

March 8, 1966

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3,238,958

MULTI-CHANNEL FLUID ELEMENTS

Filed Aug. 7, 1963

2 Sheets-Sheet 1

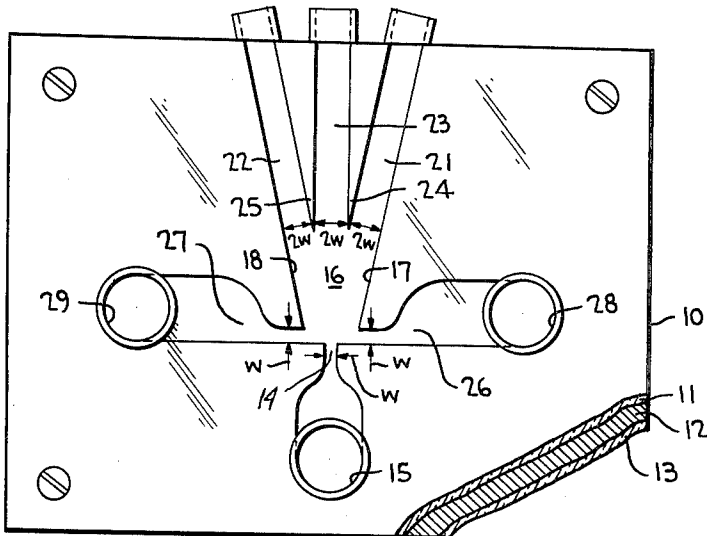


FIG. 1

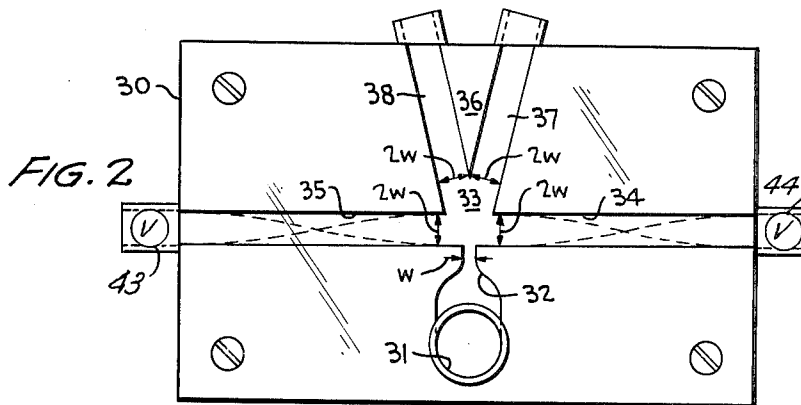


FIG. 2

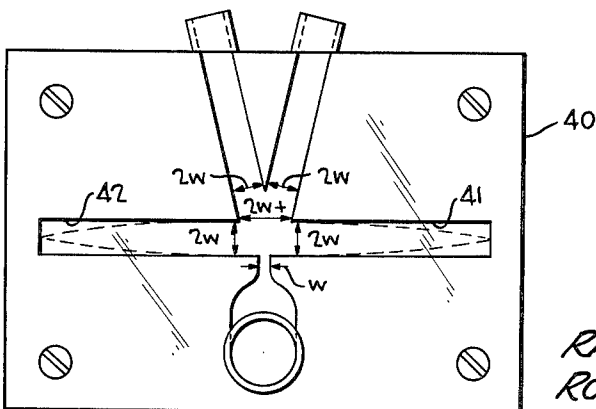


FIG. 3

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FIG. 4a

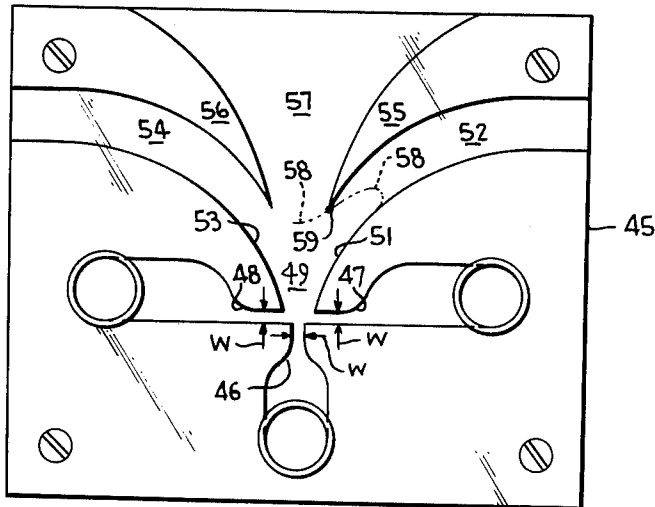
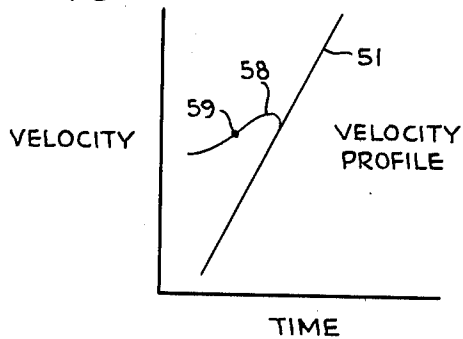


FIG. 4b



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MULTI-CHANNEL FLUID ELEMENTS

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Filed Aug. 7, 1963, Ser. No. 300,709

3 Claims. (Cl. 137-81.5)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment to us of any royalty thereon.

This invention relates to fluid amplifiers and, more particularly, to fluid amplifiers with multiple dividers.

In the development of fluid amplification, it is necessary that fluid amplifiers perform their functions while being matchable to other amplifiers or devices without loss of operating pressures and without overloading any of the components. This is accomplished in this invention by maintaining the interaction chamber of these lock-on type amplifiers at ambient conditions. In order to introduce ambient conditions into the interaction chambers, a breather channel is provided, in some examples, between a pair of dividers extending from the interaction chamber to the ambient condition. The other sides of the dividers form walls for the receivers. Also, variations of multi-splitter divider amplifier structure produced an argon pipe type amplifier wherein the control channels depend upon pipe organ characteristics for their operation.

It is therefore an object of this invention to provide a fluid amplifier which is capable of being impedance-matched to other fluid elements.

Another object of this invention is to provide a fluid amplifier in which the interaction chamber is maintained at ambient condition.

Still another object of this invention is to provide a highly stable flip-flop fluid amplifier which is capable of being impedance-matched to other fluid elements.

A still further object of this invention is to provide an organ pipe fluid oscillator with either open pipe controls or closed pipe controls.

Another object of this invention is to prevent reflection of compression, rarefaction and sonic waves in a fluid amplifier.

The specific nature of the invention, as well as other objects, uses and advantages thereof, will clearly appear from the following description and from the accompanying drawing, in which:

FIG. 1 is a plan view of a first embodiment of a bi-stable fluid amplifier constructed in accordance with the invention;

FIG. 2 is a plan view of an open end organ pipe fluid oscillator;

FIG. 3 is a plan view of a closed end organ pipe fluid oscillator;

FIG. 4a is a plan view of another embodiment of a bi-stable fluid amplifier according to the invention; and

FIG. 4b is a graph of the flow pattern of the fluid passing the end 59 of the right divider 55 in FIG. 4a.

Briefly, the elements of this invention include structure incorporating the principle of keeping the interaction chamber of fluid amplifiers at the ambient pressure condition by access channels connecting the interaction chambers and the ambient region. This principle is adaptable to several embodiments of fluid amplifiers and is utilized to assure impedance matching of connected elements. The structural modification which incorporates the above stated principle led to the organ pipe oscillators in which the opening to the ambient of the control organ pipes is variable from fully open to fully closed.

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Turning now to FIG. 1 in which is shown a typical double splitter fluid amplifier 10, the amplifier is typically made up of laminated sheets of plastic material, such as Lucite, or of metal or any other desired material. The top lamina 11 is a cover plate through which the various inputs to the fluid amplifier are applied. The center layer 12 is machined, drilled, or etched or otherwise grooved to present the openings therein which enable a primary fluid stream to be controlled by secondary fluid streams. The bottom lamina 13 has no openings therein so as to seal the unit. The fluid streams are confined between the top and bottom layers 11 and 13 so as to flow through passages provided in center layer 12.

A fluid power source, not shown, is connected to the opening 15 so as to admit a fluid power stream through power nozzle 14. The power stream is introduced into interaction chamber 16 through power nozzle 14. Chamber 16 is bounded by right sidewall 17 and left sidewall 18 and is in communication with right receiver 21, left receiver 22 and a central channel 23. Central channel 23 is separated from right receiver 21 by a first divider 24. Central channel 23 is separated from left receiver 22 by a second divider 25. Interaction chamber 16 is bounded at its lower end by the structure limiting the power nozzle 14 to a small opening, the right control nozzle 26 and the left control nozzle 27. Right control nozzle 26 is fed a control signal through opening 28 in top layer 11 of the laminated package. Left control nozzle 27 is fed a control signal through opening 29 in the top layer 11. It is to be noted that the sidewalls 17 and 18 are wider at their extremities near the power jet nozzle 14 than the width of the power nozzle 14. Further, sidewalls 17 and 18 are divergent downstream of the power nozzle 14. The three downstream passageways, receiver 21, receiver 22, and central channel 23, are either connected to atmosphere or are closed in a selected pattern or are connected to a selected load as will be discussed later in this specification.

FIG. 2 shows a second embodiment of the multi-divider fluid element of this invention. In the fluid amplifier shown in FIG. 2, the control nozzles have been removed and the original receivers have been rotated such that the original sidewalls 17 and 18 are now aligned on the same line and that the original central passage 23 has been modified to be two receivers. The device of FIG. 2 would operate with a single output receiver. The multi-divider fluid element 30, shown in FIG. 2, has a laminated construction as in FIG. 1 and other figures of this disclosure. A fluid power stream from a power source, not shown, is introduced through opening 31 in the top layer to a power nozzle 32 in the center layer. The power stream issuing from power nozzle 32 enters an interaction chamber 33. A right control channel 34 and a left control channel 35 are axially aligned and are perpendicular to the flow of the power stream as it egresses from power nozzle 32. The relationship of the sizes of the openings into the interaction chamber 33 is not critical. However, a very good relationship of sizes would be that the width of the control channels and the receivers be approximately twice the width of the power nozzle 32. With the sidewalls of the receivers 37 and 38 being divergent in configuration as provided by the divergent divider 36, the narrowest width of interaction chamber 33 that is parallel to the axis of the control channel 34 and 35 is approximately twice the width of the issuing end of control nozzle 32.

The fluid element illustrated in FIG. 3 differs from the modification shown in FIG. 2 only in the closing of the control channels to provide a right closed tube control channel 41 and a left closed tube control channel 42 in the fluid element 40. Otherwise, the structure of fluid element 40 shown in FIG. 3 is the same as the structure of fluid element 30 shown in FIG. 2.

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The species of FIG. 2 can be modified by the addition of valves 43 and 44 to vary the amount that the control channels 34 and 35 are opened and closed. This provides all of the features of both species as shown in FIGS. 2 and 3 and all of the intermediate configurations. Further, the species of FIGS. 2 and 3 can be modified with any adjustable means that can alter the width-length relationship of the control channels. This could be accomplished by adjustable sleeves, pistons, movable channel walls and the like.

The multi-divider element 45 shown in FIG. 4a has a power nozzle 46, a right control nozzle 47 and a left control nozzle 48 in the same configuration as in the fluid element 10 shown in FIG. 1. The fluid element 45 is symmetrical about the axis of the power nozzle 46. The power nozzle 46 enters an interaction chamber 49 which is bounded by a right sidewall 51 which is one of the sides of a right receiver 52 and a left sidewall 53 which is one of the sides of a left receiver 54. A right divider 55 diverges from said interaction chamber with one of its sides providing the other side of right receiver 52 and its second side forming the right sidewall of an outlet channel 57. A second divider 56 provides one side of a left output receiver 54 and the second side of divider 56 provides the left sidewall of outlet channel 57. The outlet channel 57 is equivalent to the central outlet 23 shown in FIG. 1 but is greatly widened and made as short and funnel-shaped as practicable. This results in having the interaction region 49 open to ambient pressure and precludes oscillation.

The output receivers 52 and 54 in FIG. 4a can be constructed so as to be continuous through the sidewalls of the center layer of the amplifier without bending the output streams upward through the top layer as shown in FIG. 4a. These output receivers can be constructed as shown in FIGS. 1 through 3 with no bends and no surface to cause a reflected wave and the spurious signal created thereby.

Some of the features of this bistable flip-flop fluid amplifier in FIG. 4a are that the interaction region is always at ambient pressure, the amplifier does not oscillate due to the funnel shaped-opening to ambient pressure, and the amplifier will have the same regional flow to the next unit regardless of the number of inputs thereto, because the excess is spilled off into the ambient surroundings.

FIG. 4b shows the velocity profile of the power stream when locked on one of the sidewalls such as 51 in FIG. 4a. FIG. 4b will be more fully described in the discussion of the operation of the fluid element 45 in FIG. 4a.

A variety of effects can be achieved in fluid amplification devices by the division of a space with dividers. Oscillation can be produced or eliminated, units can be combined with repeatable pressure patterns and control flows can be combined or partitioned.

In the operation of the multi-divider element as shown in FIG. 1, the normal activity of the power jet is to cling to the right or the left boundary wall, 17 or 18, and exit through the right or left outlets 21 or 22, respectively. If the power jet is on the right, that is attached to wall 17 and leaving through right outlet 21, the power jet may be flipped to the left by allowing fluid to enter the right control nozzle 26 or by withdrawing fluid from the left control nozzle 27. The power jet stream is stable in its new position when the controls are removed. If control flow is introduced in both controls in sufficient volume to equal the entrainment characteristic of the power jet stream, the power jet will be detached from the boundary walls and flow through the center passage. Unless the two dividers are very close to the power jet orifice, and the boundary walls are spaced well back from the power jet stream, the power jet stream will attach to one of the boundary walls as soon as the control streams are removed. If the right and left outlets, 21 and 22, are partially or fully blocked, the power jet stream will oscillate between the right and the left outlets producing a

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pulse flow in the center outlet 23. This action is caused by the power stream evacuating fluid between itself and a boundary wall. The power stream moves toward the wall and raises the pressure in the side outlets. For purposes of illustration, assume that the side outlet is the right control nozzle 26. This raises the pressure in the blocked right passage 21. The reverse wave of higher pressure forces the stream toward the left, that is toward lock-on wall 18. As the power stream moves toward the left, a pulse of flow exits through the center outlets and the stream continues its movement toward the left passage. The stream being closer to the left wall entrains fluid between the stream and the wall 18, and moves still further toward the left boundary wall raising the pressure in the blocked left passage 22. The wave of higher pressure back down the left passage 22 now forces the stream toward the right wall 17 sending another pulse of flow through the center passage 23 as the power stream passes the entrance thereto. The oscillation can be prevented by allowing sufficient flow to exit through the right and left passages 21 and 22 or by widening the center outlet 23 so that it is considerably wider than the power jet stream.

The oscillation is enhanced by having the lengths of the partially or fully blocked right and left passages 21 and 22 equal. The standing waves in the equal lengths reinforce each other in the proper phase relation to produce oscillation.

When the center channel 23 is closed, such closure is equivalent to a cusp-type divider as disclosed in the co-pending application Serial No. 222,748 filed September 10, 1962, by Raymond W. Warren, one of the instant inventors, Ralph G. Barclay and John G. Moorhead for "Feedback Divider for Fluid Amplifier." The closing of center channel 23 causes stabilization in the manner of the cusp-type divider discussed in the said co-pending application. In this circumstance, the multi-divider element shown in FIG. 1 can operate as an amplifier. When the three outlet passages 21, 22 and 23 are all open, this element is a stable amplifier. When outlets 21 and 22 are sufficiently blocked or closed entirely and center channel 23 is open, the fluid element will perform as an oscillator.

The above description of operation of the fluid element in FIG. 1 as an oscillator applies when the relationship of size of the openings into the interaction chamber are substantially as shown in FIG. 1. That is, with the width of the power nozzle being equal to W , the widths of the two control nozzles are also W and the three exit channels are $2W$. The center channel 23 can be less than $2W$ wide. It is further assumed that the points of the dividers 24 and 25 are at least 5 nozzle widths downstream. When the dividers are closer than $5W$, there is insufficient force from the sidewalls to prevent the power stream from egressing through the center channel 23. Also, when they are closer than $5W$, the reduced entrainment over the shorter distance does not provide a sufficient pressure differential acting on the shorter distance to effect an appreciable deflection of the power jet and therefore the power stream egresses through center channel 23. This, in effect, results in the amplifier being a proportional amplifier when the dividers are close to the power nozzle. A proportional amplifier is a fluid amplifier in which there is no wall lock-on to give stability to the power stream. The power stream is directed by its nozzle toward the receivers and is redirected to a specific receiver or group of receivers by control streams, the actual path of the power stream being determined by the momentum of the fluid flow of the power stream combined with the control streams.

Movement of the dividers toward each other narrowing the center channel 23 and opening the controls 26 and 27 tends to make the unit oscillate when the output channels are loaded. Loading is defined as being the progressive closing of an output channel such as by a piston or a valve. Oscillation of the power stream results from the

severe bending of the power stream when the stream first locks-on to a wall of a receiver which, when loaded, will not conduct the power stream outward and the power stream must seek a path outward through the central passage 23. With the divider considerably distant from the sidewall, the power stream must make a bend of such magnitude that it fails to lock-on to the wall of the central channel that is on the divider separating the loaded receiver from the central channel. With the lock-on failure, the stream continues across the central channel toward the other wall thereof and bounces back toward the first mentioned wall in said channel. This stream activity results in the stream oscillating at a stable frequency after the beginning instabilities dampen out, when both of the receivers are loaded.

Movement of the dividers away from each other opening the central channel 23 and narrowing the output channels 21 and 22 reduces or tends to eliminate the oscillation of the power stream as the output channels are loaded. With the central channel sufficiently wide and the output channels correspondingly narrow the stream from the power nozzle first locks on to an outside wall 17 or 18, travels around the point of the divider 24 or 25 whichever is closest to the locked-on wall 17 or 18, proceeds to lock on to the side of such divider and go on out the central channel 23 without oscillation. Another way of preventing oscillation is to introduce porous plugs into the output channels 21 and 22 whereby the power stream will lock-on to the conventional lock-on walls 17 or 18 and then bend to go out through the center channel and lock-on to a divider wall without oscillation.

In the example when the output channels are one half the width of the power nozzle and the central channel is twice the width of the power nozzle, the blocking of outlet channels with the control channels remaining open, the power jet will be stable in the central channel 23. If, additionally, a control flow is introduced into one of the control nozzles 26 or 27 and the other is either open or closed, the power jet will oscillate between the two outlet channels 21 and 22.

In the operation of the oscillator of FIG. 1, a comparatively high gain is required for the starting of the oscillation. This high gain can be introduced by restricting the outlet channels or by connecting a load thereto.

In the operation of the open end organ pipe oscillator shown in FIG. 2, the power stream issuing from nozzle 32 will lock-on to either of the sidewalls of chamber 33 to select outlet channel 37 or outlet channel 38. The control nozzles 26 and 27 of FIG. 1 have been replaced by control ports 34 and 35 in FIG. 2. These ports are relatively long, narrow passages. The fluid in control ports 34 and 35 is set into vibration in the tubes 34 and 35 by the blowing past the openings of the tubes by the power stream. The anti-node occurs at the open end of the tube near the power nozzle so that the displacement of fluid is a maximum at this point. It is this action of displacement of fluid at the inner end of the control tube that causes the power stream to oscillate. When the tubes 34 and 35 are of equal length, the oscillation is reinforced.

As in pipe organ pipes, the fundamental frequency of the control pipe of the oscillator in FIG. 2 is equal to the velocity of sound divided by the length of the wave traveling through such pipe at the velocity of sound. Since a closed pipe is inherently one half of the wave length of the fundamental frequency, the fundamental frequency is equal to the velocity of sound divided by two times the pipe length. The first overtone is equal to the velocity of sound divided by the pipe length. The second overtone is equal to three times the velocity of sound divided by two times the pipe length. The other overtones follow as in an organ pipe. These overtones are generated by overblowing in the oscillator of this invention as in a pipe organ.

In the operation of the open pipe oscillator shown in

FIG. 2, the relationship of the sizes of the openings into the interaction chamber 33 is such that all of the nozzles are at least as large as the power nozzle. It has been found that when the other nozzles are twice the power nozzle opening, the oscillator operates very well. It is possible to switch the mode of operation under loading to double or half the frequency. Through a prescribed pressure range or flow range, the organ pipe type of oscillators are very stable. In both the open and the closed organ pipe type oscillators, the length of the pipe determines the frequency of oscillation, since the time the control pulse to travel through the pipe is a function of the distance traveled. The width of the outlets of the control pipes can be changed by valves, for example, to vary the effective length of the pipes and, correspondingly, the frequency from the velocity of sound divided by twice the pipe length to the velocity of sound divided by four times the pipe length, that is, from an open pipe to a closed pipe. Further, the length of the pipes can be changed to effect frequency changes as by pistons, for example.

The operation of the closed pipe oscillator shown in FIG. 3 is the same as the operation of the open pipe oscillator shown in FIG. 2 with the exception of the difference of fundamental frequencies as set forth above. The fundamental frequency for the closed pipe oscillator is the velocity of sound divided by four times the length of the pipe. The first overtone is three times the velocity of sound divided by four times the length of the pipe while the second overtone is five times the velocity of sound divided by four times the length of the pipe, and so on.

The operation of the fluid device shown in FIG. 4a makes use of the multi-divider concept in still another way.

When oscillation is not desired, the center outlet is widened and made as short and funnel shaped as is practicable, as shown in FIG. 4a. This permits the interaction chamber to be open to the ambient pressure. This is desirable in order that a repeatable pressure pattern can easily be achieved when such units are coupled together. By curving the sidewalls 51 and 53, the wide center outlet 57 can be maintained while bringing the dividers 55 and 56 close to the power jet orifice to limit entrainment and preserve the energy. By limiting the width of the left and right outlet passages 52 and 54, respectively, the flow into the passages can be limited regardless of the number of inputs. The excess flow is spilled off into the center outlet 57. This preserves the higher velocity of the stream close to the wall and spills off the lower velocity portion further from the wall, as illustrated in FIG. 4b. The leading edge 58 of the power stream which is shown to be locked-on to the sidewall 51 of interaction chamber 49 in FIG. 4a shows that the velocity of the power stream is at a maximum near the wall locked-on to and such velocity diminishes as the distance from the locked-on wall becomes greater. With the point of the divider 55 positioned so as to allow that portion of the power stream as defined between a point such as 59 of the forward edge 58 of the power stream and the sidewall 51 to enter the receiver 52, it is seen that the remainder of the power stream would flow into the center outlet 57. Center outlet 57 then, is a bleed which removes the low velocity flow of the power stream. The divider 55 is positioned to cut the low velocity, low energy particles of the power stream and spill them into the center outlet 57 while directing the high velocity, high energy particles into the right receiver 52 to go on downstream. The pressure pattern of the output of the amplifier in FIG. 4a is substantially the same as the pressure pattern of the input applied thereto. The forward edge 59 of divider 55 shown as a sharp edge 59 can be blunted or rounded to reduce the possibility of knife edge oscillations. As secondary effect of the knife edge oscillation is the production of beat signals. A reflected wave in combination with a normally present

wave provides a beat signal of such magnitude as to be a spurious signal. In order to minimize the possibility of producing these beat signals, it is desirable to remove the reflected waves from the outlets. Slight blunting or rounding of the divider 59 cuts down knife edge oscillation and the diverging center outlet vents the waves to atmosphere without reflections.

So it is seen that we have provided fluid amplifiers in which impedance matching to other fluid elements is accomplished, and in which reflection of compression, rarefaction and sonic waves is accomplished.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of the invention as defined in the appended claims.

We claim as our invention:

1. In a lock-on type fluid amplifier having a power jet nozzle, left and right control nozzles, an interaction chamber having boundary walls, and left and right output receivers and wherein its operation is characterized by the power jet stream continuously producing an output signal in one of said receivers in the absence of control signals due to boundary wall attachment of said power jet stream, the improvement comprising:
 - (a) a channel centrally located between said receivers providing fluid communication between said interaction chamber and the ambient condition;
 - (b) said channel and said receivers forming a pair of divergent dividers therebetween downstream of said power jet nozzle;
 - (c) said power jet nozzle and said control nozzles having widths equal to W ;
 - (d) said receivers having widths approximately equal to $2W$;
 - (e) said central channel having a width approximately equal to $2W$;
 - (f) the upstream ends of said dividers being located at least $5W$ downstream of said power jet nozzle;
 - (g) whereby when said receivers are sufficiently blocked and said central channel is open said power jet stream will oscillate between said receivers, and
 - (h) when said receivers are open said power jet stream will attach to a boundary wall and flow out through one of said receivers as in normal operation, and
 - (i) when control flow is introduced in both of said controls in sufficient volume to equal the entrain-

ment characteristics of said power jet stream, said power jet stream will flow out said central channel.

2. The fluid amplifier according to claim 1, wherein:
 - (a) said blocked receivers are of equal length,
 - (b) whereby the oscillation of said power jet stream is enhanced as a result of standing waves in said receivers reinforcing each other in the proper phase relation.

3. In a lock-on type fluid amplifier having a power jet nozzle, left and right control nozzles, and an interaction chamber having boundary walls, and left and right output receivers and wherein its operation is characterized by the power jet stream continuously producing an output signal in one of said receivers in the absence of control signals due to boundary wall attachment of said power jet stream, the improvement comprising:
 - (a) a channel centrally located between said receivers providing fluid communication between said interaction chamber and the ambient condition;
 - (b) said channel and said receivers forming a pair of divergent dividers therebetween downstream of said power jet nozzle;
 - (c) said power jet nozzle having a width equal to W ;
 - (d) said receivers having widths approximately equal to $\frac{1}{2}W$; and
 - (e) said central channel having a width approximately equal to $2W$;
 - (f) whereby when said receivers are blocked said power jet stream will be stable in said central channel, and when a control flow issues from one of said control nozzles said power jet stream will oscillate between said receivers.

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