

Dec. 28, 1965

B. M. HORTON

3,226,023

FLUID SCALARS

Filed June 25, 1962

4 Sheets-Sheet 1

FIG. 2

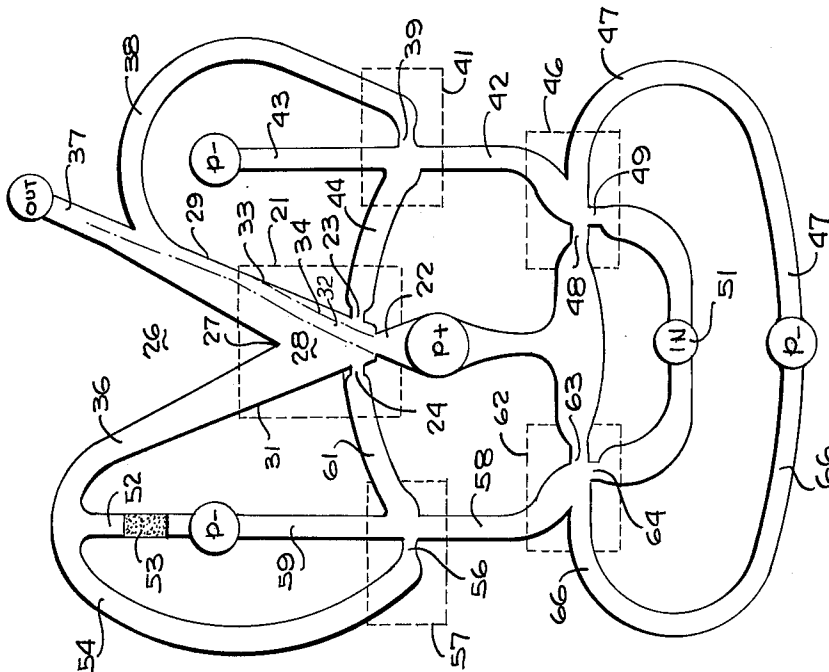


FIG. 1

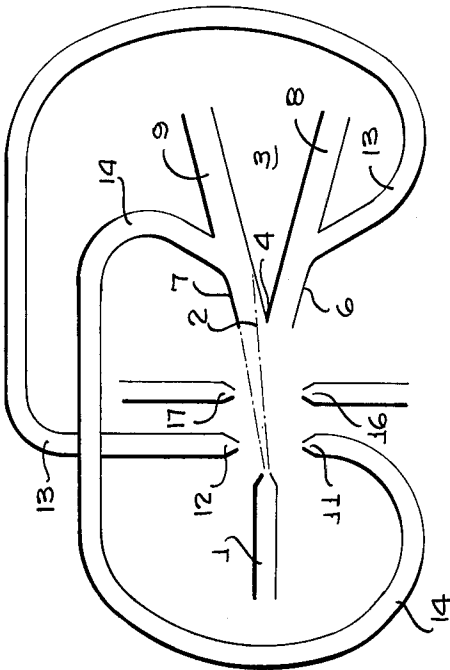
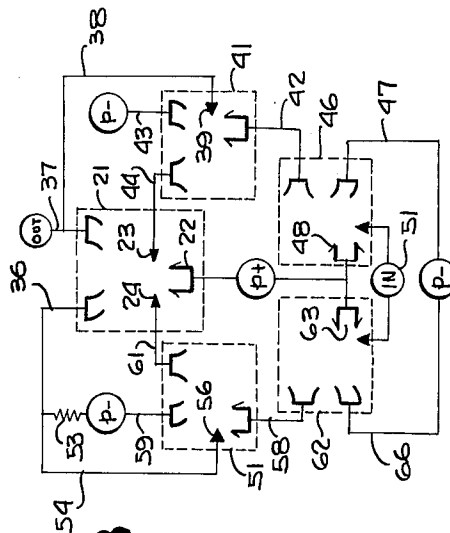


FIG. 3



INVENTOR
BILLY M. HORTON

BY *Kurwitz & Rose*

ATTORNEYS

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B. M. HORTON

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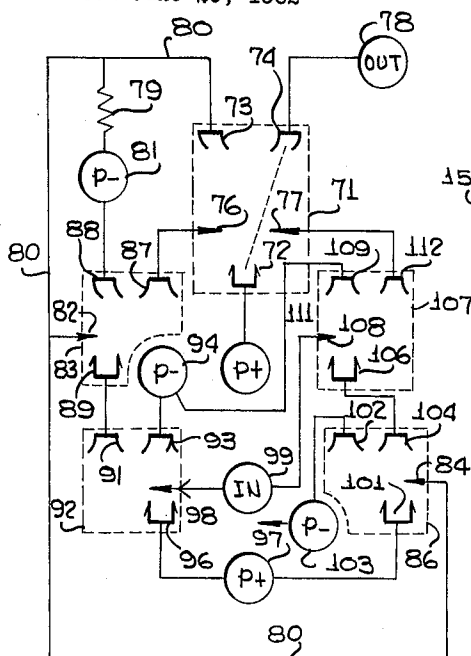


FIG. 4

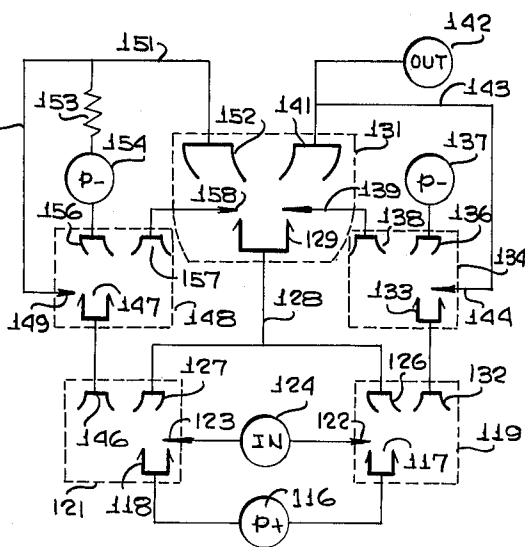


FIG. 5

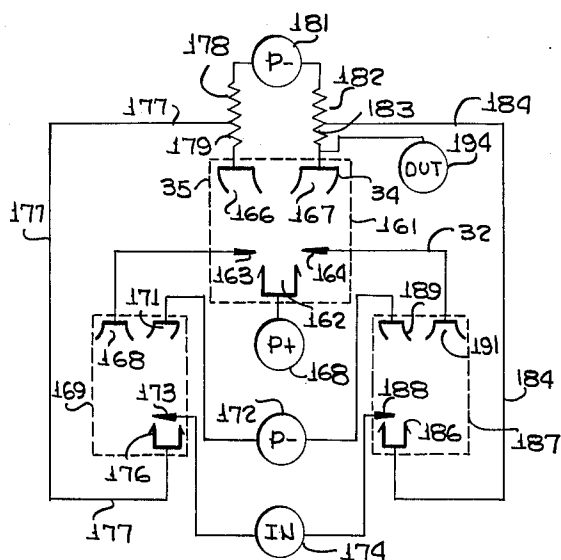


FIG. 6

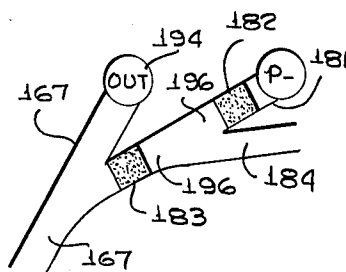


FIG. 7

INVENTOR

BILLY M. HORTON

BY *Nurwitz & Rose*

ATTORNEYS

Dec. 28, 1965

B. M. HORTON

3,226,023

FLUID SCALARS

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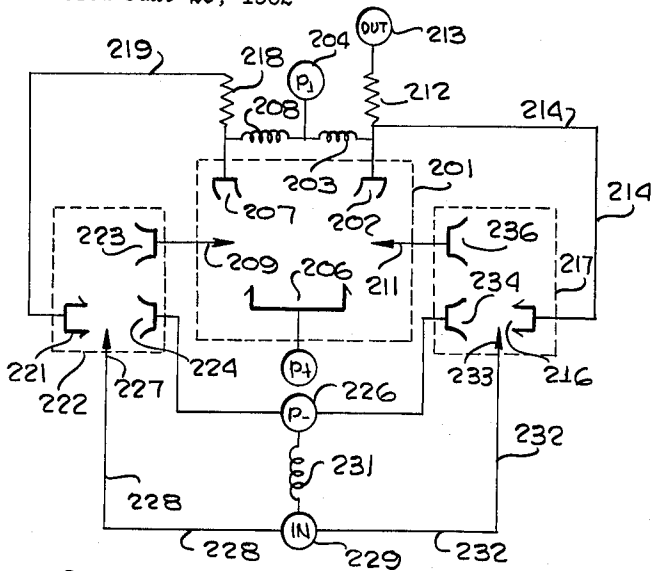


FIG. 8

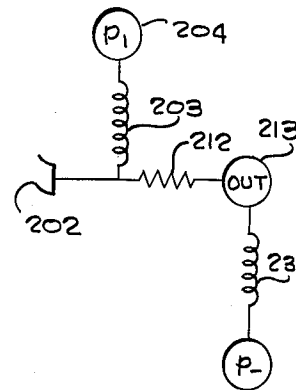


FIG. 9

FIG. 12

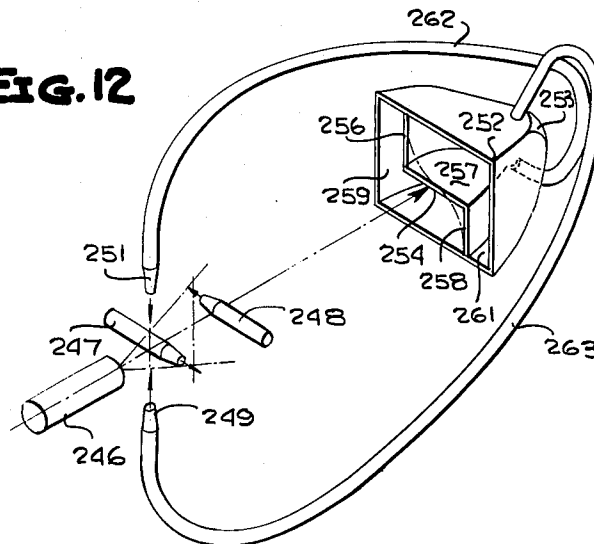
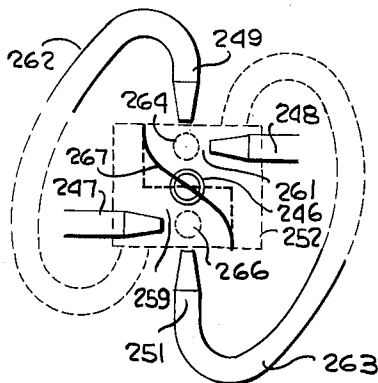


FIG. 13



INVENTOR
BILLY M. HORTON

BY *Hurwitz & Rose*
ATTORNEYS

Dec. 28, 1965

B. M. HORTON

3,226,023

FLUID SCALARS

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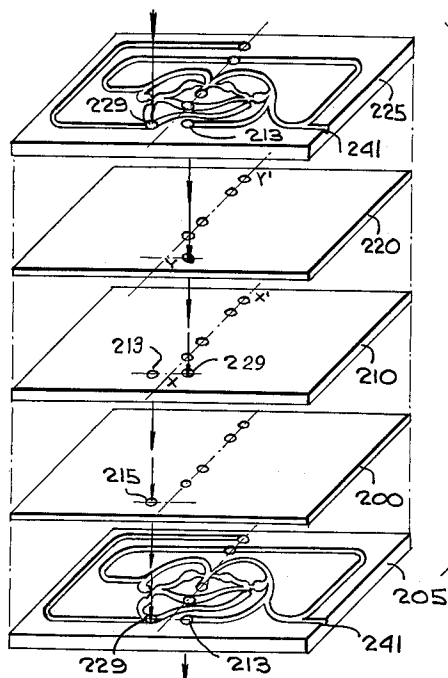


FIG. 11

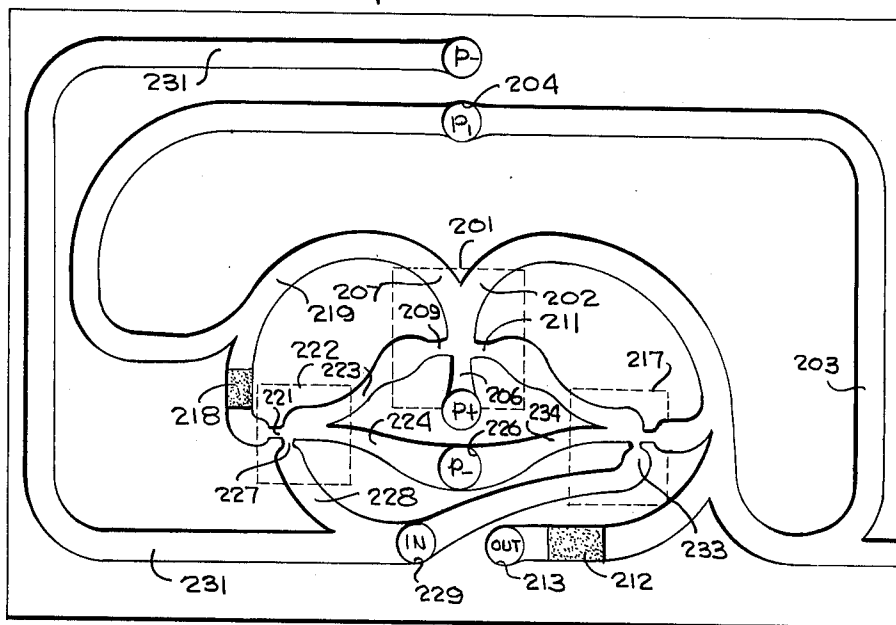


FIG. 10

INVENTOR

BILLY M. HORTON

BY *Nurwitz & Rose*

ATTORNEYS

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3,226,023

FLUID SCALARS

Billy Mitchussen Horton, 9712 Kensington Parkway,
Kensington, Md.

Filed June 25, 1962, Ser. No. 204,820

23 Claims. (Cl. 235-201)

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

The present invention relates to fluid-operated devices and more particularly to fluid-operated scalars.

Fluid amplification with no moving parts makes it possible to provide an extremely wide variety of systems in which only the fluid moves; that is, there are no mechanical moving parts. An amplifier employing the principles of pure fluid amplification is described in my copending application Serial No. 51,896 filed September 19, 1960, now Patent No. 3,122,165 and the utilization of positive feedback with such an amplifier is described in my copending application Serial No. 51,754 filed August 24, 1960. In this latter application, positive feedback is utilized in one embodiment of the invention to obtain a bistable or flip-flop type of apparatus in which all of the fluid is initially directed to one of at least two outlets of the device and upon the application of an appropriate input signal, all of the fluid flow is switched to a second outlet device.

In the copending patent application Serial No. 58,188 of Romald E. Bowles and Raymond W. Warren filed on October 19, 1960, there is described a pure fluid-operated device employing internal boundary layer effects to achieve a flip-flop type of operation. In the flip-flop devices described in either of the latter two copending applications, incoming pulses must be directed to an appropriate input nozzle or orifice in order to produce the flipping action. In order to describe the operation of these devices more fully, consider a stream of fluid issued from a power nozzle and directed, in the absence of any outside force, at the apex of a V-shaped divider located downstream from the power nozzle and, for purposes of simplicity, located on the center line of the nozzle. Control nozzles are provided on either side of the stream generally at right angles to the axis of the power nozzle. If fluid is applied to a first of the control nozzles, the stream is deflected to a first outlet port located on the opposite side of the device due to momentum interchange between the fluid in the main stream and the stream of fluid generated by the control nozzle. If a portion of the fluid directed toward the first outlet port is fed back to the first control nozzle, then, if the device is appropriately proportioned, all of the fluid in the main stream continues to flow to the first outlet port. If now fluid is applied to a second control nozzle on the same side of the device as the first outlet port interaction between the main and control streams of fluid causes the main stream of fluid to be moved transversely of the device and enter a second outlet port. If now fluid is fed back from the second outlet port to the second control nozzle, the fluid is caused to continue to flow to this port even after removal of the input signal. This action provides a flip-flop type of action but it will be noted that input pulses must be directed to the proper control nozzle, depending upon to which of the outlet ports the main stream is directed, to produce switching.

Similar results; that is, a flip-flop action, may be obtained by boundary effects without requiring an external feedback system. Reference is made to the aforesaid copending application of Bowles et al for a full description of such a device. To the extent necessary to explain the operation of the various embodiments of the present

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invention, this mechanism is described subsequently in the specific descriptions of the figures.

In order to provide a binary scalar or a scale-of-N scaling system, it is necessary to be able to produce a switching action of a flip-flop device in response to a single input pulse without regard to the condition of the flip-flop at the time this pulse is provided. Scalars, counters and shift registers may be provided by appropriately interconnecting the various types of flip-flop elements described.

It is an object of the present invention to provide a fluid-operated flip-flop or bi-stable device in conjunction with associated fluid-operated devices so as to permit an input pulse to be directed to an appropriate control nozzle of the device to provide a switching action in order to change the state of the bi-stable device.

It is another object of the present invention to provide a scale-of-N scaling device employing a pure fluid flip-flop in conjunction with pure fluid logic elements to permit routing of input pulses to a proper control nozzle in accordance with the state of the device when an input pulse is applied.

Still another object of the present invention is to employ appropriately interconnected pure fluid flip-flop elements to provide scalars, counters and shift registers.

The above and still further objects, features and advantages of the present invention will become apparent upon consideration of the following detailed description of several embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a schematic diagram of a flip-flop unit employed to explain one type of element with which the present invention may be utilized.

FIGURE 2 is a further embodiment of a scale-of-2 counter of the present invention;

FIGURE 3 is a symbolic diagram of the scalar of FIGURE 2;

FIGURE 4 is a symbolic diagram of a further embodiment of the scale-of-2 counter of the invention;

FIGURE 5 is a symbolic diagram of a still further embodiment of the scale-of-2 counter of the invention;

FIGURE 6 is a symbolic diagram of still another scale-of-2 counter of the invention;

FIGURE 7 is a schematic diagram of the flow passages employed in a portion of the device of FIGURE 6;

FIGURE 8 is a symbolic diagram of a scale-of-2 counter which may be cascaded with other scale-of-2 counters;

FIGURE 9 is a symbolic diagram disclosing the method of cascading the device of FIGURE 8;

FIGURE 10 is a schematic flow diagram of the embodiment of the invention illustrated in FIGURE 8;

FIGURE 11 is a three-dimensional exploded view illustrating the physical arrangement of the devices of FIGURE 10 in a cascaded module;

FIGURE 12 is a three-dimensional view of a three-dimensional scale-of-2 device; and

FIGURE 13 is a front planar view of the apparatus of FIGURE 12.

Referring specifically to FIGURE 1 of the accompanying drawings, there is illustrated a fluid flip-flop or bi-stable device employing a pure fluid amplifier having incorporated therein positive feedback to provide the basic bi-stable operation. A main nozzle 1 is connected to an appropriate source of pressure (not illustrated) so as to establish a fluid stream 2 directed toward a divider 3. The divider is a generally, though not necessarily, V-shaped device having an apex 4 lying along the axis of the center nozzle 1 and located downstream therefrom. A pair of side walls 6 and 7 are disposed on opposite sides of the outwardly diverging walls of the divider 3 so as to establish outlet channels 8 and 9, respectively.

The device further includes a pair of control nozzles 11 and 12 disposed on opposite sides of the nozzle and having their axes perpendicular to the axis of the nozzle 1. The control nozzles 11 and 12 are located relatively close to the power nozzle 1 and a relatively long distance away from the divider 3 so that the angle through which the stream must be deflected, in order to produce switching of the stream from outlet port 8 to the outlet port 9, and vice versa, is relatively small. This feature maintains the amount of energy which must be supplied to the control nozzles to produce switching, at a relatively low level compared with the energy of the power stream 2. It should be noted that a device of the type thus far described is more fully set forth in my aforesaid copending application Serial No. 51,896. The element is capable of mass flow, pressure, or energy amplification and for purposes of describing the present invention the elements shall be considered to be pressure amplifiers.

The outlet channel 8 has associated therewith a channel 13 communicating with the channel 8 through the side wall 6. The channel 13 is connected to the control nozzle 12 so that a portion of the fluid entering the outlet channel 8 is diverted through the channel 13 and is applied to the control nozzle. Similarly, the outlet port 9 communicates through the side wall 7 with a second feedback channel 14 connected to the control nozzle 11.

Assuming that the device has been turned on; that is, fluid has been supplied to the control nozzle 1, initially, all of the fluid flows along the axis of the nozzle 1 and divides equally at the apex 4 of the divider 3. Small aberrations in the flow stream which will inevitably occur produce an inequality in the amount of fluid applied at any instant to the outlet ports 8 and 9. The amounts of fluid fed back to the control nozzles 11 and 12 become unbalanced and, if the proportions of the system are properly chosen, i.e., the system has a loop gain of one or more, the stream is diverted completely to one of the outlet ports. A further stream is caused to impinge upon the main stream 2 such that the stream 2 is diverted towards the outlet passage 8. The amount of fluid fed back through the passage 14 diminishes and some of the fluid enters the channel 13 and is fed back to the nozzle 12 assisting the original fluid stream. Again by properly proportioning the devices and by choosing a pulse of the proper magnitude, all of the fluid may be switched to the outlet channel 8 where it will be held as a result of feedback through the channel 13. In this manner, the positive feedback connections through the channels 13 and 14 may convert what would otherwise be a proportioning fluid amplifier into a bistable device; all of this being described in greater detail in the aforesaid copending application Serial No. 51,754.

One method of converting the bistable element thus far described to a true flip-flop; that is, a device which switches the main fluid stream 2 between outlet ports 8 and 9 in response to appropriately applied incoming pulses is to provide a further pair of opposed control nozzles 16 and 17. Flow from the nozzles 16 and 17 has the same effect upon the fluid stream 2 as flow from nozzles 11 and 12. Thus, fluid issuing from nozzle 17 interacts with the stream 2 and deflects it toward the other side of the device if the stream is in the position illustrated in FIGURE 1. Of course, if the pulse is applied to the nozzle 16 with the stream in the position illustrated, the flow from nozzle 16 has no real effect upon the stream 2.

In operation, if the stream 2 is adjacent the nozzle 17 and flow issues from this nozzle, the stream is initially deflected by the flow from nozzle 11 toward the outlet passage 9. Fluid issuing from the nozzle 17 must be of sufficient momentum to cause the stream 2 to be redirected such that more of the stream enters channel 8 than channel 9. The fluid fed back to nozzle 12 is now greater than that fed back to nozzle 11 and therefore the stream 2 is further deflected toward channel 8. The effect is cumulative and the stream 2 is finally divided so that

all of its flow enters channel 8 where it is held by feedback through nozzle 12.

In order to convert the flip-flop device of FIGURE 1 to scalar; that is, a scale-of-2 counter, it is necessary to be able to accept a single input pulse and direct it to one or the other of the control nozzles 16 and 17 in accordance with the position of the stream 2 at the time the input pulse is applied. By so doing, the stream 2 is switched from one output channel to the other in response to successive input pulses to the scalar. Referring now specifically to FIGURE 2 of the accompanying drawings, there is illustrated a device which operates as a fluid scalar and in which an input pulse is directed only to that control orifice which is capable of producing switching of the fluid stream. Instead of employing positive feedback to produce a flip-flop action as utilized in the apparatus of FIGURE 1, the device illustrated in FIGURE 2 employs a bi-stable element 21 which relies upon boundary layer effect to provide the bistable operation.

The boundary layer device 21 includes a power nozzle 22, control nozzles 23 and 24, and a divider 26 having an apex 27 disposed downstream from and along the axis of the nozzle 2. The stream issuing from the nozzle 22 enters a chamber 28 having uniformly curving side walls 29 and 31 located close to the main stream and therefore which are capable of sustaining a boundary layer effect. To explain this concept briefly, assume that the stream, which is designated by the reference numeral 32, follows the path defined by dashed lines and attaches to the side wall 29 at a point 33. The stream 32 and side wall 29 define a region 34 which is quite narrow transverse to the axis of the nozzle 22 when compared with the region to the left side of the stream. The stream 32 entrains the fluid in the region 34 and reduces the pressure in this region relative to the pressure in the chamber 28 to the left of the stream. Due to this differential in pressure across the stream 32, the stream 32 is maintained in this deflected position. When it is desired to switch the stream 32 to the left side of the unit, to an outlet passage 36 and away from an outlet passage 37 to which it had previously been directed, fluid is supplied through the control orifice 23 to the region 34. Fluid is supplied at a rate such that the stream 32 cannot carry away enough of this new fluid to maintain the reduced pressure in the region 34. In consequence, the pressure in the region 34 is raised and rises above the pressure to the left of the stream 32 causing the stream to be diverted to the channel 36. In practice, the control flow may have sufficient momentum to interact with the main stream and produce deflection by momentum interchange. Alternatively, both effects, raising of pressure and momentum interchange, may be employed if the control flow is at a rate somewhat below that required for complete switching by stream interaction. In any case, upon deflection of the main stream to the other side of the device, it then attaches to the wall 31 and remains there until fluid is applied to the control orifice 24 in sufficient quantities to switch the stream 32 back to the outlet passage 37. Thus, switching between one outlet channel and another can be accomplished by providing a fluid flow to a nozzle formed in the side wall to which the fluid stream is attached. For a more complete description of boundary layer units refer to the aforesaid application, Serial No. 58,188.

Proceeding now to the description of the additional elements required to convert the apparatus thus far described to a scalar, the passage 37 communicates through the side wall 29, downstream of the apex 27 of the divider 26, with a passage 38 connected at its end remote from the passage 37 to a control nozzle 39 of a fluid and gate 41. The AND gate comprises an inlet passage 42 and outlet passage 43 which returns to the negative or low pressure side of a pump (not illustrated) employed to provide pressurized fluid to the main nozzle 22 of the bistable device 21. The AND gate 41 comprises a sec-

ond outlet passage 44 which communicates with the control orifice 23 of the bistable device 21. The passages 42 and 43 are aligned with one another so that in the absence of the application of fluid to the nozzle 39, the fluid supplied to the passage 42 proceeds directly through the device to the passage 42 and to the negative side of the pump. The passage 42 constitutes an outlet passage of a second AND gate 46 having a second outlet passage 47 returned to the low pressure side of the source. The AND gate 46 has a main power nozzle 48 connected to the positive side of the source and a control nozzle 49 to which input pulses are supplied via an inlet channel 51. In both of the AND gates 41 and 46, boundary layer effects are established between the main fluid flow and the wall of the passage returning to the low or negative side of the source which passage is aligned with the main power nozzle. The passage which is not aligned with the main power nozzle and which receives fluid as a result of the application of the pulse to the control nozzle of the device is recessed such that boundary layer effects do not occur. The reasons for this will become apparent subsequently.

The outlet passage 36 is returned to the negative side of the source via a channel 52 including therein a porous plug 53 serving as a pneumatic resistor. The porous plug 53 is employed to match the load impedance of the outlet passage 36 to the load impedance of the channel 37; more particularly, the impedance of the load device fed by the fluid proceeding through the channel 37 and the outlet aperture.

The outlet passage 36 also feeds a channel 54 communicating at its other end with a control orifice 56 of a further AND gate 57. The AND gate 57 includes a power nozzle 58 and a first outlet passage 59 aligned with the passage 58. A second outlet passage 61 of the device 57 is not aligned with the passage 58 and is connected to the control orifice 24. The main power passage 58 to the device 57 is also an outlet passage for a further AND gate 52. The AND gate comprises a power nozzle 63 connected to the positive side of the pump and a control nozzle 64 connected to the pulse inlet passage 51. The device 62 is provided with a second outlet passage 66 which is aligned with the main power nozzle 63 and is returned to the negative side of the source. The configurations of the AND devices 57 and 62 conform with the devices 41 and 46 so that boundary layer effects are established by the fluids flowing to the outlet passage aligned with supply passage but are not established when the fluid flows to the alternative outlet passage.

In operation of the device of FIGURE 2, in the absence of an input pulse, the fluid supplied to the power nozzles 48 and 63 of the AND gates 46 and 62, respectively, is returned directly to the negative side of the pump via passages 47 and 66, respectively. The portion of the fluid applied to the outlet passage 37 is fed back through the passage 38 to the control nozzle 39 of the AND gate 41 whereas no fluid is applied to the channel 54 and thus to the control nozzle 56 of the AND gate 57. If a pulse is now applied to the inlet orifice 51, it is directed to the control nozzles 49 and 64 of the AND gates 46 and 62, respectively. The main power stream passing through the main nozzle 48 of the gate 46 is now deflected, as a result of the aforesaid pulse, to the outlet channel 42 and in the AND gate 41 is deflected, by the fluid applied to the nozzle 39, to the passage 44 and thence through the nozzle 23 into the region 34. Flow into the region 34 or flow of sufficient momentum directed against the power stream, causes the stream to be deflected to the channel 36.

About one-half of the fluid applied to passage 51 is directed to the control nozzle 64 of the AND gate 62 and deflects the main power stream issuing from the orifice 63 to the outlet passage 58. However, no fluid is applied at this time to the control nozzle 56 and therefore the fluid appearing in the channel 58 flows directly to the channel 59 and is returned to the negative side

of the pump. If, on the other hand, the main power stream 32 of the bi-stable device 21 had been directed to the outlet passage 36, then fluid is applied to the control nozzle 56 of the AND gate 57 and not to the control orifice 39 of the AND gate 41. Thus, when the fluid issuing from the main power nozzle 63 of the AND gate 62 is diverted to the passage 58 by an incoming pulse the flow in the channel 58 is diverted to the passage 61 and thence to the control orifice or nozzle 24 to cause the stream 32 to switch to the outlet channel 37.

The AND gates 46 and 62 serve as amplifying devices in that the energy, mass flow or pressure available from the main power source via the main orifices or main power nozzles 48 and 62 of the device 46 and 63 may be considerably greater than the corresponding parameter of the pulses applied via the input channel 51. Thus, a relatively large signal is developed in one or the other of the channels 42 and 58 and when deflected to one of the control nozzles 23 and 24 produces relatively rapid switching of the device.

The apparatus of FIGURE 2 may be fabricated in accordance with basic techniques taught in the aforesaid copending applications and may constitute passages formed in a base plate clamped between a top and bottom wall to isolate the passages from one another. The various elements labeled P+, P-, IN and OUT in FIGURE 2 would normally constitute holes drilled through a top and/or bottom plate to permit connections to external pipes or elements for feeding the various channels of the system. One further fact that should be mentioned is that in the interaction region 28, the channels should be no deeper than the depth of the power nozzle so that the power stream performs as a deflectable partition between the two portions of the region 28. Such construction permits isolation of the regions on the two sides of the stream so that differentials in pressure may be developed therebetween. Although it is preferable that the depth of the stream be the same as that of the region 28, this is not absolutely essential to the operation of the device so long as any space above or below the stream is relatively small when considering the entrainment properties of the stream which are necessary to prevent fluid coupling between the two sides of the stream. This statement applies equally to each of the devices described in this application with the exception of the elements of FIGURES 14 and 15.

In order to simplify the drawings in this application relative to the future embodiments of the invention to be described, a shorthand type of notation will be employed in the drawings. The apparatus of FIGURE 2 is reproduced in FIGURE 3 so that a definite correlation between the symbols and an actual device is provided. The elements employed in the notation of FIGURE 3 which correspond with the various elements in the flow pattern diagram of FIGURE 2 bear corresponding reference numerals.

In the diagram of FIGURE 3, all external connections employ a labeled circle and all flow paths are designated as single lines. A fluid resistor is designated by the conventional symbol for an electrical resistor and although not illustrated in this figure, the conventional electrical symbols for various circuit elements such as capacitors and inductors are employed for fluid capacitances and fluid inductances, respectively. In the basic amplifying and/or bistable type of devices, the power nozzle is illustrated as a square U-shaped member with short lines directed outwardly and downwardly towards the base from the ends of the sides of the U. A control nozzle is an arrow and two different designations are employed for the outlet or receiving passages depending upon the type of device. If the element employs boundary layer effects then the outlet passage is represented by a straight base line connected to two generally curved parallel legs. If the device provides proportional amplification with no boundary layer effects, the outlet passage

is represented by a straight base line with two outwardly diverging straight lines.

Referring now specifically to FIGURE 4 of the accompanying drawings, there is illustrated a scalar device which is similar to that illustrated in FIGURES 2 and 3 except that none of the fluid diverted to the output channel is used in the switching function and only that fluid which is diverted to the channel not connected to the output or load is so utilized. The device includes a flip-flop element 71 including a main nozzle 72, a pair of outlet passages 73 and 74 and opposed control orifices or nozzles 76 and 77. The channel 74 is connected directly to an outlet channel 78 while the other outlet passage 73 is connected via a passage 80 and a fluid resistor 79 to a passage 81 returned to the low pressure side of the pump or to the sump from which fluid is drawn by the pump.

The passage 80 is further connected to a control nozzle 82 of a fluid AND gate 83 and also to a control nozzle 84 of another fluid AND gate 86. The fluid AND gate 83 further includes an outlet channel 87 connected to the control orifice 76 of the bistable device 71 and an outlet channel 88 connected to the passage 81. There is further provided a main power nozzle 89 which receives fluid from an outlet passage 91 of another fluid AND gate 92. The fluid AND gate 92 includes a second outlet passage 93 connected via channel 94 to the low pressure side of the pump, a main power orifice 96 connected to a channel 97 returned to the high pressure side of the pump, and a control orifice 98 connected to a channel 99 adapted to have input fluid pulses applied thereto.

The AND gate 86 includes in addition to the control nozzle 84, a main power nozzle 101 connected to the high pressure passage 97, an outlet channel 102 connected to a low pressure passage 103, and a second outlet channel 104 connected to a main power orifice 106 of a fluid AND gate 107. The fluid AND gate 107 includes a control nozzle 108 connected to the passage 99 which receives fluid input pulses, an outlet channel 109 connected via a passage 111 to the low pressure orifice 94 and an outlet channel 112 connected to the control nozzle 77 of the bistable element 71.

In operation, it is assumed that the fluid issued by the main power jet 72 of the bistable device 71 is initially flowing to the outlet channel 74 and an input pulse is applied to the input passage 99. The fluid stream is caused to switch to the outlet channel 73 by the following sequence of events: A pressurized fluid issuing from the main power nozzle 101 of the AND gate 86 proceeds directly to the outlet passage 104 in the absence of fluid being applied via the channel 78 to the control orifice 84. This fluid is issued from the main power orifice 106 of the fluid AND gate 107 and is diverted by the input pulse applied to the control nozzle 108. The fluid is diverted to the passage 112 and then proceeds to the control nozzle 77 of the bistable device causing the main stream to flip over to the channel 73. Conditions are now established under which the fluid issuing from the main power orifice 101 of the AND gate 86 is diverted to the channel 102 and thence to the low pressure side of the pump via the passage 103.

When an input pulse is applied through the input passage 99 to the control nozzle 108 of the fluid AND gate 107 and there is no fluid issuing from the main power nozzle 106, this device has no effect upon the system. However, the fluid pulse which is also applied to the control nozzle 98 of the AND gate 92 diverts the fluid from the main power nozzle 96 and the output channel 91 through which it is supplied to the main power nozzle 89 of the AND gate 83. This fluid is diverted to the output channel 87 as a result of fluid being applied to the control nozzle 82 via the passage 78 and therefore the fluid is applied to the control nozzle 76 of the bistable element 71. The fluid issued by the main power orifice 72 of the unit 71 is now diverted to the outlet pas-

sage 74 where it remains until another pulse is received.

Referring now specifically to FIGURE 5 of the accompanying drawings, there is illustrated a scalar unit in which the main power nozzle of the bistable element is fed in series with the control elements from the high pressure side of the fluid pump. Fluid under pressure is fed via an orifice 116 to main power nozzles 117 and 118 of fluid AND gates 119 and 121, respectively. The fluid AND gates 119 and 121 are provided with control nozzles 122 and 123, respectively, which are connected to a fluid input pulse orifice 124. The AND gates 119 and 121 are provided with output channels 126 and 127, respectively, connected via a common passage 128 to a main power nozzle 129 of a bistable element 131. The AND gate 119 is further provided with an outlet channel 132 connected to a main power nozzle 133 of fluid AND gate 134 having an outlet channel 136 returned to an orifice 137 connected to the low pressure side of the pump. The AND gate 134 is also provided with an outlet passage or channel 138 connected to a control orifice 139 of the bistable element 131. The bistable element 131 includes a first outlet passage 141 connected to an outlet channel 142 and also connected via a passage 143 to a control nozzle 144 of the AND gate 134. The AND gate 121 includes a second outlet passage 146 connected to a main power nozzle 147 of a fluid AND gate 148 having a control nozzle 149 connected via a channel 151 to a second outlet passage 152 of the bistable device 131. The main passage 151 is also connected via a load matching resistor 153 to an orifice 154 returned to the low pressure side of the pump. Orifice 154 is also connected to an outlet channel 156 of the AND gate 148. The AND gate 148 includes a further outlet passage 157 connected to a second control nozzle 158 of the bistable 131.

The operation of the apparatus is basically the same as those discussed above except that the fluid applied to the main power nozzle 129 of the bistable element 131 is supplied through the AND gates 119 and 121. An incoming pulse partially diverts the streams issuing from power nozzles 96 and 101 of AND gates 92 and 86, respectively, so that a part of the fluid from each is applied to both of its associated outlet passages. The advantage to this arrangement is that there is a monetary drop in pressure of the main stream in bistable unit 131 during the switching operation which reduces the amount of energy required to effect switching, thereby reducing the switching time.

In FIGURE 1, the energy for diverting the stream from one output channel to another is derived entirely from the input pulse, whereas in the apparatus of FIGURES 2 through 5 the input pulse is employed to divert fluid flow from the main pump of the system to the control nozzles of the flip-flop. The apparatus of FIGURE 6 provides a still further type of operation in which the feedback fluid is employed to effect switching in response to an input pulse. The apparatus is provided with a basic bistable element 161 employing a main power nozzle 162, control nozzles 163 and 164, and outlet passages 166 and 167. The main power nozzle 162 is connected via a passage 168 to the high pressure side of the pump. The control nozzle 163 is connected to an output passage 168 of a fluid AND gate 169 having a second output passage 171 connected to a channel 172 return to the low pressure side of the pump. A control orifice 173 of the AND gate 169 is connected to a passage 174 to which input pulses are applied. The main power nozzle 176 of the AND gate is connected via a channel 177 to the junction of two fluid resistors 178 and 179 connected between the outlet passage 166 of the bistable element 161 and a channel 181 returned to the low pressure side of the pump. Two fluid resistors 182 and 183 are connected between the passage 181 and the outlet passage 167 of the device 161. The junction of the two resistors is connected via a passage 184 to a main

power nozzle 186 of a further AND gate 187. AND gate 187 includes a control nozzle 188, connected to the input channel 174, and an output passage 189 connected to the low pressure channel 172. The AND gate 187 includes a further output passage 191 connected to the control orifice 164 of the flip-flop 161. Output fluid from the system is taken from the outlet passage 167 of the bistable unit 161.

In operation, the portion of the fluid arriving at one or the other of the outlet channels 166 and 167 of the device 161 is diverted to the main power nozzle of its associated AND gate. Fluid is applied to only one of these power nozzles depending upon the position of the stream. Upon the application of an input pulse, flow from the power nozzle of one of the AND gates is diverted to the control nozzle of the element 161 subsisting on the same side of the center line of the device as the channel to which the power stream is originally directed. The power stream is diverted to the other output channel and remains in this state until the next input pulse is received. In such a case, the input pulses may be of lower energy to produce the same result as higher energy pulses employed in FIGURES 2 through 5 or if input pulses of the same energy content are employed.

The AND gates 169 and 187 are designed to produce a maximum amplification of the signal and the control pulses applied to the bistable unit are higher energy, pressure or mass flow than the pulses employed in the systems of FIGURES 2 through 5 so as to reduce switching times.

Since the arrangement of resistors and output channels relative to such elements as 182, 183, channel 184 and the outlet channel associated therewith are different from any of those previously described, reference is made to FIGURE 7 of the accompanying drawings to disclose the physical arrangement of the passages and resistors required for such a device. The outlet channel or passage 167, employing the same numbering system as employed in FIGURE 6, is connected to the outlet orifice 194. A passage 196 extends through the right side wall, as viewed in FIGURE 7, of the passage 167 and has included therein a porous plug which serves as a first fluid resistor 183. The channel 196 branches to provide the channel 184 and above this branch point a second porous plug is placed to provide the fluid resistor 182.

The fluid entering channel 167 divides between the passages 196 and 167 in accordance with the ratio of the load on the outlet orifice 194 and the series resistors 182 and 183. Similarly, the fluid proceeding through the porous plug 183 divides between the upper portion of the channel 196 and the channel 184 in accordance with the relative impedances of the resistor 182 and the system as viewed at the entrance to passage 184. By appropriately selecting the impedance values of the resistors 182 and 183 relative to the impedance of the loads as reflected into the system, the proper division of flow may readily be obtained.

Each of the devices thus far described has been considered in the light of a unitary member operating as a scale-of-2 scaling device; that is, a single output pulse is derived for every two input pulses. If it is wished to cascade elements to provide a scale-of-N counter, greater than 2, the effects of the large fluid flow through the outlet port into the next succeeding stage of the scalar must be considered. In order to produce switching, a relatively large initial flow is required and thereafter the flow must be reduced so that it does not interfere with subsequent switching of the apparatus. More particularly, if a high level of output flow from a device were continuous, the input channel of the next stage in the scalar receives a D.C. signal. The devices can be arranged to operate with such a signal, but it is preferred to employ the techniques illustrated in FIGURE 8 of the

accompanying drawings to reduce the flow from the outlet channel after the switching has occurred.

Referring now specifically to FIGURE 8 of the drawings, there is provided a scalar device which is adapted to be cascade with prior or succeeding stages of a scalar and in which the level of the signal falls materially, after switching has occurred. The device of FIGURE 8 is basically of the same type as illustrated in FIGURE 6 in that the input pulse is employed to divert feedback fluid to produce switching in the bistable element of the scalar stage. The bistable element which is designated by reference numeral 201 has a first outlet channel 202 connected through a fluid inductance 203 to an orifice 204 connected to a regulated pressure source P_1 . The pressure required of the source P_1 is that which establishes the proper operating conditions and should be such, when considered in the light of the values of inductances and resistances specified below, to maintain a flow in passages 228 and 232 so low as to prevent operation of the AND gates 217 and 222. The element 201 is provided with a second output channel 207 connected through a fluid inductance 208 to the orifice 204 and is further provided with control nozzles 209 and 211. The outlet channel 202 is also connected through a fluid resistor 212 to an outlet passage 213 and through a channel 214 to supply fluid to a main power nozzle 216 of an amplifying fluid AND gate 217. The outlet passage 207 of the flip-flop 201 is connected through a fluid resistance 218 to a channel 219 and via the channel 219 supplies fluid to a main power nozzle 221 of a second fluid AND gate 222. The fluid AND gate 222 further comprises an output passage 223, connected to the control nozzle 209 of the flip-flop 201, and a second output channel 224 connected to the low pressure side P_- of the pump via the passage 226.

The fluid AND gate 222 also includes a control nozzle 227 connected via a passage 228 to orifice 229 to which input fluid is to be applied. The orifice 229 is connected via a fluid inductance 231 to the low pressure return channel 226. The input fluid orifice 229 is connected through a passage 232 to a control nozzle 233 of the fluid AND gate 217 which comprises outlet channels 234 and 236. The passage 234 is connected to the low pressure channel 236 and the passage 236 is connected to the control nozzle 211 of the flip-flop 201.

Considering that the output channel of each stage of a cascaded scalar is connected to the input channel of the next succeeding stage, a flow path for fluid is developed between the P_1 channel 204 and the orifice 226 of the next stage which returns to the low pressure side of the pump. This path includes in series between the higher pressure P_1 and the lower pressure P_- , the fluid inductance 203, the fluid resistance 212, and the fluid inductance 231. Referring specifically to FIGURE 9 wherein these elements are drawn apart from the remainder of the system, the fluid suffers a pressure drop in flowing through each of the elements. A specific pressure, as determined by the relative resistances of these elements, is established at the output orifice 213, or of more importance in the channels 228 and 232 of this next succeeding stage. If now the fluid stream which had previously been directed to the outlet channel 207 is switched to the outlet channel 202, the fluid inductance 203 prevents an immediate change in fluid flow from the passage 204 and in consequence the two flows to the junction of elements 203 and 212 add and the pressure rises rapidly. The increase in pressure and flow causes a sudden increase in flow through resistor 212. The fluid inductance 231 initially prevents a significant increase of fluid flow therethrough and the increase in flow through resistor 212 is directed to the channels 228 and 232 of the next stage to effect a switching action.

As the effects of the inductance of the members 203 and 231 are overcome, the flow from the source P_1 through the inductance 203 decreases and the pressure at the junction of the elements 203 and 212 also decreases. A simi-

lar effect also occurs at the output orifice 213 in that the inertance of the element 231 is gradually overcome and accepts increased flow therethrough as a result of the fluid being supplied through the outlet passage 202 of the bi-stable element 201. The pressure at the point 213 is consequently further reduced and the steady state pressure and flow are considerably less than the pressure and flow initially developed when fluid is switched to the passage 202. The above describes the function of these elements relative to the switching of the fluid to the passage 202 and, of course, the same phenomena occurs when the fluid is initially switched to the outlet passage 207.

Fluid inertances are achieved by employing passages having cross-sectional areas small relative to their lengths. This concept is described more fully in the aforesaid co-pending application 51,754. In order to physically achieve the arrangement illustrated in FIGURE 8, a structure may be employed as illustrated in FIGURE 10. In this figure, the reference numerals employed in FIGURES 8 and 9 are again employed in FIGURE 10 to designate identical elements. The passages forming the fluid inertances 203 and 231 generally extend at right angles to the main fluid channels so that they do not interrupt the fluid signal flows. The fluid resistances may comprise porous plugs and the outlet channel 213 is connected through a suitable passage to the inlet channel 229 of the next succeeding stage. The channels 228 and 232 are arranged in the manner illustrated so as to eliminate boundary layer effects relative to the fluid passing from the inlet port 229 to the passages 228 and 232 to insure equal division of flow thereto.

In the apparatus illustrated in FIGURES 8 through 10, a regulated source of pressure P_1 is employed to prevent interactions between various portions of the system. However, if suitable care is taken to isolate the various portions of the fluid system, the pressure source to which the P+ orifice is connected may be employed in place of P_1 so long as a fluid impedance is included between the orifice 204 and the junction of the inertances 203 and 208 so as to derive a suitable pressure at this junction point which is lower than the P+ pressure.

The techniques employed in FIGURES 8 through 10 may be also applied to the systems of FIGURES 2 through 7 so as to produce the initial pressure step-up followed by a later reduction in pressure so as to facilitate cascading of the various elements.

The system of FIGURE 8 is reproduced in its entirety in FIGURE 10 in the physical form in which it actually exists in a practical case. Passages are formed by cutting channels through the thickness of a generally square block of material in which the thickness is small relative to the peripheral dimensions. It will be noted that the P_1 , P+ and P- orifices are symmetrical with the vertical center line of the apparatus as viewed in the drawing whereas the input and output channels are arranged at the same vertical height but horizontally displaced by equal distances from the centerline of the device. This is done so as to facilitate cascading of flat plates to provide the scale-of-N counter in which the N is equal to two raised to a power equal to the number of plates.

Assuming that the device illustrated in FIGURE 10 is employed for each of the modules then the elements may be cascaded as illustrated in FIGURE 11. A gasket 200 has holes which are in alignment with all of the P passages in a plate 205 in which the element of FIGURE 10 is formed. The gasket 200 also has a hole in alignment with the inlet orifice 229 formed in plate 205. A second module 210 is disposed above the gasket 200 and is rotated 180° relative to plate 205 about its X-X' axis through the P orifices so that the outlet passage of this stage is aligned with the inlet passage of the stage 205 and is coupled thereto through a hole in the gasket 200. The gasket 200 has no hole in alignment with the input passage of the module 210 so as to isolate the input from the outlet passage of stage 205. The inlet pas-

sage of module 210 must communicate with the outlet passage of the next upper module 225 and this is accomplished by a gasket 220. This gasket is the same as gasket 200 but is rotated 180° about its axis Y-Y' through the P orifices. In this manner, the modules may be stacked with appropriate spacers therebetween to achieve a scaling factor equal to any power of two. An output signal may be derived from each module through a passage 241 which extends from each outlet passage through the side of the module. The entire modular structure may be sandwiched between upper and lower plates at least one of which has connections to pipes leading to the various pressurized locations in the supply system. When the apparatus is assembled to form a module, the end walls, gaskets and plates having the channels formed therein are all clamped in sealing relationship so as to provide a closed system. The channels 241 which are connected to the output passages of each module are employed to obtain a readout from the apparatus or may serve as test points in checking out the operation of the unit.

The reference numerals applied to the components of FIGURE 11 are the same as the reference numerals of the corresponding components of the device as illustrated in FIGURE 8 of the accompanying drawings and it is not believed that any further explanation of the operation is necessary since it is fully described with respect to FIGURES 8 through 10.

Each of the devices illustrated in FIGURES 1 through 10 are planar in the sense that the beam is confined to a single plane and is deflected in that plane only. As previously indicated, there are distinct advantages to such an arrangement relating to maximizing the exchange of energy between a control and a main stream when such confinement is provided. However, also as previously indicated, it is not essential to operation of such devices that this stream be confined if one is willing to accept the inefficiencies inherent in a system where the beam is not confined to its plane of deflection. There is illustrated in FIGURES 12 and 13, a device in which the beam is not confined and in which deflection of the beam occurs in two planes at right angles thereby providing a three-dimensional device. The three dimensional device is illustrated as such in FIGURE 12. It comprises a power nozzle 246, two control nozzles 247 and 248 disposed on opposite sides of the fluid stream, two opposed feedback nozzles 249 and 251 disposed at right angles to the nozzles 247 and 248. Located downstream of the power nozzle 246, as illustrated in FIGURE 12, is a receptor mechanism 252 comprising a generally rectangular box 253, the walls of which converge into a hood-like assembly for purposes which will become apparent subsequently. The box 253 is divided into two compartments by a divider 254 having three walls 256, 257 and 258. The walls 256 and 258 are parallel to one another and perpendicular to the wall 257 with the walls 256 and 257 being disposed on opposite sides relative to one another on the axis of the nozzle 246 with the wall 258 having its center disposed along the axis of the main power nozzle. The divider 254 therefore divides the opening in the bottom of the receptor 253 into interlaced L-shaped portions of outlet channels 259 and 261. The channel 259 communicates with nozzle 251 via a feedback channel 262 and the outlet passage 261 communicates with the feedback nozzle 249 via channel 263.

In this arrangement, when fluid is initially supplied to the nozzle 246, it tends to divide equally between the output channels 259 and 261 so that equal amounts of fluid are supplied to the nozzles 249 and 251. Due to slight aberrations in the system, the stream tends to fluctuate slightly from its precise center position thereby developing a larger feedback in one channel than in the other. As a result of cumulative effects produced by such action, the stream is deflected to one of the output channels 259 or 261 and is maintained in such a position

by the fluid fed back to the feedback nozzle. Assume that the fluid is initially completely deflected to the output channel 261. In such case, the stream is represented by dotted line bearing reference numeral 264 as illustrated in FIGURE 13. The fluid collected in the compartment 261 is fed back through the feedback channel 263 to the nozzle 251 which issues fluid to maintain the stream in the position illustrated. If now it is wished to cause the device to change its stable state; that is, switch the fluid to the passage 259, a pulse is fed simultaneously to the nozzles 247 and 248. The fluid stream is unaffected by the fluid issuing from the nozzle 247 but since it is disposed immediately in front of the nozzle 248, it is deflected to the left, as illustrated in both of the FIGURES 12 and 13 and now the fluid is directed to the channel 259. Fluid flows through the feedback channel 262 to the nozzle 249. When the input pulse is removed, the stream tends to return to its central position but is maintained deflected to the output channel 259 by the fluid issuing from the channel 249. So long as the stream remains deflected to the output passage, 259, the fluid continues to issue from the nozzle 249 and the stream is maintained in the dotted line position bearing the reference numeral 266. If an output pulse is again applied to the nozzles 247 and 248, the stream is deflected to the right so that the fluid flows to the outlet channel 261 and via the feedback path 263 to the feedback 251. When the incoming fluid pulse is removed, the fluid issuing from the nozzle 251 maintains the stream in the dotted line position 264. The inrtance of the passages 262 and 263 should be sufficient to maintain flow from nozzles 249 and 251, respectively, for a brief interval even if the main stream flow to one of the regions 261 or 259 is temporarily reduced. For instance, when the input pulse moves the main stream out of the flow from a feedback nozzle the stream tends to return to the vertical center of the device, as viewed in the plane of FIGURE 13. The stream then tends to divide equally between the two passages 259 and 261. The inrtance of path 262 must be sufficient to maintain output from the nozzle 249 in sufficient strength hold the stream below the center line of the receptor as viewed in FIGURE 13. By changing the shape of the divider to conform to that illustrated by solid line 267 of FIGURE 13, this problem is easily overcome.

While I have described and illustrated several embodiments of my invention, it will be clear that variations of the details of construction which are specifically illustrated and described may be resorted to without departing from the true spirit and scope of the invention as defined in the appended claims.

What I claim is:

1. A fluid pulse converter adapted to issue an alternating fluid stream from a pair of output tubes of a pure fluid amplifier incorporated in said converter as a result of a single input tube receiving a sequential series of pulsed fluid signals, said pulse converter comprising a fluid amplifier through which a fluid stream can flow, a pair of opposed control nozzles in said amplifier adapted to switch the fluid stream flowing through said amplifier from one output tube to another as a result of alternating jets of fluid issuing from said nozzles, and tube and nozzle means adapted to convert and convey successive fluid signals received thereby alternately to each of said control nozzles.

2. A fluid pulse converter for converting sequential fluid pulses into alternating fluid pulses, said converter comprising a fluid amplifier of the boundary layer type in which a pair of control nozzles are positioned to alternately deflect a fluid stream flowing therebetween to one of two output passages, an input passage for receiving said sequential fluid pulses and means responsive to the particular output passage to which said stream is flowing to direct an input fluid pulse to the control nozzle closest to said stream.

3. A fluid pulse converter for converting sequential fluid pulses into alternating fluid pulses, said converter comprising a fluid amplifier of the boundary layer type in which a pair of control nozzles are positioned to alternately deflect a fluid stream flowing therebetween to one of two output passages, an input passage for receiving said sequential fluid pulses and means responsive to both the particular output passage to which said stream is flowing and to an input fluid pulse to divert said stream to the other of said output passages.

4. The combination according to claim 3 wherein said means comprises at least one pair of fluid AND gates, passages connecting each output passage of said fluid amplifier with a control nozzle of a different fluid AND gate, passage means responsive to a fluid input pulse for supplying fluid to a power nozzle of each of said fluid AND gates and an output passage for each of said fluid AND gates positioned to receive fluid only when fluid is supplied to said passage means and said control nozzle of an AND gate, said output passages of said fluid AND gates being connected to said control nozzles of said fluid amplifier.

5. A fluid pulse converter adapted to issue an alternating fluid stream from a pair of output tubes of a pure fluid amplifier incorporated in said converter as a result of a single input tube receiving a sequential series of pulsed fluid signals, said pulse converter comprising a fluid amplifier through which a fluid stream can flow, a pair of opposed control nozzles in said amplifier adapted to receive fluid from said input tube, means responsive to said fluid stream being directed to one of said output tubes to direct the succeeding pulsed fluid signal to said control nozzle adjacent said last-mentioned output tube, and means responsive to the issuance of fluid from a control nozzle adjacent the output tube to which said fluid stream is directed to switch said fluid stream to the other of said output tubes.

6. A fluid system for converting sequential fluid input pulses to fluid pulses alternately appearing in two fluid flow conveying members, comprising a region, said two fluid flow conveying members opening into said region, means for issuing sequential fluid pulses into said region toward said fluid flow conveying members, and means for directing a fluid input pulse to a flow conveying member different from the flow conveying member to which the prior fluid input pulse had been directed.

7. A pure fluid pulse converter comprising a fluid amplifier including a pair of output passages, an interaction region and means for issuing a stream of fluid through said interaction region toward one end of each of said fluid output passages, and generally opposed control nozzles for issuing fluid against said stream of fluid so as to deflect said stream of fluid, a source of sequential input pulses, a feedback path for fluid flowing to at least one of said output passages, and fluid directing means responsive to said input pulses and the condition of fluid flow in said feedback path for directing fluid to the one of said control nozzles adjacent the output passage to which said stream of fluid is directed.

8. The combination according to claim 7 wherein there is provided two feedback paths each connected to a different one of said output passages, and wherein said fluid directing means includes at least two AND gates, said AND gates each having two signal input passages and two output channels, feedback flow in each feedback path being directed to an input passage of a different AND gate and flow resulting from an input pulse being directed to said input passages of both of said AND gates.

9. The combination according to claim 8 further comprising two additional AND gates, means applying said fluid input pulses to each of said two additional AND gates, means supplying fluid under pressure to each of said two additional AND gates, and means applying flows generated by the presence of input pulses and fluid under pressure at said two additional AND gates each to a sig-

nal input passage of a different one of said first-mentioned AND gates.

10. The combination according to claim 7 wherein said means for issuing a stream of fluid comprises means for reducing the flow of said stream of fluid upon application of an input pulse to said converter.

11. The combination according to claim 7 wherein said means for issuing a stream of fluid comprises a source of fluid under pressure, a pair of AND gates, having two output channels, one output channel of each of said AND gates directing fluid to said pure fluid amplifier to supply said stream of fluid, the other output channel of each AND gate supplying fluid to said gate means, and means for applying input pulses to said AND gates to direct fluid to said other output channels of said AND gates.

12. The combination according to claim 7 wherein said converter includes a single feedback path and wherein said fluid directing means comprises at least two AND gates each for controlling flow to a different one of said control nozzles, and means for applying flow in said feedback path to both said AND gates.

13. The combination according to claim 7 wherein said fluid directing means consists of two AND gates and wherein there is provided two feedback paths each receiving flow from a different one of said output passages, and means for supplying flows from said feedback paths each to a different one of said AND gates and for supplying input fluid pulses to said AND gates, the AND gate receiving both said fluid flows directing fluid to the control nozzle adjacent the output passage receiving said stream of fluid.

14. The combination according to claim 7 comprising a readout orifice for at least one of said output passages, and impedance means for proportioning fluid between said orifice and said feedback path.

15. The combination according to claim 7 further comprising a source of fluid under pressure, said fluid directing means directing fluid from said source of fluid to a control nozzle as a function of flow of fluid in said feedback path and a fluid input pulse.

16. The combination according to claim 7 further comprising a second fluid pulse converter to provide a staged fluid counter, each of said converters being formed as channels in a different plate, at least one further plate located between said plates in which said converters are formed, said further plate permitting communication between equal pressure points in said converters there-through, each of said converters having a fluid pulse input orifice and a fluid pulse output orifice, and means in said further plate permitting fluid flow from an output orifice of a stage in said counter to a fluid pulse input orifice in a succeeding stage.

17. A three-dimensional fluid pulse converter comprising a generally rectangular receiver, means dividing said receiver into two L-shaped generally equal compartments, means for issuing a stream of fluid toward the center of said rectangle and perpendicular to the plane thereof, feedback means from each of said compartments for maintaining said stream directed towards one of said compartments to which it is initially directed, and a pair of sig-

nal input channels for receiving an input fluid pulse, one of said input channels producing a fluid flow to discontinue flow of feedback fluid against said stream of fluid and the other of said input channels directing said stream to the other of said compartments.

18. The combination according to claim 17 wherein said input channels issue fluid at right angles to fluid issued by said feedback channels.

19. The combination according to claim 18 wherein said stream of fluid is at right angles to the fluid flows issued by said input and feedback channels.

20. A fluid scalar comprising cascaded counter stages each having a fluid signal input passage, and at least two fluid signal output passages, means for producing a stream of fluid and means responsive to successive fluid input signals applied to said fluid signal input passage to switch the stream of fluid between said output passages in alternation, means coupling one of said output passages of each counter stage to an input passage of the succeeding counter stage and means for reducing flow to said input passage of each of the succeeding counter stages at a predetermined interval after initiation thereof.

21. The combination according to claim 20 wherein each of said means responsive to successive fluid input pulses includes fluid logic means, each of said input passages being connected to said fluid logic means included in its associated counter stage and means for reducing flow from each of said input passages to its associated fluid logic means after said predetermined interval.

22. A fluid logic system comprising a first pure fluid amplifier including means for issuing a power stream, at least one output passage, and at least one input passage, means for maintaining said power stream directed to said one output passage in response to at least temporary fluid flow to said one input passage, a second fluid amplifier having a power stream input passage, at least one control stream input passage and an output means, means connecting said one output passage of said first fluid amplifier to one of said input passages of said second fluid amplifier, said last-mentioned means including means for reducing flow to said input passage of said second fluid amplifier at a predetermined interval after initiation thereof.

23. A fluid logic circuit comprising a pure fluid flip-flop having a nozzle for issuing a stream of fluid, a control nozzle and output passages, means for supplying fluid to said nozzle for issuing a source of fluid pulses, means connecting said source of pulses to said control nozzle so as to switch said stream from a first output passage to a second output passage and means responsive to said fluid pulses for reducing fluid flow to said nozzle for issuing during switching of said stream.

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LEO SMILOW, *Primary Examiner*.