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### **Published**

2010

### **Journal Title**

IEEE Sensors Journal

### **DOI**

[10.1109/JSEN.2009.2035518](https://doi.org/10.1109/JSEN.2009.2035518)

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# Self Heated Thermo-Resistive Element Hot Wire Anemometer

Richard Jozef Adamec and David Victor Thiel

**Abstract**—A microelectromechanical systems (MEMS) hot wire anemometer consisting of thermoresistive elements arranged in a differential bridge configuration is presented. The excitation of the elements to the point of self heating allows for dedicated heating elements to be omitted from the device without compromising operation or accuracy.

Overall power consumption gives air velocity, and the temperature differential of each element pair is used for wind direction calculation and has demonstrated a sensing resolution better than 1% and a repeatability better than 2%.

**Index Terms**—Anemometer, hot-wire, microelectromechanical systems (MEMS).

## I. INTRODUCTION

A bulk machined dual axis hot wire anemometer consisting of four thermoresistive elements arranged in a differential bridge configuration is presented. Where heating elements are often used on such devices [1], the sensor discussed here uses self heating of the thermoresistive sensing elements to provide the thermal energy required to generate the thermal plume and temperature differential across the surface of the device.

The central heating elements used on typical integrated hot-wire anemometers [2]–[4] use valuable real estate on the die and adds complexity and potential failure mechanisms to the design. Removal of the central heating element(s) reduces the number of elements that must be interfaced and frees up silicon real estate for other purposes, such as other sensing arrays [5].

The thermoresistive elements reported here are arranged to serve dual purposes as both the thermal sensing elements and the heating elements used to create the elevated surface temperature. The arrangement of the elements allows for dedicated heating elements to be omitted from the device without compromising operation or sacrificing accuracy. With the elimination of the central heating element(s) typically used, the element count is reduced to only four elements for the dual axis device compared to typical 5 or 8 element designs [6], [7]. Power consumption is also reduced along with an improvement in time response compared to some, more conventional, designs [8], [9].

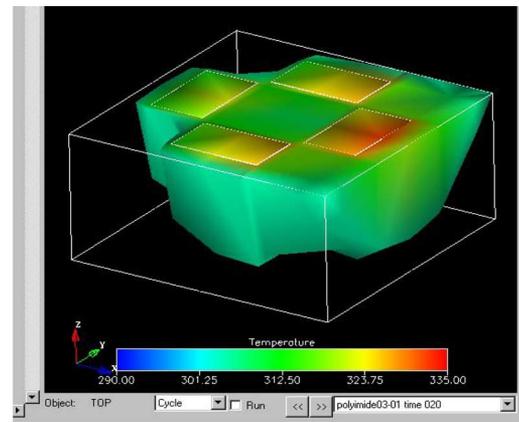
Thermal and electrical power requirements are minimized by patterning the Nickel serpentine elements on a 1  $\mu\text{m}$  bulk machined Silicon Nitride membrane that provides thermal isolation from the surrounding Silicon substrate (Fig. 1).

Manuscript received April 30, 2009; revised October 08, 2009; accepted October 08, 2009. Current version published March 10, 2010. The associate editor coordinating the review of this paper and approving it for publication was Prof. Evgeny Katz.

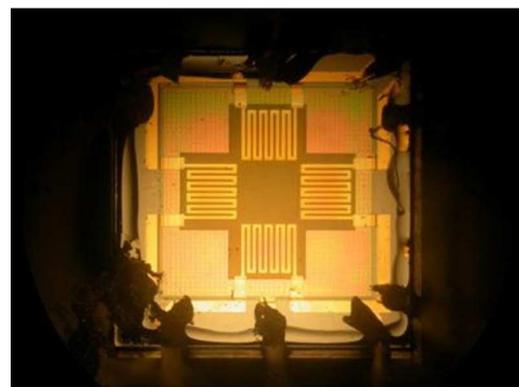
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Digital Object Identifier 10.1109/JSEN.2009.2035518



(a)



(b)

Fig. 1. Four element self heating sensor array. (a) FEM simulations showing isotherms within the  $\text{Si}_3\text{N}_4$  membrane. (b) Photomicrograph of a fabricated sensor.

Velocity information is extracted from the overall electrical power consumption of the four elements that are heated simultaneously from a common supply. Simultaneous solution of the temperature differential of opposing element pairs was used to determine the incident airflow direction and has demonstrated a sensing resolution less than 1% and a repeatable accuracy better than 2% for correctly dimensioned devices.

Field trials of these sensors have confirmed and demonstrated a reliable and robust design with exposure of the sensor surface to the environment including exposure to rain, dust and debris for periods in excess of 12 months with continuing operation.

## II. DATA AND RESULTS

Power consumption for the device was 50 mW at 25  $^{\circ}\text{C}$  for 0 m/s wind velocity. Under these conditions the constant voltage supply to the heating elements achieved an above ambient temperature of 45  $^{\circ}\text{C}$  to give an absolute element temperature of 70  $^{\circ}\text{C}$ . Temperature differentials seen as the device was rotated in a wind tunnel reached a peak of 15  $^{\circ}\text{C}$  between opposing elements.

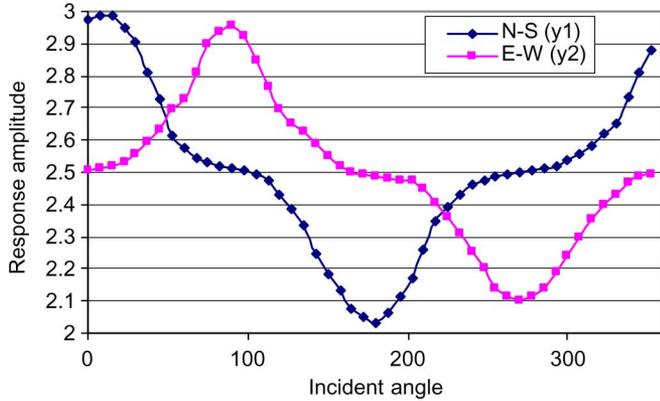


Fig. 2. Excessive element separation distances lead to an approximate  $\sin^3$  and  $\cos^3$  response as a reduction of sensitivity is introduced at angles perpendicular to the particular axis (actual recorded response).

Too much separation between elements or elements being too narrow leads to insensitivity at angles perpendicular to each axis and to distortion of the desired sine/cosine relationship of the thermal differentials. Even with this inefficient geometry being used, the relationship of the two differential signals may still be approximated by  $\sin^3$  and  $\cos^3$  functions (Fig. 2). This relationship means an analytical solution is possible via the simultaneous equation shown in (1)

$$\theta = \arctan \left[ \frac{1}{y_2 - y_{02}} \cdot [-\beta \cdot (y_{01} - y_1) \cdot (y_2 - y_{02})^2]^{\frac{1}{3}} \right] - c - \frac{\text{abs}(y_1 - y_{01})}{y_1 - y_{01}} \cdot \frac{\pi}{2} + \pi \quad (1)$$

where

- $y_1$   $x$  axis output;
- $y_{01}$   $x$  axis offset;
- $y_2$   $y$  axis output;
- $y_{02}$   $y$  axis offset;
- $\beta$  relative amplitude of axis responses;
- $c$  rotational offset of the array from  $0^\circ$ .

Using the arctan solution of (1), the unique angular solution is found (Fig. 3) independent of air speed simultaneously varying the amplitude of both the responses.

### III. CONCLUSION

A thin-film membrane hot wire anemometer with self heated sensing elements was fabricated and proven. This device omitted the commonly used centrally heated element [10] or peripheral heating elements [11] and instead used self heating

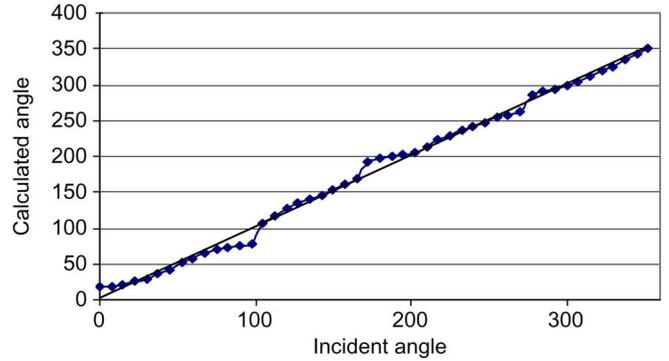


Fig. 3. Calculated solution for the  $\sin^3/\cos^3$  characteristic response of Fig. 2.

of the sensing elements. Device construction consisted of thermoresistive serpentine Nickel tracks patterned on a  $1 \mu\text{m}$  Silicon Nitride layer coating a  $600 \mu\text{m}$  silicon substrate that was reverse bulk etched to produce a membrane for thermal isolation of the Nickel tracks.

The self heating of the sensing elements concentrated the highest temperature regions at the sensing elements increasing the effectiveness of the forced convection heat transfer. The thermal distribution across the sensing area allowed successful calculation of the incident airflow angle to typically within 2% error for air flow velocities up to 20 m/s for a correctly dimensioned device. Temperature differentials between opposing elements of  $15^\circ\text{C}$  were possible at low air flow velocities with a total heating power of 50 mW in still air at an ambient temperature of  $25^\circ\text{C}$ .

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