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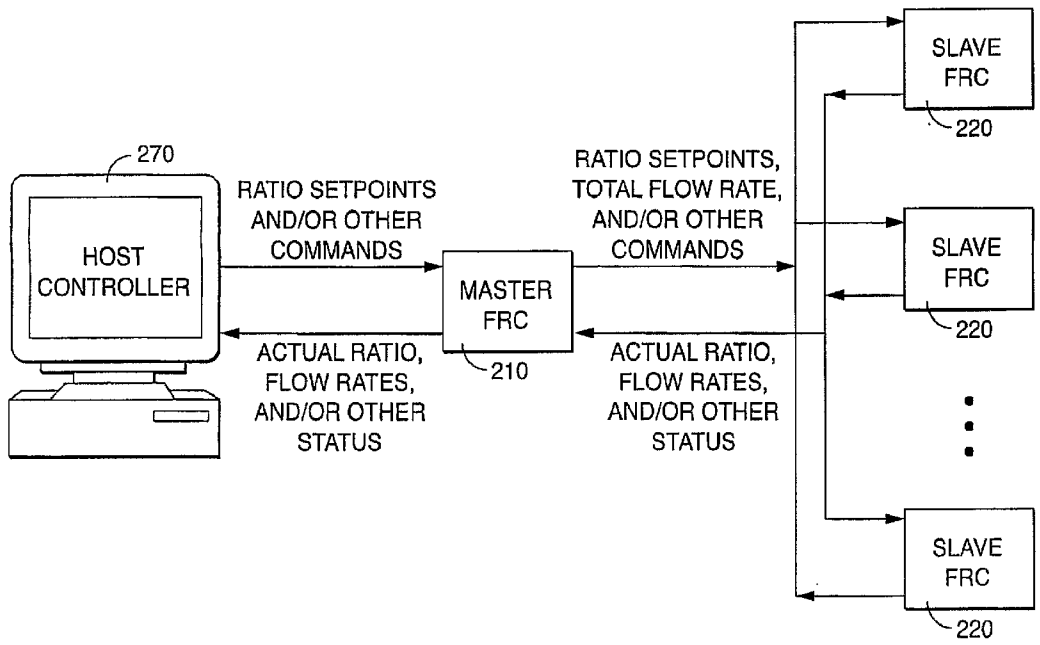
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(54) **Title:** MULTIPLE-CHANNEL FLOW RATIO CONTROLLER



(57) **Abstract:** A system for dividing a single mass flow into a plurality N of secondary flows includes an inlet configured to receive the single mass flow, a master FRC (flow ratio controller), and one or more slave FRCs. Each FRC is connected to the inlet and including at least one flow channel. The master FRC and the slave FRCs include in combination a total of N flow channels. Each flow channel i (i = 1,..., N) is connected to carry a corresponding one of the N secondary flows. In response to preselected ratio setpoints received from a host controller, the master FRC and the slave FRCs maintain ratios Q_i / Q_T (i = 1,..., N) between individual flow rates Qi (i = 1,..., N) and a total flow rate Q_T at the preselected ratio set points.

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Title

Multiple-Channel Flow Ratio Controller

BACKGROUND

[0001] In a number of applications, it may be necessary to deliver precise amounts of gases or other fluids to processing chambers and/or other processing facilities. These applications may include, but are not limited to, the fabrication of semiconductor systems.

[0002] For some applications, it may be necessary to divide or split combined process gases or other fluids among multiple processing facilities. Examples of flow splitting applications may include, but are not limited to, etching, stripping, and PECVD (Plasma Enhanced Chemical Vapor Deposition). In these cases, a single outlet of a gas box that contains the combined process gases may be connected to multiple chambers and/or processing facilities, through secondary flow channels.

[0003] An FRC (flow ratio controller) may be used to divide a primary flow among a plurality of secondary flow channels, in accordance with preselected ratios. A number of designs have been implemented for dual channel flow ratio controllers (DCFRCs), which split a single mass flow into two secondary flow channels.

[0004] In some applications, a multiple-channel flow ratio controller (MCRFC) may be needed in order to split a single mass flow into more than two secondary flows. In one approach, an MCFRC may be implemented by linking a number of DCFRCs in a cascaded configuration. The cascaded configuration may result in a high pressure drop across the MCFRC, however. Also, the cascaded set of DCFRCs may have a large footprint, and be costly. Further, the cascaded configuration for DCFRCs may constrain the total number N of flow channels to be $N = 2^n$, which may considerably decrease flexibility.

[0005] Accordingly, there is a need for improved systems and methods for implementing an MCFRC.

SUMMARY

[0006] A system for dividing a single mass flow into a plurality N of secondary flows includes an inlet configured to receive the single mass flow, and a master FRC and one or more slave FRCs connected to the inlet. The master FRC and the slave FRCs each include at least one secondary flow channel, and in combination include a number N of secondary flow channels. Each secondary flow channel i (i = 1, . . . , N) is connected to carry a corresponding one of the N secondary flows. The master FRC is configured to receive preselected ratio set points from a host controller, and to deliver to the slave FRCs the preselected ratio set points along with one or more command signals so that ratios Q_i / Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and a total flow rate Q_T can be maintained at the preselected ratio set points, where Q_i represents the individual flow rate in the secondary flow channel i, and Q_T represents a sum $Q_T = Q_1 + . . . + Q_i + . . . Q_N$ of all N individual flow rates.

[0007] A system for dividing a single mass flow into a plurality N of secondary flows includes an inlet configured to receive the single mass flow, a plurality N of secondary flow channels i (i = 1, . . . , N), and a controller. The N secondary flow channels are connected to the inlet, and are connected to carry corresponding ones of the N secondary flows. Each secondary flow channel i (i = 1, . . . , N) includes a flow sensor connected to measure a flow rate Q_i through the flow channel i, and a valve connected to regulate flow through the flow channel i in response to a control signal. The controller is configured to control the flow sensors and the valves in all of the N flow channels so as to maintain ratios Q_i/Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and a total flow rate Q_T at preselected ratio set points, where Q_i represent individual flow rates in corresponding flow channels i, and Q_T represents a sum $Q_T = Q_1 + . . . + Q_i + . . . Q_N$ of all N individual flow rates.

[0008] A gas delivery system includes a multiple-channel flow ratio controller (MCFRC) configured to divide a single gas flow into a plurality N of secondary flows. The MCFRC includes a master FRC (flow ratio controller), and one or more slave FRCs. Each FRC includes at least one flow channel, and is connected to an inlet configured to receive the single gas flow. The master FRC and the slave FRCs include in combination a total of N flow channels. Each flow

channel i (i = 1, . . . , N) is connected to carry a corresponding one of the N secondary flows. The master FRC is configured to receive preselected ratio set points from a host controller, and to deliver to the slave FRCs the preselected ratio set points along with one or more command signals so that the ratios Q_i / Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and a total flow rate Q_T can be maintained at preselected ratio set points, wherein Q_i represents individual flow rate in flow channel i, and Q_T represents a sum $Q_T = Q_1 + . . . + Q_i + . . . Q_N$ of all N individual flow rates.

[0009] A method of controlling flow in a plurality N of secondary flows that derive from a single mass flow includes connecting a master FRC and one or more slave FRCs to an inlet configured to receive the single mass flow. The master FRC and the slave FRCs include in combination a total of N flow channels, where each flow channel i (i = 1, . . . , N) is connected to carry a corresponding one of the N secondary flows. The master FRC and the slave FRCs maintain, in all of the N flow channels, ratios Q_i / Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and total flow rate Q_T at preselected ratio set points, where Q_i represents individual flow rate in flow channel i, and Q_T represents a sum $Q_T = Q_1 + . . . + Q_i + . . . Q_N$ of all N individual flow rates.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1A is a general block diagram of a gas delivery system that includes an MCFRC.

[0011] FIG. 1B shows a cascaded configuration for an MCFRC.

[0012] FIG. 2A is a general block diagram of an MCFRC that includes a master FRC and a plurality of slave FRCs linked in a parallel configuration through a digital communication network, in accordance with one embodiment of the present disclosure.

[0013] FIG. 2B illustrates in more detail one of the FRCs in the MCFRC illustrated in FIG. 2A.

[0014] FIG. 3 is a functional block diagram that illustrates the exchange of communications between a host computer, the master FRC, and the plurality of slave FRCs, in the MCFRC illustrated in FIG. 2A.

[0015] FIG. 4 is a general block diagram of an MCFRC that includes multiple flow channels and multiple control valves integrated within a single monolithic module, in accordance with another embodiment of the present disclosure.

DETAILED DESCRIPTION

[0016] A multiple-channel flow ratio controller (MCFRC) is described that includes a master FRC connected to one or more slave FRCs through a digital communication network. The master FRC, together with the slave FRCs, split an incoming flow into a plurality of secondary flows that have preselected flow ratios set by a host controller.

[0017] FIG. 1A is a general block diagram of a gas delivery system 102 that includes an MCFRC 106 configured to divide a single flow of gas Q_T into a plurality of secondary flows $Q_1, \ldots, Q_i, \ldots, Q_N$ having preselected ratios Q_i / Q_T. The MCFRC 106 receives individual gases or mixtures of multiple gases, which may be supplied from gas suppliers, for example gas tanks. The gas suppliers are shown in FIG. 1 using reference numerals 104-1, 104-2, . . . , 104-i, . . . , 104-M. A gas mixture may include, by way example, a number of different process gases and a purge gas. Many different gas mixtures may also be supplied.

[0018] A gas box 112 may deliver the individual gases or gas mixtures to the MCFRC 106, which in turn may deliver the secondary flows $Q_1, \ldots, Q_i, \ldots, Q_N$ to respective process chambers (not shown). Alternatively, the gases may be metered to different injectors or areas of a single process chamber and or other processing tools. The gas box 112 may include a plurality of gas sticks 114-1, . . . , 114-i, . . . , 114-M, each gas stick 114-i in fluid communication with a corresponding gas supplier 104-i.).

[0019] Each gas stick 114-i (i = 1, . . . , M) may individually control the flow of gas from the corresponding gas supplier 104-i (i = 1, . . , M). Each gas stick 114-i may include a mass flow controller (MFC). The MFCs for the gas sticks are illustrated in FIG. 1 as MFC_1, MFC_2, . . . , MFC_i, . . . , MFC_M within each gas stick. Each gas stick may also include a valve (not shown) positioned before and after the MFC, as described in U.S. Patent No. 6418954 for example. The gas sticks 114-i may each provide a controllable gas passageway so that a precisely metered amount of a gas (or a combination of gases) can be supplied to the MCFRC 106. The MCFRC 106 may then accurately split/divide the gas or combination of gases into secondary flows Q_i, each having preselected flow ratios Q_i / Q_T. The gas sticks 114-i may each be provided with other components (not shown) for monitoring or controlling gases, such as filters, purifiers, pressure transducers, and valve controllers.

[0020] The gas sticks 114-i may connect together, for example to an outlet manifold 116, to allow the gas flows from each stick to be mixed if desired prior to leaving the gas box 112. The outlet manifold 116 is connected to the MCFRC 106, as shown in FIG. 1.

[0021] The MCFRC 106 includes a plurality of secondary flow channels 122-1, . . . , 122-i, . . . , 122-N. Each secondary flow channel 122-i includes a flow sensor 124-i and a valve 126-i. The sensor 124-i measures the flow rate though the secondary flow channel 122-i, and generates a flow rate signal for use in controlling the valve 126-i, which regulates the mass flow through the secondary flow channel 122-i. The sensors 124-i and valves 126-i are thus used together to control the output mass flows Q_i in the secondary flow channels, and thus the flow ratios $a_i = Q_i/Q_T$, where Q_T is the sum of the flows in all N of the secondary flow channels, i.e. $Q_T = Q_1 + \ldots + Q_i + \ldots Q_N$. The outlets 130-1, . . . , 130-i, . . . , 130-N of each of the secondary flow channels may be connected to one or more corresponding processing chambers or other facilities (not shown).

[0022] A controller 136 for the MCFRC 106 may be configured to receive inputs α_i representing the preselected values or set points of the ratios of the flow rates Q_i through each of the flow channels 122-i with respect to the total flow rate Q_T. The controller 136 may be configured, among other things, to control and maintain the preselected ratios α_i at the preselected set points.

[0023] MCFRCs may be implemented by using DCFRCs as building blocks, in which case it may be possible to build upon the existing hardware and software in the DCFRCs. FIG. 1B illustrates an MCFRC 150 that builds upon DCFRCs by linking a plurality of DCFRCs 160 in a cascade configuration. The MCFRC 150 having the cascaded configuration may be easily implemented, with little or no modification to existing hardware or software. The MCFRC 150 may therefore be made readily available to customers using existing DCFRCs that are commercially available, including for example the Delta II FRCs manufactured by MKS Instruments, Inc. A cascaded set of DCFRCs may result, however, in an undesirably high pressure drop across the MCFRC. Each additional DCFRC that is added onto the cascade configuration would contribute to a corresponding increase in pressure drop across the MCFRC. A cascaded set of DCFRCs may also result in high costs and lack of flexibility for the consumer because the number of DCFRCs is greater than that of the parallel configuration which is discussed in the next paragraph.

[0024] In accordance with one embodiment of the present disclosure, illustrated in FIG. 2A, a master FRC 210 and a plurality of slave FRCs 220 are linked in a parallel configuration through a digital communication network. FIG. 2A is a general block diagram of an MCFRC 200 in which the master FRC 210 and the slave FRCs 220 are all connected to an inlet 205 configured to receive the single mass flow. The master FRC 210 and the slave FRCs 220 each include at least one secondary flow channel. In combination, the master FRC and the slave FRCs include a total of N secondary flow channels 222-i (i = 1, . . . , N). Each secondary flow channel 222-i (i = 1, . . . , N) is connected to carry a corresponding one of the N secondary flows.

[0025] In the exemplary embodiment illustrated in FIG. 2A, the master FRC 210 as well as all the slave FRCs 220 are shown as dual-channel FRCs that have two secondary flow channels each. The master FRC 210 is illustrated as

including secondary flow channels 222-1 and 222-2, respectively carrying secondary flows Q_1 and Q_2. The slave FRCs 220 are illustrated as each including two secondary flow channels 222-(j-1) and 222-j (where in the illustrated example j = 3, . . . , N, since the master FRC includes the first two flow channels 222-1 and 222-2).

[0026] Although the exemplary embodiment illustrates the master and the slave FRCs as having two secondary flow channels each, it should be understood that in other embodiments of the present disclosure, any number (including one) of secondary flow channels may be included by either the master FRC 210 or by any one of the secondary FRCs 220. Further, although the master FRC 210 is illustrated as including the first two flow channels 222-1 and 222-2, in other embodiments of the present disclosure, the master FRC 210 may include any different ones of the flow channels, including but not limited to flow channels 222-(j-1) and 222-j, and flow channels 222-(N-1) and 222-N.

[0027] A host controller 270, which may be a host computer for example, is configured to send the preselected flow ratio setpoints to the master FRC 210. The master FRC 210 delivers the flow ratio setpoints along with other control commands to the slave FRCs 220 so as to maintain ratios Q_i / Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and the total flow rate Q_T at preselected ratio set points, where Q_i represents the individual flow rate in flow channel i, and Q_T represents a sum $Q_T = Q_1 + \ldots + Q_i + \ldots Q_N$ of all N individual flow rates. The host controller 270 may query the status of the master FRC and/or the slave FRCs and the actual flow ratio in each flow channel i.

[0028] In one embodiment, the master FRC 210 and the slave FRCs 220 may be configured to communicate with each other and with the host controller 270 through a digital communications network. The network may include, but is not limited to, one or more of the following: Ethernet TCP/IP; UDP/IP; DeviceNet; CAN (Controller Area Network); RS-232; and RS-485. A digital communication bus 230, shown in FIG. 2A, enables communications between the master FRC 210 and the slave FRCs 220, or the master FRC 210 and the host controller 270.

[0029] FIG. 2B illustrates in more detail an exemplary one of FRCs that make up the MCFRC 200 illustrated in FIG. 2A. The FRC 300 shown in FIG. 2B is a dual-channel FRC 300 (although FRCs having a number of channels different from two may also be used). The FRC 300 may be either a master FRC or one of the slave FRCs in the MCFRC 200 shown in FIG. 2A, and includes secondary flow channels 322-i and 322-(i-1). Each secondary flow channel 322-i includes a flow sensor 324-i connected to measure flow through the corresponding flow channel 322-i, by analogy to the flow sensors 124-i illustrated in FIG. 1A. Each secondary flow channel 322-i further includes a valve 326-i connected to regulate the flow through the corresponding flow channel 322-i, by analogy to the valves 126-i illustrated in FIG. 1A.

[0030] The dual-channel FRC 300 further includes a valve controller 350 that is connected to the flow sensors and the valves in the dual-channel FRC 300, and that is configured to provide control signals to each valve in the dual-channel FRC 300, in response to the ratio set points from the host controller, so as to control mass flow in the corresponding flow channels until the ratios between the individual flow rates and Q_T satisfy the ratio set points for the corresponding flow channels.

[0031] FIG. 3 is a functional block diagram that illustrates in more detail the exchange of communications that may take place between the host controller 270, the master FRC 210, and the plurality of slave FRCs 220, in the MCFRC 300 illustrated in FIG. 2A. As seen in FIG. 3, each slave FRC 220 is configured to measure flow rates through its flow channels, and to communicate the measured flow rates to the master FRC. Each slave FRC 220 is further configured to compute actual ratios between the measured flow rates through its flow channels and the total flow rate Q_T, which the slave FRC 220 receives from the master FRC 210. Each slave FRC 220 also reports to the master FRC the actual ratios that it computed.

[0032] The master FRC 210 also measures flow rates through its flow channels. The master FRC 210 computes the total flow rate Q_T by summing the measured flow rates through its own flow channels, as well as all the flow rates measured by, and received from, all the slave FRCs 220.

[0033] The master FRC 210 is further configured to receive from the host controller 270 command signals that indicate what the preselected ratio set points are. The master FRC 210 then communicates to all the slave FRCs 220 the total flow rate Q_T and the preselected ratio set points.

[0034] The master FRC 210 and each one of the slave FRCs 220 are responsive to the preselected ratio set points, as contained in the command signals from the host controller 270, to control mass flow through their respective flow channels until all of the ratios Q_i / Q_T (i = 1, . . . , N) satisfy the preselected ratio set points.

[0035] The master FRC 210 can be further configured to report to the host controller 270 the measured flow rates and the actual ratios that the master FRC 210 has received from each slave FRC.

[0036] FIG. 4 is a general block diagram of another embodiment of an MCFRC 400 configured to divide a single incoming mass flow Q_T into a plurality N of secondary flows Q_i (i = 1, . . . , N). In this embodiment, the MCFRC 400 includes multiple flow channels and multiple control valves that are all integrated within a single monolithic module, without a master-slave configuration described above in conjunction with FIGs. 2A, 2B, and 3. The MCFRC 400 includes an inlet 405 configured to receive an incoming single mass flow Q_T, and a plurality N of secondary flow channels 422-i (i = 1, . . . , N) connected to the inlet 405.

[0037] Each secondary flow channel 422-i in the MCFRC 400 is connected to carry a corresponding one of the N secondary flows Q_i (i = 1, . . . , N). Each flow channel 422-i (i = 1, . . . , N) includes a flow sensor 424-i connected to measure a flow rate Q_i through the flow channel i, and a valve 426-i connected to regulate flow through the flow channel i in response to one or more control signals from a controller 470.

[0038] The controller 470 is configured to control the flow sensors 424-i and the valves 426-i in all of the N flow channels 422-i so as to maintain ratios Q_i/Q_T (i = 1, . . . , N) between the individual flow rates Q_i (i = 1, . . . , N) in each flow channel and the total flow rate Q_T at preselected ratio set points α_i. As in previously described embodiments of an MCFRC, Q_i represents individual flow

rates in corresponding flow channels i, and Q_T represents a sum $Q_T = Q_1 + \ldots + Q_i + \ldots Q_N$ of all N individual flow rates. As also previously described, the preselected ratio set points α_i may be input into the computer by a customer, or other user or operator.

[0039] In sum, systems and methods have been described for multiple-channel flow ratio control. The systems and methods described above can be used in numerous applications, including but not limited to etching, stripping, and PECVD (Plasma Enhanced Chemical Vapor Deposition). The master-slave configuration for an MCFRC, described above in conjunction with FIG.s 2A, 2B, and 3, provides a cost-efficient and flexible method and system for multiple-channel flow ratio control. With this configuration, the total number N of secondary flow channels may be either fixed or variable. Compared to a cascaded configuration, the master-slave configuration may also substantially reduce footprint.

[0040] While certain embodiments have been described of systems and methods for multiple-channel flow ratio control, it is to be understood that the concepts implicit in these embodiments may be used in other embodiments as well. The protection of this application is limited solely to the claims that now follow.

[0041] In these claims, reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." All structural and functional equivalents to the elements of the various embodiments described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference, and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public, regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 U.S.C. §112, sixth paragraph, unless the element is expressly recited using the phrase "means for" or, in the case of a method claim, the element is recited using the phrase "step for."

What is claimed is:

1. A system for dividing a single mass flow into a plurality N of secondary flows, the system comprising:

an inlet configured to receive the single mass flow;

a master FRC (flow ratio controller) and one or more slave FRCs, each FRC connected to the inlet and including at least one secondary flow channel;

wherein the master FRC and the slave FRCs in combination include a number N of secondary flow channels, each flow channel i (i = 1, . . . , N) connected to carry a corresponding one of the N secondary flows; and

wherein the master FRC is configured to receive preselected ratio set points from a host controller, and to deliver to the slave FRCs the preselected ratio set points along with one or more command signals so that ratios Q_i / Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and a total flow rate Q_T can be maintained at the preselected ratio set points, where Q_i represents individual flow rate in flow channel i, and Q_T represents a sum $Q_T = Q_1 + \ldots + Q_i + \ldots Q_N$ of all N individual flow rates.

2. The system of claim 1,

wherein the master FRC is configured to compute the total flow rate Q_T by summing the N individual flow rates Q_i (i = 1, . . . , N) through corresponding flow channels i (i = 1, . . . , N), and communicate to all the slave FRCs the total flow rate Q_T and the ratio set points; and

wherein the master FRC and each slave FRC are responsive to the ratio set points from the host controller to control mass flow through their respective flow channels until all of the ratios Q_i / Q_T (i = 1, . . . , N) satisfy the ratio set points.

3. The system of claim 2,

wherein each slave FRC is configured to measure flow rates through its flow channels, and to communicate the measured flow rates to the master FRC; and

wherein each slave FRC is further configured to compute actual ratios between the measured flow rates through its flow channels and the total flow rate Q_T received from the master FRC, and to report the actual ratios to the

master FRC.

4. The system of claim 3,

wherein the master FRC is further configured to report to the host controller the measured flow rates and the actual ratios from each slave FRC.

5. The system of claim 2, wherein the master FRC is further configured to measure flow rates through the flow channels in the master FRC, and to compute the total flow rate Q_T by summing the measured flow rates through the flow channels in the master FRC with the flow rates measured by and received from all the slave FRCs.

6. The system of claim 1, wherein the master FRC and the slave FRCs are dual-channel FRCs, each dual channel FRC respectively including two of the N flow channels.

7. The system of claim 1,

wherein each flow channel i (i = 1, . . . , N) includes:

a flow sensor connected to measure flow through the flow channel i; and

a valve connected to regulate flow through the flow channel i.

8. The system of claim 7, wherein each FRC includes a valve controller connected to the flow sensors and the valves in that FRC, the valve controller configured to provide a control signal to each valve in that FRC, in response to the ratio set points from the host controller, so as to control mass flow in the corresponding flow channels until the ratios between the individual flow rates and Q_T satisfy the ratio set points for the corresponding flow channels.

9. The system of claim 1, further comprising a digital communication bus, and wherein the master FRC and the slave FRCs are further configured to communicate with each other and with the host controller through the digital communication bus.

10. The system of claim 9, wherein the digital communication bus is connected to a network that comprises at least one of: Ethernet TCP/IP; UDP/IP; DeviceNet; CAN (Controller Area Network); RS-232; and RS-485.

11. The system of claim 1, wherein the number N of flow channels is fixed.

12. The system of claim 1, wherein the number N of flow channels is variable.

13. The system of claim 1, wherein the master FRC and the slave FRCs are connected to each other in a parallel configuration.

14. A system for dividing a single mass flow into a plurality N of secondary flows, the system comprising:

an inlet configured to receive the single mass flow;

a plurality N of secondary flow channels i (i = 1, . . . , N) connected to the inlet and connected to carry corresponding ones of the N secondary flows, each flow channel i (i = 1, . . . , N) including a flow sensor connected to measure a flow rate Q_i through the flow channel i, and a valve connected to regulate flow through the flow channel i; and

a controller configured to control the flow sensors and the valves in all of the N flow channels so as to maintain ratios Q_i/Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and a total flow rate Q_T at preselected ratio set points, wherein Q_i represent individual flow rates in corresponding flow channels i, and Q_T represents a sum $Q_T = Q_1 + \ldots + Q_i + \ldots Q_N$ of all N individual flow rates.

15. The system of claim 14, wherein the inlet, the plurality N of secondary flow channels, and the controller are integrated within a single monolithic module.

16. The system of claim 14, wherein the plurality N of secondary flow channels are connected to each other in a parallel configuration.

17. A gas delivery system including a multiple-channel flow ratio controller configured to divide a single gas flow into a plurality N of secondary flows, wherein the multiple-channel flow ratio controller includes:

a master FRC (flow ratio controller) and one or more slave FRCs, each FRC including at least one flow channel and connected to an inlet configured to receive the single gas flow, wherein the master FRC and the slave FRCs include

in combination a total of N flow channels, and wherein each flow channel i (i = 1, . . . , N) is connected to carry a corresponding one of the N secondary flows; and

wherein the master FRC is configured to receive preselected ratio set points from a host controller, and to deliver to the slave FRCs the preselected ratio set points along with one or more command signals so that the ratios Q_i / Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and a total flow rate Q_T can be maintained at preselected ratio set points, wherein Q_i represents individual flow rate in flow channel i, and Q_T represents a sum $Q_T = Q_1 + \ldots + Q_i + \ldots Q_N$ of all N individual flow rates.

18. A method of controlling flow in a plurality N of secondary flows that derive from a single mass flow, the method comprising:

connecting a master FRC and one or more slave FRCs to an inlet configured to receive the single mass flow, the master FRC and the slave FRCs including in combination a total of N flow channels, each flow channel i (i = 1, . . . , N) connected to carry a corresponding one of the N secondary flows; and

the master FRC and the slave FRCs maintaining, in all the flow channels, ratios Q_i / Q_T (i = 1, . . . , N) between individual flow rates Q_i (i = 1, . . . , N) and total flow rate Q_T at preselected ratio set points, wherein Q_i represents individual flow rate in flow channel i, and Q_T represents a sum $Q_T = Q_1 + \ldots + Q_i + \ldots Q_N$ of all N individual flow rates.

19. The method of claim 18, wherein the act of the master FRC and the slave FRC maintaining the ratios at the preselected ratio set points further comprises:

the master FRC controlling flow through its flow channels until the ratios between the individual flow rates through the flow channels of the master FRC and Q_T satisfy the ratio set points for these flow channels; and

the master FRC transmitting one or more command signals to the slave FRCs, so that the slave FRCs control flow through their respective flow channels until the ratios between the individual flow rates through the flow channels of the slave FRCs and Q_T satisfy the ratio set points for these flow channels.

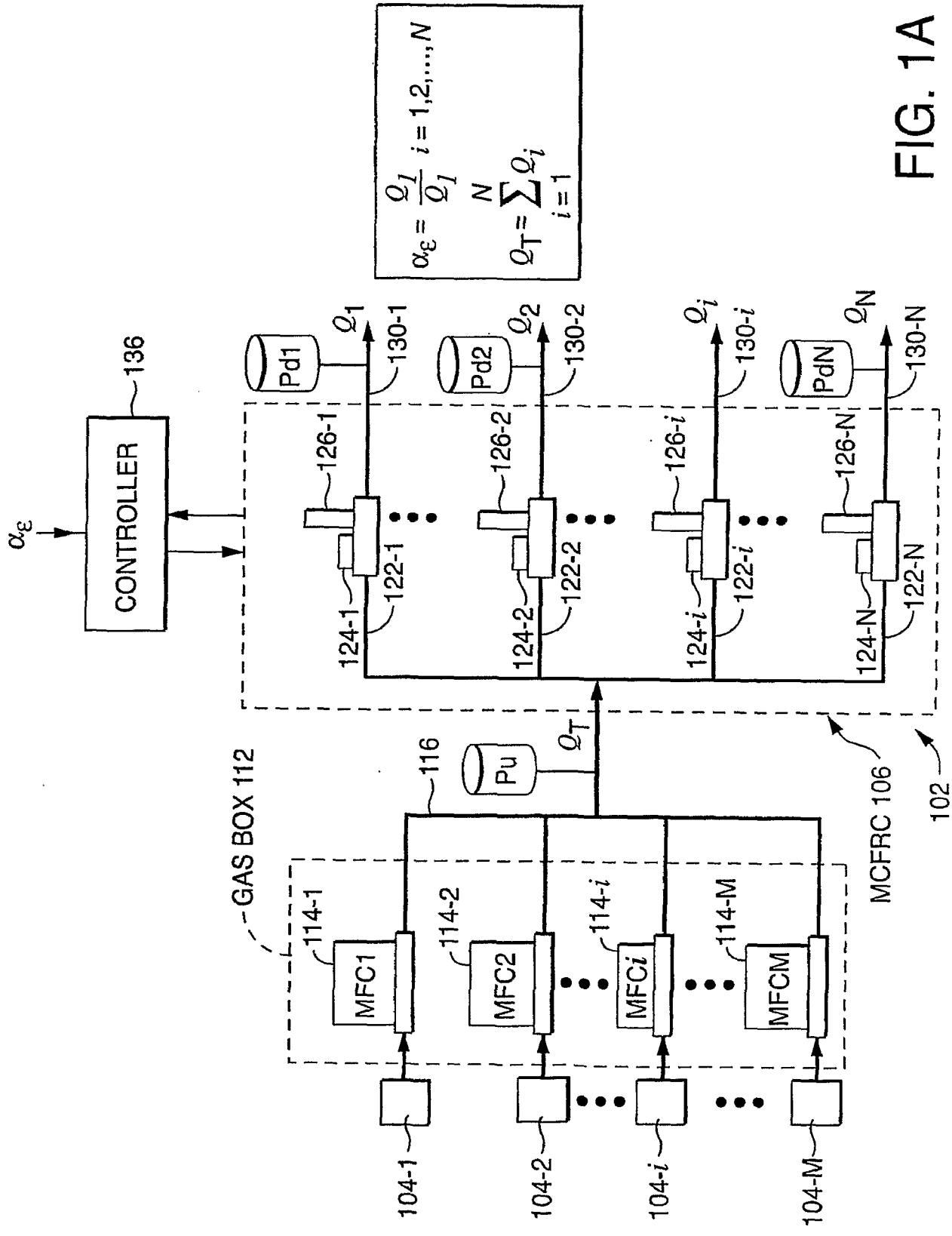

$\alpha_\varepsilon = \frac{Q_1}{Q_1}$ $i = 1,2,...,N$
$Q_T = \sum_{i=1}^{N} Q_i$
136
CONTROLLER
α_ε
GAS BOX 112
MCFRC 106
102
116
Pu
Q_T
Pd1
Pd2
PdN
Q_1
Q_2
Q_i
Q_N
130-1
130-2
130-i
130-N
126-1
126-2
126-i
126-N
122-1
122-2
122-i
122-N
124-1
124-2
124-i
124-N
114-1
114-2
114-i
114-M
MFC1
MFC2
MFCi
MFCM
104-1
104-2
104-i
104-M

FIG. 1A

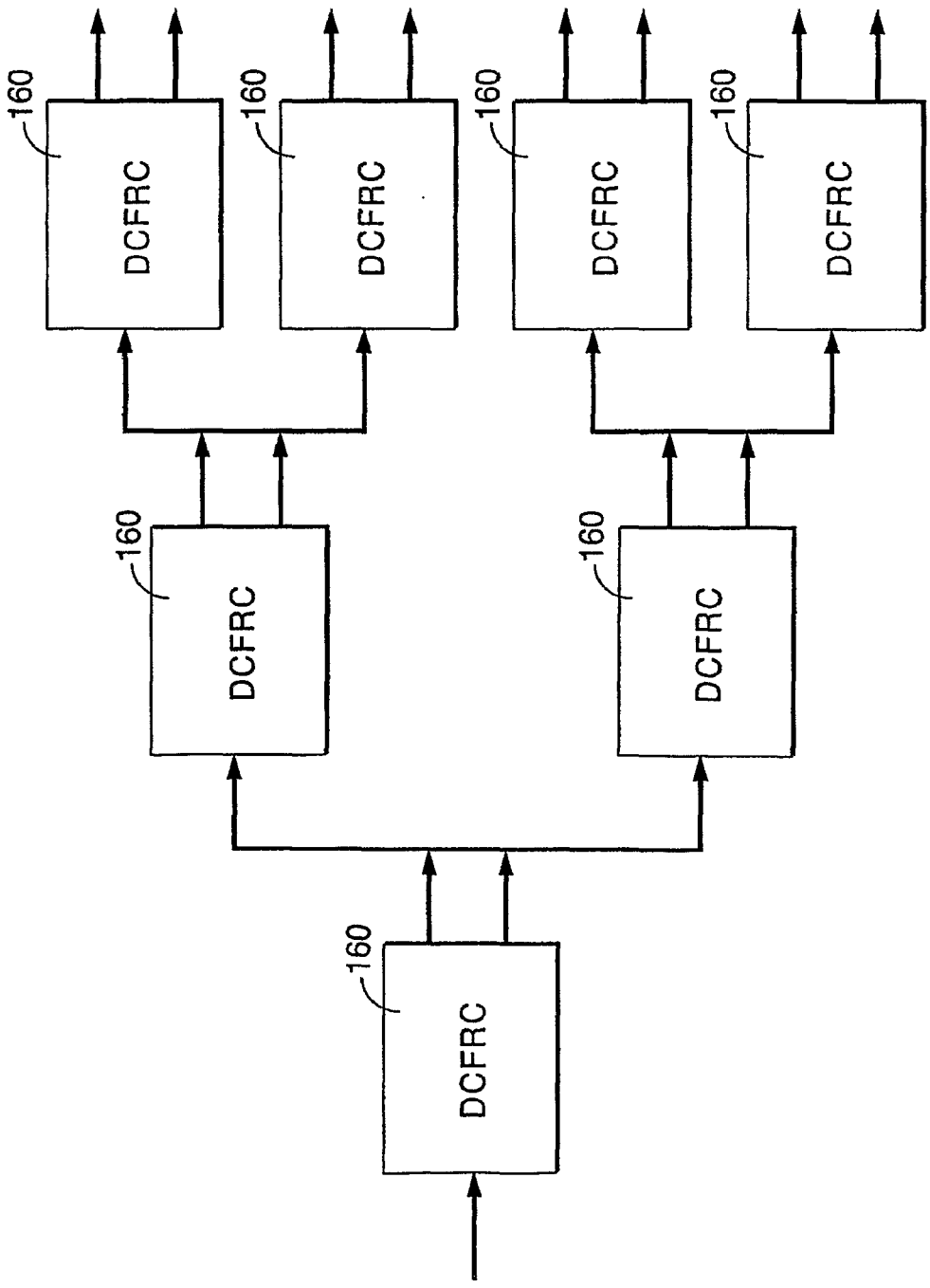

160
DCFRC
160
DCFRC
160
DCFRC
160
DCFRC
160
DCFRC
160
DCFRC
160
DCFRC
MCFRC 150

FIG. 1B

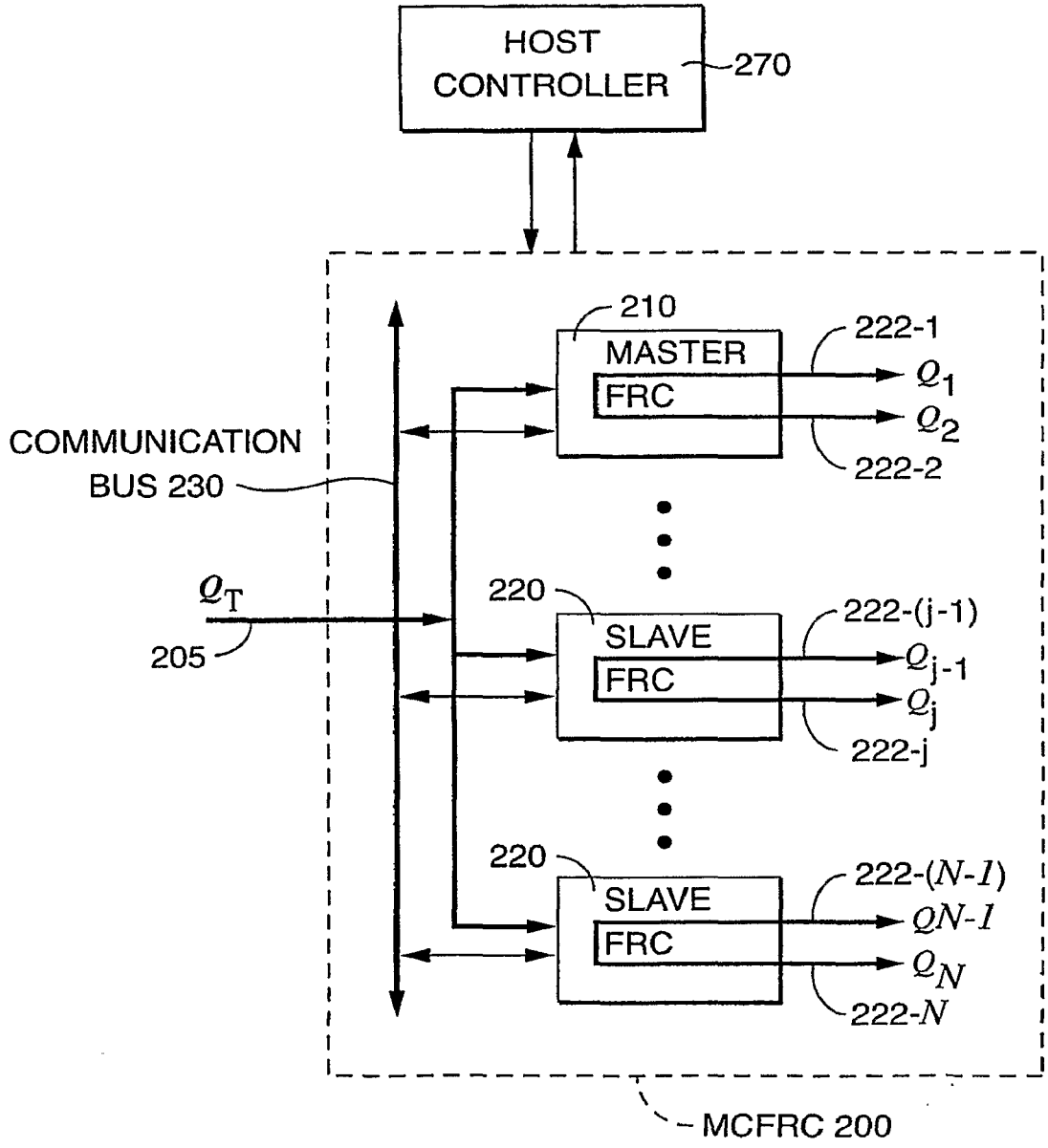

HOST CONTROLLER
270
210
MASTER
FRC
222-1
Q_1
Q_2
222-2
COMMUNICATION BUS 230
Q_T
205
220
SLAVE
FRC
222-(j-1)
Q_{j-1}
Q_j
222-j
220
SLAVE
FRC
222-(N-1)
Q_{N-1}
Q_N
222-N
MCFRC 200

FIG. 2A

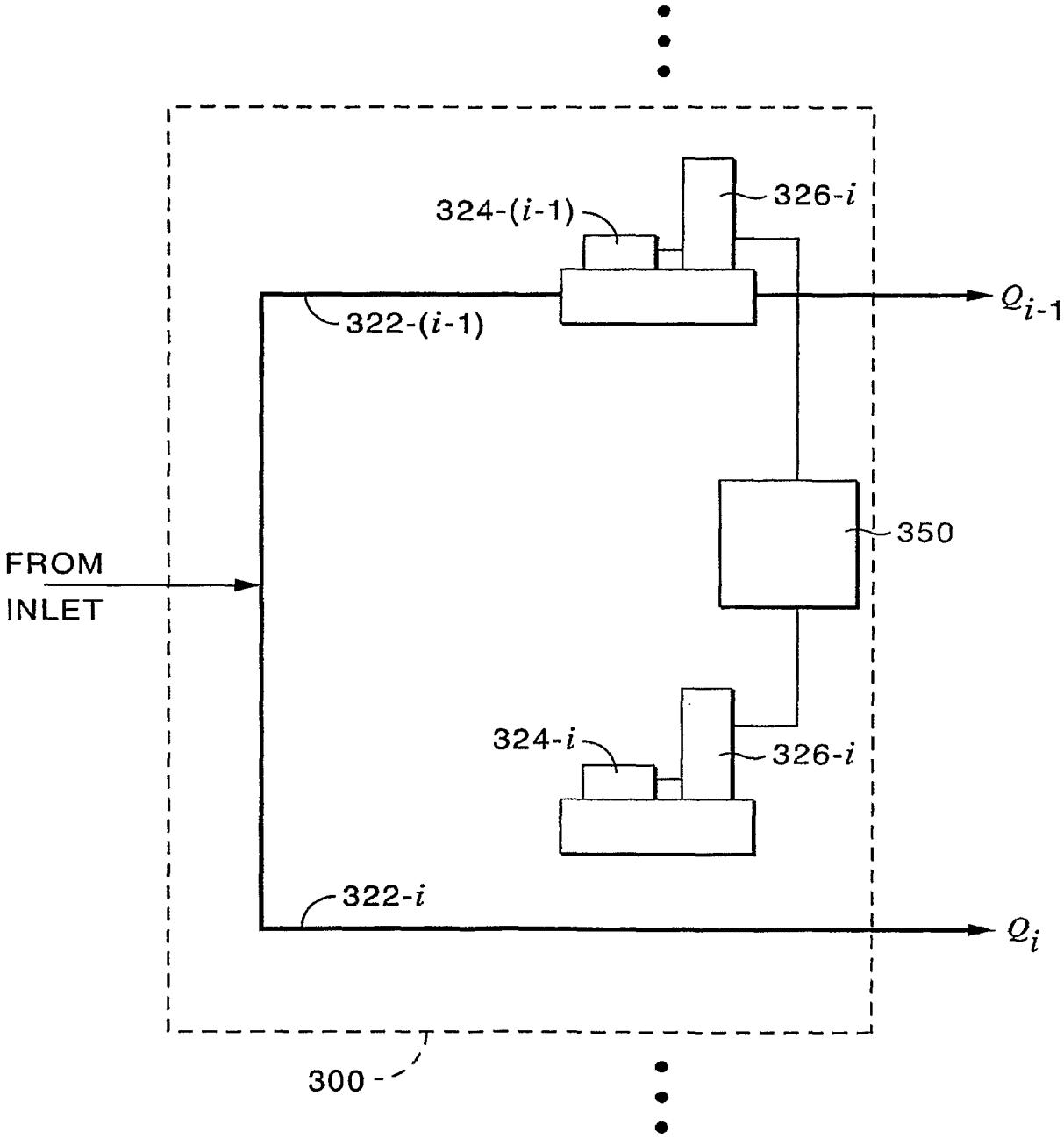


FIG. 2B

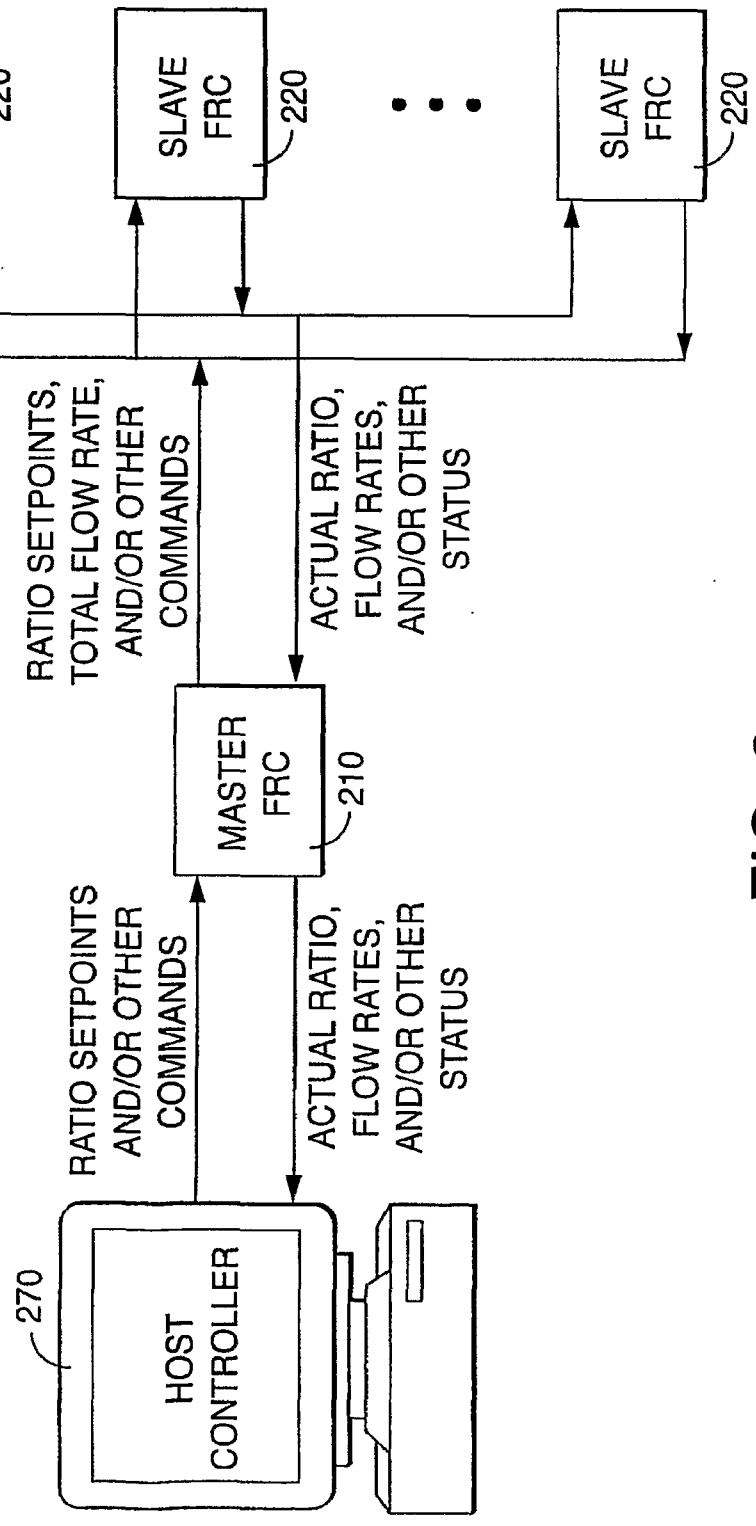

SLAVE FRC
220
SLAVE FRC
220
SLAVE FRC
220
RATIO SETPOINTS, TOTAL FLOW RATE, AND/OR OTHER COMMANDS
ACTUAL RATIO, FLOW RATES, AND/OR OTHER STATUS
MASTER FRC
210
RATIO SETPOINTS AND/OR OTHER COMMANDS
ACTUAL RATIO, FLOW RATES, AND/OR OTHER STATUS
270
HOST CONTROLLER

FIG. 3

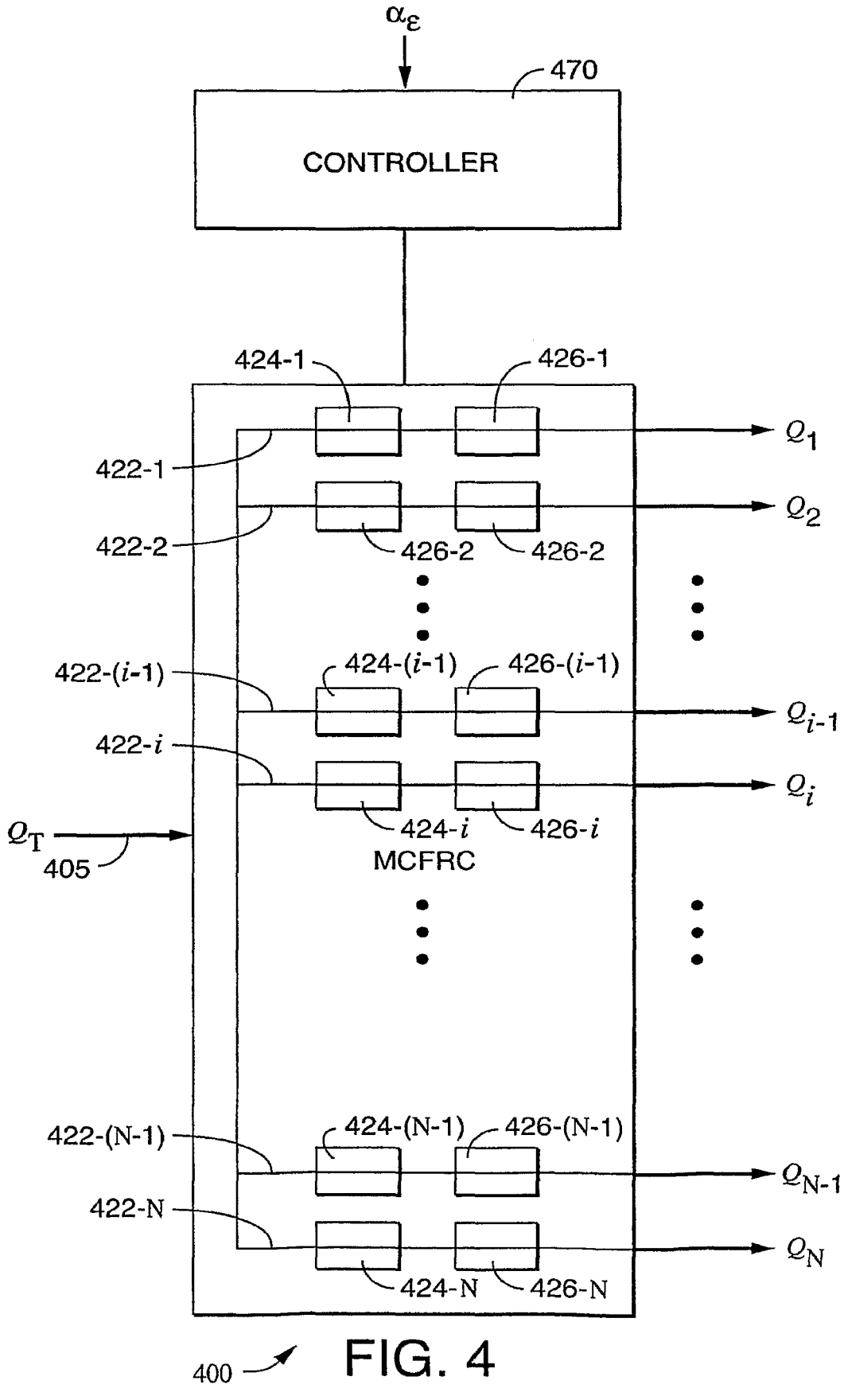

α_ε
470
CONTROLLER
424-1
426-1
422-1
422-2
Q_1
Q_2
426-2
426-2
422-(i-1)
422-i
424-(i-1)
426-(i-1)
Q_{i-1}
Q_i
Q_T
405
424-i
426-i
MCFRC
422-(N-1)
422-N
424-(N-1)
426-(N-1)
Q_{N-1}
Q_N
424-N
426-N
400

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/005429

A. CLASSIFICATION OF SUBJECT MATTER
INV. G05B19/43 G05D11/13

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G05B G05D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 333 272 B1 (MCMILLIN BRIAN K [US] ET AL) 25 December 2001 (2001-12-25) figure 3 column 4, lines 1-37 column 5, line 65 - column 7, line 56	1-19
X	WO 02/095519 A (UNIT INSTR INC [US]; LULL JOHN M [US]; VALENTINE WILLIAM S [US]) 28 November 2002 (2002-11-28) abstract page 1, line 24 - page 2, line 21 page 7, line 16 - page 10, line 25	1-19

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2007	27/07/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Schriefl, Josef

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2007/005429

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 369 031 A (GOLDMAN JON C ET AL) 18 January 1983 (1983-01-18) figures 1,5. column 2, lines 20-28 column 3, line 62 - column 4, line 33 column 5, line 21 - column 8, line 29	1,7-19
X	US 2003/130807 A1 (AMBROSINA JESSE [US] ET AL) 10 July 2003 (2003-07-10) the whole document	14-16
A	US 6 418 954 B1 (TAYLOR MATTHEW THOMAS [US] ET AL) 16 July 2002 (2002-07-16) cited in the application the whole document	1-19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2007/005429

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-13,17-19

   System for dividing a single mass flow into a plurality of secondary flows, the system comprising a master flow ratio controller and one or more slave flow ration controllers

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2. claims: 14-16

   System for dividing a single mass flow into a plurality of secondary flows, each flow channel comprising a flow sensor and a valve connected to regulate flow though the flow channel

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2007/005429

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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