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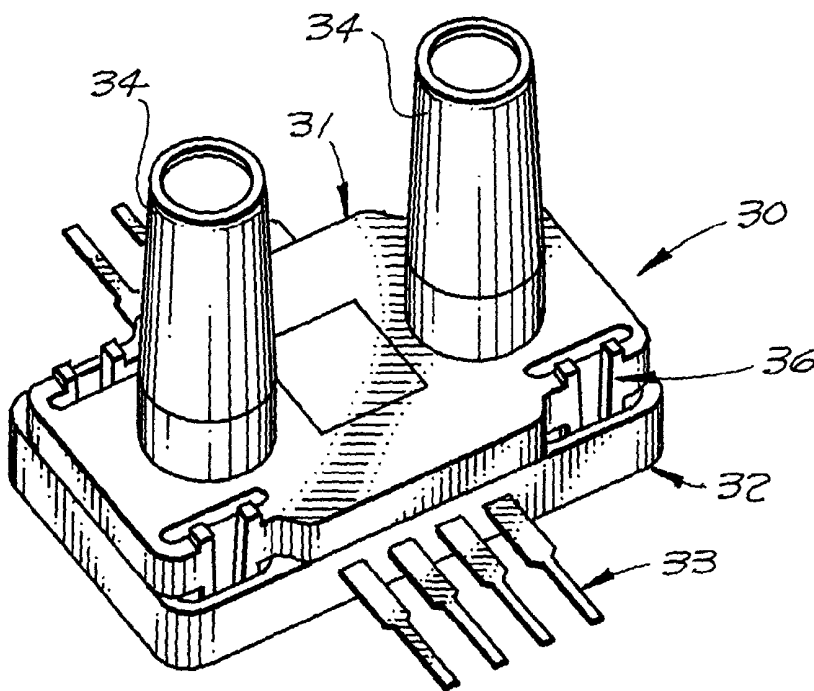
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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: MICROELECTRONIC FLOW SENSOR



(57) Abstract: A system (e.g. 30, 230, 330, 430, 530) for sensing or measuring the motion of a fluid 43 such as air. The system (e.g. 30, 230, 330, 430, 530) typically has a two-part (e.g. 31, 32, 231, 232, 331, 332, 431, 432, 531, 532) plastic body containing an internal flow passage (e.g. 41, 341, 441, 541). The parts (e.g. 31, 32, 231, 232, 331, 332, 431, 432, 531, 532) of the body may snap together with an adhesive. A transducer or an electronic sensor (e.g. 38) is typically located within the flow passage (e.g. 41, 341, 441, 541), which may measure mass flow rate and may have two resistive thermal devices (RTDs) (e.g. 54, 55) located on either side of a heat source (e.g. 52). The body may have two elongated port tubes (e.g. 34, 434, 534, 535) configured to attach to tubing. The port tubes (e.g. 34, 434, 534, 535) may contain venturis (e.g. 64, 564, 565), and may be substantially straight and

substantially parallel, forming a U shape. A metal lead frame (e.g. 33, 233, 333, 433, 533) may be provided in electrical communication with the sensor (e.g. 38). The lead frame (e.g. 33, 233, 333, 433, 533) may be integrally molded within the body, and may have a lower coefficient of thermal expansion than the body. The internal flow passage (e.g. 41, 341, 441, 541) and the sensor (e.g. 38) may be substantially symmetrical and measure the flow rate of the fluid 43 substantially equally in either flow direction. The system (e.g. 30, 230, 330, 430, 530) may be configured for surface mounting or for through-hole mounting, and may be a dual in-line type.

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MICROELECTRONIC FLOW SENSOR**BACKGROUND OF THE INVENTION**

1. Field of the Invention

5 This invention relates generally to systems and devices for sensing or measuring the motion of fluids and producing an electrical signal indicative of such motion.

2. Description of the Related Art

10 There are many situations where it is necessary or desirable to sense or measure the velocity, pressure, or flow rate of a fluid. Such situations include fluids that are both liquids and gasses and include both internal and external flow. For example, such systems or devices may be used to measure the air-speed of an aircraft, the water flow rate in a canal, pipeline, or river, the air flow rate into an internal combustion engine, or the flow rate through a ventilation duct in a heating, ventilating, and air-conditioning (HVAC) system of an office building. In many such applications, such as where electronic controls are used, it is necessary or desirable for such measuring devices to provide an electronic output that can be displayed on an electronic display or directly interface with an electronic control system. Many such systems and devices have been developed over the years including hot wire systems and systems and devices that measure velocity or flow rate indirectly by measuring pressure or pressure differences. Systems and devices that measure velocity or flow rate indirectly by measuring pressure or pressure differences include those that use structures that extend into the flow stream such as pitot tubes, and those that measure from the side of the flow stream such as venturi meters.

25 Some flow measurement systems or devices impede the flow to some degree, such as weirs and orifice plates, while others, such as pitot tubes, typically do not impede the flow significantly. In some applications, some degree of obstruction of the flow is not a problem, such as a weir wall used to measure the flow rate in a stream. However, in other applications, it is necessary or desirable to impede the flow as little as possible, such as applications where significant amounts of energy are required to generate the flow. Where the flow rate of a fluid is the desired parameter to be measured, many systems and devices measure the flow rate by measuring the velocity at one or more locations, and using the velocity to calculate the flow rate. The flow rate may be either a volumetric flow rate or a mass flow rate.

Historically, systems for measuring the motion of fluids, such as flow sensors, have been stand-alone systems of their own. They have been bulky, expensive, quite large and not suitable for integration into small electronic systems. There has also been a lack of flexibility in design preventing incorporation into a variety of subsystems.

5 More recent use of thick film hybrid type airflow sensing products have greatly reduced size and improved integration potential using single in-line electrical connections. They also have electrical input and output requirements more compatible with typical electronic products. Some such products have the additional advantage of being manifold mountable, which reduces system space requirements and allows semi-
10 automation of the pneumatic part of product assembly. While these examples are improvements over prior art, they still require manual electronic assembly at high cost and low throughput. In addition, their size is still typically the largest component in a control system circuit. There is a clear lack of a small sensor, particularly for airflow, that can be assembled by automated equipment and handled, as are other electronic
15 components.

Previous solutions have included alternative sensing techniques, like differential pressure sensors, which typically suffered from poor accuracy. The other sensors have problems of their own, being expensive and of limited availability in standard package configurations.

20

SUMMARY OF THE INVENTION

It is an object of this invention to provide a system for measuring the motion of a fluid, the system having a maximum of features and capable of being manufactured in a very small standard package. Other objects of the invention are to provide an
25 improved system that will integrate control systems, lower cost, reduce power consumption, and reduce size while implementing highly automated mass assembly manufacturing. Further objects of the invention include that the product be compatible with factory automation, that it have improved interchangeability, that it have a minimum number of parts and that it be readily capable of being modified for manifold
30 mount, minimum pressure drop or controlled pressure drop applications.

In furtherance of these objects, the present invention provides a system for sensing the motion of a fluid that has a body with an internal flow passage, an electronic sensor located within the flow passage, and a metal lead frame that is in electrical communication with the sensor and integrally molded with the body. The

body may be made of two parts that are joined by a joint that may snap together or attach with an adhesive, heat staking, or ultrasonic welding. The body may have outside dimensions of width, depth, and height that are each less than 1.5 inches, or may have a volume of less than 0.25 cubic inch. The body may be made of plastic or thermal plastic, and the metal of the lead frame may have a lower coefficient of thermal expansion than the plastic to reduce leakage between the two. Specifically, the metal may have a coefficient of thermal expansion that is less than 10 parts per million per degree Celsius and the plastic may have a coefficient of thermal expansion that is greater than 50 parts per million per degree Celsius. The body may have two elongated port tubes configured to attach to tubing, and the port tubes may each have a venturi. The sensor may have an RTD and a heat source. In one embodiment, the internal flow passage and the sensor are substantially symmetrical and the system is configured to measure the flow rate of the fluid substantially equally in either flow direction. In this embodiment, the sensor may comprise two RTDs located on either side of a heat source. The fluid sensed with the present invention may be a gas, such as air. The system may be configured for surface mounting or for through-hole mounting. The motion that is sensed may be flow rate, or specifically, mass flow rate. The lead frame may have pins on substantially opposite sides. The body may have pins from the lead frame projecting from one side that are all in substantially the same plane, or may have pins from the lead frame projecting from two sides where the pins from each side are in substantially the same plane. The system may also comprise a control system for a heating, ventilating, and air-conditioning system, or even the heating, ventilating, and air-conditioning system itself.

The present invention also provides a system for sensing the pressure or flow rate of a fluid with a body that has an internal flow passage and is formed from two parts that are joined by a joint that has an elastomeric seal that is integral with one part. There is also a transducer located within the flow passage. The two parts of the body may be attachable to each other with snap connectors, and the body may have outside dimensions of width, depth, and height that are each less than 1.5 inches. The body may have a port tube, which may have a venturi, and may be substantially straight. The system may be a dual in-line package.

The present invention further provides a system for measuring the flow rate of a gas with a body that has an internal flow passage and is formed in two parts that are

configured to snap together. There is also a sensor located within the flow passage. The body may have outside dimensions of width, depth, and height such that width multiplied by depth multiplied by height is less than 0.5 cubic inch.

5

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the accompanying figures, in which like reference numbers indicate similar elements, and in which:

FIGS. 1 – 10 illustrate a first exemplary embodiment of the present invention,
10 and specifically:

FIG. 1 is an isometric assembly view;

FIG. 2 is an exploded isometric view illustrating the major components;

FIG. 3 is an isometric bottom view of the flow tube component;

FIG. 4 is a top view which also shows where FIGS. 5, 6, and 7, are taken;

15 FIG. 5 is a cross-sectional end view showing exemplary embodiments of the seal and the joint between the flow tube and the base, and also showing where FIG. 9 is taken;

FIG. 6 is a cross-sectional side view showing exemplary embodiments of the seal, the joint between the flow tube and the base, the internal flow passage, and an of
20 the internal structure of the system, and also showing where FIG. 10 is taken;

FIG. 7 is a top view detail illustrating an exemplary embodiment of the snap-fit feature, which also shows where FIG. 8 is taken;

FIG. 8 is a cross-sectional side view detail illustrating an exemplary embodiment of the snap-fit feature;

25 FIG. 9 is a cross-sectional end view detail illustrating an exemplary embodiment of the seal; and

FIG. 10 is a cross-sectional side view detail illustrating an exemplary embodiment of the seal;

30 FIG. 11 is a cross-sectional side view illustrating an exemplary embodiment of a representative electronic sensor chip;

FIGS. 12 – 14 illustrate a second exemplary embodiment of the present invention and showing an exemplary embodiment of venturis in the port tubes, and specifically;

FIG. 12 is an isometric assembly view;

FIG. 13 is a partially exploded isometric view which illustrates an exemplary embodiment of how the flow tube and base fit together; and

FIG. 14 is a cut-a-way partially-exploded isometric view showing exemplary
5 embodiments of the venturis and lead frame;

FIG. 15 illustrates a third exemplary embodiment of the present invention configured to mount on a manifold;

FIGS. 16 – 18 illustrate a fourth exemplary embodiment of the present invention and specifically:

10 FIG. 16 is an exploded isometric view illustrating an exemplary embodiment of the major components;

FIG. 17 is a top view; and

FIG. 18 is an end view; and

15 FIG. 19 illustrates through a cross-sectional side view a fifth exemplary embodiment of the present invention, and specifically illustrates an exemplary embodiment of an asymmetrical internal flow passage with dissimilar venturis in the port tubes at different distances from the chip, and the chip mounted at an angle relative to the flow passage.

20 DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

The present invention provides an apparatus or system for sensing or measuring the motion of a fluid. For example, embodiments of the present invention may be used to measure flow rate. The present invention generally measures mass flow rate (units of mass per unit of time) more directly than volumetric flow rate (units of
25 volume per unit of time). This is because the present invention directly measures heat transfer, which is more closely proportional to mass flow rate. However, embodiments of the present invention may also be used to measure or calculate volumetric flow rate or pressure (force per unit of area). For instance, volumetric flow rate is approximately proportional to mass flow rate where pressure is nearly constant. In addition, flow rate
30 is generally related to pressure differential (i.e. pressure drop across the present invention). These parameters can be used to calculate other values as well, as would be understood by a skilled artisan.

In many applications, the fluid sensed or measured is a gas, and may be air, or alternatively, may be nitrogen, oxygen, carbon dioxide, or the like, or mixtures thereof.

Some embodiments of the present invention are general-purpose sensors, which have many potential applications. Embodiments of the present invention may be used, as an example, in heating, ventilating and air-conditioning (HVAC) systems. Specifically, embodiments of the present invention may be used in control systems for HVAC systems. However, the present invention has uses in many commercial, industrial, medical, military, and other applications as would be appreciated by a person skilled in the art. In addition, due to consistent output between different units, in many applications, the present invention does not require calibration. As a specific example, for some embodiments, the output may be expected to vary by as little as 4% between units.

The present invention may be constructed or made smaller than the prior art (e.g. for a range of flows from -200 standard cubic centimeters per minute of air (sccm) to +200 sccm). The ability to be made in small sizes and still perform well is both novel and a significant advantage of many embodiments of the present invention. However, the present invention may also be made in larger sizes, e.g. for measuring large flows. Another way to measure larger flows is to divert a portion of the flow through a smaller version of the present invention. As an example, several pitot tubes distributed across a cross-section of an HVAC duct may be manifolded together and connected to the present invention with tubing. In such an arrangement, the flow through the present invention may be related to the average velocity pressure of the flow through the duct, which may be related to the average velocity, which in turn is related to the flow rate. It is preferable that the total flow (e.g. through the duct) be substantially proportional to the flow through the present invention, or otherwise related in a known mathematical relationship.

Referring now to the figures, FIGS. 1 – 10 illustrate a first exemplary embodiment **30** of the present invention, a snap-together elastomerically sealed package. This design allows for a variety of products to be built with only minor tooling changes, some of which are illustrated in the various embodiments shown. As can be seen in FIG. 1, first exemplary embodiment **30** has a body which comprises two main parts: flow tube **31** and base **32**, which may be configured to snap together or are snap attachable, e.g. via snap connectors **36**. Four snap connectors **36** are shown, although another number of snap connectors **36** or other methods of forming a snap-together body could be used. In first exemplary embodiment **30**, flow tube **31** has two port tubes **34**, and base **32** has lead frame **33**, typically molded into it. First exemplary

embodiment **30** could be mounted with base **32** resting on a surface (not shown), i.e. a surface mount, or could be mounted with port tubes **34** extending through holes in a surface (not shown), i.e. a through-hole mount.

FIG. 2 shows the major components of first exemplary embodiment **30** in an exploded view. In addition to the major components discussed with reference to FIG. 1, FIG. 2 shows chip **38** and gasket **39**. In a typical installation, some type of fluid conduit (not shown), such as pipe, hose, or tubing, attaches to port tubes **34**. For instance, 5 mm or 0.2-inch flexible tubing may be used. Port tubes **34** are typically elongated, as shown, and configured to attach to tubing. For instance, port tubes **34** may be tapered or ribbed on the outside to facilitate attachment of tubing. The connection to such tubing typically results in less than 1-% leakage. The fluid to be measured typically flows through one piece of the tubing, into one of the port tubes **34**, across chip **38**, out the other port tube **34**, and returns through another piece of tubing (not shown). In other words, the fluid to be measured typically flows through internal flow passage **41**, which is illustrated, for example, in FIG. 6. Internal flow passage **41** may be formed by base **32** and flow tube **31**, and may include port tubes **34**. Chip **38** is typically located within internal flow passage **41**. Some embodiments of the present invention may work best (e.g. be most consistent and accurate over the range of flows), particularly in smaller configurations, where Internal flow passage **41** has a smooth surface finish and sharp radius internal corners are avoided.

The present invention typically has a sensor or transducer, which may be an electronic sensor, typically located within an internal flow passage and of a type that produces an electrical output. Chip **38** is an exemplary embodiment of such a sensor or transducer. Chip **38** may be an electronic sensor such as a micromachined silicon thermal to electronic transducer chip. In first exemplary embodiment **30**, chip **38** is mounted in recess **48** in base **32**, as shown in FIG. 2. Recess **48** is preferably configured such that when installed, chip **38** is flush with the surrounding material of base **32** to minimize the generation of turbulence at the edges of chip **38**. In some configurations, chip **38** comprises one or more resistive thermal devices (RTDs) located near a heat source. For example, in one configuration, chip **38** comprises two RTDs located on either side of a heat source. More than one heat source may be used. An RTD typically comprises an electrical conductor with a resistance to the flow of electricity through it, the material being selected such that the electrical resistance varies with temperature. Thus, the temperature of an RTD can be sensed, for

example, by passing a fairly constant electrical current through the RTD and measuring the voltage across it. In an exemplary embodiment where two RTDs are located on either side of a heat source, for either flow direction through internal flow passage 41, one RTD is substantially upstream of the heat source, and the other RTD is substantially downstream of the heat source. Thus, as the fluid flows through internal flow passage 41, the fluid flowing past the downstream RTD has been heated by the heat source, while the fluid flowing past the upstream heat source has not. From the difference in temperature between the two RTDs, the flow rate through internal flow passage 41 may be determined.

FIG. 11 illustrates one exemplary embodiment of chip 38, a microbridge, which may be used to measure mass flow rate. In the embodiment shown, chip 38 is formed on silicon substrate 51, and comprises bridges 58 and 59, located in the flow of fluid 43. Bridge 58 contains RTD 54, while bridge 59 contains RTD 55. RTDs 54 and 55 may be thin film platinum put down as evaporated platinum film. Bridges 58 and 59 may be formed by depositing a layer of silicon nitride on silicon substrate 51, depositing the platinum film, and then etching the silicon nitride out from under the platinum film. In the exemplary embodiment shown in FIG. 11, heater 52 comprises two substantially equal parts, one on bridge 58, and one on bridge 59. A wheat stone bridge may be used, which may be set to 160 degrees Celsius. Because the components are generally small, the response time is generally short, for instance, about 1 msec. The exemplary embodiment of chip 38 may use 50 mW of electricity at 10 V DC (plus or minus 5%), and may output 0 to 60 mV. In one embodiment:

$$V_{\text{out}} = 1 + (0.0186)M - (5.1\text{E-}5)M^2 + (8.4\text{E-}8)M^3 - (7\text{E-}11)M^4 + (2.3\text{E-}14)M^5$$

where M is mass flow rate in sccm. However, variations in supply voltage may result in a proportional variation in output.

Lead frame 33, as shown for example in FIG. 2, is a conductor, usually metal, and typically provides the electrical connections to chip 38. In other words, lead frame 33 is typically connected to, or in electrical communication with, the electronic sensor or chip 38. Lead frame 33 may be integrally molded within the body (e.g. within base 32). In other words, lead frame 33 may be placed within the mold when part of the body (e.g. base 32) is formed, so that the material (e.g. plastic) of the body surrounds part of lead frame 33. Lead frame 33 may be dual, in other words, have pins for

connections on at least two approximately opposite sides (as shown). Alternatively, lead frame **33** may be single, meaning that it has pins on just one side (not shown). Lead frame **33** may be in-line, meaning that all pins on each side are substantially in one plane (as shown). On the other hand, the pins of lead frame **33** may be arranged
5 differently, e.g. in a circle or in multiple planes. Accordingly, first exemplary embodiment **30** with lead frame **33** as shown on the figures with pins on two sides and the pins in substantially the same plane on each side herein embodies a dual in-line package.

To obtain a good seal between lead frame **33** and base **32** over a range of
10 temperatures, which is desirable in many applications, the materials may be selected so that the coefficient of thermal expansion of lead frame **33** is below the coefficient of thermal expansion of the surrounding body (e.g. base **32**). For instance, the coefficient of thermal expansion of lead frame **33** may be less than 10 parts per million per degree Celsius (PPM/°C). As an example, lead frame **33** may be bronze or nickel-iron. Base
15 **32** may be formed from a non-conducting material, for instance, plastic. Where a wide temperature range is desirable, base **32** may be a thermal plastic, i.e. one suitable for the temperature range desired. For example, embodiments of the present invention may have a storage temperature range of 20 to 60 degrees Celsius, and an ambient operating temperature range of 0 to 60 degrees Celsius at a maximum relative
20 humidity of 95%. To obtain a good seal between base **32** and lead frame **33**, base **32** may be made of a material with a coefficient of thermal expansion greater than 50 PPM/°C. For example, base **32** may be made of polyetherimide, polysulfone, or syndiotactic polystyrene. The material that base **32** is made of should generally be capable of maintaining a smooth finish to facilitate forming a good seal as will be
25 discussed with reference to other figures below. The smooth surface finish also reduces the turbulence in the flow of the fluid during use. Flow tube **31**, as shown in FIG. 3, may be formed from the same material as base **32**, or from another material, preferably having similar characteristics.

As mentioned above, first exemplary embodiment **30** is made of two parts (flow
30 tube **31** and base **32**) that are configured to snap together. Various mechanisms can provide this snap feature, many of which are known in the art. The exemplary embodiment snap mechanism shown comprises snap connectors **36**, and is shown best in FIGS. 2, 3, 7, and 8. In other words, in the exemplary embodiment shown, the two parts of the body (e.g. flow tube **31** and base **32**) are preferably attachable to each

other with snap connectors **36**. As seen best in FIG. 3, snap connectors **36** may be constructed with loops **46**. Loops **46** are preferably part of (e.g. integrally molded with in one continuous piece) one of the parts of the body, e.g. flow tube **31** as shown. As seen best in FIG. 2, in the embodiment depicted, loops **46** are configured to fit into
5 holes **47** in base **32**. As shown best in FIG. 8, when flow tube **31** is installed onto base **32**, each loop **46** may go into a hole **47** and deform outward elastically over a projection **45**, and snap back into place. Thus, typically attaching flow tube **31** to base **32** at the location of each snap connector **36**. An interference fit may be provided, for instance, between projection **45** and loop **46** to prevent relative motion between flow
10 tube **31** and base **32** when they are assembled. An interference fit at this location also helps to maintain a constant and precise distance between the top of chip **38** and flow tube **31**, the benefit of which is described in more detail below.

As is illustrated in FIGS. 5 and 6, there is a joint **42** between flow tube **31** and base **32**. In other words, flow tube **31** and base **32** are joined by joint **42**. Since flow
15 tube **31** and base **32** typically form the top and bottom of internal flow passage **41**, joint **42** is preferably sealed to reduce, or ideally eliminate, leakage through joint **42**. There are several ways to seal joint **42**, one of which is illustrated in first exemplary embodiment **30**, particularly in FIGS. 5, 6, 9, and 10. In first exemplary embodiment **30**, joint **42** is sealed with a seal or gasket **39**. Gasket **39** is preferably formed from a
20 compressible material with a smooth surface such as rubber, or more commonly, synthetic rubber. In other words, gasket **39** is preferably an elastomer or an elastomeric seal. In such an embodiment, there is preferably an open space **49** (as shown in FIGS. 9 and 10) on at least one side of gasket **39** to allow for expansion of gasket **39**. Gasket **39** may be a separate piece, or may be molded into base **32** or flow
25 tube **31**. Molding gasket **39** into base **32**, as an example, has the advantages of preventing leakage of the fluid **43** between base **32** and gasket **39**, and also reduces the number of parts, thus typically simplifying manufacturing. In this example where gasket **39** is molded into base **32**, compressing gasket **39** against flow tube **31** typically results in a good seal between gasket **39** and flow tube **31** as well. Thus, gasket **39**
30 seals joint **42**. Other ways to obtain a good seal include using o-rings, heat staking, ultrasonic welding, and the use of glue or adhesives. Many such methods are well known in the art; and may eliminate the need for a snap feature (e.g. snap connectors **36**) to connect flow tube **31** to base **32**. Specifically, adhesives may be employed as

dispensed liquids, b-stage preforms, or predispensed and b-staged on flow tube **31**, on base **32**, or on both.

The vertical distance from the top of the sensor chip **38** to the surface of the mating flow tube **31** may be controlled in order to obtain a consistent cross-sectional area and achieve improved accuracy and interchangeability between different units (e.g. exemplary embodiment **30**). One method to control this distance is to have smooth horizontal mating surfaces on the molded parts (i.e. on flow tube **31** and base **32**) at joint **42**. In embodiments where a sealant or adhesive is used to attach the body parts, it is preferable to apply the adhesive to vertical surfaces rather than to the horizontal surface of joint **42**. Use of a sealant or adhesive on the horizontal surfaces of joint **42** typically results in less consistent vertical dimensions. An expansion space, e.g. in the vertical direction, may help to prevent the sealant from affecting vertical tolerances. In first exemplary embodiment **30**, a minimum amount of variation of vertical distance due to surface imperfections in mating surfaces is achieved by the interference snap fit used to assemble the body (flow tube **31** and base **32**). In other embodiments, the same effect is achieved with controlled clamping forces during welding or adhesive bonding.

One feature or novelty of the present invention is that it may typically be fabricated in sizes smaller than the prior art. Specifically, prior art devices are typically no smaller than 1 1/2 inches on each side, thus occupying a volume of at least 3.375 cubic inches. In contrast, embodiments of the present invention may have a body (e.g. flow tube **31** and base **32**) with outside dimensions of width, depth, and height that are each less than 1.5 inches. The present invention may, as an example, have outside dimensions of width, depth, and height such that width X (multiplied by) depth X height is less than (<) 0.5 cubic inch. The present invention may even be, for example, as small as about 1 inch by 1/2 inch by 1/2 inch, thus occupying a volume of about 0.25 cubic inches. It may be even smaller. Thus, embodiments of the present invention may have a body (e.g. flow tube **31** and base **32**) with a volume of less than 0.25 cubic inch.

FIGS. 12 – 14 illustrate second exemplary embodiment **230**. Second exemplary embodiment **230** is generally similar to first exemplary embodiment **30** except as shown or indicated herein, and typically has a chip **38**, which may be as described above, located within an internal flow passage. Specifically, second exemplary **230** typically does not have snap connectors **36**. Second exemplary embodiment **230**

typically has a body comprised of two major parts, flow tube **231** and base **232**, between which there is a joint **242**. In other words, flow tube **231** and base **232** are joined by joint **242**. Joint **242** may be secured or attached with a sealant or adhesive. Alternatively, or in addition, there may be an interference or snap fit between flow tube

5 **231** and base **232**. Joint **242** may include an elastomeric seal, which may be integral with either flow tube **231** or base **232**.

Lead frame **233** is similar to lead frame **33** described above, except that the pins of lead frame **233** are bent downward as shown. Other pin angles could be used on either embodiment. FIG. 14 illustrates how lead frame **233** may be embedded or

10 molded within base **232**. Lead frame **233** typically comprises a plurality of pins or conductors, e.g. eight, as typically shown in the figures. As shown best in FIG. 14, each of the conductors in lead frame **233** typically terminate close to chip **38** so that chip **38** may readily be electrically connected to lead frame **233**. Chip **38** is typically electrically connected to lead frame **233** in ways known in the art. Although generally

15 electrically isolated (i.e. electrically insulated from each other) when manufacturing is complete, the plurality of conductors of lead frame **233** may be formed from one piece of plate or sheet metal prior to being molded into base **232**. With such a manufacturing process, part of the sheet metal is trimmed off after base **232** is molded, leaving the electrically isolated conductors or pins. The pins of lead frame **233** are

20 generally configured for electrical connection to external devices or connectors (e.g. female connectors) in ways known in the art.

An exemplary embodiment of port tubes **34** is illustrated, for example, in FIG. 14. Although illustrated in FIG 14 in second exemplary embodiment **230**, the exemplary embodiment of port tubes **34** shown in FIG. 14 may be used with first

25 exemplary embodiment **30** described above, fourth exemplary embodiment **430** described below, or other embodiments, typically including many not shown. Port tubes **34** may be substantially straight, as shown, and the two port tubes **34** may be substantially parallel (i.e. have substantially parallel centerlines). This may result, as shown, in internal flow passage **41** being substantially U shaped. Port tubes **34** may

30 be hollow and have a relatively thin wall. Such a configuration minimizes the pressure drop at the maximum flow rate, typically about 1 standard liter per minute (slpm). However, turbulence may be created, e.g. near chip **38**, which may result in inaccuracies. Alternatively, port tubes **34** may contain features to restrict the flow and reduce turbulence. For instance, filters, orifice plates or venturis **64** (shown) may be

provided inside port tubes **34**. Venturis **64** offer the advantage over orifice plates (not shown) that they typically result in less turbulence at chip **38**. Locating the features that restrict the flow (e.g. venturis **64**) far away from chip **38**, and maintaining a smooth surface finish within internal flow passage **41**, also generally reduces the turbulence at chip **38**. The venturis **64** may be integrally molded with port tubes **34** and flow tube **31**. In addition to reducing turbulence, features to restrict the flow (e.g. venturis **64**) typically create a controlled and specific pressure drop at a given flow rate. For instance, configurations of the present invention may typically pass about 0.2 slpm at 10 mbar or may have a pressure drop of about 872 Pa at a mass flow rate of about 200 sccm of air.

The present invention may be configured to provide substantially equal performance for flow in either direction. In such an embodiment, flow tube **31**, base **32**, and chip **38** may be configured such that internal flow passage **41** has the same shape in either direction. In other words, in such an embodiment, internal flow passage **41** is symmetrical. In addition, chip **38** is typically parallel to the flow passage and the internal shapes or geometries of the two port tubes **34** are substantially identical. In this embodiment, if port tubes **34** contain venturis **64**, then the two venturis **64** are typically substantially the same shape and substantially the same distance from chip **38**. In other embodiments, the present invention may be designed to measure flow only in one direction, or to have a different output for flow in one direction, as compared with the other. See for example, FIG. 19, which is described in detail below. In such embodiments, the internal flow passage **41** may not be symmetrical. As an example, the port tubes **34** may not be the same. For instance venturis **64** may have different shapes or geometries, or may be different distances from chip **38**. In other such non-symmetrical embodiments, only one port tube **34** may be provided. In addition, in non-symmetrical embodiments, in order to reduce turbulence or reduce the potential for contamination from dirt, chip **38** may be rotated out of the horizontal and into the flow, e.g. as shown in FIG. 19. In other words, chip **38** may be oriented an angle relative to the flow. This angle may be small, for instance, about 15 degrees from being parallel to the flow passage (e.g. internal flow passage **541** in FIG 19).

FIG. 15 illustrates third exemplary embodiment **330**, which is configured for mounting on a manifold. Third exemplary embodiment **330** is generally similar to first exemplary embodiment **30** or to second exemplary embodiment **230**, except that third

exemplary embodiment **330** typically does not have port tubes **34**. Third exemplary embodiment **330** typically has a body comprised of two main parts, flow tube **331** and base **332**, which are typically joined by joint **342**. Joint **342** may be similar to joints **42** or **242** described above. Joint **342** may include an elastomeric seal, which may be integral with either flow tube **331** or base **332**. Third exemplary embodiment **330** typically has a transducer or chip (not shown), which may be as described above (e.g. chip **38**), located within an internal flow passage **341**. Although not shown in FIG. 15, flow tube **331** and base **332** may be joined with snap connectors **36**, or other snap features as described above. Third exemplary embodiment **330** typically has ports **334** in face **351** of flow tube **331**. A seal may be formed between the manifold and face **351**, e.g. with gaskets, o-rings, sealant, or other means known in the art. FIG. 15 also illustrates an alternate shape for the pins of the lead frame, herein lead frame **333**. Lead frames with pins the shape of lead frame **333** may be used on many of the embodiments of the present invention. Lead frame **333** may be similar to lead frames **33** or **233** described above except as to shape of the pins as shown.

FIGS. 16 through 18 illustrate fourth exemplary embodiment **430**. Fourth exemplary embodiment **430** is generally similar to the exemplary embodiments described above except as noted herein or shown in the figures. Fourth exemplary embodiment **430** typically has a body comprising two parts, flow tube **431** and base **432**, which are typically joined with joint **432**. Flow tube **431** and base **432** may be joined or attached, e.g. with an adhesive, to form internal flow passage **441**, typically in a manner that forms a seal between flow tube **431** and base **432**. Joint **442** may include an elastomeric seal, which may be integral with either flow tube **431** or base **432**, or joint **442** may include a sealant, which may also serve as an adhesive. Flow tube **431** may have port tubes **434** as shown, generally similar to the port tubes **34** of first exemplary embodiment **30** and second exemplary embodiment **230** described above, or flow tube **431** may be configured for manifold mounting (not shown) similar to third exemplary embodiment **330** described above. On the other hand, port tubes **434** may be asymmetrical similar to port tubes **534** and **535** described below with reference to FIG. 19. In exemplary embodiment **430** shown, chip **38** and lead frame **433** are attached to base **432**. Lead frame **433** is typically in electrical communication with chip **38**, usually via conductors within base **432**. For example, base **432** may be a thick film network. Chip **38** may be as described above for other embodiments, and is generally located within internal flow passage **441**.

FIG. 19 illustrates a fifth exemplary embodiment **530**. Fifth exemplary embodiment **530** is generally similar to the exemplary embodiments described above except as noted herein. Fifth exemplary embodiment **530** typically has a body comprising two parts, flow tube **531** and base **532**, which may be joined with joint **542** (e.g. in one of the ways described above) to form internal flow passage **541**. Joint **542** may include an elastomeric seal or gasket, which may be integral with either flow tube **531** or base **532**. Flow tube **531** may have port tubes **534** and **535** as shown, except as shown and noted generally similar to the port tubes **34** of first exemplary embodiment **30** and second exemplary embodiment **230** described above. Port tubes **534** and **535** may have devices to restrict the flow, e.g. venturis **564** and **565** as shown. In fifth exemplary embodiment **530**, lead frame **533** is shown molded into base **532** at the ends or shorter sides rather than at the longer sides. Such a configuration could be used with many of the embodiments of the present invention, including those described above. In addition, in exemplary embodiment **530**, lead frame **533** could be similar to the lead frames described above with reference to other exemplary embodiments. Fifth exemplary embodiment **530** is asymmetrical, and consequently, typically provides different output for flows in the two different directions. Specifically venturis **564** and **565** may be different shapes or may be a different distance from chip **38**, both such conditions being shown. In addition, chip **38** may be mounted at an angle with respect to the flow as shown, and as described above. Chip **38** may be as described above for other embodiments, and is typically located within internal flow passage **541**. Fifth exemplary embodiment **530** may be suitable for use with flow only in one direction, e.g. in the direction indicated.

In the foregoing specification, the invention has been described with reference to specific exemplary embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present invention. In addition, benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential features or elements of any or all the

claims. As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such
5 process, method, article, or apparatus.

CLAIMS

What is claimed is:

1. A system (e.g. 30, 230, 330, 430, 530) for sensing the motion of a fluid 43, the system (e.g. 30, 230, 330, 530) comprising:
 - a body having an internal flow passage (e.g. 41, 341, 441, 541);
 - an electronic sensor (e.g. 38) located within said flow passage (e.g. 41, 341, 441, 541); and
 - a metal lead frame (e.g. 33, 233, 333, 533), said lead frame (e.g. 33, 233, 333, 533) in electrical communication with said sensor (e.g. 38), said lead frame (e.g. 33, 233, 333, 533) integrally molded with said body.
2. The system (e.g. 30, 230, 330, 530) according to Claim 1, said body comprising a first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) and a second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532), said first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) and said second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) being joined by a joint (e.g. 42, 242, 342, 542).
3. The system (e.g. 30, 230, 330, 530) according to Claim 2, said first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) and said second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) being configured to snap together.
4. The system (e.g. 30, 230, 330, 530) according to Claim 2, said first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) being attached to said second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) with an adhesive.
5. The system (e.g. 30, 230, 330, 530) according to Claim 2, said first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) being attached to said second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) with heat staking.

6. The system (e.g. 30, 230, 330, 530) according to Claim 2, said first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) being attached to said second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) with ultrasonic welding.
7. The system (e.g. 30, 230, 330, 530) according to Claim 1, said body having outside dimensions of width, depth, and height that are each less than 1.5 inches.
8. The system (e.g. 30, 230, 330, 530) according to Claim 1, said body having a volume of less than 0.25 cubic inch.
9. The system (e.g. 30, 230, 330, 530) according to Claim 1, said body being substantially comprised of plastic.
10. The system (e.g. 30, 230, 330, 530) according to Claim 9, said plastic being thermal plastic.
11. The system (e.g. 30, 230, 330, 530) according to Claim 9, said metal having a lower coefficient of thermal expansion than said plastic.
12. The system (e.g. 30, 230, 330, 530) according to Claim 9, said metal having a coefficient of thermal expansion that is less than 10 parts per million per degree Celsius.
13. The system (e.g. 30, 230, 330, 530) according to Claim 9, said plastic having a coefficient of thermal expansion that is greater than 50 parts per million per degree Celsius.
14. The system (e.g. 30, 230, 330, 530) according to Claim 9, said metal having a coefficient of thermal expansion that is less than 10 parts per million per degree

Celsius and said plastic having a coefficient of thermal expansion that is greater than 50 parts per million per degree Celsius.

15. The system (e.g. 30, 230, 530) according to Claim 1, said body comprising two elongated port tubes (e.g. 34, 534, 535), said port tubes (e.g. 34, 534, 535) being configured to attach to tubing.

16. The system (e.g. 30, 230, 530) according to Claim 15, said port tubes (e.g. 34, 534, 535) each comprising a venturi (e.g. 64, 564, 565).

17. The system (e.g. 30, 230, 330, 530) according to Claim 1, said sensor (e.g. 38) comprising an RTD (e.g. 54, 55) and a heat source (e.g. 52).

18. The system (e.g. 30, 230, 330) according to Claim 1, said internal flow passage (e.g. 41, 341, 441) and said sensor (e.g. 38) being substantially symmetrical such that said system (e.g. 30, 230, 330) is configured to measure the flow rate of the fluid 43 substantially equally in either flow direction.

19. The system (e.g. 30, 230, 330) according to Claim 18, said sensor (e.g. 38) comprising two RTDs (e.g. 54, 55) located on either side of at least one heat source (e.g. 52).

20. The system (e.g. 30, 230, 330, 530) according to Claim 1, the fluid 43 being a gas.

21. The system (e.g. 30, 230, 330, 530) according to Claim 20, the gas being air.

22. The system (e.g. 30, 230, 530) according to Claim 1, said system (e.g. 30, 230, 530) being configured for surface mounting.

23. The system (e.g. 30, 230, 530) according to Claim 1, said system (e.g. 30, 230, 530) being configured for through-hole mounting.
24. The system (e.g. 30, 230, 330, 530) according to Claim 1, the motion being flow rate.
25. The system (e.g. 30, 230, 330, 530) according to Claim 24, the flow rate being mass flow rate.
26. The system (e.g. 30, 230, 330, 530) according to Claim 1, the lead frame (e.g. 33, 233, 333, 533) having pins on substantially opposite sides.
27. The system (e.g. 30, 230, 330, 530) according to Claim 1, said body having a first side, the lead frame (e.g. 33, 233, 333, 533) having a first set of pins projecting from said first side, said first set of pins all being in substantially the same plane.
28. The system (e.g. 30, 230, 330, 530) according to Claim 27, said body having a second side, the lead frame (e.g. 33, 233, 333, 533) having a second set of pins projecting from said second side, said second set of pins all being in substantially the same plane.
29. The system (e.g. 30, 230, 330, 530) according to Claim 1, the system (e.g. 30, 230, 330, 530) further comprising a control system for a heating, ventilating, and air-conditioning system.
30. The system (e.g. 30, 230, 330, 530) according to Claim 29, the system (e.g. 30, 230, 330, 530) further comprising the heating, ventilating, and air-conditioning system.

31. The system (e.g. 30, 230, 530) according to Claim 1, said body comprising a first part (e.g. 31, 32, 231, 232, 531, 532) and a second part (e.g. 31, 32, 231, 232, 531, 532); said first part (e.g. 31, 32, 231, 232, 531, 532) and said second part (e.g. 31, 32, 231, 232, 531, 532) being configured to snap together; said body comprising two port tubes (e.g. 34, 534, 535), each said port tube (e.g. 34, 534, 535) comprising a feature to restrict the flow; said body being comprised substantially of plastic; said body having outside dimensions of width, depth, and height that are each less than 1.5 inches; said fluid 43 being air; and said motion being flow rate.

32. A system (e.g. 30, 230, 330, 430, 530) for sensing the pressure or flow rate of a fluid 43, the system (e.g. 30, 230, 330, 430, 530) comprising:

a body having an internal flow passage (e.g. 41, 341, 441, 541), said body comprising a first part (e.g. 31, 32, 231, 232, 331, 332, 431, 432, 531, 532) and a second part (e.g. 31, 32, 231, 232, 331, 332, 431, 432, 531, 532), said first part (e.g. 31, 32, 231, 232, 331, 332, 431, 432, 531, 532) and said second part (e.g. 31, 32, 231, 232, 331, 332, 431, 432, 531, 532) being joined by a joint (e.g. 42, 242, 342, 442, 542);

said joint (e.g. 42) comprising an elastomeric seal (e.g. 39), said elastomeric seal (e.g. 39) being integral with said first part (e.g. 31, 32, 231, 232, 331, 332, 431, 432, 531, 532); and

a transducer (e.g. 38) located within said flow passage (e.g. 41, 341, 441, 541).

33. The system (e.g. 30) according to Claim 32, said first part (e.g. 31, 32) being attachable to said second part (e.g. 31, 32) with snap connectors (e.g. 36).

34. The system (e.g. 30, 230, 330, 430, 530) according to Claim 32, said body having outside dimensions of width, depth, and height that are each less than 1.5 inches.

35. The system (e.g. 30, 230, 430, 530) according to Claim 32, said body comprising a port tube (e.g. 34, 434, 534, 535), said port tube (e.g. 34, 434, 534, 535) comprising a venturi (e.g. 64, 564, 565).

36. The system (e.g. 30, 230, 430, 530) according to claim 35, said port tube (e.g. 34, 434, 534, 535) being substantially straight.

5 37. The system (e.g. 30, 230, 330, 430, 530) according to Claim 32, said system (e.g. 30, 230, 330, 430, 530) being a dual in-line package.

38. The system (e.g. 30, 230, 530) according to Claim 32, said first part (e.g. 31, 32) being snap attachable to said second part (e.g. 31, 32), said body having outside
10 dimensions of width, depth, and height that are each less than 1.5 inches, and said body comprising port tubes (e.g. 34, 434, 534, 535) that are substantially straight and substantially parallel.

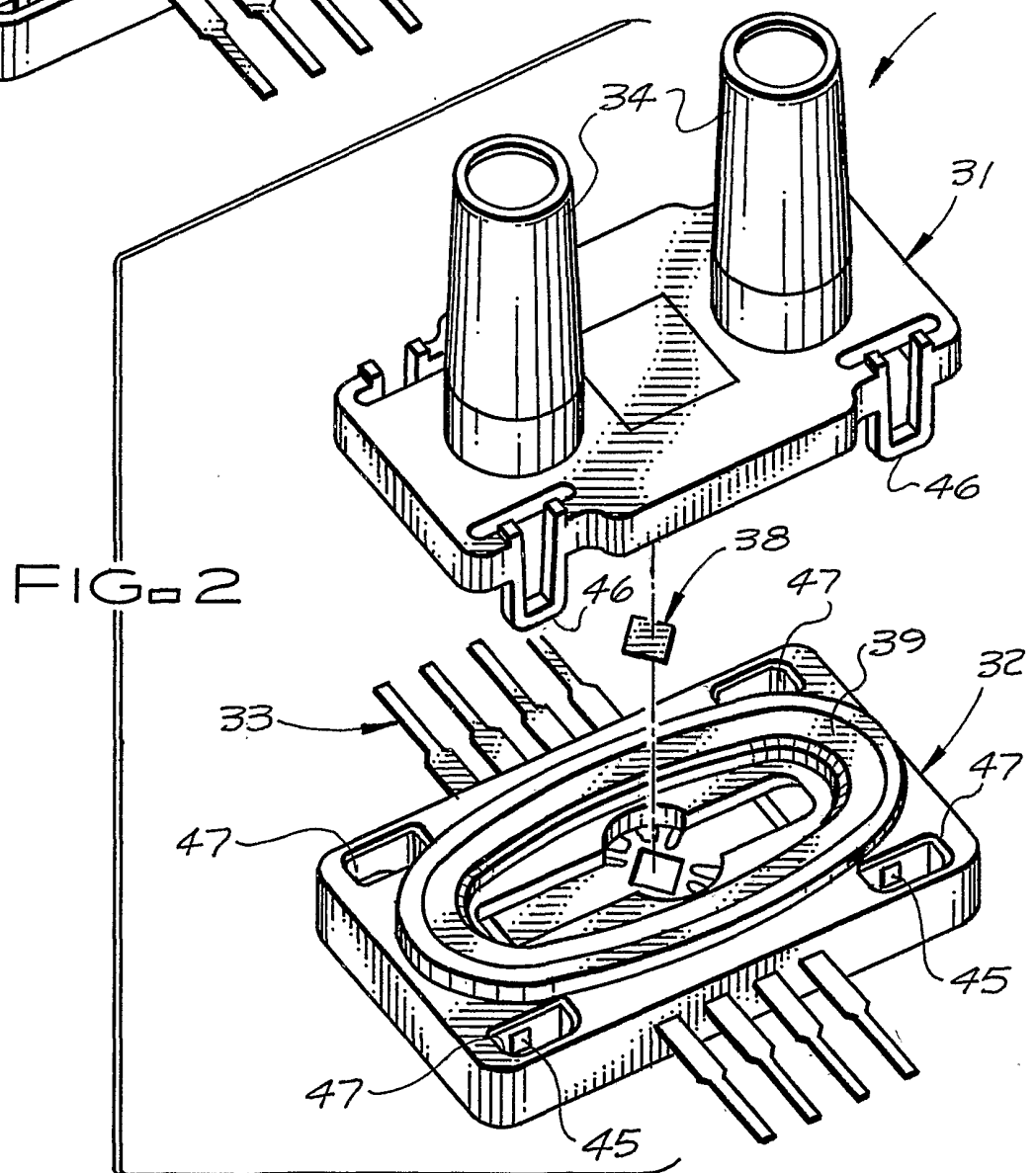
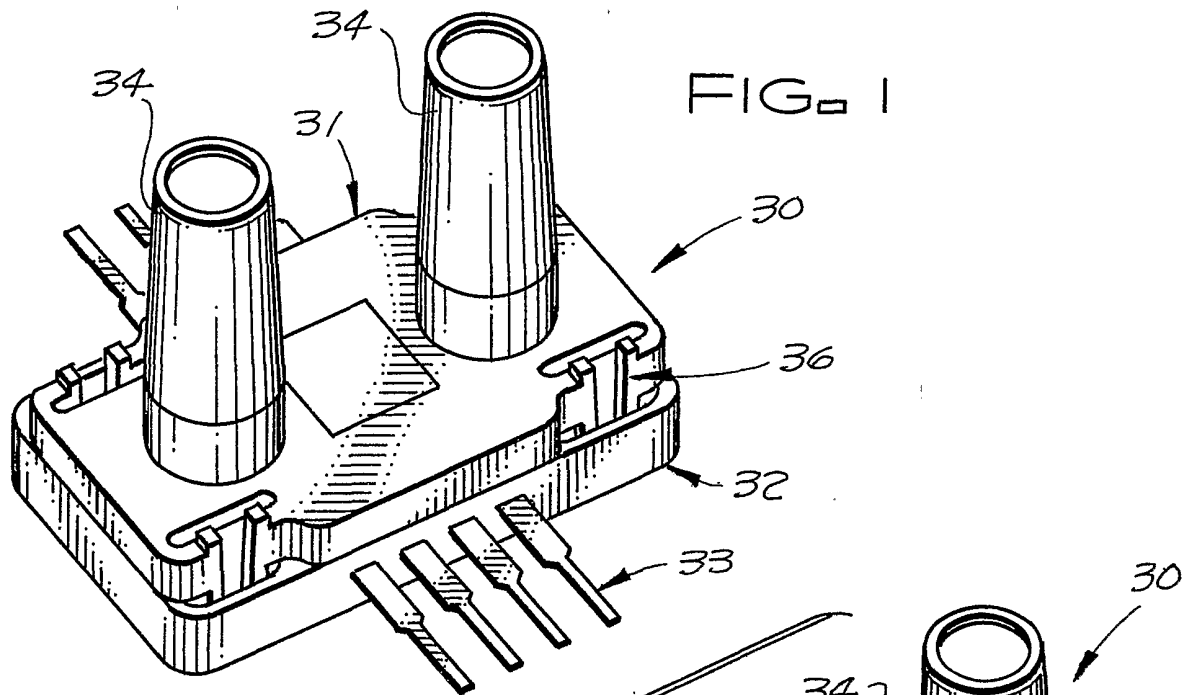
39. A system (e.g. 30, 230, 330, 530) for measuring the flow rate of a gas, the system (e.g. 30, 230, 330, 530) comprising:

5 a body having an internal flow passage (e.g. 41, 341, 441, 541), said body comprising a first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) and a second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532), said first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) and said second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) being joined by a joint (e.g. 42, 242, 342, 542); said first part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) and said second part (e.g. 31, 32, 231, 232, 331, 332, 531, 532) being configured to snap together; and
10 a sensor (e.g. 38) located within said flow passage (e.g. 41, 341, 441, 541).

40. The system (e.g. 30, 230, 330, 530) according to Claim 39, said body having outside dimensions of width, depth, and height such that width multiplied by depth multiplied by height is less than 0.5 cubic inch.

41. The system (e.g. 30, 230, 330) according to Claim 39, said body having outside dimensions of width, depth, and height such that width multiplied by depth

multiplied by height is less than 0.5 cubic inch; said internal flow passage (e.g. 41, 341, 441) and said sensor (e.g. 38) being U-shaped and substantially symmetrical such that said system is configured to measure the flow rate of the gas substantially equally in either flow direction; said sensor (e.g. 38) comprising two RTDs (e.g. 54, 55) located on either side of at least one heat source (e.g. 52); and the gas being air.



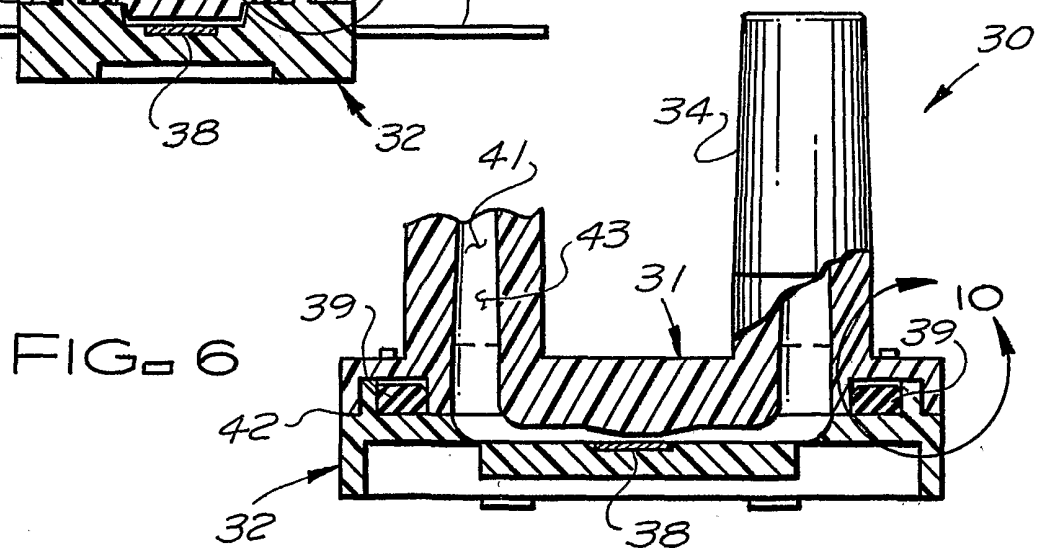
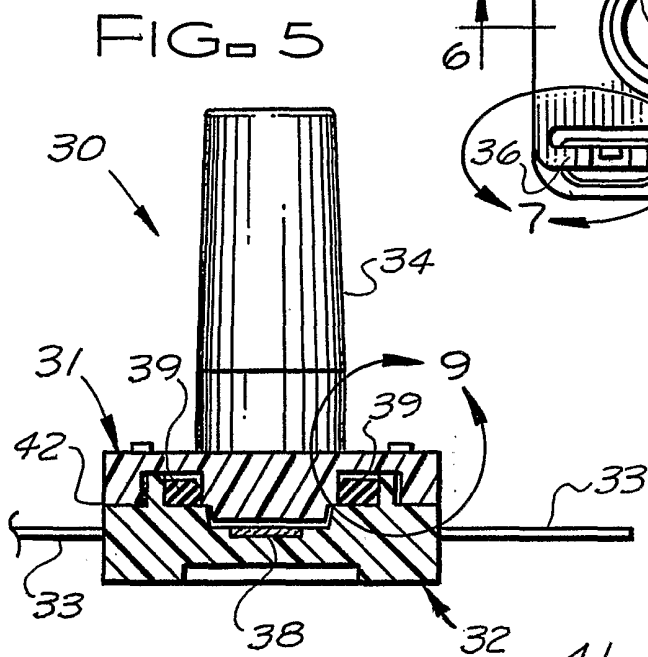
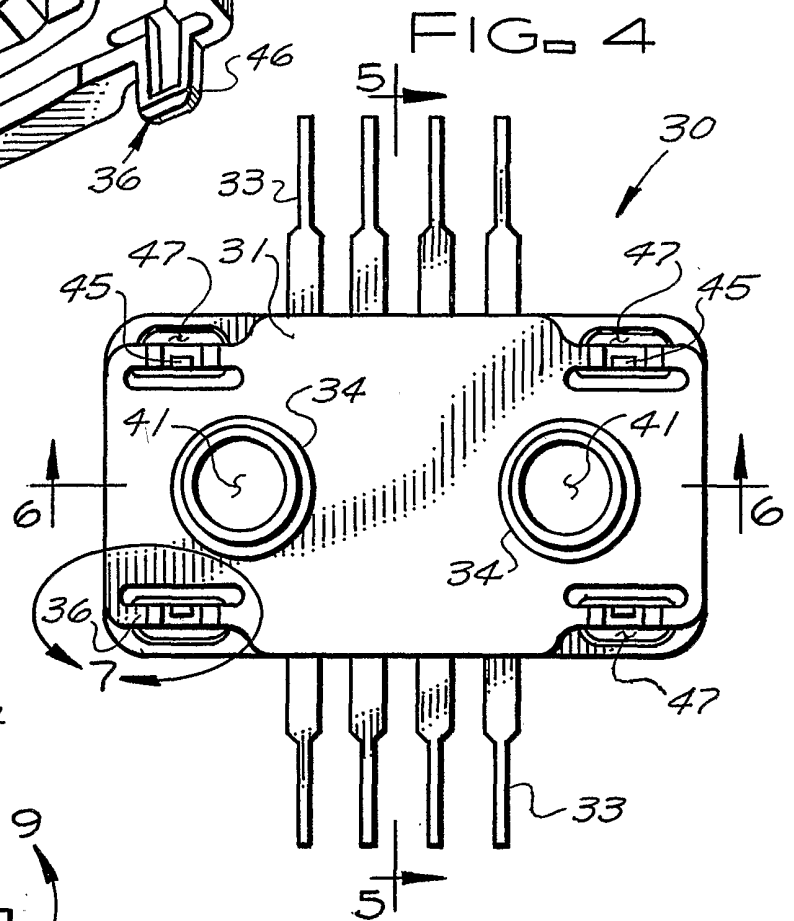
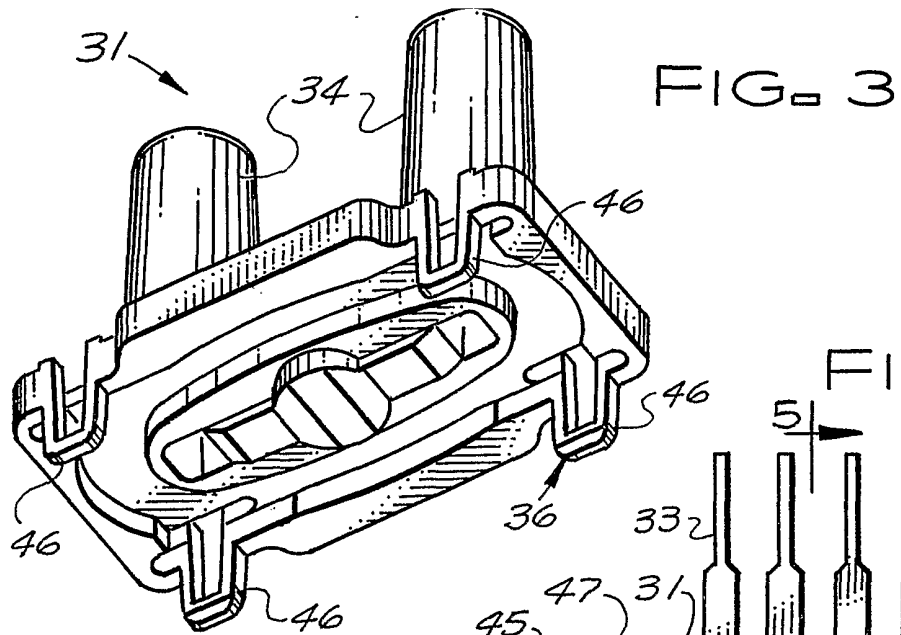


FIG. 7

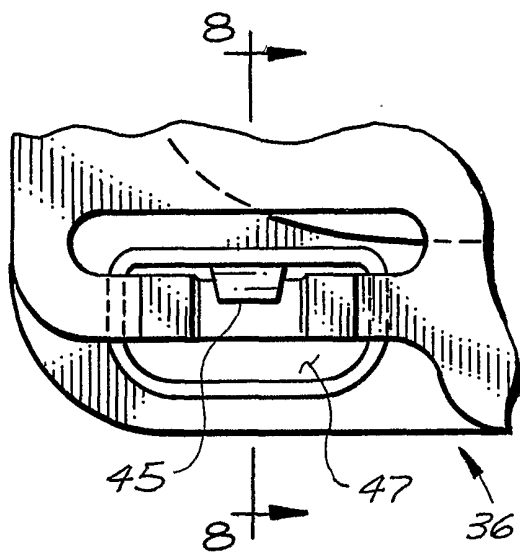


FIG. 8

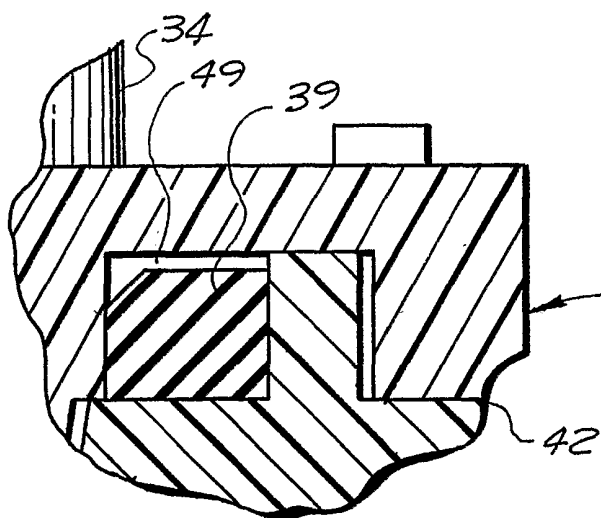
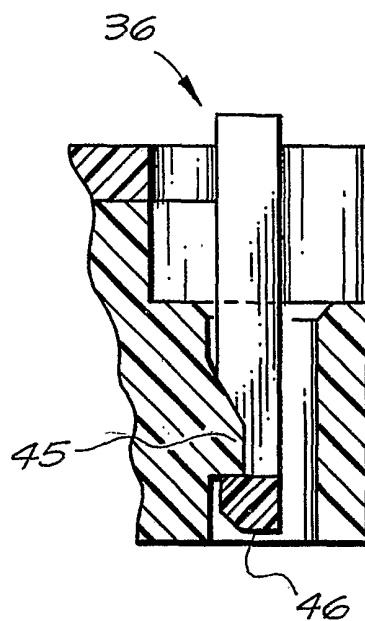


FIG. 9

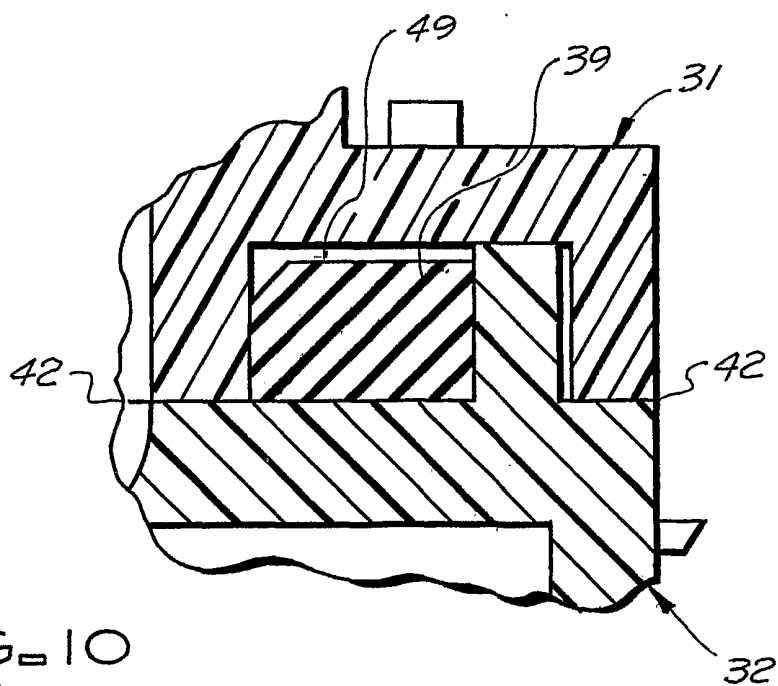


FIG. 12

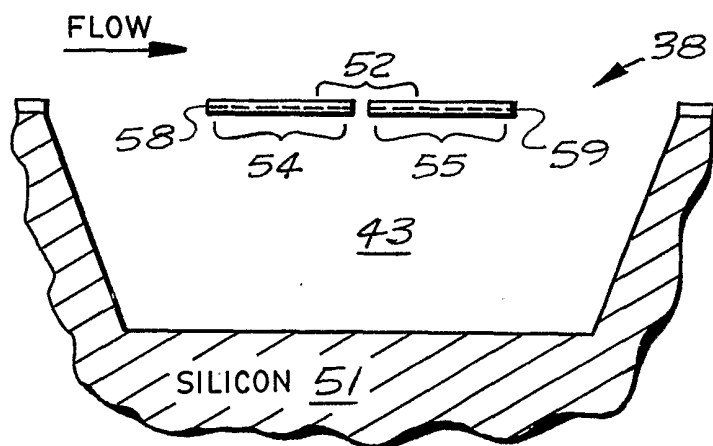
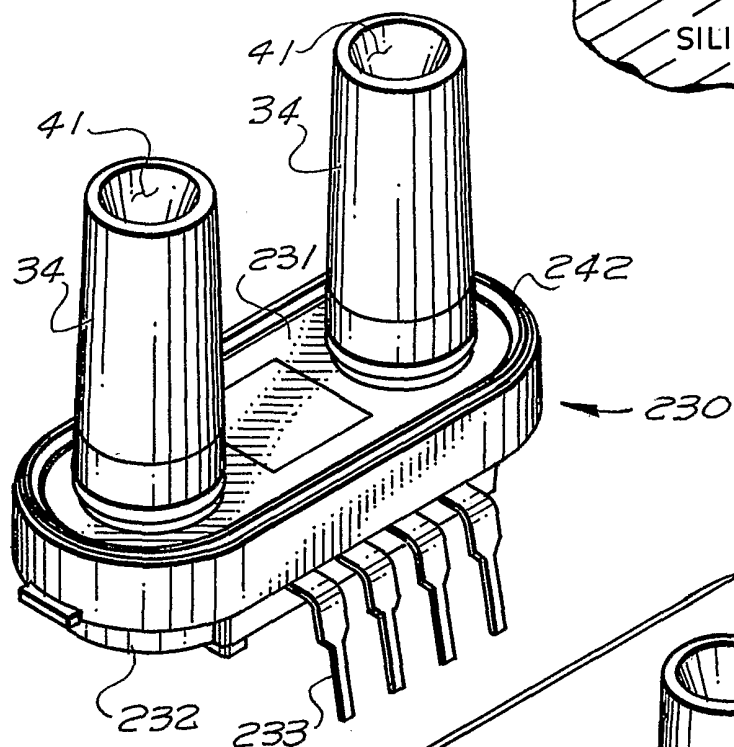
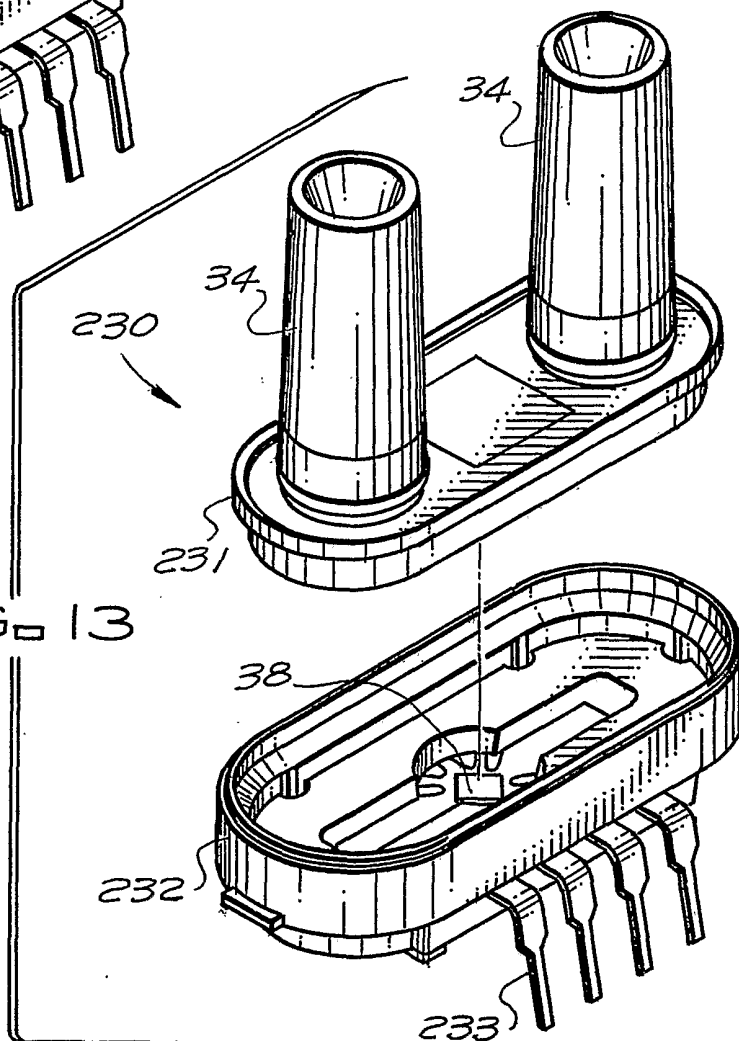


FIG. 11

FIG. 13



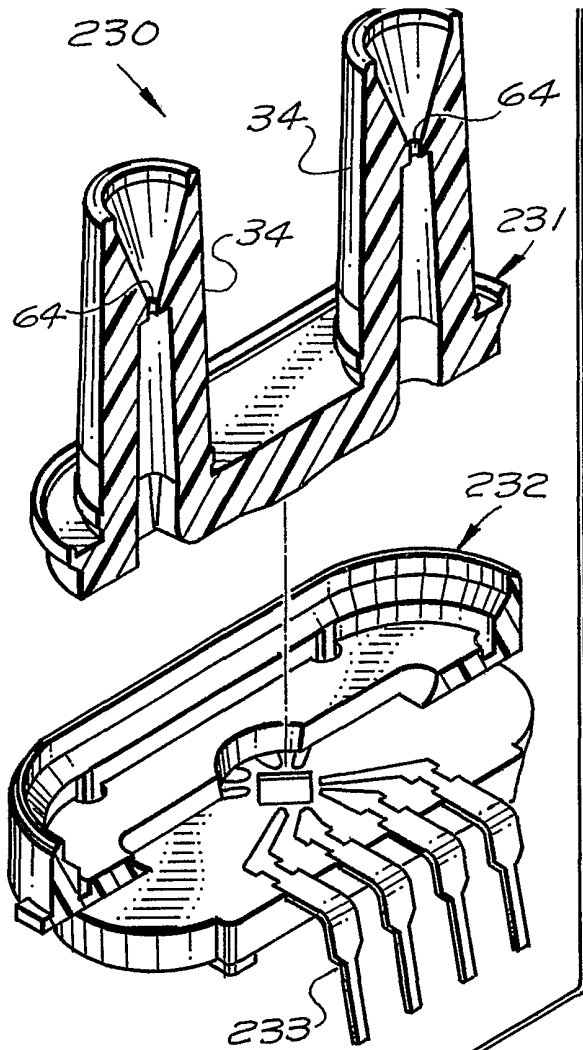


FIG. 14

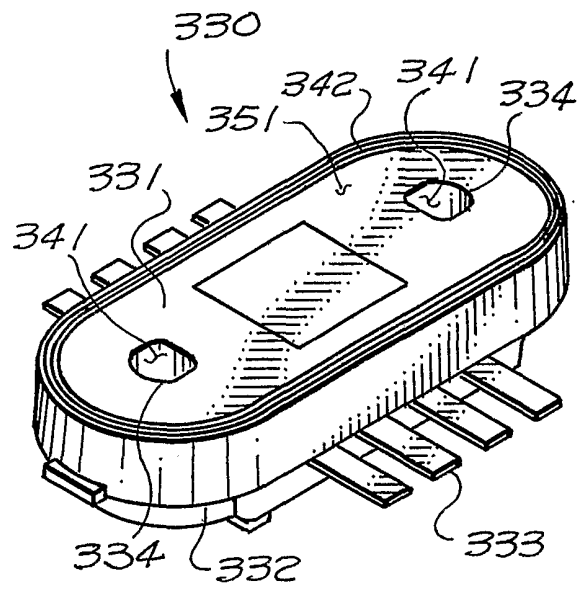


FIG. 15

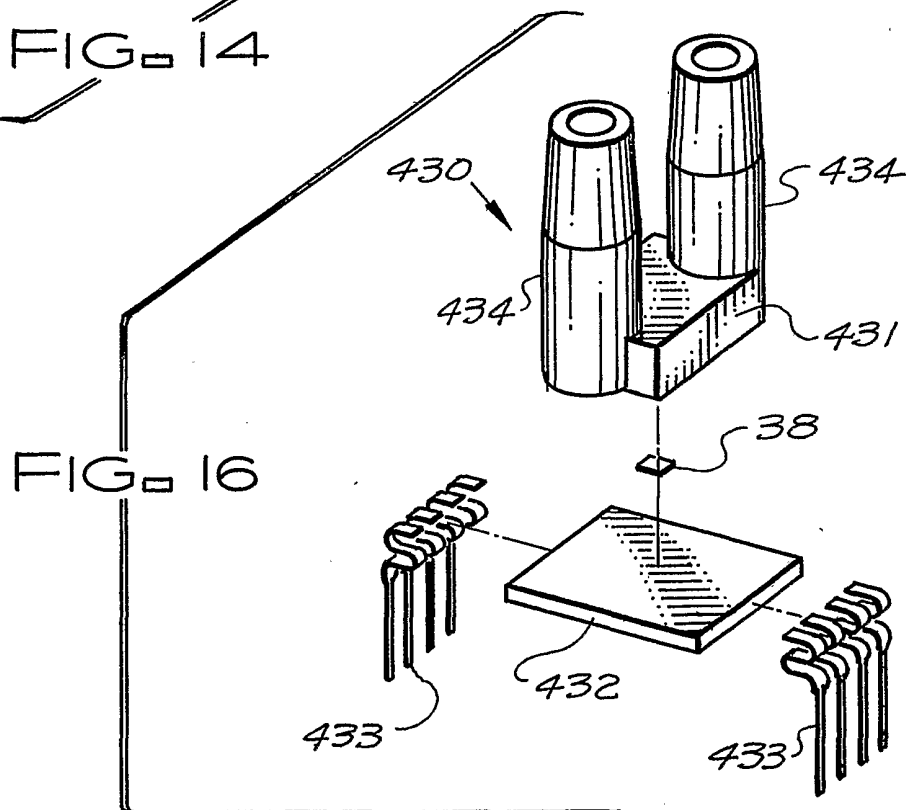


FIG. 16

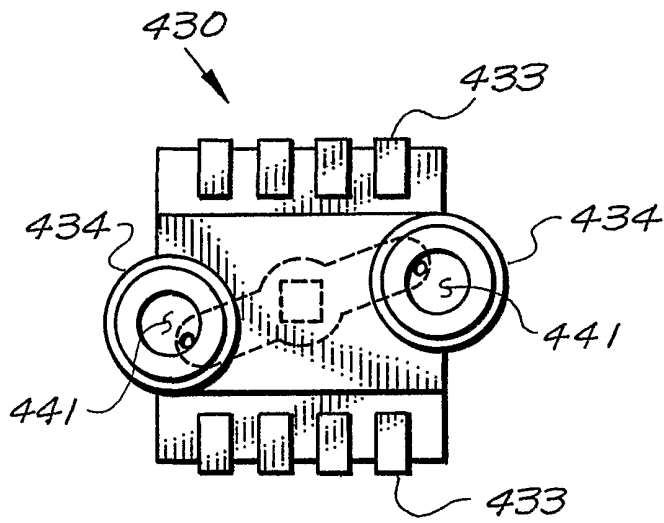


FIG. 17

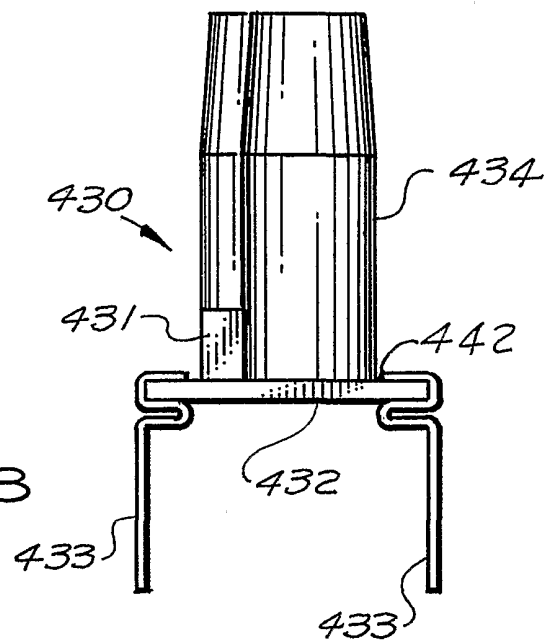


FIG. 18

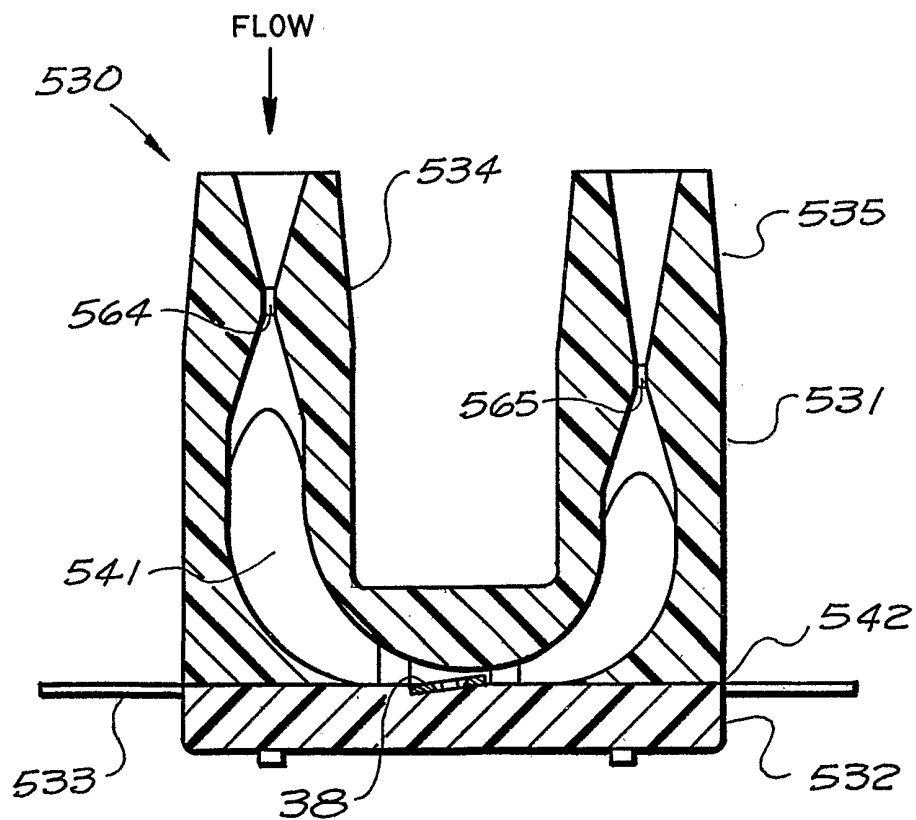


FIG. 19