipe liner. The electrodes must not corrode in contact with the process fluid; some magnetic flowmeters have auxiliary transducers installed to clean the electrodes in place. The applied magnetic field is pulsed, which allows the flowmeter to cancel out the effect of stray voltage in the piping system.

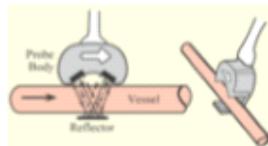
Ultrasonic (Doppler, transit time) flow meters

[Ultrasonic flow meters](#) measure the difference of the transit time of [ultrasonic pulses](#) propagating in and against flow direction. This time difference is a measure for the average velocity of the fluid along the path of the ultrasonic beam. By using the absolute transit times both the averaged fluid velocity and the speed of sound can be calculated. Using the two transit times t_{up} and t_{down} and the distance between receiving and transmitting transducers L and the inclination angle α one can write the equations:

$$v = \frac{L}{2 \sin(\alpha)} \frac{t_{up} - t_{down}}{t_{up} t_{down}} \text{ and } c = \frac{L}{2} \frac{t_{up} + t_{down}}{t_{up} t_{down}}$$

where v is the average velocity of the fluid along the sound path and c is the speed of sound.

Ultrasonic flow meters are also used for the measurement of natural gas flow.^[8] One can also calculate the expected speed of sound for a given sample of gas; this can be compared to the speed of sound empirically measured by an ultrasonic flow meter and for the purposes of monitoring the quality of the flow meter's measurements. A drop in quality is an indication that the meter needs servicing.^[9] Recently, Ultrasonic flow meters are also being used for measurement of LNG flow.



Schematic view of a flow sensor.

Measurement of the [Doppler shift](#) resulting in reflecting an [ultrasonic](#) beam off the flowing fluid has also been used in the past. Due to limited accuracy this method is only suitable for applications that do not require a high accuracy. By passing an ultrasonic beam through the tissues, bouncing it off a reflective plate, then reversing the direction of the beam and repeating the measurement, the volume of [blood](#) flow can be estimated. The frequency of the transmitted beam is affected by the movement of blood in the vessel and by comparing the frequency of the upstream beam versus downstream the flow of blood through the vessel can be measured. The difference between the two frequencies is a measure of true volume flow. A wide-beam sensor can also be used to measure flow independent of the cross-sectional area of the blood vessel.

For the Doppler principle to work in a flowmeter it is mandatory that the flow stream contains sonically reflective materials, such as solid particles or entrained [air bubbles](#).

Laser Doppler flow measurement

A beam of laser light impinging on a moving particle will be partially scattered with a change in wavelength proportional to the particle's speed (the [Doppler effect](#)). A [Laser Doppler velocimeter](#) (LDV), also called a [laser Doppler anemometer](#) (LDA), focuses a laser beam into a small volume in a flowing fluid containing small particles (naturally occurring or induced). The particles scatter the light with a Doppler shift. Analysis of this shifted wavelength can be used to directly, and with great precision, determine the speed of the particle and thus a close approximation of the fluid velocity.

A number of different techniques and device configurations are available for determining the Doppler shift. All use a [photodetector](#) (typically an [avalanche photodiode](#)) to convert the light into an electrical waveform for analysis. In most devices, the original laser light is divided into two beams. In one general LDV class, the two beams are made to intersect at their focal points where they [interfere](#) and generate a set of straight fringes. The sensor is then aligned to the flow such that the fringes are perpendicular to the flow direction. As particles pass through the fringes, the Doppler-shifted light is collected into the photodetector. In another general LDV class, one beam is used as a reference and the other is Doppler-scattered. Both beams are then collected onto the photodetector where [optical heterodyne detection](#) is used to extract the Doppler signal.^[11]

Anemometer



THE ROBINSON ANEMOMETER

A hemispherical cup anemometer of the type invented in 1846 by John Thomas Romney Robinson

An **anemometer** is a device for measuring [wind](#) speed, and is a common [weather station](#) instrument. The term is derived from the Greek word *anemos*, meaning wind, and is used to describe any airspeed measurement instrument used in [meteorology](#) or [aerodynamics](#). The first known description of an anemometer was given by [Leon Battista Alberti](#) around 1450.^[1]

Anemometers can be divided into two classes: those that measure the wind's speed, and those that measure the wind's pressure; but as there is a close connection between the pressure and the speed, an anemometer designed for one will give information about both.

Velocity anemometers

Cup anemometers



Cup-type anemometer with vertical axis, a sensor on a remote [meteorological station](#) deployed on [Skagit Bay, Washington](#) July–August, 2009.

A simple type of anemometer, invented (1846) by Dr. [John Thomas Romney Robinson](#), of [Armagh Observatory](#). It consisted of four [hemispherical](#) cups each mounted on one end of four horizontal arms, which in turn were mounted at equal angles to each other on a vertical shaft. The air flow past the cups in any horizontal direction turned the cups in a manner that was proportional to the wind speed. Therefore, counting the turns of the cups over a set time period produced the average wind speed for a wide range of speeds. On an anemometer with four cups it is easy to see that since the cups are arranged symmetrically on the end of the arms, the wind always has the hollow of one cup presented to it and is blowing on the back of the cup on the opposite end of the cross.

When Robinson first designed his anemometer, he asserted that the cups moved one-third of the speed of the wind, unaffected by the cup size or arm length. This was apparently confirmed by some early independent experiments, but it was incorrect. Instead, the ratio of the speed of the wind and that of the cups, the anemometer factor, depends on the dimensions of the cups and arms, and may have a value between two and a little over three. Every previous experiment involving an anemometer had to be repeated.

The three cup anemometer developed by the Canadian John Patterson in 1926 and subsequent cup improvements by Brevoort & Joiner of the USA in 1935 led to a cupwheel design which was linear and had an error of less than 3% up to 60 mph (97 km/h). Patterson found that each cup produced maximum torque when it was at 45 degrees to the wind flow. The three cup anemometer also had a more constant torque and responded more quickly to gusts than the four cup anemometer.

The three cup anemometer was further modified by the Australian Derek Weston in 1991 to measure both wind direction and wind speed. Weston added a tag to one cup, which causes the cupwheel speed to increase and decrease as the tag moves alternately with and against the wind. Wind direction is calculated from these cyclical changes in cupwheel speed, while wind speed is as usual determined from the average cupwheel speed.

Three cup anemometers are currently used as the industry standard for [wind resource assessment](#) studies.

Windmill anemometers

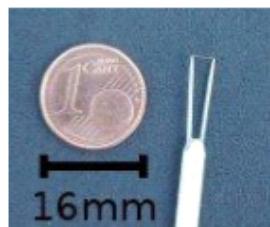


A windmill style of anemometer

The other forms of mechanical velocity anemometer may be described as belonging to the [windmill](#) type or propeller anemometer. In the Robinson anemometer the axis of rotation is vertical, but with this subdivision the axis of rotation must be parallel to the direction of the wind and therefore horizontal. Furthermore, since the wind varies in direction and the axis has to follow its changes, a [wind vane](#) or some other contrivance to fulfill the same purpose must

be employed. An *aerovane* combines a propeller and a tail on the same axis to obtain accurate and precise wind speed and direction measurements from the same instrument. In cases where the direction of the air motion is always the same, as in the ventilating shafts of mines and buildings for instance, wind vanes, known as air meters are employed, and give most satisfactory results.

Hot-wire anemometers



Hot-wire sensor

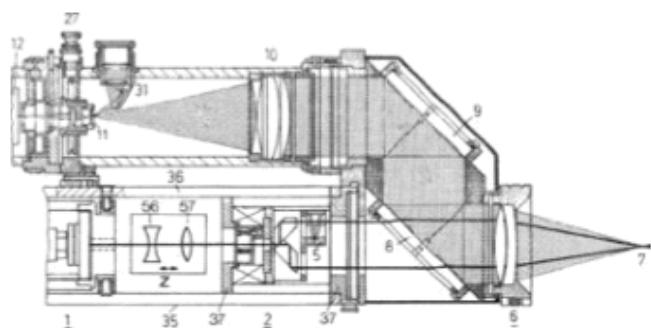
Hot-wire anemometers use a very fine wire (on the order of several micrometres) electrically heated up to some temperature above the ambient. Air flowing past the wire has a cooling effect on the wire. As the electrical resistance of most metals is dependent upon the temperature of the metal ([tungsten](#) is a popular choice for hot-wires), a relationship can be obtained between the resistance of the wire and the flow speed.^[2]

Several ways of implementing this exist, and hot-wire devices can be further classified as CCA (Constant-Current Anemometer), CVA (Constant-Voltage Anemometer) and CTA (Constant-Temperature Anemometer). The voltage output from these anemometers is thus the result of some sort of circuit within the device trying to maintain the specific variable (current, voltage or temperature) constant.

Additionally, PWM ([pulse-width modulation](#)) anemometers are also used, wherein the velocity is inferred by the time length of a repeating pulse of current that brings the wire up to a specified resistance and then stops until a threshold "floor" is reached, at which time the pulse is sent again.

Hot-wire anemometers, while extremely delicate, have extremely high frequency-response and fine spatial resolution compared to other measurement methods, and as such are almost universally employed for the detailed study of turbulent flows, or any flow in which rapid velocity fluctuations are of interest.

Laser Doppler anemometers



Drawing of a laser anemometer. The laser is emitted (1) through the front lens (6) of the anemometer and is backscattered off the air molecules (7). The backscattered radiation (dots) re-enter the device and are reflected and directed into a detector (12).

Laser Doppler anemometers use a beam of light from a [laser](#) that is divided into two beams, with one propagated out of the anemometer. Particulates (or deliberately introduced seed material) flowing along with air molecules near where the beam exits reflect, or backscatter, the light back into a detector, where it is measured relative to the original laser beam. When the particles are in great motion, they produce a [Doppler shift](#) for measuring wind speed in the laser light, which is used to calculate the speed of the particles, and therefore the air around the anemometer.^[3]

Sonic anemometers



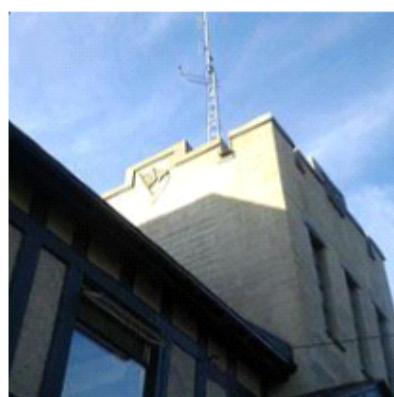
3D ultrasonic anemometer

Sonic anemometers, first developed in the 1950s, use [ultrasonic sound waves](#) to measure wind velocity. They measure wind speed based on the time of flight of sonic pulses between pairs of [transducers](#). Measurements from pairs of transducers can be combined to yield a measurement of velocity in 1-, 2-, or 3-dimensional flow. The [spatial resolution](#) is given by the path length between transducers, which is typically 10 to 20 [cm](#). Sonic anemometers can take measurements with very fine [temporal resolution](#), 20 [Hz](#) or better, which makes them well suited for [turbulence](#) measurements. The lack of moving parts makes them appropriate for long term use in exposed automated weather stations and weather buoys where the accuracy and reliability of traditional cup-and-vane anemometers is adversely affected by salty air or large amounts of dust. Their main disadvantage is the distortion of the flow itself by the structure supporting the transducers, which requires a correction based upon wind tunnel measurements to minimize the effect. An international standard for this process, [ISO 16622 Meteorology—Sonic anemometers/thermometers—Acceptance test methods for mean wind measurements](#) is in general circulation. Another disadvantage is lower accuracy due to precipitation, where rain drops may vary the [speed of sound](#).

Since the speed of sound varies with temperature, and is virtually stable with pressure change, sonic anemometers are also used as [thermometers](#).

Two-dimensional (wind speed and wind direction) sonic anemometers are used in applications such as weather stations, ship navigation, wind turbines, aviation and [weather buoys](#). Three-dimensional sonic anemometers are widely used to measure gas emissions and ecosystem fluxes using [eddy covariance](#) method when used with fast-response [infrared gas analyzer](#) or [laser](#)-based analyzer.

Pressure anemometers



[Britannia Yacht Club](#) clubhouse tour, burgee, and wind gauge on roof

The first designs of anemometers which measure the pressure were divided into plate and tube classes.

Tube anemometers



[Helicoid](#) propeller anemometer incorporating a [wind vane](#) for orientation.

James Lind's anemometer of 1775 consisted simply of a glass U tube containing a liquid [manometer](#) (pressure gauge), with one end bent in a horizontal direction to face the wind and the other vertical end remains parallel to the wind flow. Though the Lind was not the first it was the most practical and best known anemometer of this type. If the wind blows into the mouth of a tube it causes an increase of pressure on one side of the manometer. The wind over the open end of a vertical tube causes little change in pressure on the other side of the manometer. The resulting liquid change in the U tube is an indication of the wind speed. Small departures from the true direction of the wind causes large variations in the magnitude.

The highly successful metal pressure tube anemometer of William Henry Dines in 1892 utilized the same pressure difference between the open mouth of a straight tube facing the wind and a ring of small holes in a vertical tube which is closed at the upper end. Both are mounted at the same height. The pressure differences on which the action depends are very small, and special means are required to register them. The recorder consists of a float in a sealed chamber partially filled with water. The pipe from the straight tube is connected to the top of the sealed chamber and the pipe from the small tubes is directed into the bottom inside the float. Since the pressure difference determines the vertical position of the float this is a measured of the wind speed.

The great advantage of the tube anemometer lies in the fact that the exposed part can be mounted on a high pole, and requires no oiling or attention for years; and the registering part can be placed in any convenient position. Two connecting tubes are required. It might appear at first sight as though one connection would serve, but the differences in pressure on which these instruments depend are so minute, that the pressure of the air in the room where the recording part is placed has to be considered. Thus if the instrument depends on the pressure or suction effect alone, and this pressure or suction is measured against the air pressure in an ordinary room, in which the doors and windows are carefully closed and a newspaper is then burnt up the chimney, an effect may be produced equal to a wind of 10 mi/h (16 km/h); and the opening of a window in rough weather, or the opening of a door, may entirely alter the registration.

While the Dines anemometer had an error of only 1% at 10 mph (16 km/h) it did not respond very well to low winds due to the poor response of the flat plate vane required to turn the head into the wind. In 1918 an aerodynamic vane with eight times the torque of the flat plate overcame this problem.

Effect of density on measurements

In the tube anemometer the pressure is measured, although the scale is usually graduated as a velocity scale. In cases where the density of the air is significantly different from the calibration value (as on a high mountain, or with an exceptionally low barometer) an allowance must be made. Approximately 1½% should be added to the velocity recorded by a tube anemometer for each 1000 ft (5% for each kilometer) above sea-level.

9.Laser scanning

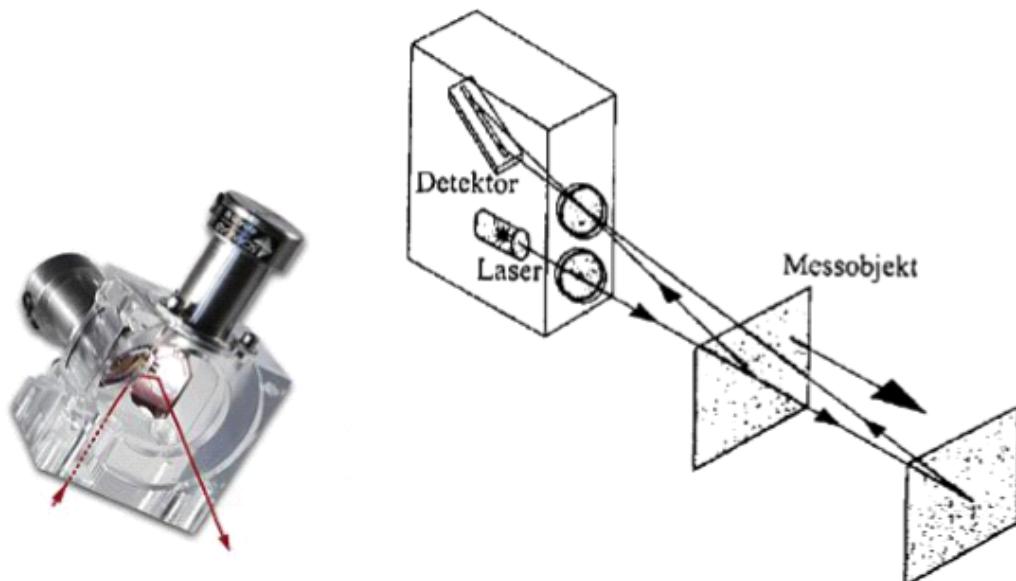
In modern engineering, the term 'laser scanning' is used to describe two related, but separate meanings. The first, more general, meaning is the controlled **deflection of laser beams**, visible or invisible. Scanned laser beams are used in [stereolithography](#) machines, in [rapid prototyping](#), in machines for material processing, in [laser engraving](#) machines, in ophthalmological laser systems for the treatment of [presbyopia](#), in [confocal microscopy](#), in [laser printers](#), in [laser shows](#), in [Laser TV](#), in [LIDAR](#), and in [barcode scanners](#).

The second, more specific, meaning is the controlled steering of laser beams **followed by a distance measurement** at every pointing direction. This method, often called [3D object scanning](#) or [3D laser scanning](#), is used to rapidly capture shapes of objects, buildings and landscapes.

This article focuses on the general meaning, i.e., on the methods and applications of scanned laser beams.

Technology

Scanning mirrors



Laser scanning module with two galvanometers, from Scanlab AG. The red arrow shows the path of the laser beam.

Most laser scanners use moveable mirrors to steer the laser beam. The steering of the beam can be **one-dimensional**, as inside a laser printer, or **two-dimensional**, as in a laser show system.

Additionally, the mirrors can lead to a **periodic** motion - like the rotating *mirror polygons* in a barcode scanner or so-called *resonant galvanometer* scanners - or to an **freely addressable** motion, as in servo-controlled [galvanometer](#) scanners. One also uses the terms [raster scanning](#) and [vector scanning](#) to distinguish the two situations.

To control the scanning motion, scanners need a [rotary encoder](#) and control electronics that provides, for a desired angle or phase, the suitable electrical current to the motor or galvanometer. A software systems usually controls the scanning motion and, if 3D scanning is implemented, also the collection of the measured data.

In order to position a laser beam in **two dimensions**, it is possible either to rotate one mirror along two axes - used mainly for slow scanning systems - or to reflect the laser beam onto two closely spaced mirrors that are mounted on orthogonal axes. Each of the two flat or polygonal mirrors is then driven by a galvanometer or by an electric motor. Two-dimensional systems are essential for most applications in material processing, confocal microscopy, and medical science.

Some applications require to position the focus of a laser beam in **three dimensions**. This is achieved by a servo-controlled lens system, usually called a 'focus shifter' or 'z-shifter'.

Many laser scanners further allow changing the laser intensity.

In laser projectors for laser TV or laser displays, the three fundamental colors red blue and green are combined in a single beam and then reflected together over the two mirrors.

The most common way to move mirrors is, as mentioned, the use of an [electric motor](#) or of a [galvanometer](#). However [piezoelectric actuators](#) or [magnetostrictive actuators](#) are alternative options. They offer higher achievable angular speeds, but often at the expense of smaller achievable maximum angles.

Scanning refractive optics

When two [Risley prisms](#) are rotated against each other, a beam of light can be scanned at will inside a cone. Such scanners are used for tracking missiles. (See www.optra.com)

When two [optical lenses](#) are moved or rotated against each other, a laser beam can be scanned in a way similar to mirror scanners. (See www.haasli.com)

Material effects

Some special laser scanners use, instead of moving mirrors, [acousto-optic deflectors](#) or [electrooptic deflectors](#). These mechanisms allow the highest scanning frequencies possible so far. They are used, for example, in [laser TV](#) systems. On the other hand, these systems are also much more expensive than mirror scanning systems.

Phased array scanning

Research is going on to achieve scanning of laser beams through [phased arrays](#). This method is used to scan [RADAR](#) beams without moving parts. With the use of [Vertical-cavity surface-emitting laser](#) (VCSELs), it might be possible to realize fast laser scanners in the foreseeable future.

Applications

3D object scanning

[3D object scanning](#) allows enhancing the [design process](#), speeds up and reduces [data collection](#) errors, saves time and money, and thus makes it an attractive alternative to traditional data collection techniques. 3D scanning is also used for [mobile mapping](#), [surveying](#), scanning of buildings and building interiors, and in [archaeology](#).

Material processing

Depending on the power of the laser, its influence on a working piece differs: lower power values are used for [laser engraving](#) and [laser ablation](#), where material is partially removed by the laser. With higher powers the material becomes fluid and [laser welding](#) can be realized, or if the power is high enough to remove the material completely, then [laser cutting](#) can be performed. Modern lasers can cut steel blocks with a thickness of 10 cm and more or ablate a layer of the cornea that is only a few micrometers thick.

The ability of lasers to harden liquid polymers, together with laser scanners, is used in [rapid prototyping](#), the ability to melt polymers and metals is, with laser scanners, to produce parts by [laser sintering](#).

The principle that is used for all these applications is the same: [software](#) that runs on a [PC](#) or an [embedded system](#) and that controls the complete process is connected with a scanner card. That card converts the received vector data to movement information which is sent to the

scanhead. This scanhead consists of two mirrors that are able to deflect the laser beam in one level (X- and Y-coordinate). The third dimension is - if necessary - realized by a specific optic that is able to move the laser's focal point in the depth-direction (Z-axis).

Scanning the laser focus in the third spatial dimension is needed for some special applications like the laser scribing of curved surfaces or for in-glass-marking where the laser has to influence the material at specific positions within it. For these cases it is important that the laser has as small a focal point as possible.

For enhanced laser scanning applications and/or high material throughput during production, scanning systems with more than one scanhead are used. Here the software has to control what is done exactly within such a multihead application: it is possible that all available heads have to mark the same to finish processing faster or that the heads mark one single job in parallel where every scanhead performs a part of the job in case of large working areas.

Barcode readers

Many [barcode readers](#), especially those with the ability to read bar codes at a distance of a few meters, use scanned laser beams. In these devices, a semiconductor laser beam is usually scanned with the help of a resonant mirror scanner. The mirror is driven electromagnetically and is made of a metal-coated polymer.

Space flight

When a space transporter has to dock to the space station, it must carefully maneuver to the correct position. In order to determine its relative position to the space station, laser scanners built into the front of the space transporter scan the shape of the space station and then determine, through a computer, the maneuvering commands. Resonant galvanometer scanners are used for this application.

script4_EMV

Donnerstag, 9. September 2021 10:00



EMV von Leiterplatten und Geräten,

Theorie und Praxis

Inhalt

1. Was bedeutet EMV	4
2. Kopplung.....	6
3. Koaxialkabel	16
4. Stromverteilung in Leitern	22
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6. EMV von Stromversorgungssystemen.....	28
7. HF-Dichtes Gehäuse	34

Nur in den wenigsten Fällen wird sich ein EMV-gerechtes
Design „von selber“ ergeben.
Wir müssen EMV-gerecht konstruieren.

Wir müssen gezielte Maßnahmen zur Beherrschung der EMV
setzen.

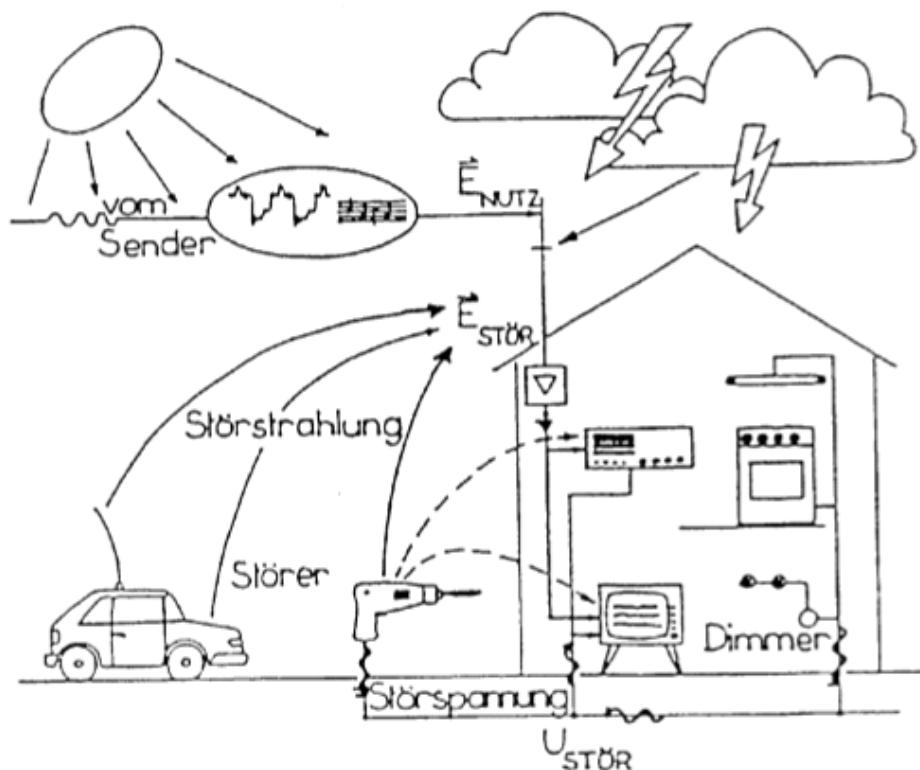
Diese werden zusätzliche Kosten verursachen, die wir
aufbringen müssen.

Wie überall sind wir gefordert, diese Kosten auf Minimum zu
halten.

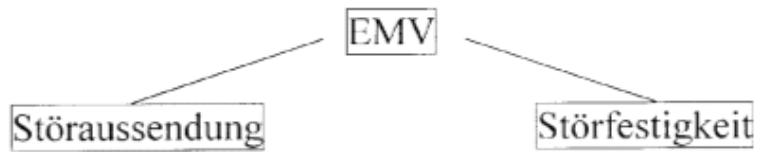
1. Was bedeutet EMV

Definition:

ElektroMagnetische Verträglichkeit ist die Fähigkeit eines elektrischen oder elektronischen Gerätes oder einer Anlage in seiner elektromagnetischen Umgebung bestimmungsgemäß zu funktionieren, ohne dabei andere Geräte und Anlagen zu beeinflussen.



Daraus erkennt man zwei Hauptbetrachtungsrichtungen:



Begrenzung der
Störspannungen und
Störströme auf Leitungen,
Begrenzung der Aussendung
von Störfeldern.

Störfestigkeit gegen
Störspannungen und
Störströme auf Leitungen,
Störfestigkeit gegen
Störfelder.

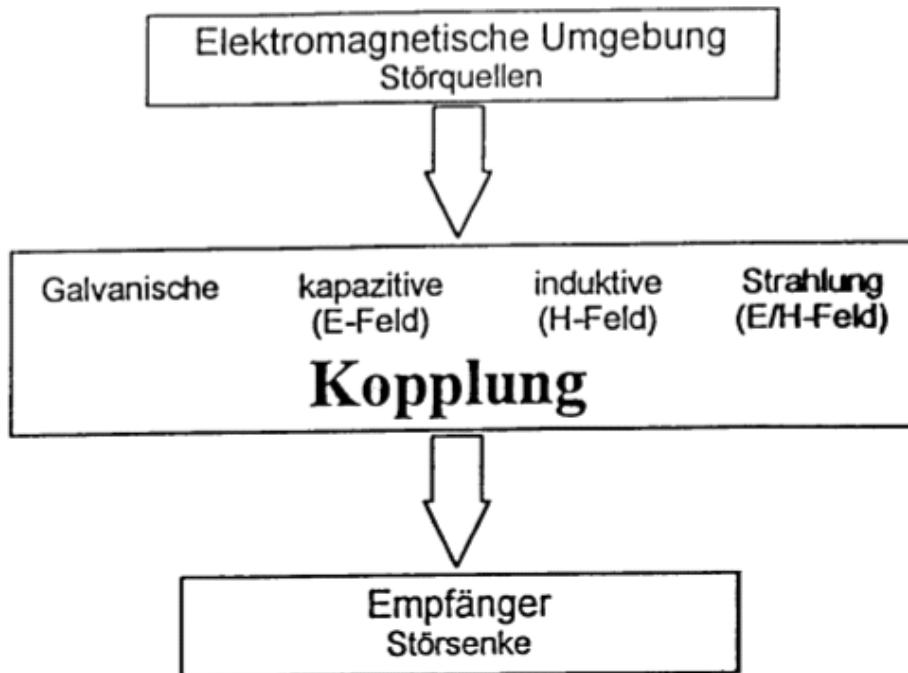
Aus physikalischer Sicht sind Störaussendung und Störfestigkeit gleichwertig. Der Unterschied besteht im Standpunkt, den wir bei der Bewertung der EMV einnehmen.

2. Kopplung

Der einzige Grund, warum es EMV-Probleme gibt, besteht darin, daß alle Wechselstromkreise miteinander verkoppelt sind.

Es ist nur eine Frage des Ausmaßes!

Kopplungsarten



Oft wird versucht, die Störenergie durch Kurzschlüsse unschädlich zu machen.

Dabei ist zu beachten, daß diese meist nur reflektiert wird und die Probleme können anderenorts auftreten.

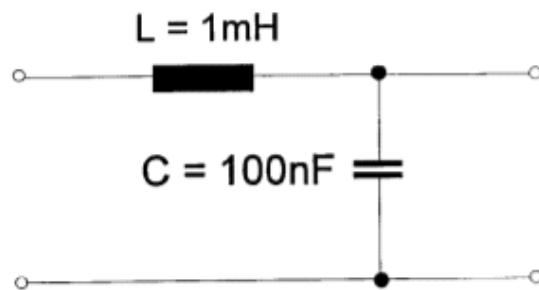
Um die Störenergie wirklich unschädlich zu machen,
muß sie **absorbiert** werden.
(....in Widerständen in Wärme umgesetzt werden.)

Als Absorber können wirken:

- Reelle Widerstände, die bewußt vorgesehen sind, z. B. Abschlußwiderstände,
- Verlustbehaftetes Dielektrikum, z. B. Entstörkondensoren,
- Verlustbehaftete Ferrite, z. B. Absorberdrosseln,
- Leitungswiderstände, z. B. Tastkopfkabel.

Bauteile zur Bekämpfung der EMV:

Beispiel:



? Dämpfung bei 100MHz.

Theoretisch:

$$Z_L = \omega L = 2 * \pi * 10^8 * 10^{-3} = 628 \text{ k}\Omega$$

$$Z_C = 1 / (\omega C) = 1 / (2 * \pi * 10^8 * 10^{-9}) = 15,92 \text{ m}\Omega$$

Überschlägig, ohne Rücksicht auf die Phasenlage:

$$15,92 * 10^{-3} / 628 * 10^3 = 25,35 * 10^{-9}, \text{ das sind } -151,92 \text{ db.}$$

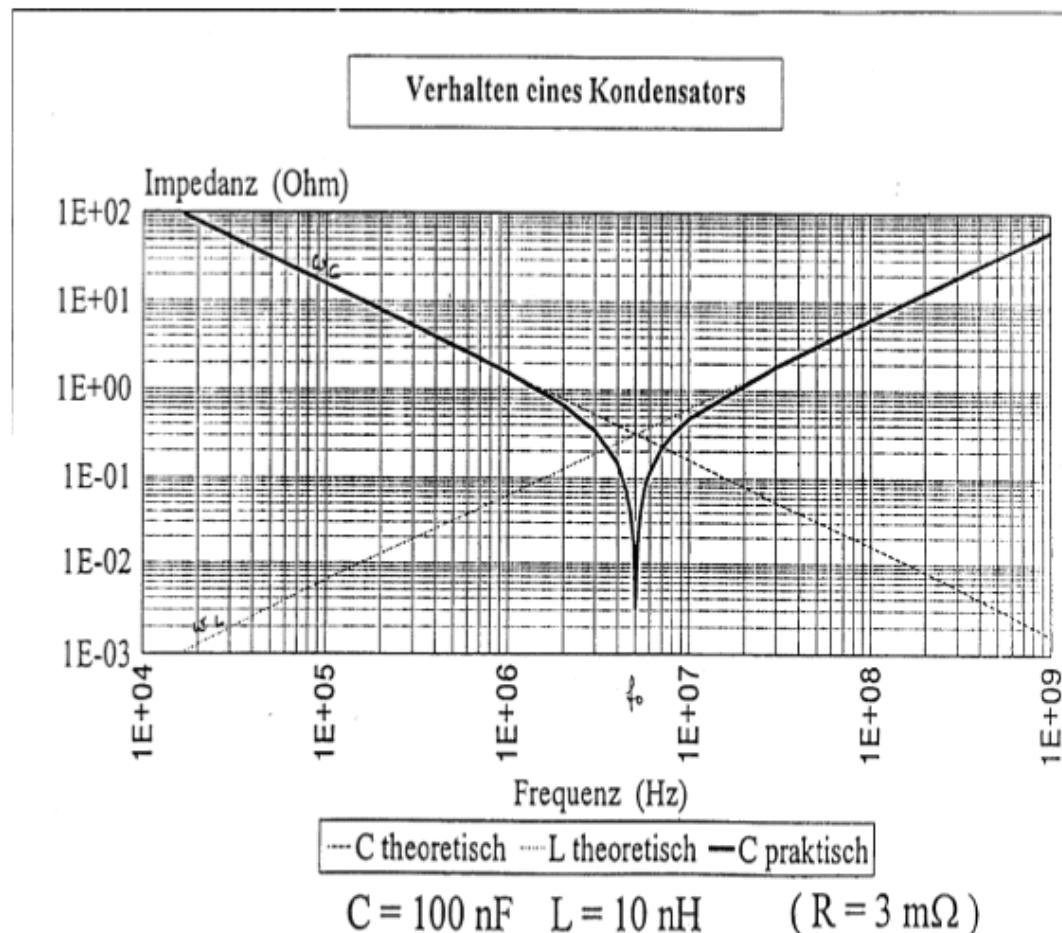
In der Realität:

$$Z_L = 16\Omega$$

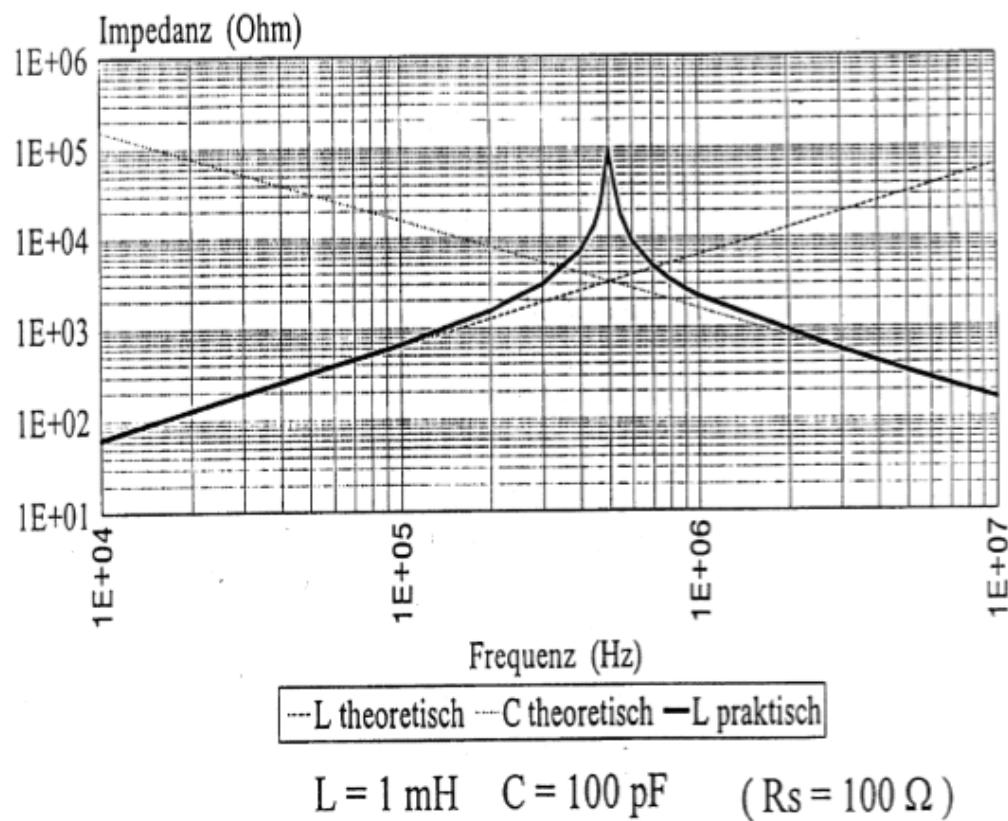
$$Z_C = 6\Omega$$

Überschlägig, ohne Rücksicht auf die Phasenlage:

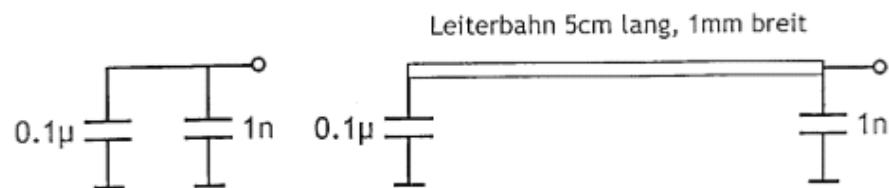
$$1 / (16+6) * 6 = 0,273, \text{ das sind } -11,3 \text{ db.}$$



Verhalten einer Drossel

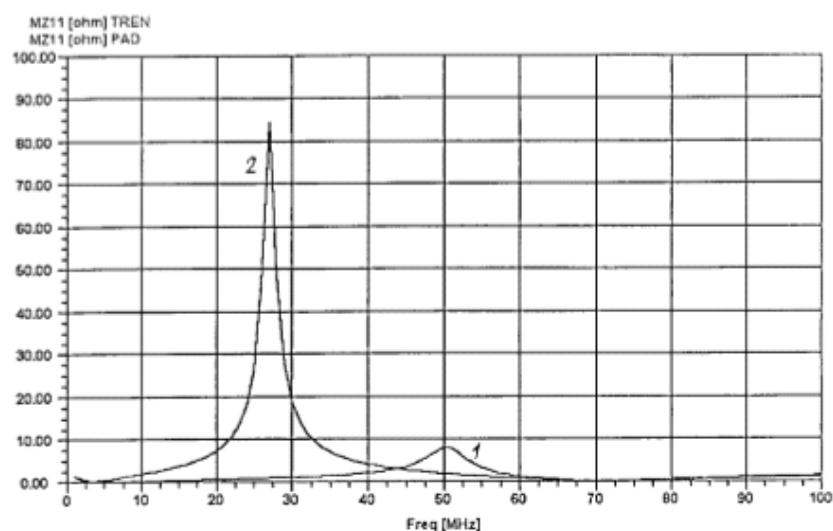


Verschiedene Placierungen von Abblock-Kondensatoren



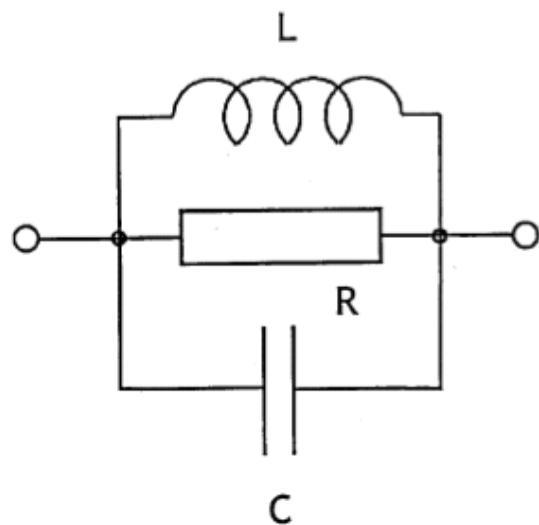
Im linken Fall sind die Kondensatoren unmittelbar nebeneinander placiert. Im rechten Fall sind sie durch eine 5 cm lange und 1 mm breite Leiterbahn, die 1,5 mm Substratdicke über der Massefläche führt, getrennt.

Verschiedene Placierungen von Abblock-Kondensatoren



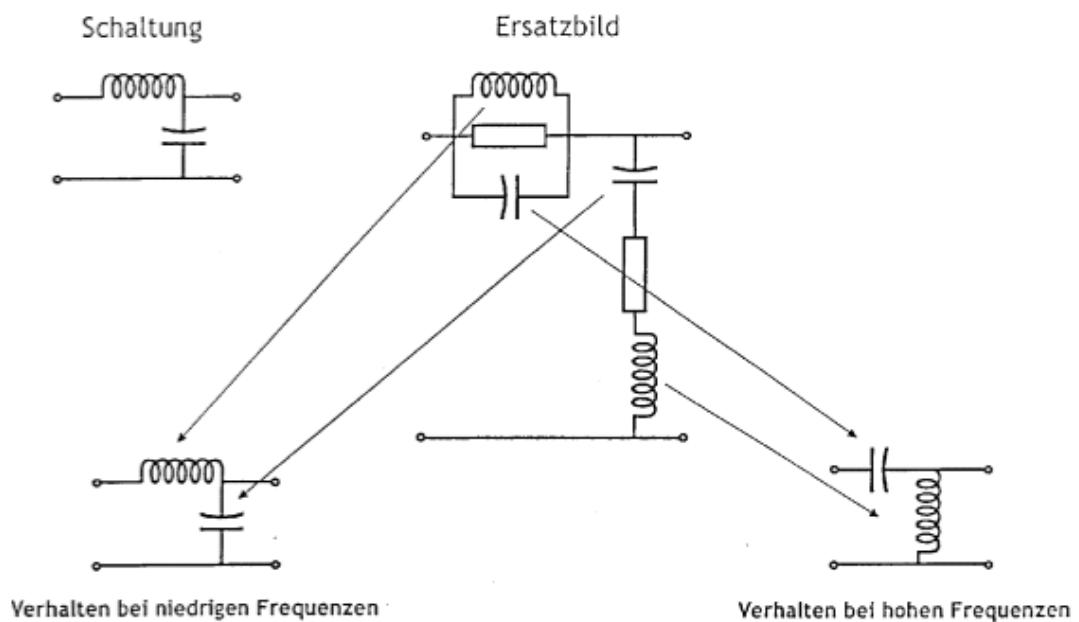
Die Kurve Nr.1 zeigt den Impedanzverlauf von $100\text{nF}/1\text{nF}$, die unmittelbar nebeneinander placiert sind. Die Kurve Nr.2 zeigt den Verlauf für die Kondensatoren, die durch die Leiterbahn getrennt sind.

Ersatzschaltbild einer Spule



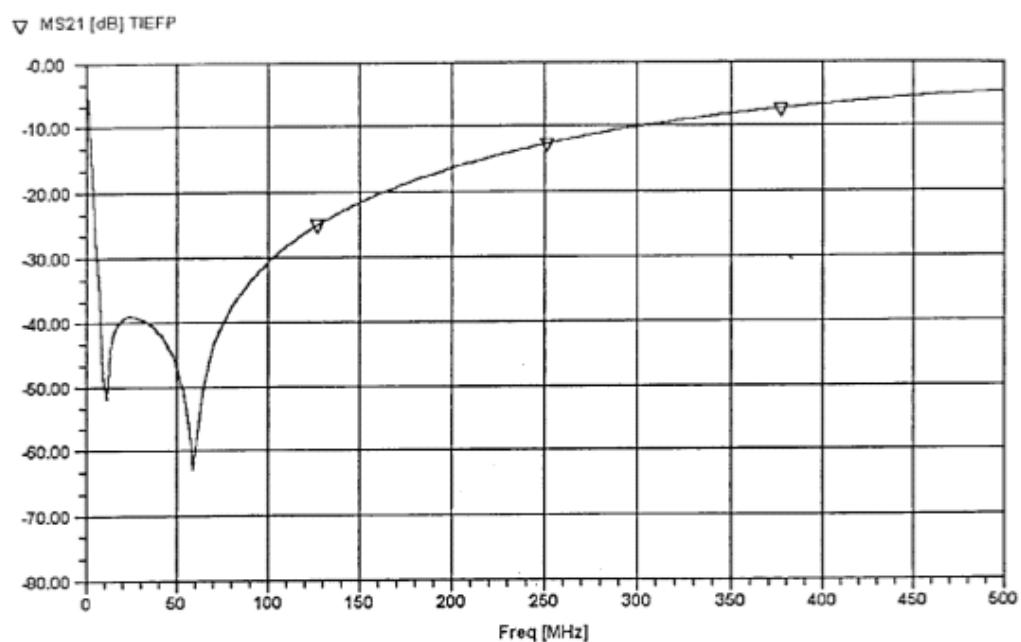
Das Spulenersatzschaltbild stellt die Komponenten einer Spule als konzentrierte Bauelemente dar. Das Modell ist nicht nur deshalb problematisch, sondern bei allen Ferritspulen ist außer R auch noch L frequenzabhängig.

Frequenzabhängigkeit des realen Tiefpasses



Bei Frequenzen unterhalb der Bauelementeresonanzen ist die Spule induktiv und der Kondensator kapazitiv. Oberhalb der Resonanzen ist es umgekehrt. Mit der Überschreitung der Bauelementeresonanzen ändert die Schaltung ihren Charakter total.

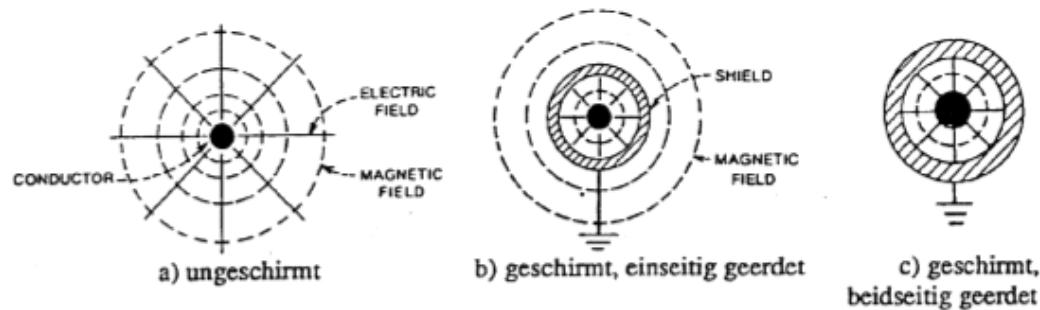
Frequenzabhängigkeit des realen Tiefpasses



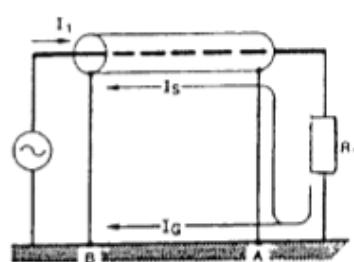
Das Verhalten des realen Tiefpasses ist das einer Bandsperre. Dies hat seine Ursache in den Bauteilresonanzen. Allerdings werden gerade im Bereich der Resonanzen besonders hohe Dämpfungen erreicht. Das kann man in der Praxis nutzen.

3. Koaxialkabel

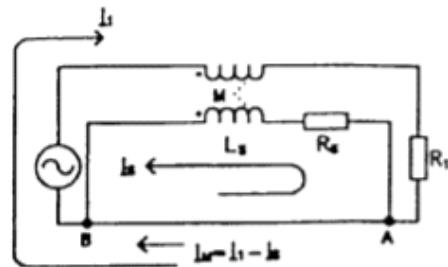
Wirkung gegen Emission magnetischer Felder:



Das Bild zeigt die elektrischen und magnetischen Feldlinien eines geschirmten und eines ungeschirmten Einzelleiters im freien Raum. Bei einem beidseitig nicht aufgelegtem Schirm würde das Feldbild genau wie in Bild a) aussehen. Legt man den Schirm an einem Ende an Masse, so enden die elektrischen Feldlinien auf dem Schirm. Die magnetischen Feldlinien bleiben weitgehend unverändert. Bei beidseitig aufgelegtem Schirm erhält man (oberhalb der **Grenzfrequenz** des Koaxialkabels) das Feldbild c).



Schematische Darstellung



Ersatzschaltbild

Diese Frequenzabhängigkeit kann man aus dem Ersatzschaltbild herleiten. Um ein Austreten magnetischer Feldlinien aus dem Koaxialkabel zu verhindern, muß der Strom im Kabelmantel gleich groß, jedoch entgegengesetzt orientiert sein wie der Strom im Mittelleiter. Daher darf kein Strom über die Masse von A nach B zurückfließen. Die Maschengleichung für die Masseschleife über den Kabelmantel lautet:

$$I_s (j\omega L_s + R_s) - I_1 j\omega M = 0$$

wobei

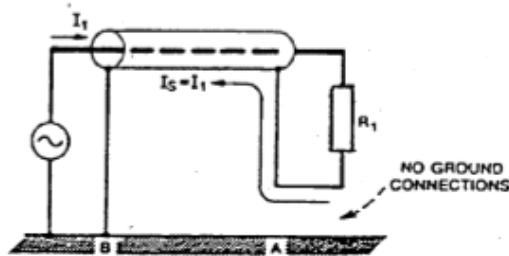
MGegeninduktivität zwischen Schirm und Innenleiter des Koaxialkabels.

Mit $M = L_s$ erhält man für den Strom am Schirm

$$I_s = I_1 j\omega / (j\omega + R_s / L_s) = I_1 j\omega / (j\omega + \omega_{GM})$$

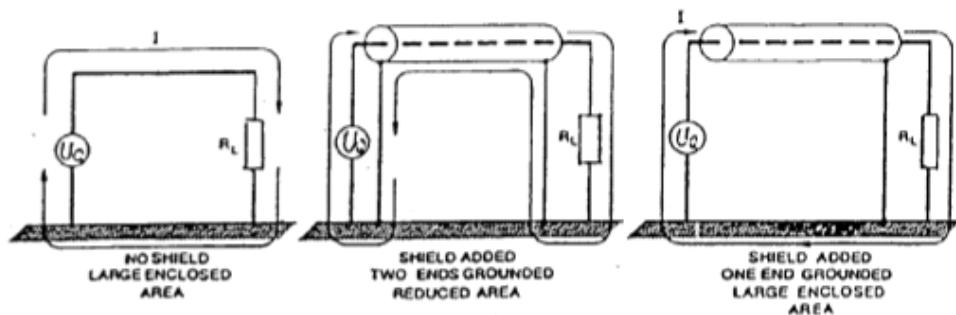
Für Frequenzen weit oberhalb der Grenzfrequenz ω_{GM} wird wegen der Gegeninduktivität zwischen Schirm und Mittelleiter $I_s = I_1$. Unterhalb von etwa $5\omega_{GM}$ verschlechtert sich die Schirmwirkung für das Magnetfeld, weil ein Teil des Stromes über Masse zurückfließt.

Um bei **sehr niedrigen Frequenzen** die Emission magnetischer Felder zu vermindern, kann man die Masseverbindung an einem Ende der Leitung auf trennen. Dies erzwingt, daß der gesamte Strom durch den Schirm zurückfließt.

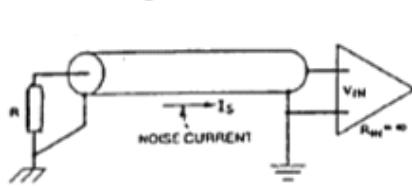


Wirkung gegen magnetische Einstreuung

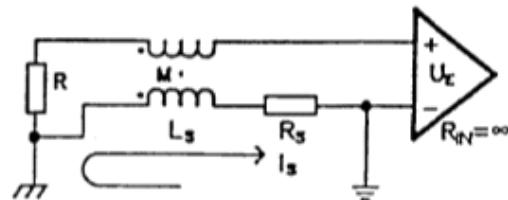
Die beste Schutzmaßnahme gegen magnetische Einstreuung in eine geschirmte Leitung ist die Verringerung der wirksamen Schleifenfläche.



Schleifenfläche bei unsymmetrischer Signalübertragung über eine geschirmte Leitung



Schematische Darstellung



Ersatzschaltbild

Die magnetische Einstreuung lässt sich jedoch nicht auf null reduzieren. In der Masseschleife aus Schirm und Masse wird ein Störstrom I_S induziert. Dieser erzeugt einen Spannungsabfall am Widerstand des Kabelmantels. Weiters wird über die Gegeninduktivität zum Mittelleiter in diesem eine Spannung induziert.

Am Eingang des Verstärkers liegen somit die folgenden Störspannungen:

$$U_E = -j\omega M I_S + j\omega L_S I_S + R_S I_S$$

Da $L_S = M$ wird $U_E = R_S I_S$

Immer, wenn im Kabelschirm Strom fließt, entsteht infolge Spannungsabfall am Widerstand des Schirmes eine Störspannung an der Last.

Sogar bei nur einseitig aufgelegtem Schirm können infolge kapazitiver Kopplung Ströme am Schirm fließen.

Höchstmögliche Störsicherheit erhält man daher bei niedrigen Frequenzen nur dann, wenn

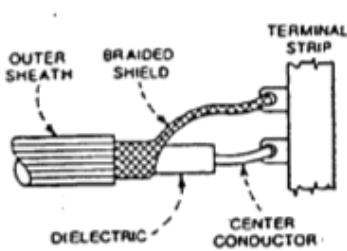
- der Schirm nicht Teil des Signalstromes ist,
- ein Ende des Stromkreises potentialfrei (ohne Masseverbindung) arbeitet.

Wirkung gegen Einstrahlung bei hohen Frequenzen:

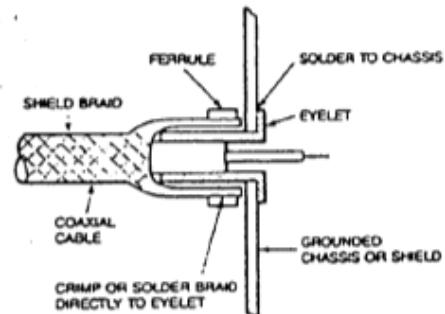
Bei hohen Frequenzen besteht ein Koaxialkabel praktisch aus drei voneinander isolierten Leitern:

- Mittelleiter
- Innenfläche des Schirmes
- Außenfläche des Schirmes.

Innen- und Außenfläche sind durch den Skineffekt separiert. Der, im vorigen Kapitel diskutierte Einkoppelmechanismus für Störspannungen tritt daher bei hohen Frequenzen nicht auf. Signalstrom und Strom im Außenleiter fließen über keinen gemeinsamen Widerstand.



falsch ("Pigtail")



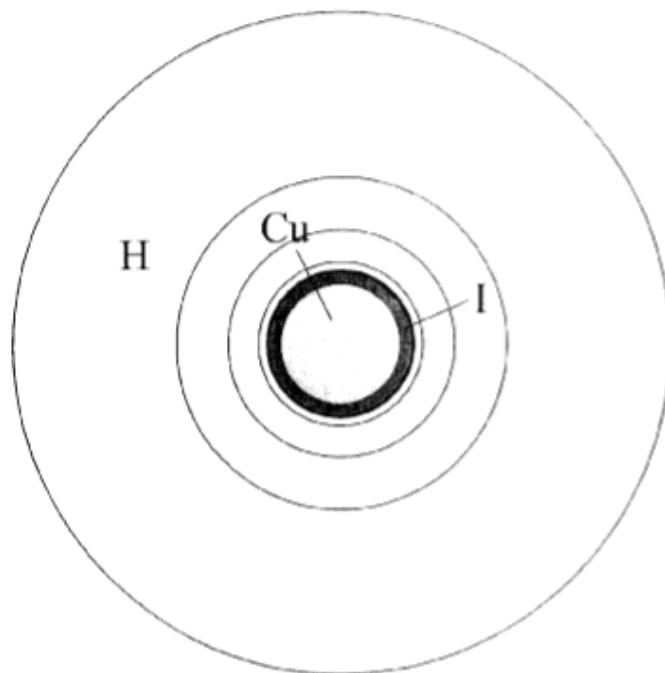
richtig

Grundsätzlich sollte man davon ausgehen, daß der Schirm eines Koaxialkabels immer beidseitig aufgelegt werden muß.

Nur in speziellen, berechtigten Fällen, sollte man davon abweichen.

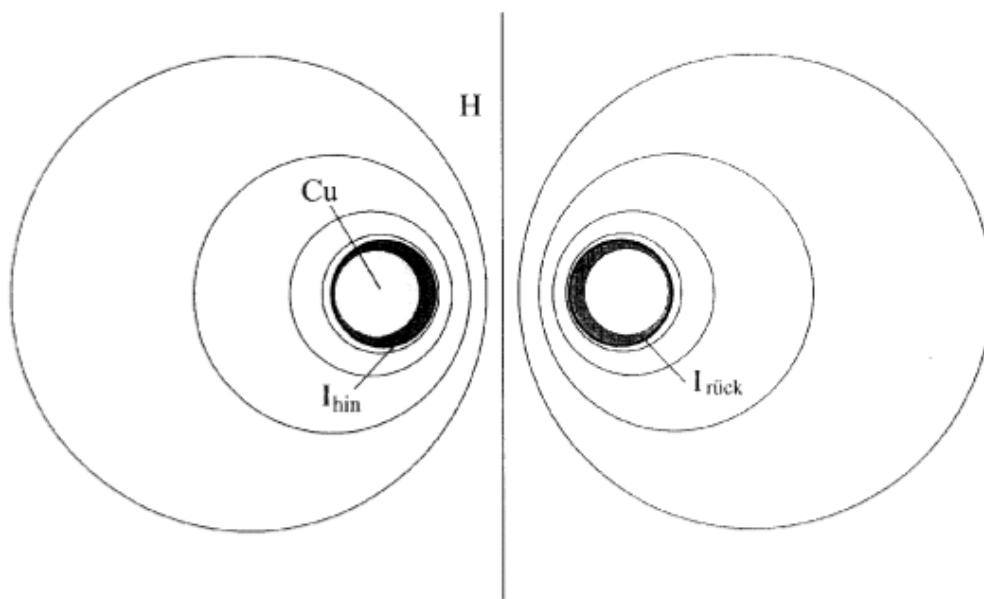
4. Stromverteilung in Leitern

Stromverteilung in runden Leitern



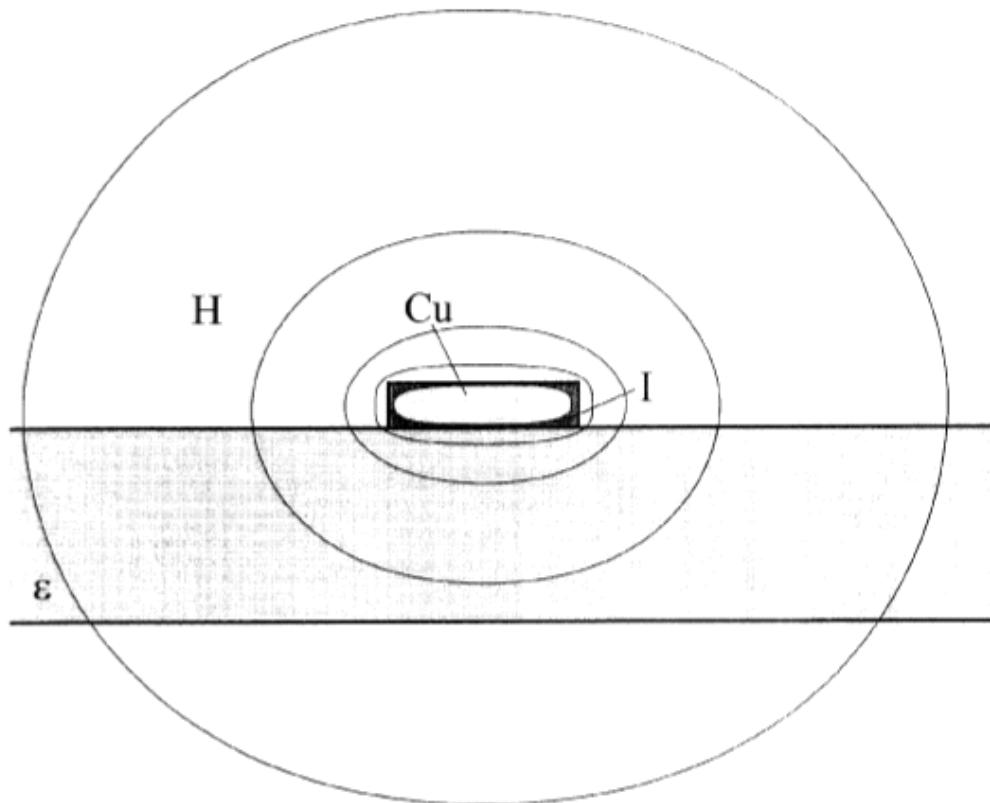
Der Strom wird infolge des Skineffektes an die Außenhaut gedrängt.

Stromverteilung in Zwillingsleitungen



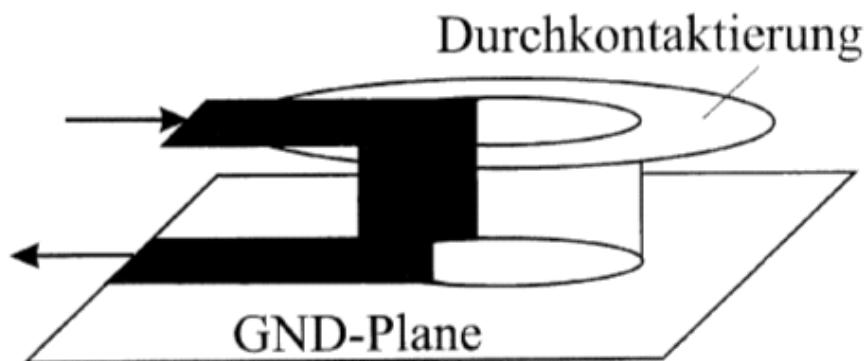
Der Strom wird in Richtung höchste Feldstärke gedrängt. Er fließt vorwiegend an der, dem Rückleiter zugewandten Seite.

Stromverteilung in Flachleitungen



Der Strom wird aufgrund des Skineffektes an die Stirnseiten und in den Bereich der Ecken gedrängt. (Gebiete größter H - Feldstärke.)

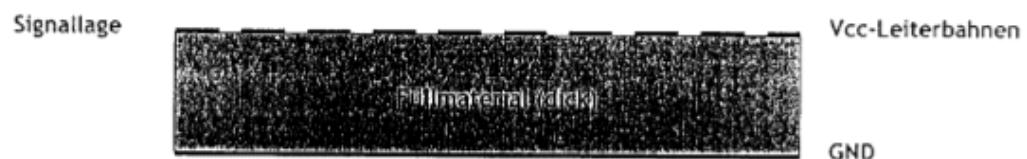
Stromverteilung an der Durchkontaktierung



Der Strom fließt an der Leiterbahnunterseite. Von hier aus läuft er über die vordere Unterkante des Lötauges auf die Vorderseite der Durchkontaktierung. Die Rückseite der Durchkontaktierung ist praktisch stromlos.

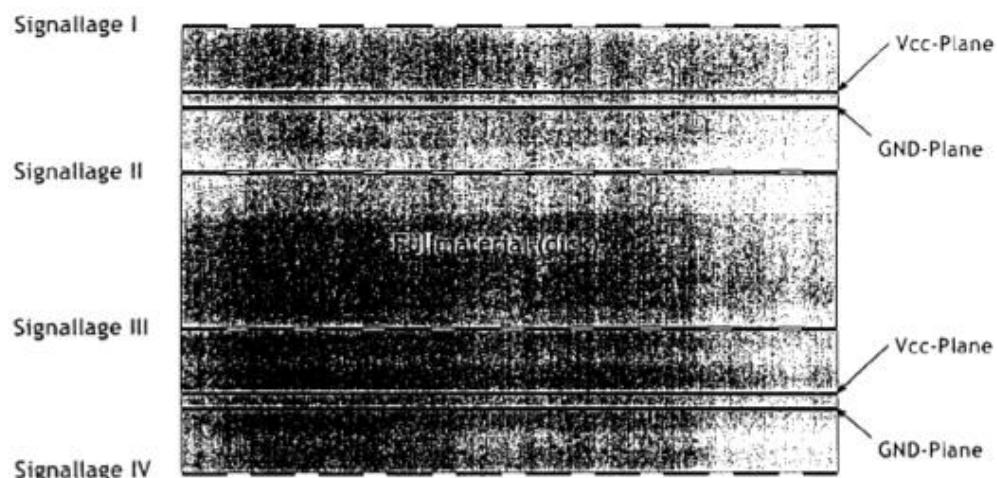
5. EMV bei Platinen

2 - Lagen'- Platine



Die Platine ist in bezug auf die richtige Führung der EM-Energie korrekt ausgelegt. Eine breitbandige Entkopplung des Versorgungssystems ist nicht möglich.
Man wird selten mit nur zwei Lagen auskommen.

8 – Lagen - Multilayer



Dieser Aufbau setzt sich aus zwei getrennten 4-Lagen-Systemen zusammen. Wegen der Gesamtdicke der Platte werden schon Kompromisse beim gewünschten Abstand der Signallage von den Flächen nötig.

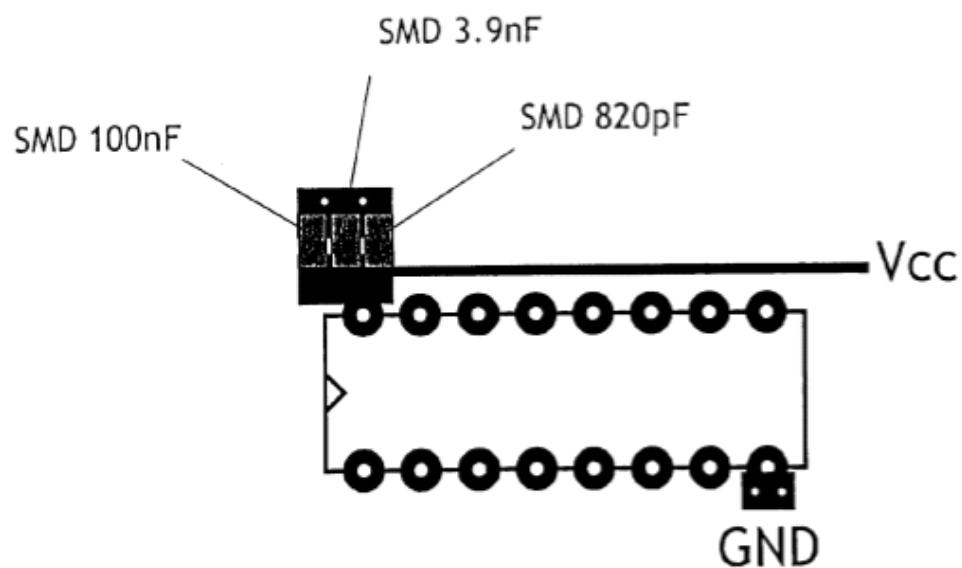
6. EMV von Stromversorgungssystemen

Die 4 Aufgaben der Abblockung der Stromversorgung:

- Welligkeit auf der Versorgungsspannung des einzelnen Bausteins mindern. (Minimale Spannung sicherstellen)
- Störpegel, den ein IC erzeugt, von anderen fernhalten. (Unterbrechung des Störfades „Versorgungsspannungsleitung“)
- Abstrahlung aus dem Versorgungssystem mindern.
- Vcc-Fläche zur brauchbaren Signalmasse machen.

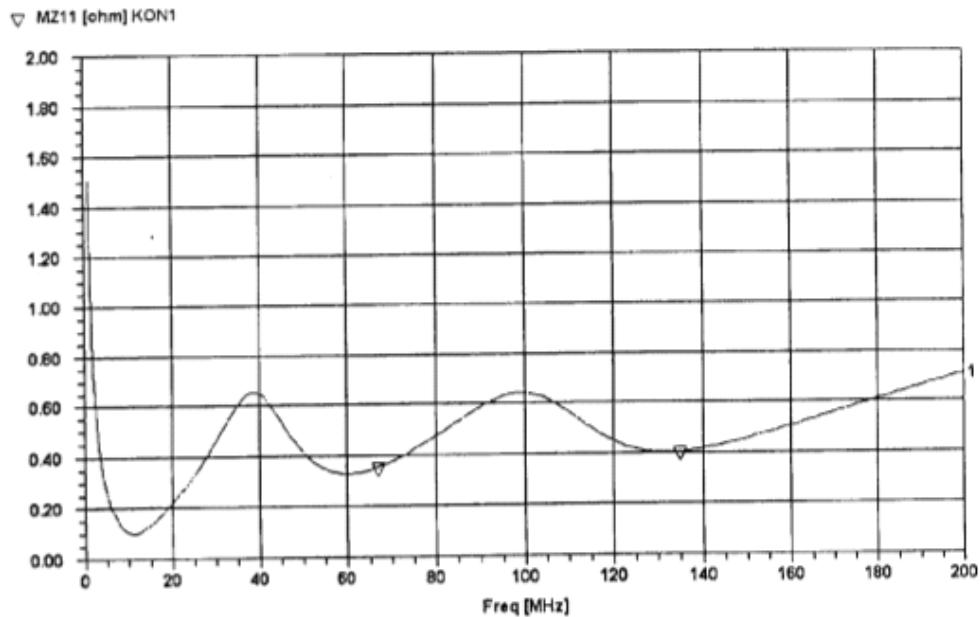
Es wird leicht übersehen, daß die Abblockung des Versorgungssystems nicht nur die Betriebsspannung stützen soll.

Breitbandentkopplung mit Kondensatorgruppe



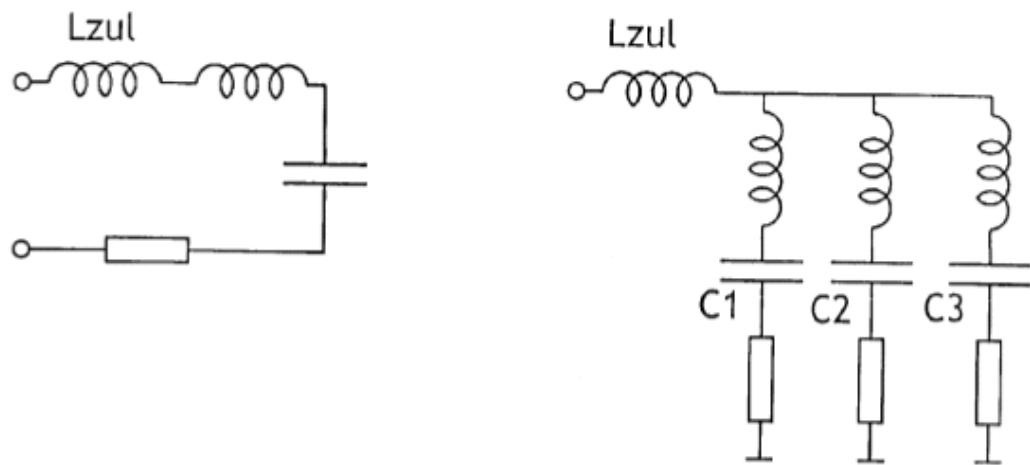
Die 3 Kondensatoren sind hinsichtlich ihrer Kapazitätswerte so ausgesucht, daß sie eine Gruppe bilden, deren Parallelresonanzen nicht mehr störend sind. Sie liegen alle unter 1 Ohm. (Material: X7R)

Impedanzverlauf der Breitband – Entkopplung (Simulation)



Die Kondensatorgruppe bleibt mit ihrer Impedanz bis 200MHz innerhalb von 0,8 Ohm. Allerdings verbietet der wachsende Aufwand die Verwendung dieses Verfahrens für größere Bandbreiten.

Problematik der Kondensatoranbindung



- Beide Konstruktionen leiden unter dem Problem der induktiven Zuleitung. Sie müßte kleiner als 1nH sein, um bis 1000MHz wirksame Entkopplungen zu erreichen.

Insbesondere Kondensatorgruppen müßten wegen ihres hohen Aufwandes für möglichst viele Baugruppen wirksam sein. Dies ginge aber nur bei einer extrem geringen Impedanz der Anbindung.

Leiterbahnen als Leitungen

Elektrische Länge von Leiterbahnen:

- Eine 4 cm lange Leiterbahn hat bei 375MHz bereits eine elektrische Länge von 1/10 der Wellenlänge.
- Bei 1000MHz ist diese Leiterbahn schon länger als $\frac{1}{4}$ der Wellenlänge.

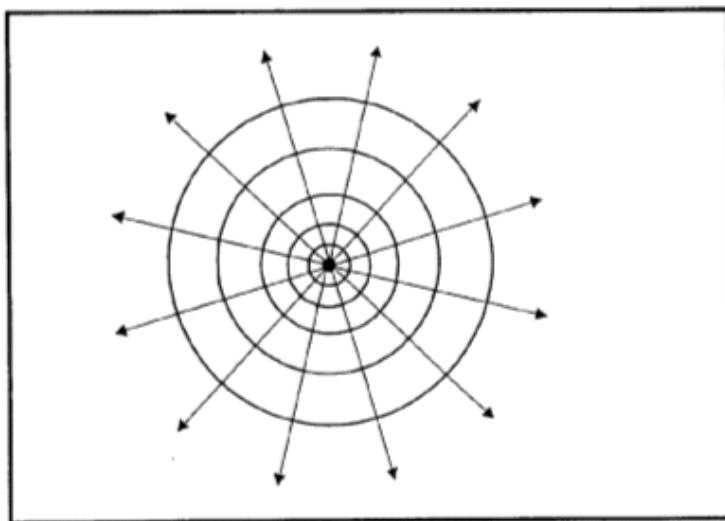
Bei den breitbandigen Störspektren, die von heutigen, digitalen integrierten Schaltungen ausgehen, können selbst kurze Leiterbahnen nicht mehr als reine Induktivitäten angesehen werden.

Absorption

Wellenausbreitung im Vcc/GND System

Absorptives Flächensystem

- Was an der Kante nicht ankommt, wird dort nicht abgestrahlt.
- Absorption verhindert die Entstehung von Resonatoren im Flächensystem.

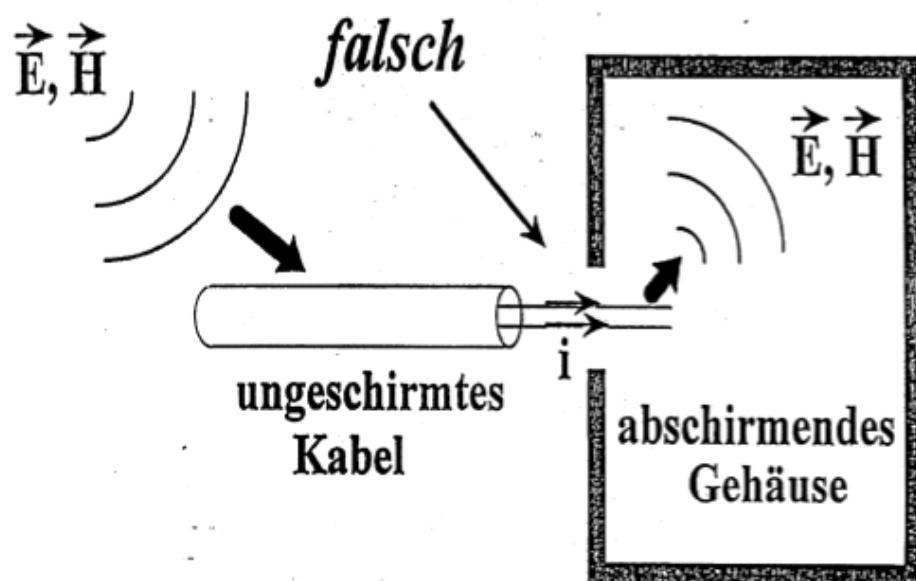


Punktförmige Absorption gelingt nur bei Ausbreitung entlang dünner Leitungen. Flächige und räumliche Absorption ist komplizierter. Zur Zeit sind nur wenig brauchbare Konzepte verfügbar.

7. HF-Dichtes Gehäuse

- Gehäuseteile bestehen aus gut leitenden Materialien. (Alu, Messing...)
- Gehäuseteile besitzen gut leitende Oberflächen. (Frontplatten!) z. B. zinkchromatiert.
- Die Gehäuseteile sind mit Kontaktfedern, Kontaktstreifen oder mit mehreren Schrauben miteinander verbunden um großflächige Kontaktstellen zu erhalten um so Schlitzantennen zu verhindern.
- Das Gehäuse ist allseits geschlossen, Durchbrüche und Durchführungen sind auf das notwendige Mindestmaß beschränkt, um Aperturstrahlung zu verhindern.

Fehlerhafte Einführung eines Kabels in einen
Faraday-Käfig oder ein Gerätegehäuse



Richtige Einführung eines Kabels in einen Faraday-Käfig oder ein Gerätegehäuse

