

14 High sound level Microflown

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Fig. 8.1 (previous page): The first micromachined

14.1 Introduction

Above 140dB, acoustics becomes non linear. For testing it is then relevant to measure sound pressure and particle velocity simultaneously of the sound field. The standard Microflown sensor works up to 135dB PVL (re. 50nm/s), see chapter 3: 'the Microflown'.

For aerospace applications, a particle velocity probe is developed that is able to measure the particle velocity up to 170dB PVL (re. 50nm/s), requiring of course proper calibration.

The Microflown sensor is capable of measuring the acoustic particle velocity. There is a demand to measure the particle velocity at higher levels than is possible at this moment, up to 170dB (re. 50nm/s). To reduce the flow through the sensor it is encapsulated with stretched linen cloth, Fig. 14.1.

This encapsulated sensor is less sensitive than the standard sensor but it is not possible to calibrate at these high levels with current calibration techniques. The piston on a sphere calibration method makes use of the ratio of pressure and velocity at 30cm distance from the source. But it is not possible to generate 170dB at such a distance.

In the middle of a standing wave tube the particle velocity is measured and related to the pressure at the endplate. High enough levels can be reached, but the relation between sound pressure and particle velocity is not valid anymore.

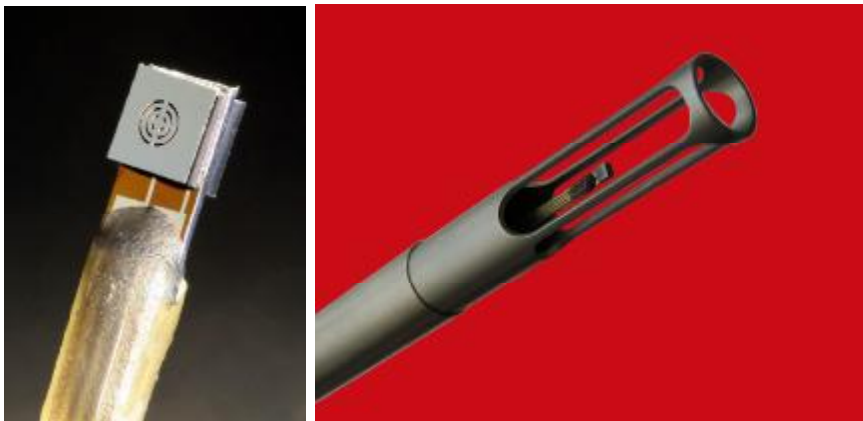
In this paper a calibration technique is proposed based on a monopole sound source. The air is forced by an enclosed speaker through a small tube. At the end of the tube the sound is emitted omni-directionally and thus a monopole sound source is created. At the opening of the tube there is a high amount of particle velocity and theoretically no sound pressure. The velocity at the opening can be determined with a reference pressure microphone at a certain distance.

High sound level Microflown



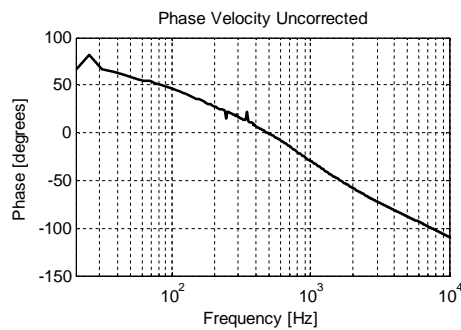
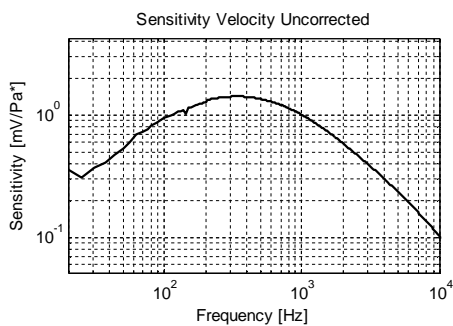
Fig. 14.1: High level particle velocity probe.

14.2 Commercial High dB Microflown



Sensitivity

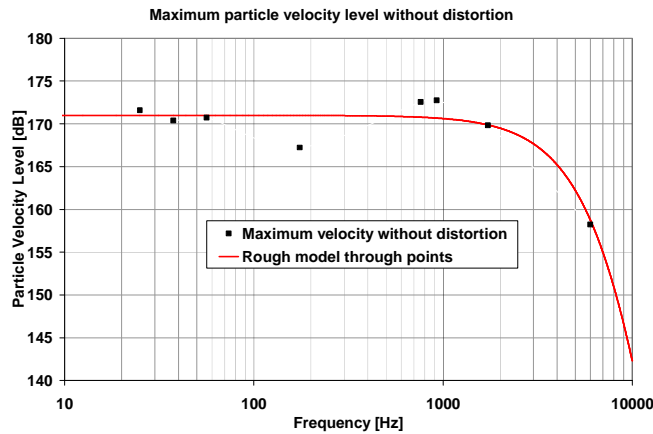
LFS=1.68mV/Pa*, [Su=0.70V/(m/s), =142Hz, fc2u=760Hz,
fc3u=13720Hz, C1u=193[Hz], C2u=1300Hz, C3u=19430Hz



Measurement of the maximum level

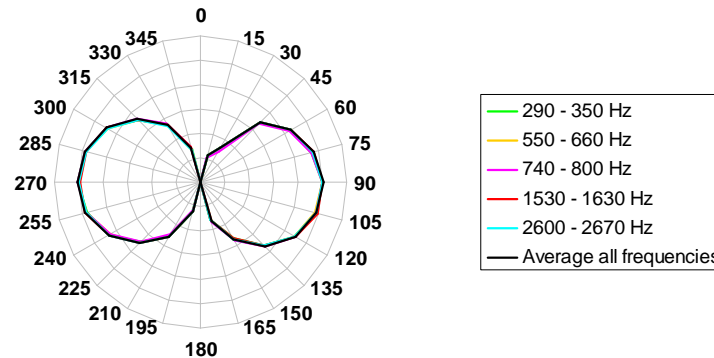
The velocity is measured at the entrance of the pipe of a monopole sound source. The actual particle velocity level present at this point can be recalculated from the sound pressure at a known distance. Two sources are used to be able to produce high enough levels in a broad frequency range.

Each time the monopole source is powered by a sine with high amplitude. The time response of the sensor will show a distortion at high enough levels. This will give second harmonics in the frequency domain (or third harmonics etc.). The points displayed in the graph indicate level that is measured where the distortion at the double frequency is less than 20dB. For instance the PVL value at 175Hz is slightly lower. But because it is (very) inconvenient for the testing operator the signal was not increased more. So the actual value is likely to be higher.

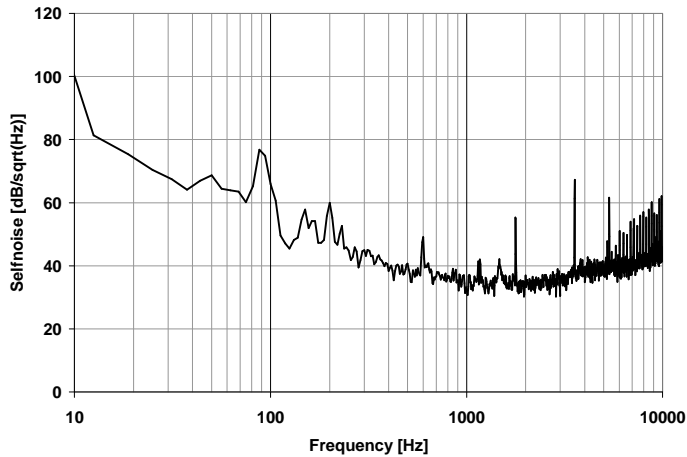


Directivity

Directivity velocity probe



Selfnoise



14.3 Monopole calibration

A monopole sound source is created if a sound wave emits from a tube with a diameter much smaller than the wavelength. The relationship between sound pressure at a certain distance to the particle velocity at the opening of a monopole sound source is given by:

$$p(r) = i r c k \frac{Q}{4 p r} e^{-i k r} = i r c \frac{2 p f}{c} \frac{u A}{4 p r} e^{-i k r} = i \frac{r f A}{2 r} u e^{-i k r} \quad (14.1)$$

With Q the source strength of the monopole [m^3/s], r the distance from the source [m], A the area of the source opening [m^2]

To get a feeling for the figures, a particle velocity level of 170dB is required for this application; 170dB equals 16m/s. If a measurement frequency of 100Hz is taken as example, and an exit area (of the monopole source) of 0.003m^2 , the sound pressure level is 3Pa. And 3Pa equals 103dB SPL.

With the low frequency sound source developed by Microflown Technologies (Fig. 14.2) it is possible to generate high particle velocity levels. With an additional narrow intake the velocity is increased even more.

The sound source has an omni directional radiation at lower frequencies and behaves therefore as a true monopole. This set up is constructed and tested. Eq (14.1) is verified with a normal calibrated Microflown that measures the particle velocity level at the source mouth and a pressure microphone at 1 meter distance.



Fig. 14.2: Low frequency monopole sound source.

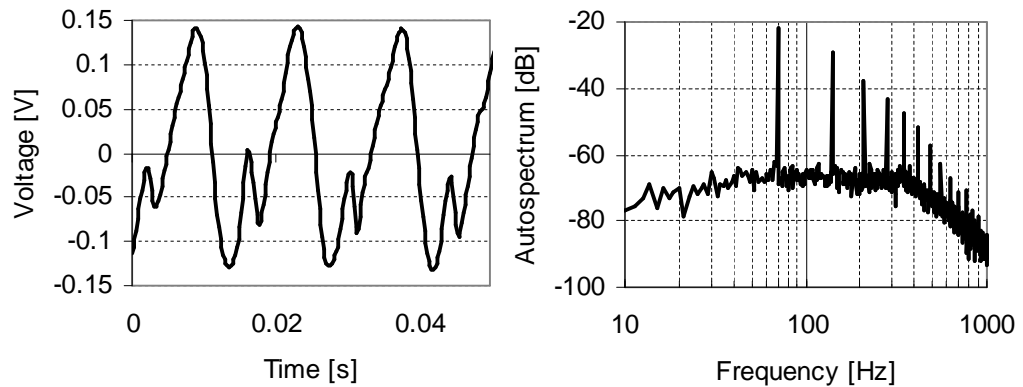


Fig. 14.3: Monopole response at 170dB. Left: Sensor time response. Right: 2nd harmonic is 7 dB lower.

The source is powered with a 70Hz sine and 170dB (re. 50nm/s) is present at the tube opening calculated from the reference pressure at a distance. However the velocity signal is highly distorted, see Fig. 14.3. The time signal does not show a smooth sine wave and the 2nd harmonic is only 7dB lower.

DC wind at high levels

Although the set up works also for high levels, an additional effect occurs: the source is generating wind at higher levels. The wind is generated due to a non linear effect: the loudspeaker pushes the air out in the shape of a jet and sucks the air inward in an omni directional way, see Fig. 14.4. With a DC flow sensor a flow of 12.8m/s is measured at the monopole opening. The probe is susceptible to this flow and is overloaded.

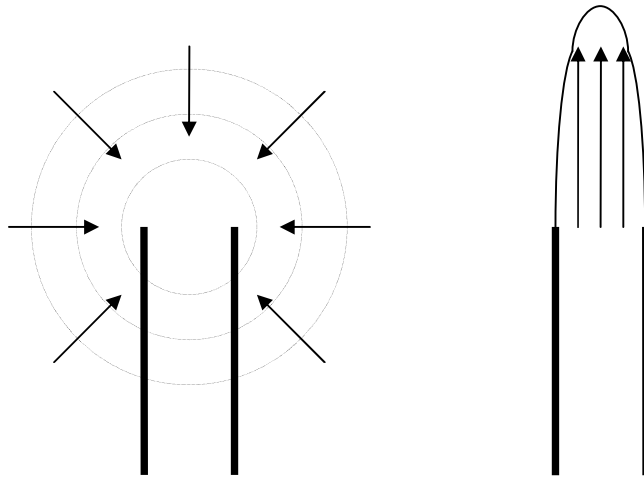


Fig. 14.4: flow around a monopole. Left: omni directional inward flow, right: outward jet.

14.4 Dipole calibration

Two equal monopole sound sources are positioned close to each other and are driven in anti phase to avoid the overloading of the sensor due to DC flow, Fig. 14.5. The monopole sources form together a dipole.

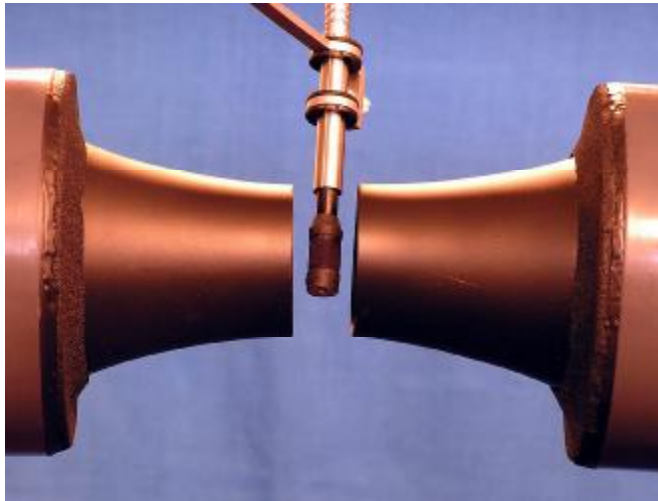


Fig. 14.5: Dipole created from two monopole sound sources.

When the sources are powered in anti-phase less turbulence is created. Air particles are moved between the two sources instead of being pushed to the surrounding environment. Because of the lower turbulence level it now is possible to measure higher AC particle velocity level. The sound pressure radiation from this dipole is also very low which makes it more convenient for the test engineer to measure, Fig. 14.6.

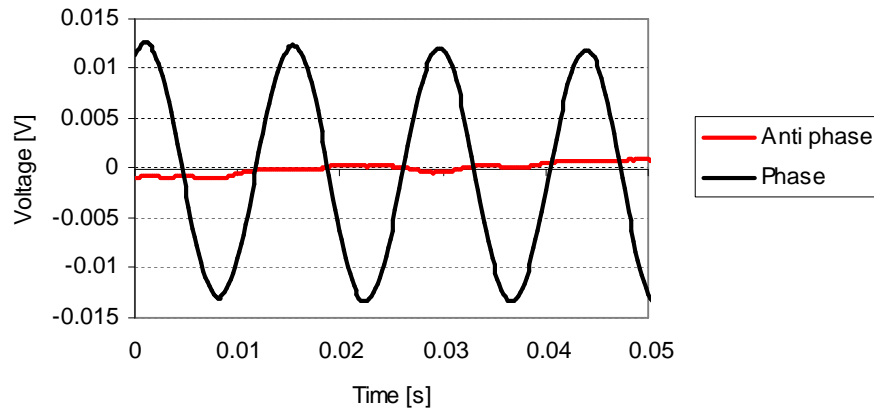


Fig. 14.6: Sound pressure at 50cm distance. The sources are powered with 70Hz in phase and anti-phase.

6dB dipole gain

When a dipole is created the monopole relation between sound pressure at a distance and the particle velocity between the sources is not valid anymore. However when the signal is decreased so the sensor will not overload it is shown that the particle velocity level is doubled when two sources are powered in anti-phase compared to the single monopole situation as is shown in Fig. 14.7.

This shows there is no energy loss or change of behavior of the sources when another source is turned on. Therefore the particle velocity at the opening of a monopole can be calculated. Also the particle velocity between the dipole is known with a 6dB increase of signal.

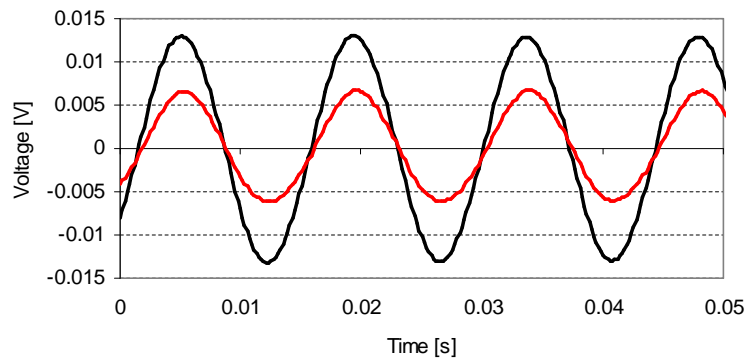


Fig. 14.7: The particle velocity doubles if two sources are powered in anti-phase and a dipole is created.

14.5 170dB particle velocity level

In first stage a single monopole sound source is powered with a 70Hz sine of roughly 10Watts. A sound pressure of 1.9Pa is present at 50cm

distance from the source. From this the particle velocity at the opening can be calculated.

$$\begin{aligned}
 u &= p \frac{2r}{\rho f A} = p \frac{2r}{r f \rho d^2} \\
 &= 1.9[Pa] \frac{2 * 0.5[m]}{1.2[kg/m^3] * 70[Hz] * \rho * 0.065[m]^2} \\
 &= 6.7[m/s] = 163[dB] \text{ (re. } 50\text{nm}^3/\text{s)}
 \end{aligned}
 \tag{2}$$

In second stage the other source is also powered but in anti-phase with a power consumption of roughly 20Watts. The 6dB gain should be added because of the dipole situation and from this can be calculated 169dB is present between the sources.

The dipole is causing 6dB velocity gain relative to a single monopole, so that 169dB PVL value is generated. Less turbulence is induced so it is possible to measure the particle velocity without overloading the sensor due to wind. The time response is not distorted much and the harmonic signals are more than 20dB lower, Fig. 14.8.

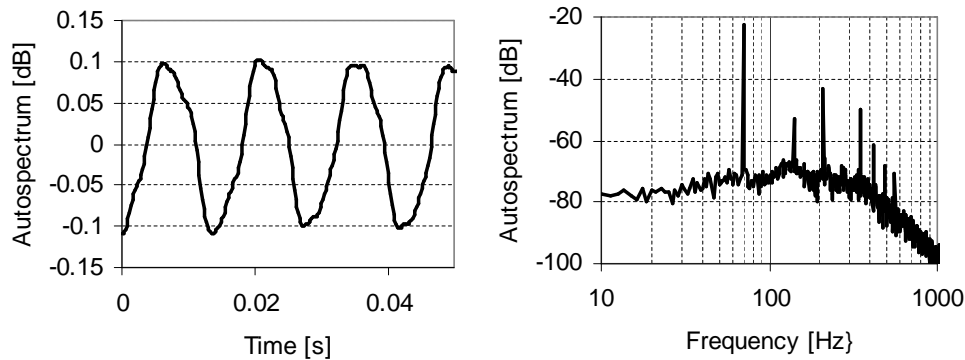


Fig. 14.8: Sensor response due to a 70 Hz, 169dB PVL signal. Left: time signal. Right: The auto spectrum.

14.6 True particle velocity sensor

The sensor is rotated to prove the sensor is still measuring particle velocity. The original sensor has a figure-of-eight sensitivity, meaning the phase shift is 180 degrees when the probe is positioned in the opposite direction and the sensitivity is zero in the non sensitive direction. In Fig. 14.9 is shown this is also the case with the high velocity probe.

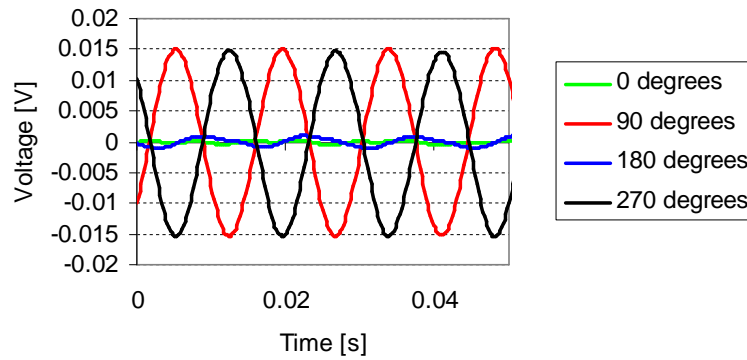


Fig. 14.9: Time signal due to rotation of the probe.

In a next experiment the sources are powered in phase. Now the sound pressure is doubled compared to a monopole situation. Exactly between the sources the particle velocity is goes to zero, Fig. 14.10 and Fig. 14.11. This indicates that the sensor is truly velocity sensitive and not pressure sensitive. Previous versions of the probe had sound leakages or parts where vibrating which made the sensor partially pressure sensitive. The particle velocity level increases when the probe is shifted from the middle and is moved closer to one of the sources.

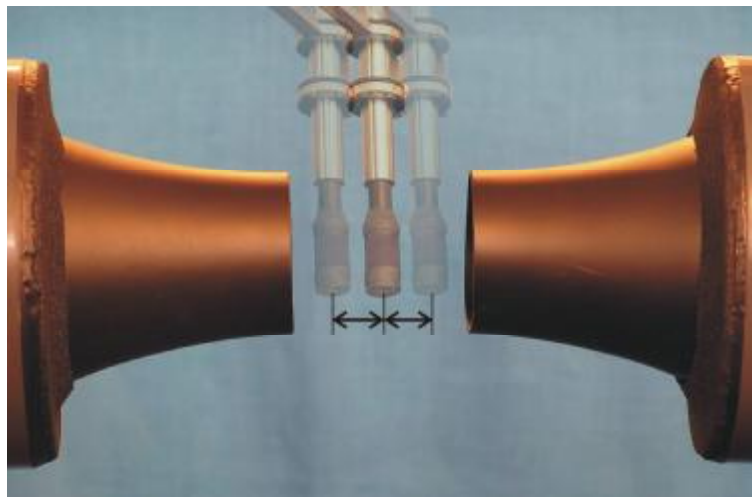


Fig. 14.10: Two sources in phase. The probe is moved from the center close to each source.

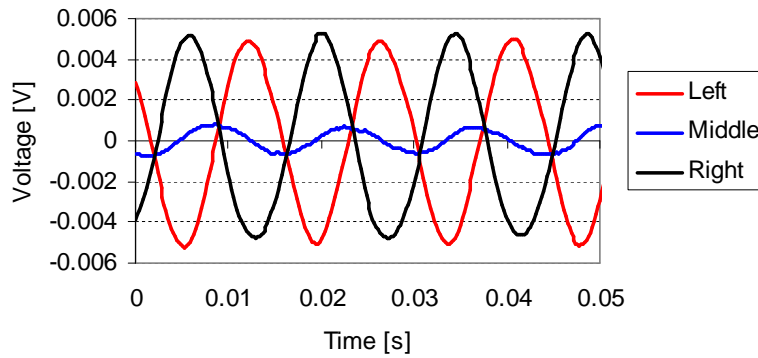


Fig. 14.11: Particle velocity signal between two equal sources powered in phase.

14.7 Broadband calibration

To calibrate all frequencies a random white noise signal is set on one monopole and the transfer function to a reference microphone is measured.

A model that is based on the one of the regular particle velocity sensor is used to approach the measured response. The difference with the model of the regular sensor is that there is an extra high pass filter coefficient f_{CF0} for the amplitude and C_0 for phase, Eq. (3), (4). This behavior is caused by the material added to the sensor. The cloth wrapped around the sensor is reducing the low frequencies more than higher frequencies. The new high level particle velocity sensor is roughly 65dB less sensitive than a regular particle velocity sensor.

$$Sensitivity = \frac{LFS}{\sqrt{1 + \frac{f_{CF0}^2}{f^2}} \sqrt{1 + \frac{f_{CF1}^2}{f^2}} \sqrt{1 + \frac{f^2}{f_{CF2}^2}} \sqrt{1 + \frac{f^2}{f_{CF3}^2}}} \quad (14.3)$$

$$Phase = \tan^{-1} \frac{C_0}{f} + \tan^{-1} \frac{C_1}{f} - \tan^{-1} \frac{f}{C_2} - \tan^{-1} \frac{f}{C_3} \quad (14.4)$$

Coefficients used to describe the sensor response:

Sensitivity parameters			Phase parameters		
LFS	=	0.2 V/(m/s)			
f_{CF0}	=	700 Hz	C_0	=	700 Hz
f_{CF1}	=	100 Hz	C_1	=	40 Hz
f_{CF2}	=	700 Hz	C_2	=	700 Hz
f_{CF3}	=	20000 Hz	C_3	=	20000 Hz

To determine the sensitivity the microphone is placed at 20cm distance and the high dB probe at the opening. With Eq. (1) now the sensitivity can be determined, Fig. 14.12 left.

The phase response however is too much disturbed because reflections influence the pressure microphone. It is not possible to calibrate the amplitude at the opening of the source but the phase between pressure and velocity is exactly 90 degrees at lower frequencies. With less influence of reflections the phase response now is smooth, Fig. 14.13 right. At higher frequencies (220Hz) it becomes difficult to measure pressure and velocity exactly at one spot and the phase starts to deviate.

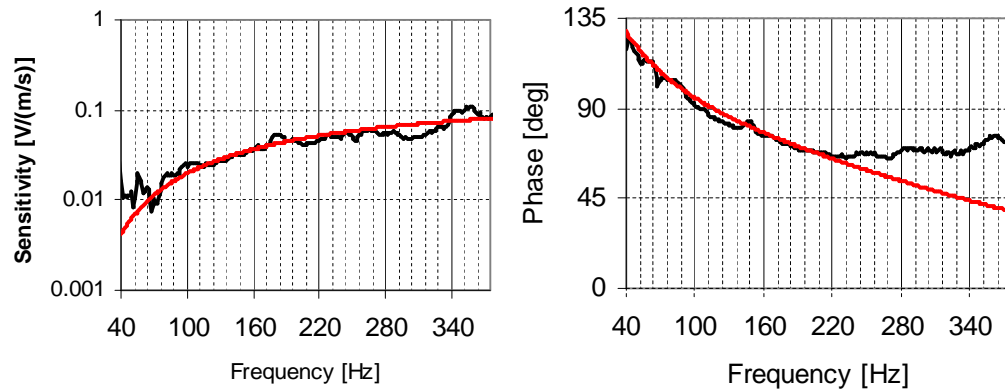


Fig. 14.12: Sensor sensitivity left. Phase response right (black line measured response, red fitted model)

The selfnoise is measured, see Fig. 14.13.

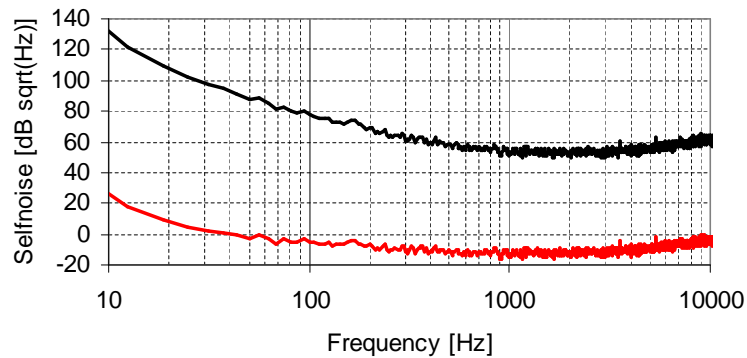


Fig. 14.13: Selfnoise regular particle velocity sensor (red), high dB particle velocity sensor (black).

14.8 References

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