137-13. OR 3,574,309 SR

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Continuation-in-part of application Ser. No. 662,273, Aug. 18, 1967, now abandoned.

[54] CHAMBERED FLUIDIC AMPLIFIER

3 Claims, 8 Drawing Figs.

[52] **U.S. Cl.** **137/81.5**
[51] **Int. Cl.** **F15c 1/18**
[50] **Field of Search** 137/81.5

[56] **References Cited**

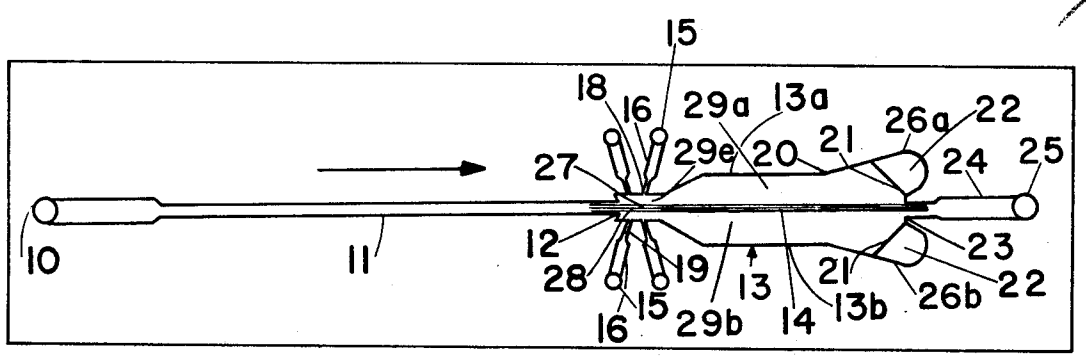
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ABSTRACT: A supply tube projects fluid flow into a chamber closely surrounding but not contacting the projected flow in its laminar state; the chamber has at least one wall narrowly spaced from the path of the projected laminar supply stream, and at least one wall sufficiently spaced from this path to permit reverse circulation in the chamber; the application of a control flow transversely against the projected laminar flow causes a disruption thereof with interaction of the projected disrupted flow with the chamber walls; a receiver axially aligned with the supply tube senses the effects of control flow upon the supply flow, the switching between controlled and uncontrolled states being enhanced by the interaction between the supply flow and the confining chamber.

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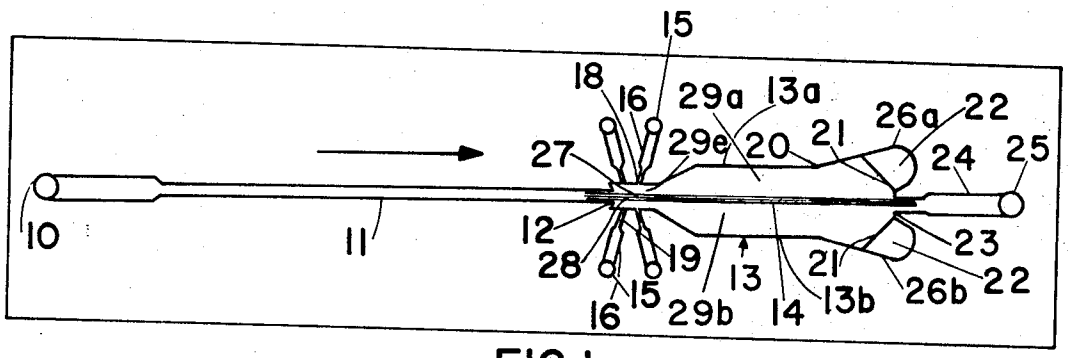


FIG. 1

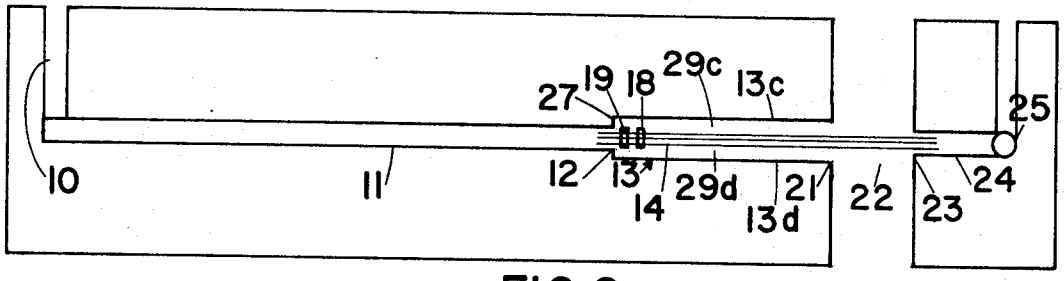


FIG. 2

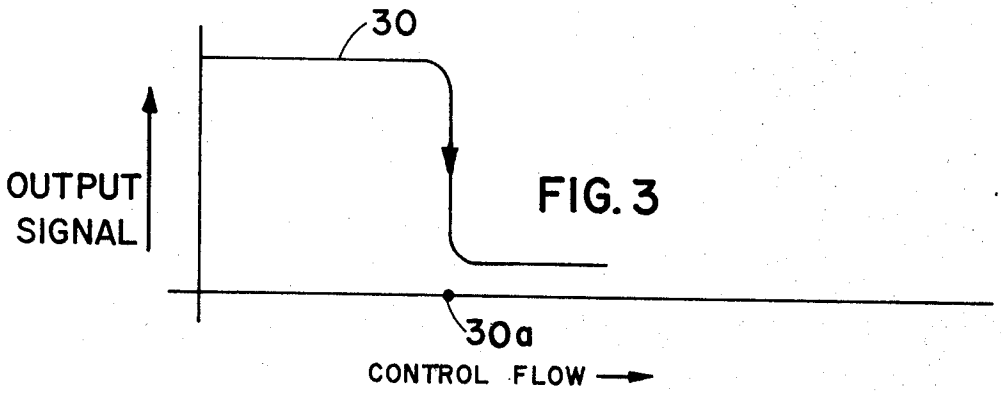


FIG. 3

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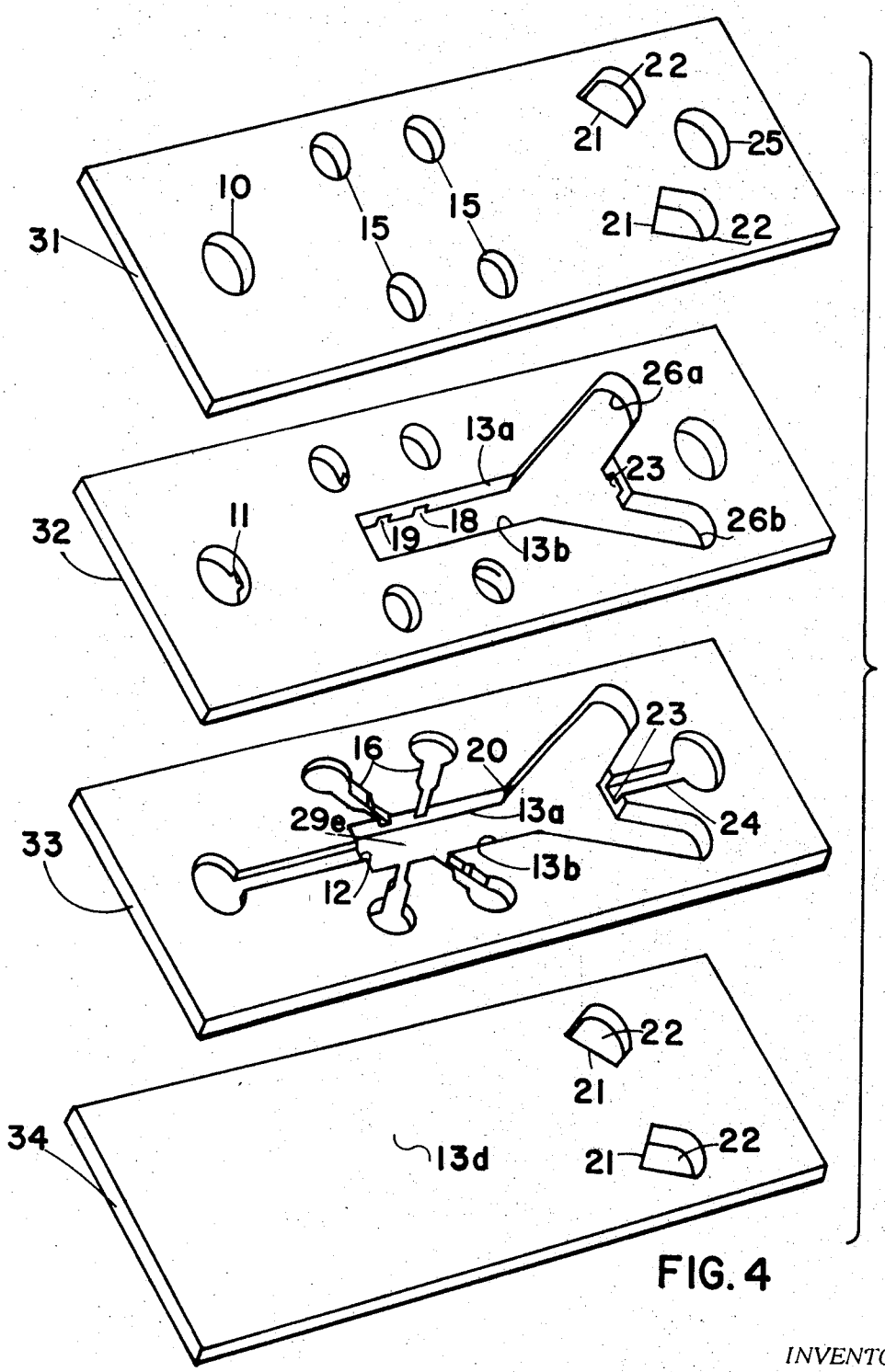


FIG. 4

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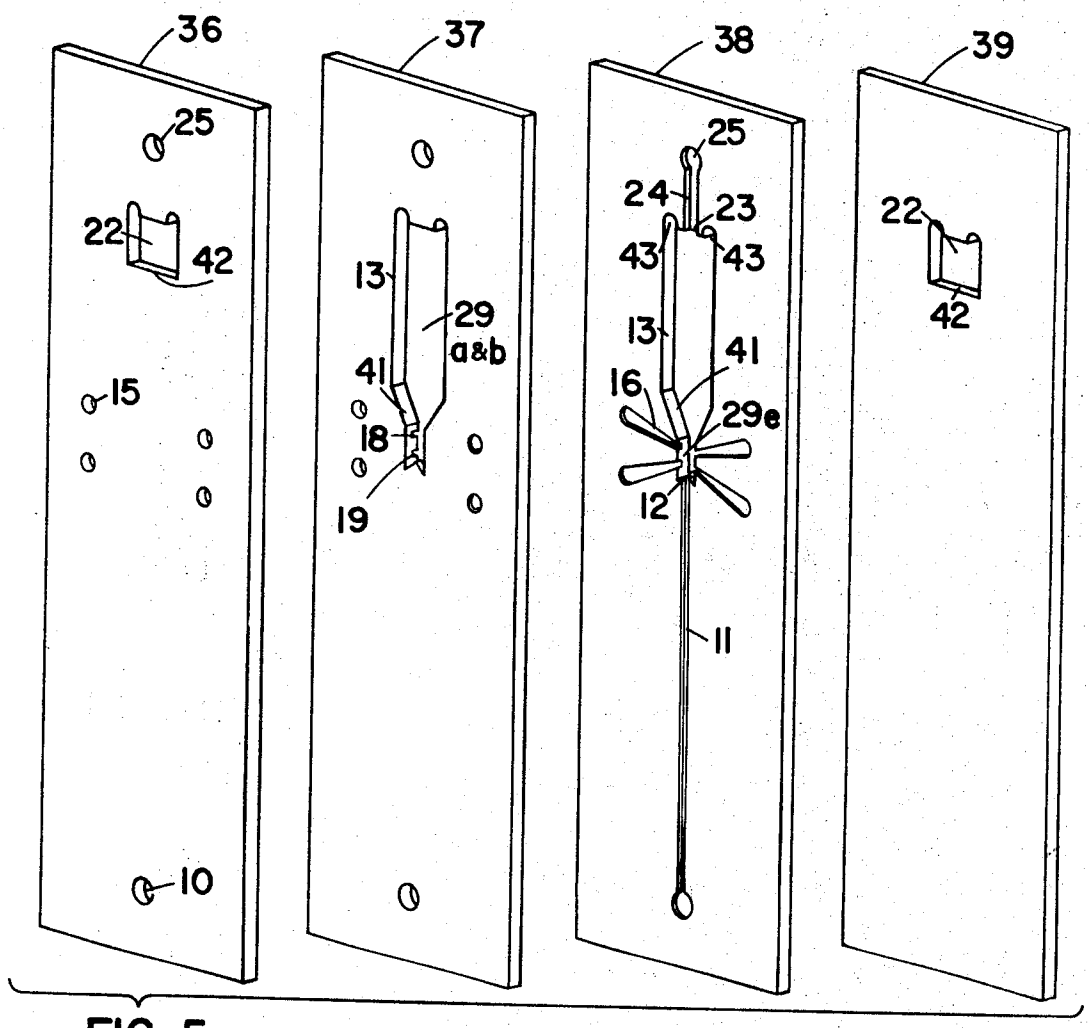


FIG. 5

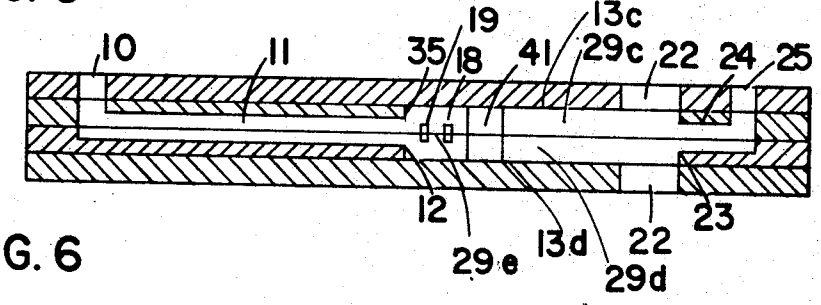


FIG. 6

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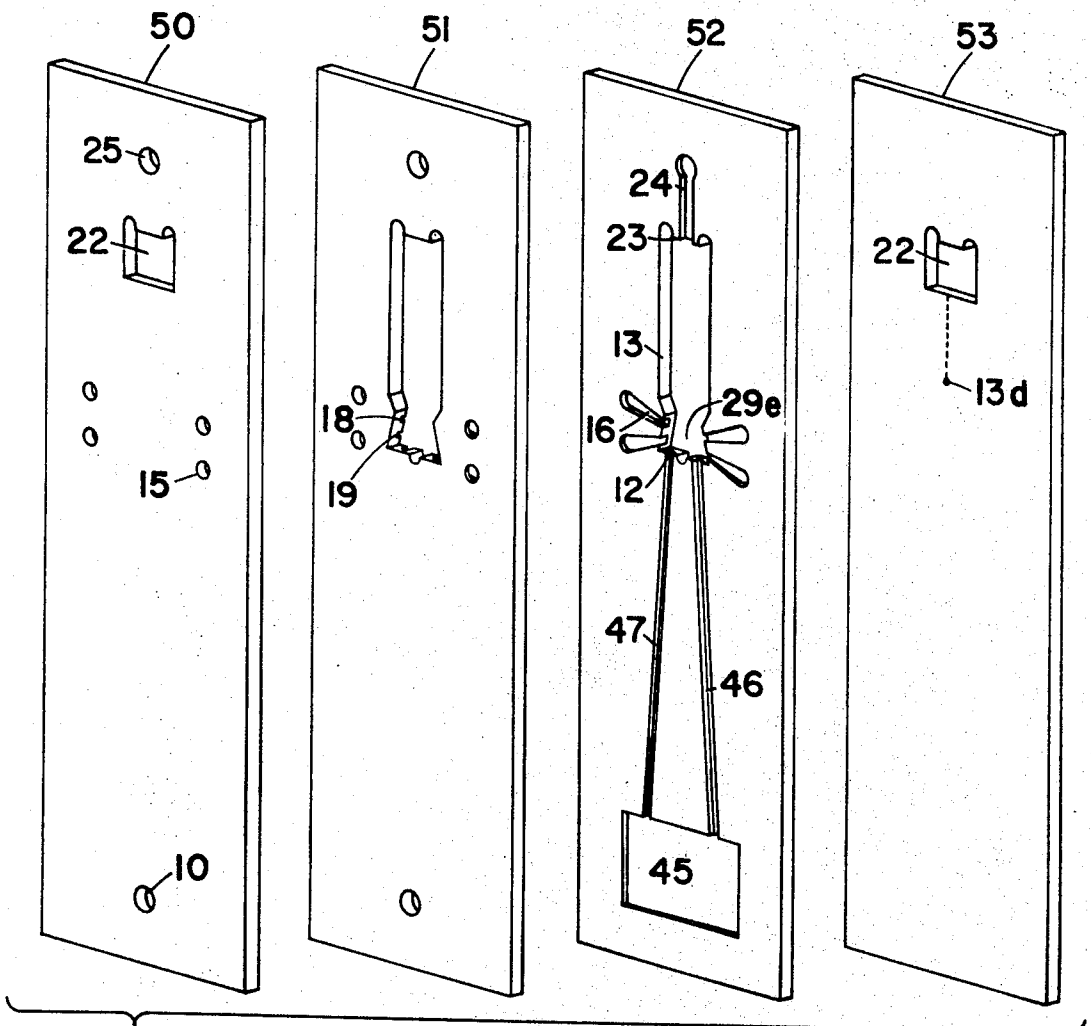


FIG. 7

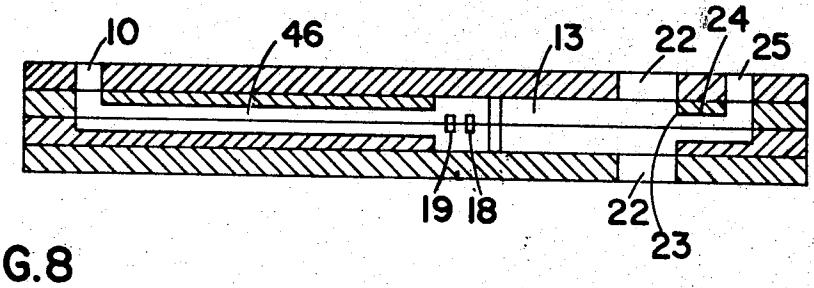


FIG. 8

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CHAMBERED FLUIDIC AMPLIFIER

This application is a continuation-in-part of U.S. Ser. No. 622,273 filed Aug. 18, 1967 and now abandoned for Fluidic Turbulence Amplifier With Wall Attachment.

This invention relates to fluidic amplification, and more particularly to an improved fluidic amplifier providing for high gain and improved fan-out capabilities.

The prior art includes a variety of fluidic elements having an output signal which is a function of an input control signal, there usually being some gain in the signal conversion. These fluidic devices operate on various principles. A common type is the wall attachment fluidic element in which a turbulent flow is moved between stable attached positions by the action of a control jet directed at a cross section of the supply flow. Another type is disclosed in Hall U. S. Pats., Nos. 1,205,530 and 1,628,723, in which a laminar flow is controllably disrupted by a control jet impinging transversely upon the laminar flow with the output of the device being taken from means adapted to sense the difference between the laminar and disrupted conditions.

The fluidic devices of the prior art have various limitations, the laminar turbulence elements being susceptible to influences imposed by the external environment, such as noise or vibration, with consequent erratic operation of the device. Additionally, the power-switching capabilities of these devices are generally quite low. The wall attachment fluidic devices have a relatively low efficiency, and must generally operate at high-pressure levels, requiring large amounts of supply air; consequently they require a large fluidic power supply in many applications.

Generally applied to fluidic devices of the type discussed, the term efficiency describes the ratio of fluidic power available from the output to the fluidic power furnished to the supply of a device. Wall attachment devices typically display low efficiency according to this definition.

Fluidic devices of the type generally exemplified by the embodiments in the Hall patents above may operate at conveniently low-pressure levels, typically in the order of inches of water, but generally have low-power gain and fan-out. These devices typically display low-power gain, defined as the ratio of fluidic power required for switching to the fluidic power at the output controlled thereby. Fan-out is generally the ability of a fluidic device to control a plurality of additional devices; fan-out is a function of efficiency and impedance matching. These devices of the Hall type generally display a higher efficiency than the wall attachment type.

Considering the limitation of available fluidic devices, there is a distinct need for fluidic devices having improved characteristics over those devices presently in the art. For example, Ser. No. 661,605, now U.S. Pat. No. 3,490,477 issued Jan. 20, 1970, is directed to an improved fluidic element having operating characteristics superior to devices previously available.

It is an object of the present invention to provide a fluidic device having improved characteristics, including an acceptably high efficiency and power gain suitable for practical applications.

It is another object of this invention to provide an improved type of fluidic device in which the action of a control jet impinging upon a supply stream is in effect augmented by interaction in a chamber to thereby provide improved operating characteristics of the device.

Briefly stated, the invention provides a closely confining chamber into which a supply flow is projected with a control jet being introduced into said chamber transversely to said supply stream, the combination being adapted to cause interaction between the supply stream and the confining chamber thereby enhancing the change in output condition consequent upon the application of a control flow.

As a consequence of the enhancement of the change in output condition, the power gain of a device constructed in accordance with the invention is improved, with quite reliable switching being effected by a relatively low power control signal. Additionally, for the condition of the device in which the output is reduced to a minimum, it is found that a relatively low power of control signal will satisfactorily reduce the output signal to a negligible level, a function not readily obtained with conventional Hall types of devices. It is especially desirable to have a device exhibiting a practically zero output condition.

It should be understood that the science of fluidics, being relatively new, is in an infant state, and that the most advanced practitioners of the art are unable to accurately or completely describe their models. It follows that all the behavior of any fluidic device can not now be exhaustively described, and in fact much is not known. In particular, there exist at present difficulties with the theoretical description of the present invention. As complete a description of the invention will be given as is presently available to the invention, such as will enable those skilled in the art to practice the invention. It must be understood, however, that the description hereunder may be subject to augmentation and revision at some later date as additional information becomes available.

In general, additional objectives and advantages of the present invention will be apparent from the specification below taken in conjunction with the drawings therewith in which:

FIG. **1** is a diagrammatic cross-sectional representation of an embodiment of the invention showing the condition of projected laminar flow;

FIG. **2** is a diagrammatic cross-sectional view of the embodiment of FIG. **1** taken along the axial centerline of the supply and receiver conduits and normal to FIG. **1**;

FIG. **3** is a graphic representation of the relationship of control flow to output signal;

FIG. **4** is an exploded view of an etched circuit embodiment of the invention;

FIG. **5** is an exploded view of another embodiment of the invention;

FIG. **6** is a cross-sectional view of the embodiment of FIG. **5**;

FIG. **7** is an exploded view of an embodiment of the invention employing a plurality of supply conduits; and

FIG. **8** is a cross-sectional view of the embodiment of FIG. **7**.

Referring now to FIG. **1**, a diagrammatic cross-sectional view of an embodiment of the invention is shown, the cross section being taken along an axis common to fluidic supply and receiver conduits **11** and **24**, and also being oriented to show the larger dimension of chamber **13** normal to said axis. The scale of the representation of FIG. **1** is chosen for convenience of explanation, the preferred embodiments being in the order of one-half or smaller than the size of the representation in FIG. **1**.

A source of fluid supply is connected to supply input port **10**. The fluid supply is conveniently air elevated above atmosphere to appear at supply input **10** at an illustrative pressure of three-quarters p.s.i.g. A supply conduit **11** projects the supply flow through supply conduit end **12** into enclosure of chamber **13**, with the length of conduit **11** between input **10** and supply conduit end **12** being sufficient to establish a laminar flow condition of the projected supply fluid throughout the length of chamber **13**. For the flow rates particularly useful with the invention, the length to diameter ratio of supply conduit **11** should be more than 35. According to well-known fluidic principles, the Reynolds number of the supply flow projected into chamber **13** should be just low enough to achieve laminar flow therethrough. That is to say, there is a working region of Reynolds numbers for the supply flow projected from supply conduit **11**, corresponding to laminar flows which would tend to disrupt at some point downstream of the receiver **24** pickup end **23**.

Chamber **13** has its walls **13***a* and **13***b* separated from projected laminar stream path **14** throughout the length of chamber **13**, this separation providing for chamber regions **29***a* and **29***b* therebetween. These regions **29***a* and **29***b* prevent interaction between projected laminar stream **14** and the walls

of chamber 13; in addition, the separation between projected laminar stream 14 and walls 13*a* and 13*b* of chamber 13 is sufficient to allow a circulation of flow in chamber 13 upstream through regions 29*a* and 29*b*; this upstream circulation allows for entrainment normally involved with a projected laminar stream, and thereby tends to reduce the production of a pressure drop in chamber area 29*e* proximate supply conduit end 12.

Control ports 15 each open into area 29*e* of chamber 13 in a manner to impress a control flow transversely upon projected laminar flow 14. Control ports 15 are connected by conduits 16 into the sides of chamber 13 at inlet points 18, 19 near supply conduit end 12. Control conduits 16 and inlets 18, 19 are adapted to direct a control flow transversely against projected laminar stream 14 at point 27, 28 respectively quite close to the emergence of the supply stream from supply conduit end 12, these points 27, 28 being in chamber area 29*e*.

In the embodiment of FIG. 1, chamber 13 is relatively narrow from supply conduit end 12 through region 29*e*, which region 29*e* includes the control points 27, 28. From region 29*e*, chamber 13 expands to a larger area 29*a* and 29*b* which continues downstream to chamber point 20, where chamber 13 diverges into two wings 26*a* and 26*b* communicating with atmospheric points 22. Axially aligned with supply tube 11, and located at the downstream end of chamber 13 is receiver conduit 24 having an inlet 23 facing the projected laminar stream path 14 in a manner to impress upon receiver conduit 24 a signal related to the condition of operation. The signal impressed upon receiver conduit 24 is connected to output port 25 for transmission to appropriate apparatus. Receiver conduit 24 is disposed intermediate wings 26*a* and 26*b*.

Referring to FIG. 2, a diagrammatic cross-sectional view along the supply and receiver conduit axes oriented to show the smaller dimension of chamber 13 normal to said axis, walls 13*c* and 13*d* are spaced closely with laminar stream path 14 along the length of chamber 13 from supply conduit end 12 downstream to receiver inlet 23; these chamber walls 13*c* and 13*d* extend up to the chamber wings 26*a* and 26*b* to terminations 21 to thereby define atmospheric accesses 22 for chamber 13.

Taken together, then, walls 13*a*, 13*b*, 13*c* and 13*d* define an enclosing surround of the supply stream projected from supply conduit 11, the chamber formed thereby having a dimension defined by walls 13*c* and 13*d* which is narrow relative to a wider dimension formed by walls 13*a* and 13*b*.

Confining walls 13*c* and 13*d* of chamber 13 are positioned closely proximate the projected laminar stream path 14 along its traverse of chamber 13. The separation between walls 13*c* and 13*d* and projected laminar stream path 14 for an illustrative embodiment approximately one-half the size of the scale of FIG. 1 may conveniently be in the range of 0.005—0.020 inch. These separations define chamber regions 29*c* and 29*d* on either side of the laminar flow path 14 between walls 13*c* and 13*d* respectively. It is to be noted that the drawing of FIG. 2 emphasizes this extremely small separation. In the embodiment of FIG. 2, the close positioning of chamber walls 13*a* and 13*d* with projected laminar stream path 14 is shown to be symmetrical. However, it is to be understood that the invention will function with one of the chamber walls 13*c* or 13*d* being closer than the other. It is desirable that the projected supply stream, in the laminar condition of operation, traverse the confines of chamber 13 without coming in contact with the walls thereof, to thereupon impress on receiver conduit 24 a maximum output signal, this laminar condition representing the ON condition of the fluidic device.

In the operation of the embodiment of FIG. 1, a source of control signal is connected to a port 15, and transferred by a conduit 16 to a chamber control inlet 18; the control flow is projected from inlet 18 against the side of the projected laminar supply flow at a control point 27 in chamber region 29*e*; this projected control flow interacts with the projected supply stream to thereby disrupt it downstream from control point 27. The supply and control flows have rates chosen to produce controlled disruption of the projected supply flow in the volume of chamber 13 that is, downstream from control point 27 and upstream of receiver inlet 23. Such a disrupting effect on the projected supply flow tends to cause the supply flow to effectively expand in chamber 13, this expansion tending to increase in volume with the distance downstream from control point 27. That is to say, the disrupted supply stream tends to occupy regions 29*a*, *b*, *c*, *d*, in chamber 13 downstream from control point 27. It appears that at a relatively short distance downstream from control point 27, the expansion of the disrupted supply flow is sufficient to bridge the narrow spacing of chamber regions 29*c* and 29*d* to effectively cause contact with the most closely facing chamber walls 13*c* and 13*d* to cause an interaction therewith. Such interaction probably enhances the tendency of the supply stream to disrupt, making the disrupted supply flow further expand to more fully occupy the available volume in chamber 13, particularly regions 29*a* and 29*b* enclosed by chamber walls 13*a* and 13*b*.

The distance between chamber walls 13*c* and 13*d* is very small, which distance may be termed the minor axis of chamber 13 normal to the supply conduit receiver conduit axis; the distance between chamber walls 13*a* and 13*b* is somewhat larger, but limited, which distance may be termed the major axis of chamber 13 normal to the supply receiver conduit axis. Taken together, these major and minor axes of chamber 13 define a limited area for the disrupted supply flow to occupy. It appears that the interaction between disrupted supply flow and chamber walls 13*a*, *b*, *c*, and *d*, has a regenerative aspect, in that an increased disruption effect occurs as a consequence of the chamber 13 confinement. Also, this interaction tends to produce a more even distribution of disrupted flow through the available volume of chamber 13. Additionally, it would appear that this enhancement consequent upon confinement by the chamber enclosure has the effect of reducing the required control flow to achieve satisfactory cutoff; this effect is consistent with the relatively high-power gain obtained with the use of this device. Therefore, at sensing end 23 of receiver conduit 24, the effect thereon of the generally disrupted supply flow is reduced to a minimum, with the supply flow in its disrupted condition tending to egress to atmosphere through atmospheric ports 22.

It is noted that in going from the laminar to the disrupted condition of the supply flow, a slight reduction in the pressure appearing at control ports 15 is generally observed. This effect may be observed at a control port 15 alternate from the controlled port 15. This observation gives the inference that the pressure in region 29*e* is similarly reduced as a consequence of the transition to the disrupted condition. This effect may be because the disrupted condition of the supply flow is in effect a restriction upon the migration of reverse flow from atmospheric ports 22 through chamber regions 29*a* and 29*b* to the control region 29*e* proximate control point 27.

Referring to FIG. 3, the relationship between control flow and output signal is illustrated by plot 30. At low control flows below the level of point 30*a*, the effect of the control flow on the projected laminar stream 14 is insufficient to cause disruption. When control flow is increased to point 30*a* the disruption effect occurs, and the output sensed by receiver conduit 24 drops to a very low value. With a high impedance control source, the observed switching of the output occurs as nearly as may be observed at the same point 30*a* for increasing or decreasing signals. However, a tendency for a device of the invention to exhibit different effective control impedances between OFF and ON conditions may be utilized to provide an apparent discontinuity in the control signal as it switches the state of the device. If the control source has a low impedance, as the control signal is varied through the switching region, the effective impedance of the fluidic device will alter. When pressure is the control parameter, the volumetric flow is the control parameter, a pressure jump is observed. Such an effect may be utilized in many ways, for example, to produce an effective control dead-band which enhances the stability of the

device, preventing oscillation of the output while the control signal hovers in the switching region.

Referring to FIG. 4, an exploded set of etched plates 31, 32, 33, and 34 is illustrated which when sandwiched together in the relationship indicated and sealed together by appropriate bonding processes forms another embodiment of the invention. Plate 31 contains the supply port inlet 10, control ports 15, outlet port 25, and a pair of chamber atmospheric accesses 22. Another pair of accesses 22 are in plate 34. The body of the fluidic device is etched in plates 32 and 33, with each plate containing a symmetrical one-half of the device. In each plate 32, 33, chamber 13 is etched completely therethrough so that with plates 32 and 33 assembled together the depth of chamber walls 13*a* and 13*b* are equal to the combined thickness of plates 32 and 33. Supply conduit 11, control conduits 16, and receiver conduit 24 are etched only part way into each plate 32, 33, so that when assembled, conduits 11, 16 and 24 have a depth equal to the combined etching depth in plates 32 and 33. Thereby, the distance of chamber wall 13*d* which is provided by plate 34, from the projected laminar stream path 14 is defined, this distance corresponding to the difference between the depth conduit 11 is etched into plate 33, and the full thickness of plate 33.

It may be noted that in the embodiment of FIG. 4, chamber region 29*e* adjacent supply conduit end 12 is relatively large, not being necked down as in the chamber 13 shown in FIG. 1. This configuration may require more control power, the control conduit inlets 18 and 19 being further from the projected supply stream; a possible advantage is a lower pressure drop in chamber region 29*e*, as the reverse flow circulation path is relatively more open with this configuration.

The embodiment of the exploded view of FIG. 5, showing etched plates 36, 37, 38 and 39, differs in some particulars from the embodiments of FIGS. 1 and 4. The shape of chamber 13 resembles somewhat a wine bottle with its mouth being open to supply conduit end 12 and its base points 43 being positioned proximate and on either side of end 23 of receiver conduit 24. An expanding neck portion 41 of chamber 13 connects the relatively small mouth region 29*e* of chamber 13 to the generally enlarged downstream area 29*a* and *b* of chamber 13. Chamber 13 is completely enclosed downstream from supply conduit end 12 to points 42, each point 42 forming one edge of atmospheric access ports 22.

FIG. 6 shows a cross-sectional view of the embodiment of FIG. 5, sandwiched together and sectioned along the axes of supply tube 11 and receiver tube 24, and showing the narrow dimension of chamber 13. Step 35, not to scale in the drawing, provides for a small distance between the outside diameter of supply tube 11 and chamber wall 13*c*, the distance illustratively being in the region of 0.015 inch. This step 35 provides the clearance between the projected supply flow in its laminar condition and chamber wall 13*c*.

FIG. 7 shows yet another embodiment of the invention with an exploded set of etched plates 50, 51, 52, 53 which when assembled in the manner indicated forms an embodiment of the device. FIG. 8 is a cross-sectional view generally taken along one of the supply tubes 46, 47 of the embodiment of FIG. 7, and along the narrow dimension of chamber 13. It may be seen that the mouth region 29*e* of chamber 13 is somewhat enlarged providing for the application of two supply conduits 46 and 47 to make communication into region 29*e* of chamber 13. Upon application of a control signal to conduit 16, interaction with the projected supply stream from conduit 47 occurs, disrupting it, and in turn disrupting the projected supply stream from conduit 46. The combined disruption takes place in the manner more fully described in connection with the invention disclosed in application Ser. No. 621,191 filed Mar. 7, 1967 now U.S. Pat. No. 3,457,934 issued Jul. 29, 1969. In general, both projected laminar streams from conduits 46 and 47 impinge at inlet 23 of receiver conduit 24, providing for a relatively high output in the ON condition considering the overall size of the device selected. The effects of a control signal upon both the projected supply streams, taken in combination with the interaction of the disrupted combined supply flow with the proximate chamber walls thereby produces a more complete dissemination of the flow throughout chamber 13 thereby promoting supply egress through atmospheric ports 22. The result of this combination achieves a high-power gain fluidic device.

It is generally observed that with the fluidic devices of the invention, the effects of external noises and vibrations are attenuated. It is supposed the provision of the enclosure surrounding the projected supply stream for a major portion of its traverse serves to effectively shield the fluidic device from unwanted influences. In addition, fluidic devices constructed according to the invention generally demonstrate improved power gain. The device of the invention also demonstrates an increased fan-out, or loading, capability, in that the receiver output of the device may serve to actuate a larger number of fluidic elements than many devices of the prior art.

In addition to manufacturing the fluidic devices of the invention from etched plates, as may be conveniently accomplished by employing conventional technology including photoengraving, plastic molding of the devices provides a convenient and economical method of fabrication.

While there has been shown what is considered to be a preferred embodiment of the invention, it will be manifest that many changes and modifications may be made therein without departing from the essential spirit of the invention.

I claim:

1. In a known fluid logic device of the type comprising:
first conduit means adapted to receive at one end a fluid under pressure and to project the fluid out from the other end in a narrow stream of laminar flow;
second conduit means axially aligned with said first conduit means and spaced a substantial distance downstream from the outlet end thereof to receive said narrow stream of laminar flow;
control means including means to direct against said narrow stream a control action to cause complete turbulence thereof without deflection of the stream;
that improvement which includes:
first and second opposed wall means positioned along the axis of fluid projection between said first and second conduit means and on opposite sides of the stream, each of said first and second wall means being close to but slightly spaced from the respective side of said stream when said stream is in laminar flow state so as not to interact therewith in laminar state, both said first and second wall means being sufficiently close to said axis to interact with the fluid when said stream is placed in said turbulent state by said control means; and
third and fourth opposed wall means between said first and second wall means respectively to form a chamber therewith, said third and fourth wall means being spaced from said axis by a substantial amount greater than the spacing of said first and second wall means from said axis and sufficient to prevent interaction between said fluid and said third and fourth wall means when in said turbulent condition.

2. A fluid logic device as claimed in claim 1, wherein said first and second wall means are spaced from said laminar stream a distance which is at least 0.005 inch and less than approximately 0.020 inch.

3. The method of producing a logic output which comprises the steps of:
projecting a laminar stream of fluid towards a sensing element responsive to the pressure of said stream, said stream being free from interaction with any adjacent structure while in laminar state;
directing a control effect laterally against said stream of fluid to cause turbulence thereof without deflection; and
confining two opposite sides of said turbulent fluid while maintaining the intervening opposite sides of said turbulent fluid unconfined and free from interacting effects so as to develop a regenerative action producing maximum

turbulence of the fluid with small control effect and wherein said first opposite sides of said turbulent stream are confined by presenting to those sides wall means extending along said stream, said wall means being

presented at a distance from the stream in its laminar state of at least 0.005 inch and less than approximately 0.020 inch.