Determining the pressure sensitivity (and other parameters) of a microphone from measurements of the velocity of the membrane.

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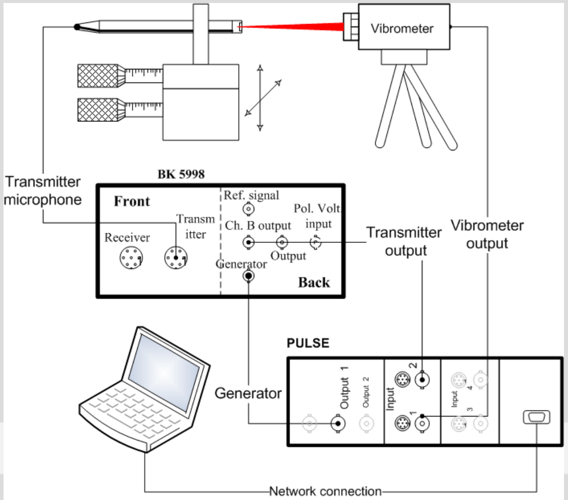
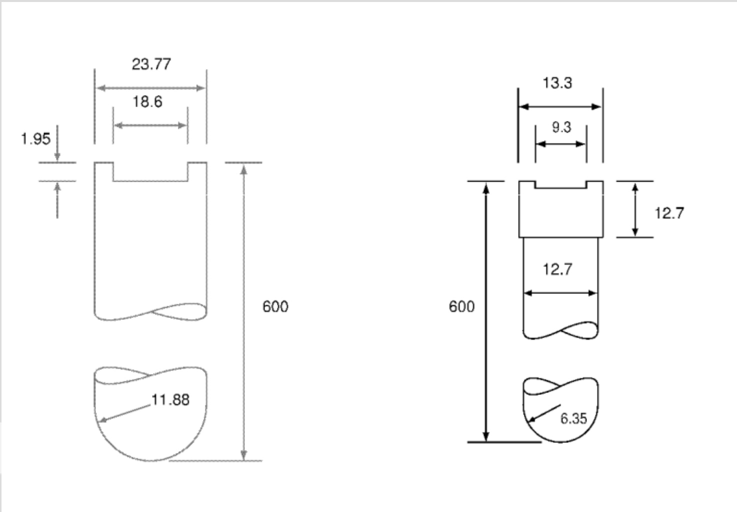
Motivation

- **Numerical calculations of the pressure, free-field, and random-incidence response of a condenser microphone are carried out on the basis of an assumed displacement distribution of the membrane:**
  - Valid at frequencies below the resonance frequency.
  - Invalid at high frequencies due to heavily coupling with damping of film air between back plate and membrane, higher modes in the back cavity.

- **Possible Solution(s):**
  - Use a complete model of the microphone for predicting the movement of the membrane.
  - *To measure the velocity distribution of the membrane by means of a non-contact method, such as laser vibrometry, and use the measured velocity in the numerical calculations.*

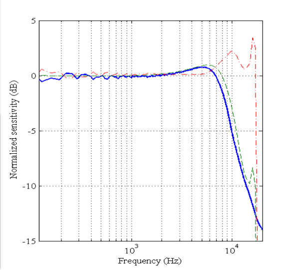
Hybrid method: Laser vibrometry + BEM

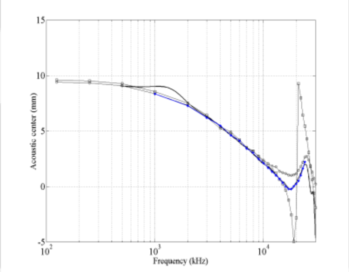


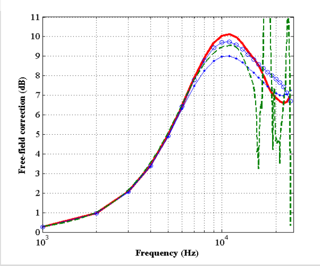


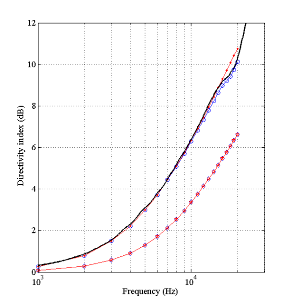
$$v(r)$$

$$C(P)\,p(P) = \int_L \int_\theta \left(p(Q)\frac{\partial G(R)}{\partial n} + jkz_0 v(Q) G(R) \right) d\theta \rho(Q)\, dL(Q) + 4\pi p^I(P).$$

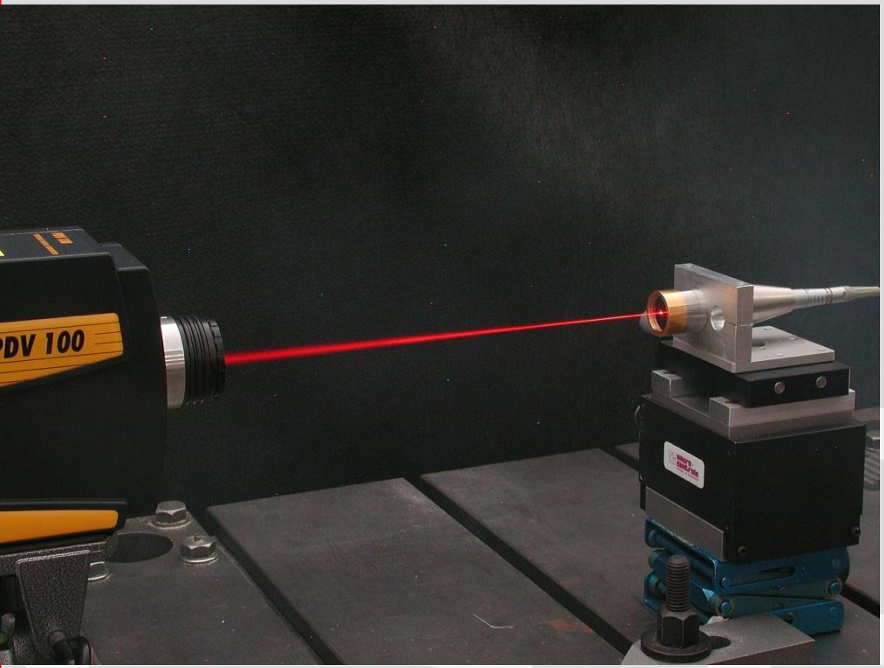


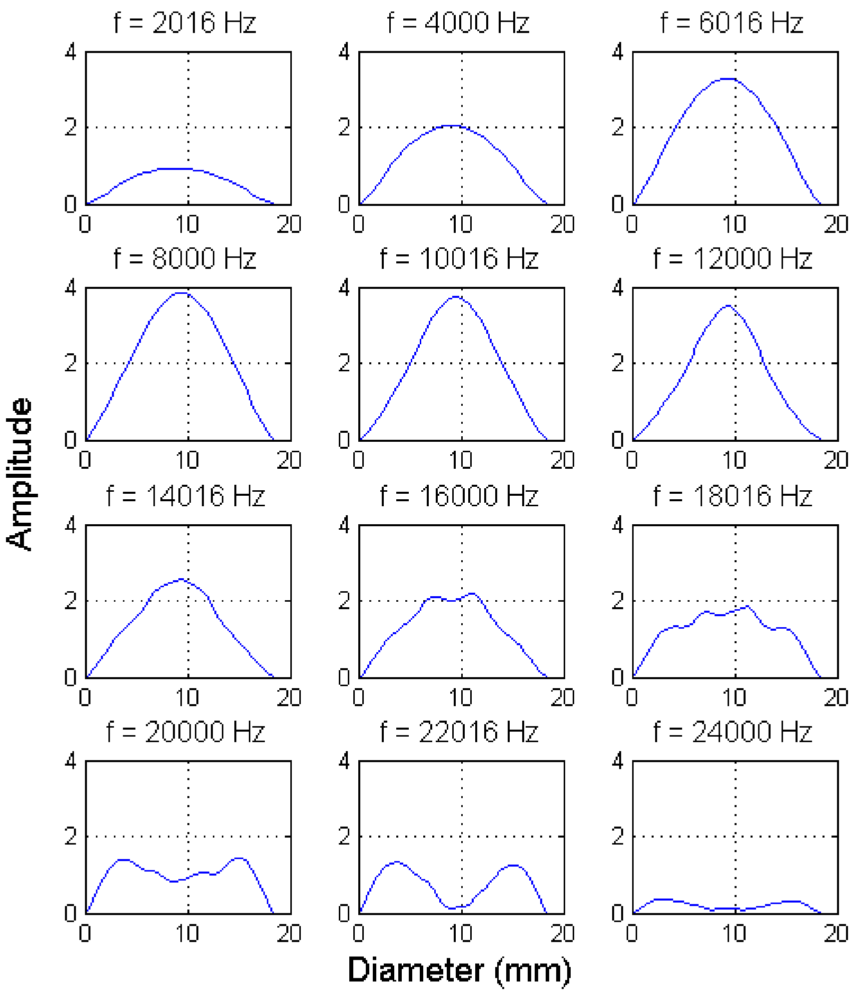




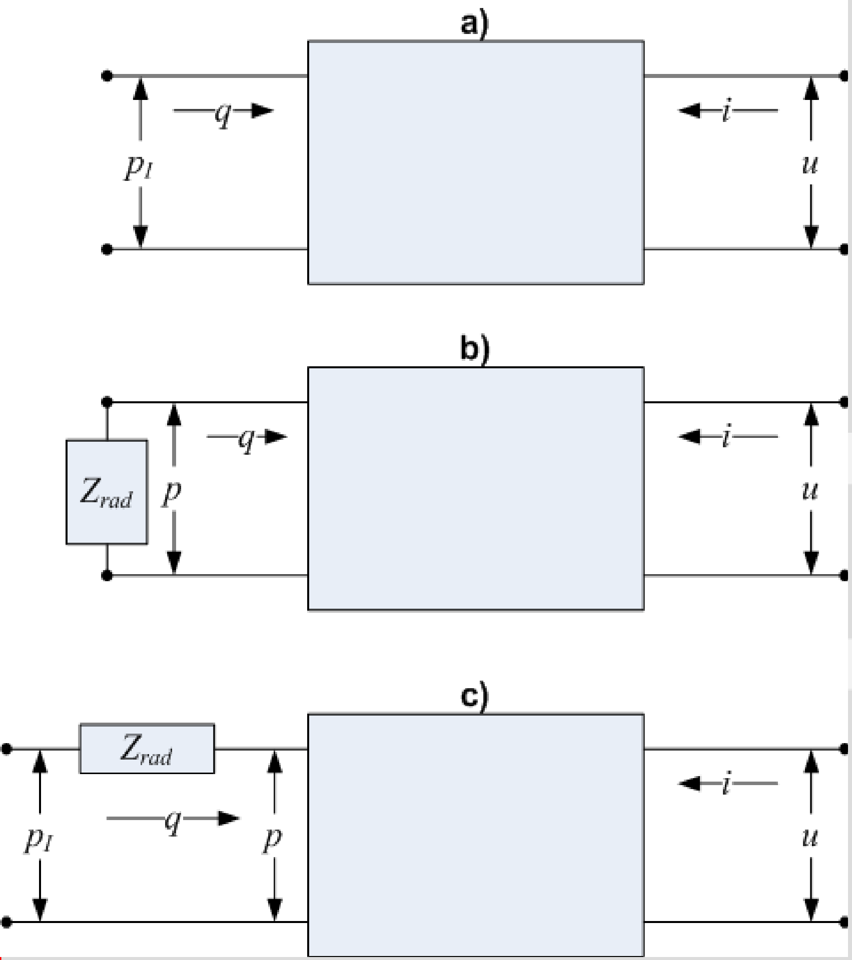


Laser vibrometer measurements





Results of the hybrid method: pressure sensitivity



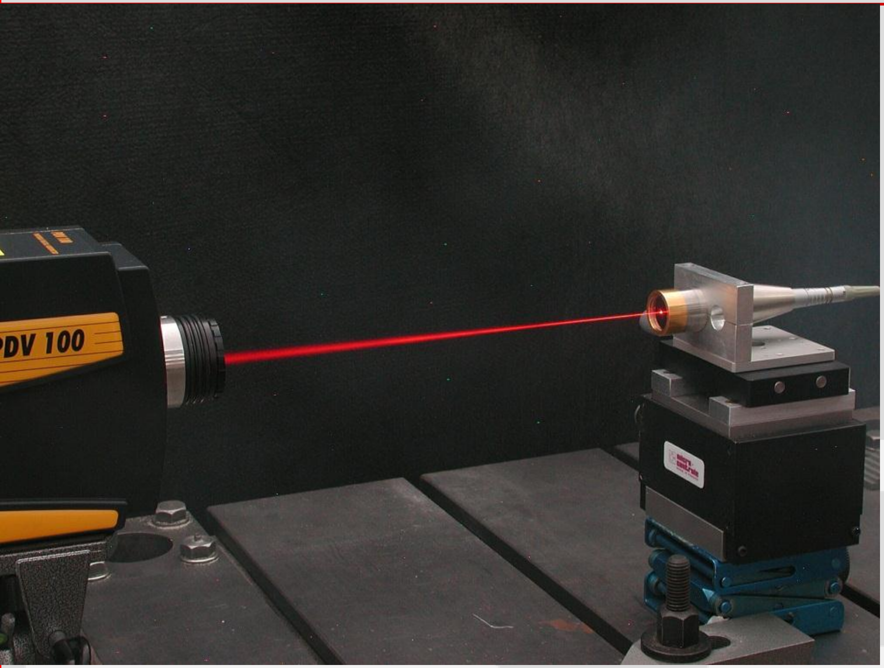
- Sensitivity of a condenser microphone:

$$M_{\mathrm{p}} = \frac{u_{i=0}}{p} = -\frac{q_{p=0}}{i}$$

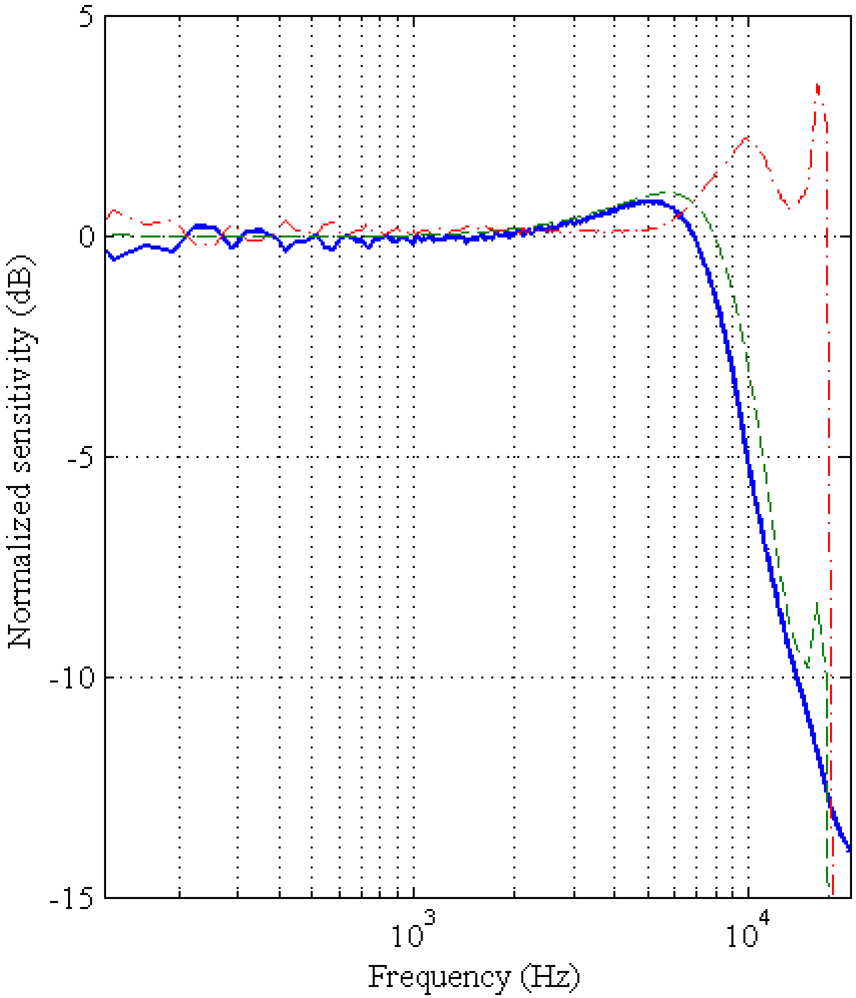
- As a source:

$$-\frac{q}{i} = M_{\mathrm{p}} \frac{Z_{\mathrm{a}}}{Z_{\mathrm{a}} + Z_{\mathrm{rad}}},$$

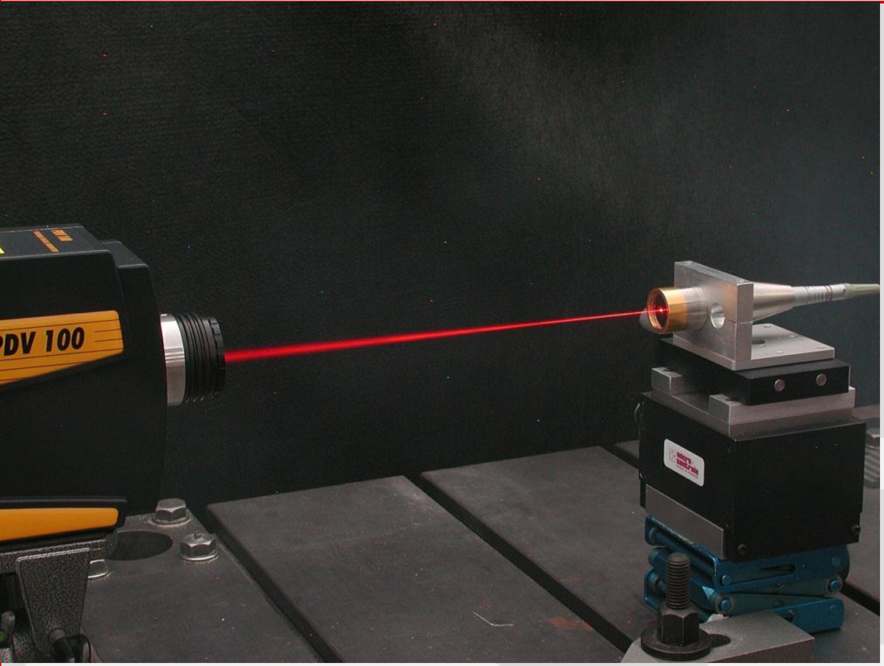
Results of the hybrid method: pressure sensitivity

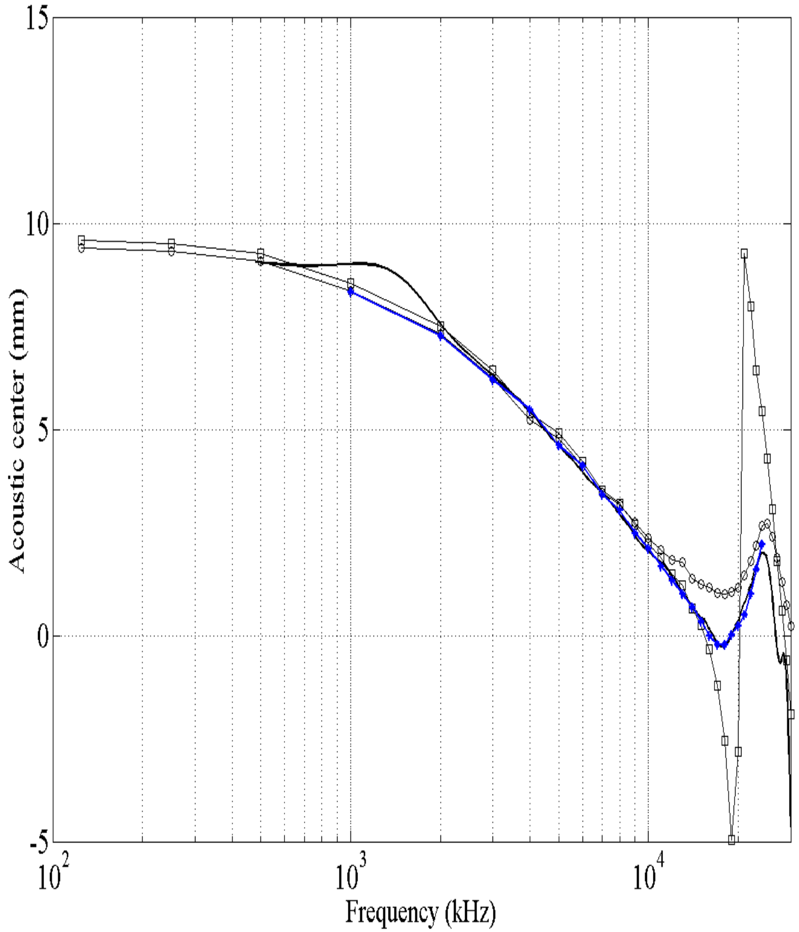


$$M_p = \frac{2\pi \int_{S_M} v(r) r dr}{\bar{i}}.$$



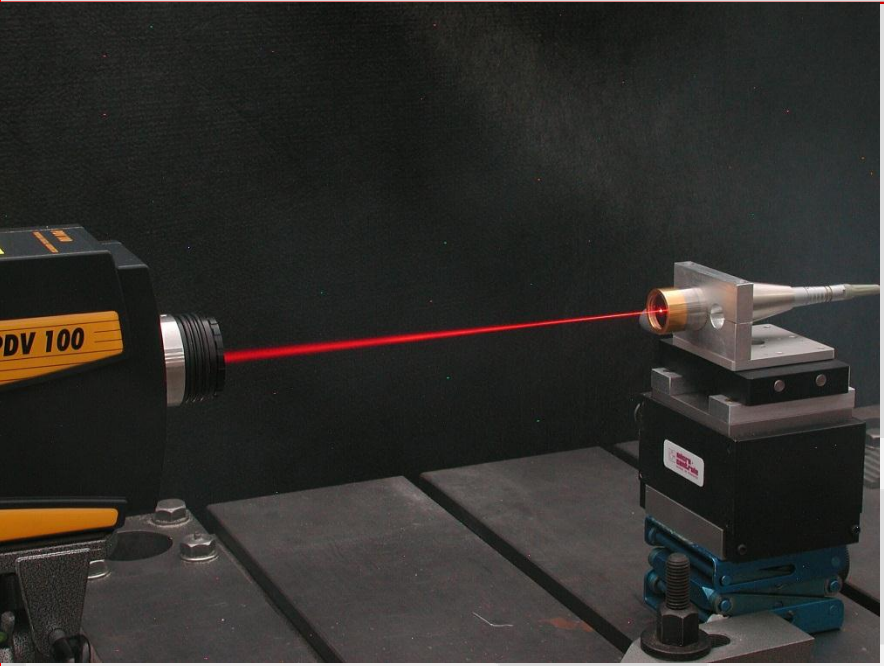
Results of the hybrid method : acoustic centre

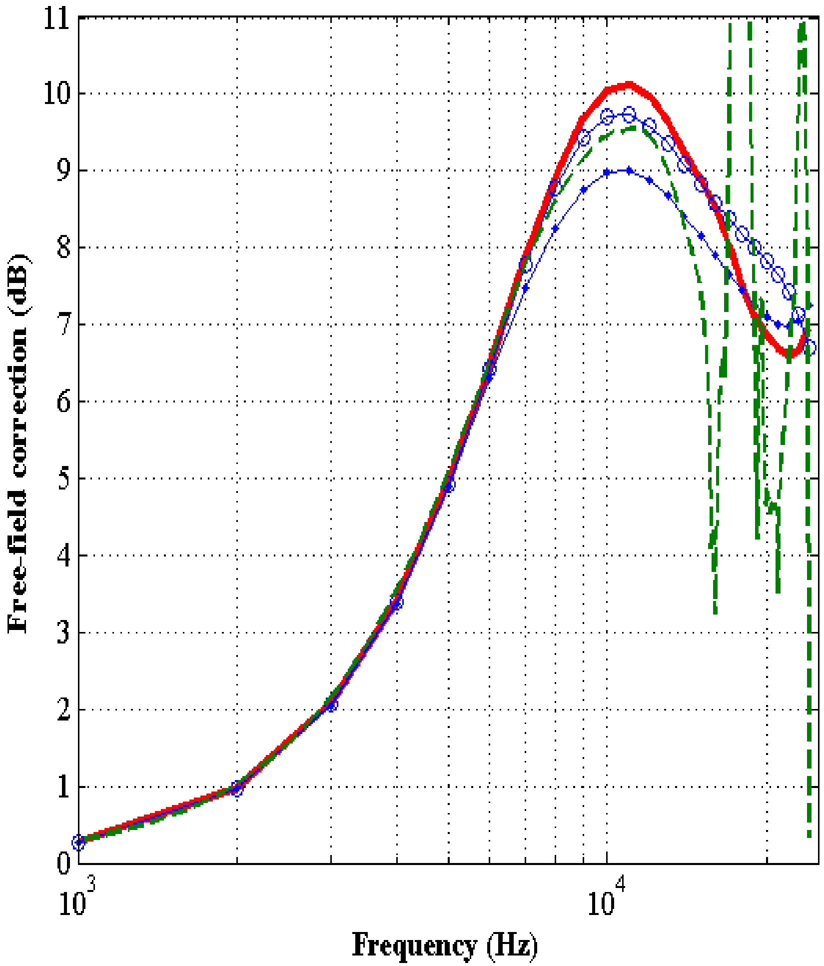




$$x(k,r) = r + |p(r)| / \left(\partial |p(r)| / \partial r \right)$$

Results of the hybrid method : free-field response

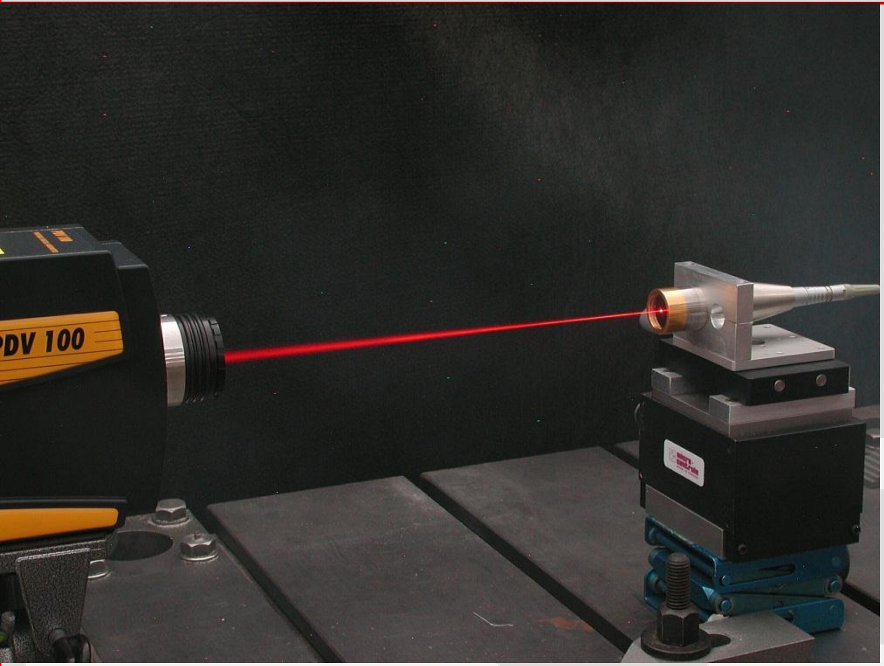




$$C_{ff} = 10\log\left\{\left|M_{ff}\right|^2 / \left|M_p\right|^2\right\},$$

$$C_{ff} = 20\log_{10}\left\{\int\left(p(r)/p_0\right)\cdot v(r)rdr \Big/ \int v(r)rdr\right\},$$

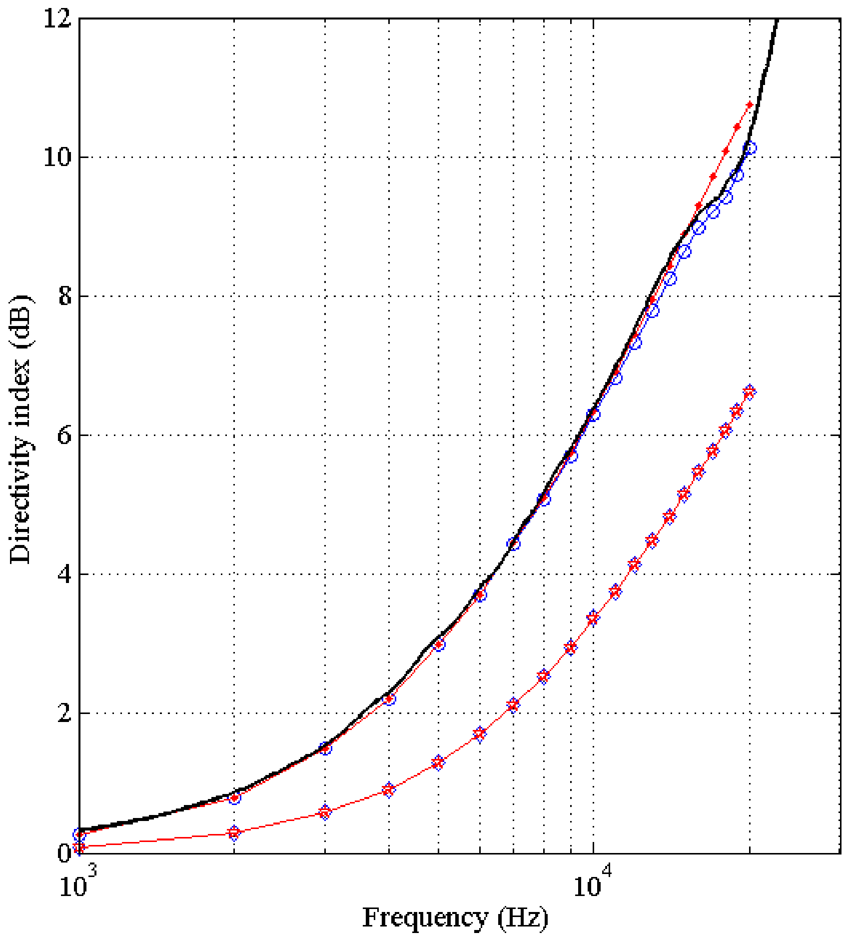
Results of the hybrid method : directivity index



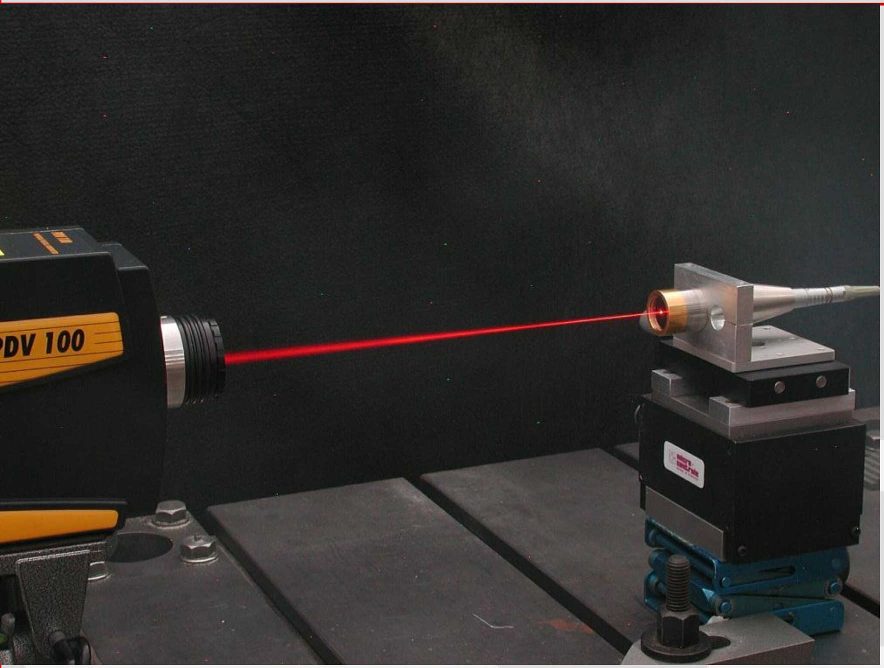
$$Q(f) = \frac{4\pi \left| H(f, \theta_0, \phi_0) \right|^2}{\int_0^{2\pi} \int_0^{\pi} \left| H(f, \theta, \phi) \right|^2 \sin\theta d\theta d\phi},$$

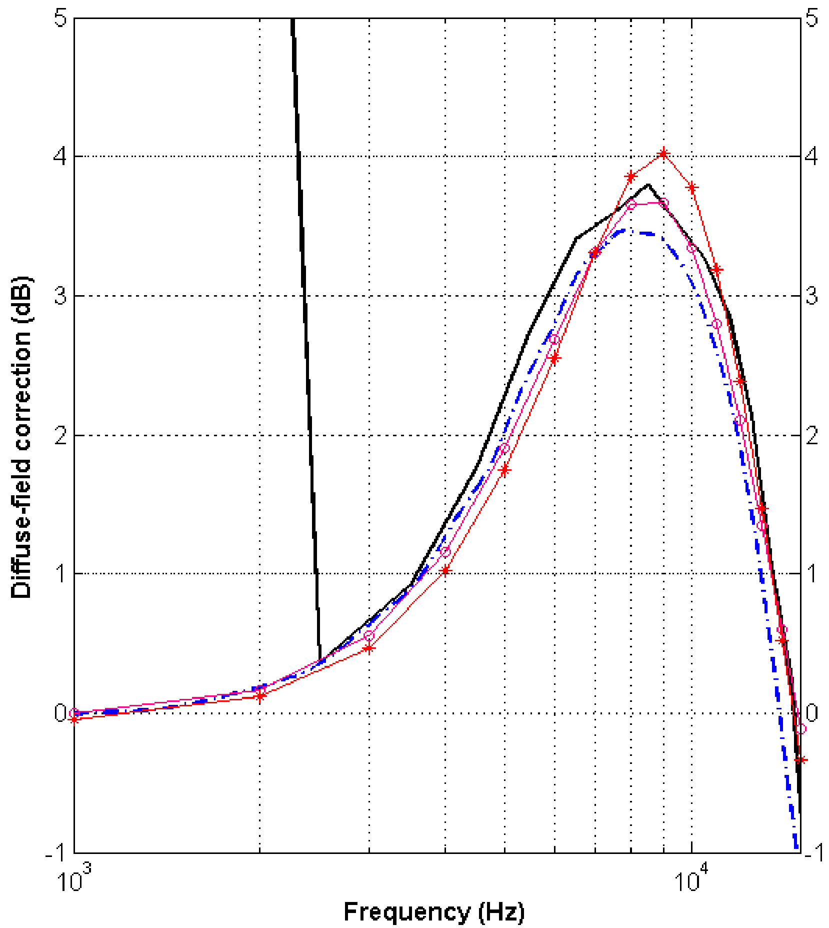
$$Q(f) = \frac{2\left| H(f, \theta_0) \right|^2}{\sum_{n=1}^{\pi/\Delta\theta} \left| H(f, \theta) \right|^2 \sin\theta_n \Delta\theta}.$$

$$D = 10 \log Q.$$



Diffuse-field response (LS1)



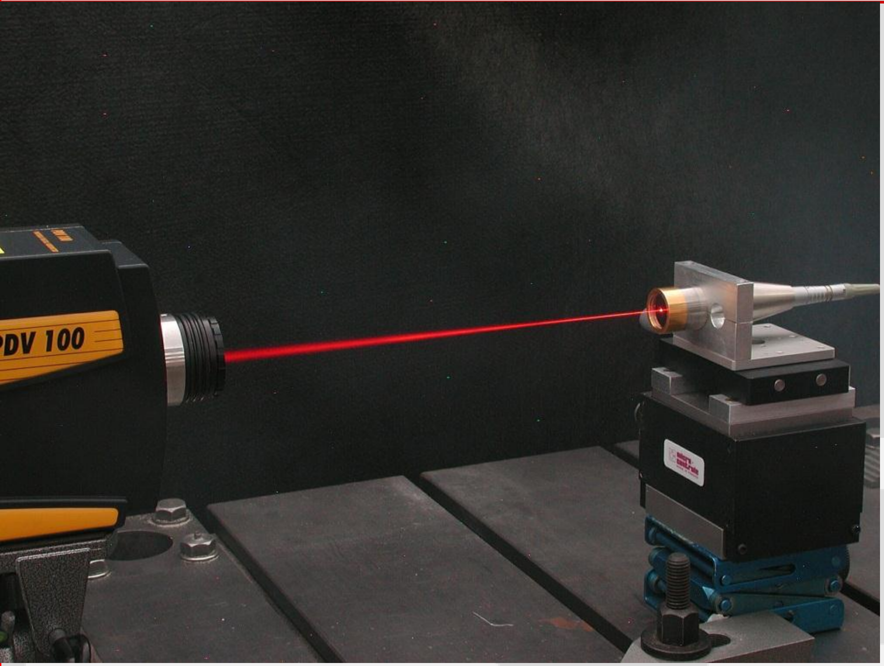


$$P = (4\pi)\left(\frac{\rho f}{2}\right)^2\left(\frac{i^2}{\rho c}\right)M_d^2, \qquad P = \frac{1}{2}\left|v_{out}\right|^2 S\,\mathrm{Re}\{Z_{rad}\}. \qquad Z_{rad} = \left(\frac{p}{v_{out}}\right)_{on\ S}.$$

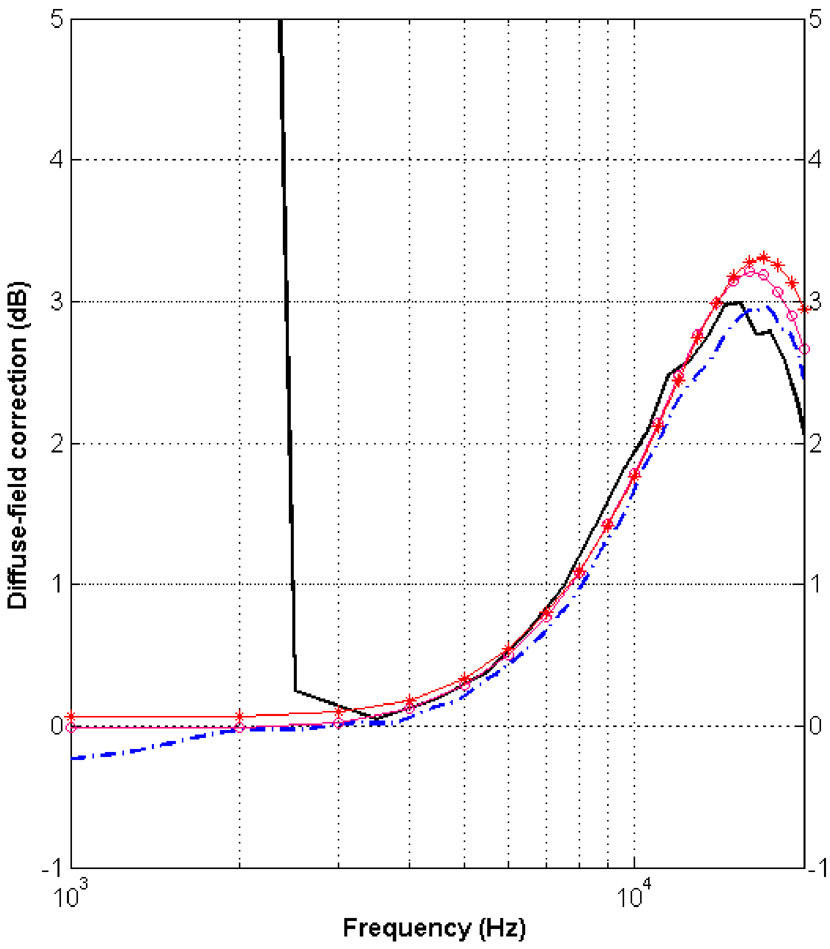
$$M_d^2 = \frac{\left|v_{out}\right|^2}{i^2}\frac{Sc}{\pi\rho f^2}\mathrm{Re}\{Z_{rad}\}. \qquad M_p = -q/i$$

$$\frac{M_d^2}{M_p^2} = \frac{c}{2\pi\rho f^2 S}\mathrm{Re}\{Z_{rad}\}.$$

Diffuse-field response (LS2)



$$\frac{M_d^2}{M_p^2} = \frac{c}{2\pi\rho f^2 S} \mathrm{Re}\{Z_{\mathrm{rad}}\}.$$



Conclusions

- **Measurements using laser vibrometer → no general assumption can be made for the behavior of any given microphone.**

- **Results of the hybrid method:**
  - pressure sensitivity,
  - acoustic center
  - free-field correction
  - directivity index

→ In good agreement with the experimental results obtained by traditional methods.

- **The hybrid method can be used for validating new experimental setups.**
  - The hybrid method can be used in production environments to check the responses of a prototype microphone without the need of a complete calibration setup.
  - The hybrid method is not a substitute of an individual calibration of a particular transducer.

Laser vibrometer measurements: other microphones & phase