A Compact Mass Flow Controller with Improved Noise Resistance, Designed for Mounting on Manufacturing Equipment

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In the factory automation (FA) market, cost and size are often more important than performance and functions for mass flow controllers that are mounted on manufacturing equipment. To meet this market demand, we have developed a low-cost, compact, and easy-to-use mass flow controller that provides performance and functions suitable for mounting on equipment. Its noise resistance is substantially better than that of existing product lines, and it is not affected by noise even if the source is nearby.

1. Introduction

Mass flow controllers have mainly been used for process gas flow control in semiconductor production. Against the backdrop of the recent increase in the need for automation for quality stabilization, higher efficiency, and energy conservation, mass flow controllers have also been applied in the general industrial market for uses, such as burner air-fuel ratio control for glass processing and brazing and atmospheric gas control in industrial furnaces.

We market digital mass flow controllers that combine an ultrafast response flow rate sensor and a proportional valve. Two varieties are sold, an advanced-function controller*1 and a low-price controller*2. In the FA market, however, in some cases neither type is suitable for use with manufacturing equipment because of cost or required specifications.

To meet market demand, we developed a low-cost, compact, and easy-to-use mass flow controller, model F4H, which provides performance and functions suitable for mounting on equipment. The F4H controller utilizes the characteristics of the ultrafast response flow rate sensor, thereby achieving a fast response that takes a settling time of only 0.3 seconds (typ.) to reach a state with a flow rate within ±2 % FS of the set flow rate from the fully closed state. In addition, its noise resistance performance has been greatly improved in comparison with conventional controllers, and it is not affected by nearby noise sources. We also considered design unification and the use of common hardware and firmware for flowmeter products when developing model F4H controllers.

This paper introduces the F4H and describes its characteristics, reporting results that confirm its fast response and noise resistance performance.

Fig. 1. External view of an F4H series mass flow controller

*1 Digital mass flow controller model MQV□□□□
*2 Panel-mount mass flow controller model MPC□□□□

2. Overview of F4H Series Mass Flow Controllers

Fig. 1 shows the appearance of the F4H, and Table 1 lists its basic specifications.

Table 1. Basic specifications of the F4H compact digital mass flow controller

Valve system	Solenoid proportional valve (normally closed)
Full-scale flow (equivalent nitrogen amounts)	F4H9050: 50.00 mL/min (normal) F4H9200: 200.0 mL/min (normal) F4H9500: 500.0 mL/min (normal) F4H0002: 2.000 L/min (normal) F4H0005: 5.000 L/min (normal) F4H0020: 20.00 L/min (normal) Note: The above values expressed in L/min (normal) are volumetric flow rates at 0 °C and 1 atmosphere.
Applicable gas types	Air/nitrogen, oxygen, argon, carbon dioxide, hydrogen, and helium
Response	0.3 s (typ.) to reach the set flow rate ±2 % FS
Control range	2 to 100 % FS (4 to 100 % FS for F4H9050)
Accuracy	±1 % FS (±2 % FS for F4H9050)
Repeatability	±0.2 % FS + 1 digit or less
Material of gas-contacting parts	SUS316, fluoropolymer, and fluoroelastomer
Connection method	9/16-18 UNF, Rc1/4, 1/4 Swagelok equivalent, and 1/4 VCR equivalent
Communication specifications	Method: RS-485 (three-wire system) Protocol: CPL, Modbus RTU Connection: RJ45 × 2
Power supply	Rated voltage: DC 24 V; Current consumption: 300 mA max.
External dimensions	76 (W) × 100 (H) × 28 (D) mm (excluding the protrusion of fittings and connectors)
Mass	Approximately 700 g (excluding fittings)

2.1 Characteristics

The F4H has the following characteristics.

(1) Fast control response

The F4H controller uses a combination of an ultrafast response flow rate sensor, a proportional valve, and PID control. It thereby achieves a fast response that takes only 0.3 s (typ.) to stabilize within ±2 % FS of the set flow rate when starting in the fully closed state.

(2) Compact and thin controller

We designed the F4H to provide only the functions necessary for equipment, thereby keeping it compact and thin, reducing its volume by 50 % compared with that of advanced function models of our conventional controller *1. Its 28-mm thin body reduces the piping distance in parallel installations. It also supports vertical piping, which cannot be used with conventional controllers. These advantages make it possible to enhance flexibility in installation and reduce the space necessary for installation within the customer's equipment.

(3) Switches for settings, LEDs, and ports are all on top

On the F4H, switches for settings, LED indicators, and external connection ports are all situated on the top face. This arrangement allows the piping connection, changes in settings, and the LED indicators to be easily checked after piping work is done, improving convenience for workers.

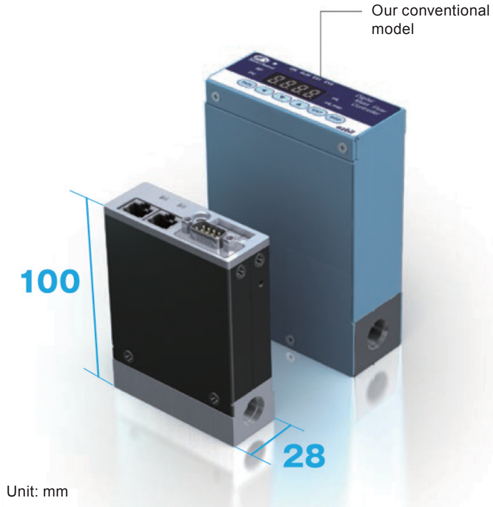


Fig. 2. Comparison with a conventional model

(4) Design unification and use of shared components for flowmeter products

There was no common promotional concept for our previous mass flow products, and a different design was adopted for each one. We defined "reliable, sophisticated, and flexible" as the promotional concept for the F4H and later models, adopting a black body and silver face as a unifying design for our flowmeter products.

In addition, we decided to use common hardware and firmware elements in our flowmeter products and to design each functional block separately. This approach is expected to help shorten the flowmeter development period and reduce the necessary hours of labor.

(5) All F4H models are equipped with communication functions as a standard feature

We provided all models with communication functions as IoT support. These functions allow various types of information held by the F4H to be transmitted to host equipment. The transmitted information can be used not only for failure diagnosis of the F4H itself, but also for connected equipment.

In addition, changing the method of connecting to a PLC from analog signals to RS-485 reduces the number of analog I/O modules and connection cables.

Monitorable information

Set flow rate, instantaneous flow rate, valve driving current, alarm history, number of times the valve is actuated, model number/serial number, parameters settings, etc.

Settable items

Gas type, gas conversion factor, flow rate range, valve control/fully open/fully closed, alarm/event reset, flow rate unit change, etc.

(6) Operation using a single power supply

Conventional mass flow controllers need two types of power supply (±15 V DC), which are not often used in general applications. They also require the power supplies to be dedicated to mass flow controllers. The F4H operates on a single DC 24 V power supply, as do our conventional MQV models, and accordingly they can be used with an inexpensive general-purpose power supply, which can be shared with other equipment.

We also provide the controller with a power supply jack for an AC adapter connection so that power supply wiring can easily be carried out for simple applications, such as experiments.

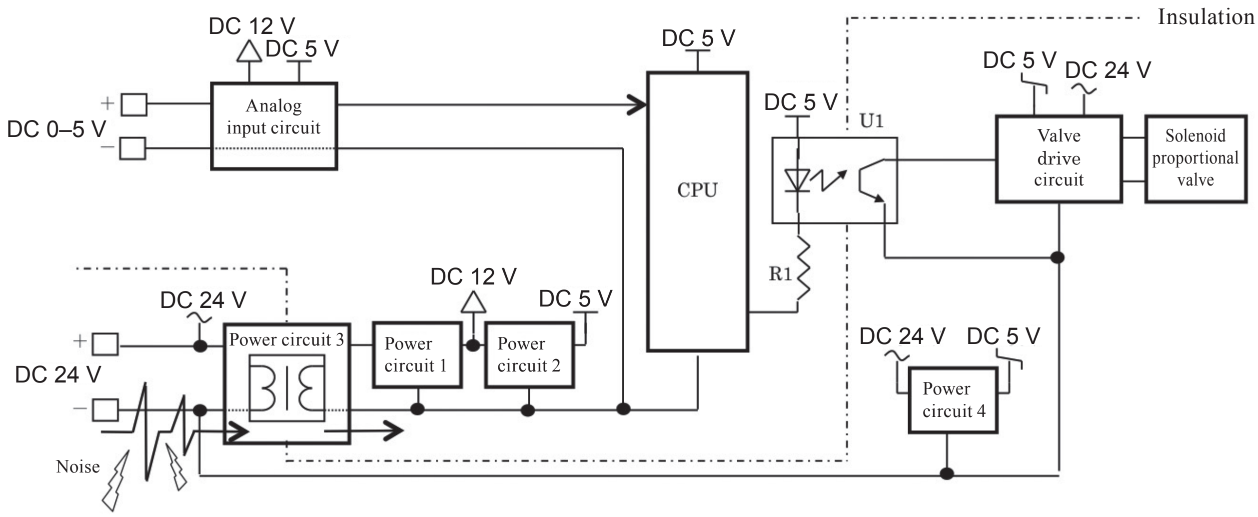


Fig. 3. Isolation between the power circuit and the signal circuit

(7) Multi-gas support

The type of gas used can be changed using the gas-type setting function. This function eliminates the necessity to use different mass flow controllers for different gas types and helps to reduce the number of controllers installed on equipment and the number of models selected and stored by users.

(8) Noise resistance

The F4H's valve drive circuit is isolated from other circuits as illustrated in figure 3. We thereby realized isolation between the power circuit and the analog circuit for a small-capacity isolated power supply (power circuit 3) (Patent No. 5132617). This isolation prevents incoming noise through power supply wires from affecting analog signals, ensuring excellent noise resistance performance.

In addition, we shortened the distance between the sensor and the sensor CPU and adopted digital signal processing for the stages after the sensor CPU. This approach shortened the analog signal section and thereby reduced the effects of noise.

2.2 Application example

Figure 4 shows an application example of sputtering equipment for vacuum deposition (hard disks, Blu-ray discs, liquid crystal panels, touch-panel glass, etc.).

In this application example, a mass flow controller is used to supply argon, oxygen, and nitrogen, and importance is placed on the following points.

A. Flow control is stable, without effects from high-frequency power supply noise.

B. Total productivity can be increased by faster rates of reactive sputtering deposition.

The noise resistance and fast control response of the F4H are effective in achieving these points. The F4H has excellent noise resistance, facilitating stable flow control, preventing variations in quality, and enhancing yield. In addition, its fast control response makes possible reactive sputtering in transition mode, enhancing productivity.

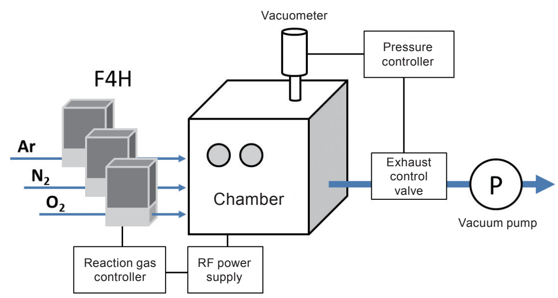


Fig. 4. Example of an application for sputtering equipment

3. System Configuration

Figure 5 shows the configuration block for the F4H.

The configuration can be roughly divided into the flow rate measurement section, the settings-display-connection section, the control circuit, and the proportional valve.

(1) Flow rate measurement section

The flow rate measurement section has a very simple structure. Flow rate sensors are installed on the wall of the flow channel, and rectifying wire gauze is attached upstream of the sensors.

(2) Settings-display-connection section

Switches for the main settings, the LED indicators, and the external connections are all located on the top of the F4H.

Its three rotary switches for communication settings are used to set communication speed and other parameters, and communication addresses.

Two LEDs for indicating the status of the product display different lighting and blinking patterns to show the ON/OFF status of the power supply, the status of communications, and so on.

The F4H is equipped with a D-sub 9-pin male connector for external connection and two RJ45 connectors. The D-sub 9-pin male connector is used for DC 24 V power, analog input and output, external contact input, and event and alarm output. The two RJ45 connectors are used for RS-485 communication, allowing daisy-chain connection of multiple controllers.

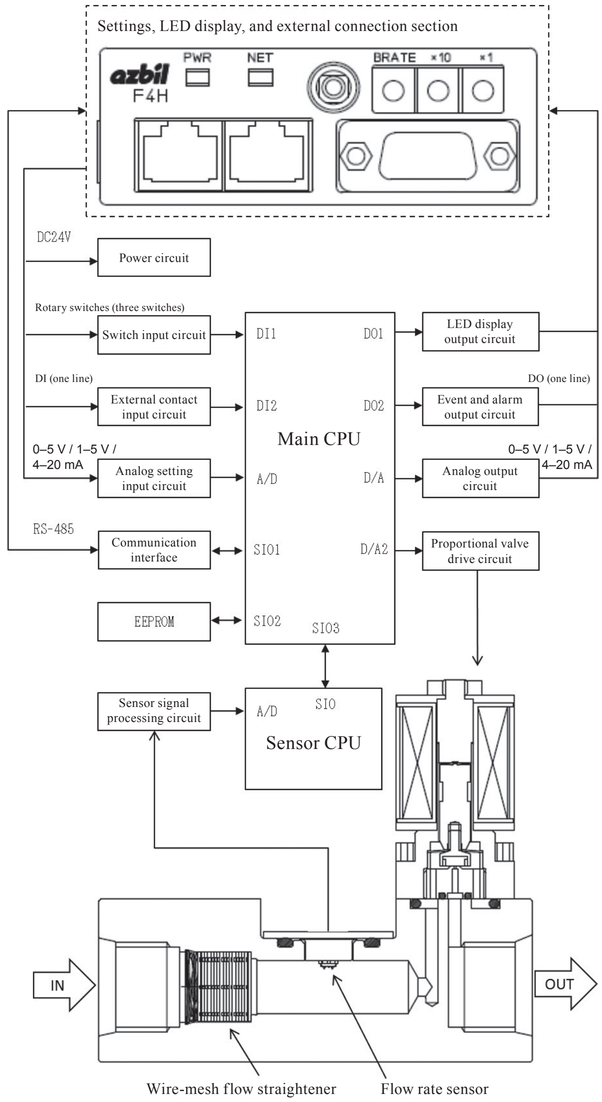


Fig. 5. Configuration block diagram

(3) Control circuit

Control flow rate signals produced by flow rate sensor are converted into flow rate data in the sensor CPU and then transmitted to the main CPU. The main CPU compares the flow rate data with the set flow rate and then outputs the drive current for flow control to the proportional valve on the basis of the results of the comparison.

RS-485 communication enables the writing of the flow rate setting and the reading of the control flow rate. It also enables the reading and writing of other settings and the reading of information, such as events and alarms.

As is the case with our conventional mass flow controllers, the flow rate setting can be changed using external analog input, and the control flow rate can be sent as external analog output. Accordingly, connection to external equipment can be established via an analog interface.

The F4H is also equipped with rotary switches for communication setting (three switches), external contact input (one line), and event alarm output (one line), which allow users to set and allocate functions.

(4) Proportional valve

We adopted a normally closed solenoid proportional valve. To provide the valve with the capability of performing not only proportional flow control but also shutoff operations, we made it flat in shape in order to produce a flow-to-close structure, in which gas flows in the direction opposite to the gas flow direction in ordinary proportional valves (gas flows from the valve body to the valve seat).

4. Shared Hardware/Firmware Design

As described in 2.1 (4), we considered using hardware/firmware common to flowmeter products as we designed each function block of the F4H.

Fig. 6 illustrates flowmeters consisting of common elements. They can be roughly classified into three types.

(1) Low-price flowmeters

A low-price flowmeter consists of a body containing the flow path, an ultrafast flow rate sensor, and a sensor CPU for processing sensor signals.

(2) Advanced-function flowmeters

Advanced-function flowmeters are made by adding a main CPU in order to provide low-price flowmeters with various functions on the basis of flow rate data.

(3) Flow controllers

Flow controllers are made by adding a valve-drive circuit and a proportional valve to high-functionality flowmeters.

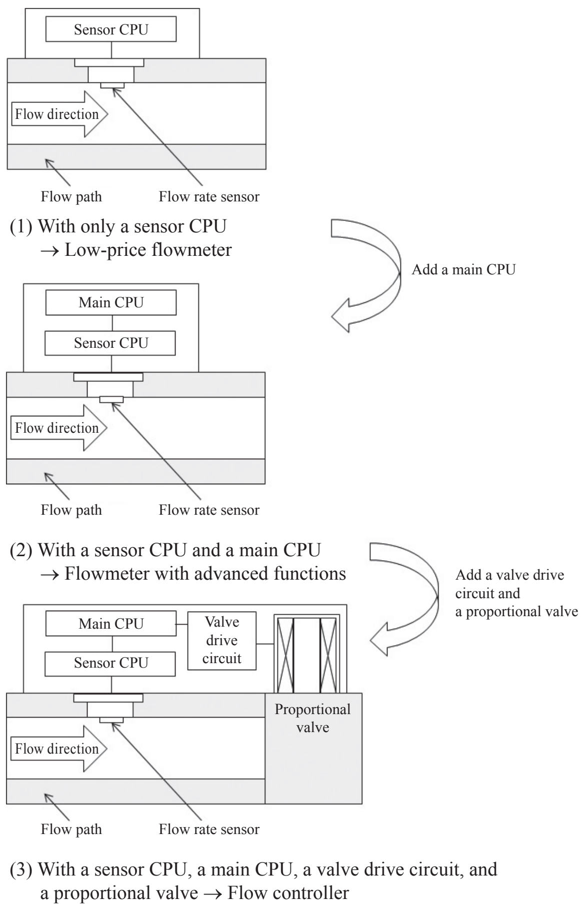


Fig. 6. Flowmeters consisting of shared elements

For the firmware for the CPUs, the circuits related to each CPU, and the flow path, we designed each block separately according to function. Necessary functions can therefore be selected and combined to meet purpose and application. This approach is expected to contribute to shorter development periods and fewer hours of labor for future flowmeters.

Based on the assumption of future expansion of the communication functions of the F4H, we designed its top panel to be equipped with the settings, display, and external connection section. There are various communication methods, and each one uses a different type of connector. We designed the top panel in such a way that it can be used for all of the communication methods expected in future expansion.

5. Results of Performance Tests

We ran performance tests to verify the fast control response and noise resistance characteristics of the F4H.

5.1 Confirmation of fast response

We used the equipment illustrated in figure 7 to check the response when control is started in the fully closed state of the proportional valve. Figure 8 shows the results.

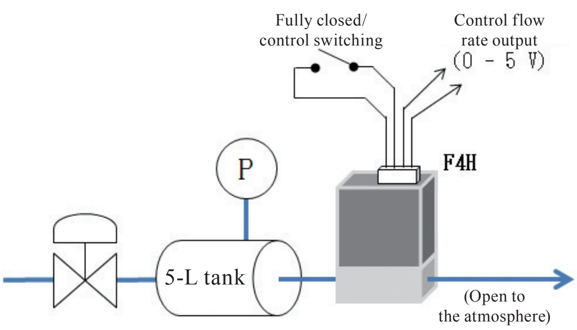
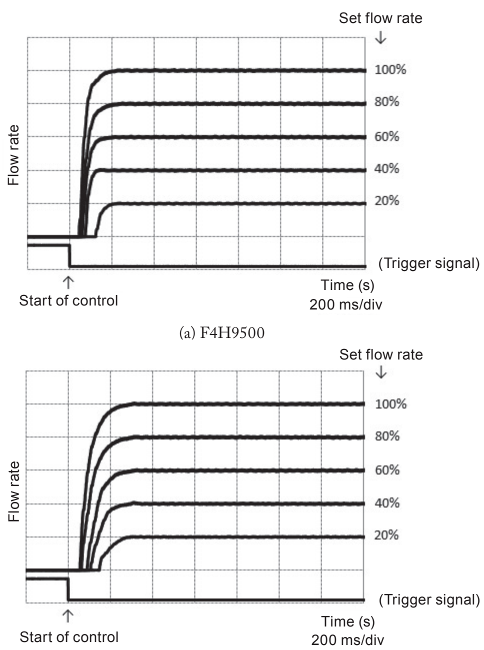


Fig. 7. Control response measurement equipment

(F4H9500: 500 mL/min range product; F4H0002: 2 L/min range product)



(a) F4H9500

(a) F4H0002

Fig. 8. Control characteristics when control is started in the fully closed state

(Fluid: Air; Differential pressure for operation: 0.2 MPa; Horizontal axis: 200 ms/div; Vertical axis: 20 % FS/div)

Testing was performed at the five flow rate settings of 20, 40, 60, 80, and 100 % of the full-scale flow rate using air as fluid under a standard differential pressure of 0.2 MPa. Settling was reached within 300 ms from the start of control at all of the set flow rates.

5.2 Confirmation of noise resistance

We used the radio-frequency (RF) immunity test equipment illustrated in figure 9 for RF immunity testing on the F4H (power circuit: isolated) and a conventional digital mass flow controller (power circuit: non-isolated). We then compared their noise resistance performance.

Test conditions

- Application conditions
  Frequency range: 150 kHz to 80 MHz
  (1 % steps and 1-second retention)
  Modulation: 1 kHz, 80 % amplitude modulation
  Application level: 3 Ve.m.f
- Application location: Power line
- EUT setting: SP 50 % FS
  PV 0-5 V output
- Criteria: (1) Control flow rate shift: Within the range of ±2 % FS
  (Confirmed at 0-5 V output of the standard device)
  (2) 0-5 V output shift: Within the range of ±2 % FS

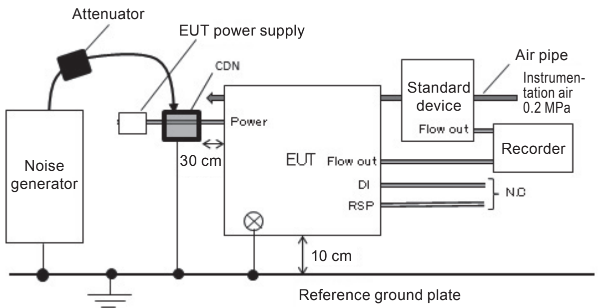
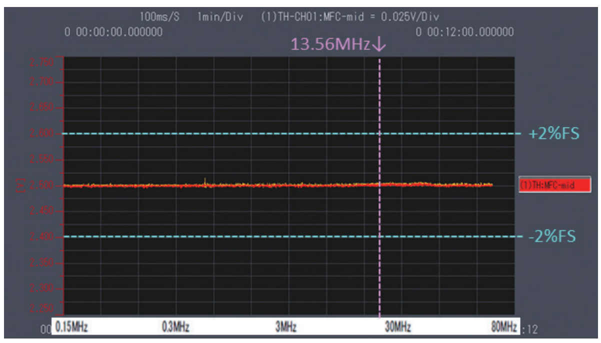


Fig. 9. RF immunity test equipment

Figure 10 shows the results of the comparison of noise resistance between the F4H and a conventional digital mass flow controller.

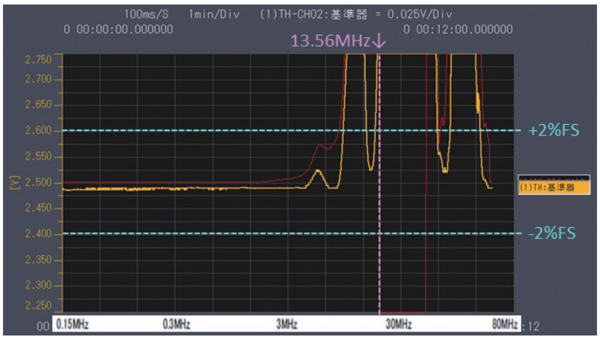
The non-isolated conventional digital mass flow controller develops instability in flow control at around 13.56 MHz, the main power supply radio frequency for the sputtering equipment, and in the high-frequency band. On the other hand, the F4H maintains stable flow control in the whole test frequency range from 150 kHz to 80 MHz.



(a) EUT: The F4H type

(Red line: EUT 0-5 V output; Yellow line: Standard device 0-5 V output)

Fig. 10. Comparison of noise resistance (a)



(b) EUT: Non-isolated conventional digital mass flow controller

(Red line: EUT 0-5 V output; Yellow line: Standard device 0-5 V output)

Fig. 10. Comparison of noise resistance (b)

6. Conclusions

The performance testing demonstrated that the F4H is excellent in controllability based on both fast response and noise resistance. It is therefore suitable as a mass flow controller for mounting on manufacturing equipment and test equipment for FA applications.

7. Future Plans

In this development project, we adopted RS-485 (CPL communication/Modbus RTU) as the method of communication and made it a standard feature of the F4H. There is also demand for mass flow controllers supporting various other communication methods, and it is also desirable to meet that demand. We will carefully examine the communication methods required in the market and consider expanding the communication capabilities of the F4H series.

Reference

(1) Osamu Momose, Junichi Isetani: “Development of CMQ Series Digital Mass Flow Controllers,” in the “Micro Flow Sensor” volume of Savemation Review, pp. 74–80

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