A fluidic device is disclosed having two input jets arranged to interact, selectively producing one of three possible outputs. A first output is produced by the presence of either of the jets in the absence of the other jet. A second output is produced by the simultaneous presence of both jets where the velocity of the first jet substantially exceeds the velocity of the second jet. The third output is produced by the simultaneous presence of both jets where the velocity of the two jets is substantially equal.
FIG. 5

FIG. 6

<table>
<thead>
<tr>
<th>C</th>
<th>OR (CONDUIT 118)</th>
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<tbody>
<tr>
<td></td>
<td>SECOND AND (CONDUIT 121)</td>
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<tr>
<td>PRESSURE RATIO</td>
<td>FIRST AND (CONDUIT 120)</td>
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<tr>
<td>B</td>
<td></td>
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<tr>
<td>A</td>
<td></td>
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<tr>
<td></td>
<td>OR (CONDUIT 118)</td>
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<td></td>
<td>ACTIVE OUTPUT</td>
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MUTIPLE OUTPUT FLUIDIC GATE

This invention relates to a fluidic device and more particularly to such a device having a plurality of selectively produced outputs, specifically, a passive half adder having at least one exclusive OR output and at least two AND outputs.

BACKGROUND OF THE INVENTION

In communication and other systems having an analog input signal, it is necessary to convert the analog signal into a digital signal before the information can be handled by the logic of the system's control circuitry. The digital signal is commonly in 1-out-of-2 (binary) form, 1-out-of-8 (octal) form or 1-out-of-10 (decimal) form. The input signal is then processed to perform the necessary logic functions and provide the system control.

In those systems in which the analog input signal comprises a continuously variable voltage signal, conversion into the desired digital format is rather straightforward. Modern electronic discriminators and filters are very effective for detecting particular voltage levels and generating the corresponding information.

If the input signal is a fluidic analog signal of continuously variable pressure rather than an electrical analog signal, use of electrical logic circuitry necessitates conversion of the fluid analog signal into an electrical analog signal which is then discriminated and converted into electrical digital form.

When it is desired to have the control signals from the control circuitry in a fluidic format, it is necessary to re-convert the logic circuit output from an electrical signal into a corresponding fluidic signal. If the electronic logic and discriminators are eliminated and replaced with fluidic devices, the necessity is removed for converting the input signals from fluidic analog to electrical analog and for converting the output signals from electrical signals back into fluidic signals. Not only is such an arrangement more economical, but the size required for the control circuitry is minimized while the reliability of the control circuitry is increased by eliminating two unnecessary operations.

Unfortunately, fluidic devices designed in the past for such discrimination and filtering operations have been ineffective. As a result, sophisticated electronics were more suitable, despite the conversion and reconversion operations, than were the complicated and unreliable fluidic devices.

My invention provides a fluidic device which is effective for discriminating a variable pressure analog signal and converting it into a digital fluidic signal. This eliminates any necessity for electronic circuitry in a completely fluidic system. This is particularly advantageous where the system operates in a high temperature environment, near high radiation levels, or when subjected to shock or vibration. Such environmental conditions are hostile to electronic devices, but have essentially no effect on fluidic devices.

DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENT

Fluid logic devices may be constructed from any rigid, nonporous material, including glass, ceramic, plastic and metal. Such devices generally comprise a base, into which the desired passages are impressed or etched, and a cover providing a fluid-tight seal. The cover is secured to the base by any of a number of methods, such as adhesives, fasteners, clamps, or the like. For ease of illustration, the drawings of FIGS. 1 to 5 depict a device having a glass cover. This was done to permit the interior of the device to be shown without the confusing presence of cross-section lines. This should in no way be interpreted as a limitation on the materials suitable for use in the device, since any rigid, nonporous material is applicable.

This device relies upon several fluid flow phenomena, among them the Coanda effect, momentum exchange and knife edge attachment. The Coanda effect, also called the wall attachment phenomenon, results when a fluid jet flows past a wall. Between the flowing jet and the wall, an ambient fluid is trapped, resulting in a reduced pressure in the entrainment region. Turbulence increases the entrained flow, and the resulting pressure differential across the jet causes it to move closer to the wall. The closer the jet comes to the wall, the greater the force imbalance becomes.

Regenerative effects cause the jet to rapidly assume a stable state in which the unbalance forces are reduced to zero and a state of equilibrium is attained. This occurs when the restraining force exerted by the wall on the jet equals the imbalance force. When this point is reached, the jet is so close to the wall, and the forces acting on it have become so strong, that the jet is effectively "attached" to the wall. To break the attachment, an equilibrium must be disturbed to such an extent that a separation between the wall and the jet is introduced. As the separation point moves down the wall, the jet becomes "unlocked."

A second fluid flow phenomenon, momentum exchange, occurs when two moving fluid jets impinge on each other. Each jet has a certain momentum due to its velocity and mass. When the jets impinge on each other they mutually alter the path of the other jet. Since the jets add vectorially, it should be apparent that jets intersecting at an angle greater than 90° have a component in opposition to a component of the other jet. As a result, they tend to cancel each other, to an extent depending on the angle between them. The opposition of the two jet components might also increase turbulence levels, leading to a faster degeneration of the resultant jet.

However, if the jets intersect at 90° or less, all components of the two jets are mutually assisting or additive. As a result, a single resultant jet will be formed having a total pressure dependent upon the pressure of the two jets. The angle of the resultant jet relative to the other two jets will be a predictable function of the relative velocities of the two jets. For example, if the two jets are perpendicular to each other and of approximately equal pressure, since jet velocities vary directly with the pressure acting on them, the jet velocities are also equal and the resultant jet will move away at an angle of 135° to either jet. If one input is at a higher pressure than the other, so that its jet has a higher velocity, the resultant jet is located farther from the original direction of the lower velocity jet.

FIG. 4 shows the device of FIG. 1 with the fluid flow path indicated for the two jets concurrently interacting where the velocity of the two jets is substantially equal;

FIG. 5 shows the device of FIG. 1 with the fluid flow path indicated for the two jets concurrently interacting where the velocity of one jet substantially exceeds the velocity of the other;

FIG. 6 shows graphically the active output for varying ratios between the pressure of the two inputs; and

FIG. 7 shows an alternate embodiment of my invention in plan view.

For convenience, reference characters are consistent throughout the figures, although only those characters referred to in the description of the illustrative embodiment are shown in each figure.

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For convenience, reference characters are consistent throughout the figures, although only those characters referred to in the description of the illustrative embodiment are shown in each figure.

SUMMARY OF THE INVENTION

In an illustrative embodiment of my invention, a fluidic cavity is arranged so that two fluidic inputs are located to generate respective fluid jets with their axes transverse to each other. Downstream from the two inputs are three output ports. One of three associated output signals is selectively produced depending upon the relative condition of the two inputs. A first output is produced by the presence of either jet in the absence of the other jet. A second output is produced by the appearance of both jets with substantially equal velocities. A third output is produced by the simultaneous presence of both jets where the velocity of one substantially exceeds the velocity of the other.

FIG. 1 is a plan view of the device embodying my invention; FIG. 2 shows the device of FIG. 1 with the fluid flow indicated for a first input jet alone; FIG. 3 shows the device of FIG. 1 with the fluid flow path indicated for a second input jet alone;
The particular device 100 illustrated in FIG. 1 comprises a first fluid inlet, passage 101, and a second fluid inlet, passage 102, which connect to independent fluid pressure sources (not shown). The jets are selectively pressurized fluid, depending upon system conditions. The inlets 101 and 102 communicate respectively with nozzles 104 and 105 which are substantially perpendicular to each other. The nozzles act to generate a fluid jet when fluid pressure is present at the respective inlet.

The action of the jets within the device is a function of the respective internal geometry of the device, the actual dimensions of which are not particularly significant. By the way of illustration, the geometry of the device may be more meaningfully given in terms of relative dimensions, using the width \( b \) of nozzles 104 and 105 as a unit measure. The length of wall 107 is in the approximate range between \( a \) and \( 4b \). Wall 108 has a radius \( R \) of approximately \( 2b \). Wall 111 has a length approximately equal to \( b \). Wall 112 has a length in the approximate range of \( 10b \) to \( 15b \). Angle \( \alpha \) of wall 112, leading to receiver 114 and conduit 118, is in the range between \( 0^\circ \) and approximately \( 30^\circ \). The angle \( \theta \) of wall 110 leading to receiver 120 and conduit 125 is approximately \( 75^\circ \) and angle \( \beta \) of receiver 126 and conduit 121 is approximately \( 30^\circ \).

The flow lines in FIG. 2 represent the jet pattern in device 100 when pressurized fluid is present at inlet 101 alone. The exclusive jet issues from nozzle 104 and flows past wall 107. Due to the Coanda effect, the jet attaches itself to wall 107. After flowing past wall 107, the jet is deflected by the curved wall 108. When the jet leaves wall 108 at cusp 109, it has been redirected in a generally downward direction. The jet continues in the direction, with the jet diverging slightly due to the slight increase in pressure resulting from the returning flow into the circulation region.

The jet is deflected once again, this time by wall area 112, so that it is received at the output port receiver 114 which connects to fluid conduit 118. Pressurized fluid in conduit 118 is indicative of an exclusive OR condition, in this case flow from inlet 101 in the absence of flow from inlet 102. Loading effects, or effects of impedance mismatches in the system that could cause back pressure at receiver 114, are relieved by providing a vent 117 to the system reference pressure (to the atmosphere or back to a fluid return tank, for example).

The flow pattern of FIG. 3 is established by the appearance of pressurized fluid at inlet 102 but not at inlet 101. The same entrainment wall attachment condition described above causes the jet from nozzle 105 to attach to wall section 111. The attached jet flows from wall 111 to wall 112 and is carried to receiver 114. Once again an exclusive OR condition is indicated by pressurized fluid in conduit 118, this time resulting from inlet 102 and not inlet 101. Vent 117 again provides for the release of fluid pressure under high load conditions so that the device is maintained at, or near, atmospheric or tank pressure and the integrity of the jet is retained for all load conditions.

The resultant jet placement, when flow is simultaneously present at both inputs, depends initially upon momentum exchange. As shown in FIG. 4, if a jet is concurrently present at both nozzles 104 and 105, they will act upon each other as indicated. If the two jets are of substantially equal velocity, each possesses a substantially equal momentum and the resultant jet will be at an angle of approximately \( 15^\circ \) to either incoming jet.

FIG. 8 wall section 108 provides a "pocket" in which circulation is established by the flow of the resultant jet. The circulation creates a relatively lower pressure region within the pocket in the area of cusp 109. The pressure of the low pressure region is dependent upon the relationship between the edge of the jet and the cusp 109. This phenomenon, known as "knife edge attachment," creates the lower pressure and exerts a force to position the resultant jet near the cusp. The flow of the resultant jet past cusp 109 results in attachment of the jet to wall 110 and the delivery of the jet to receiver 125, and into fluid conduit 120. The presence of pressurized fluid at conduit 120 is indicative of a first AND condition, resulting from the interaction of the simultaneous, and substantially equal velocity, input jets.

If jets simultaneously issue from nozzles 104 and 105, but the jet from nozzle 104 is at a substantially higher velocity than the jet from nozzle 105, the flow pattern of FIG. 5 is obtained. Once again a resultant jet is produced by the interaction of the simultaneous input jets. However, since the jet from nozzle 104 is at a substantially higher velocity than the jet from nozzle 15, it contains substantially more momentum. The resultant jet is therefore positioned closer to the original direction of the high pressure jet. As a result, the deflected jet attaches to cusp 109, separates from wall 110 due to its higher velocity, and is delivered at receiver 126 which connects to fluid conduit 121. The presence of pressurized fluid in conduit 121 is indicative of a second AND condition, resulting from the jet at nozzle 105 having a low pressure relative to the jet at nozzle 104.

Device 100 is useful in the previously indicated application of an analog-to-digital converter. By applying a constant pressure signal to inlet 101, and a continuously varying pressure signal to inlet 102, or vice-versa, a one-out-of-three output signal is obtained. The output signal, appearing either at OR output 118, the first AND output 120, or the second AND output 121, is a useful representation of the analog signal in digital form.

For example, if the pressure at inlet 102 is held at a constant pressure and the pressure at inlet 101 is varied, the active output may be ascertained by reference to FIG. 6. When the pressure ratio \( P_{in}/P_{ref} \) is less than a critical value \( A \), or output 118 will be active. As the pressure at inlet 101 is increased, the pressure ratio exceeds \( A \) with the result that the active output switches from OR output 118 to output 120 giving the first AND indication. If the pressure at inlet 101 is increased further, a critical value \( B \) is reached where the active output switches from output 120 to output 121 giving the second AND indication. If the pressure at inlet 101 is increased still further, a critical value \( C \) is reached where the active output switches form output 121 back to OR output 118. The jet from inlet 102 now has such a low pressure, relative to the pressure at inlet 101, that it is effectively nonexistent and the jet from inlet 102 may be considered as existing alone.

Obviously, the values of \( A, B, \) and \( C \) will vary depending upon the fluid used, the device size, and the pressures employed. But, since the pressure at inlet 102 is constant and known, the pressures at inlet 101, corresponding to the pressure ratio at which the device switches, could be readily ascertained.

This device could also be effectively used as a monitoring device, which is required to determine the system condition producing a varying fluid pressure, inlet 101 could be connected to the source to be monitored. This would result in a jet from nozzle 104 having a velocity that would vary according to the variation in pressure of the monitored source. If a signal of constant pressure is provided at inlet 102, and it has a properly selected bias pressure, an output would normally be present in conduit 120.

If the pressure at inlet 101 is increased beyond some predetermined level, so that the critical pressure ratio \( B \) is exceeded, the resultant jet switches to produce an output in conduit 121. Conduit 121 could then be connected either to an over-pressure alarm or to a device that would automatically adjust the pressure being monitored. If the pressure at inlet 101 were to drop below a predetermined value, the pressure ratio would fall below the critical value \( A \) and the resultant jet would switch to conduit 118, indicating a low pressure condition. Conduit 118 could similarly connect to an under-pressure alarm or to a device that would automatically adjust the pressure. Although a device having a single OR output and two AND outputs was disclosed, additional use of ordinary skill in the art that two OR outputs could also be provided. For instance, the device disclosed could be modified so that wall 107 would direct an attached jet to a second OR.
output. This output would indicate the exclusive presence of a jet from restrictor 104, while existing OR output 118 would become indicative of the exclusive presence of a jet from restrictor 105.

Such a device is shown in FIG. 7. In view of the previous description, the operation of this device should be obvious without showing the flow pattern for each state of the device. When a jet from nozzle 105 appears alone, it attaches to wall 111 to be delivered to receiver 114 and conduit 118, as with the prior device. However, if a jet appears at nozzle 104 alone, this device will produce a change over the prior device. The jet from nozzle 104 will attach to wall 107, which will deliver the attached jet to receiver 114' connecting to conduit 118'.

Thus, a second OR signal, distinct from the first, will be created by the output signal from conduit 118'. As with the prior device, the outputs from conduits 120 and 121 indicate the two AND states to be distinguished.

The disclosure of a two AND output device should not be taken as limiting. The device could be supplied with three, four, or more AND outputs. Each would be indicative of a particular range of pressure ratios. It should be recognized however, that as the number of outputs is increased, the sensitivity of the device is also increased along with a related decrease in reliability. This results from the increased incidence of unintended switching of the more sensitive device due to unavoidable pressure variations in the input jets, effects of output loading, etc.

Numerous other applications for this device may be envisioned by a designer having skill in the fluidic art. A variety of refinements may be made in the basic device to suit the specific applications without departing from the intended scope of my invention.

What I claim is:

1. A fluidic logic device having a plurality of selectively produced and mutually exclusive output signals comprising a first fluid input; a first aperture connected to the first input for generating a first fluid jet in response to the presence of pressurized fluid at the first input, the velocity of the jet being proportional to the pressure of the fluid at the first input; a second fluid input; a second aperture connected to the second input and located adjacent the first aperture for generating a second fluid jet transverse to the axis of the first jet in response to the presence of pressurized fluid at the second input, the velocity of the jet being proportional to the pressure of the fluid at the second input; a third aperture connected to the third input for generating a third fluid jet in response to the presence of pressurized fluid at the third input, the velocity of the jet being proportional to the pressure of the fluid at the third input; and a fourth aperture connected to the fourth input for generating a fourth fluid jet in response to the presence of pressurized fluid at the fourth input, the velocity of the jet being proportional to the pressure of the fluid at the fourth input; a second aperture connected to the second input and located adjacent the first aperture for generating a second fluid jet transverse to the axis of the first jet in response to the presence of pressurized fluid at the second input, the velocity of the jet being proportional to the pressure of the fluid at the second input; a first receptive positioned to receive either generated jet in the absence of the other jet and to produce a first fluid output signal indicative of that condition; a second receptive positioned to receive a jet resulting from the concurrent generation of the first and second jets at substantially equal velocities and to produce a second fluid output signal indicative of that condition; a third receptive positioned to receive a jet resulting from the concurrent generation of the second and third jets at substantially equal velocities and to produce a third fluid output signal indicative of that condition; and a fourth receptive positioned to receive a jet resulting from the concurrent generation of the first and third jets at substantially equal velocities and to produce a fourth fluid output signal indicative of that condition.

2. A fluidic logic device in accordance with claim 1 further including means for redirecting the first jet from its normal axis in the absence of the second jet so that the first jet is received by the first receptive.

3. A fluidic logic device having a plurality of selectively produced and mutually exclusive output signals comprising a first fluid input; a first aperture connected to the first input for generating a first fluid jet in response to the presence of pressurized fluid at the first input, the velocity of the first jet being proportional to the pressure of the fluid at the first input; a second fluid input; a second aperture connected to the second input and located adjacent the first aperture for generating a second fluid jet transverse to the axis of the first jet in response to the presence of pressurized fluid at the second input, the velocity of the second jet being proportional to the pressure of the fluid at the second input; a first receptive positioned to receive either generated jet in the absence of the other jet and to produce a first fluid output signal indicative of that condition; a second receptive positioned to receive a jet resulting from the concurrent generation of the first and second jets at substantially equal velocities and to produce a second fluid output signal indicative of that condition; a third receptive positioned to receive a jet resulting from the concurrent generation of the first and second jets when the velocity of the first jet substantially exceeds the velocity of the second jet and to produce a third fluid output signal indicative of that condition; and a fourth receptive positioned to receive a jet resulting from the concurrent generation of the second and third jets when the velocity of the second jet substantially exceeds the velocity of the first jet and to produce a fourth fluid output signal indicative of that condition.

4. A fluidic logic device in accordance with claim 3 wherein the chamber further includes a delivery wall, positioned intermediate the apertures and the first receptive, to which the second jet attaches in the absence of the first jet for delivering the attached second jet and the redirected first jet to the first receptive.

5. A fluidic logic device in accordance with claim 3 wherein the second aperture connected to the second input and located adjacent the first aperture for generating a second fluid jet transverse to the axis of the first jet in response to the presence of pressurized fluid at the second input, the velocity of the second jet being proportional to the pressure of the fluid at the second input; a first receptive positioned to receive either generated jet in the absence of the other jet and to produce a first fluid output signal indicative of that condition; a second receptive positioned to receive a jet resulting from the concurrent generation of the first and second jets at substantially equal velocities and to produce a second fluid output signal indicative of that condition; a third receptive positioned to receive a jet resulting from the concurrent generation of the first and second jets when the velocity of the first jet substantially exceeds the velocity of the second jet and to produce a third fluid output signal indicative of that condition; and a fourth receptive positioned to receive a jet resulting from the concurrent generation of the second and third jets when the velocity of the second jet substantially exceeds the velocity of the first jet and to produce a fourth fluid output signal indicative of that condition.

6. A fluidic logic device in accordance with claim 3 wherein the second aperture connected to the second input and located adjacent the first aperture for generating a second fluid jet transverse to the axis of the first jet in response to the presence of pressurized fluid at the second input, the velocity of the second jet being proportional to the pressure of the fluid at the second input; a first receptive positioned to receive either generated jet in the absence of the other jet and to produce a first fluid output signal indicative of that condition; a second receptive positioned to receive a jet resulting from the concurrent generation of the first and second jets at substantially equal velocities and to produce a second fluid output signal indicative of that condition; a third receptive positioned to receive a jet resulting from the concurrent generation of the first and second jets when the velocity of the first jet substantially exceeds the velocity of the second jet and to produce a third fluid output signal indicative of that condition; and a fourth receptive positioned to receive a jet resulting from the concurrent generation of the second and third jets when the velocity of the second jet substantially exceeds the velocity of the first jet and to produce a fourth fluid output signal indicative of that condition.

7. A fluidic logic device having a plurality of selectively produced and mutually exclusive output signals comprising a first fluid passage; a first nozzle communicating with the first passage for generating a first fluid jet in response to fluid flow in the first passage where the velocity of the first jet is proportional to the pressure of the fluid in the first passage; a second fluid passage; a second nozzle communicating with the second passage and adjacent the first nozzle for generating a second fluid jet, along an axis transverse to the axis of the first jet, in response to fluid flow in the second passage where the velocity of the second jet is proportional to the pressure of the fluid in the second passage; a first receiver for receiving either generated jet in the absence of the other jet; a first fluid conduit communicating with the first receiver for producing an exclusive OR fluidic logic signal in response to receipt of a jet by the first receiver; a second receiver for receiving a resultant jet produced by the concurrent generation of first and second jets of substantially equal velocity; a second fluid conduit communicating with the second receiver for producing a first AND fluidic logic signal in response to receipt of a jet by the second receiver;
a third receiver for receiving a resultant jet produced by the concurrent generation of first and second jets where the velocity of the first jet substantially exceeds the velocity of the second jet;
a third fluid conduit communicating with the third receiver for producing a second AND fluidic logic signal in response to receipt of a jet by the third receiver;
a walled chamber communicating with the first and second nozzles in which the concurrently generated first and second jets interact and including a first wall section, adjacent the first nozzle, to which the first jet attaches in the absence of the second jet;
a second wall section, contiguous to the first section, for deflecting the attached first jet away from its normal axis to an altered axis which intersects the normal axis of the second jet;
a third wall section, adjacent the second nozzle, to which the second jet attaches in the absence of the first jet; and
a fourth wall section, contiguous to the third section, for delivering to the first receiver both the attached second jet and the altered first jet.

8. A fluidic logic device in accordance with claim 7 wherein the walled chamber further includes a cusp, contiguous to the second section, for both positioning the jet resulting from the concurrent generation of first and second jets of substantially equal velocity so that it is received by the second receiver, and for positioning the jet resulting from the concurrent generation of first and second jets where the velocity of the first jet exceeds the velocity of the second jet so that it is received by the third receiver.

9. A fluidic device for selectively producing a plurality of mutually exclusive output signals comprising a first input source of pressure $P_1$ for selectively generating a first fluid jet;
a second input source of pressure $P_2$ for selectively generating a second fluid jet transverse to the axis of the first jet;
a first wall located so that the first jet attaches thereto when the pressure ratio $P_1/P_2$ is very high;
a second wall located so that the second jet attaches thereto when the pressure ratio $P_1/P_2$ is very low;
a first jet receiver, located to receive the jet attached to the first wall, for producing a first output signal indicative of the condition where $P_1/P_2$ is very high;
a second jet receiver, located to receive the jet attached to the second wall, for producing a second output signal indicative of the condition where $P_1/P_2$ is very low; and a plurality of intermediate jet receivers, each located to receive the resultant of concurrently generated first and second jets for a particular and predetermined intermediate pressure ratio $P_1/P_2$, thereby producing a plurality of individual and mutually exclusive output signals indicative of the particular ratio $P_1/P_2$. * * * * *