

(19)



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(11)

EP 0 926 647 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
30.06.1999 Bulletin 1999/26

(51) Int. Cl.⁶: G08B 17/12

(21) Application number: 99200961.3

(22) Date of filing: 07.09.1993

(84) Designated Contracting States:
CH DE FR GB IT LI NL

(30) Priority: 08.09.1992 IL 10309492
01.01.1993 IL 10429893
07.09.1993 IL 10535193

(62) Document number(s) of the earlier application(s) in
accordance with Art. 76 EPC:
93630065.6 / 0 588 753

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Remarks:

This application was filed on 29 - 03 - 1999 as a
divisional application to the application mentioned
under INID code 62.

(54) Method for detecting a fire condition

(57) A method of detecting a fire condition in a monitored region includes concurrently monitoring the region by a first sensor sensitive to radiation within a first bandwidth which includes the CO₂ emission band, by a second sensor sensitive to radiation within a second bandwidth which includes wavelengths mainly lower than the CO₂ emission band, and by a third sen-

sor sensitive to the radiation within a third bandwidth which includes wavelengths higher than the CO₂ emission band. The measurements of all these sensors are utilized in determining the presence or absence of the fire condition in the monitored region.

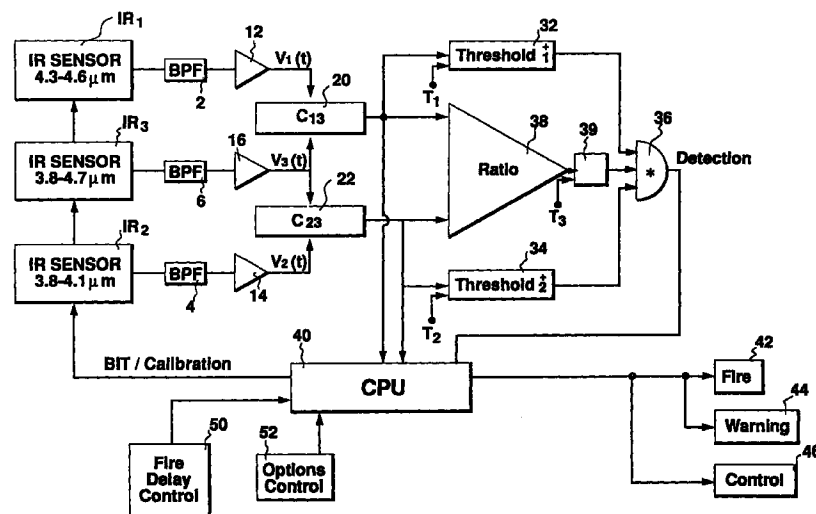


FIG. 1

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Description

[0001] The present invention relates to a method for detecting a fire condition in a monitored region, and particularly to such a method effective at relatively long ranges and/or with relatively small fires.

[0002] One of the problems in detecting fire conditions, particularly at long ranges or of small fires, is the high false alarm rate. Thus, the range of detection can be increased by increasing the sensitivity of the system, e.g., by appropriately setting the amplification level and/or the threshold level. However, this increase in sensitivity also tends to increase the false alarm rate caused by spurious radiation sources, such as sunlight, artificial light, welding, electrical heaters, ovens, etc., or by other sources of noise. Such spurious radiation sources might not be large enough to activate short-range detectors, but may be large enough to activate detectors whose sensitivity has been increased to increase the range. A false alarm may result in a costly discharge of the fire extinguisher; and if the fire extinguisher is of the type requiring replacement before reuse, the false alarm may disable the fire extinguisher system until it has been replaced or recharged.

[0003] A number of attempts have been made for increasing the range of a fire detector system without substantially increasing the false alarm rate. Some described systems utilize two sensors in different spectrum ranges, as illustrated in US Patents 3,653,016, 3,665,440, 3,825,754, 3,931,521, 4,639,598 and 4,983,853. Other described systems utilize an AC coupling and a level ratio test, as illustrated in US Patent 4,455,487. In another proposed system, the detector examines the frequency characteristics of monitored signals produced by a sensor in order to distinguish between fire-produced radiation and spurious radiation.

[0004] US-A-4 220 857 discloses a method of detecting a fire condition according to the preamble of the independent claim.

[0005] WO-86/06859 a fire sensor circuit with cross-correlation of the output signals of detectors responsive to heat and light.

[0006] The object of the invention is to improve alarm generation reliability in fire detection.

[0007] According to the invention this objection is achieved in

a method of detecting a fire condition in a monitored region, including using sensors each of which is sensitive to radiation within a respective band with ad processing their output signals to determine the existence of fire in the monitored region, by the following operations:

(a) concurrently monitoring said region by a first sensor [IR₁] sensitive to radiation within a first bandwidth which includes the CO₂ emission band, by a second sensor [IR₂] sensitive

to radiation within a second bandwidth which includes wavelengths mainly lower than the CO₂ emission band, and by a third sensor [IR₃] sensitive to the radiation within a third bandwidth which includes wavelengths higher than the CO₂ emission band. and producing first, second and third measurements of radiation variations emitted from said monitored region;

(b) determining two cross-correlation values, a first of said two cross-correlation values [C₁₃] being determined by cross-correlating said first and third measurements, and a second of said two cross-correlation values [C₂₃] being determined by cross-correlating said second and third measurements;

(c) forming a function of said two cross-correlation values;

(d) comparing said function with a predetermined threshold; and

(e) utilizing the results of said comparison in determining the presence or absence of a fire condition in the monitored region.

[0008] Several embodiments of fire detection systems are described below for purposes of example.

[0009] In some described embodiments, the third sensor senses infrared radiation over a broad band. Particularly good results have been obtained when the first sensor senses infrared radiation within the 4.4-4.7 μm band, the second sensor senses radiation within the 3.8-4.1 μm band, and the third sensor senses radiation within the 3.8-4.7 μm band.

[0010] In another described embodiment, the third sensor senses infrared radiation within a bandwidth which includes wavelengths mainly higher than the CO₂ emission band. Particularly good results were obtained with respect to the latter embodiment when the first sensor senses infrared radiation within the 4.3-4.6 μm band, the second sensor senses radiation within the 3.8-4.2 μm band, and the third sensor senses radiation within the 4.8-5.1 μm band.

Fig. 1 is a block diagram illustrating one apparatus for detecting a fire condition in accordance with the present invention;

Fig. 2 is a block diagram illustrating the correlation circuit with respect to two of the sensors in the apparatus of Fig. 1;

Fig. 3 illustrates a preferred arrangement of the three infrared sensors in the apparatus of Fig. 1;

Fig. 4 illustrates a set of curves helpful in understanding the method and apparatus of Fig. 1 for detecting fire conditions;

Fig. 5 is a block diagram illustrating another apparatus for detecting a fire condition not covered by the attached claims;

Fig. 6 is a block diagram illustrating the auto-correlation circuit for effecting auto-correlation of the out-

put of one of the sensors, it being appreciated that a similar circuit is used for each of the other two sensors; and

Figs. 7 and 8 are block diagrams illustrating two further forms of apparatus constructed in accordance with the present invention.

[0011] The apparatus illustrated in Fig. 1 comprises three sensors, namely IR_1 , IR_2 and IR_3 , for concurrently monitoring the radiation emitted from the monitored region. The outputs of the three IR sensors IR_1 , IR_2 and IR_3 , are fed to bandpass filters 2, 4, 6, and to amplifiers 12, 14, 16, respectively, to produce three measurements of the radiation variations emitted from the monitored region within the three bands of the filters 2, 4, 6. These measurements, as outputted from their respective amplifiers 12, 14, 16, are indicated by the three varying signals $V_1(t)$, $V_2(t)$ and $V_3(t)$, respectively.

[0012] The three amplifiers 12, 14, 16, are tuned to amplify the signals from their respective bandpass filters 2, 4, 6 within a frequency range of 2-10 Hz. This is the flame flicker frequency, so that their respective output signals will represent the measurements of the three sensors within their respective bandwidths at the flame flicker frequency.

[0013] The apparatus illustrated in Fig. 1 further includes two correlation circuits 20, 22, for producing correlation values between the measurement of the third sensor IR_3 and the other two sensors IR_1 and IR_2 , respectively. Thus, correlation circuit 20 determines the correlation value between signal $V_3(t)$ produced by sensor IR_3 and signal $V_1(t)$ produced by sensor IR_1 , and outputs a first correlation value C_{13} representing the correlation between these two measurements. Similarly, correlation circuit 22 determines the correlation value between signal $V_3(t)$ produced by sensor IR_3 and signal $V_2(t)$ produced by sensor IR_2 , and outputs a correlation value C_{23} representing the correlation between these two measurements.

[0014] Correlation is effected between each pair of signals by converting the analog outputs of the respective sensors, moving one signal over the other, and summing the product of all the points, as described for example in the above-cited US Patent 4,639,598. The result of the correlation is a time dependent signal. Fig. 2 illustrates the correlation circuit 20 for effecting correlation in this manner between the outputs of the two sensor IR_1 and IR_3 . It will be appreciated that the correlation circuit 22 for effecting correlation between the two sensors IR_2 and IR_3 would be the same.

[0015] The first correlation value C_{13} from correlation circuit 20 is inputted into a comparator 32 and is compared with a predetermined threshold value T_1 ; similarly, the second correlation value C_{23} from correlation circuit 22 is inputted into a second comparator 34 and is compared with a second threshold value T_2 . When the respective correlation value C_{13} , C_{23} , is equal to or exceeds the respective threshold value, comparators

32, 34 output a signal of binary value "1"; and at all other times, the comparators output a signal of a binary value "0". The outputs of the two comparators 32, 34 are fed to an AND-gate 36.

[0016] The two correlation values C_{13} , C_{23} from the correlation circuits 20, 22 are also inputted into a ratio-determining circuit 38. Circuit 38 determines the ratio of these two correlation values and outputs a correlation-ratio signal. The latter signal is fed to a third comparator 39 where it is compared with a threshold value T_3 , and similarly outputs a "1" or "0" to the AND-gate 36.

[0017] The system illustrated in Fig. 1 further includes a CPU 40 which, among other functions, stores the threshold values applied to the comparators 32, 34 and 39, and receives the signal outputted from the AND-gate 36. It will thus be seen that a "1" output from AND-gate 36 indicates the coincidence of the following three conditions: (1) the first correlation signal C_{13} equals or exceeds the predetermined threshold of comparator 32; (2) the second correlation value C_{23} equals or exceeds the predetermined threshold of comparator 34; and (3) the ratio of the two correlation values C_{13} and C_{23} equals or exceeds the predetermined threshold of comparator 39. When all these conditions are present, AND-gate 36 outputs a signal to the CPU 40 indicating that a fire condition is present in the monitored region. The CPU may then output a signal to a fire alarm unit 42, to a warning unit 44, or to a control unit 46, e.g., to actuate a fire extinguisher.

[0018] The CPU 40 may include other optional controls, for example a fire delay control 50 to delay the actuation of the fire alarm, in order to better assure that the condition is not a false alarm. Other optional controls, indicated by block 52, may also be inputted to the CPU 40 such as a sensitivity adjustment control. The CPU 40 further includes BIT (built-in test)/calibration devices, as known, for testing and/or calibration purposes.

[0019] Fig. 3 illustrates a preferred arrangement of the infrared sensors, wherein they are arranged in a straight line, with the middle sensor IR_2 being sensitive to radiation below the CO_2 emission band. In this example, sensor IR_1 at one end senses radiation within the 4.3-4.6 μm band; the intermediate sensor IR_2 senses radiation within the 3.8-4.1 μm band; and sensor IR_3 at the opposite end senses radiation within the 3.8-4.7 μm band.

[0020] The above described apparatus defines a fire condition as an IR source which alternates at a frequency of 2-10 Hz (the flame flicker frequency) and which emits strongly in the CO_2 emission band (4.3-4.6 μm), and weakly below the CO_2 emission band (3.8-4.1 μm). These emission bands are more clearly seen in Fig. 4. Curves a-f of Fig. 4 particularly show that the atmospheric influences are smallest within the narrower range of 4.36-4.54 μm . In order to minimize the atmospheric influences it is preferable to use the narrower band of 4.36-4.54 μm for the IR sensor IR_1 detecting the emissions within the CO_2 emission band.

[0021] The use of the third sensor IR_3 substantially increases the sensitivity of the system, to increase the range of fire detection and/or decrease the size of a detectable fire, without substantially increasing the false alarm rate. Thus, the measurement of each of the two sensors IR_1 , IR_2 includes a signal component and a noise component. In case of a large fire or a close fire, the signal component would normally be much larger than the noise component, and therefore the ratio of their two outputs would be more closely equal to the ratio of the respective signal components. However, in the case of a small fire, or a fire at a large distance from the detector, the noise component becomes much larger than the signal component, and therefore the ratio of the outputs of the two sensors IR_1 , IR_2 would be closer to the ratio of their noise components, which is a meaningless value. However, by adding the third sensor IR_3 to produce a measurement concurrently with the measurements of the other two sensors IR_1 , IR_2 , the signal component of the third sensor is in phase with the signal components of the other two sensors and therefore increases the signal component of the overall signal, without increasing the noise component since the noise component of the third sensor is out of phase with the noise components of the other two sensors. The overall result is an improvement in the signal-to-noise ratio in the overall system, thereby increasing its sensitivity without significantly increasing its false alarm rate.

[0022] The threshold values T_1 , T_2 , T_3 utilized in comparators 32, 34 and 39 may be predetermined in advance by simulating the type of fire condition to be detected, and then determining these threshold values such that a "1" is outputted in each of the three comparators under such a simulated fire condition. These threshold values can be stored in the CPU 40 and used in the monitoring process, or can be optionally modified, e.g., by the optional control block 52, to obtain any desired sensitivity and permissible false alarm rate according to any particular application. The optional control block 50 in Fig. 1 may be used for preselecting the time duration during which a fire condition must be detected before actuating the warning alert 44, the fire alarm 42, or the control device 46 such as a fire extinguisher system.

[0023] The apparatus illustrated in Fig. 5 is very similar to that illustrated in Fig. 1. To facilitate understanding, the same reference numerals have been used for corresponding parts, and the new parts are identified by reference numerals starting with "100".

[0024] Thus, as shown in Fig. 5, the output of sensor IR_1 , after passing through its bandpass filter 2 and amplifier 12, is auto-correlated without normalization in auto-correlation circuit 100 to produce auto-correlation value C_{11} . In a similar manner, the outputs of the two sensors IR_2 and IR_3 are auto-correlated in circuits 102 and 104, respectively, to produce second and third auto-correlation values C_{22} and C_{33} , respectively.

[0025] The ratio of the first auto-correlation value C_{11}

from circuit 100, and of the second auto-correlation value C_{22} from circuit 102, is determined in a ratio circuit 106, and is compared to a predetermined threshold value 108. Similarly, the ratio of the second and third auto-correlation values, from circuits 102 and 104, respectively, is determined by ratio circuit 110, and its output is compared to a predetermined high threshold value in circuit 112, and also to a predetermined low threshold value in circuit 114.

[0026] The outputs of threshold circuits 108 and 114 are fed to AND-gate 36, with the outputs of the other signals as described above. The output of that gate is fed to the CPU (40, Fig. 1) for use in determining the presence or absence of a fire condition in the monitored area in the same manner as described above.

[0027] Fig. 6 illustrates the auto-correlation circuit 100 for sensor IR_1 . The auto-correlation value is determined by moving the signal outputted from sensor IR_1 over itself, without normalization, and summing the products of all the points of the two signals. It will be appreciated that auto-correlation circuits 102 and 104 for the two other sensors IR_2 , IR_3 are constructed and operate in the same manner.

[0028] Figs. 7 and 8 are block diagrams illustrating two forms of apparatus which are very similar to those described above; to facilitate understanding, the same reference numerals have been used for corresponding parts.

[0029] The system illustrated in Fig. 7 thus includes three sensors IR_1 , IR_2 and IR_3 , for concurrently monitoring the radiation emitted from the monitored region. The outputs of the sensors are fed via the three bandpass filters 2, 4, 6 and their respective amplifiers 12, 14 and 16, to produce three measurements of the radiation variations emitted from the monitored region within the three bands of the filters.

[0030] Each of the three measurements is auto-correlated with respect to itself without normalization to produce three auto-correlation values C_{11} (block 100), C_{22} (block 102) and C_{33} (block 104). Auto-correlation value C_{11} is compared with auto-correlation value C_{22} in a ratio circuit 106 to produce a correlation ratio (C_{11}/C_{22}) which is compared with a predetermined threshold in circuit 108. Auto-correlation value C_{22} is compared with auto-correlation value C_{33} in a ratio circuit 110, to produce a correlation ratio (C_{33}/C_{22}) which is compared with another predetermined threshold in circuit 112. In addition, the auto-correlation value C_{11} is compared with a threshold in circuit 114. The results of these three comparisons are fed to AND-circuit 36 and utilized in determining the presence or absence of a fire condition in the monitored area, such that the AND-circuit 36 produces an output (to CPU 40, Fig. 1) indicating a fire condition when there is coincidence between all its inputs.

[0031] AND-circuit 36 includes a fourth input which represents the cross-correlation value between the measurement of the first sensor IR_1 and the second sensor IR_2 after normalization. Thus, the circuit illus-

trated in Fig. 1 produces a cross-correlation value C_{12} representing the cross-correlation between the measurements of sensors IR_1 and IR_2 . This cross-correlation value is normalized in circuit 118 by multiplying this value by itself, and dividing the product by the product of the auto-correlation value C_{11} received from circuit 100 and the auto-correlation value C_{22} received from circuit 102. The output of circuit 118 is compared with another threshold in circuit 120 and is applied as the fourth input into the AND-circuit 36.

[0032] Thus, the AND-circuit 36 will produce an output, indicating a fire condition, only when there is coincidence between all four of its inputs. If any of its inputs is "0", no fire condition will be indicated.

[0033] The arrangement illustrated in Fig. 7 has been found to have a relatively high sensitivity to detecting fires and a relatively low false alarm rate, particularly when the first sensor IR_1 is sensitive to radiation within the 4.3-4.6 μm band, the second sensor IR_2 is sensitive to radiation within the 3.8-4.2 band, and the third sensor IR_3 is sensitive to radiation of about 4.8-5.1, preferably 5.0 μm .

[0034] However, it has been found that the system as described above may be falsely actuated to indicate a fire condition when a welding operation is being performed in the monitored area, which welding operation involves the evaporation of a coating of an organic material on the welding electrode. Such organic materials, when evaporated, produce an emission within the CO_2 bandwidth. However, it has also been found that if in the illustrated system the second sensor IR_2 is selected to be sensitive to radiation within the 0.2-1.5 band (which is also below the CO_2 emission band), particularly of a wavelength from 1.3-1.4 μm , the rate of false alarms caused by such a welding operation occurring in the monitored area is substantially reduced.

[0035] Fig. 8 illustrates a system which is substantially the same as described above with respect to Fig. 7, and which operates in substantially the same manner, except that the fourth input to the AND-gate 36 is produced by the cross-correlation of the output of the first sensor IR_1 with the third sensor IR_3 , rather than with the second sensor IR_2 . Thus, box 116 in Fig. 7 indicating the cross-correlation value C_{12} , is replaced by box 216 in Fig. 8 indicating the cross-correlation value C_{13} ; this value is normalized in circuit 218 and compared to a predetermined threshold in circuit 220 before being applied as the fourth input to the AND-gate 36. Circuit 218 normalizes the value C_{13} by multiplying it by itself, and dividing the product by the product of the auto-correlation values C_{11} and C_{33} .

[0036] In all other respects, including the change in sensor IR_2 in order to reduce its sensitivity to false alarms produced by a welding process occurring in the monitored area, the system illustrated in Fig. 8 is constructed and operates in substantially the same manner as described above with respect to the system of Fig. 7.

Claims

1. A method of detecting a fire condition in a monitored region, including using sensors each of which is sensitive to radiation within a respective band with and processing their output signals to determine the existence of fire in the monitored region, characterized by the following operations :

- (a) concurrently monitoring said region by a first sensor [IR_1] sensitive to radiation within a first bandwidth which includes the CO_2 emission band, by a second sensor [IR_2] sensitive to radiation within a second bandwidth which includes wavelengths mainly lower than the CO_2 emission band, and by a third sensor [IR_3] sensitive to the radiation within a third bandwidth which includes wavelengths higher than the CO_2 emission band, and producing first, second and third measurements of radiation variations emitted from said monitored region;
- (b) determining two cross-correlation values, a first of said two cross-correlation values [C_{13}] being determined by cross-correlating said first and third measurements, and a second of said two cross-correlation values [C_{23}] being determined by cross-correlating said second and third measurements;
- (c) forming a function of said two-cross-correlation values;
- (d) comparing said function with a predetermined threshold; and
- (e) utilizing the results of said comparison in determining the presence or absence of a fire condition in the monitored region.

2. The method according to Claim 1, wherein said function is a ratio of said two cross-correlation values, said ratio being compared with said predetermined threshold [T_3] to determine the presence or absence of a fire condition in the monitored region.
3. The method according to Claims 2 or 3, wherein said first sensor [IR_1] senses radiation within the 4.3-4.6 μm emission band, said second sensor [IR_2] senses radiation within the 3.8-4.1 emission band; and said third sensor [IR_3] senses radiation within the 3.8-4.7 μm emission band.
4. The method according to Claim 1, wherein said second sensor [IR_2] senses radiation within the 1.3-1.4 μm emission band.

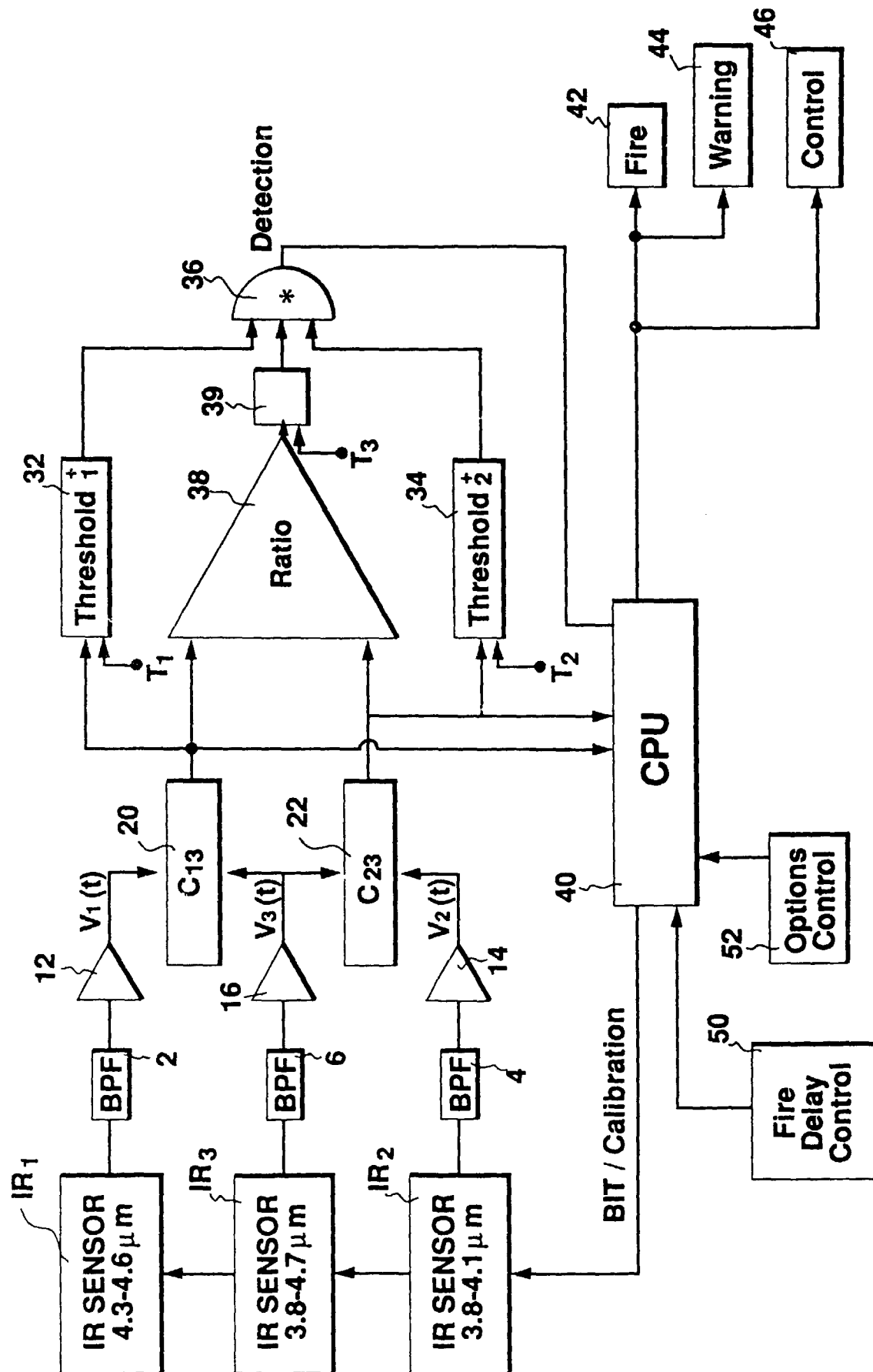


FIG. 1

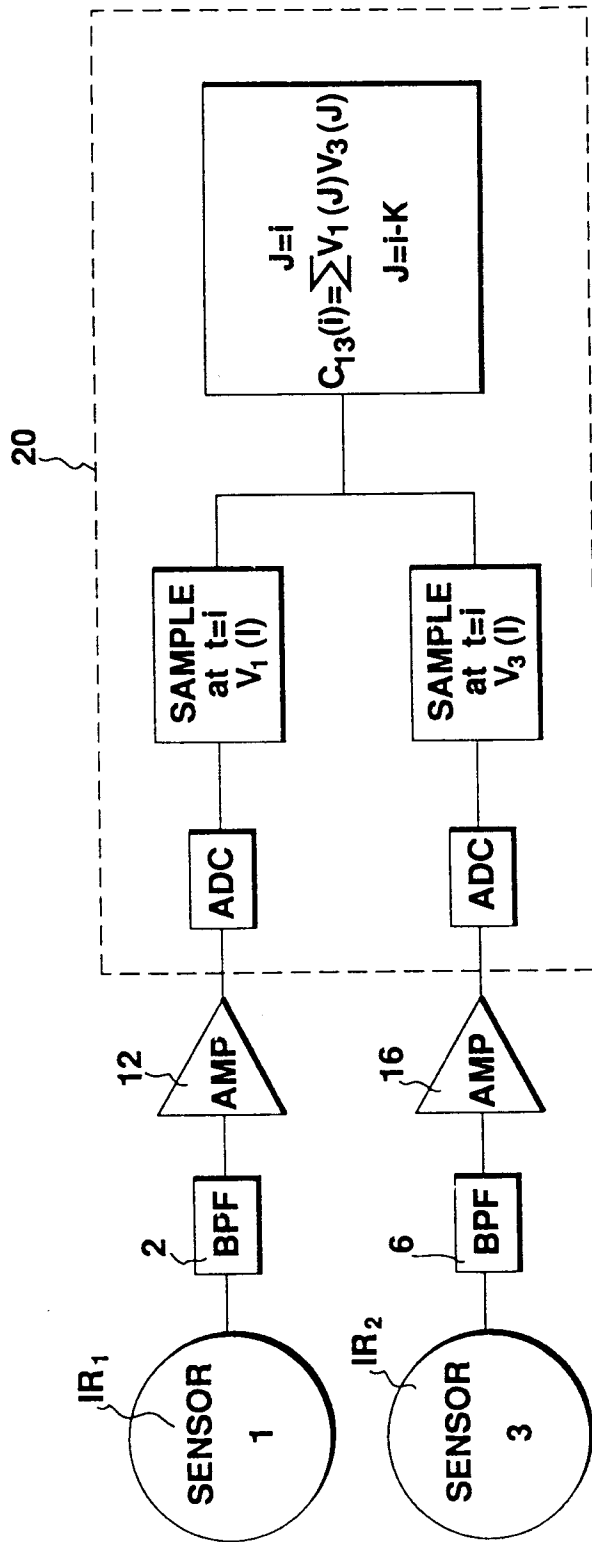


FIG . 2

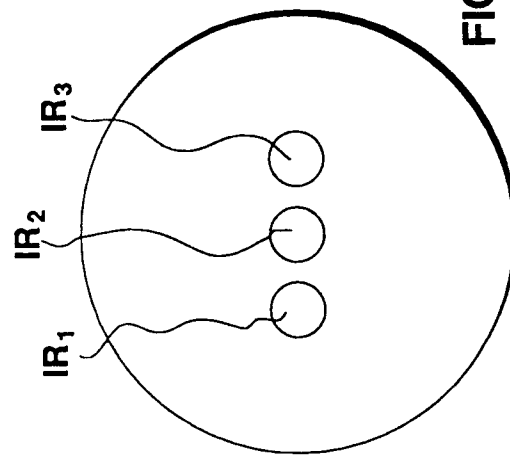
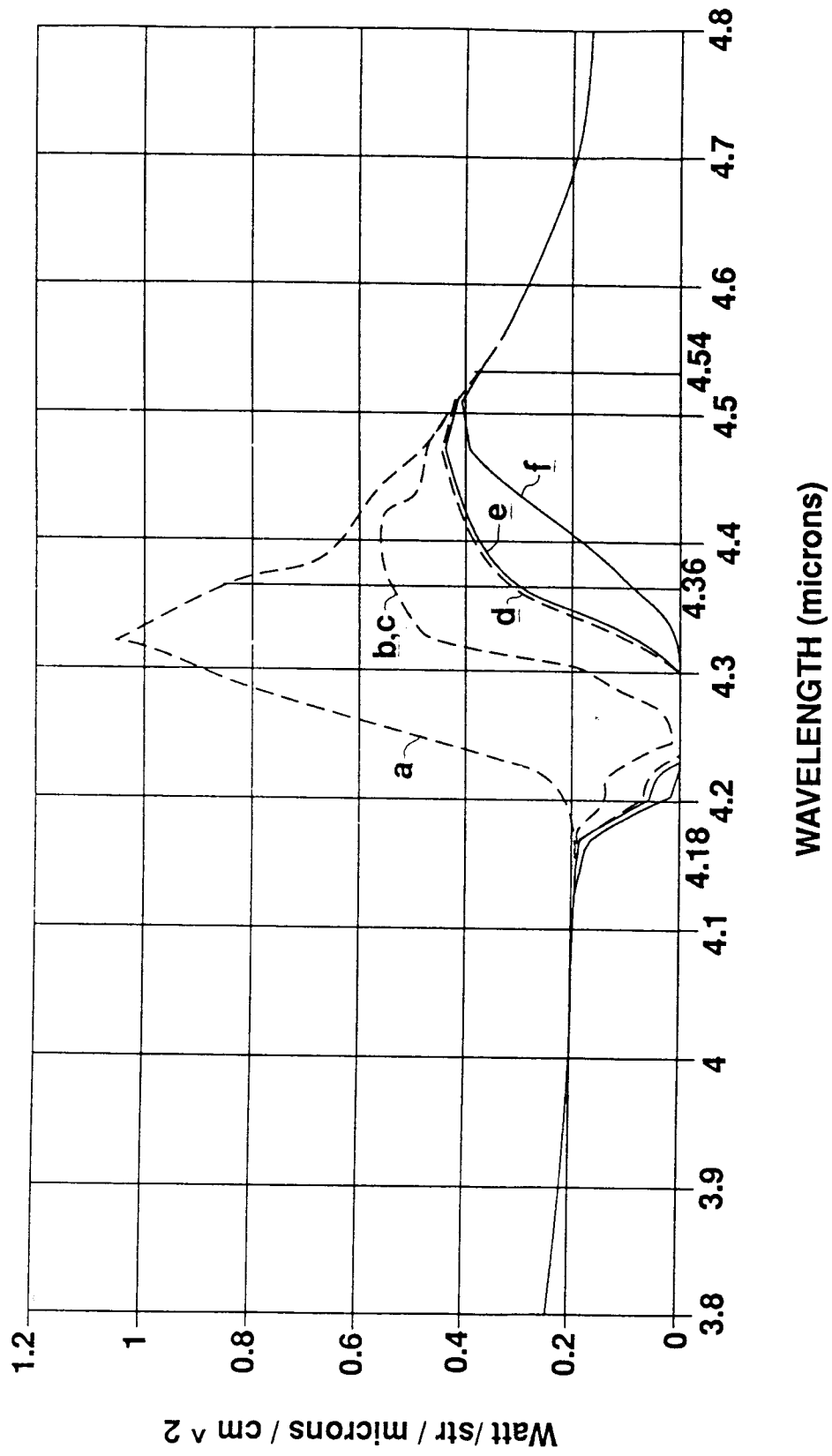


FIG . 3



a - 5m, 0.1% CO2 c - 5m, 0.3% CO2 e - 5m, 1% CO2
 b - 15m, 0.1% CO2 d - 15m, 0.3% CO2 f - 15m, 1% CO2

FIG . 4

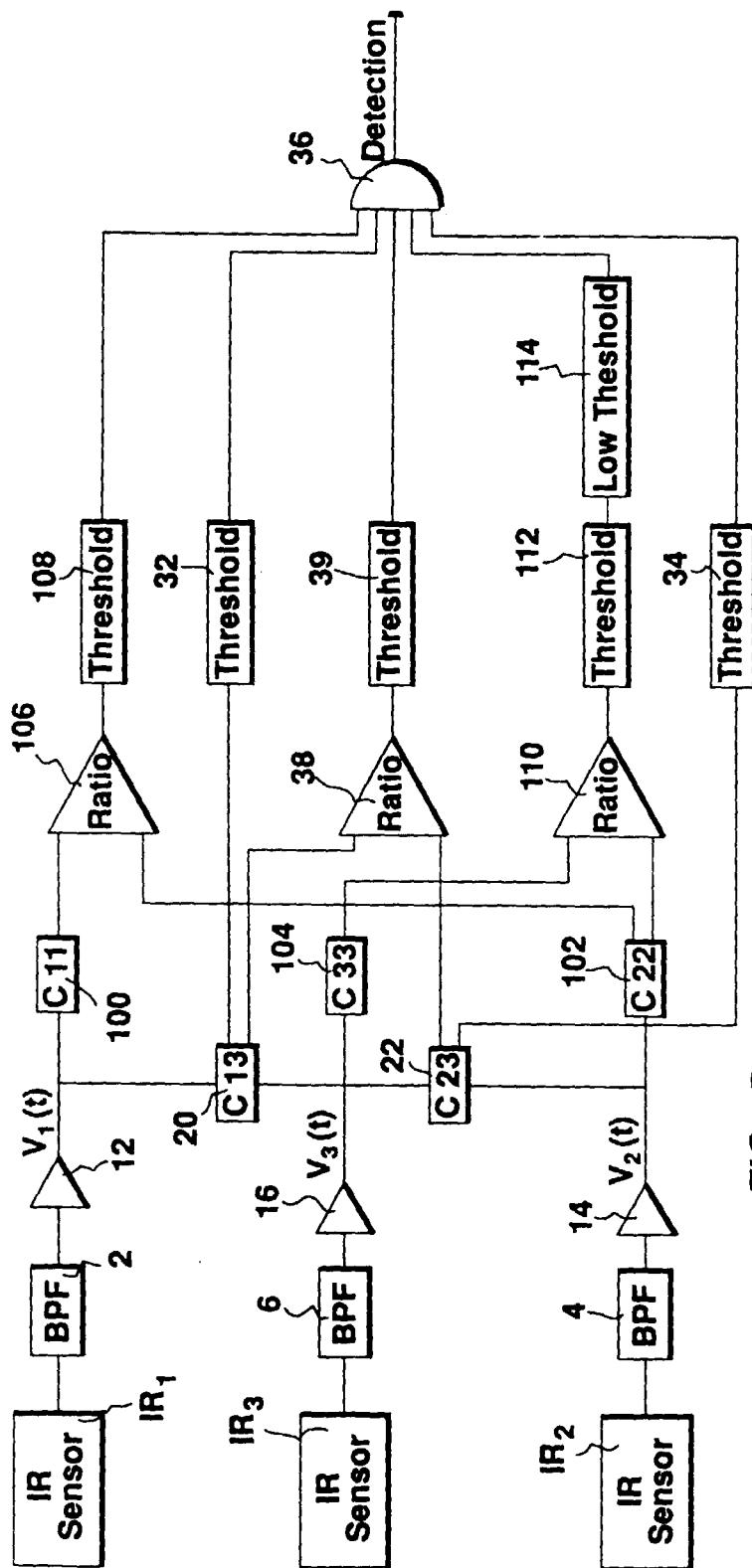


FIG. 5

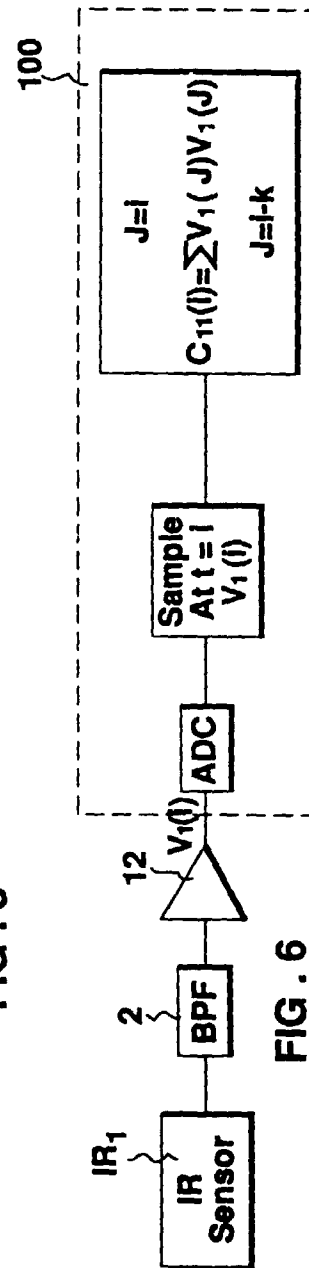


FIG. 6

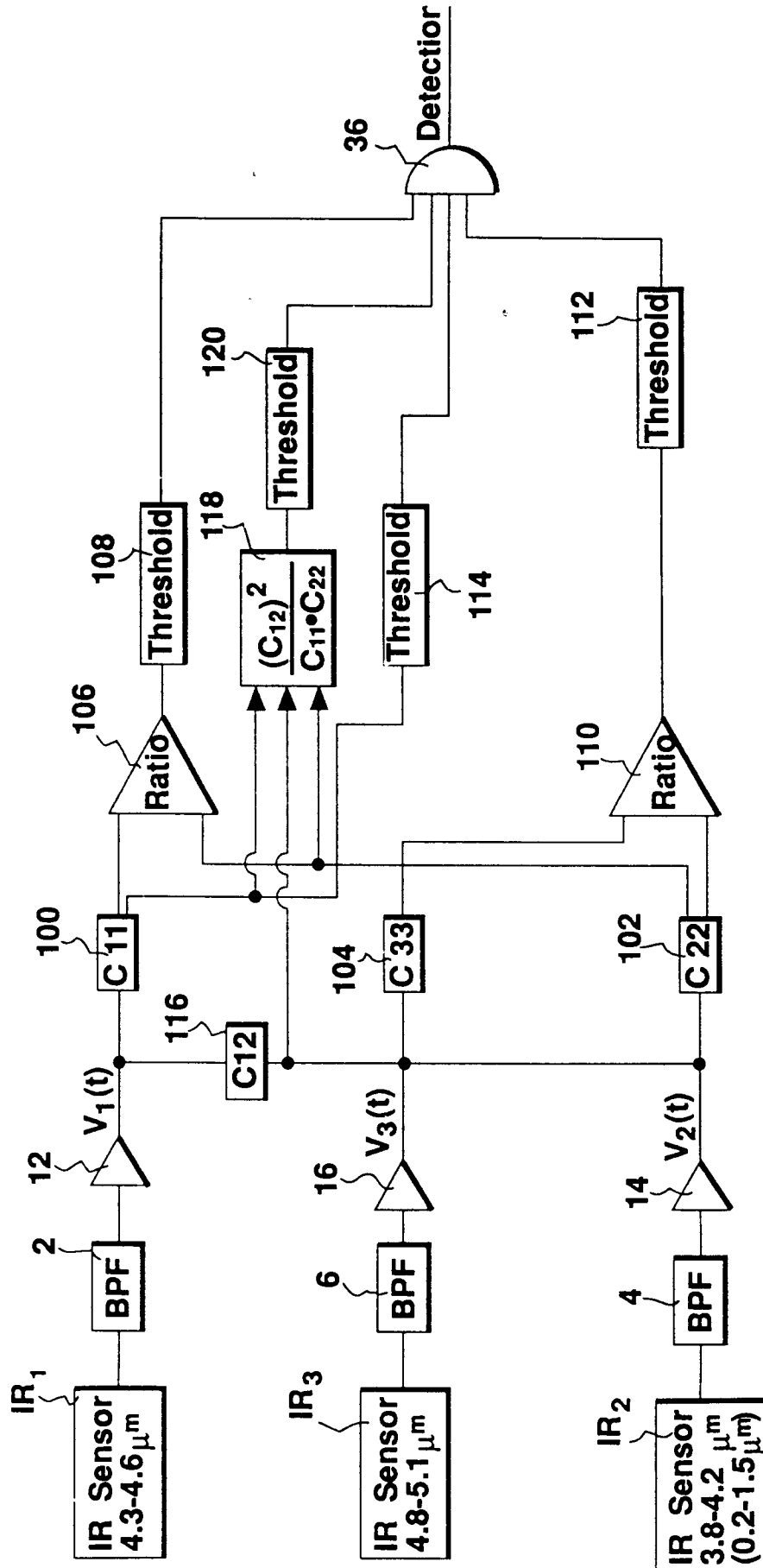


FIG. 7

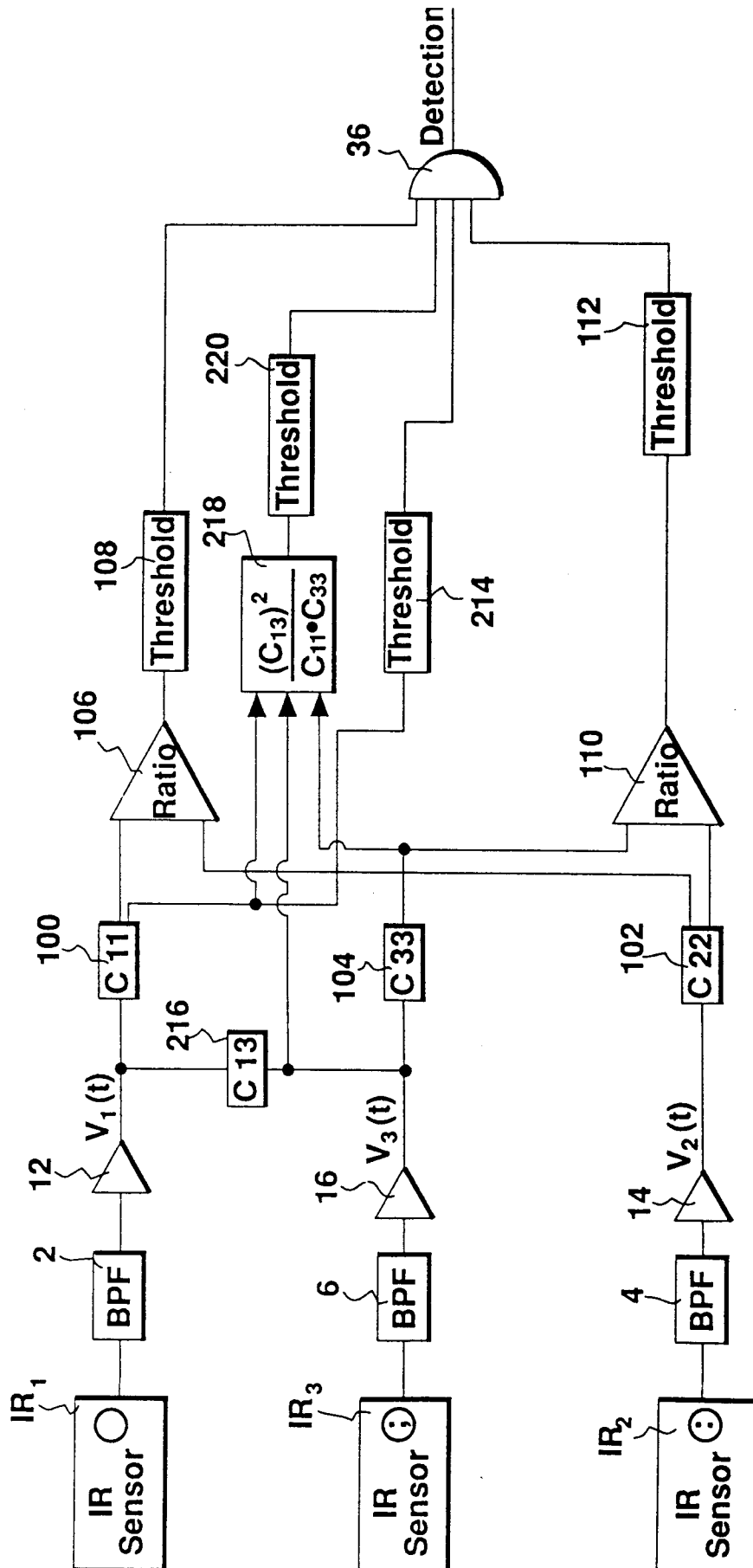


FIG . 8