

Measurement of loudspeaker parameters: A pedagogical approach

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LAUM



Le Mans
Université



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Outline

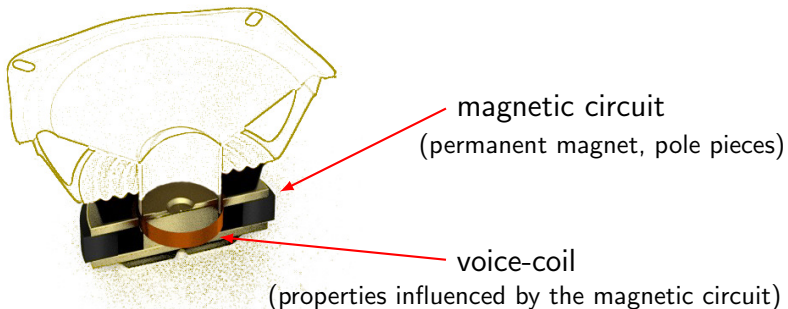


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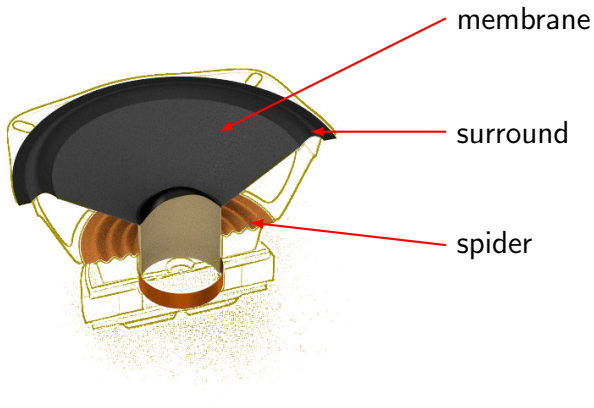
electrodynamic loudspeaker
basic principle and linear TS model

loudspeaker measurement
a pedagogical approach

electrical part of a loudspeaker

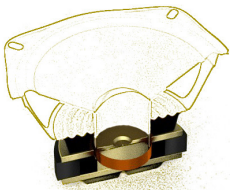


mechanical part of a loudspeaker



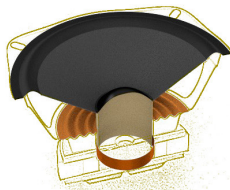
force factor

force factor **Bl** = coupling between
the **electrical** and the **mechanical** part



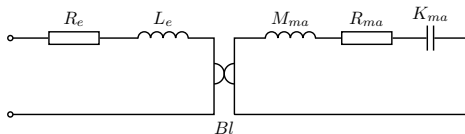
current
voltage

vs.



force
velocity

linear model of a loudspeaker (Thiele-Small model)



Electrical part:

R_e ... Electrical Resistance

L_e ... Electrical Inductance

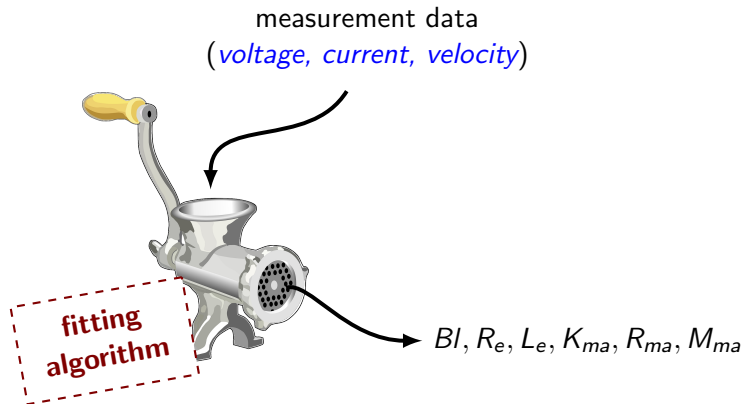
Mechanical part:

M_{ma} ... Moving mass

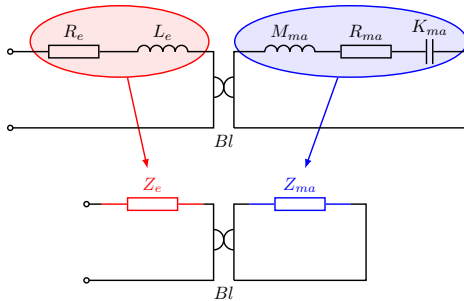
R_{ma} ... Mechanical Resistance

K_{ma} ... Mechanical Stiffness

Loudspeaker parameters estimation - **classical approach**



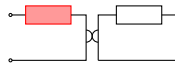
other linear models of loudspeaker



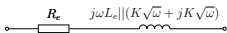
$Z_e \dots$ Electrical Impedance

$Z_{ma} \dots$ Mechanical Impedance

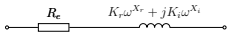
electrical impedance



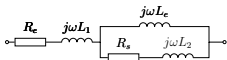
a) Thiele (1975)



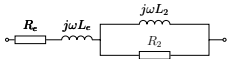
b) Vanderkooy (1988)



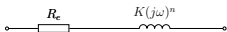
c) Wright (1989)



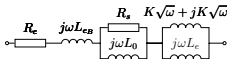
d) Murray (1994)



e) Klippel (2000)

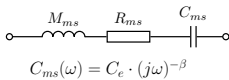
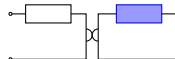


f) Leach (2002)

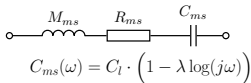


g) Thorborg, Unruh (2008)

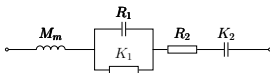
mechanical impedance



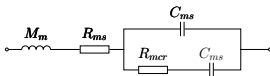
a) Knudsen, Jensen (1993)
EXP model



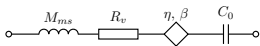
b) Knudsen, Jensen (1993)
LOG model



c) Dobrucki (1994)



d) Agerkvist, Thorborg (2008)



e) Novak (2016)

Outline

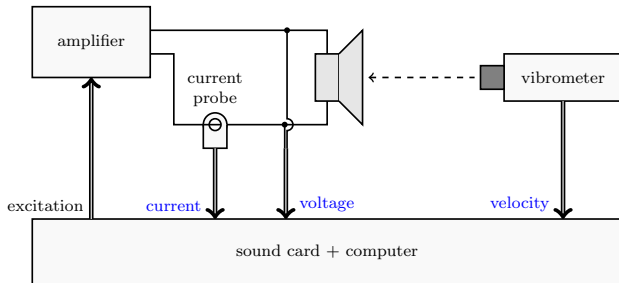


electrodynamic loudspeaker
basic principle and linear TS model

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loudspeaker measurement
a pedagogical approach

Measurement setup



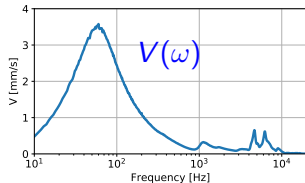
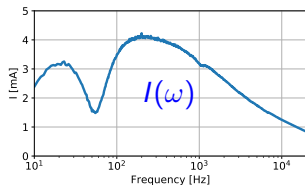
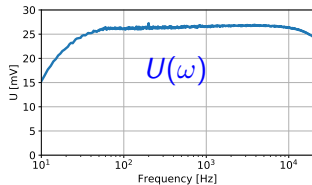
Use **any large band signal** such as
swept-sine, multi-tone, MLS, ...

to get

voltage $U(\omega)$

current $I(\omega)$

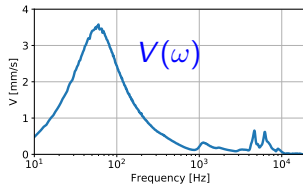
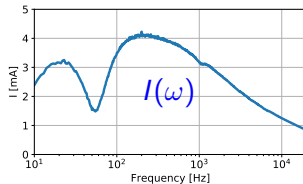
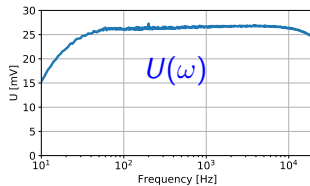
velocity $V(\omega)$



BI estimation

BI estimation

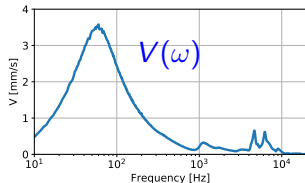
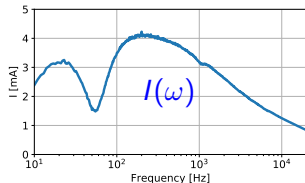
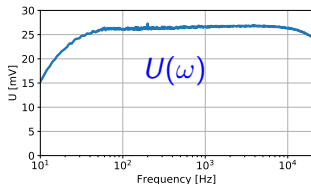
$$U(\omega) = Z_e(\omega) \cdot I(\omega) + BI \cdot V(\omega)$$



BI estimation

$$U(\omega) = Z_e(\omega) \cdot I(\omega) + BI \cdot V(\omega)$$

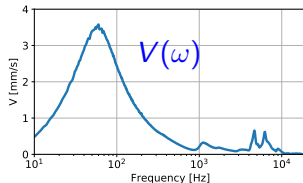
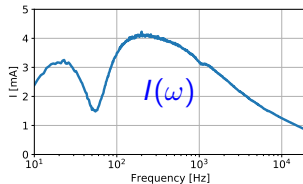
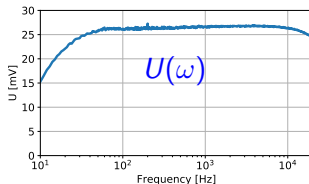
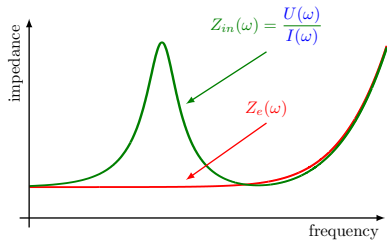
$$Z_e(\omega) = \frac{U(\omega)}{I(\omega)} - BI \cdot \frac{V(\omega)}{I(\omega)}$$



BI estimation

$$U(\omega) = Z_e(\omega) \cdot I(\omega) + BI \cdot V(\omega)$$

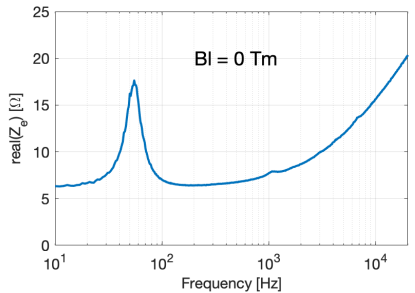
$$Z_e(\omega) = \frac{U(\omega)}{I(\omega)} - BI \cdot \frac{V(\omega)}{I(\omega)}$$



BI estimation

$$Z_e(\omega) = \frac{U(\omega)}{I(\omega)} - \cancel{BI} \frac{V(\omega)}{I(\omega)}$$

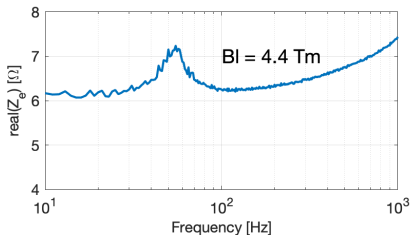
```
for BI = 0:0.5:7
    Ze = Zin - BI*V./I;
    semilogx(freq, real(Ze));
    pause;
end
```



BI estimation

$$Z_e(\omega) = \frac{U(\omega)}{I(\omega)} - \cancel{BI} \frac{V(\omega)}{I(\omega)}$$

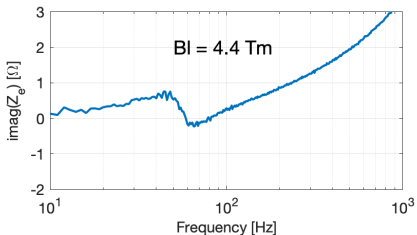
```
for BI = 4.4:0.05:5.4  
    Ze = Zin - BI*V./I;  
    semilogx(freq, real(Ze));  
    pause;  
end
```

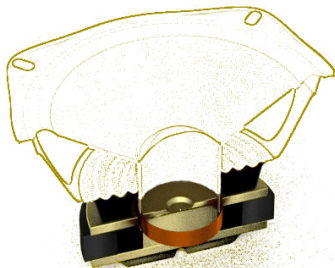


BI estimation

$$Z_e(\omega) = \frac{U(\omega)}{I(\omega)} - \textcircled{BI} \frac{V(\omega)}{I(\omega)}$$

```
for BI = 4.4:0.05:5.4  
    Ze = Zin - BI*V./I;  
    semilogx(freq, imag(Ze));  
    pause;  
end
```

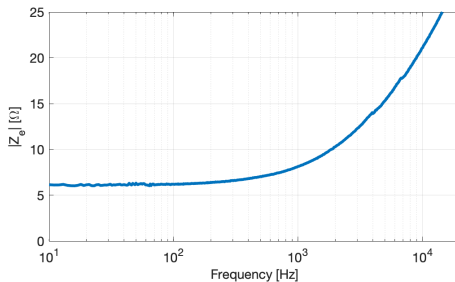




Electrical Impedance Z_e

Electrical Impedance

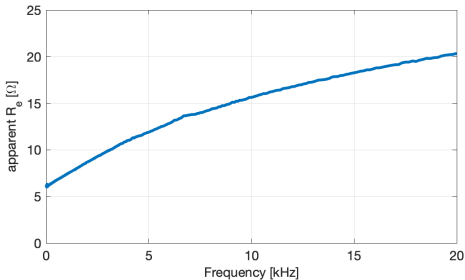
$$Z_e(\omega) = \frac{U(\omega)}{I(\omega)} - BI \cdot \frac{V(\omega)}{I(\omega)}$$



Apparent Resistance

$$Z_e = R_e + j\omega L_e$$

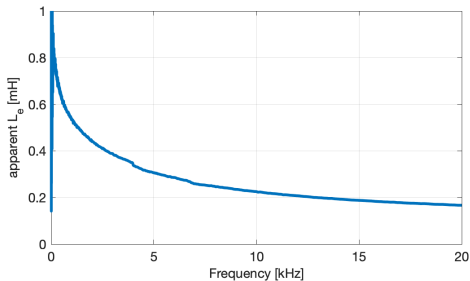
$$\Re\{Z_e\} = R_e$$

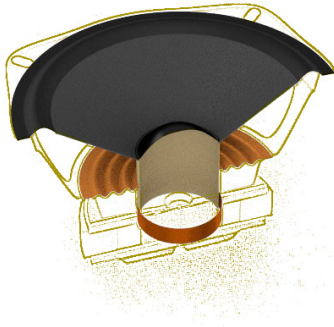


Apparent Inductance

$$Z_e = R_e + j\omega L_e$$

$$\frac{\Im\{Z_e\}}{\omega} = L_e$$

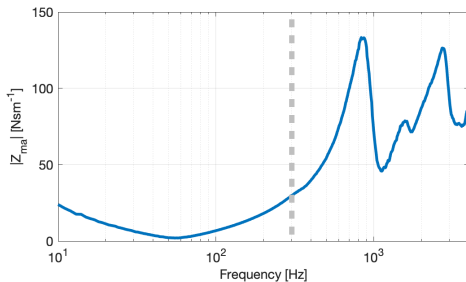




Mechanical Impedance Z_{ma}

Mechanical Impedance

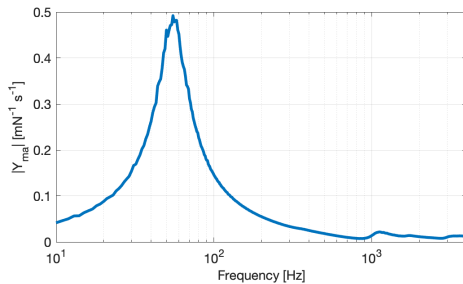
$$Z_{ma} = BI \frac{I(\omega)}{V(\omega)} = j\omega M_{ma} + R_{ma} + \frac{K_{ma}}{j\omega}$$



shows clearly the frequency limit of piston motion

Mechanical Admittance

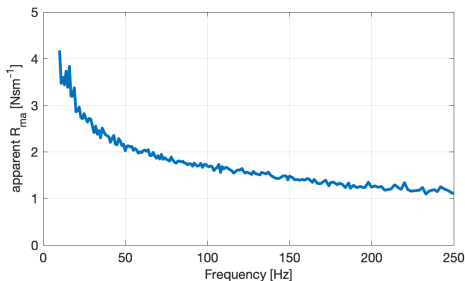
$$Y_{ma} = \frac{1}{Z_{ma}}$$



Apparent Mechanical Losses

$$Z_{ma} = BI \frac{I(\omega)}{V(\omega)} = j\omega M_{ma} + R_{ma} + \frac{K_{ma}}{j\omega}$$

$$\Re\{Z_{ma}\} = R_{ma}$$



- [1] A. Novak (2016), "Modeling Viscoelastic Properties of Loudspeaker Suspensions Using Fractional Derivatives", J. Audio Eng. Soc. Vol. 64(1), pp. 35-44.

M_{ma} and K_{ma} estimation

$$Z_{ma} = Bl \frac{I(\omega)}{V(\omega)} = j\omega M_{ma} + R_{ma} + \frac{K_{ma}}{j\omega}$$

$$\Im\{Z_{ma}\} = \omega M_{ma} - \frac{K_{ma}}{\omega}$$

M_{ma} and K_{ma} estimation

$$\Im\{Z_{ma}\} = \omega M_{ma} - \frac{K_{ma}}{\omega}$$

$$K_{ma} = \omega^2 M_{ma} - \omega \Im\{Z_{ma}\}$$

M_{ma} and K_{ma} estimation

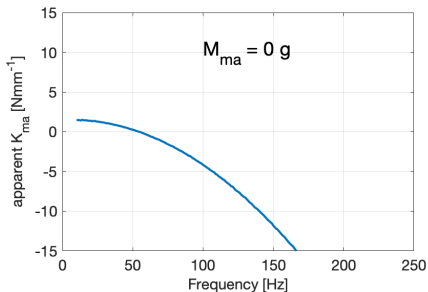
$$\Im\{Z_{ma}\} = \omega M_{ma} - \frac{K_{ma}}{\omega}$$

$$K_{ma} = \omega^2 \textcircled{M_{ma}} - \omega \Im\{Z_{ma}\}$$

M_{ma} and K_{ma} estimation

$$K_{ma} = \omega^2 \cancel{M_{ma}} - \omega \Im\{Z_{ma}\}$$

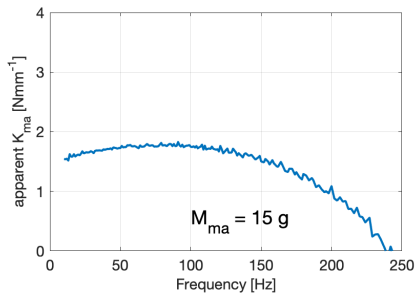
```
w = 2*pi*f;  
for Mma = 0:20  
    Kma = w.^2*Mma/1000 - w.*imag(Zma);  
    semilogx(freq, real(Kma/1000));  
    pause;  
end
```



M_{ma} and K_{ma} estimation

$$K_{ma} = \omega^2 \cancel{M_{ma}} - \omega \Im\{Z_{ma}\}$$

```
w = 2*pi*f;  
for Mma = 15:0.2:16.6  
    Kma = w.^2*Mma/1000 - w.*imag(Zma);  
    semilogx(freq, real(Kma/1000));  
    pause;  
end
```



Conclusion

loudspeaker measurement a pedagogical way

- ▶ no headless parameter fitting
- ▶ Bl estimated independently of other parameters
- ▶ electrical and mechanical impedance separation
- ▶ frequency dependent parameters
- ▶ models can be fitted (if needed) on separate quantities

thank you for attention ...

<https://ant-novak.com/>

[1] A. Novak (2016), "Modeling Viscoelastic Properties of Loudspeaker Suspensions Using Fractional Derivatives", J. Audio Eng. Soc. Vol. 64(1), pp. 35-44.