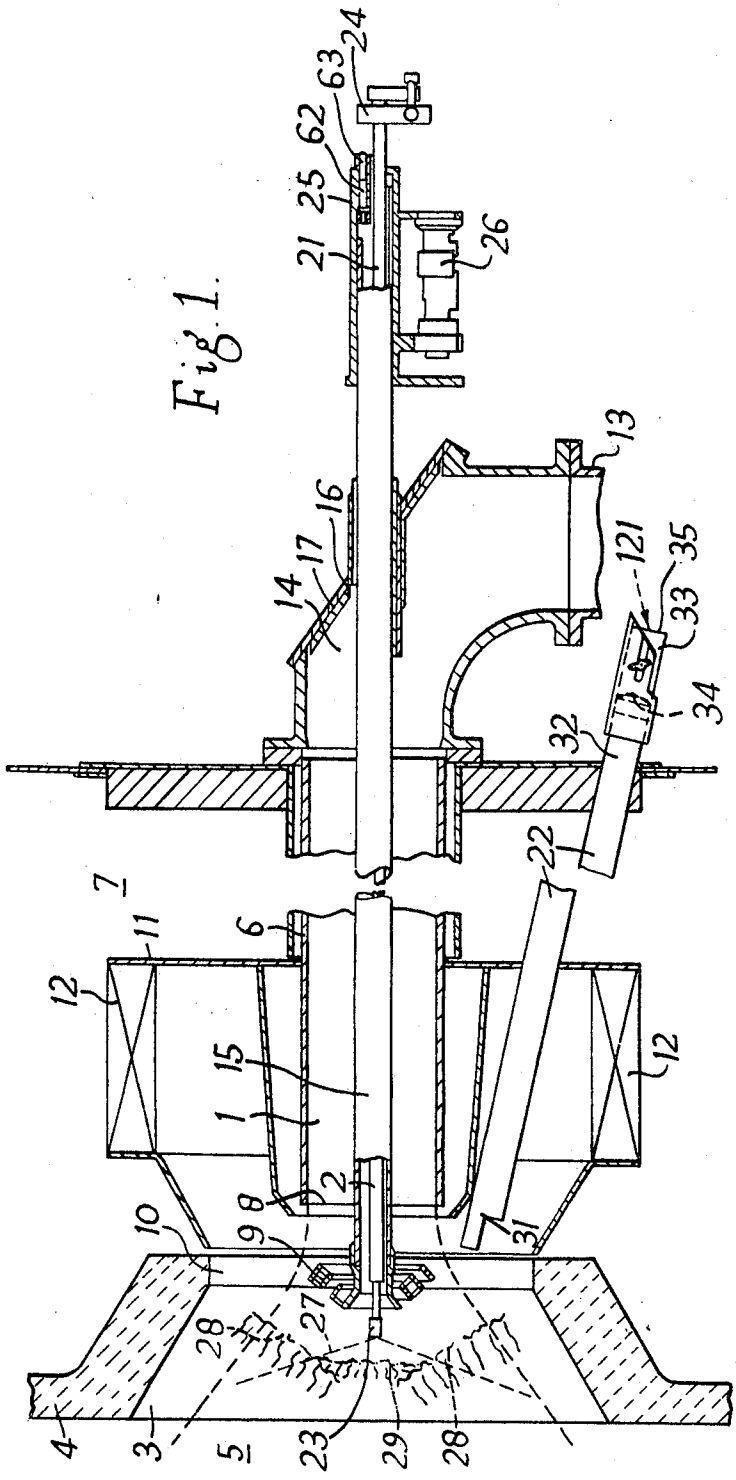
Sept. 1, 1970 O. W. DUMPLETON 3,526,770

FLAME PHOTOMETER USING PHOTOVOLTAIC CELL HAVING LOGARITHMIC RESPONSE

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Fig. 1.



INVENTOR
Owen W. Dumpleton

BY J. P. Moran
ATTORNEY

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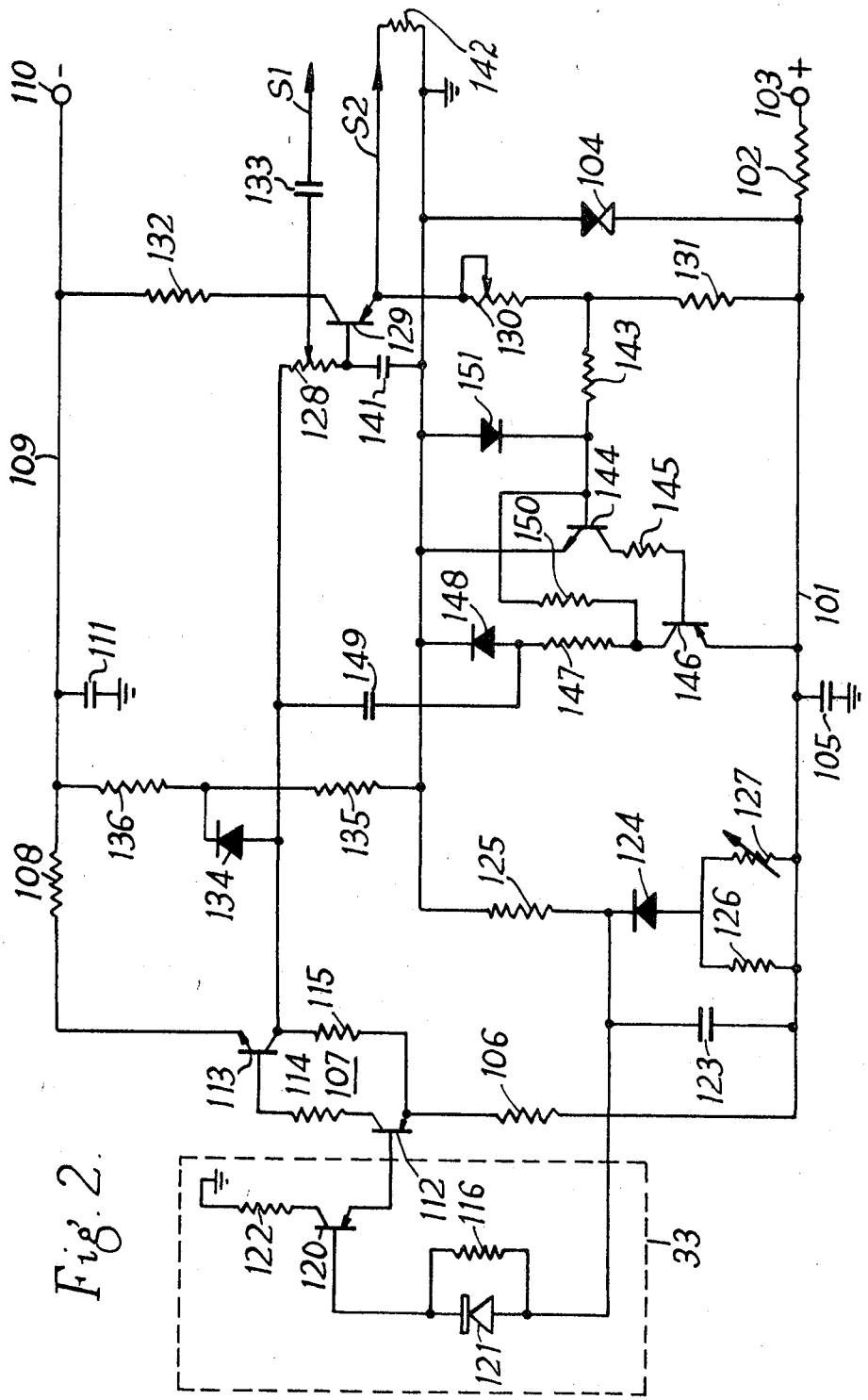


Fig. 2.

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FLAME PHOTOMETER USING PHOTOVOLTAIC CELL HAVING LOGARITHMIC RESPONSE

Owen W. Dumpleton, North Harrow, Middlesex, England, assignor to Babcock & Wilcox Limited, London, England, a corporation of Great Britain

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ABSTRACT OF THE DISCLOSURE

An arrangement of apparatus for monitoring a flame from a burner is provided in which a photovoltaic device having a logarithmic response characteristic is utilized in conjunction with an electrical circuit to obtain an output representative of the ratio of flame radiation flicker to average flame radiation.

Flame monitoring apparatus is useful in connection, for example, with water tube boiler furnaces having a plurality of burners and in such application radiation responsive means in the form of photo-conductive cells may be placed at the outer ends of sighting tubes in line with the flame fronts of the burners and connected in electronic circuits so that the photo-cells, responding to radiations from the burner flames, may cause actuation of desired indicating and/or alarm and/or control means, as for example, means to sound an alarm and to cut off fuel supply to a burner if combustion at the burner becomes unsatisfactory. Since an efficient or healthy flame at a burner tends to produce a characteristic flicker or high frequency fluctuation, the radiation therefrom which is absent or not present to the same degree if the combustion at the burner is inefficient, the flicker response of the cell is useful for monitoring. As pointed out in British Pats. Nos. 962,800, 976,621 and 976,622, it is advantageous to compare the flicker component of the cell radiation with the average radiation of the cell since thereby healthy combustion may be detected even if the cell flicker responses are weakened by causes such as possible deposits on sight glasses of the sighting tube and in those patents means are described for making comparisons between the flicker component of the radiation and the average radiation of certain photo-conductive cells and electronic circuits yielding outputs representative of such comparisons.

The present invention is based on the appreciation that the derivation of a circuit output which is representative of the ratio of flame radiation flicker to average flame radiation may be facilitated by the proper exploitation of a photo-cell to receive the radiations which has certain suitable characteristics. According to the invention, in apparatus for monitoring a flame from a burner, including radiation responsive means arranged to receive flame radiation and connected in an electronic circuit adapted to provide an output representative of the ratio of flame radiation flicker to average flame radiation, the radiation responsive means is a photovoltaic device arranged so that the E.M.F. generated thereacross is proportional or substantially so to the logarithm of the illumination thereof by flame radiation and the E.M.F. fluctuations thereacross are detected to provide the desired output.

A suitable photovoltaic device may be a silicon photovoltaic cell having the characteristic that when operated at constant current therethrough or at a very low current therethrough the E.M.F. thereacross in volts (v) is proportional to the logarithm of the radiation at the cell measured in lumens per square foot (L), i.e. v is proportional to log L. This equation can lead to the differential equation that dv is proportional to dL/L, which may be physically interpreted as a statement that a measurement of voltage fluctuations across the cell having an amplitude equal to dv gives a measure of the ratio of radiation fluctuations of amplitude dL at the cell to the average radiation L at the cell. Thus if the said ratio remains the same because the combustion efficiency at a burner monitored by apparatus properly using said cell remains high the measurement of voltage fluctuations across the cell will remain constant in spite of the depositing of dust on sight glasses or other causes reducing the transmission of radiation from the flame to the cell.

It will be understood that the formation of an output representative of the ratio of flame radiation flicker to average flame radiation and suitable to cause actuation of desired indicating and/or alarm and/or control means when the appropriate conditions arise may require the amplification of voltage fluctuations across the cell arising from flame flicker and may require the rectification of the amplified fluctuations.

Suitably the flame monitoring apparatus when applied to monitoring the flame of a burner of a water tube boiler furnace provides not only a signal representative of the ratio of flame radiation flicker to average flame radiation but an additional signal derived from the cell response and representative of the average radiation at the cell, which signal may be used for additional indicating and/or alarm and/or control purposes. Thus the value of said additional signal may be such as to denote unserviceability of the flame monitoring apparatus by reason of excessive deposits on sight glasses between the flame and the cell, or, if it is known that the apparatus is serviceable, may denote that the flame is extinguished. The additional signal, instead of or in addition to being used for the said indicating and/or alarm and/or control purposes may be used to interrupt the passage of the first signal, whereby indicating devices, for example, to which the first signal passes, may not falsely show efficient combustion at a burner not in operation, which it might otherwise do if the cell responds to radiation reflected by some surface from another burner in operation in the same furnace.

The invention will now be described by way of example with reference to the accompanying drawings in which:

FIG. 1 is a sectional side elevation of a pulverized coal burner arranged at a combustion chamber firing port and having an oil burner arranged coaxially thereof; and

FIG. 2 is a circuit diagram of an electrical network for generating output signals in dependence upon fluctuating burner flame illumination of a silicon photovoltaic cell.

Referring to FIG. 1 of the drawings, a pulverized coal burner **1** and an oil lighting-up and auxiliary burner **2** are arranged for discharge of respective fuels at a firing port **3** in a water-cooled side wall **4** of a combustion chamber **5**. The pulverized coal burner **1** is of the kind which tends to give a flame surrounding a space or hollow core near the burner and about the axis and in which pulverized coal entrained by a stream of primary combustion air is conducted to the firing port in a pipe **6** which extends axially of the firing port; the pipe **6** extends through a windbox **7** on the outer side of the combustion chamber wall **4**, and the pulverized coal and primary air shortly after leaving the open end **8** of the pipe **6** impinge upon a pulverized fuel burner vaned diffuser or impeller **9** which is arranged at the throat or narrowest part **10** of the firing port **3** and which is adapted to give radially outwardly directed components of motion to pulverized coal particles as well as to promote mixing between the primary air and secondary combus-

tion air that flows through the throat **10** around the diffuser **9** and comes from the windbox **7**. The secondary air is admitted to the throat under control of an air register **11** comprising an annular row of rotatable vanes **12** which can be closed upon one another to an adjustable extent to vary the air through-flow area.

The pulverized coal and primary air are supplied to the burner by a vertical conduit **13** outside the windbox **7** and through an elbow piece **14** secured at one end to the pipe **6** and at the other end to the conduit **13**. The diffuser **9** is secured at the inner end of a tubular member **15** which extends axially of the port within the pipe **6** and through an aperture **16** in a cover plate **17** of the elbow piece **13**. Supported within the tubular member **15** and extending longitudinally thereof and outwardly beyond the tubular member is the barrel **21** of the oil burner **2**, which is pressure-atomizing and which comprises an atomizer head **23** secured in relation to the inner end of the barrel **21** and a burner tail piece **24** to which the outer end of the barrel **21** is secured. At the outer end of the tubular member **15** the burner barrel **21** is slidably supported by part of a support bracket **25**, which bracket is secured to the tubular member **15** and carries a pneumatic cylinder (not shown) of piston and cylinder means for moving the burner tail piece **24**, and therewith the burner barrel **21** and the atomizer head **23**, longitudinally of the tubular member **15**. The support bracket **25** also carries an oil valve box **26** to which oil for the oil burner is supplied and from which an oil hose (not shown) leads to the burner head.

The support bracket **25** also carries a pneumatic cylinder (not shown) of piston and cylinder means for moving longitudinally an igniter tube (not shown) also extending within the tubular member **15** and arranged to one side of the burner barrel **21** and carrying at its inner end an electric spark igniter tip.

When the burner tail piece, burner barrel and burner atomizer head are projected inwardly towards the combustion chamber **5** the atomizer head attains the operative position shown in which it is within the firing port **3** and nearer the combustion chamber than the pulverized fuel burner diffuser **9**, and the oil spray **27** from the atomizer head does not impinge upon the diffuser. When the burner tail piece, burner barrel and burner atomizer head are retracted outwardly away from the combustion chamber the atomizer head **23** attains an inoperative position in which it lies within the tubular member **15**. When the igniter tube is in its projected operative position it lies within the firing port **3** and nearer the combustion chamber than the atomizer head **23** while it is in its retracted inoperative position it also lies within the tubular member **15**.

When the pulverized coal burner **1** alone is operated and the coal flame therefrom is normal, ignition of coal particles commences within the firing port **3** at a short distance from the diffuser **9** and the flame front may be at an annular surface or region roughly in the position indicated by the broken wavy line **28**. When the oil burner **2** alone is operated and the oil flame therefrom is healthy, ignition of atomized oil commences within the firing port **3** at a short distance from the atomizer head **23**, which is in projected position, and the flame front will be at a line or zone roughly in the position indicated by the wavy chain line **29**.

A sighting pipe **22** is provided for enabling a silicon photovoltaic cell **121** (not visible in FIG. 1 but which will be referred to in connection with FIG. 2) arranged outside the windbox **7** to view the flame fronts. The sighting pipe **22** is vertically below the pipe **6**, its inner end **31** is open and is at a location below and somewhat outwardly of the diffuser **9**, its outer end carries a flame sighting head **33** in which the cell **121** is housed and the pipe **22** is inclined so that radiation from the flame fronts can pass outwardly along it. The flame sighting head **33** has a suitable lens **34** at its inner end and suitably the cell **121** is mounted within the flame sighting head on a printed circuit panel (not shown) located in relation to the inner face of the outer end plate **135** of the head. The said printed circuit panel in the interior of the flame sighting head also carries besides the cell **121**, a transistor **120** and resistors **116** and **122** (not shown but which will be referred to in connection with FIG. 2).

Referring to FIG. 2, an electric network generating output signals in dependence upon fluctuating illumination of the cell **121** includes a positive line **101**, supplied through a resistor **102** from +15 volts terminal **103**, stabilized in potential with respect to earth by a Zener diode **104** and connected to earth through a capacitor **105**, which is connected through a resistor **106** to an amplifier **107** which is connected through a resistor **108** to a negative line **109** supplied from a −15 volt terminal **110** and connected to earth through a capacitor **111**. The amplifier comprises a p-n-p transistor **112** having its emitter connected to the resistor **106**, an n-p-n transistor **113** having its emitter connected to the resistor **108**, a resistor **114** connected between the collector of the transistor **112** and the base of the transistor **113** and a resistor **115** connected between the emitter of the transistor **112** and the collector of the transistor **113**.

The input to the amplifier **107** is provided from the emitter, which is connected to the base of the transistor **112**, of the transistor **120** already mentioned, which is of the p-n-p type and of which the base is connected to the cathode of the silicon photovoltaic cell **121**, which is of type MS4B of Ferranti Limited. The collector of the transistor **120** is connected to earth through the already mentioned resistor **122**. The anode of the cell is connected to a point, connected to line **101** through a capacitor **123**, between a diode **124** and a resistor **125** in a voltage-dividing chain connected between the line **101** and earth and comprising, in series, a fixed resistor **126** and a variable resistor **127** connected in parallel to the line **101**, the diode **124** and the resistor **125**. The cell is shunted by the already mentioned resistor **116**.

The collector of the transistor **113** is connected through a tapped resistor **128** to the base of a p-n-p transistor **129** of which the emitter is connected through a variable resistor **130**, and, in series therewith, a resistor **131** to the positive line **101** while the collector of the transistor **129** is connected through a resistor **132** to the negative line **109**. A signal S1 depending upon the flicker in the illumination of the cell is taken through a capacitor **133** from the tapping point on the resistor **128**. The collector of the transistor **113** is also connected through a diode **134** other end is connected to earth and a resistor **136** of which the other end is connected to the negative line **109**. The base of the transistor **129** is connected to earth through a capacitor **141**. A signal S2 depending upon the average illumination of the cell **121** is taken from the emitter of the transistor **129**. It is assumed that the means receiving the signal S2 provides a resistance path **142** to earth.

The point of connection between the resistors **130** and **131** is connected through a resistor **143** to the base of an n-p-n transistor **144**, of which the emitter is connected to earth while the collector is connected through a resistor **145** to the base of a p-n-p transistor **146**. The emitter of the transistor **146** is connected to the positive line **101** and the collector thereof is connected through a resistor **147** and, in series therewith, a diode **148** to earth. The collector of the transistor **113** is connected with a capacitor **149** to the junction between the resistor **147** and the diode **148**. The collector of the transistor **146** is connected through a resistor **150** to the base of the transistor **144**. The base of the transistor **144** is also connected to earth through a diode **151**.

The circuit is adapted to operate so that when the cell **121** receives normal characteristic flickering radiation from at or near the flame front of a pluverized fuel flame due to the operation of the burner **1** and/or an atomized oil flame due to the operation of the burner **2**, the cell responds to generate a fluctuating E.M.F. which is am-

plified so that a fluctuating E.M.F. is produced at the collector of the transistor **113**. The flicker component of this E.M.F. gives rise to the signal **S1**. The current through the cell is small and the said signal **S1**, in view of the logarithmic character of the cell response to radiation, is representative of the ratio of the flicker component of the cell radiation to the average cell radiation. By suitable choice of circuit components it is arranged that the said flicker component consists wholly or mainly of the higher frequencies characteristic of the flame front. The signal **S1** is preferably passed to an amplifier the output of which is rectified to produce a signal for desired indicating and/or recording and/or controlling purposes. The capacitance **141** shunts to earth the fluctuating component of the E.M.F. applied to the base of the transistor **129**, so that the output of the transistor **129**, which is traversed by current flowing from earth through the resistor **142** to the transistor and from the transistor through the resistor **132** to the negative line **109**, is a D.C. signal **S2** representative of the average cell radiation.

When the signal **S1** denotes that the ratio of flame radiation fluctuations or flicker to average radiation at the cell has an appropriate value the flame is healthy or efficient. If the radiation of the cell by a healthy flame changes, e.g. if it falls somewhat owing to partial interruption of the radiation path to the cell, the signal **S2** will change but the signal **S1** will continue to have the value denoting a healthy flame. This circumstance will be due to this, that by virtue of the logarithmic characteristic of the cell the output voltage fluctuations at the cell are not only directly proportional to the corresponding radiation fluctuations at the cell but also inversely proportional to the average radiation at the cell and both radiation fluctuations and average radiation at the cell fall proportionately if the radiation path to the cell becomes partially interrupted.

The values of the signals **S1** and **S2** may be displayed on the dials of indicating meters (not shown). The said meters may be mounted on a panel with a plurality of lamps of which the illuminations are arranged to denote various conditions of burner operation, for which purpose means may be provided to yield a signal indicative of the presence or absence of oil pressure at the oil burner, means may be provided to yield a signal indicative of the delivery or lack of delivery of pulverized fuel into the primary air stream therefor and the support bracket **25** (FIG. 1) may carry a housing **62** for a photo-conductive cell **63** which is arranged to receive radiation passing along the tubular member **15** in the upper half thereof. An example of a way of labelling and controlling the illumination of such lamps is described in British Pat. No. 976,621.

The transistors **144** and **146** are normally non-conducting. The resistance value of the resistor **130** is adjusted so that when the E.M.F. of the signal **S2** rises above a value representing a predetermined low value of cell radiation, the junction point between the resistors **130** and **131**, connected through the resistor **143** to the base of the transistor **144**, rises above a value enabling the transistor **144** to conduct, whereupon, by virtue of the conduction of the transistor **146** and the feed back through the resistor **150** a cumulative or trigger action takes place and the conductions of the transistors **144** and **146** rise to maxima. When the transistor **146** is conductive current flows through the diode **148**, which enables the flicker component of the fluctuating E.M.F. at the collector of the transistor **113** to be substantially short circuited through the capacitor **149** to earth and the signal **S1** is substantially annulled. Thus the circuit ceases to supply a significant signal **S1** when the burner is not in operation.

The transistor **120** is a silicon junction transistor and is housed in the flame sighting head **33** together with the silicon cell **121** so that it may have the same or approximately the same ambient temperature as the cell and thereby exert a compensation for changes in the characteristic of the cell with temperature. Similarly and for a similar reason preferably the transistor **112** and the diode **124** are both silicon circuit elements and are positioned one near to the other so as to have the same or substantially the same ambient temperature.

The diode **151** is provided to make possible a current from earth through the resistor **143**, when the transistors **144** and **146** are non-conducting, which will ensure suitable reduction of the voltage from the emitter to the base of the transistor **144** existing under normal circumstances.

The capacity **141** is suitably of larger value than necessary to annul the flicker component at the base of the transistor **129**, so that the signal **S2** is damped against immediate full responses to transient variations of average cell illumination.

The diode **134** is provided in order to ensure a certain value of the signal **S2** even in the absence of cell illumination. The diode **124** is selected with the aim of providing compensation for the variation with temperature of the characteristics of the transistor **112**. The resistance **116** is a relatively high resistance.

What is claimed is:

1. Apparatus for monitoring a flame from a burner, comprising a photovoltaic device having a logarithmic response characteristic, the device being operated such that the output E.M.F. thereacross is proportional to the logarithm of flame illumination thereof, an electrical circuit connected to receive the output of the device and detect variations in the E.M.F., the variations being a measure of the ratio of flame radiation flicker to average flame radiation, the electrical circuit providing an output representative of the ratio, and means connected to the output of the electrical circuit and actuatable thereby.

2. Apparatus as claimed in claim **1**, wherein the photovoltaic device is a silicon photovoltaic cell.

3. Apparatus as claimed in claim **2**, wherein the cathode of the cell is connected to the base of a p-n-p silicon transistor to control the current through said transistor, said transistor being positioned so as to have the same ambient temperature as the cell.

4. Apparatus as claimed in claim **3**, wherein the electrical circuit comprises first and second circuit chains, the transistor is arranged to control the base current of a second silicon transistor in the first chain, the first chain is connected between a source of positive potential and a source of negative potential, the second chain is a voltage-dividing chain comprising electrical resistance in series with a silicon diode and further electrical resistance and is connected from the source of positive potential to earth, the anode of the cell is connected to the point of connection between the diode and the further electrical resistance, and the second silicon transistor and diode are positioned one near the other so as to have the same ambient temperature.

5. Apparatus as claimed in claim **4**, further comprising means for annulling the output representative of said ratio when the average intensity of radiation received by the cell becomes lower than a predetermined fixed value.

6. Apparatus as claimed in claim **5**, wherein the electrical circuit further comprises, a third circuit chain, a conductor carrying a fluctuating potential from the fluctuations of which the output representative of the ratio is derived, a capacitor and second diode through which the conductor is connected to earth, the second diode being in the third circuit chain, and the third circuit chain being normally non-conducting and rendered conducting by feedback means when the average intensity of radiation received by the cell becomes lower than a predetermined value.

7. Apparatus as claimed in claim **6**, wherein the third circuit chain includes a normally non-conducting p-n-p transistor controlled by a normally non-conducting n-p-n transistor, the feedback means comprises a resistor connected from the base of the normally non-conducting n-p-n transistor to a point between the second diode and

capacitor and also to the collector of the normally non-conducting p-n-p transistor, and the conductor is substantially short circuited to earth through the capacitor and second diode when the average intensity of radiation received by the cell becomes lower than the predetermined value.

8. Apparatus as claimed in claim **7**, wherein the electrical circuit also provides an output signal representative of the average value of radiation received by the cell.

9. Apparatus as claimed in claim **2** wherein the electrical circuit has a p-n-p silicon transistor connected therein, the cathode of the cell is connected to the base of the transistor, and the transistor compensates for a change in the cell's response characteristic occasioned by a change in temperature of the cell.

10. Apparatus as claimed in claim **2** wherein the cathode of the cell is connected to the base of a p-n-p transistor of the circuit, and the transistor is positioned so as to have the same ambient temperature as the cell.

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