United States Patent [19]

Woods

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[54] **LAMINAR FLUIDIC MULTIPLIER**

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[73] Assignee: **The United States of America as represented by the Secretary of the Army,** Washington, D.C.

[22] Filed: **Aug. 14, 1974**

[21] Appl. No.: **497,412**

[52] **U.S. Cl.** **137/819;** 137/834

[51] **Int. Cl.²** **F15C 1/14**

[58] **Field of Search** 137/807, 818, 819, 834, 137/836

[56] **References Cited**

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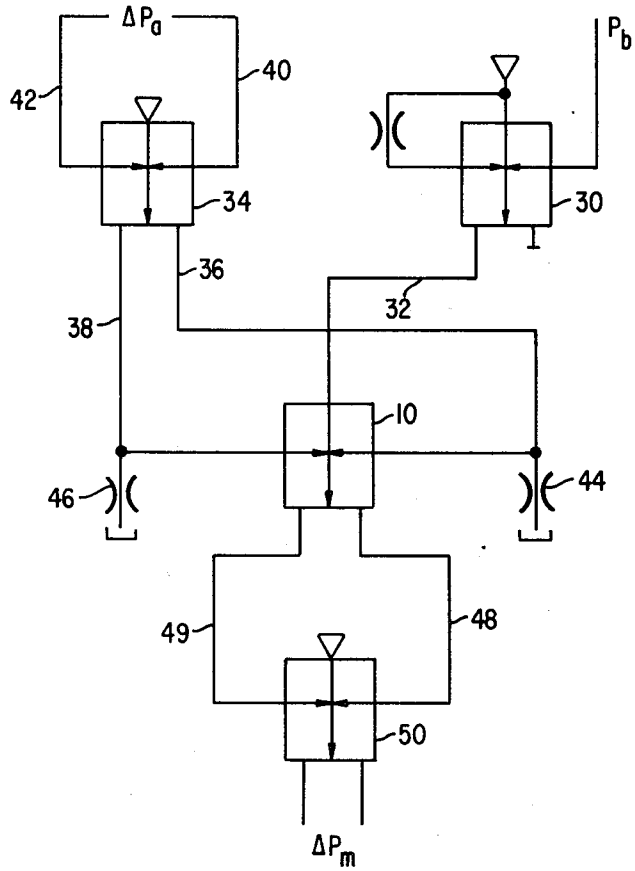
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Attorney, Agent, or Firm—Nathan Edelberg; Robert P. Gibson; Saul Elbaum

[57] **ABSTRACT**

A fluidic multiplier which comprises a proportional fluidic amplifier operated in the laminar region. The gain of the amplifier is proportional to the power jet pressure, thereby providing an output signal which is the product of the input signal and the supply pressure. A preconditioning and buffering circuit is also disclosed for linearizing and isolating the multiplier from other circuitry.

2 Claims, 10 Drawing Figures



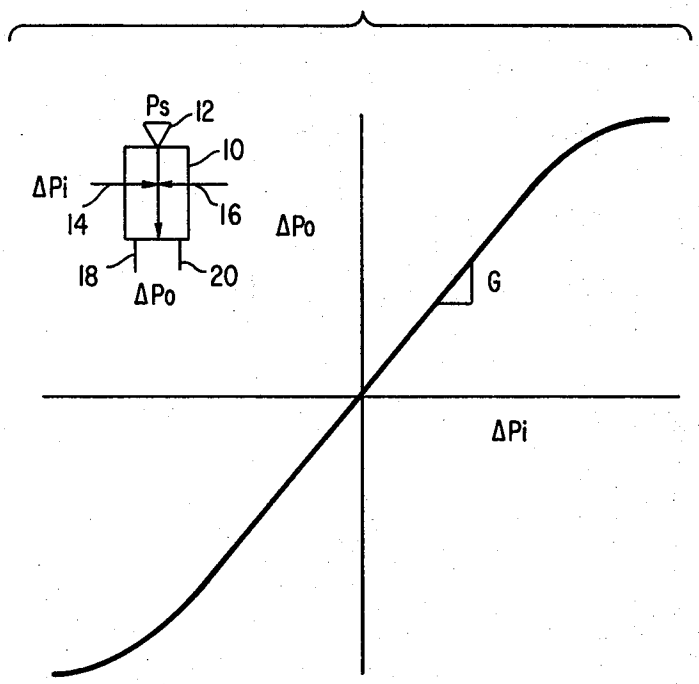

Ps
12
10
ΔPi
14
16
ΔPo
18
ΔPo
20
G
ΔPo
ΔPi

FIG. 1

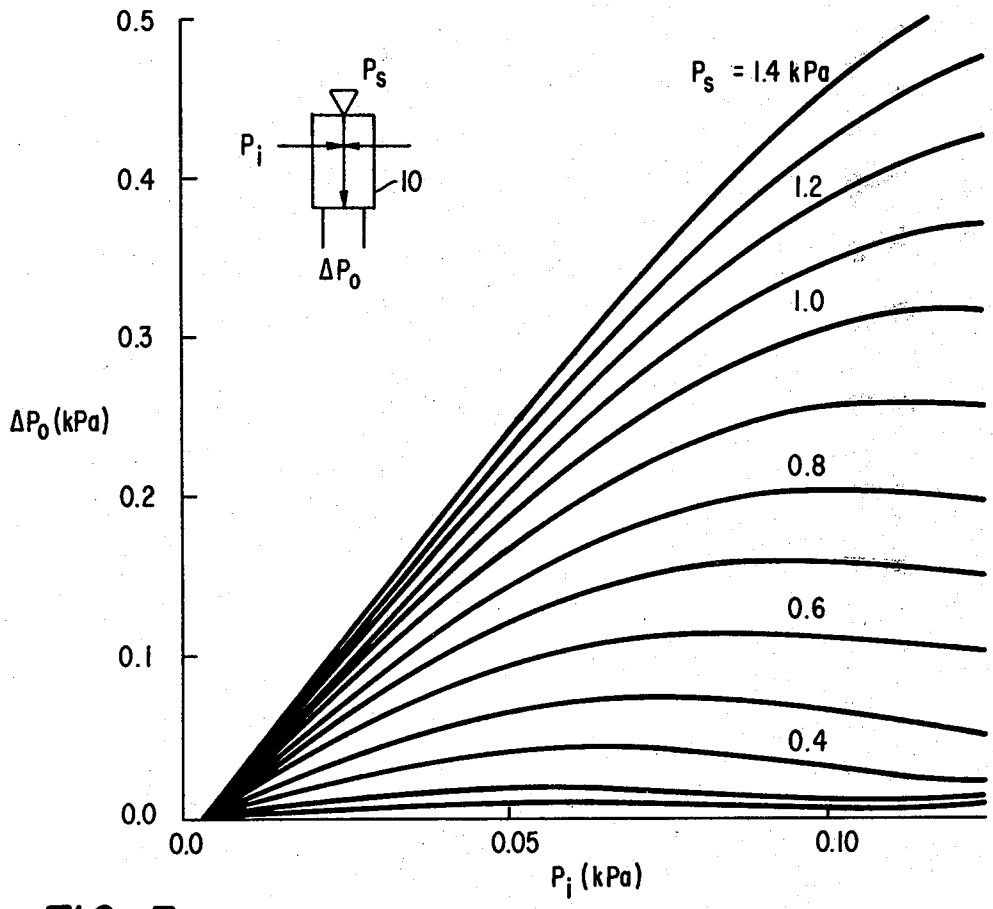

0.5
0.4
0.3
0.2
0.1
0.0
ΔP0 (kPa)
Ps
Pi
10
ΔP0
Ps = 1.4 kPa
1.2
1.0
0.8
0.6
0.4
0.0
0.05
0.10
Pi (kPa)

FIG. 3

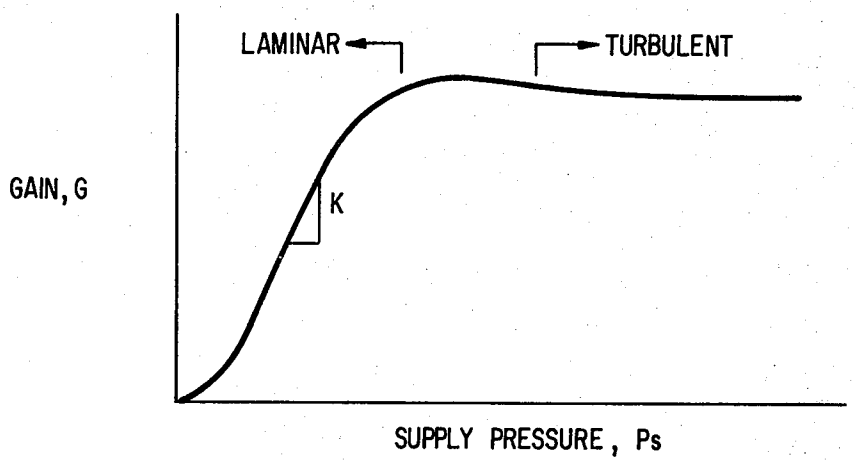

LAMINAR
TURBULENT
GAIN, G
K
SUPPLY PRESSURE, Ps

FIG. 2

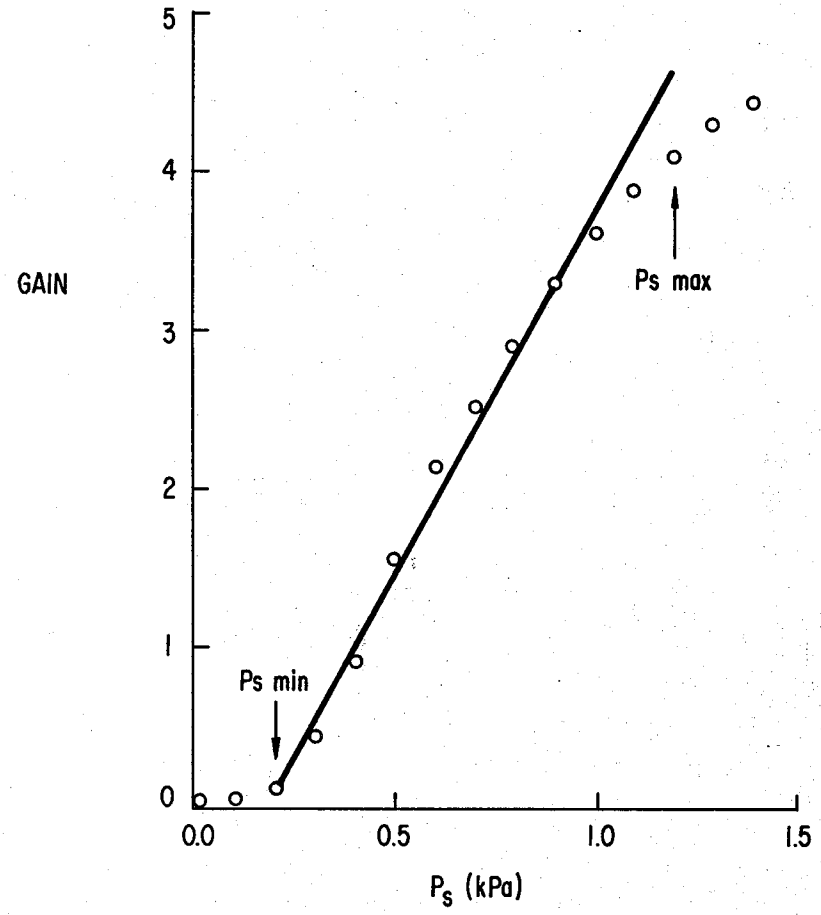

GAIN
5
4
3
2
1
0
Ps min
Ps max
0.0
0.5
1.0
1.5
Ps (kPa)

FIG. 4

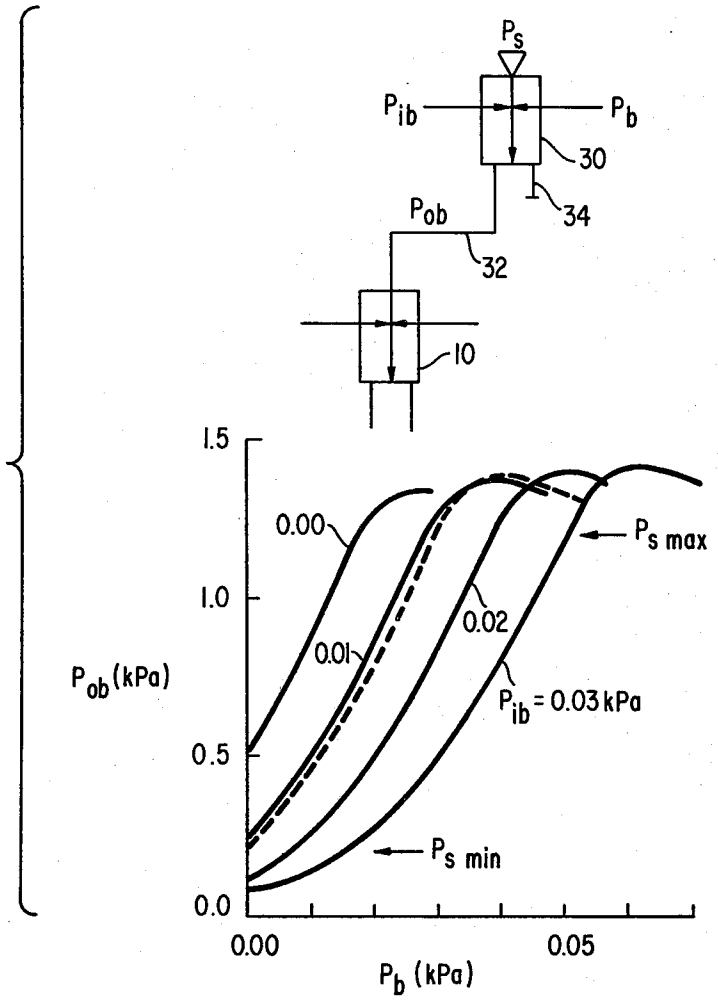

P_s
P_{ib}
P_b
30
34
P_{ob}
32
10
1.5
1.0
0.5
0.0
0.00
0.05
P_{ob} (kPa)
P_b (kPa)
0.00
0.01
0.02
P_{ib} = 0.03 kPa
P_s max
P_s min

FIG. 5

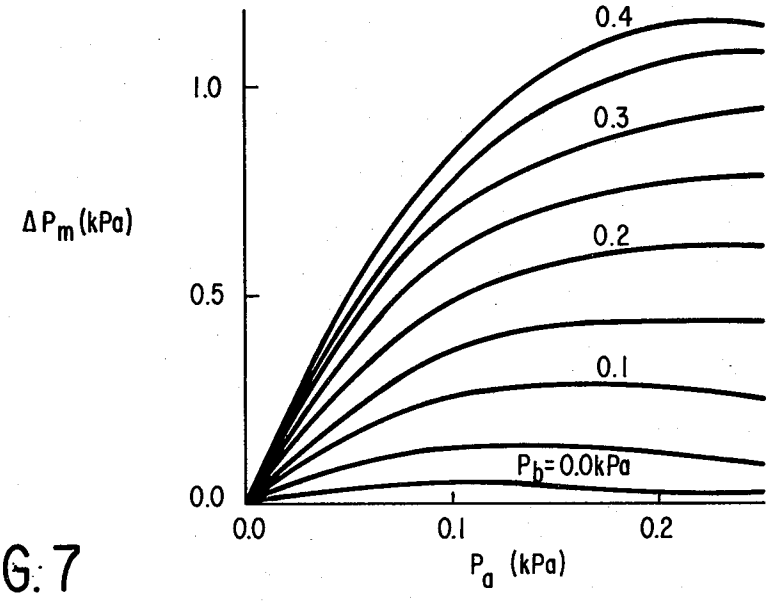

1.0
0.5
0.0
0.0
0.1
0.2
ΔP_m (kPa)
P_a (kPa)
0.4
0.3
0.2
0.1
P_b = 0.0 kPa

FIG. 7

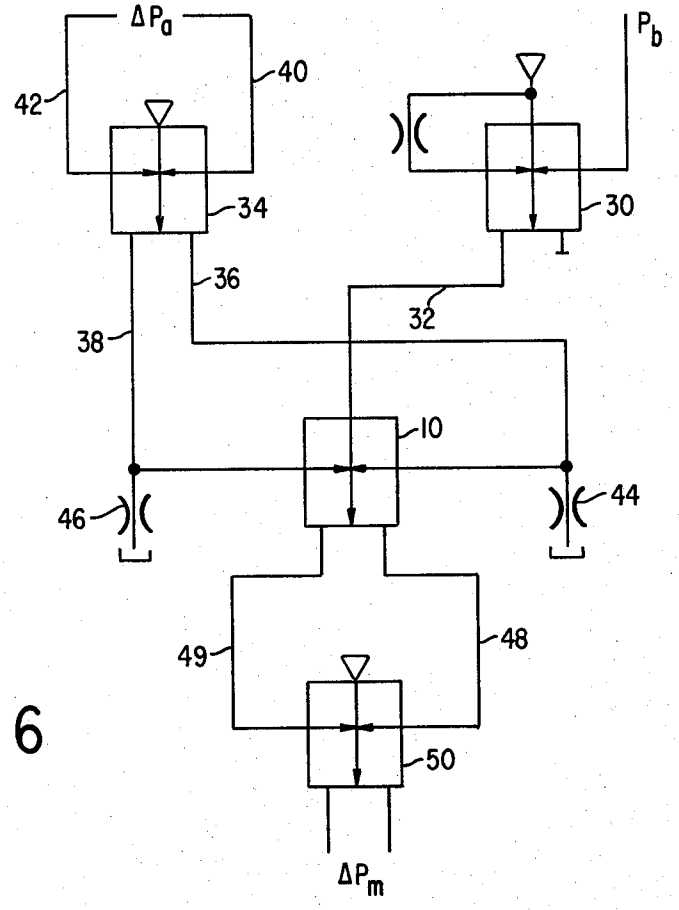

ΔPa
Pb
42
40
34
30
36
32
38
10
46
44
49
48
50
ΔPm

FIG. 6

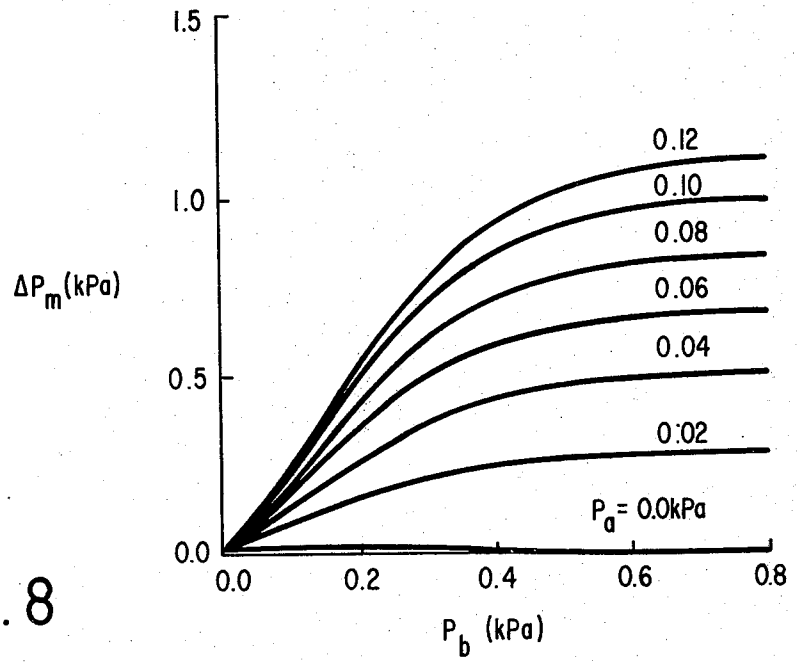

1.5
1.0
0.5
0.0
ΔPm(kPa)
0.12
0.10
0.08
0.06
0.04
0.02
Pa = 0.0kPa
0.0
0.2
0.4
0.6
0.8
Pb (kPa)

FIG. 8

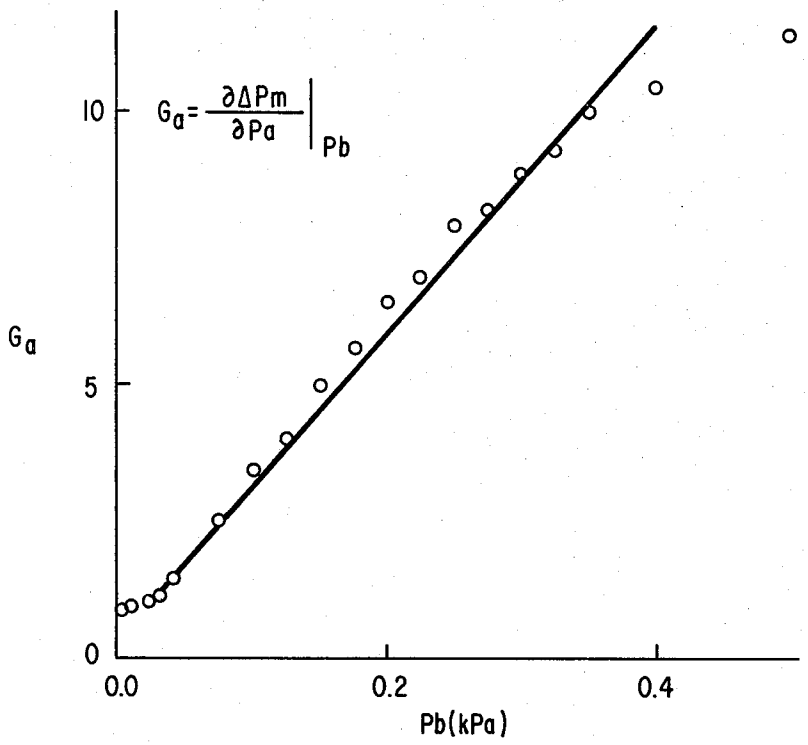

$G_a = \frac{\partial \Delta Pm}{\partial Pa}\Big|_{Pb}$
10
5
0
G_a
0.0
0.2
0.4
Pb(kPa)

FIG. 9

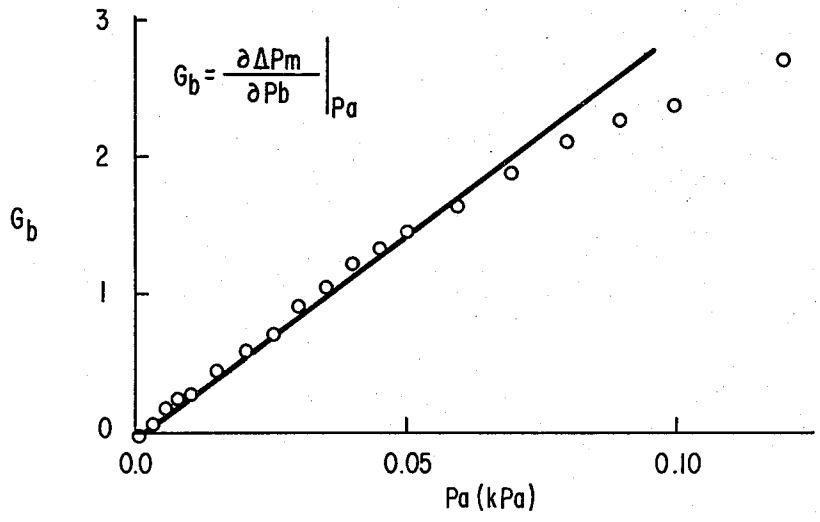

$G_b = \frac{\partial \Delta Pm}{\partial Pb}\Big|_{Pa}$
3
2
1
0
G_b
0.0
0.05
0.10
Pa (kPa)

FIG. 10

LAMINAR FLUIDIC MULTIPLIER

RIGHTS OF THE GOVERNMENT

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

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to fluidic amplifiers and, more particularly, to a fluidic amplifier operated as a gain changer or multiplier.

2. Description of the Prior Art

Multiplication or gain change is a function often required in fluidic computation and control circuits. Applications include the straight multiplication of two signals for computation purposes; the division of one signal by another which may be accomplished, for example, by placing a multiplier in the feedback loop of a high gain amplifier; function generation such as, for example, squaring; and gain change, i.e., varying the system gain for control purposes.

In spite of the great need for fluidic multipliers as evidenced by the foregoing requirements, prior art fluidic multipliers are lacking in performance, simplicity, and availability. Prior art approaches in the development of suitable fluidic multipliers have been to utilize inherent device characteristics or to build circuits which accomplish the desired effect. Most of the prior art devices fall into the category of gain changers since the second input decreases the gain of the device with increasing input. A true multiplier, however, increases gain with both inputs and has zero gain at zero input. Thus, a nonlinear inversion of the second input is generally required to convert gain changers into true multipliers.

One prior art approach as described in U.S. Pat. No. 3,638,671 achieves multiplication with the aid of moving parts. In this device, the differential output pressure is a function of the supply pressure and the position of a pin located in the interaction region. A pair of bellows are utilized to convert pressure to position. Such an arrangement, while generally sound, is disadvantageous when no moving parts are required. A quarter-square multiplier circuit is also known in the art (see, for example, U.S. Pat. No. 3,495,774) which again is generally workable, but is complex and lacking in linear range. Other prior art approaches to fluidic multipliers include U.S. Pat. Nos. 3,499,460; 3,530,870; and 3,687,150 in which a dual-differencing amplifier circuit is utilized in which the offset on nonlinear transfer curves determines the circuit gain. Such circuits reduce the gain to zero in an inverse manner, but also lack linearity and range.

OBJECTS AND SUMMARY OF THE INVENTION

It is accordingly a primary object of the present invention to provide a novel and unique fluidic amplifier which may be utilized as a gain changer or multiplier which overcomes the above-mentioned disadvantages of prior art fluidic multipliers.

Another object of the present invention is to provide a fluidic multiplier which has a greatly improved range over prior art devices and in which the gain is linearly proportional to the input supply pressure.

An additional object of the present invention is to provide a fluidic multiplier circuit having preconditioned inputs and a buffered output which increases the performance of the multiplier and isolates the same from the environment in which it is utilized.

The foregoing and other objects are achieved in accordance with one aspect of the present invention through the provision of a fluidic multiplier which comprises a proportional fluidic amplifier operated in the laminar region. It is shown that such an amplifier has an output signal which is the product of its input signal and the supply pressure, thereby allowing operation as a gain changer or multiplier. In accordance with another aspect of the present invention, a fluidic multiplier circuit is provided in which the fluidic multiplier has a pair of fluid amplifiers operating as signal preconditioners and an output fluid amplifier operating as a buffer by means of which improved performance and isolation may be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

Various objects, features and attendant advantages of the present invention will be more fully appreciated as the same becomes better understood from the following detailed description of the present invention when considered in connection with the accompanying drawings, in which:

FIG. **1** is a graph illustrating the output pressure versus the input pressure for a proportional amplifier;

FIG. **2** is a graph illustrating the gain versus the supply pressure for the proportional amplifier illustrated in FIG. **1**;

FIG. **3** is a graph illustrating the transfer characteristics of the proportional fluid amplifier of the present invention for various supply pressures;

FIG. **4** is a graph illustrating experimental results of the gain obtained for various supply pressures according to the present invention;

FIG. **5** illustrates preconditioning circuitry utilized in connection with the present invention and a graph helpful in understanding the operation thereof;

FIG. **6** illustrates a preferred embodiment of a fluidic multiplier circuit having preconditioning and output buffering in accordance with the present invention;

FIGS. **7** and **8** are graphs of the transfer characteristics of the circuitry of FIG. **6**; and

FIGS. **9** and **10** are graphs which illustrate the gain dependence of the circuitry illustrated in FIG. **6**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is illustrated at **10** a proportional fluidic amplifier having a power supply nozzle input **12**, a pair of signal inputs **14** and **16**, and output channels **18** and **20**. The graph illustrates the input pressure ΔP_i versus the output pressure ΔP_o, the slope of the curve representing the gain G and generally being linear. FIG. **2** illustrates for the amplifier **10** the gain dependence upon the supply pressure P_s. It is seen from FIG. **2** that when the amplifier **10** is operated in the turbulent region, the gain is constant. However, in the laminar region, the gain falls off to zero in an approximate straight line curve having a slope K. Although the gain dependence upon the supply pressure of proportional amplifier **10** when operated in the laminar region is a generally undesirable characteristic, such characteristic forms the basis of the present invention.

It may be observed from FIG. 1 that from the transfer characteristic

$$\Delta P_o = G \Delta P_i,$$

and, from FIG. 2, the gain-supply pressure characteristic

$$G = KP_s,$$

that the output signal ΔP_o is the product of the input signal ΔP_i and the supply pressure P_s, i.e.,

$$\Delta P_o = KP_s \Delta P_i.$$

The primary input, referred to hereinafter as signal A, comprises the input signal to the amplifier, while the secondary input, referred to hereinafter as signal B, comprises the amplifier's supply pressure. It is seen from FIG. 2 that in the laminar region the transfer gain can be changed almost linearly from zero to a maximum value with increasing supply pressure; thus, the proportional amplifier **10** operated in the laminar region according to the present invention may be utilized as either a multiplier or a gain changer. Mathematically speaking, a porportional amplifier **10** is operated in the laminar region when its supply pressure P_s has a Reynolds number R defined as follows:

$$R = \sqrt{\frac{2P_s}{\rho}} \frac{\omega}{\nu} < 1000$$

wherein P_s is the power supply pressure; ρ is the fluid density; w is the power nozzle width of amplifier **10**; and V is the kinematic viscosity.

FIG. 3 illustrates the transfer characteristics for various supply pressures obtained from a commercially available proportional amplifier **10** operated in the laminar region according to the present invention. The best mode of operation resulted from a center-vented proportional amplifier **10** having a power nozzle width of 0.5 millimeters (0.020 inches) and as aspect ratio of 0.5. The transfer characteristics illustrated in FIG. 3 attest to the linearity, low noise, and data consistency achieved according to the present invention.

FIG. 4 is a further graph of the small signal gain versus supply pressure of the device described in connection with FIG. 3. The curve depicted in FIG. 4 can be best characterized by a straight line having a slight offset. The points at which the curve deviate more than plus or minus 10 percent from the straight line (with offset) are designated P_s min and P_s max.

If precise computation is not required, the device described above in connection with FIGS. 3 and 4 serves well as a multiplier or as an excellent gain changer with no further modifications. It is possible, however to enhance the linearity and performance of the basic proportional amplifier in accordance with another aspect of the present invention. For optimum operation of the fluidic multiplier according to the present invention, the following three conditions should be met:

1. The gain versus power supply pressure curve (FIG. 4) should be offset to allow the gain curve to pass through zero;
2. The mean input level to the multiplier should be carefully staged to avoid unexpected gain degradation of the multiplier; and
3. The mean output level of the multiplier (which varies with supply pressure) should be held constant to avoid level sensitivity problems in suceeding stages.

Further, the input and output signal levels should be consistent with the fluidic circuitry in which the multiplier will be utilized.

The offsetting of the gain versus the power supply pressure curve may be accomplished by using a biased fluid amplifier **30** having single-sided transfer characteristics as seen in FIG. 5. One output **34** of preconditioning amplifier **30** is biased off, while the other output **32** is utilized as the supply pressure input to multiplier **10**. The supply pressure P_s of amplifier **30** is selected such that its output pressure P_{ob} at saturation is slightly greater than P_s max. The input bias signal P_{ib} of amplifier **30** is selected such that P_{ob} equals P_s min at a null input signal P_b. In this manner, the supply pressure P_{ob} to the multiplier **10** ranges from P_s min to P_s max as the input signal P_b varies from zero, thereby allowing the gain of multiplier **10** to be linearized with respect to P_b.

The connection of biased fluid amplifier **30** to the multiplier **10** of the present invention via line **32** is shown again in FIG. 6, which also illustrates a second preconditioning amplifier **34** which includes a pair of inputs **40** and **42** and a pair of outputs **36** and **38** which are respectively fed to the inputs of multiplier **10**. Preconditioning amplifier **34** is required to provide a predictable, low mean input level to multiplier **10** in order to isolate multiplier **10** from an arbitrary driving signal. Amplifier **34** operates with the same supply pressure as amplifier **30** and is also provided, by means of fluid resistors **44** and **46**, with a large attentuation of the output signal in order to match signal levels to the multiplier **10**.

Since the supply pressure via line **32** to multiplier **10** varies, the mean output level of the multiplier varies. Such a variation in mean output level may affect the gain of a succeeding stage. For proper staging, an output buffer amplifier **50** is provided to receive the output from multiplier **10** via lines **48** and **49**. The supply pressure and power nozzle of buffer amplifier **50** should be selected so that the maximum output signal from multiplier **10** is below saturation of buffer amplifier **50** in order to provide a low mean input level. The mean output level of buffer amplifier **50** will thus be constant, and normal staging techniques may be utilized to other circuitry.

The circuitry depicted in FIG. 6 has been tested experimentally and in a best mode utilizes amplifiers having 0.5 millimeter power nozzle widths with an aspect ratio of 0.5. The supply pressures, bias offset, and attenuation were selected in accordance with the above-mentioned criteria. The transfer characteristics of such a circuit for input channels A and B are shown respectively in FIGS. 7 and 8. It is seen from FIGS. 7 and 8 that the circuitry described in FIG. 6 can be used as a true multiplier since the circuit has zero gain with zero input in both channels A and B, while the gain increases linearly with respect to both inputs, better seen with reference to FIGS. 9 and 10. FIGS. 9 and 10 illustrate the experimental performance of the circuitry of FIG. 6 wherein the input range (range being the ratio of maximum signal to minimum signal in which there is less than 10 percent deviation from the linear approximation) of the A-channel (amplifier inputs) is greater than 50:1, while the B-channel (power supply) range is 20:1. Since all amplifiers were operated with laminar flow, signal noise was several hundred below the maximum signals.

It is seen that I have provided an extremely simple fluidic multiplier which utilizes the laminar flow char-

acteristics of a proportional amplifier to provide gain change or multiplication. The prior art disadvantages such as component nonlinearities, input signal inversion, and limited functional range have been overcome.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described herein.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A fluidic multiplier circuit, which comprises:

a proportional fluidic amplifier operated in the laminar region having a supply pressure input and a pair of signal inputs and a pair of outputs;

a biased fluid amplifier having a supply pressure, an output and a single-sided transfer characteristic, said output connected to said supply pressure input of said proportional fluidic amplifier; and

a preconditioning fluid amplifier having a supply pressure equal to that of said biased fluid amplifier and an output connected to said pair of signal inputs of said proportional fluidic amplifier.

2. The fluidic multiplier circuit according to claim 1, further comprising a buffer amplifier having a pair of inputs connected to said pair of outputs of said proportional fluidic amplifier, said buffer amplifier including means for providing a constant mean output level therefrom.

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