

April 5, 1966

L. G. BLEVINS

3,245,067

DETECTION OF PRODUCTS OF COMBUSTION

Filed May 24, 1963

3 Sheets-Sheet 1

Fig. 1.

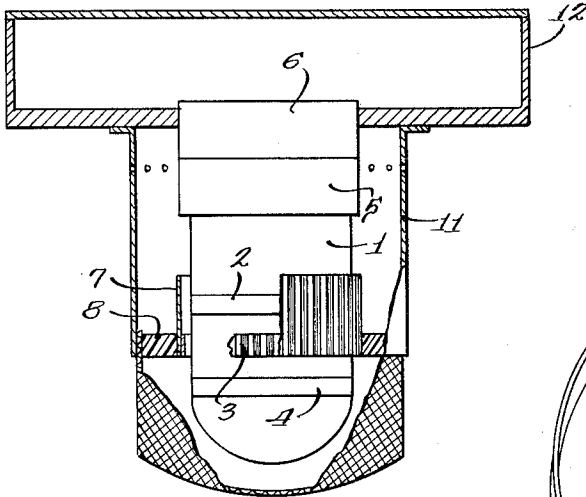


Fig. 2.

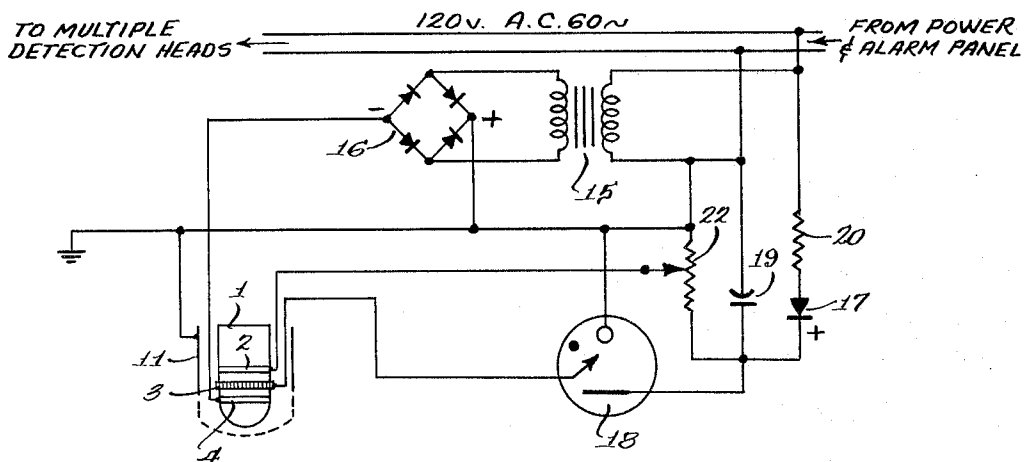
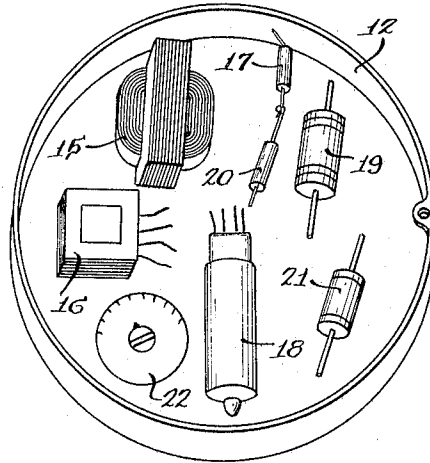


Fig. 3.

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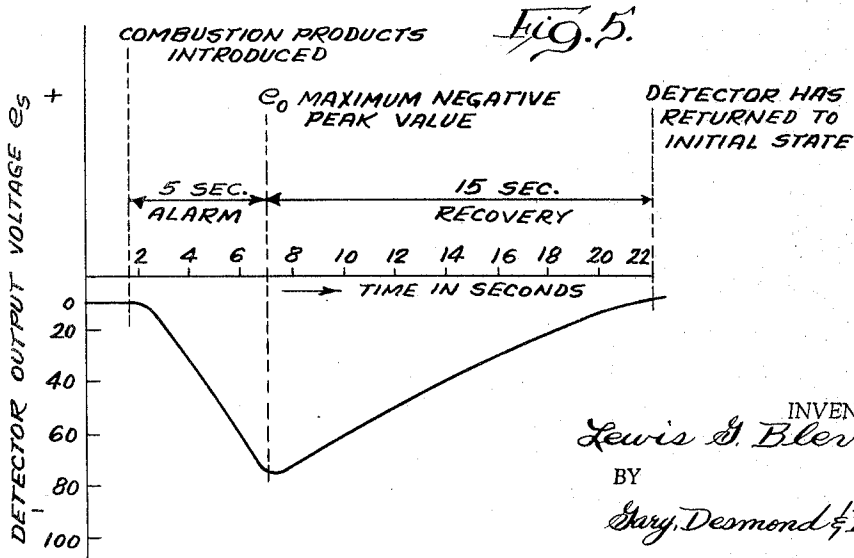
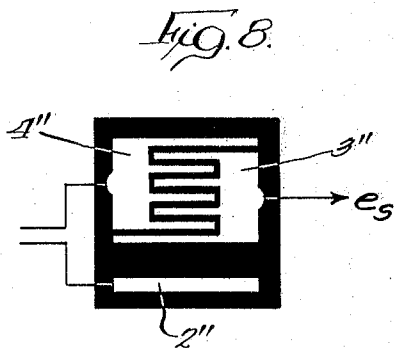
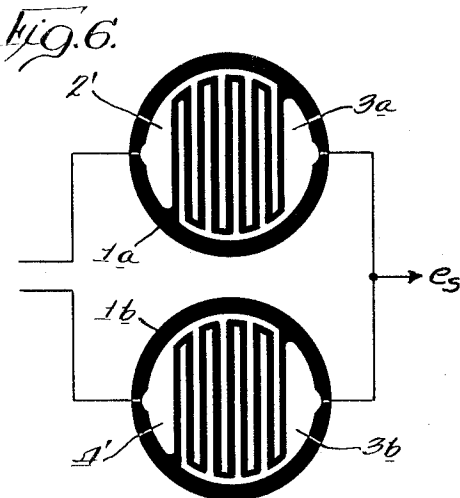
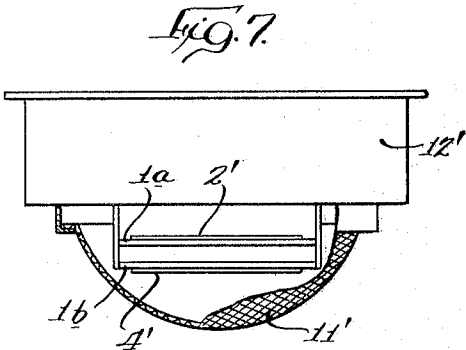
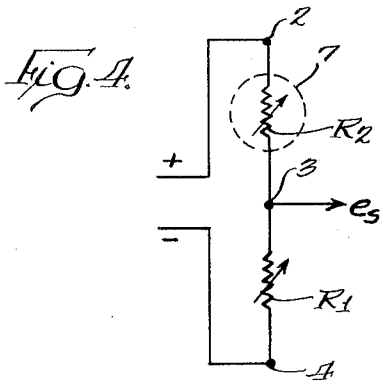
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DETECTION OF PRODUCTS OF COMBUSTION

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3 Sheets-Sheet 2



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DETECTION OF PRODUCTS OF COMBUSTION

Filed May 24, 1963

3 Sheets-Sheet 3

Fig. 9.

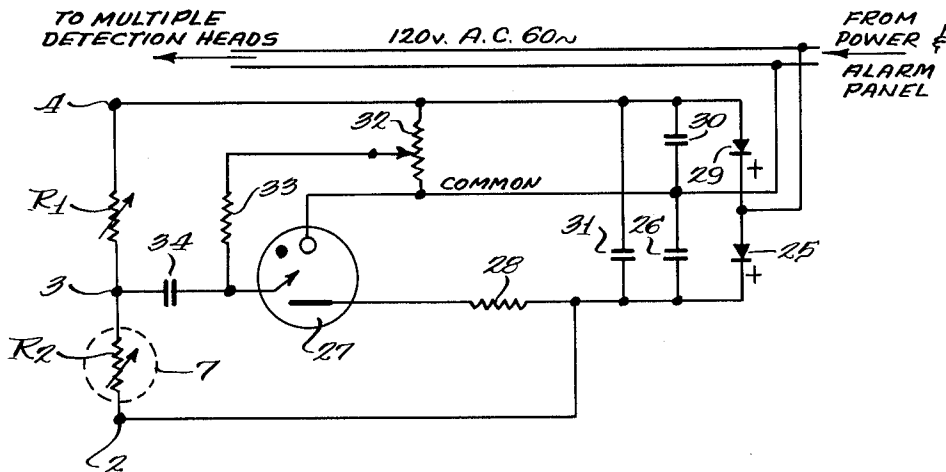
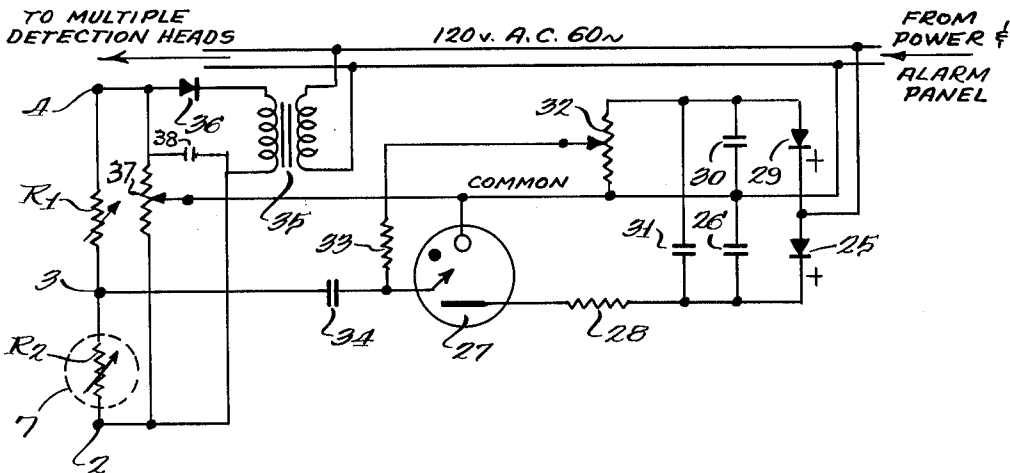


Fig. 10.



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3,245,067

DETECTION OF PRODUCTS OF COMBUSTION
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tronics, Inc., Skokie, Ill., a corporation of Illinois
Filed May 24, 1963, Ser. No. 283,070
16 Claims. (Cl. 340-228)

This application is a continuation-in-part of my co-
pending application Serial No. 204,545, filed June 22,
1962, now abandoned.

The present invention relates to apparatus for sensing
or detecting a predetermined abnormal environmental
condition in an atmosphere, such as the existence of
products of combustion in the atmosphere of a room or
other space thereby to warn of the imminence of fire; and
particularly, to an improved early warning fire detector
for detecting fire in its incipient stage.

In general, a fire is comprised of and passes sequential-
ly through four stages; first, the incipient stage wherein
only invisible products of combustion are given off and
the fire is not humanly discernible because there is no
smoke, flame or sensible degree of heat; second, the
smoke stage; third, the flame stage; and fourth, the heat
stage generated by the flames. The first or incipient stage
is generally of long duration, i.e., hours, days or weeks,
and creates of itself practically no hazard to humans or
property. Once the fire passes into the smoke stage, it
progresses very rapidly and in minutes or even seconds
will be characterized by smoke, flame and heat, each of
which results in a high degree of hazard, causes property
damage and perils human life.

Heat, or fourth stage fire detectors are well-known in
the art, the same usually comprising thermally responsive
resistors (thermistors), bimetal elements (thermostats),
and the like. Smoke or second stage fire detectors are
also well-known, the same usually comprising a light
source and photocell means purportedly operating on the
theory that smoke will cause sufficient obscuration or
dimming of the light beam to trigger the photocell.
These detectors suffer the severe disadvantage that they
are incapable of acting until the fire has attained a
high hazard level, is actually causing property damage
from smoke or from smoke, flame and heat, and human
life has been jeopardized or lost.

To avoid property damage, but most importantly to
avoid subjecting human beings to peril, injury and death
due to fire, it is imperative to detect and warn of the im-
minence of the high hazard stages of the fire, i.e., smoke,
flame and heat, before they occur; in other words, to
detect and warn of the fire during its incipient or invis-
ible stage.

Prior to the present invention, there was only one fire
detector, within the realm of my knowledge, capable of
detecting a fire in its incipient stage. That detector is
predicated upon ionization principles, utilizing radio-
active material in an atmosphere sampling ionization
chamber to ionize the air passing therethrough. The de-
tector operates as a function of the decrease in ionization
capability of the radioactive material resulting from the
fact that the invisible products of combustion given off
by an incipient fire are of larger particle size and slower
moving than the air particles usually making up the
ambient atmosphere in which the chamber is located.
The necessity for ionization, and the use of unshielded
radioactive materials cause this detector to be a possible
source of danger, place the same in conflict with the laws
of many municipalities and states, and contribute to the
high cost of the detector.

The object of the present invention is to provide im-
proved apparatus for detecting a fire in its incipient stage
that is of simple and economical manufacture and im-

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proved operating characteristics, that is not dependent
upon smoke, flame or heat (but will operate upon oc-
currence of any one or more of the three), and that does
not require ionization of the air or use of radioactive
materials; wherefore the invention eliminates all of the
disadvantages of the prior art while attaining the optimum
in fire detection, especially the capability of detecting a
fire before the same reaches a high hazard level jeopard-
izing property and human lives.

The invention is predicated upon the facts that a fire,
even in its incipient stage, produces a very rapid in-
crease in the water vapor content of the atmosphere
and also gaseous products of combustion that are of
relatively large particle size and relatively slow-moving;
that variations in water vapor content result in a cor-
responding variation in the surface resistivity of many
materials; and that the relatively large particles com-
prising the products of combustion have a greater degree
of electrical conductivity than the air particles of the
normal ambient atmosphere. It is the object of the inven-
tion to utilize either or both, preferably both, of these
phenomena to provide means for detecting the presence
of products of combustion well before a fire reaches the
humanly sensible stage of smoke, flame or heat.

Specifically, the invention proposes the application to
fire detection of electrical impedance means sensitive to
either or both of the electrical conductivity and water
vapor content of the atmosphere, and operable as a func-
tion of the rapid increase in conductivity and/or water
vapor content that occurs upon initiation of a fire. Since
an increase in water vapor content will generally act to
increase electrical conductivity, water vapor will herein
be included within the intended meaning of the broader
term electrical conductivity, through water vapor may in
fact be the only criterion sensed.

In application of our impedance means to fire detec-
tion, and in fire detection apparatus heretofore known
in the art, a bridge circuit is employed including a first
sensor (thermistor, thermostat, photocell or ionization
chamber) exposed to ambient atmosphere and constitut-
ing detecting means and a second sensor like the first but
shielded from ambient atmosphere and comprising means
for compensating the first sensor or detecting means with
respect to certain predetermined changes in the atmos-
phere or in the criterion selected for purposes of detec-
tion (heat, smoke or decreased capacity for ionization);
the output of the bridge thus formed being coupled to a
trigger device adapted to actuate an alarm upon occur-
rence of a predetermined degree of imbalance between
the detecting means and the compensating means.

Considering the foregoing, the present invention resides
in an improved early warning fire detector comprising, in
combination, a bridge circuit having detecting means for
detecting the presence of products of combustion in the
atmosphere, means for compensating the detecting means
with respect to slowly changing atmospheric conditions,
an electrical input to said means and an electrical output
from said means, and alarm trigger means coupled to
said output, characterized in that said detecting means
and said compensating means comprise impedance means
sensitive to the change in electrical conductivity occurring
between air and air-laden with products of combustion,
both of said impedance means being exposed to the atmos-
phere and the one thereof comprising the compensating
means having a relatively delayed response to changes
in the electrical conductivity of the air, whereby the de-
tecting impedance means produces a signal to trigger the
alarm upon occurrence of the rapid change in the electri-
cal conductivity of the atmosphere when a fire starts.

The invention further provides an early warning fire
detector operating as a function of the rate of change of

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the water vapor content of the atmosphere to which it is exposed, i.e., the rapid rate of change in the water vapor content of the atmosphere occurring upon initiation of a fire, characterized in that the above described detecting impedance means and compensating impedance means both comprise substrate means the surface resistivity of which varies in relation with variations in the water vapor content of the atmosphere contacting the same and spaced electrodes on said substrate means defining a pair of input electrode means and output electrode means.

Moreover, the invention, in its preferred embodiment, provides an early warning fire detector operating as a consequence of both the change in the water vapor content and the change in the electrical conductivity of the atmosphere to which it is exposed upon initiation of a fire, characterized in that at least the detecting impedance means is comprised of substrate means as above defined and closely adjacent input and output electrodes adapted to be bridged by the relatively large, electrically conductive particles comprising the products of combustion.

Other objects and advantages of the invention will become apparent in the following detailed description.

Now, in order to acquaint those skilled in the art with the manner of making and using my improved means for detecting products of combustion, I shall describe, in connection with the accompanying drawings, preferred embodiments of my device and the preferred manners of making and using the same.

In the drawings:

FIGURE 1 is a side view, partly in section and partly in elevation, of one embodiment of my improved device for detecting products of combustion;

FIGURE 2 is a top plan view of the detector with its cover plate removed showing the power supply and signal means thereof;

FIGURE 3 is a schematic circuit diagram of the detector and its power supply and signal means;

FIGURE 4 is a schematic diagram of the impedance means provided by the embodiment of the invention shown in FIGURE 1;

FIGURE 5 is a graphic representation of the signal produced by the detector of the invention upon exposure to air laden with products of combustion;

FIGURE 6 is a combined schematic diagram and plan view of a second embodiment of the impedance means of the present invention;

FIGURE 7 is a side view, partly in section and partly in elevation, of an embodiment of my improved device utilizing the impedance means of FIGURE 6;

FIGURE 8 is a combined schematic diagram and plan view of a further embodiment of the impedance means provided according to this invention;

FIGURE 9 is a schematic diagram of an improved power supply and signal circuit for my detector; and

FIGURE 10 is a schematic diagram of further improved circuit for my detector.

In view of the altered understanding of the mode or theory of operation of my detector, I have illustrated in the accompanying drawings what I now regard to be the preferred embodiments of my invention and have not shown the structure illustrated in said co-pending application as that structure is no longer the best mode contemplated by me for carrying out my invention.

Referring to the drawings, one embodiment of my improved detecting device is shown in detail in FIGURES 1 and 2. In this embodiment, the detector unit comprises a cylindrical glass tube 1, which is essentially a conventional glass radio tube envelope. While not necessary, this tube may if desired have a conductive coating on its inner surface and may be fully or partially evacuated and/or may be charged with a selected gas. The internal treatment of the tube may be helpful in some cases, but the essence of the detecting unit is the exterior surface of the tube and the means applied thereto.

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The tube 1 is equipped with three external electrodes, namely three spaced bands 2, 3 and 4 encircling the tube. The upper and lower bands 2 and 4 are preferably formed by firing drawn lines of silver onto the surface of the tube, the two bands having straight edges and being uniformly spaced from one another about the circumference of the tube. The intermediate electrode 3 may be formed in the same manner if desired, but I have successfully employed a corrugated band of highly conductive material secured about the tube in intimate contact therewith. The electrode 3 is positioned on the tube centrally between the electrodes 2 and 4 with its opposite edges spaced equal distances from the electrodes 2 and 4 about the full circumference of the tube, whereby the intermediate electrode 3 comprises a common output electrode for a pair of impedance means comprised, respectively, of electrodes 2 and 3 and the intervening surface of the tube 1, and electrodes 4 and 3 and the intervening surface of the tube.

Each of the electrodes 2, 3 and 4 is connected by a suitable lead to a conventional base 5 for the tube 1, which base is adapted to be plugged into a conventional adapter or socket 6. As shown in FIGURE 1, the tube is preferably mounted in inverted position on and depends downwardly from the base 5.

The upper impedance means, i.e., the impedance defined by electrodes 2 and 3, is intended as a balancing or compensating impedance to prevent actuation of the detector as a consequence of normally occurring atmospheric changes, such as temperature, humidity and barometric pressure changes, which usually occur at a relatively slow rate. To shield this impedance so that it will compensate for relatively slowly occurring changes, but will not compensate quickly for rapidly occurring changes, I mount a corrugated shield 7 of insulative material on the corrugated electrode 3 and extend this shield from the electrode 3 well beyond the electrode 2 in completely encircling relation to the electrode 2 and the tube 1. Also, I provide a disc 8 of insulative material between the shield 7 and a protective housing 11 so that atmospheric air can pass between the electrodes 3 and 2 only via the ducts defined by the corrugations of the electrode 3 and shield 7, thereby to provide a restricted passage to atmosphere for the purpose of balancing out slowly changing ambient conditions due to natural and artificial causes.

The housing 11, which is an overall protective housing, encloses the aforementioned detector elements. Housing 11 consists of a suitable metal or plastic enclosure equipped at its lower extremity with a perforated, screen or mesh section that permits free passage of the atmosphere and products of combustion to the area of the tube 1 below the insulative disc 8, i.e., to the lower impedance means defined by electrodes 3 and 4 and to the restricted passages defined by the corrugated members 3 and 7. Above the disc 8, the housing 11 is preferably imperforate, except for a few vent apertures near its upper extremity, so as to maintain the shielded condition of the compensating or balancing impedance. At its upper end, housing 11 is attached to a base 12 within which the socket 6 is secured.

Base 12 (FIGURE 2) is a molded, or otherwise fabricated, insulative enclosure which houses the detector's electronic and electrical components and circuitry. Specifically, the base 12 is hollow and open at its top, the top end thereof being adapted for reception of a detachable cover plate (not shown) which is equipped with electrical contacts which mate with a matching and locking or mounting means facilitating detachable mounting of the detector on a terminal box or the like mounted on the ceiling of a room or space to be protected by the detector.

Housed within the base 12 are a transformer 15, a full-wave rectifier 16, a half-wave rectifier 17, a triggering device 18, a capacitor 19, fixed resistors 20 and 21, and a variable resistor or potentiometer 22. Transformer 15 is an isolation transformer for electrically isolating the

full-wave rectifier 16 from the line circuit, the rectifier comprising a pulsating power supply for the impedance unit. Half-wave rectifier 17 provides D.C. power to energize the alarm triggering device 18. Capacitor 19 smoothes the pulsating output of rectifier 17. Resistor 20 is a low value protective resistance to protect half-wave rectifier 17 from the peak charging current of smoothing capacitor 19. Resistor 21 is incorporated to provide sufficient current passage in the normal "non-alarm" state for operating a supervisory relay at the main panel of an installation. Potentiometer 22 affords a sensitivity control.

With reference to FIGURE 3, the rectifier 17 provides a source of positive direct current at a potential approximately equal to that of the peak value of the signal circuit voltage which is supplied to the alarm trigger device 18. Full-wave rectifier 16 and transformer 15 provide a source of pulsating full-wave rectified direct current isolated from the signal line wiring, the positive side of which is grounded and the negative terminal of which is wired to the lower electrode 4 of the detecting impedance. Electrode 2 of the compensating impedance is coupled via potentiometer 22 with the opposite side of the power supply. The output electrode 3 of the impedance means is coupled directly to the trigger element of the alarm trigger device 18, and the protective housing 11 is suitably grounded. The electrical voltage change resulting from the introduction of combustion products into detector housing 11 and hence to the detecting impedance 4-3 is derived from the common output electrode 3 to actuate the alarm trigger 18. The power supply to the impedance unit may be pulsating D.C. as shown in FIGURE 3, direct current as shown in FIGURE 9, or alternating current. Depending upon the character of the power supply and the emitted signal resulting, the trigger device 18 may be a hot or cold gaseous trigger tube, a solid state device such as a triode transistor, or a vacuum tube—so long as the device is characterized by an electrical input impedance of at least 10^9 ohms minimum, capable of actuation by an incremental voltage change of the order of magnitude of 25 volts or less, to produce a transition in the output from a non-conducting state to a conducting state, the conducting state representing sufficient conductance at the operating potential to actuate a standard alarm relay at the main panel.

Potentiometer 22 is preferably a screw driver adjusted, lock-type variable resistance equipped with a calibrated dial scale reading 0 to 10. Resistor 22 is used as a "threshold sensitivity" adjustment so that the detector may be adjusted to suit local environmental conditions.

As illustrated in FIGURE 4, the assembly of tube 1 and electrodes 2, 3 and 4 (indicated at points 2, 3 and 4 in FIGURE 4) forms an impedance bridge which is comprised of the impedance formed by, i.e. the surface resistivity of, the surface of the tube lying between the electrodes 2-3 and 3-4 respectively. With a cylindrical tube and uniform spacing of the electrode 3 from the electrodes 2 and 4, the two impedances, indicated at R-1 and R-2, are equal and oppositely connected so that the output e_s of the bridge is normally 0. The detecting impedance R-1 is freely open to air flow, whereas the balancing or compensating impedance R-2 has only restricted exposure to air flow, as indicated by the dotted line representing shield 7 in FIGURE 4.

I have found that the surface resistivity of a conventional glass radio tube varies inversely with the amount of water vapor in the medium contacting the surface of the tube. Consequently, at relatively low humidity, the surface resistivity of the tube is relatively high, whereas at high humidity the surface resistivity of the tube is relatively low. The maximum surface resistivity of the electrode substrate, i.e., the tube 1, in the circuit of FIGURE 3 cannot be greater than the resistance of the gas tube trigger element, which generally has a resistance of about 10^{10} ohms. Thus, at a practical low limit of rela-

tive humidity, the substrate preferably has a surface resistivity not exceeding 10^9 ohms. A suitable low level limit of relative humidity may be 5%, and a suitable high level limit may be considered to be 90-95%, for detectors intended for use in normal atmospheres occupied by human beings. The change in the surface resistivity of a substrate suitable to provide a reliable output signal of sufficient magnitude to trigger the device 18 may be as little as 10 megohms out of 1000 megohms base, or as little as 1% if the surface resistivity is of adequate magnitude. As stated, I find that ordinary radio tube glass affords a sufficient magnitude of surface resistivity, and a sufficient change in surface resistivity upon variation in the water vapor content of the atmosphere, to facilitate provision of a practical detector.

As will be appreciated, change in the relative humidity of an atmosphere will occur relatively slowly under normal conditions, even if the change is due to sudden opening of a door, turning on the hot water tap in a sink, or the like. This relatively slow change in humidity will of course change the surface resistivity, or in the alternative the surface conductivity, of the substrate, but since the change occurs relatively slowly the compensator shield 7 permits the change to take place substantially simultaneously over both impedance areas of the substrate, i.e., the impedance area between electrodes 2 and 3 and the impedance area between electrodes 3 and 4. Consequently, the two impedances R-1 and R-2 remain equal and balance one another so that the output voltage e_s remains at 0.

However, when a fire starts, there is an extremely fast increase in the water vapor content of the air, and also an extremely rapid increase in the conductivity of the atmosphere due to the presence therein of additional water vapor and products of combustion. This extremely rapid change immediately affects the detecting impedance R-1 between the electrodes 3 and 4, but any affect thereof on the balancing impedance R-2 between electrodes 2 and 3 is delayed because of the restrictions to air flow provided by the corrugated elements 3 and 7, i.e., the compensator shielding means. Consequently, there is a sharp drop in detecting impedance R-1, or in the alternative a sharp increase in the conductivity of the surface forming the impedance, whereby a sharp pulse is produced at the electrode 3 to provide a signal e_s of sufficient potential to trigger the device 18. This in turn results in a sharp current draw through the device 18 producing a signal back through the power supply lines to a power and alarm panel, the signal being utilized to energize a relay or the like for the purpose of actuating a suitable alarm, such as warning lights, bells, sirens, etc.

The triggering signal produced by the device of the invention is preferably a sharp pulse of significant magnitude but short duration, as revealed by FIGURE 5. With the electrode 4 supplied from the negative side of the full-wave rectifier 16, the signal voltage that results from entry of products of combustion into the detector is negative going and has a wave shape as plotted against time, see FIGURE 5, which is the preferred relationship. However, by suitable connection of the components, the signal could be positive going if desired. Also, as indicated in FIGURE 5, the response of the detection unit to products of combustion is substantially instantaneous, the signal commencing within a fraction of a second of the introduction of combustion products and developing to its negative peak within 5 seconds. Moreover, compensation is accommodated at such rate that within 20 seconds after introduction of products of combustion, the detection unit has been fully compensated and returned to its initial balanced state.

The detection means of the present invention is thus seen to be essentially a wattless system that is not reliant upon principles of ionization and does not require current draw nor the use of radioactive materials for purposes

of ionization. The device is very simply and economically, yet reliably constituted of a small number of components taking maximum advantage of the natural phenomena occurring when a fire starts to produce a humanly understandable alarm signal well before the fire progresses to the humanly sensible and damaging stages of smoke, flame and heat. The entire detection unit is of very small size and is constituted in its entirety as illustrated in FIGURE 1. Substantially any desired number of these units may be coupled in parallel over a two-wire supply and alarm circuit as illustrated in FIGURE 3 to provide optimum early warning fire detection in a building, a portion of a building, an equipment enclosure, etc.

The heart of the detection system of the present invention is, of course, the impedance bridge, and while the tube-type impedance unit shown in FIGURE 1 has excellent operating characteristics, it is not the only impedance assembly I have found suitable. For example, the substrate may comprise any one of a number of materials having surface resistivity characteristics of the nature above described, i.e., a surface resistivity no greater than about 10^9 ohms at lowest humidity, and a minimum variation in surface resistivity in the order of about 1% between 5% and 95% relative humidity at average room temperatures. Examples of such materials are various glasses, Bakelite #140 produced by Union Carbide Plastics Co. of New York, New York; various materials, even insulating materials, appropriately coated with a dried slurry of a mixture comprised of four hundred parts lithium chloride in one million parts cobalt oxide; etc. I have also successfully used a substrate comprised of an epoxy fiberglass coated with a dried aqueous solution of sodium carbonate comprised of one part sodium carbonate in ten parts water, but I am not presently able to attest to the service life of this substrate. In general, it may be stated that the detection device of the present invention is a high impedance device, and the substrate should be selected accordingly.

Also, the substrate need not be in the form of a cylinder, but may for example be in the form of one or more flat discs or plates having grids or electrodes formed thereon in a variety of manners, such for example, as three concentric circles.

Referring to FIGURES 6 and 7, I have illustrated by way of example a modified form of the impedance means of the device of my invention. As shown, there are two identical impedance components each comprised of a thin flat disc of a substrate material selected in accordance with the foregoing and bearing a pair of interleaved grid-type electrodes. The compensating impedance is illustrated as comprising a substrate disc 1a and a pair of grid electrodes 2' and 3a, and the detecting impedance as comprising a substrate disc 1b and grid electrodes 3b and 4'. In a circuit such as shown in FIGURE 3, the power supply is to the grids 2' and 4', and the grids 3a and 3b are interconnected to provide a signal output e_s .

Each of the two impedance components may be fabricated by screening conductive silver circuit paint in the selected grid pattern onto the selected substrate and firing (heat treating) the assembly to form solid silver electrodes, or may be formed by known photo-etching processes. Alternatively, the grid electrodes may be etched in the copper laminate of a printed circuit board, and a coating, such as sodium carbonate, may be applied to the substrate and oven dried; or a suitable coating may be applied to a glass or ceramic substrate onto which the desired electrode pattern has been screened. The substrate may suitably be $1\frac{1}{2}$ to 2 inches in diameter and about $\frac{1}{16}$ inch or more thick. With grid patterns such as shown in FIGURES 6 and 8, the interleaved fingers of the two electrodes have a spacing commensurate with the voltage applied to the bridge circuit, which may be about $\frac{1}{10}$ inch, and may be as little as $\frac{1}{64}$ inch or less. The smaller spacing is preferred to the extent it may ac-

curately be maintained in production and is not susceptible to contamination or electrode migration, as this imparts to the impedance means a greater sensitivity to the presence in atmosphere of the relatively conductive products of combustion.

The impedance means of FIGURE 6 would suitably be incorporated in a commercial embodiment in the manner shown in FIGURE 7. In this embodiment, the detector impedance 1b is mounted lowermost with its electrodes 3b and 4' facing downwardly so as to be freely exposed to the atmosphere and air flow, and the compensating or balancing impedance 1a is mounted above the impedance 1b with its electrodes 2' and 3a facing upwardly so as to be relatively shielded from air flow. Both electrodes are suspended in any suitable manner from the lower surface of a hollow base 12', which is essentially the same as the base 12 illustrated in FIGURES 1 and 2, and the two impedance units are suitably enclosed within a perforate or fenestrated housing 11'. In FIGURE 7, the grid electrodes 2' and 4' have been specifically illustrated to reveal the fact that the same face upwardly and downwardly, respectively. It is to be understood, however, that the electrodes may not actually protrude above the surface of the substrate, or at least not to a visual degree. The resultant assembly affords all the advantages of the previously described embodiment of the invention, and attains the further advantage that the same is of extremely small size. Specifically, the embodiment of the invention shown in FIGURE 7 may be as small as 3 inches in diameter and $1\frac{3}{4}$ to 2 inches high.

A flat unitary impedance unit taking particular advantage of the relatively high conductivity of products of combustion in the presence of water vapor is illustrated in FIGURE 8. This unit comprises a thin flat plate of a suitable substrate material provided on its surface with a pair of interleaved grid-type electrodes 3'' and 4'' and a bar-type electrode 2'' spaced from the interleaved grids 3'' and 4''. The interleaved fingers of the grids 3'' and 4'' are spaced from one another within the range previously indicated for the FIGURE 6 embodiment of the invention, and preferably have as small a spacing therebetween as is commercially feasible. The grid 3'' particularly includes an outboard finger (the lower finger as shown in FIGURE 8) which extends between the grid 4'' and the electrode 2'' to shield the two from one another. The electrode 2'' is suitably spaced from said outboard or lower finger of the grid 3'' by a distance of $\frac{1}{4}$ to $\frac{1}{2}$ inch. The surface of the substrate lying between the lower finger of grid 3'' and electrode 2'' constitutes the compensating impedance of the unit, and the surfaces of the substrate lying between the interleaved fingers of the grids 3'' and 4'' constitute the detecting impedance of the unit. As illustrated, power is supplied to the electrodes 2'' and 4'', and the electrode 3'' comprises a common output electrode from which the signal e_s is derived.

In use, the impedance between electrodes 2'' and 3'' is equal and of opposite sign to the total impedance of the circuit including electrodes 3'' and 4'' under normal atmospheric conditions, so that there is no output signal to be derived from the output grid 3''. On occurrence of a fire, the relatively large size particles of the products of combustion will with relative ease bridge across the small spacing between the interleaved fingers of the electrodes 3'' and 4'' to reduce the resistivity or increase the conductivity of the impedance 3''-4'', but the products of combustion will not readily bridge (or bridge to an equal degree) across the wide space between the electrodes 2'' and 3'', whereby the resistivity of this impedance is not lowered to the same degree as impedance 3''-4'', whereby the bridge becomes unbalanced and the electrode 3'' will emit a signal to trigger the alarm circuit.

As will be appreciated, the impedance unit of FIGURE 8 thus affords the same advantages as the impedance units of FIGURES 1 and 6, but the same is even more compact

and economical and may be embodied in a very small detector housing assembly.

Referring now to FIGURE 9, I have shown an alternate power supply and alarm circuit equally applicable to the impedance units of FIGURES 1, 6 and 8, and differing from the circuit of FIGURE 3 in two respects. First, the circuit of FIGURE 9 provides direct current power supply to the impedance unit. Second, and most important, the circuit provides improved signal differentiating and sensitivity adjustment means for the detector. As shown, the compensating impedance R-2 is supplied with direct current at a positive potential from a half-wave rectifier and smoothing capacitor combination 25-26. This same source also supplies the anode of an alarm trigger device 27, which is essentially the same as the trigger device 17 previously described. Preferably, a resistance 28 is coupled in series with the anode. The detecting impedance R-1 is supplied with a source of negative direct current at a potential approximately equal to but of sign opposite from that supplied to the impedance R-2 from a half-wave rectifier and smoothing capacitor combination 29-30, whereby the impedances R-1 and R-2 are supplied at potentials of equal magnitude but opposite sign, so that their combined output at point 3 is normally 0. Preferably, the entire power supply circuit is bridged by an additional capacitor 31 to mitigate ripple in the output of the two rectifiers.

While the output point 3 of the impedances R-1 and R-2 could be coupled directly to the trigger element of the device 27, it is a particular advantage of the present invention to incorporate, first, sensitivity adjustment, and second, signal differentiation into the circuit. As to the first feature, a potentiometer 32 is coupled between the power supply to the detecting impedance and to the common return line and the output of the potentiometer is connected, preferably via a resistor 33 of high impedance, to the trigger element of the trigger device 27. The potentiometer 32 thus affords means for adjusting the bias on the gas tube or other trigger device independently of the signal voltage derived at point 3. Consequently, by appropriate adjustment of potentiometer 32, the trigger device can be adjusted to breakdown at a signal voltage amplitude falling anywhere within the range of from 1 volt up to the trigger device's measured breakdown value. This in turn permits operation from a signal voltage source having an internal impedance of between 10^5 ohms and 10^{10} ohms. In other words, the particular connection of the potentiometer 32 makes possible the biasing of the trigger element at its breakdown voltage.

The desired bias is accomplished by applying a voltage greater than the trigger's breakdown value through a very large resistance 33 to the trigger element, effectively to "self-bias" the device. The trigger current is limited to a very small value by resistor 33 thus "keeping" the discharge in the "Townsend" region and maintaining it at the grid breakdown voltage. The trigger device may then be fired by applying to the trigger element the signal voltage pulse. I find that a one-volt pulse amplitude across any value of impedance between 10^5 ohms and 10^{10} ohms will fire the trigger device. This is because the voltage appearing between the grid and cathode of the device is the sum of the biasing voltage and the pulse voltage. Thus, potentiometer 32 affords an excellent sensitivity control.

Also, by virtue of the now present facility for biasing the trigger device at its breakdown voltage, I am able to effect a capacitive coupling of the signal producing means to the trigger device, and I specifically provide a coupling capacitor 34 between output point 3 and the trigger element.

Depending upon the intended scope of application of the detector, the capacitor 34 may be fixed or it may be adjustable. Where the environmental application and the conditions to be detected are known, a capacitor of fixed value may be selected to attain the desired results.

Alternatively, an adjustable capacitor may be adjusted to facilitate attainment of particular objectives. In general, the purpose of the coupling capacitor 34 is to differentiate between unwanted slow rate of change signals and the sharp pulse signals resulting from the rapid rate of change occurring upon initiation or inception of a fire. In other words, the capacitor is selected or adjusted so that signal voltage pulses of less than a predetermined magnitude over greater than a predetermined time (and thus indicative of less than a certain rate of change) may be rejected, i.e., be prevented from breaking down the trigger device, and only signals of a greater magnitude signifying a greater rate of change will be effective to trigger the device 27 and produce a sensible signal at the main alarm panel.

The coupling capacitor 34 thus greatly facilitates rejection of signals that might possibly result from the sudden opening of a door between two vastly different environmental conditions, the presence of a number of people smoking cigars or cigarettes, and so on.

When the device of the invention is put into use, there will be an initial current draw to charge the capacitors 26, 30, 31 and 34, but thereafter the detection means is essentially a wattless system attaining all of the advantages previously described herein. As with the circuit of FIGURE 3, the circuit of FIGURE 9 facilitates the coupling of substantially any desired number of detection assemblies in parallel over a two-wire supply and alarm circuit to provide optimum detection for products of combustion wherever desired.

Referring now to FIGURE 10, I have illustrated a circuit combining the more desirable features of FIGURES 3 and 9. Specifically, I have provided a D.C. power supply and biasing circuit for the trigger device essentially the same as illustrated in FIGURE 9, an isolating D.C. power supply for the detecting and balancing impedance assembly, and impedance bridge means for said impedance assembly to facilitate accurate balancing of the bridge should variations exist between impedances R-1 and R-2 in commercial mass production.

As shown in FIGURE 10, the anode of the trigger device 27 is supplied with a source of direct current at positive potential from the rectifier-capacitor combination 25-26 via resistor 28. Biasing direct current of negative potential is supplied to the trigger element of device 27 from the rectifier-capacitor combination 29-30, potentiometer 32 and resistor 33, whereby the trigger device may be biased to respond to any desired signal voltage by appropriate adjustment of potentiometer 32. This adjustment also facilitates coupling of the impedance assembly output 3 to the trigger by a fixed or adjustable capacitor 34. The net result is a stable trigger device of high sensitivity responsive only to preselected signal conditions.

To energize the impedance assembly, I provide an isolating transformer 35 energized from the power supply lines and a half-wave rectifier 36 for supplying direct current of negative potential to the input tap 4 of the detecting impedance R-1. This source also supplies D.C. of negative potential to a potentiometer 37 connected in parallel with the impedances R-1 and R-2, and having an adjustable tap connected to the common return line. Preferably, a capacitor 38 bridges the impedance assembly R-1, R-2, 37 to smooth the power supply thereto. As a consequence of the potentiometer 37, the compensating or balancing impedance R-2 is supplied with D.C. of positive potential normally to balance the two impedances. The benefits of a separate D.C. supply to the detecting and compensating impedances are many, notable among which are mitigation of drift of the impedance assembly toward a static condition or toward a triggering condition, improved stability of the impedance bridge, and improved recovery following detection and emission of a triggering signal.

Moreover, the device now incorporates the potentiometer 37 in the impedance bridge to aid in attaining the above benefits, to afford an adjustment accommodating exact balance between impedances R-1 and R-2 despite discrepancies between the two resulting from mass production tolerance variations (or in the alternative to permit greater tolerance than would otherwise be the case), and to provide means for imposing a predetermined bias on the impedance assembly should that prove desirable.

A further advantage of the potentiometer 37 or a comparable impedance is alleviation of the limitations previously placed on the substrate for the detecting and compensating impedances R-1 and R-2. Specifically, with the circuit of FIGURE 10, it is not necessary to limit suitable substrate materials to a maximum surface resistivity of 10^9 ohms. In fact, I have successfully employed a pebble-glass substrate having a surface resistivity of 10^{11} ohms in the physical configuration illustrated in FIGURE 6 and have obtained excellent results with the same. Pattern glasses, such as pebble glass, are generally commendable for use in the present invention.

For purposes of experimentation and development, I prefer to utilize in the circuit of FIGURE 10 adjustable potentiometers 32 and 37 and adjustable capacitance means 34. It will be appreciated, however, that in a commercial structure one, two or all of these components may have fixed values. For example, the potentiometer 32 may be replaced by a resistor having a fixed center tap for imposing a predetermined negative bias on the trigger tube to approach the tube breakdown value; the potentiometer 37 may be replaced by a resistor having a fixed center tap to impose a positive or negative bias within a predetermined range on the impedance bridge; and/or the capacitor may be of fixed value to afford discrimination between signals of less and greater than a predetermined magnitude.

By virtue of the variables that may thus be incorporated in the circuit, either by appropriate selection or by appropriate adjustment of the components, the device of the present invention, in addition to its capability for detection of products of combustion in an atmosphere of varying temperature and humidity, may if desired be utilized for detecting the existence of particular environmental conditions such as the presence of the fumes. Also for example, by replacing the compensating impedance R-2 with a resistor of fixed value, utilizing a substrate for the detecting impedance having a predetermined surface resistivity at a selected degree of relative humidity, and appropriately selecting and/or adjusting the potentiometer 32, the capacitor 34 and/or the potentiometer 37, the device may be utilized to signal the existence of a predetermined relative humidity where humidity may be important in a chemical or manufacturing process or the like. Also, the compensating or balancing impedance R-2 may be replaced by a differentiating network of resistance and capacitance to afford a partial compensation or balancing effect to facilitate detection of environmental conditions beyond the range of compensation for which the differentiating network is devised. Other uses and applications of this invention will, of course, become apparent to those skilled in the art.

Also, embodiments of the invention other than those specifically illustrated herein will be readily apparent to those skilled in the art. Whatever its physical embodiment, the present invention provides a highly economical and effective means for detecting fire in its incipient stage, and completely obviates ionization principles and sources. All of the objects and advantages of the invention have thus been shown herein to be attained in a convenient, economical and practical manner.

While I have shown and described what I regard to be the preferred embodiment of my invention, it will be appreciated that various changes, rearrangements and modi-

fications may be made therein without departing from the scope of the invention, as defined by the appended claims.

I claim:

1. An early warning fire detector comprising a detection chamber freely opened to air flow and a balancing chamber having a restricted entry for air flow, impedance means exposed in each of said chambers sensitive to the electrical conductivity of the air in the respective chamber, said impedance means being energized at less than the ionization potential of air and comprising a bridge subject to variation in potential to produce a signal upon access of products of combustion to said detection chamber and not to said balancing chamber.

2. An early warning fire detector characterized by a bridge circuit comprised of a pair of impedance means sensitive to the increase in electrical conductivity occurring between air and air-laden with products of combustion, each of said impedance means being exposed for contact by the air with one comprising balancing means accommodating delayed access thereto of air and the other comprising detecting means accommodating rapid access thereto of air.

3. Means for detecting fires in their incipient stage comprising a pair of impedances sensitive to the differences in electrical conductivity occurring between air and air-laden with products of combustion, said impedances being exposed for contact by the air and coupled in a bridge circuit energized at less than the ionization potential of the air contacting said impedances, one of said impedances comprising a balancing impedance having exposure to ambient atmosphere but being shielded from air flow to respond to relatively slowly changing atmospheric conditions and the other comprising a detecting impedance having free exposure to ambient atmosphere and being freely exposed to air flow to respond promptly to changing atmospheric conditions thereby to produce a signal upon occurrence of the rapid change in the atmosphere when a fire starts.

4. A fire detector characterized by the combination of three spaced electrodes, impedance means between said electrodes sensitive to the increase in electrical conductivity occurring between air and air-laden with products of combustion, both of said impedance means being exposed for contact by the air but one having a slower response to said change than the other, a pulsating source supplied between the two outer ones of said electrodes, and trigger means coupled to the center electrode.

5. A fire detector comprising an impedance bridge characterized by substrate means the surface resistivity of which varies in predetermined relation with variations in the water vapor content of the media contacting the same, and spaced electrodes on said substrate means defining a pair of input electrode means, output electrode means and a pair of impedances formed by the surface areas of said substrate means between the respective input electrode means and the output electrode means, one of said impedances having a delayed response to variations in the water vapor content of the media and the other impedance having prompt response thereto.

6. A fire detector as set forth in claim 5, wherein said substrate means comprises two substrate elements each bearing on a surface thereof an input electrode and an output electrode, the two output electrodes being interconnected, said elements being positioned with the electrodes of one facing toward and the electrodes of the other being relatively shielded from a source of products of combustion.

7. A fire detector as set forth in claim 5, wherein said electrode means comprises input and output electrode means disposed closely adjacent to one another to be responsive to the relative conductivity of products of combustion in the presence of water vapor, and a second input electrode spaced a greater distance from said out-

put electrode means to have relatively delayed response to products of combustion.

8. A fire detector as set forth in claim 5, wherein said substrate means comprises a cylinder and said electrode means comprise spaced conductive bands encircling said cylinder.

9. A fire detector as set forth in claim 5, wherein said substrate means comprises a cylinder and said electrode means comprise spaced conductive bands encircling said cylinder, and shielding means for one of the input bands comprising corrugated means encircling said cylinder about at least said one input band for preventing access of the media to said one input band except via the ducts defined by said corrugated means.

10. A fire detector comprising an impedance bridge including substrate means the surface resistivity of which varies inversely with variations in the relative humidity of the atmosphere contacting the same, the surface resistivity of said substrate means being no greater than about 10^9 ohms per square centimeter at about 5% relative humidity, and having a change in surface resistivity of at least about 10 megohms in a 1000 megohm base over the range of from about 5% to 95% relative humidity, and spaced electrodes on said substrate means defining a pair of input electrode means, output electrode means and a pair of impedances formed by the surface areas of said substrate means between the respective input electrode means and the output electrode means, one of said impedances having a delayed response to variations in the water vapor content of the atmosphere and the other impedance having prompt response thereto.

11. An early warning fire detector including a bridge circuit having an input, an output and a pair of variable impedances governing the output, and alarm trigger means coupled to the output of the bridge; characterized in that both impedances comprise substrate means the surface resistivity of which varies in relation to the water vapor content of the atmosphere contacting the same and contact means on said substrate, the substrate means of both impedances being exposed to the atmosphere and automatically compensating one another for normal relatively slowly occurring atmospheric changes, one of said impedances having a delayed response to changes in the atmosphere, the contacts of the other impedance being close together and freely exposed to the atmosphere and sensitive to the rapid changes in the atmosphere upon occurrence of a fire to change the output of the bridge and trigger said trigger means.

12. An early warning fire detector characterized by the combination of a pair of impedance means sensitive to the water vapor content of the air, one of said impedance means having relatively delayed response to changing air conditions, said impedance means being connected in a bridge circuit with said one impedance means compensating the other impedance means for normal relatively slowly occurring changes in the water vapor content of the air, and trigger means coupled to the output of the bridge for sensing the change in output caused by the change in the potential across said other impedance means due to the rapid change in the water vapor content of the air upon initiation of a fire.

13. An early warning fire detector characterized by the combination of a pair of impedance means sensitive to the increase in electrical conductivity between air and air-laden with products of combustion, both of said impedance means being exposed to the air but one being relatively shielded from the air to delay the exposure thereof to change in air conditions, said impedance means being connected in a bridge circuit with said one impedance means compensating the other impedance means for normal relatively slowly occurring changes in the air, and trigger means coupled to the output of the bridge for sensing the change in output caused by the change in the potential across said other impedance means due to

the rapid increase in the electrical conductivity of the air upon occurrence of a fire.

14. Means for detecting predetermined environmental conditions comprising an electrical bridge including detecting means and compensating means together defining a signal source having a high internal impedance, a trigger device including a trigger electrode and a pair of output electrodes and arranged to conduct current between said output electrodes upon application of a signal of a certain magnitude between said trigger electrode and one of said output electrodes, a power source coupled to said output electrodes, a bias source, potentiometer means connected across said bias source to provide an adjustable bias voltage, means applying said adjustable bias voltage in series between said trigger electrode and said one of said output electrodes, and means for coupling said signal source to said trigger electrode.

15. Means for detecting predetermined environmental conditions comprising an electrical bridge including detecting means and compensating means together defining a signal source having a high internal impedance, a trigger device including a trigger electrode coupled to said source and a pair of output electrodes and arranged to conduct current between said output electrodes upon application of a signal of a certain magnitude between said trigger electrode and one of said output electrodes, a power source coupled to said output electrodes, a bias source, potentiometer means connected across said bias source to provide an adjustable bias voltage, means applying said adjustable bias voltage in series between said trigger electrode and said one of said output electrodes, and series capacitor means between said signal source and said trigger electrode to cooperate with said potentiometer means in rejecting signals below said certain magnitude.

16. Means for detecting predetermined environmental conditions comprising an electrical bridge including detecting means and compensating means together defining a signal source having a high internal impedance, a trigger device including a trigger electrode and a pair of output electrodes and arranged to conduct current between said output electrodes upon application of a signal of a certain magnitude between said trigger electrode and one of said output electrodes, two oppositely poled rectifier means for connection to an A.C. source to respectively define a power source and a bias source separate from said power source, means coupling said power source to said output electrodes, adjustable potentiometer means coupled to said bias source for developing an adjustable bias voltage, means applying said adjustable bias voltage in series between said trigger electrode and said one of said output electrodes, and series capacitor means coupling said signal source to said trigger electrode.

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