AN OVERVIEW OF MICROFLOWN TECHNOLOGIES

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Summary

The Microflown is an acoustic sensor measuring particle velocity instead of sound pressure, which is usually measured by conventional microphones. Since its recent invention it is mostly used for measurement purposes (1D and 3D-sound intensity measurement and acoustic impedance). The Microflown is also used for measuring DC-flows, that can be considered as particle velocity with a frequency of 0Hz. Furthermore the Microflown is used in the professional audio as a low frequency add on microphone for pressure gradient microphones (figure of eight; directional microphones). Due to its small dimensions and silicon based production method the Microflown is very suitable for mobile applications like mobile telephones or smartcards. Nowadays sound-energy determination, array applications and three-dimensional impulse response are under investigation. Although the Microflown was invented only some years ago, the device is already commercially available.

Introduction

The Microflown [1] was invented at the University of Twente in 1994 [2]. At first research efforts were aimed at finding construction and calibration methods. Later co-operation with several science groups and industry was established to find applications [6], [12] and [9].

Apart from developing applications, the research nowadays involves modelling the behaviour of the Microflown [4], [5] and investigating materials that must lead to improved signal to noise ratio and reduced power consumption.

The Microflown does not measure fluctuating air pressure. Instead, it measures the velocity of air particles across two tiny, resistive strips of platinum that are heated to about 200°C. In fluid dynamics, the motion of gas or liquid particles is called a flow, hence the name Microflown, which is sensitive to the movement of air rather than pressure.

A few years after its invention, the Microflown became commercial available [17].

Fig. 1: Symbols of a Microflown and a microphone. The two lines in the Microflown symbol represent the two temperature sensors, the one line in the microphone symbol represents the membrane.

The Microflown

The Microflown is made by microtechnology, which is a follow-up of microelectronics that started its revolution after the invention of the transistor by Shockley in the Bell laboratories in 1947. It has been successfully realised in three variations, a cantilever type (see Fig. 2), a bridge type (see Fig. 3) and a through-the-wafer type (see Fig. 4).

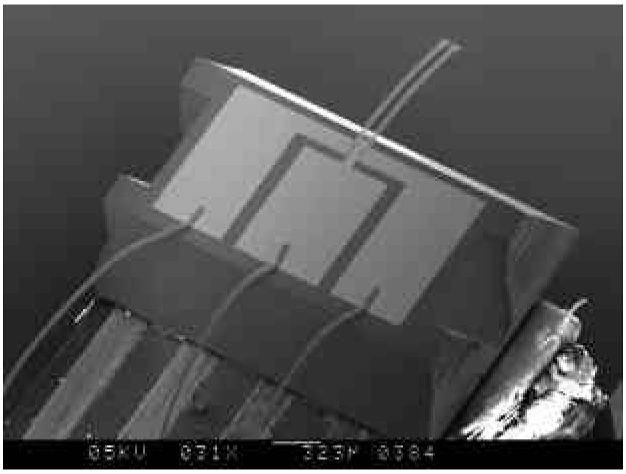

Fig. 2: Scanning electron microscope (SEM) photo of a cantilever type of Microflown. The two wires that are sticking out are the actual Microflown, the three squares are the “bondpads” that are used to make electrical connections and the three wires in the lower part of the picture are wirebonds: aluminium wires that are 80 micron in diameter.

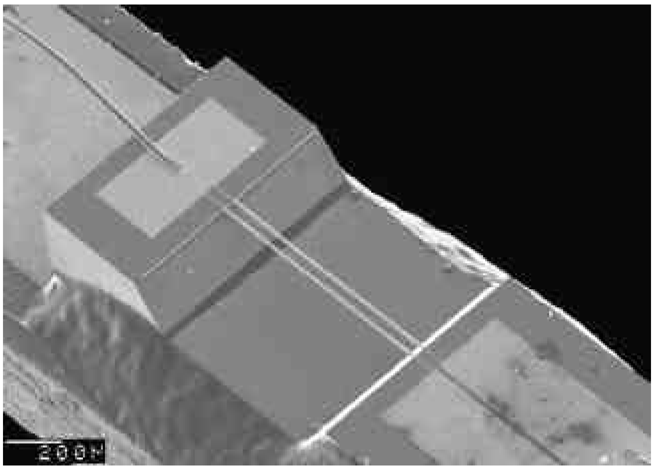

Fig. 3: SEM photo of a part of a bridge type of Microflown. At the top of the sample a wire-bond is visible. The sample is glued on a printed circuit board, the glue can be seen at the side of the sample.

The first Microflown was fabricated as a cantilever type. At that time it was assumed that the sensing-wires had to be free in the sound field. The package gain effect (see below, “working principle”) however showed that: the wires should be close to a rigid boundary and to create a high corner frequency (i.e. sensitivity for high tones) the wires should be made as thin as possible. The bridge type is used nowadays because it can meet these requirements. The sensor wires are clamped at both sides resulting an improved mechanical stability. The length of the sensors is 1mm, the width is 5µm and the thickness is 200nm platinum plus 150nm silicon-nitride.

Microflowns have three wire-bonds that take care of the electrical connections. The wire-bonds are bonded in a standard ultrasonic manner to the platinum bondpads.

The fabrication of Microflowns in a cleanroom requires a certain number of standard process steps. Before any process is allowed to start, wafers need to be cleaned. This is both to avoid contamination of equipment and to be sure that processes are starting with fresh wafers. After cleaning, a thin (300nm) silicon-nitride layer is deposited on the wafer. This layer is used as a mask for the wet chemical etching and as a carrier for the sensors (Fig. 5a).

The wafer is now covered completely with a silicon nitride layer and on one side a photolithographic (or photoresist) layer is deposited. This layer is deposited as a liquid on the wafer as it is spinning at a certain speed. The rotation speed and viscosity of the photoresist liquid define the thickness of photoresist.

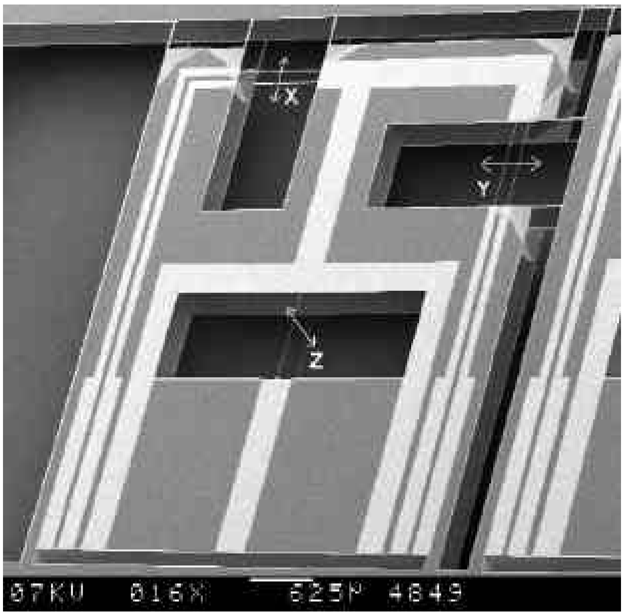

Fig. 4: Realisation of a three dimensional Microflown, the z-direction is a through the waver type of Microflown.

After the wafer is heated to harden the photoresist it is put under a mask and illuminated. The pattern that is illuminated will be removed by the development of the photoresist layer.

To create the sensors and bondpads, a (200nm) platinum layer is deposited with a sputter technique. This layer will be the actual sensor layer and bond-pads to establish electrical connections to the printed circuit board. The platinum layer is patterned with a lift off technique: only where the photoresist layer is removed the platinum layer will remain (Fig. 5b).

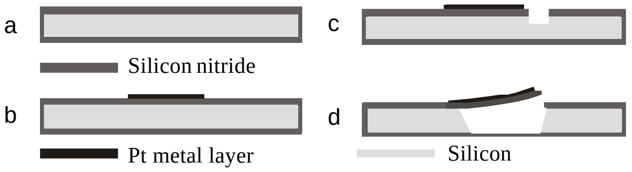

Fig. 5: Schematic production steps of the cantilever Microflown.

When the patterned platinum layer is ready, the silicon nitride layer is etched. In this way the wet chemical etchand is able to set the cantilevers free. Before this can take place, again photolithography step has to be completed. The place where the photoresist layer is removed, the silicon nitride layer will be removed too. The silicon nitride layer is removed by reactive ion etching (Fig. 5c).

Wet anisotropic wet chemical etching (KOH) will create the channel and will set the cantilever bridges free (Fig. 5d).

Working principle

The operation principle is briefly explained here, a more detailed mathematical model of the Microflown model is presented in [4] and [5].

The temperature sensors of the Microflown are implemented as platinum resistors and are powered by an electrical current dissipating an electrical power causing it to heat-up. An increase of the temperature of the sensors leads to an increase of the resistance as well. If no particle velocity is present the sensors will have a typical operational temperature of about 200ºC to 400ºC and all the heat is transferred in the surrounding air. When particle velocity is present, it asymmetrically alters the temperature distribution around the resistors. The temperature difference of the two sensors quantifies the particle velocity.

Low frequency sensitivity (LFS)

A single wire can also be deployed as a velocity sensor, however the underlying principles of anemometer and Microflown operation are different. To explain the operation of the Microflown, first only one wire is examined.

The anemometer operates due to the convective cooling down of the wire. It operates from 1cm/s upwards (in air) for which Kings law applies (the cooling down is proportional to the square root of the velocity). An anemometer cannot distinguish between positive and negative velocity direction.

For lower air velocities the wire will not cool down and Kings law does not apply. Although it does not cool down, due to the convection, the temperature distribution around the hot wire will alter. To calculate this due-to-convection-altered temperature profile, perturbation theory can be used [4], [5].

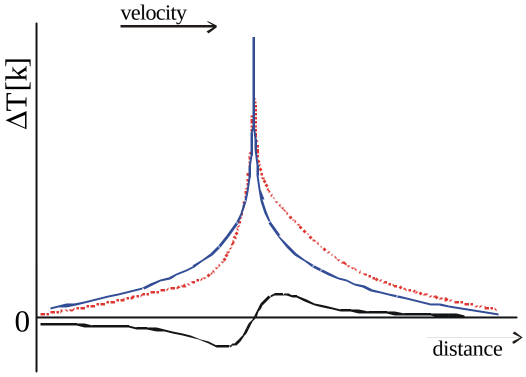

Fig. 6: The temperature distribution around one wire. Solid line: no flow, dotted line: due to convection perturbed temperature profile. The lower line is the perturbation due to small convection, at the position of the wire the perturbation is zero: the wire will not cool down.

A Microflown consists of two heated wires. It operates in a flow range of 100nm/s up to about 0.1-1m/s. A first order approximation shows no cooling down of the sensors. Particle velocity causes the temperature distribution of both wires to alter and the total temperature distribution causes both wires to differ in temperature; because it is a linear system, the total temperature distribution is simply the sum of the temperature distribution of the two single wires.

Due to the convective heat transfer, the upstream sensor is heated less by the downstream sensor and vice versa. Due to this operation principle, the Microflown can distinguish between positive and negative velocity direction.

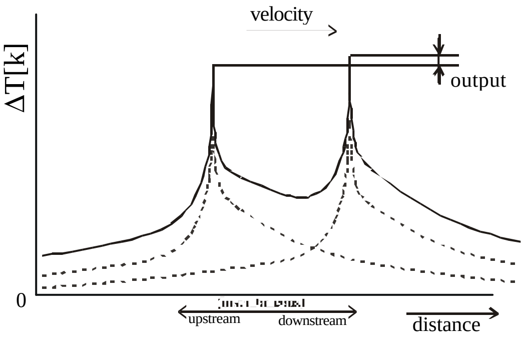

Fig. 7: Dotted line: temperature distribution due to convection for two heaters. Both heaters have the same temperature. Solid line: sum of two single temperature functions: a temperature difference occurs.

Two forms of heat transport play a role; heat diffusion and convection (radiation is negligible here).

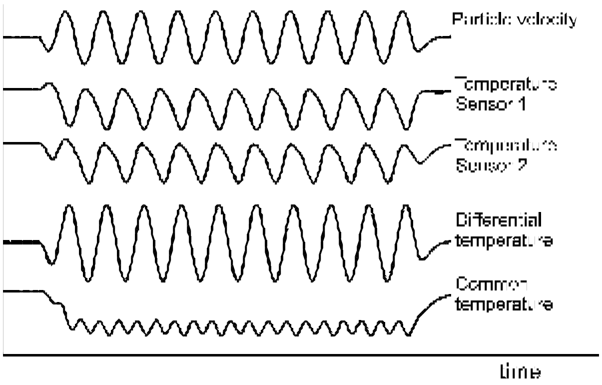

Fig. 8: Measured temperatures of the Microflown due to an acoustic disturbance. Due to particle velocity both temperature sensors cool down but in a different manner. The temperature difference is proportional to the particle velocity. The sum signal (common signal) represents a sort of hot wire anemometer and measures the common temperature drop. It has an illustrative double frequency that is common for hot wire anemometry.

For large sensor spacing, the effects of the (one-dimensional) convective heat transfer (due to particle velocity) is reduced by the (three-dimensional) diffusion. In other words, for a large sensor spacing, the convective heat transfer does not reach the other sensor and because of this the temperature of the sensors will not alter (the perturbation is zero for large distance, see Fig. 6).

If the sensors are brought very close to each other, almost no temperature differences are possible since a temperature difference results in a relatively large diffusion heat transfer in the opposite direction.

Temperature variations of the two sensors due to a high level sound wave (in this case both wires cool down as well) are shown in Fig. 8.

Frequency response

At higher frequencies the sensitivity of the Microflown is decreasing. This high-frequency roll-off is caused by diffusion effects (to which the time it takes heat to travel from one wire to the other is related). The effect can be estimated by a first order low pass frequency response that has a (diffusion) corner frequency (f_d) in the order of 500Hz-2kHz (depending on geometry and operating temperature).

The second high frequency roll-off is caused by the heat capacity (thermal mass) and shows an exact first order low pass behaviour that has a heat capacity corner frequency ($f_{heat\ cap}$) in the order of 2kHz to 15kHz for modern Microflowns (depending on geometry and operating temperature). These effects are explained in more detail in [4] and [5].

A good approximation of the frequency response of a Microflown can be described with:

$$output = \frac{LFS}{\sqrt{1+f^2/f_{heatcap}^2}\sqrt{1+f^2/f_d^2}} \qquad (1)$$

LFS being the low frequency sensitivity, the output signal at frequencies below the thermal diffusion corner frequency.

The underlying model of the frequency dependent behaviour due to the diffusion effects is represented by a complex expression containing a Bessel function. Regarding the frequency response this expression can quite well be approximated by a first order low pass behaviour, however such a simple model cannot describe the phase response [4], see further below: "the ½" ICP Microflown".

Package gain

Apart from protection of Microflown's fragile sensors packaging has several effects. The particle velocity level rises considerably (10dB to 30dB depending on geometry) and the phase response slightly alters.

The increase of particle velocity level inside the package (the so-called package gain) is mainly caused by a channelling effect, the particle flow is 'forced' through the package.

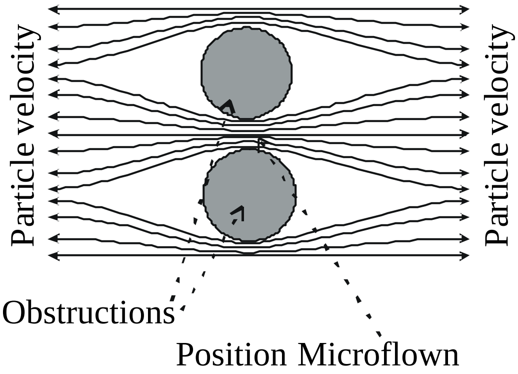

Fig. 9: A well-chosen package will result in a particle velocity gain (top view).

Fig. 10: An example of a package with a gain of 9 to 13dB: the half-inch particle velocity probe.

Fig. 11 shows the phase and amplitude response of the ½" package.

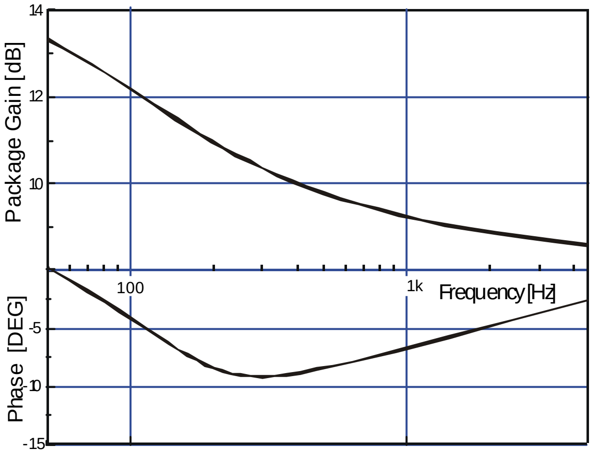

Fig. 11: Phase and amplitude response of the package of a half-inch particle velocity probe.

Electronics

The preamplifier for the Microflown has to fulfil two needs: it has to power the Microflown (to heat the sensors) and it should convert only the differential resistance variation into an appropriate output signal.

The electronic circuit depicted in Fig. 12 can fulfil these demands.

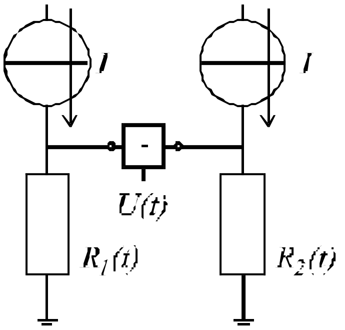

Fig. 12: Measuring a differential resistance variation (R_1 and R_2 are the sensor wires of a Microflown).

The variation of the resistors due to sound is denoted as *DR*, the non-varying part as *R*, which for one wire yields:

$$R(t) = R + \Delta R = R \cdot \left(1 + \frac{\Delta R}{R}\right) \tag{2}$$

For two wires with nominal value $R_1 = R_2 = R$ the output signal for differential resistance variations equals:

$$\begin{aligned} &U(t) = U + DU = \\ &IR_1\left(1 + \frac{DR_1}{R_1}\right) - IR_2\left(1 + \frac{DR_2}{R_2}\right) = 2IR\frac{DR}{R} \end{aligned} \tag{3}$$

The common resistance variations are suppressed. The relative differential resistance variation *DR/R* is defined as:

$$\frac{\Delta R}{R} = \frac{R_1(t) - R_2(t)}{R} \tag{4}$$

The signal to noise ratio of this circuit is given by:

$$\begin{aligned} \frac{S}{N} &= \frac{2IR\frac{DR}{R}}{\sqrt{4kTR_1Bw + 4kTR_2Bw}} \\ &= \frac{1}{\sqrt{4k}} \cdot \frac{1}{\sqrt{Bw}} \cdot \sqrt{\frac{2P}{T}} \cdot \frac{DR}{R} \end{aligned} \tag{5}$$

Where *2P* is the total power dissipation in the Microflown (so the dissipation in both wires), T the absolute temperature, *k* Bolzmann’s constant and *Bw* the bandwidth. It shows that the signal to noise ratio of differential varying resistors is dependent on the power dissipated in the resistors and the temperature of the resistors, not of the resistor value itself.

1/f noise is dominant under frequencies below 1 to 10kHz but it is not taken into account in this model.

CE gadget

A circuit that has been used frequently is the common emitter CE configuration [3], see Fig. 13.

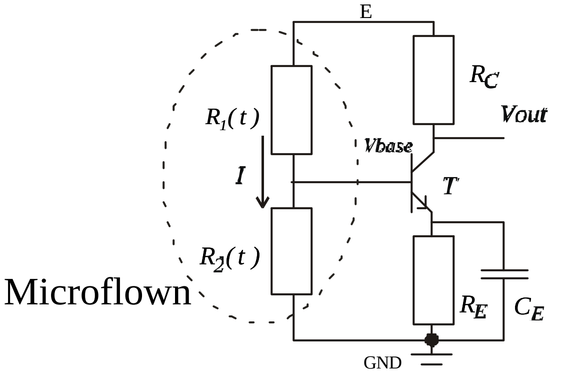

Fig. 13: CE configuration with a half Wheatstone bridge as input.

The Microflown is configured as one half of a Wheatstone bridge. The transfer function is defined as:

$$V_{base} = \tfrac{1}{2}E + IR\frac{DR}{R} \tag{6}$$

Common resistance variations are suppressed due to the nature or the circuitry. The total transfer function for differential resistor variations is then given by:

$$V_{out} = 19.3 \cdot E \cdot V_{Rc} \frac{DR}{R} \tag{7}$$

If the base series resistance is chosen much smaller than the nominal (hot) resistance of the Microflown, the circuit will not significantly add to the total noise and the signal to noise ratio will remain at the optimal value as stated in Eq. (5). A disadvantage is the low power supply rejection ratio and a stable power supply (for example a battery) is therefore advisable.

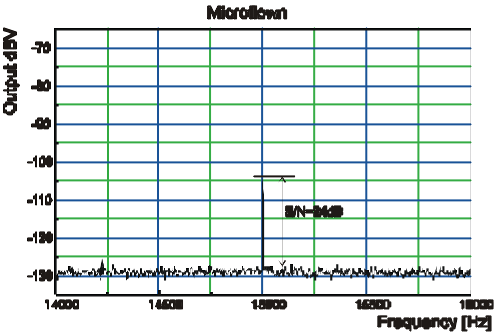

Fig. 14: A pure sine tone of 15kHz and 62dB PVL was measured by a ½” ICP probe.

As an example a pure sine tone of 15kHz and 62dB PVL (re. 50nm/s) was measured by a ½” probe. The signal to noise ratio is 24 dB so 40dB sound can still be measured at these frequencies. The autospectrum of the signal is depicted in Fig. 14.

The ½”ICP Microflown

One of the most used velocity probes is the ½” ICP Microflown. It operates on a ICP powering which means that it is powered with a 4mA DC current and it has a voltage readout (the maximal voltage is 27V). It can be used op to approximately 100dB PVL (re. 50nm/s). (in a plane wave a certain PVL in dB corresponds to the same amount number of SPL in dB re. 20µPa).

Frequency response/ signal to noise ratio

The frequency response of the ½” ICP probe can be modelled by:

$$Output = \frac{245mV}{\sqrt{\left(1+\left(\frac{10}{f}\right)^2\right)\left(1+\left(\frac{f}{600}\right)^2\right)\left(1+\left(\frac{f}{2600}\right)^2\right)}} \tag{8}$$

The circuitry has a DC filtering that has a 10Hz low frequency roll off. The diffusion corner frequency is 600Hz and the thermal mass corner frequency is 2.6kHz.

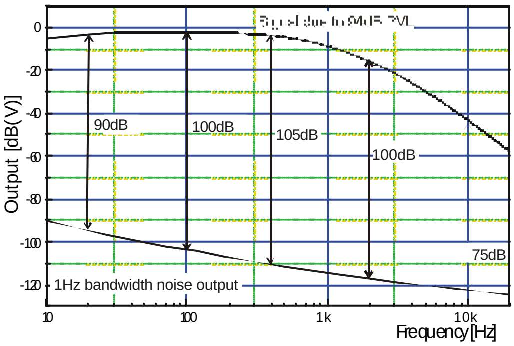

Fig. 15: Measured output of a ½” ICP Probe: the signal is due to 94dB PVL, the noise spectrum is given in dB(V)/√Hz.

Phase response

The phase response of an un-packaged Microflown cannot be modelled by a second order low pass system. Furthermore the package influences on the phase response, see Fig. 11. The phase response can only be determined by a calibration measurement. The phase response of a half-inch ICP probe is depicted below and can be fitted by:

$$Phase = -1.52 \cdot tg^{-1}\left(\frac{f}{914}\right) \tag{9}$$

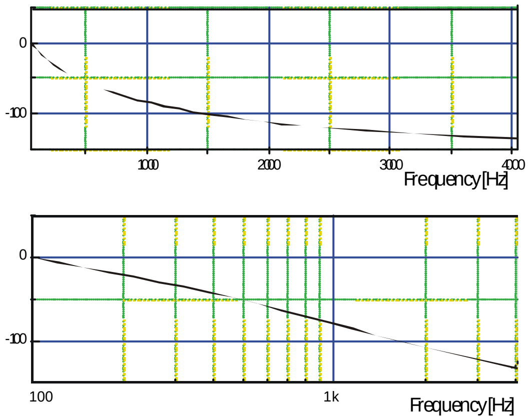

Fig. 16: Phase response of a half-inch ICP probe.

Polar pattern

Since the Microflown is sensitive for particle velocity, a vector value, the polar pattern (directionality) has a cos(θ) or a figure of eight response. Measured responses at different frequencies are depicted below.

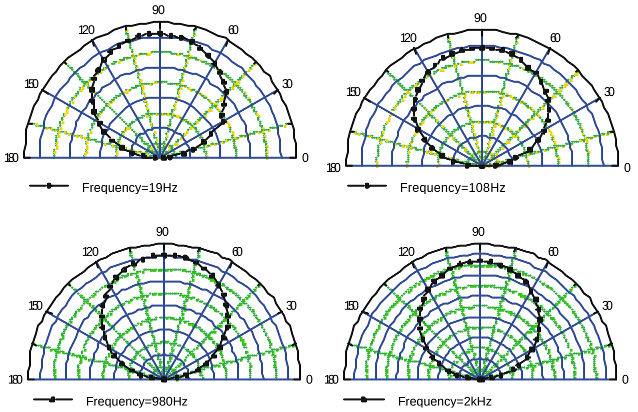

Fig. 17: Polar patterns of a ½" ICP Microflown at different frequencies (linear scale, only half the response is measured).

Calibration

Since a reference particle velocity microphone does not exist, the main concern calibrating the Microflown is to provide a known particle velocity for the probe. Measuring the sound pressure in a configuration for which the specific acoustic impedance is known solves this problem. The particle velocity is calculated from the quotient of the sound pressure and the specific acoustic impedance.

Several calibration methods to determine the frequency response of the Microflown have been tested over the years. Three methods came out best: an anechoic calibration, a standing wave tube (SWT) calibration and a time frame method in a long tube [3], [8], [15]. The SWT method is used mostly and will be explained below.

Standing wave tube (SWT)

In a tube the sound waves are plane below the cut-off frequency:

$$f_c = \frac{c}{1.71 \cdot d} \tag{10}$$

Using d as the diameter of the tube and c the speed of sound. The sound wave can only travel in one direction. In a standing wave tube, a rigidly terminated tube with rigged sidewalls, all the sound is reflected at the end of the tube [15].

The specific acoustic impedance inside the SWT can be calculated by solving the wave equation. The air is excited by a piston (or a loudspeaker) with amplitude U at the left-hand end and is terminated by a rigid boundary at the right hand end, see Fig. 18.

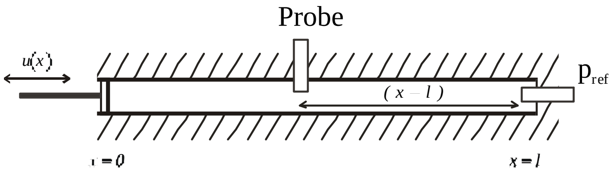

Fig. 18: A tube that is rigidly terminated at x=l and in which the fluid is driven by a vibrating piston at x=0.

The ratio of the particle velocity ($u_{probe}=u(x)$) and the sound pressure at the end of the tube is given by:

$$\frac{u_{probe}}{p_{ref.}} = \frac{i}{rc}\sin(k(l-x)) \tag{11}$$

The relation of the particle velocity and the reference sound pressure at the end of the tube turns out to be a simple sine function. The phase shift between them equals plus or minus 90 degrees.

If thermal viscous effects (damping) are taken into account, Eq. (11) will alter in to [16]:

$$\frac{u_{probe}}{p_{probe}} = \frac{i}{rc}\frac{\sinh G(k(x-l))}{G} \tag{12}$$

With G the viscothermal wave propagation coefficient, given by:

$$G = i + \frac{1+i}{\sqrt{2}}\left(\frac{g-1+s}{ss}\right) \tag{13}$$

Here g=1.4 represents the ratio of specific heat of air, s=0.845 the square root of the Prandtl number and s the shear wave number. For s yields:

$$s = \frac{d\sqrt{w}}{2}\sqrt{\frac{r}{m}} = 346d\sqrt{f} \tag{14}$$

With $\mu=17.1\cdot10^{-6}$ [Pa·s] the dynamic viscosity and $\rho=1.3$ [kg/m^3] the density. To use this model the shear wave number must be much larger than unity, which is in practical cases true. The viscothermal wave propagation coefficient can be simplified to:

$$G = i + \frac{1+i}{332d\sqrt{f}} \tag{15}$$

As can be seen, for higher frequencies or large diameters, G will reach i and Eq (12) will simplify to Eq. (11).

A set of standing wave tubes of acceptable dimensions can be used from 15Hz up to 4kHz. An 8 meters tube and 15cm diameter has a frequency span from 15Hz up to 1kHz and a 75cm, 5cm diameter tube has a frequency span from 100Hz up to 4kHz. For higher frequencies a small ($1m^3$) anechoic room is used, see Fig. 19.

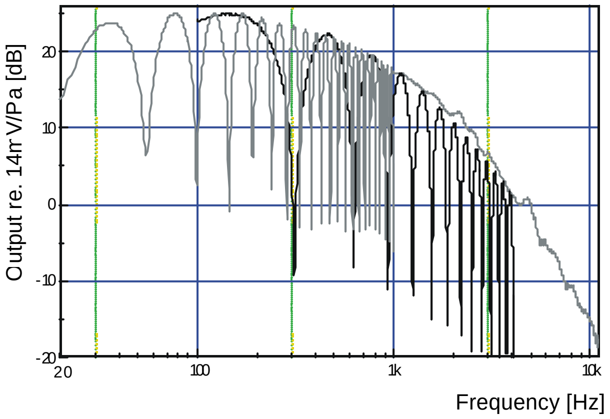

Fig. 19: amplitude response of ½" ICP probe in a large (8m/16cm) standing wave tube (grey line, 20Hz-1kHz), in a short (75cm/4,5cm) standing wave tube (black line, 100Hz-4kHz) and in a small ($1m^3$) anechoic room (grey line, 1kHz-12kHz).

Fig. 19 shows an amplitude calibration result of a ICP probe. For frequencies below 4kHz the SWT calibration is used. Corresponding to Eq. (11), it has a modulus sine response. At the maximums the sine function values unity and the calibration result is in fact anechoic.

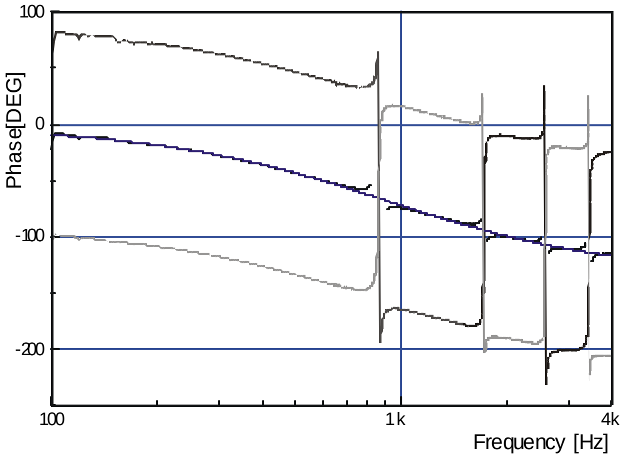

Fig. 20: Phase response of a ½" ICP probe. Solid black: in phase, solid grey out of phase, in between them: average of in and out of phase and the model.

The phase shift between particle velocity and sound pressure in a standing wave tube is ±90°. The phase shift between a sound wave coming from the front and from or behind a Microflown equals 180°. So if the two phase-responses in a standing wave tube are measured and averaged, the free-field phase response theoretically obtained, see Fig. 20. Only at the frequencies where the tube-response shifts from +90° to -90°, the average value seems to ripple. This is caused by the damping of the tube [16].

Applications

Applications of the Microflown are found where the features of the sensor are valued most. Its ability to determine particle velocity in a simple reliable manner makes the sensor a powerful tool in sound intensity, acoustic impedance and sound energy measurements.

Its directionality and high signal to noise ratio at lower frequencies are exploited in the high-end sound recording applications.

Because of its construction techniques (compatible to integrated circuit) and it miniature size it is suitable for mass-market applications like mobile telecom and smartcards.

Acoustic impedance

Only a few months after its invention the Microflown was used for the determination of acoustic input impedance (i.e. the ratio of sound pressure and particle velocity) of a horn loudspeaker. Major conclusion was that direct measurement of horn input acoustic impedance is performed faster, easier, and more accurate by using a Microflown [12].

The Microflown is also successfully used in standing wave tube set-ups for determination of the reflection coefficient of acoustic materials. First experiments showed that the results of Kundt's tube (that operates with two microphones) could be repeated with two Microflowns with satisfactory results [9]. Later research showed that it is possible to determine the reflection coefficient in a different way.

Imagine the sample in the tube is fully sound reflecting, so all the sound put into the tube is reflected at the end. The sound intensity (the net flow of sound energy in one direction) in the tube is therefore zero. If on the other hand the sample is fully sound absorbing, the sound intensity will be large, depending on the amount of noise that is generated by the loudspeaker. The loudness can be determined by other acoustic quantity, the sound energy density. The ratio of the intensity and the energy is a measure for the reflection coefficient. Both sound energy and sound intensity are measured by the use of a microphone and a Microflown at the same position in the tube [10].

Sound intensity

Sound intensity is defined as the time averaged product of the instantaneous pressure *p(t)* and the corresponding instantaneous particle velocity ***u(t)*** at the same position:

$$\boldsymbol{I} = \frac{1}{T}\int_0^T p(t)\cdot \boldsymbol{u(t)}\,dt \qquad (16)$$

where the intensity ***I*** and the velocity ***u*** are vectors.

The combination of a microphone and Microflown makes it possible to measure broadband (10Hz-20kHz) sound intensity (and sound energy and acoustic impedance) in a simple and straightforward manner.

A p-u sound intensity probe is created by a miniature microphone that is placed nearby the Microflown, see Fig. 21.

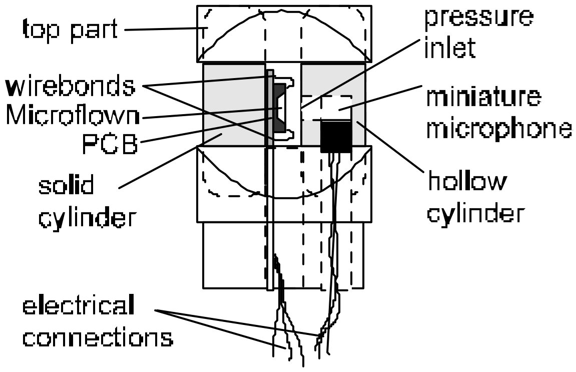

Fig. 21: Schematic drawing of the half-inch p-u sound intensity probe.

Advantages of this p-u sound intensity probe are:

(1) The complete acoustic spectrum can be measured at once.
(2) The same accessories (mountings, windscreen etc.) as a half inch microphone can be used (it is simply one ½" probe)
(3) No special analyser is needed, the soundcard of a PC can be used. (Free software can for instance be obtained at [17])
(4) Simple calibration tools are available.
(5) The p-u sound probe is low cost.

Influence of wind

The Microflown is a DC flow (wind) sensor so the influence for wind is supposed to be substantial. The use of a traditional windshield however will suppress the influence of wind [6], [19].

In an anechoic room the intensity was determined using one sound source (loudspeaker) at a distance of 1.2m and a fan at a distance of 1.0m from the intensity probe; the loudspeaker and the fan were at opposite sides of the probe. When the fan was switched on the wind velocity at the intensity probe was about 3.4 m/sec. Difference in intensity (with/without wind) is depicted below.

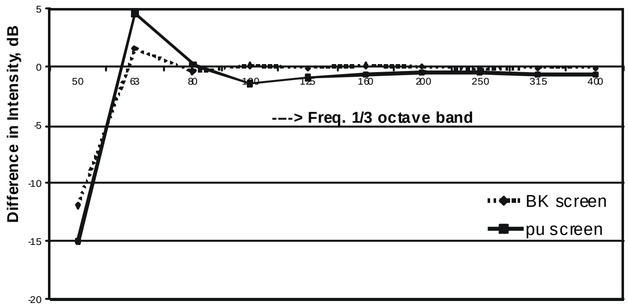

Fig. 22: Difference in intensity, influence of 3.4m/s wind.

Signal to noise ratio p-u probe

The signal to noise ratio (S/N) of a p-**u** sound intensity probe is much higher than the S/N of the auto-spectrum of separate probes. This is related to the fact that the cross-spectrum of two non-correlated noise sources (the selfnoise of the microphone and Microflown) is theoretically zero.

Fig. 23 shows the noise level of a calibrated half inch p-**u** probe given in dB SIL and measured in 1Hz bandwidth (sound intensity level has a reference of 1pW; in a plane wave a certain SIL in dB corresponds to the same amount number of SPL in dB).

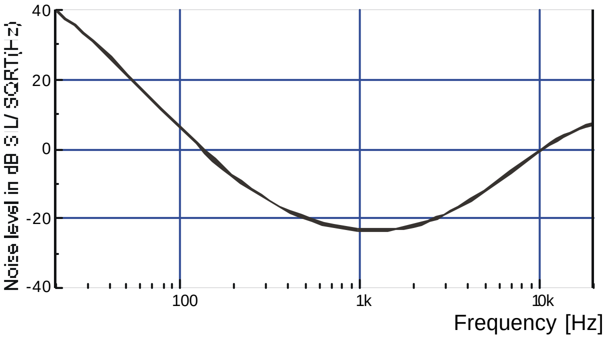

Fig. 23: Noise level of a half inch p-**u** probe in dB SIL (re. 1pW)/vHz.

For all frequencies sound levels well below the threshold of hearing can be measured with this ½" p-**u** sound intensity probe.

3D p-u intensity

A one-dimensional p-**u** sound intensity probe can be extended to a three-dimensional probe using three Microflowns and a pressure microphone (p-**u**^{3}). All the probes are still in one plane, see Fig. 24. The advantage of this is that the p-**u**^{3} sound probe can be positioned near to a sound source (the p-**u** method can also be used in the near field) and the probe can measure up to 20kHz. The set-up has been tested with positive results [7].

In the near future a miniature three-dimensional sound intensity probe can be expected that is based on a three-dimensional Microflown and a miniature sound pressure microphone. An example of a three-dimensional Microflown is depicted in Fig. 25.

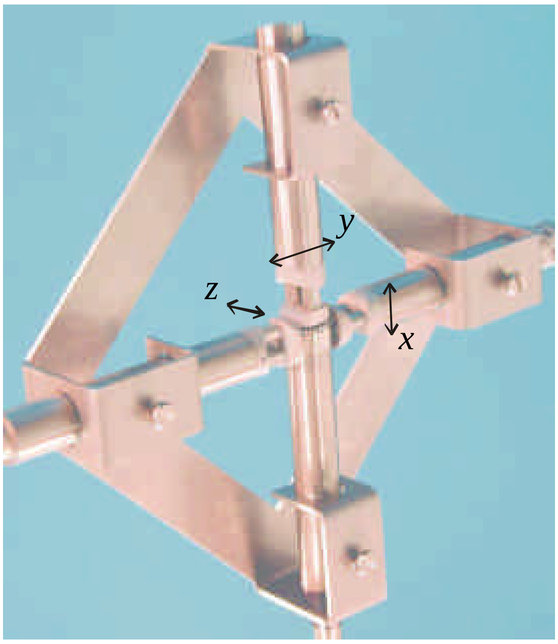

Fig. 24: Three dimensional p-u sound intensity probe based on half-inch probes.

u-u: sound pressure probe

In a similar manner as the particle velocity can be determined by the sound pressure gradient, the sound pressure can be determined by measuring the particle velocity gradient (by using the linearised equation of mass conservation) [13].

$$p(x,t) = -\frac{\rho c^2}{\Delta x}\int u(x+\Delta x,t) - u(x,t)dt$$

The spacing between the Microflowns is Δx and should be small compared to the wavelenght of interest. It may be remarkably that the sound pressure that is determined has a $\cos^2(\theta)$ polar pattern.

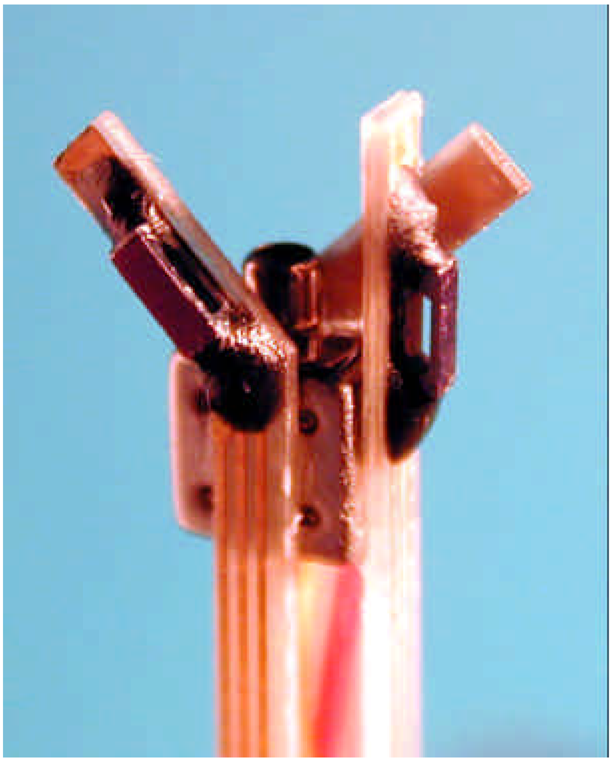

Fig. 25: Realisation of an ultra-miniature three-dimensional sound (intensity) probe (5×5×5mm).

With the use of a u-u probe sound intensity can be determined in a similar manner as the traditional p-p probe. The polar pattern however will not be the traditional figure of eight ($\cos(\theta)$) but a $\cos^3(\theta)$ shape. See further below “velocity gradient Microflown”.

III sound reproduction

Several applications in the sound reproduction have been found and examined.

Helmholz sound pressure probe

A Microflown has been packaged in such way that is able to detect (omni directional) sound pressure instead of particle velocity. The usable bandwidth is 3.4kHz which makes is suitable for mass markets like mobile telephones and toys [14].

Add on Microflown

The bandwidth of sound covers three decades: 20Hz-200Hz, 200Hz-2kHz and 2kHz-20kHz. A conventional, high-end pressure gradient microphone can cover only the last two decades. The signal to noise ratio of a pressure gradient microphone is low at lower frequencies. This is related to the fact that at lower frequencies the signal is decreasing (due to the reduced pressure gradient) and noise is increasing (due to 1/f noise). Compared to a pressure gradient microphone, the Microflown has a relative high signal to noise ratio in the lower two decades ($S/N_{re.1Pa}$>100dB/$\sqrt{Hz}$) and the directionality remains. The polar pattern of both types of microphones is similar; a figure of eight. To reach a full bandwidth, the Microflown will be used to pick up frequency sound waves up to 250Hz, whereas a high quality pressure gradient microphone (a MK8 Schoeps) is used to cover the 250Hz to 16kHz bandwidth. The preamplifier of the add-on Microflown is designed to operate on the standard 48V Phantom powering.

The add-on Microflown has been realised and its sensitivity adjusted to that of the pressure gradient microphone. The full-band velocity microphone assembly is tested in a Blumlein configuration [11].

Velocity gradient Microflown

With two closely spaced Microflowns, velocity gradient can be measured and with this gradient the sound pressure can be determined. The polar pattern of this sound pressure has a $\cos^2(\theta)$ shape. The sum of both closely spaced Microflowns has still a $\cos(\theta)$ shape. The sum of the calculated sound pressure and the average particle velocity will create a unidirectional microphone (that can only be used at lower frequencies).

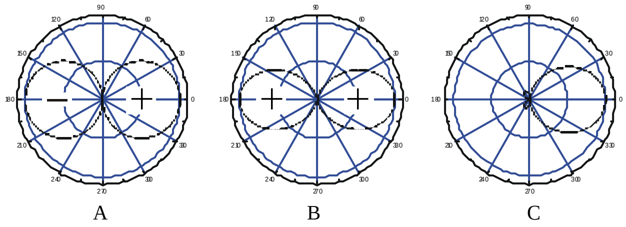

Fig. 26: With the use of a velocity gradient method a low frequency unidirectional microphone can be realised.

If, using this method, “40% calculated sound pressure” and “60% particle velocity” is applied, a low frequency super cardioid will be created.

Mobile telecom

For mobile applications the small size and silicon based production technique of the Microflown are the mayor benefits. Because of this, the Microflown can be incorporated on a chip. In that way a one chip GSM mobile telephone can be realised for instance. This saves space and mounting and costs.

In the limited bandwidth of speech (3400Hz-3.4kHz) the selfnoise is 30dB(A) at 10mW power dissipation.

References

(Papers can be found at [17])

[1] H-E. de Bree, P. Leussink, T. Korthorst, H. Jansen, T. Lammerink, M. Elwenspoek, **The Microflown; a novel device measuring acoustical flows**, Sensors and Actuators: A, Physical, volume SNA054/1-3, pp 552-557, 1996.

[2] H-E. de Bree, Lammerink, Elwenspoek, Fluitman, **Use of a fluid flow-measuring device as a microphone and system comprising such a microphone, Patent PCT/NL95/00220, 1995.**

[3] H-E de Bree, **The Microflown**, Ph.D. thesis, ISBN 9036509262, 7 February 1997.

[4] J.W. van Honschoten, G.J.M. Krijnen, V.B. Svetovoy, H-E. de Bree, M.C. Elwenspoek, **Optimisation of a two-wire thermal sensor for flow and sound measurements**, MEMS Interlagen 2001

[5] V.B. Svetovoy, I.A.Winter, **Model of the µ-flown microphone,** Sensors &Actuators 86 (2000), 171-181.

[6] W.F. Druyvesteyn, H-E. de Bree, **A new sound intensity probe; comparison to the Bruel & Kjaer p-p probe**, J. audio Eng. Soc., Vol. 48, 2000 No. 1/2 January/February.

[7] W.F. Druyvesteyn, H-E. de Bree, **A New acoustic measurement probe; the Microflown**, IOA London, 1999.

[8] R.Raangs, H-E de Bree and W.F. Druyvesteyn, **a low cost sound intensity probe**, AES Amsterdam, 2001

[9] F.J.M. van der Eerden, H-E. de Bree, H. Tijdeman, **Experiments with a new acoustic particle velocity sensor in an impedance tube**, Sensors and Actuators A69, (1998) 126-133.

[10] H-E. de Bree, F.J.M. van der Eerden, J.W. van Honschoten, **A novel technique for measuring the reflection coefficient of sound-absorbing materials**, ISMA25, International Conference on Noise and Vibration, September 13-15, 2000 - Leuven, Belgium.

[11] H-E. de Bree, **Add-on Microflown for a high-end pressure gradient microphone**, presented at the 109th LA AES September, 2000 (no. 5181).

[12] H. Schurer, P. Annema, H.–E. de Bree, C. H. Slump and O. E. Herrmann, **Comparison of two methods for measurement of horn input impedance,** Published in the Proceedings of the 100th AES convention, Copenhagen, 1996.

[13] H-E. de Bree, T. Korthorst, P. Leussink, H. Jansen, M. Elwenspoek, **A method to measure apparent acoustic pressure, Flow gradient and acoustic intensity using two micromachined flow microphones, Eurosensors X, Leuven**, 1996.

[14] H-E. de Bree, Philip Ekkels, Dick Ekkelkamp, Gijs Krijnen, **The sound pressure Microflown; a novel way of transducing sound pressure**, presented at the MME convention in Sweden 2000.

[15] H-E. de Bree, W.F. Druyvesteyn, M. Elwenspoek, **Realisation and calibration of a novel half-inch p-u sound intensity probe**, 106th AES Munchen, 1999.

[16] J.W.van Honschoten, H-E. de Bree, F.J.M. van der Eerden, G.J.M. Krijnen, **The influence of viscothermal effects on calibration measurements in a tube**, presented at the LA AES 2000.

[17] **Www.microflown.com**

[18] L.G. Evers, H-E de Bree, H.W. Haak A.A. Koers, **The Deelen Infrasound Array for recording sonic booms and events of CTBT interest,** proceedings 9th int. meeting on Low Frequency Noise and Vibration, Aalborg, May 2000.

[19] H-E. de Bree, Henri V. Jansen, Theo S.J. Lammerink, Gijs J.M. Krijnen, Miko Elwenspoek, **Bi-directional fast flow sensor with a large dynamic range**, MME, 1998.