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On

MICROMACHINED FORCE-BALANCE ANEMOMETER

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Micromachined Force-Balance Anemometer

A micromachined force-balance accelerometer is adapted to a different use.

NASA's Jet Propulsion Laboratory, Pasadena, California

A micromachined force-balance anemometer has been developed by modifying the design of a micromachined force-balance accelerometer that responds to accelerations as small as 10^{-9} × normal Earth gravitation (about 10^{-8} m/s^2). The anemometer thus offers the advantages of the accelerometer; namely, high sensitivity, wide dynamic range, bipolar response, athermality, robustness, compactness, and low power consumption.

Both the accelerometer and anemometer versions of the design include a proof mass suspended on springs in a housing. The proof mass is in the form of two square plates, called "force plates," that are bonded together to form a single plate. The springs are thin beams (flexure springs) that lie alongside the edges of the proof mass (see figure). The springs are flexible enough to allow displacement of the proof mass along the *z* axis, but stiff enough to resist significant displacement of the proof mass along the *x* and *y* axes.

The housing includes two plates, called "quad platens," between which the proof mass is suspended on the spring flexures. In its equilibrium (non-spring-deflection) position, the proof-mass force plates lie parallel to the quad platens and about midway between them. Patterned metal coatings on the faces of the force plates and on the quad platens serve as electrodes for controlled electrostatic deflection of the proof mass and as electrodes of capacitive proximity sensors for measuring the *z* displacement of the proof mass. The quad platens are so named because each one is divided into four electrode areas. In the anemometer version, quad platens are perforated (the central half of each electrode area is removed) to allow gas to flow.

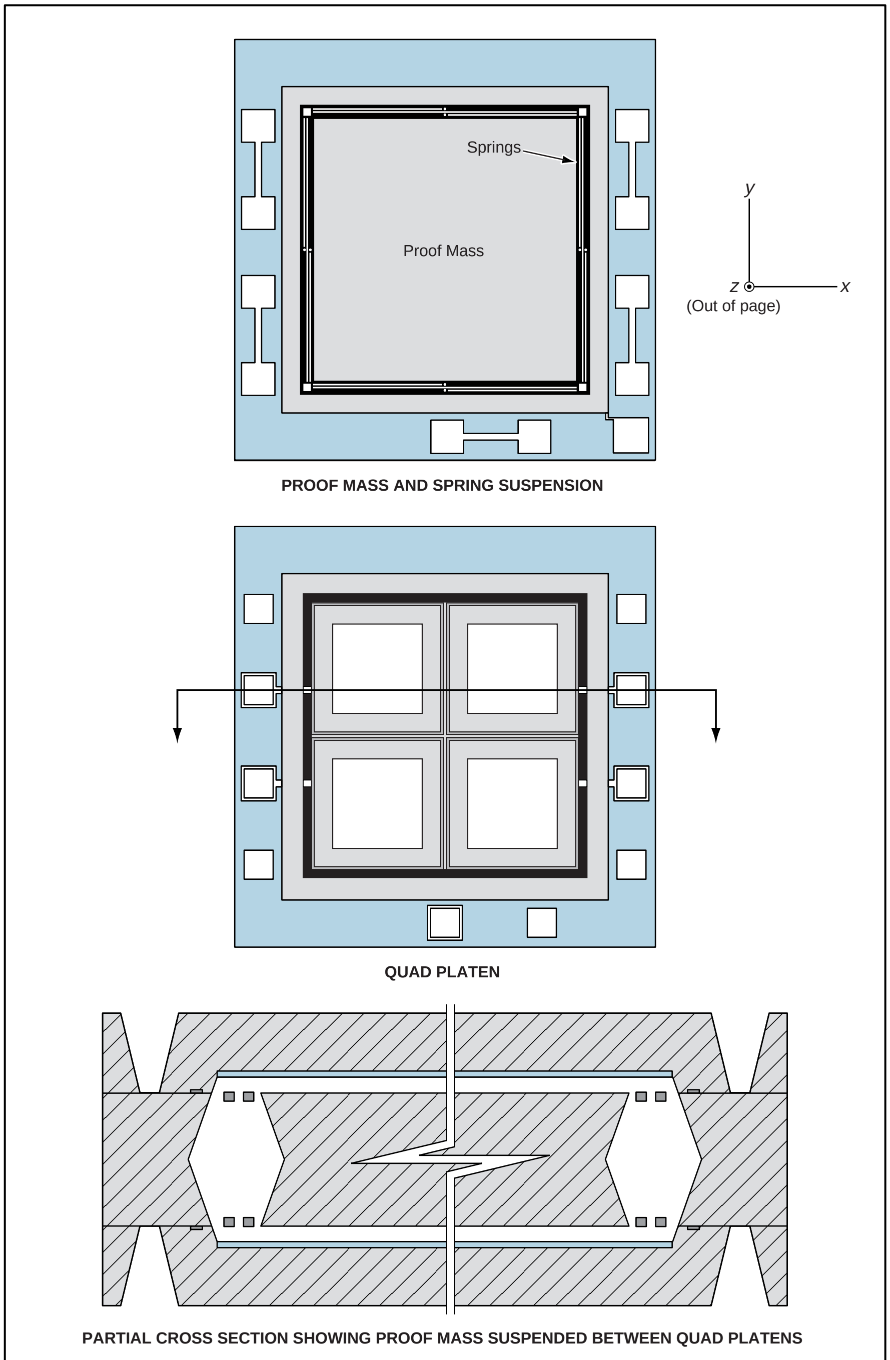
In operation, the outputs of the capacitive displacement sensors are processed through a feedback control system that applies voltages between the quad platens and force plates to keep the proof mass centered at or near the equilibrium position. These voltages serve as measures of the force with which the proof mass is deflected by acceleration (in the case of the accelerometer) or by pitot static force (in the case of the anemometer).

During handling, the proof mass can be "caged" to protect its delicate spring suspension. This is accomplished by applying an electrostatic-deflection voltage to clamp the proof mass against one of the quad platens. Submicron-thick electrically insulating surface layers prevent electrical contact between facing electrodes while allowing the interelectrode gap to become small enough to enable a small battery to generate an electric field sufficient to maintain clamping.

The overall dimensions of the micromachined anemometer are less than 2 by 2 by 0.2 cm. The dynamic range is 10^6. The frequency band of high sensitivity ranges from less than 1 to hundreds of hertz.

This work was done by Frank T. Hartley and David Crisp of Caltech for **NASA's Jet Propulsion Laboratory***.*

NPO-20129



The **Proof Mass Is Suspended** on delicate springs. The spring suspension is not deflected during operation, and sensitivity is determined by precision of capacitance measurement.

JPL **NTR Inventor's Report**

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1. Novelty

The novelty of this micromachined sensitive anemometer lies in the innovative adaption of attributes, processing techniques and majority of production masks of a nano-g accelerometer. Electrostatic caging protects the flimsy baffle plates from handling, launch and landing shock while the flexure design and hi-polar electrostatic force feedback control design provides a direct and wide dynamic range measurement of wind force.

2. Technical Disclosure

A. Problem

Robust, small, low power anemometer that is athermal, sensitive and has a large dynamic range.

B. Solution

Modify a hi-polar electrostatic force feedback nano-g accelerometer to measure the static force on a plate suspended perpendicular to gas flow (wind).

C. Description and Explanation

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c. Description and Explanation

The proof mass of the accelerometer (Figure 1) is 1 cm per side and supported on spring flexures that are very compliant in plane but stiff in all other modes. It is this large plate that will be presented to the 'wind' and on which the pitot static force will apply. Two of these proof masses are bonded together as illustrated in Figure 4.

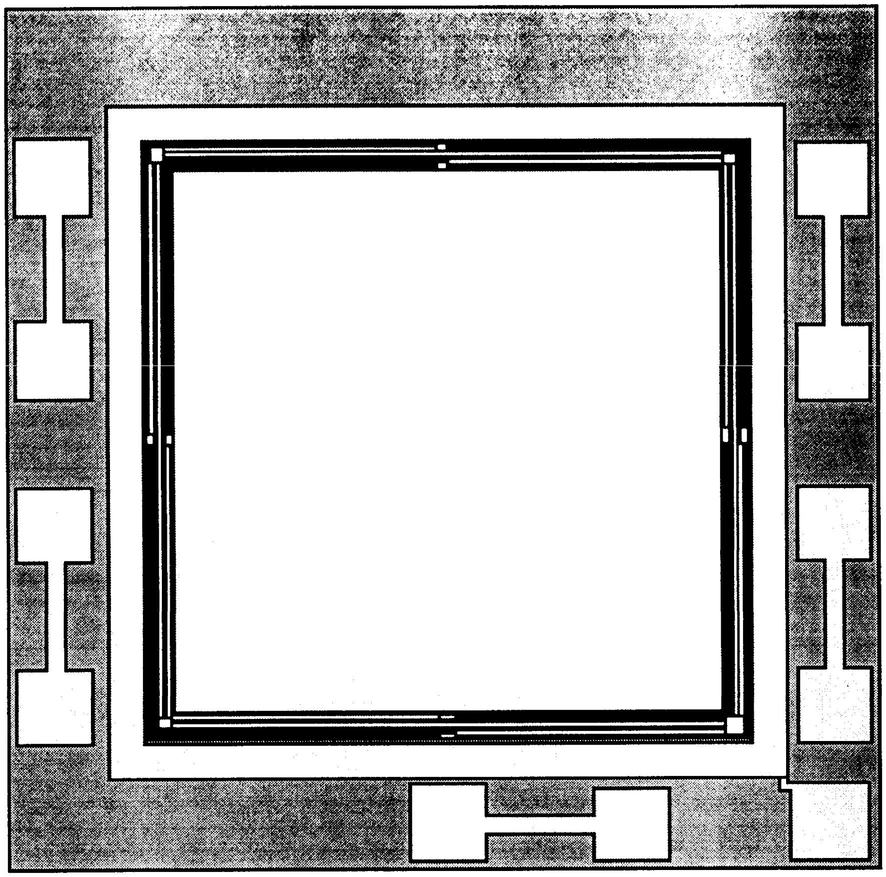

Figure 1 Proof Mass - Force Plate Schematic

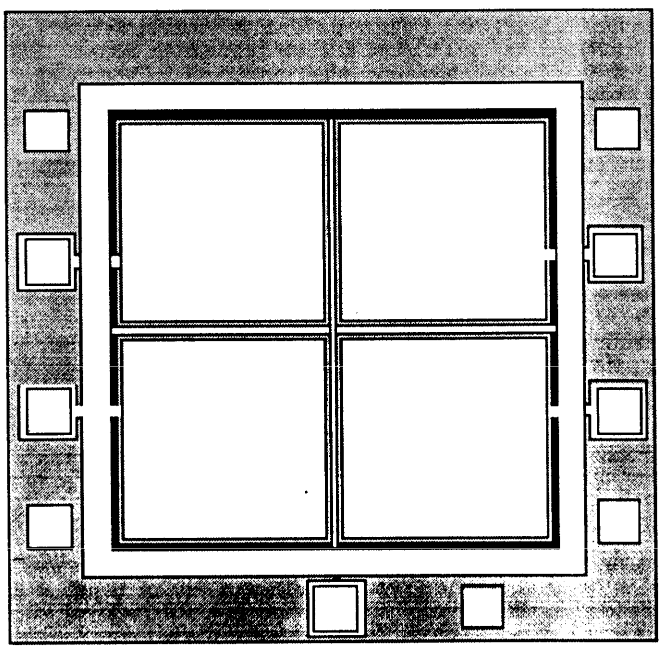

Figure 3 Perforated Quad Platens

The quad platen wafer is trenched 10 μm over whole platen area prior to oxidation of an insulation layer from the bulk silicon. The platen metal is deposited and the metal quad platens masked and etched (Figure 2) prior to the application of a thin insulation layer. and contact pads. For the anemometer the center 50% of each of the quad plates is removed as illustrated in Figure 3.

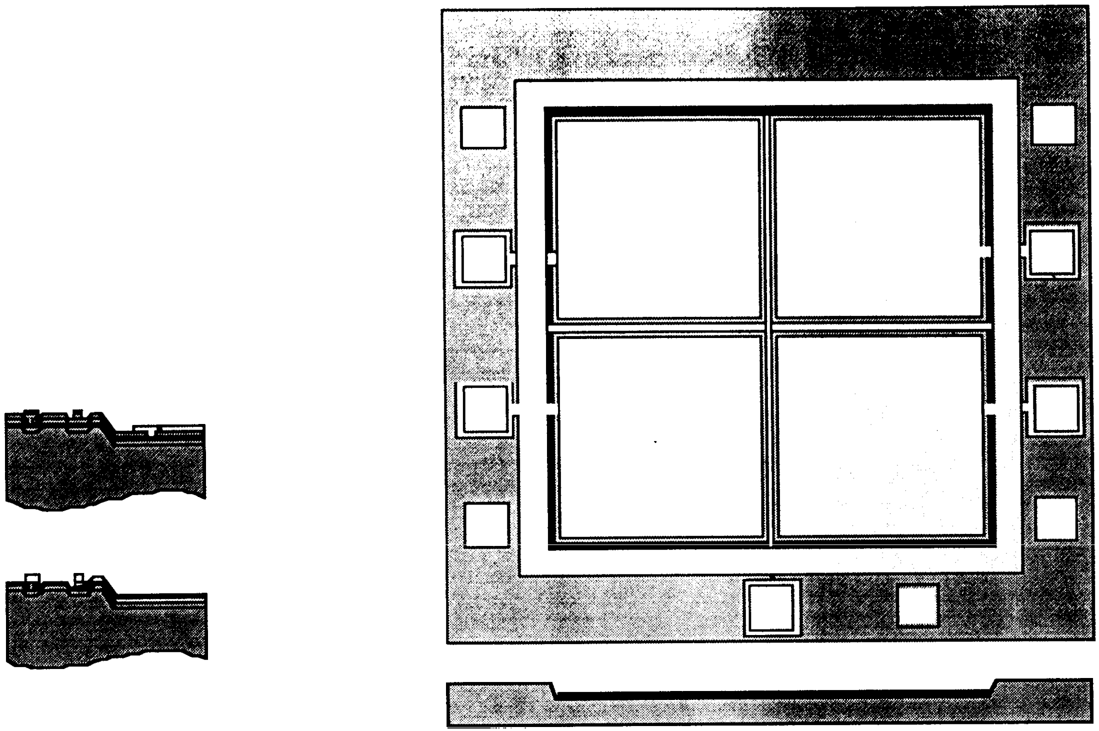

Figure 2 Quad Platen Schematic

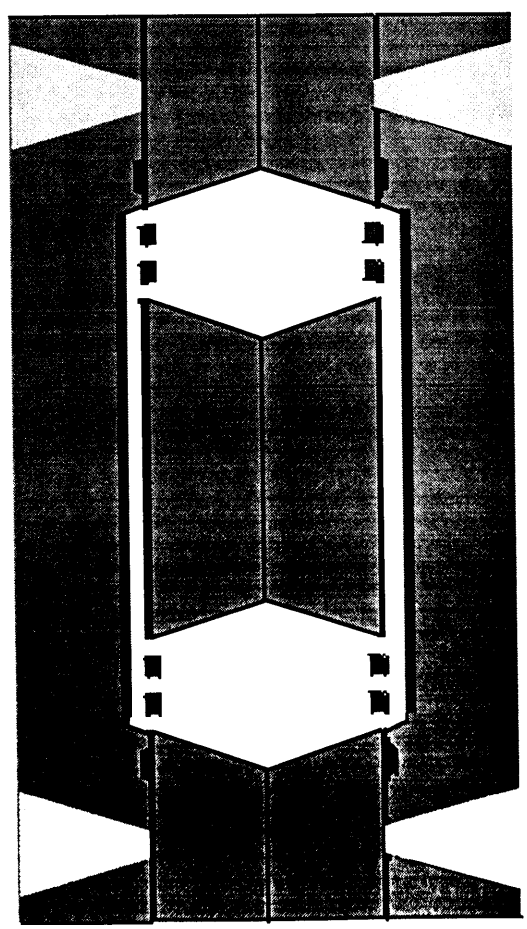

Figure 4 Cross Section of Anemometer {NTS}

The anemometer is then fabricated out of two proof mass (force plate) and two perforated quad dice eutectically bonded together as illustrated in Figure 4. Connections are then made to both force plates and each set of quad plates from both sides of the assembled unit.

During handling, launch etc., the force plate is clamped to either of the quad plates by means of a small battery and the large electric field created across sub-microns of insulation. The separation capacitance's of each quad plate, with respect to its' facing force plate, is measured and applied, via a control algorithm, to the opposite platen in such a way that the force platens are held stationary in the center of the cavity. When the force plate is mounted perpendicular to the gas flow vector of interest the pitot static force (pressure x aperture area) applied from either side of the anemometer is determined from the aggregate voltages on each set of quad plates.

The micromachined anemometer dimensions are less than 2 cm square and 2 mm thick, it does not need to be mounted in a tube and two (or three) of them mounted orthogonaly (60°) will provide wind velocity. A unit mounted horizontally would provide a measurement of vertical drafts. The hi-polar force balanced arrangement of this anemometer provides for a wide dynamic range (10^6) and a bandwidth from sub-Hertz to hundreds of Hertz. The zero flexure deflection design and electrostatic actuator control ensure the anemometer is athermal and the relatively large baffle plates ($0.5\ cm^2$) and compliant suspension ensure high sensitivity.