Micro-Flow Based Differential Pressure Sensor

Abstract:

Microbridge Technologies Canada, Inc has developed a micro-air-flow sensor, integrated on-chip with analog CMOS signal conditioning circuitry and with analog adjustability using Rejustors. The thermo-anemometer flow sensing principle, combined with a micro-flow channel having very high flow-impedance, allows accurate sensing of low differential pressures. The flow-impedance is pre-defined at the die-level, dramatically relaxing demands on subsequent packaging operations. Individual units require only simple offset and gain compensation, leaving barometric pressure correction and temperature correction to be implemented in "standard" post-sensor lookup tables. This enables field-replaceable micro-air-flow sensors, not requiring field calibration. The high flow impedance improves robustness vis-a-vis variability of connection hoses, changing gas filter properties, and humidified air, …. The technology enables substantial price-reductions with performance and ease-of-use improvements over present solutions.

Basic Thermo-Anemometer-Type Micro-Air-Flow Sensing:

Thermo-anemometer type micro-air-flow sensors have been well known for several decades. As shown in Fig. 1 (top view and side view), the air travels through a flow-channel, which guides the air over a central heating element, which locally heats a small volume of gas. The heated volume is displaced by the flow in one direction or the other, which in turn unbalances the temperatures in a pair of temperature-sensors, positioned symmetrically on each side of the heating element.

The speed with which the air flows through the flow channel is determined by the difference in pressure between the two ends of the flow channel, and by the flow-impedance of the flow channel, measured in (pressure-difference) per (flow rate in ml/s).

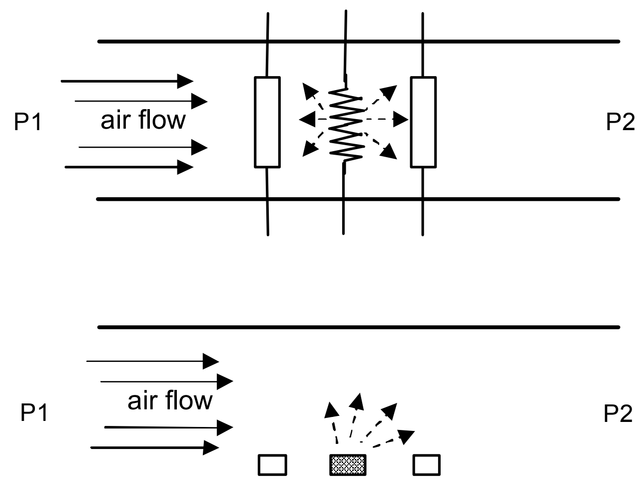

Fig. 1

Therefore, micro-flow sensors can be used as sensors for differential air pressure, as long as the pneumatic impedance of the micro-flow sensor is consistent enough unit-to-unit, and high enough to not overly affect the ambient pressures, P1 and P2, at the two ends of the flow channel (and high enough to minimize air leakage through the flow channel).

Microbridge's Integrated Micro-Air-Flow Sensor:

Fig. 2 conceptually summarizes Microbridge's integrated micro-air-flow sensor. As shown in the diagram, the chip consists of the thermo-anemometer-type (TA-type) sensing element, integrated flow-channel, and analog sensor conditioning circuit (1um CMOS), with Rejustors. The chip is approximately 1.7mm x 2.5mm. It is powered by 5VDC and provides analog outputs, Vout-a (including Offset and Gain adjustment) and Tsens (the on-chip-sensed ambient temperature).

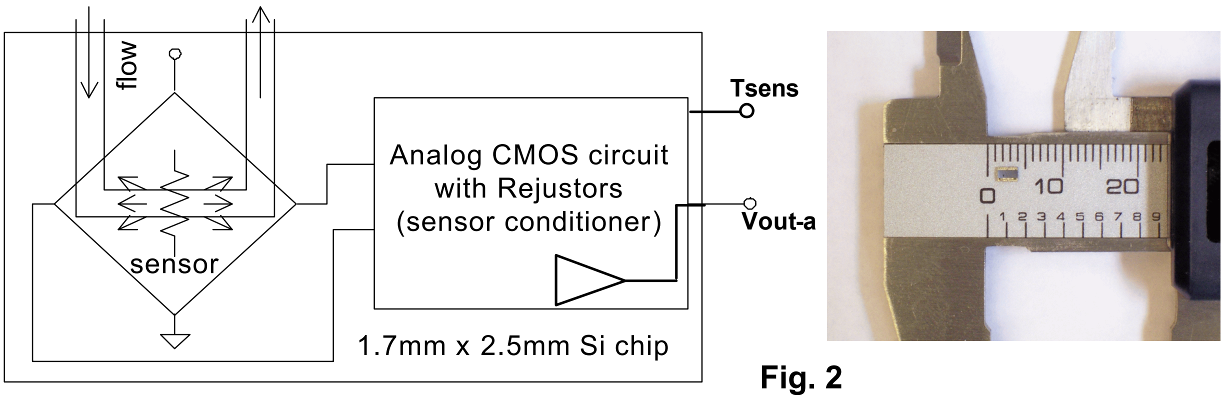

Fig. 2

The sensor conditioning circuit can be designed to provide low-Gain or high-Gain. Fine-calibration of manufacturing variations is done using Rejustors embedded within the analog CMOS circuit.

While the prototypes described in this article are powered by 5V, the technology also allows nominal supply voltages 2.5V to 5V for both sensor and CMOS.

High Flow-Impedances → Benefits:

The flow-impedance of Microbridge's sensor-die can be designed to be anywhere in a range ~1kPa/(ml/s) to ~200kPa/(ml/s). In this paper we consider two manufactured prototypes, called Type-A (25kPa/(ml/s)), and Type-B (60kPa/(ml/s)). These flow-impedances substantially exceed the presently-available ranges in the market.

High flow impedance is an important feature of micro-flow sensors, generally useful in many applications:

- Long tubing connections can be used without changing calibration, allowing the sensor to remain calibrated, even though it is used with differing tubing lengths/diameters, because the overall flow impedance is still dominated by the sensor flow channel geometry, not the tubing.
- It allows the use of gas filters whose flow-impedance is prone to change over time and use, since overall flow impedance is still dominated by the sensor flow channel geometry, not the gas-filter.
- In shunt configurations, there is low flow through the sensor, which makes the sensor easier to protect from contaminants.

Most importantly in the context of Microbridge's sensors, these high flow impedances substantially reduce demands on subsequent packaging operations, giving more flexibility with package types.

Packaging the Micro-Flow Sensor:

In most sensors presently in the market, the flow impedance is largely determined / affected by the packaging, which is prone to dimensional and alignment variations. Microbridge's sensors are far less affected by the package. Fig. 3 shows two generic examples of configurations suitable for packaging Microbridge's sensors.

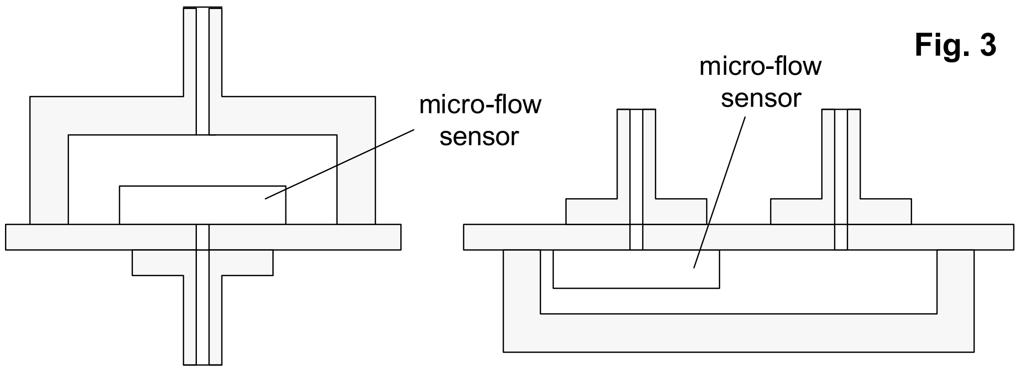

Fig. 3

Manufactured Prototype Micro-Flow Sensors Raw Un-Amplified Response:

As part of basic characterization of manufactured devices Fig. 4 compares the raw, unamplified response (in mV vs. differential pressure in Pa), of raw micro-flow sensor prototypes, Type-A and Type-B, described above. As expected due to its lower flow-impedance, Type-A sensors (sensors #1 and #2) have higher pressure-sensitivity than Type-B (sensor #3). The sensors have monotonic pressure-response in a wide pressure range:

- Type-A → up to 1500 – 2000Pa
- Type-B → up to >3000Pa.

Note that for Type-A, the curves become flatter for differential pressures greater than about 2000Pa. All of the sensors have non-linearity of sensitivity which is very typical for thermo-anemometers.

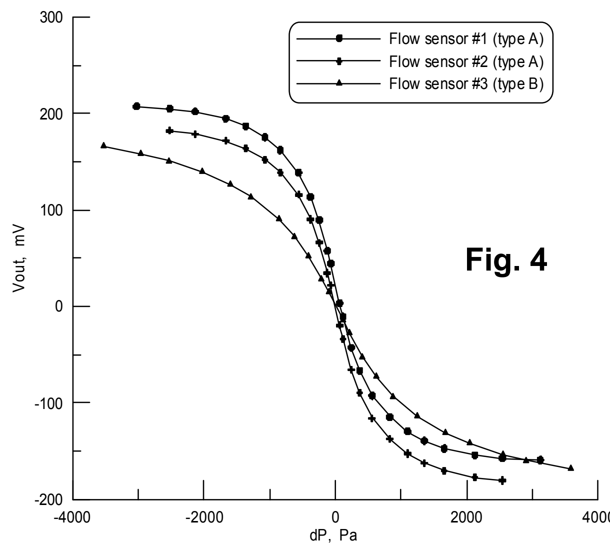

Fig. 4

Low-Gain-Amplified Micro-Flow Sensors Response After Offset and Gain Adjustment:

Fig. 5 shows sets of normalized and Offset-adjusted response curves for low-Gain amplified sensor prototypes. For Gain adjustment of Type-A sensors, the curves were all normalized to their values at 500Pa differential pressure, and for Type-B the curves were all normalized to their values at 2000Pa.

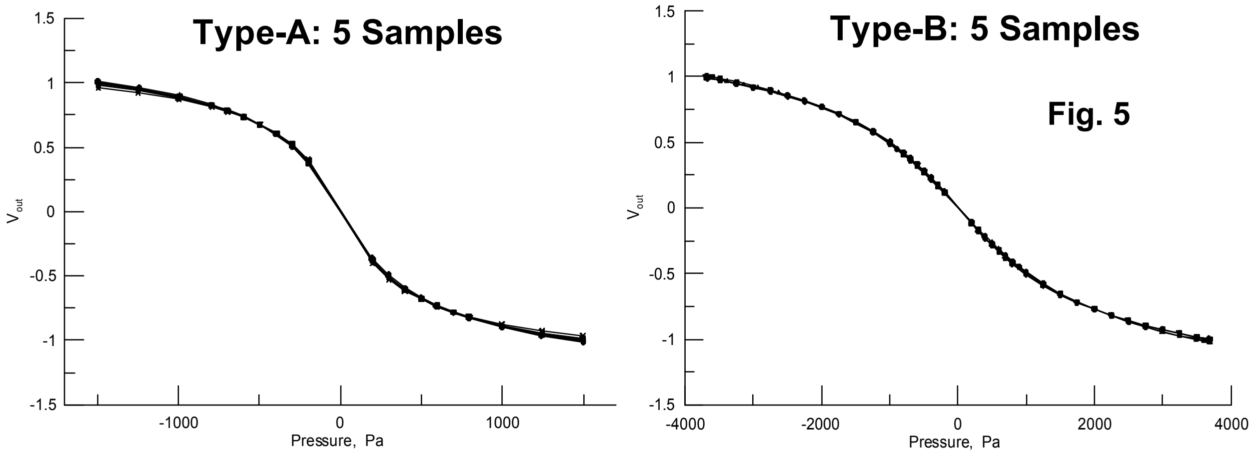

Fig. 5

All of the sensors have non-linearity of sensitivity, typical for thermo-anemometers. The characteristic curves are very reproducible, up to at least +/-1000Pa (Type-A) and at least +/-2000Pa (Type-B).

The normalized full-scale voltages can be scaled by design of the on-chip CMOS and Rejustors.

Application of Un-Amplified or Low-Amplified Micro-Flow Sensors:

Such un-amplified (or low-amplified) sensors are for applications (e.g. medical) needing high dynamic range such as ~10^4x and higher, and non-linear response approximately proportional to $(\text{pressure})^{0.5}$ at high differential pressures. In such cases, the characteristic non-linear response can be linearized using "standard" digital correction.

In order to evaluate the noise performance, the output signal of the raw un-amplified sensor (Type-A) was measured vs. time during 10s and 100s time-intervals. The measurements are shown in Fig. 6.

With discernible monotonic response from 0.1Pa up to 1500 to 2000Pa, the un-amplified sensor has dynamic range greater than 10^4x.

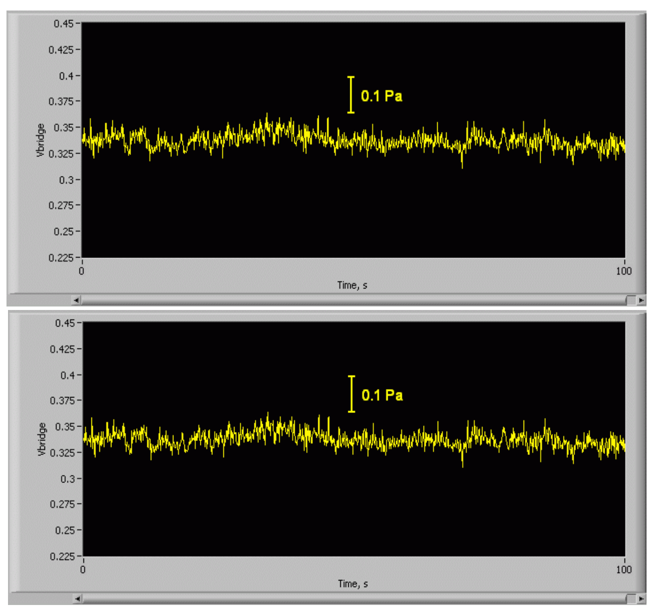

Fig. 6

Response of Amplified Micro-Flow Sensors After Offset and Gain Adjustment:

As indicated in Fig. 2, the manufactured micro-flow sensors have on-chip CMOS signal conditioning circuitry, including amplification. In this case, the signal can be amplified such that it saturates before any significant pressure-non-linearity (e.g. at +/-50Pa for Type-A, or at +/-250Pa for Type-B). The results measured at room-temperature are shown in Figs. 7 and 8. The Zero-Offsets have been compensated by trimming the associated on-chip Offset-Rejustors, and the Sensitivities have all been adjusted to a common value, by trimming the on-chip Gain-Rejustors. Within the 5 samples in each Type, the corrected linear curves are the same within 0.5%.

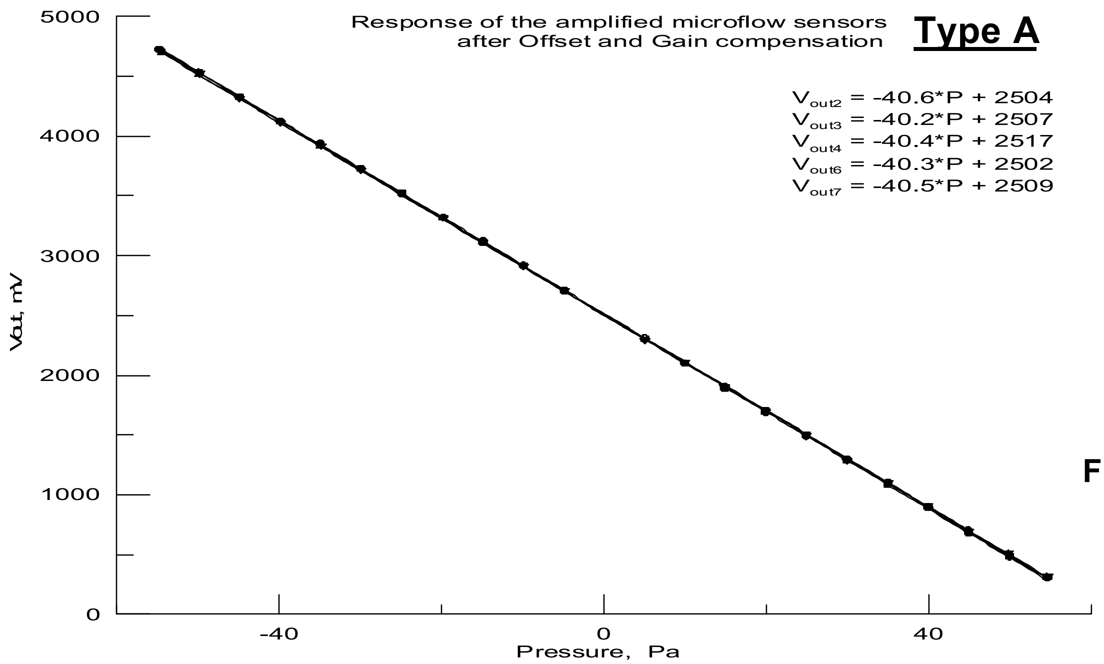

Fig. 7

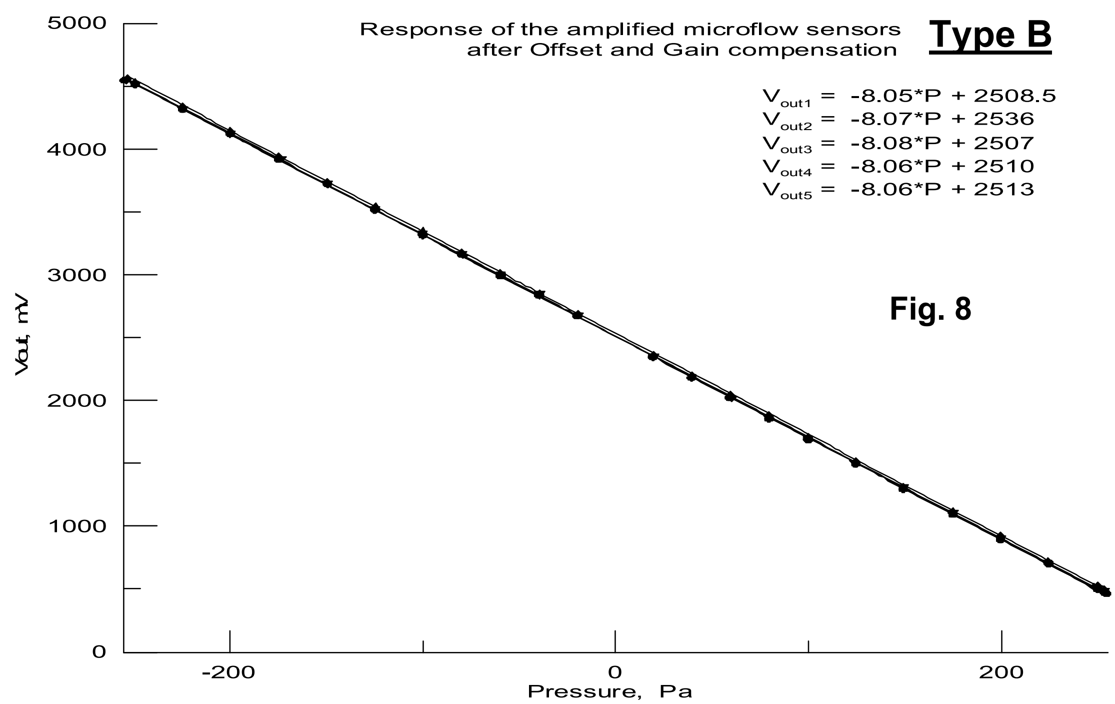

Fig. 8

In order to evaluate the noise performance, the output signal of the raw amplified sensor (Type-A) was measured vs. time during 10s and 100s time-intervals. The measurements are shown in Fig. 9.

With discernible monotonic response from 0.1Pa up to >50Pa, the amplified sensor has dynamic range greater than 10^2x.

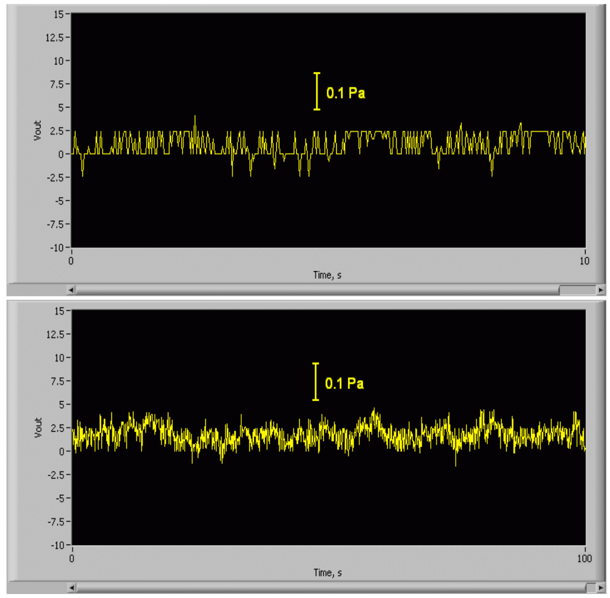

Fig. 9

Conclusion – Field-Replaceable Micro-Flow Sensors:

As discussed above, two modes of use are available:

- Mode-1: Un-amplified or low-gain amplified, for applications (e.g. medical) needing high dynamic range, ~10^4x and intentionally non-linear response, where the output varies roughly as the square-root of differential pressure at high differential pressures.
- Mode-2: Amplified such that the amplified signal saturates before any significant pressure-non-linearity, useful for applications needing linear response and dynamic range ~10^2x (e.g. automotive, industrial, HVAC).

In both modes, simple Offset and Gain compensation enable field-replaceable sensors with very repeatable performance. In both cases, post-correction (e.g. digital correction) can be “standard” for all sensors of a given Mode:

- In Mode-1, for low-gain-amplified sensors, after simple offset and gain correction, the resulting curve is typical for thermal-anemometers, and does not vary significantly with minor manufacturing variations, up to at least greater than +/-1000Pa or +/-2000Pa pressure.
  - ➔ Post-correction can consist of a lookup table for “standard” correction of pressure-non-linearity, barometric pressure and ambient temperature, none of which vary significantly from unit to unit.
- In Mode-2, for amplified sensors, the linear curves are the same within 0.5%.
  - ➔ Post-correction can consist of a lookup table for “standard” correction of barometric pressure and ambient temperature, neither of which vary significantly from unit to unit.

In both modes, the sensors are field-replaceable without needing individual unit-by-unit field calibration.

The sensor’s pressure range is determined by the die-level flow-impedance, and on-chip amplification. Since the offset and amplification are on-chip-adjustable, this enables the creation of a pre-calibrated micro-flow sensor die, which can be more-easily packaged than typical micro-flow sensors in the market today.

This technology enables substantial price and / or performance and / or ease-of-use improvements.

Performance Comparison Table:

Parameter	Microbridge		Competitor #1		Competitor #2
	Un-amplified micro-flow sensor Type A (B)	Amplified micro-flow sensor Type A (B)	-	-	-
Pressure range	+/-2000Pa (+/-4000Pa)	+/-50Pa (+/-250Pa)	-5 .. 125Pa	-100 .. 3500Pa	+/-1000Pa
Output voltage (FSO)	+/-200mV	4.3V	4V	4V	20mV@600Pa
Resolution	0.1Pa (0.5Pa)	0.1Pa (0.5Pa)	0.1Pa	0.5Pa	NA
Response time	~1ms	~1ms	40ms	40ms	1 - 3ms
Pneumatic impedance	25kPa/(ml/s) (60kPa/(ml/s))	25kPa/(ml/s) (60kPa/(ml/s))	0.06kPa/(ml/s)	1.75kPa/(ml/s)	0.5kPa/(ml/s)
Excitation (VDC)	5V	5V	5V	5V	10V