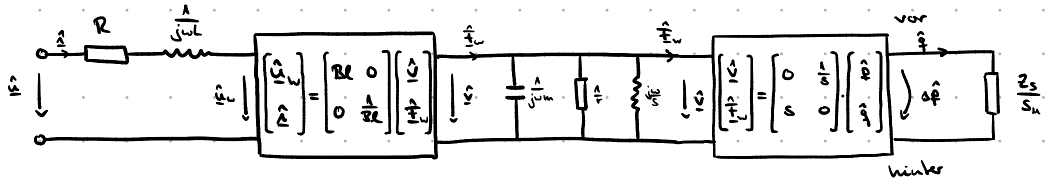
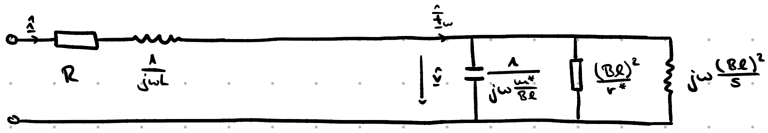
Formelsammlung EA

e.d.W.



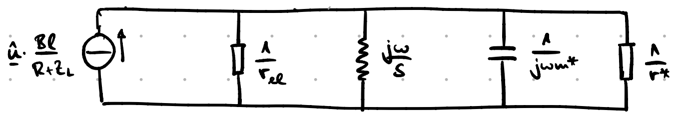
$$\omega_0\big|_{i=0} = \sqrt{\frac{s}{m}} \qquad r = \frac{s}{\omega_0 \cdot Q_{mech}}\Big|_{i=0}$$

e.d.W. Zsmf



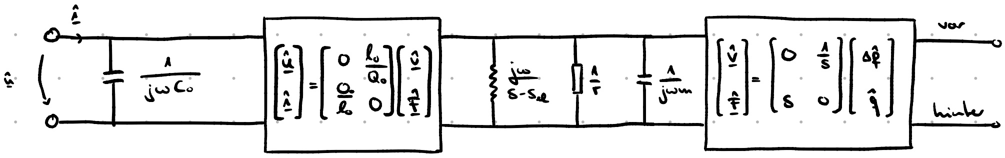
$$\omega_0^* = \sqrt{\frac{s}{m^*}} \qquad r^* = \frac{s}{\omega_0^* \, Q^*_{mech}} \qquad r_{ak} = S_M \, \varrho_- c \cdot 0{,}06\,(ka)^4 \qquad m_{ak} = \varrho_- \cdot \frac{8}{3} a^3$$

e.d.W. Schallwand



$$r_{ak} = \frac{1}{2} \varrho_- c \, S_M \, (ka)^2 \qquad m_{ak} = \varrho_- \cdot \frac{8}{3} a^3$$

e.s.W Platte



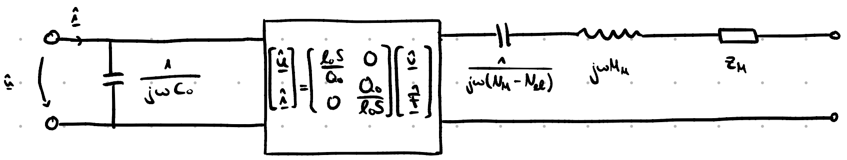
$$C_0 = \frac{\varepsilon_0 A}{l_0} \qquad s_{el} = \frac{Q_0^2}{C_0 l_0^2} = \varepsilon \cdot S \frac{u_0^2}{l_0^3} = \frac{S^2}{N_{el}} \qquad r = \frac{s - s_{el}}{\omega_0 Q_{mech}}$$

$$\omega_0 = \sqrt{\frac{s - s_{el}}{m}} \qquad l_{krit} = \sqrt{\frac{s_{el}}{s}} \cdot l_0$$

$s_{el} \Rightarrow N_{el} = \frac{S^2}{s_{el}}$

MECH AKUSTIK

e.s.W. Membr.



$$\omega_g = \frac{1}{Z_a (N_M^* + N_v)} \qquad \omega_0 = \sqrt{\frac{1}{M_M}\left(\frac{1}{N_M^*} + \frac{1}{N_v}\right)} \qquad B_0 = \frac{N_M^* \cdot N_v}{N_M^* + N_v} \, \frac{Q_0}{\varepsilon \cdot S^2}$$

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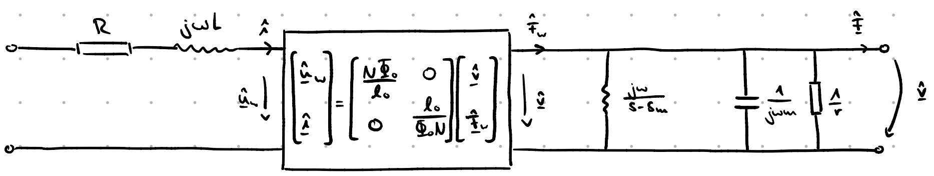
e.m.W.

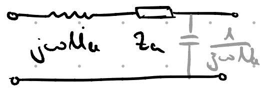


$$r = \frac{s - s_m}{\omega_0 Q_{mech}} \qquad \omega_0 = \sqrt{\frac{s - s_m}{m}} \qquad s_m = \frac{2\Phi^2}{\mu_0 l_0 S} \qquad L = \frac{N^2 \mu_0 S}{R - l_0}$$

Längsmatrix $\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$ Quermatrix $\begin{bmatrix} 1 & 0 \\ \frac{1}{Z} & 0 \end{bmatrix}$

Kanal

kurz: $l \ll \lambda \;\hat{=}\; l \approx 0.1 \cdot \lambda$



- N_a meist $< M_a, Z_a$
- Reibung $\leftarrow$ $\omega_g = \frac{8\mu}{a^2 \rho_-}$ $\rightarrow$ Masse
- „sehr klein" $\hat{=}$ Reibung

$\Delta l = \frac{8}{3\pi} \cdot a$ Wand

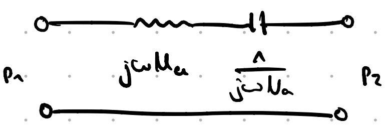
$\Delta l = 0.6 \cdot a$ Frei

Membran

$T_0 = \frac{\text{Radialkraft}}{\text{Umfang} \cdot h}$

transf. ak. $N_a = \frac{\pi a^4}{8 T_0 h}$

transf. ak. $M_a = 1.33\, \rho_M \frac{h}{\pi a^2}$



Schallfeld

$Z_{s,ak} = \frac{Z_s}{S}$

Kolben + Wand

$Z_s = \rho_- c \left(\frac{1}{2}(ka)^2 + j\frac{8}{3\pi} ka\right)$

$Z_s \approx j\rho_- c \frac{8}{3\pi} ka = j\rho_- c\, \omega \frac{8}{3\pi} a^2$

$m^* = \rho_- \frac{8}{3} a^3$

Freies Rohrende

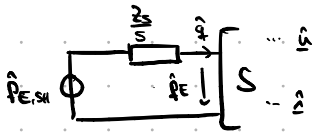
$Z_s = \rho_- c \left(\frac{1}{4}(ka)^2 + j0{,}6\, ka\right)$

Kreisplatte im Feld

$ka \ll 1$

$Z_s = \rho_- c \left(0{,}06\,(ka)^4 + j\frac{8}{3\pi} ka\right)$

Empfänger



$\hat{p}_E = \hat{p}_{E,SH} - \frac{Z_s}{S} \cdot \hat{q}$

e.d.W als „Lautsprecher"

$\omega_0^* = \sqrt{\frac{s}{m^*}}$ $Q = \frac{s}{r^* \cdot \omega_0}$

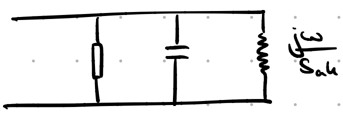
elektrischer Teil:
- Leicht $(0 \ldots 4 \cdot f_0)$
- LR2 Modell $(4 \cdot f_0 \ldots 40 f_0)$
- Leach Modell $(0.007\,(j\omega)^{0.7})$

in Box

$\omega_{0,Box} = \sqrt{\frac{s + s_{ak}}{m^*}}$ $s_{ak} = \frac{S_M^2}{N_V}$

$\frac{Q^*_{T,Box}}{Q^*_T} = \sqrt{1 + \frac{s_{ak}}{s}}$

+ mechan. Nachgiebigkeit



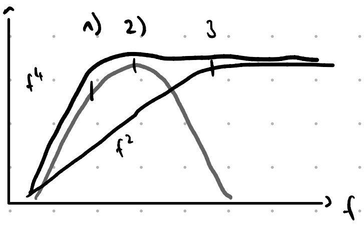
Bei $V_{AS} \approx V$: $\omega_{td} = \omega_0 \cdot \sqrt{2}$

in BR-Box

1) $\omega_D = \sqrt{\frac{s}{m^* + m_{BR}}}$

2) $\omega_{BR} = \sqrt{\frac{s_{ak}}{m_{BR}}}$

3) $\omega_{LS} = \sqrt{\frac{s + s_{ak}}{m}}$



el. statische Wandler

$F = \frac{1}{2} \varepsilon \frac{S U^2}{l_0^2}$ quad. Kennlinie U^2

$\hat{F} = \varepsilon \frac{S}{l_0} U \cdot \hat{u} = \frac{C_0}{l_0} U_0 \cdot \hat{u} = \frac{Q_0}{l_0} \cdot \hat{u}$

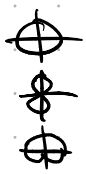
$s_{el} = \varepsilon \cdot S \frac{U_0^2}{l_0^3}$ neg. Feder $\quad N_{el} = \frac{S^2}{s_{el}} \quad \hat{F} = -\varepsilon S \frac{U_0^2}{l_0^3} \hat{\xi}$

$r = \frac{s - s_{el}}{\omega_0 Q_{mech}} \quad \omega_0 = \sqrt{\frac{s - s_{el}}{m}} \quad l_{krit} = \sqrt{\frac{s_{el}}{s}} \cdot l_0$

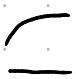
Mikrofon

$B = \frac{\hat{u}}{\hat{p}} \Big|_{i=0}$

Druckempf.
Grad. empf.
Kombination



Gradient:
Fernfeld $-\mathrm{grad}\, p \sim \omega$
Nahfeld $-\mathrm{grad}\, p$ unab. ω



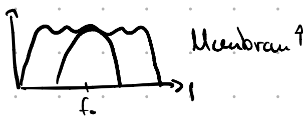
Kondensatormikro

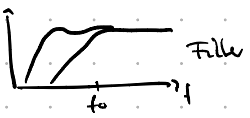
$$\omega_g = \frac{1}{Z_a (N_M^* + N_V)}$$

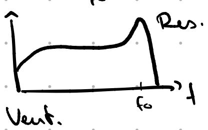
$$\omega_0 = \sqrt{\frac{1}{M_M} \left(\frac{1}{N_M^*} + \frac{1}{N_V} \right)}$$

$$B_0 = \frac{N_M^* \cdot N_V}{N_M^* + N_V} \frac{Q_0}{\varepsilon \cdot S^2}$$

$B_0 \uparrow \hat{=} U_0 \uparrow, l_0 \downarrow$
$N_M^* \uparrow$ aber $\omega_0 \downarrow$

Studio


Bühne


MEMS


Messung


ele. magnetische Wandler

$F = \frac{\Phi^2}{\mu_0 S}$ quadr. Kennlinie

$\hat{F} = \frac{\Phi_0 N}{l_0} \hat{i} \qquad \hat{u} = \frac{\Phi N}{l_0} \hat{v}$

$s_m = \frac{2\Phi^2}{\mu_0 S l_0}$ neg. Feder

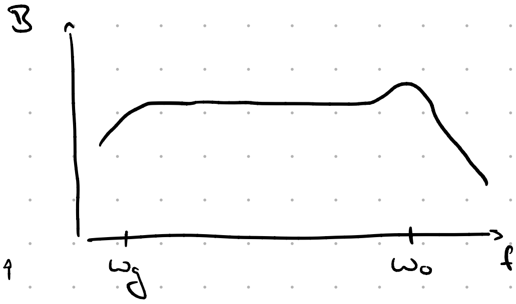
$l_{krit} = \sqrt[3]{\frac{s_m}{s}} \cdot l_0$

$R_{m,ges} = R_{mLuft} + R_{mMat} = \frac{l_0}{\mu_0 S} + \frac{l_{mat}}{\mu_0 \mu_r S}$

Symm. Wandler

$F = \frac{2\Phi N}{l_0} \cdot \hat{i} = s_m \cdot \hat{\xi}$

$s_m = \frac{2\Phi^2}{\mu_0 S l_0}$



e-Feld

$\vec{E} = \frac{\vec{F}}{Q}$

$D = \varepsilon \cdot \vec{E} \qquad \varepsilon = \varepsilon_0 \varepsilon_r$, $\varepsilon_0 = 8{,}854 \cdot 10^{-12} \frac{As}{Vm}$

$U = \int \vec{E}\, d\vec{s}$

$Q = \oiint \vec{D}\, d\vec{a}$

$F_{Punkt} = \vec{e}_r \frac{Q_1 Q_2}{4\pi r^2 \varepsilon}$

$F_{Platte} = \vec{e}_x \frac{1}{2} \frac{\varepsilon S U^2}{x^2}$

$$\begin{tikzcd}
Q \arrow[rr, leftrightarrow, "Q = \oiint \vec{D} d\vec{A}"] \arrow[d, leftrightarrow, "Q = C \cdot U"'] & & \vec{D} \arrow[d, leftrightarrow, "\vec{D} = \varepsilon \vec{E}"] \\
U \arrow[rr, leftrightarrow, "U = \int \vec{E} d\vec{s}"'] & & \vec{E}
\end{tikzcd}$$

magn. Feld

$\vec{H}$

$B = \mu \cdot \vec{H} \qquad \mu = \mu_0 \cdot \mu_r$?

$\mu_0 = 1{,}237 \cdot 10^{-7} \frac{Vs}{Am}$

$\Theta = \oint \vec{H}\, d\vec{s}$

$\Phi = \iint \vec{B}\, d\vec{A} \qquad \Phi = \frac{\Theta}{R_{m,ges}}$

$\Theta = R_m \cdot \Phi$

$R_m = \frac{l}{\mu S} = R_{m,Luft} + R_{m,Mat}$
$= \frac{l_0}{\mu_0 S} + \frac{l_{mat}}{\mu_r \mu_0 S}$

$F = \frac{1}{2} \frac{\Phi^2}{\mu_0 S}$

$L = N \cdot \frac{\Phi}{i}$

MECH → ELEKTR. (FI)

$\frac{1}{r}$		$\frac{1}{r}$
m		$\frac{1}{j\omega m}$
$\frac{1}{s}$		$\frac{j\omega}{s}$
Imp $\frac{F}{v}$	Adm.	$\frac{\hat{i}}{\hat{u}}$
Adm. $\frac{v}{F}$	Imp.	$\frac{\hat{u}}{\hat{i}}$

AKUSTIK → ELEKTR. (PU)

	$\hat{p}$	$\hat{u}$	
	$\hat{q}$	$\hat{i}$	
Reibung	Z_a		Z_a
Masse	M_a		$j\omega M_a$
Nachg.	N_a		$\frac{1}{j\omega N_a}$

ak. Kanal: $j\omega M_a$ / Z_a

Membran: $\begin{bmatrix} 1 & j\omega M_a + \frac{1}{j\omega N_a} \\ 0 & 1 \end{bmatrix}$

Mechanisch ⟷ Akustisch

Nachgiebigkeit	$\frac{j\omega}{S_{ak}}$	$\frac{1}{j\omega N_a}$
Masse	$\frac{1}{j\omega M_{ak}}$	$j\omega M_a$
Reibung	$\frac{1}{r_{ak}}$	Z_a

ESB – Formeln

$$M_a = \frac{\rho_0 \cdot l^*}{S} \qquad \mu = 1{,}8 \cdot 10^{-5}\ \frac{kg}{m^3}$$

$$Z_a = \frac{\Xi\, l^*}{S} \qquad \Xi = \begin{cases} \frac{8\mu}{a^2} & \bigcirc \\ \frac{12\mu}{h^2} & \square \end{cases}$$

$$N_a = \frac{V}{\rho_0 \cdot c^2} = \frac{V}{\kappa \cdot p_0} \quad \text{adiabatisch}$$

$$N_a = \frac{V}{p_0} \quad \text{isotherm}$$

Wandler Eigenschaften

$$Z_{el} \approx \frac{\hat{u}_a}{\hat{i}_a} \cdot R \quad \text{mit } R = 1k\Omega$$

$$Z_N = 1.25 \cdot Z_{el,min}$$

$$P_N = \tilde{u} \cdot \tilde{i} = \frac{\tilde{u}^2}{Z_N}$$

$$\text{PMPO } P_{musik} = \frac{u^2}{2Z_N}$$

$$L_u = 20 \lg\left(\frac{E_u}{E_{u0}}\right) \qquad E_{u0} = \frac{2 \cdot 10^{-5}\,\mathrm{Pa}}{1\sqrt{V \cdot A}}$$

TS - Parameter

R_e	R_e	Ω
L_e	L, Z_L	$\frac{Vs}{A} = H$
Bl	Bl	$\frac{Vs}{m}$
S_D	S_m	m^2
C_{ms}	$\frac{1}{s}$	$\frac{m}{N}$
M_{ms}	m^*	kg
R_{ms}	r^*	$\frac{kg}{s}$
C_{mes}	$\frac{m^*}{(Bl)^2}$	$\frac{As}{V} = F$
L_{ces}	$\frac{(Bl)^2}{s}$	$\frac{Vs}{A} = H$
R_{es}	$\frac{(Bl)^2}{r^*}$	Ω
F_s	$\frac{1}{2\pi}\sqrt{\frac{s}{m^*}}$	Hz
V_{as}	$\frac{\rho_0 \cdot c^2 S_m^2}{s}$	m^3
Q_{ms}	$\frac{s}{\omega_0^* r^*}$	
Q_{es}	$\frac{R \cdot s}{\omega_0^* (Bl)^2}$	
Q_{ts}	$\frac{1}{\frac{1}{Q_{ms}} + \frac{1}{Q_{es}}}$	

Umwandlungen:

Volumen

$1\ mm^3 = 1 \cdot 10^{-9}\ m^3$

$1\ cm^3 = 1 \cdot 10^{-6}\ m^3 =$

$1\ liter = 1 \cdot 10^{-3}\ m^3 = 0{,}001\ m^3$

Fläche

$1\ mm^2 = 1 \cdot 10^{-6}\ m^2$

$1\ cm^2 = 1 \cdot 10^{-4}\ m^2 = 0{,}0001\ m^2$