This is a continuation-in-part of applicants' copending application, Serial No. 211,778, filed February 19, 1951.

This invention relates to improved methods and apparatus for detecting and/or supervising fires. In particular, the methods and apparatus of this invention utilize to advantage certain unique properties of fire flame hereinafter described in detail.

Detection apparatus heretofore used for the protection of life and property from fire have been numerous and varied as to the mode of operation. Most of these devices, however, have the basic shortcoming that they are not fundamentally fire detectors, but rather detectors of some secondary effect of fire, such as temperature change, increase in average light intensity, the presence of smoke, or the burning or melting action of the flame itself. These devices are, therefore, susceptible to erroneous operation when these effects occur for reasons other than the presence of fire.

For example, thermally-responsive fire detectors are particularly subject to false operation when required to operate under conditions of widely varying ambient temperature, unless their critical operational temperature is set at a high level which usually reduces their usefulness as safety devices. The major defect of these devices, however, is that they are not instantly responsive to fire but actually require the fire to make considerable headway before the necessary thermal level to activate the detectors can be attained.

Fire detectors which are responsive to average light intensity can be made to operate falsely when subjected to intense light energy from artificial and natural sources. Likewise, smoke from controlled combustion sources will activate smoke-responsive fire detectors, because these detectors are not actually responsive to the presence of flame in a prohibited area. Smoke detectors are also subject to an objectionable time delay before sufficient smoke density can be attained at a detection point to actuate an alarm.

From a comparative aspect, the most satisfactory way to detect fire is by monitoring a volume for the presence of flame therein. This should be accomplished by apparatus which responds instantly and exclusively to fire flame. Furthermore, if the detecting apparatus for any reason loses its capability to perform the aforementioned features of operation, a visual or audible alarm should be immediately given so that the necessary repairs can be made.

Accordingly, it is an object of this invention to instantly and accurately detect fires without the occurrence of false fire alarms.

Another object is to improve the operativity reliability of fire detection apparatus whereby the instant the detection apparatus is incapable of fully performing its prescribed functions, an alarm is given.

Another object is to minimize the frequency of the periodic maintenance checks heretofore required to insure proper operation of fire detection apparatus.
pulses must be received from the limiter within a time interval of one second before sufficient potential can be developed by the discriminator to actuate the apparatus which controls the fire alarm. This feature of the invention also conclusively assures that the fire alarm will not be operated by momentary accidental fluctuations in illumination as might occur with rapid on and off switching of lights, inasmuch as the frequency of these fluctuations, when compared with respect to the time fraction in which they occur, in some cases actually exceeds the lower frequency limit of the band pass amplifier. A novel self-monitoring feature of this invention continually supervises the ability of the fire detection apparatus to fulfill its prescribed functions. This feature obviates the periodic checking of the operability of fire detection apparatus heretofore required. The monitoring apparatus utilizes an oscillator which continually transmits a check signal comprising a continual train of impulses throughout all the detector elements. This signal is, in turn, continually transmitted through the aforementioned band pass amplifier, limiter, and discriminator, and also the apparatus which actuates the fire alarm. If for any reason this signal is not thusly transmitted continuously and without interruption, a positive visual or auditory alarm is given indicating that the detecting apparatus is incapable of performing its prescribed functions. Prompt correction of the defect will restore the detecting apparatus to proper operating condition. The fire alarm is not actuated by the self-monitoring signal because the fundamental frequency thereof is limited to approximately one cycle per second, and, therefore, cannot be integrated sufficiently by the discriminator circuit to produce an output potential large enough to actuate the fire alarm.

A second embodiment of this invention is disclosed herein which is particularly adapted to the detection and supervision of unintentional fires in vehicles, particularly in aircraft; whereas the embodiment of the invention previously described is preferably used in the detection of unintentional fires in buildings and other accessible areas, although it may be used to full advantage to supervise certain types of vehicle compartments in which only knowledge of the initiation of a fire is necessary and desirable.

A principal object of the second embodiment of the invention is to improve the supervision of fires in vehicles whereby both the occurrence and the termination of fires therein can be instantly and accurately determined. Another object is to improve the operative reliability of fire detecting and supervising apparatus for vehicles whereby the capability of the apparatus to fully perform its prescribed functions can be easily and quickly monitored prior to or during vehicle operation.

Another object is to minimize the replacement and maintenance of fire detecting and supervising apparatus for vehicles by improvements which make it unnecessary to replace or repair, in the usual case, any of the apparatus components after a detected fire.

Another object is to provide fire detecting and supervising apparatus for vehicles which is relatively small in size, light in weight and low in cost. Other specific objects of the second embodiment of the invention will appear from the description which follows hereinafter.

While the principles of operation of this embodiment of the invention and the structure for practicing same are generally applicable to vehicles of all types, the description which follows hereinafter will be particularly concerned with the detection and supervision of fires in aircraft because of the particular vulnerability of this type of vehicle to fire.

The very factors which promote aircraft flying efficiency, for example, lightness of structure, reduction in the weight and frontal area of the power plant, the use of light metals which have poor heat resistance, and improvement in the volatility of fuels, necessarily increase the dangers of fire in aircraft. High altitude flying has introduced new hazards, such as arcing in electrical systems, and inadequacy of cooling in air-cooled engines, and has given rise to the requirement for supercharging and oxygen supply systems which are in themselves potential sources of fire. The modern airplane is a complex assembly often powered by several engines, and equipped with a vast number of intricate electrical, hydraulic and mechanical devices for performing the various indicating, control, and communication functions necessary for operation and navigation of the craft. Stringent space requirements dictate that large quantities of high octane gasoline be carried in wing tanks, in proximity to the engine nacelles. While considerable research and effort has been directed toward minimizing fire hazards in the design and arrangement of electrical and hydraulic systems and toward the development of fireproof fuel tanks, it is inevitable that increasing complexity of any mechanism which utilizes highly combustible fuels should result in an increasing probability of fire. The hazard is aggravated in the case of the military airplane by the carrying of explosives and exposure to enemy gunfire.

As a result of extensive investigation by military and civilian authorities, both in this country and abroad, it has been determined that the fires most disastrous and difficult to control, that is, fires occurring in flight, usually start in the engine, and that such fires can be extinguished in flight without serious damage to the airplane if the pilot is warned of the fire and applies the proper firefighting measures in time. The need for quick action and especially for quick detection has been dramatically illustrated in several known instances where fire in an engine nacelle has caused wing failure in less than a minute after the fire started and before the pilot was aware that his engine was on fire. In short, one of the major conclusions to be drawn from such investigations is that the virtual elimination of serious accidents due to fire in flight, with the resulting incalculable saving in lives and property, can be achieved, and at present requires only the development of a reliable alarm system capable of instantly detecting the outbreak of fire. In such a device, reliability is as important as quick action. The usual fire fighting procedures involve shutting down the engine, which may necessitate a forced landing. It can readily be appreciated that one or two such experiences as a result of false alarms may lead pilots to disregard the fire warning system.

Experiments have been made with a variety of fire alarm devices and several types are currently used on aircraft. The detecting elements may be generally classified as thermocouples, thermal expansion switches, and fusible elements. The fundamental disadvantage of such elements for fire detection purposes is that they are temperature-responsive, rather than flame-responsive, and are therefore subject to an inherent time delay which may vary considerably depending upon the location of the element from the flame and on local conditions affecting heat transmission. To insure reasonably quick operation, temperature-responsive elements must be placed in the engine so as to be downwind from and fairly close to the possible sources of fire, and the elements themselves are usually destroyed when fire occurs. A device must be taken, also, to insure that the detecting elements are not so located as to be cooled by air currents, as, under such conditions, these devices have failed to give warning of a serious fire burning only a short distance away.

This difficulty can be minimized only by the utilization of each new type of engine installation to determine the proper location of detecting elements, and the use of a large number of detecting elements. The thermocouple types of detectors and some of the thermal expan-
sion types require frequent, delicate adjustment and must be used with sensitive circuits which are unstable in operation. Being essentially mechanical switching devices, they are susceptible to vibration and acceleration. The fusible type is additionally objectionable because it is destroyed on operation and must be replaced, and does not permit checking of the system. In order to provide anything approaching complete fire protection, a large number of such elements, spaced not more than a few inches apart, would be required all around each engine. An alternative, the continuous strip element of the fusible type, is now considered by aircraft authorities to be obsolete because of many inherent mechanical checks in its use. Since the weight of the elements themselves and the wiring for such complete protection would be prohibitive, the present fire detection systems on aircraft necessarily represent a compromise between weight and safety considerations.

Furthermore, the development of jet propulsion for aircraft has given rise to a fire detection problem for which the thermally operated systems are wholly inadequate. In comparison to a reciprocating engine of comparable power, the potential danger area of a jet engine is considerably greater, and the normal ambient temperature in the engine nacelle is considerably higher, necessitating the cooling of the jet pipe to be avoided, as efficiency is dependent on maintaining a jet temperature as high as the internal metal parts will withstand. Insulation between the engine and the surrounding structure is ordinarily provided only by a relatively narrow air gap between the engine itself and a conical metal shroud. It is apparent that, with such an arrangement, the occurrence of fire, upon failure of a high-pressure fuel line or turbine blade, for example, is likely to be so rapid and localized that even very closely spaced thermal detectors would fail to respond in time to prevent severe damage to the aircraft. Difficulties from false alarms are also encountered because of the rapid temperature fluctuations and the small differential between normal operating and excessive temperatures.

The fire apparatus of the second embodiment of this invention, which is particularly adapted for use in aircraft, further exploits the flame modulating characteristics of fire flame hereinbefore set forth whereby many of the disadvantages of conventional aircraft fire detectors are substantially eliminated. As was previously disclosed, a frequency analysis of the radiant energy emanating from the flame affords the opportunity of utilizing the intensity therefrom, in all cases, amplitude modulated.

As was further disclosed, if a unique range of fire flame modulating frequencies exists for a particular installation, apparatus which is responsive only to this range can be constructed to provide exclusive fire flame response.

The embodiment of the fire apparatus of this invention which was particularly constructed for aircraft differs greatly in the following aspects from the embodiment which was particularly constructed for fire detection in buildings or other accessible locations.

The fire apparatus for aircraft comprises a novel latching feature whereby the extinguishment of a fire within, for example, an aircraft engine nacelle, can be reliably indicated by the apparatus. A visual inspection to ascertain the continuance or extinguishment of a fire is not practical in aircraft because, among other reasons, the fire may be wholly confined within an enclosed compartment or a portion of the aircraft not easily supervised by visual inspection. Knowledge of the progress of a detected fire within aircraft is essential so that the pilot can intelligently plan the necessary course of action. For example, if a fire within an aircraft nacelle persists, the pilot would possibly attempt a forced landing, but if such a fire is extinguished for one reason or another, a forced landing probably would not be attempted. This feature of operation is not incorporated in the first embodiment of this invention because in fire warning systems for buildings and other accessible structures, including certain vehicle compartments, the continuance of the fire alarm until a manual alarm-removing operation takes place is desirable so that attention will be brought to the fact that a fire has occurred.

A second difference between the two embodiments of the invention appears in the testing arrangement utilized to supervise the capability of the apparatus to perform their fire detecting functions. The testing arrangement for the first embodiment continuously transmits a check signal comprising a continual train of impulses throughout the apparatus as previously described. The testing arrangement for vehicle fire apparatus as disclosed in the second embodiment operates only in response to the manual operation of a test switch which checks one fire detector channel at a time. The specific reasons for this structural difference will appear from the detailed description which appears hereinafter.

A third embodiment of the invention is disclosed herein which is particularly adapted to the supervision of intentional fires.

The principal object of this embodiment of the invention is to provide a completely reliable and instantaneous indication of the presence and the termination of an intentional or wanted fire. This type of apparatus can be used, for example, to supervise the continuous existence of flame in the burner of jet aircraft or the continued existence of flame in an oven or the like. This apparatus can also be used to produce a control function responsive to the termination of a fire.

This embodiment of the invention differs from the first two embodiments described in that the circuit structure is economically designed to produce the requisite reverse mode of operation. That is, output indications are to be provided in the absence of flame and not in response to the initiation or detection of a fire. Broadly speaking, this reverse function is accomplished with a band-pass amplifier, the output of which is filtered to produce a direct-current bias. This bias is removed from the power tube which controls the operation of the output circuit of the apparatus whenever the monitored fire flame goes out for any reason.

In order that all of the features of this invention and the mode of operation thereof may be readily understood, a detailed description follows hereinafter with particular reference being made to the drawings, wherein:

Fig. 1 is a schematic circuit diagram of the first embodiment of the fire detection apparatus of this invention;

Fig. 2 is a perspective view of a photo-responsive fire detection element suitable for use in the circuit of Fig. 1;

Fig. 3 is a fire detection element assembly suitable for housing the element of Fig. 2;
Fig. 4 is a schematic diagram of the second embodiment of the fire apparatus of this invention which is particularly adapted for use in aircraft and is a simplified perspective view of a fire detector pick-up unit suitable for use in the circuit of Fig. 4.

Fig. 5 is a simplified perspective view of the fire apparatus of the second embodiment of this invention, together with a plurality of pick-up units, in a jet aircraft when the plane is in flight.

Fig. 7 is a simplified showing of the installation of the fire apparatus of the second embodiment of this invention, together with a plurality of pick-up units, in a reciprocating engine type aircraft; and

Fig. 8 is a schematic diagram of the third embodiment of this invention which is suitable for supervising intentional fires.

Referring now to Fig. 1, fire detection elements 1, 2 and 3 are serially connected between terminals 4 and 5. These detection elements are preferably photoconductive cells which are sensitive to both visible and invisible light, such as, for example, lead sulfide photoconductive cells. In actuality, these elements are usually disposed at a distance from one another on the walls or ceilings of a building under fire supervision. The series impedance presented by elements 1, 2 and 3 to terminals 4 and 5 varies inversely to the amount of cell-responsive radiant energy impinging upon the elements. The maximum number of fire detection elements which can be connected in series depends, generally, upon the amplification of the apparatus which is to utilize the impulses therefrom. In the particular preferred embodiment of this invention shown in Fig. 1, one to six elements connected between terminals 4 and 5 have operated satisfactorily.

A positive breakdown potential is applied to electrode A3 of gas diode T2 through resistor 20. Serially-connected capacitors 18 and resistors 9 and 10 are connected across gas diode tube T2. Components 9, 10, 16, 20 and T2 comprise a relaxation oscillator which continually transmits a one cycle per second self-monitoring signal throughout the fire detection apparatus. The output signal of this oscillator developed across resistor 9 is applied in series with the potential between terminals 4 and 5 to terminal 4 and ground.

The positive energizing potential for detection elements 1, 2 and 3 is applied through load resistor 7. Resistor 22 and capacitor 13 comprise an RC filter section for minimizing the alternating current components of the positive potential applied to elements 1, 2 and 3 through resistor 7 and to diode T3 through resistor 20.

A high voltage positive potential is applied to conductor 21 by conductor 38 from power supply output terminal 39. The power supply includes transformer 50, which has a primary winding connected to alternating-current supply terminals 52 and 53, a center-tapped step-up secondary winding 49, and a step-down filament winding 51. Anodes A2 and P3 of full-wave rectifier tube TE4 are connected directly to the end terminals of secondary winding 49. The center tap of secondary winding 49 is connected directly to ground. Cathode C4 is connected directly to a filter section having a capacitor 47 input between cathode C4 and ground, and an inductor 45 connected to the positive potential terminal of capacitor 47. Voltage regulator tube T3 and its associated limiting resistor 42 are connected directly between ground and the left terminal of inductor 45. The regulated output voltage of the power supply appears between terminal 39 and ground.

Second winding 51 energizes parallel-connected filaments F3, F4, F5, F6, F7, and F8. This winding also energizes filament F0 in a circuit which includes relay winding I.

The positive potential on conductor 21 is applied to anode A3 through load resistor 18. Control grid G4 is connected to terminal 4 by serially-connected resistor 11.

and capacitor 6. The common junction of resistor 11 and capacitor 6 is connected to ground through resistor 8. The T section, comprising serially-connected capacitors 14 and 17 connected between control grid G0 and anode A1, and resistor 14 connected between the junction of said capacitors and ground, is a high-pass degenerative feedback network for tube T3, whereby currents of frequencies greater than 25 cycles per second are attenuated by the T amplifier stage. Low-frequency components below 5 cycles per second applied between terminal 4 and ground are attenuated by the L section comprising capacitor 6 and resistor 8. Resistor 11 isolates the output of the degenerative feedback network at the lower terminal of capacitor 15 from the relatively low impedance of detecting elements 1, 2 and 3, so that the feedback potential applied to control grid G4 will not be excessively attenuated.

The output signal potential developed across load resistor 18 by tube T3 is coupled to control grid G3 of tube T5 by serially-connected capacitor 19 and resistor 22. A positive potential from conductor 21 is applied to anode A5 through load resistor 27. The T section, comprising serially-connected capacitors 24 and 26 connected between control grid G5 and anode A5, and resistor 23 connected between the junction of said capacitors and ground, is a high-pass degenerative feedback network for tube T5. Components having frequencies greater than 25 cycles per second are further attenuated by the amplifier stage comprising tube T3 and its associated components. Low-frequency components of less than 5 cycles per second appearing between the lower terminal of resistor 18 and ground are attenuated by the L section comprising capacitor 19 and serially-connected resistors 22 and 25. Resistor 22 isolates the output of the degenerative feedback network appearing at the lower terminal of capacitor 24 from the relatively low impedance of the lower terminal of resistor 18 with respect to ground so that the feedback potential applied to control grid G5 will not be excessively attenuated.

Tubes T1 and T3 and their associated components, therefore, generally comprise a band pass amplifier for amplifying potentials applied between terminal 4 and ground and having a frequency in the range of 5 to 25 cycles per second. All other frequencies generated by detecting elements 1, 2 and 3 are relatively attenuated by the band pass amplifier stages.

The output signal of the band pass amplifier which is developed across load resistor 27 is coupled to control grid G3 by serially-connected capacitor 28 and resistor 30. Grid return resistor 29 is connected between ground and the junction of capacitor 28 and resistor 30. Tube T4 is biased to a negative voltage greater than cutoff by the potential drop created across cathode resistor 32 by current supplied through resistor 34 from high voltage terminal 39. A positive potential is applied to anode A5 through load resistor 31.

Tube T4 and its associated components provide grid and plate limiting so that only negatively directed impulses of substantially the same amplitude and substantially square wave form appear between the lower terminal of resistor 31 and ground in response to both positive and negative impulses of varying amplitudes applied to the input of tube T4 by the output of the band pass amplifier. That is, negative impulses applied to the input of tube T4 do not develop a positively directed impulse between the lower terminal of resistor 31 and ground because tube T4 is biased to a value exceeding cut-off by the biasing potential of cathode resistor 32. Positive impulses applied to the input of tube T4, which exceed the cut-off bias value, develop negatively directed impulses of constant amplitude between the lower terminal of resistor 31 and ground because of the limiting action of grid-current flow through resistor 30 and saturation plate-current flow through resistor 31.

The substantially square negative impulses developed
across load resistor 31 are applied to the differentiation network comprising capacitor 33 and resistor 35. Anode A3 and control grid G3 of tube T3 are connected directly to one another, so that tube T3 operates as a diode. The space path of this diode shunts resistor 35 directly. Therefore, the positive impulses generated by differentiation in capacitor 33 and applied to tube T3 are shorted to ground by the low impedance presented thereto by tube T3. However, the negative impulses generated by differentiation in capacitor 33 and applied to tube T3 are not shorted to ground because of the high impedance presented thereto by tube T3. Accordingly, these negative impulses charge capacitor 37 through resistor 36. Any charge on capacitor 37 discharges through resistors 35 and 36. The time constant of the charging path for capacitor 37 is shorter than the discharge time constant. Therefore, the greater the number of negative impulses applied to the input of tube T3 within a specified time interval, the greater the potential developed across integrating capacitor 37. The differentiation, rectification and integrating components together comprise a low-frequency discrimination network.

In the preferred embodiment of Fig. 1, the component values affecting the time constant for the charge and discharge circuits for capacitor 37 are selected so that a specified negative potential value will appear across capacitor 37 when five or more negative impulses are applied to tube T3 within an interval of one second. When this value of negative potential is applied to control grid G3, the plate current thereof is kept to a value below the operate and release values for fire relay FA.

Before energization of trouble relay TR and fire relay FR, cathode C5 is connected directly to ground by a path which includes the break contact of the continuity transfer of trouble relay TR. After energization of fire relay FR and trouble relay TR, cathode C5 is connected directly to ground by a path which includes the make contact of relay FR and the make contact of the continuity transfer of relay TR.

If the potential across capacitor 37 is sufficiently negative to keep the anode A3 current flowing through relay FR below the operate or hold release values, as the case may be, the break contact of relay FR is closed. If the upper make contact of trouble relay TR is also closed and double-pole double-throw switch S is in the upper or operate position shown in the drawing, audible fire alarm FA is energized by current flow from the secondary of transformer 48 in a circuit which includes the break contact on relay FR, the upper make contact on relay TR, fire alarm FA, and the upper pole of switch S, back to the secondary winding of transformer 48.

Operation of the fire alarm FA, therefore, requires fire relay FR be released, trouble relay TR be operated, and switch S be in the operate position shown in the drawing.

The amplitude of the plate-current flow in the anode A3-cathode C3 space path of tube T3 controls the operation of trouble relay TR. This current flows from the positive terminal 39 of the power supply through conductor 38, conductor 21, the secondary winding of transformer 48, the upper pole of switch S when positioned in the operate position, fire alarm FA, relay TR, anode A3-cathode C3 space path, resistor 46, make contact on relay FR, and the break contact of the continuity transfer of relay TR to ground. Operation of relay FR is, therefore, required to initially actuate relay TR. After relay TR is actuated, resistor 46 is grounded through the output end of the circuit and the continuity transfer of relay TR and operation of relay FR is no longer required. Tube T3 is normally biased to cut-off by the potential drop across resistor 46 created by current flow through resistor 44 from power supply terminal 39.

Resistor 43 interconnects the junction of serially-connected resistors 40 and 41. Diode T5 connects anode A5 directly to the upper terminal of resistor 40 so that the output of tube T5 is direct-current coupled to the input of tube T5.

When trouble relay TR is released, the lower break contact thereon completes the circuit connected thereto so that current flow from battery B energizes audible and/or visual trouble alarm TA. The energizing circuit for the trouble alarm TA is completed whenever the apparatus of Fig. 1 is incapable of performing its prescribed function. If, for example, the filament supply voltage should fail, the break contact on relay I closes, grounding control grid G3, thereby causing relay TR to release the break contact thereon and to complete the trouble alarm circuit. The full mean output of the auxiliary trouble supervision provided by the trouble relay TR and its associated trouble alarm circuit will be readily apparent from a portion of the description which follows herein-after.

The fire detection apparatus of this invention is in operative readiness whenever switch S is placed in the upper position shown in Fig. 1, and audible fire alarm FA will be operated whenever a fire is detected. If it is desired to fire-test the apparatus without operating the audible alarm, switch S should be positioned in its lower, or test position. This positioning disconnects the fire alarm FA from the secondary winding of transformer 48 and connects test lamp TL thereto. This lamp is energized if the break contact on the fire relay is closed. If the apparatus responds properly to a test fire, a sufficiently large negative potential appears across capacitor 37 to reduce the current flow through tube T3 to a value below the hold value for relay FR, thereby causing the closure of the break contact on relay FR and the consequent lighting of test lamp TL.

Visual and/or audible trouble alarm TA is actuated whenever switch S is in its lower test position, thereby indicating that the fire detection apparatus is in an operative readiness. That is, fire alarm FA cannot be operated in response to a detected fire. The operation of the trouble alarm during a testing operation is, therefore, a continual reminder that switch S should be returned to its upper or operate position after the test has been completed. This actuation of trouble alarm TA is caused by the grounding of control grid G3 through a circuit which includes the bottom pole of switch S, thereby releasing trouble relay TR and closing the lower break contact thereon.

Trouble alarm TA is also operated whenever the detecting apparatus is incapable of fully performing its functions. This feature of the invention will be more fully described later, results in part from the continual self-monitoring output signal generated by the relaxation oscillator comprising gas diode T3 and its associated components.

The detailed operation of the circuit of Fig. 1 prior to the detection of a fire is as follows: before the application of power to the circuit, switch S is placed in the upper or operate position so that the fire alarm FA will be operated if and when radiant energy from fire flame impinges upon one or more of fire detecting elements 1, 2 or 3. A suitable alternating-current potential is then applied to terminals 52 and 53 to energize the primary windings of transformers 48 and 50. The output potential of secondary winding 51 heats filaments F1, F2, F3, F4, and F5. Filament F5 is also heated by current from secondary winding 59 flowing in a path which includes relay winding 1. Relay I is accordingly energized, thereby opening the break contact thereon and removing ground from control grid G3.

Full-wave rectifier tube T8 operates in the conventional manner to transform the alternating-current potential from secondary winding 49 to full-wave direct-current impulses appearing between cathode C3 and grid I. The further section comprising diode T7 and resistor 45 substantially filters the alternating-current components from the full-wave direct-current impulses applied thereto. The
relatively smooth direct-current potential appearing between the left-hand terminal of inductor 45 and ground is voltage-regulated by gas diode T1 and its current-limiting resistor 42. A voltage-regulated positive potential, therefore, appears between terminal 39 and ground. This positive potential is applied to anode As through conductor 33, conductor 21 and relay winding FR, and ground potential is applied to cathode Cs through the break contact of the continuity transfer on trouble relay TR. In the absence of fire, insufficient negative bias is applied to control grid Gs to prevent the operation of fire relay FR, because the charge on capacitor 37 is that produced solely by the signal impulses transmitted thereto through band pass amplifier tubes T1 and T2, and limiter tube T4 by the relaxation oscillator comprising components 9, 10, 16, 20 and T2. A detailed explanation of the transmission of these oscillator signals follows hereinafter.

The consequent closure of the make contact on fire relay FR, due to the operation of said relay by the plate current of tube Ts grounds the upper terminal of resistor 46 in a path which includes the make contact of fire relay FR and the break contact of the continuity transfer of trouble relay TR. The positive potential of terminal 39 applied to cathode resistor 46 through resistor 44 biases tube Ts to cut-off. The positive potential of terminal 39 is also applied to anode As through a path which includes conductor 38, conductor 21, the secondary winding of transformer 48, fire alarm FA, and trouble relay TR.

This cut-off bias is overcome by a positive signal applied to control grid Gs of tube Ts by the relaxation oscillator output signal appearing across resistor 9. This output signal is applied to terminal 4 through serially-connected fire detection elements 1, 2 and 3. The frequency of this signal is approximately one cycle per second, but because of the relative strength thereof, it is transmitted through the band pass amplifier stages comprising tubes T1 and T2, notwithstanding the five cycles per second low-frequency cut-off of this amplifier. This signal passes through limiter tube T4 and appears across integrating capacitor 37 in sufficient amplitude to apply a negative potential to control grid Gs which reduces the plate-current flow through fire relay FR to a value slightly greater than the release value thereof. This decrease in current flow through relay winding FR raises the potential of anode As of gas diode T3. Because of the constant voltage characteristics of diode T3, the potential of cathode Cs is also increased by the same increment. This positive increment is divided by connected resistors 40 and 41, and a portion thereof is applied to control grid Gs through resistor 43 in sufficient amplitude to overcome the cut-off bias of tube Ts and cause sufficient current flow in the anode As-cathode Cs space path to energize trouble relay TR.

The energization of trouble relay TR transfers ground to cathode Cs from a path, which before energization of trouble relay TR included the make contact of fire relay FR and the break contact of the continuity transfer of trouble relay TR to a path which includes the make contact of fire relay FR and the make contact of the continuity transfer of trouble relay TR. The operation of fire relay FR is, therefore, unaffected by the operation of trouble relay TR.

The operation of the trouble relay TR opens the lower break contact thereon and prevents battery B from applying an operating current to trouble alarm TA.

The trouble relay TR is not energized by current flow from the secondary winding of transformer 48 because the energizing circuit thereon includes the opened break contact of energized fire relay FR. The plate current for tube Ts is considerably smaller than the operate value for fire alarm FA.

Thus, when a fire is not detected by any of elements 1, 2 and 3, fire relay FR is actuated, preventing the operation of the fire alarm FA, and the trouble relay TR is also actuated preventing the operation of trouble alarm TA.

Because of the novel mode of operation of trouble relay TR, the capability of the fire detection apparatus to perform its prescribed functions is continually monitored. If the relaxation oscillator output signal across resistor 9 is not continually transmitted through serially-connected fire detection elements 1, 2 and 3, and pass amplifier tubes T1 and T2, limiter tube T4, the discriminating network including tube Ts and integrator capacitor 37, and tube Ts to control grid Gs, trouble relay TR will permit closure of its break contact and consequent operation of trouble alarm TA. Operation of the trouble alarm will, therefore, immediately reveal any defective operation in the aforementioned components so that the necessary repairs may be made.

Likewise, if the fire alarm should burn out, or switch S be removed from its operate position, or the secondary winding of transformer 48 be opened, the trouble relay TR will release its lower break contact and operate the trouble alarm TA. A burning out of filament 10 will permit closure of the break contact of relay I and ground control grid Gs thereby de-energizing trouble relay TR and operating trouble alarm TA. Accordingly, the fire detection apparatus of this invention, for all practical purposes, is self-checking so that at any time it is incapable of detecting a fire and operating a fire alarm in response thereto, a trouble alarm will be given so that the necessary repairs can be made.

Furthermore, a shorting of most of the tube electrodes for tubes T1, T3, T4 and T3 to their respective filament holder will apply a resulting signal to integrating capacitor 37 sufficiently large to release fire relay FR and thereby operate the fire alarm FA. This is because the filament potential of secondary winding 51 is great enough to transmit a sufficiently large signal to capacitor 57 to simulate a fire. With caps 6 working in the secondary circuit components to assure the release of fire relay FR in response to a tube short, the potential of secondary winding 51 should be much greater than that required for the circuit filament. In this case the filament holder are supplied from an intermediate tap on the filament winding. The detailed operation of the circuit of Fig. 1 after the detection of fire is as follows: with switch S in the operate position as shown in Fig. 1 and fire relay FR and trouble relay TR being operated as hereinbefore described, if radiant energy emanating from fire impinges on one or more of fire-detecting elements 1, 2 or 3, a negative potential is developed across integrating capacitor 37 which reduces the plate current for tube Ts to a value having a magnitude less than the hold value for fire relay FR, thereby releasing the contacts thereon. The closure of the break contact on the fire relay completes the energizing circuit for the fire alarm FA, thereby warning of the presence of a fire in the area supervised by the detecting elements 1, 2 and 3.

The secondary winding of transformer 48 supplies the fire alarm FA energizing current in a circuit which includes the break contact of fire relay FR, the upper make contact of trouble relay TR, fire alarm FA, the upper section of switch S in the position shown in Fig. 1, and a conductor returning to the secondary winding of transformer 48.

The negative potential across capacitor 37 which causes the release of fire relay FR is developed as follows: the radiant energy impinging upon one or more of fire-detecting elements 1, 2 and 3 causes a modulation of the series impedance thereof at the same modulating frequencies present in the fire flame. This impedance variations develops a voltage drop across load resistor 7 having the same frequency components. The potential applied to terminals 4 and 5, therefore, is amplitude modulated at the same frequencies as the fire flame. The potential across terminals 4 and 5 is applied in series with the relaxation oscillator output signal developed across resistor 9 to terminal 4 and ground.

The frequency components in the range of 5 to 25
cycles per second applied between terminal 4 and ground are amplified by band pass amplifier tube T4 and its associated amplifier components, thereby developing an amplified signal across load resistor 18. The signal developed across load resistor 18 is coupled by serially-connected capacitor 19 and resistor 22 to control grid G3 of tube T3, which tube, together with its associated components, comprises a second band pass amplifier stage. The transmitted components are, therefore, further amplified and they ultimately appear across output load resistor 27. This signal is coupled to control grid G2 of limiter tube T4 by serially-connected capacitor 28 and resistor 30. The negatively directed alterations thereof are limited completely by limiter tube T4 because tube T4 is biased to a value exceeding cut-off. When the potential of the positive alternations of the signal developed across resistor 29 exceeds the bias potential across resistor 32, grid-current flow through resistor 30 and saturation plate-current flow in resistor 31 limits the negatively directed impulses developed across resistor 31 in the conventional manner. Accordingly, only negatively directed impulses of constant amplitude are developed across load resistor 31 of limiter tube T4.

These negatively directed impulses are differentiated by capacitor 33 and resistor 36. Any positive impulses which are generated by differentiation in capacitor 33 are shorted out by the low impedance presented thereto by tube T4. The negative impulses generated by differentiation are not shorted out by tube T4 and, therefore, charge capacitor 37. Because of the selectivity of component values hereinbefore explained, the charging time constant for capacitor 37 is shorter than its discharge time constant. Therefore, the greater the number of impulses applied to capacitor 37 within a given time interval, the greater the value of negative potential integrated. When five impulses per second are applied to capacitor 37, the integrated potential is sufficiently great to reduce the plate current flow in tube T4 below the hold voltage for fire relay FR, thereby actuating fire alarm FA as hereinbefore explained.

The requirement that at least five impulses be applied to capacitor 37 in a second before sufficient integration occurs, prevents a false alarm from occurring in response to rapid on and off switching of the load.

It is possible to have two light cycles generated in an interval of less than a fifth of a second by this switching operation. A signal will, therefore, be transmitted through the band pass amplifier stages. The integrator circuit, however, will discriminate against this signal because at least five impulses per second are required to produce sufficient integration to release fire relay FR.

Operation of fire alarm FA may be stopped by moving switch S to its lower or reset position so as to open the fire alarm circuit. If the fire has been extinguished, a repolingition of the switch to its upper or operate position will not complete the energizing circuit for fire alarm FA, because the break contact of fire relay FR is opened by the reparation of fire relay FR. The fire detection apparatus is, therefore, easily placed in readiness to detect a second fire without replacement or maintenance of components.

If it is desired to test the operation of the apparatus in response to a controlled testing flame without operating the alarm, switch S is positioned to its lower or reset position. This disconnects fire alarm FA from the secondary winding of transformer 48 and connects test lamp TL thereto. Therefore, when the testing of fire relay FR is in a manner herebefore explained, test lamp TL is energized by current flow from the secondary winding of transformer 48 flowing in a circuit which includes the break contact of fire relay FR, test lamp TL, and the upper section of switch S, in its lower switch position, back to the secondary winding of transformer 48.

It should be noted that, whenever switch S is positioned in its reset or test position, control grid G4 is grounded, thereby causing trouble relay TR to release its lower armature and complete the energizing circuit for trouble alarm TA. The operation of this alarm is a continual reminder that switch S should be reset after the test to its operate or upper position so that the apparatus will again be able to operate the fire alarm in response to a detected fire.

There is shown in Fig. 2 a lead sulfide photoconductive cell suitable for use as a fire-detecting element for the circuit of Fig. 1. The cell comprises two aquadag circular rings 55 and 56 painted on the inner side of hermetically sealed envelope 54. A lead sulfide layer provides a photoresponsive electrical path between the aquadag rings. External electrical connections are made to rings 55 and 56 by socket contact to contacts 57 and 58, respectively. This cell structure is particularly useful in fire-detecting apparatus because it provides fire detection in a hemispherical volume represented by shell 60. Consequently, very few of these cells are required to supervise a large volume for fire. A more detailed disclosure of the structure and operation of the photoconductivity cell shown in Fig. 2 may be found in U. S. Patent No. 2,636,100, issued April 21, 1953, to N. Andersen.

The cell of Fig. 2 can be protectively mounted on a wall or ceiling by the housing assembly shown in Fig. 3. This assembly comprises a hollow container 61 which is preferably recessed in wall or ceiling 62, thereby exposing only the bottom portion of the assembly, which portion includes the photoresponsive portion of the cell. The glass envelope 54 of the cell is protected by translucent cover 63, which cover should be constructed of a material that does not appreciably absorb the radiant energy emanated by fire flame. The necessary connections to the cell are made by conductors 64 and 65. The portion of these conductors outside box 61 interconnecting a plurality of cells should preferably be located within a metallic conduit.

A substantial portion of the circuitry of the embodiment of this invention shown in Fig. 4 is identical to that of Fig. 1. In particular, the band pass amplifier comprising tubes T1 and T3 and their associated components is the same as the band pass amplifier of Fig. 1. Likewise, the limiter circuit comprising tube T4 and its associated components is the same as the limiter circuit shown in Fig. 1. The circuit components of Figs. 1 and 4 which have corresponding functions are identified with the same reference characters, and explanation of the operation thereof can be had by referring to the appropriate portion of the detailed description of the circuit of Fig. 1 hereinbefore set forth.

The input signal to the band pass amplifier comprising tubes T1 and T3 is developed across load resistor 89, which resistor is commonly connected in the anode circuits for mixer tubes T11, T12, and T13. This signal is applied to control grid G1 by serially-connected capacitor 87 and resistor 88. Anodes A11, A23 and A33 of the mixer tubes are connected in multiple with respect to one another so as to develop a common output across load resistor 89, whereas the inputs to mixer tubes T11, T12 and T13 at terminals A, B and C, respectively, are isolated from one another to provide a signal mixing function. Photoconductive cells P1, P2 and P3 of fire detector pick-up units D1, D2 and D3 are connected to terminal A through isolating resistors 66, 67 and 68, respectively; photoconductive cells P4, P5 and P6 of fire detector pick-up units D4, D5 and D6 are connected to terminal B through isolating resistors 71, 72, 73 and 74, respectively. The energizing currents for the three sets of photoconductive cells P1 to P3, P4 to P5, and P6 to P6 are supplied through load resistors 75, 76 and 77, respectively. Resistors 78, 79 and 80 aid in keeping the direct-current potential on line 1 at a substantially constant value during the operative life of the circuit apparatus. Coupling capacitor 81
and grid-return resistor $R_4$, coupling capacitor $C_2$ and grid-
return resistor $R_5$, and coupling capacitor $C_3$ and grid-
return resistor $R_6$ provide conventional RC inputs for mixer tubes $T_1$, $T_2$ and $T_3$, respectively.

Each of detector units $D_1$ to $D_9$ comprises a corres-
ponding photoconductive cell $P$ and test lamp $L$. Each of the photoconductive cells $P$ and its associated test lamp $L$ are preferably located within a housing of the general type shown in Fig. 5, whereby the light energy from lamp $L$ can impinge upon the active surface of photoconduc-
tive cell $P$ in response to the operation of test lamp $L$. Referring in particular to Fig. 5, the assembly thereof comprises a metallic tubular housing 122, a portion of which is bent in an arcwise, so as to show the positioning of photoconductive cell $P$ therein. The photosensitive area of this cell shown generally at 121 comprises the common area between electrodes 123 and 124. Lamp $L$ is located within shell 125, which shell is screwed to a side portion of housing 122. The light from test lamp $L$ passes through narrow slit 126 in shell 125, and a portion of the components thereof are transmitted through filter window 120 so as to strike the active portion of photoconductive cell $P$ at 121. The operation of test lamp $L$ is used to simulate a fire and thereby test the fire alarm status of the circuit under fire test explained in detail. A complete structural description of a photoelectric cell device similar to the fire detector housing shown in Fig. 5 is disclosed in U. S. Patent No. 2,631,247, issued March 10, 1953, to E. Shaw.

Test switch $TS$ comprises nine test positions and a tenth operate position $O$. When test switch $TS$ is positioned at one of the test positions, the corresponding test lamp $L$ is energized by the potential applied by secondary winding 112 through interrupter INT. Interrupter $INT$ may be any conventional apparatus for interrupting or otherwise opening the test lamp energizing circuit at a frequency within the operating range of the band pass amplifier comprising tubes $T_1$ and $T_3$. This operating range is, in the case of most aircraft, between the limits of 5 and 25 cycles per second. Interrupter $INT$ may, therefore, have an interrupting frequency of, say, 10 cycles per second.

If test switch $TS$ is positioned at $O$, none of test lamps $L$ are energized because there is no ground return path for any of the lamps through secondary winding 112.

Photoconductive cells $P_1$ to $P_9$ are connected in parallel with respect to one another in the circuit of Fig. 4 so as to provide fail-safe fire protection. That is, if one or more of the fire detector pick-up units $D$ is destroyed by fire or rendered inoperative for any reason, the remaining detector units will nonetheless be capable of detecting a fire satisfactorily or of indicating the termina-
tion of a detected fire. In the circuit of Fig. 1, fire detection elements 1, 2 and 3 are serially connected. Therefore, the failure of one of said units will render the remaining units inoperative. Such an occurrence is not critical in the embodiment of Fig. 1 because the transmission of the check signal of the apparatus of Fig. 1 is interrupted by failure of one of the serially-connected detection elements. This transmission failure of the check signal will cause the operation of trouble alarm $TA$, thereby giving an indication of trouble. However, in the apparatus shown in Fig. 4 adapted to aircraft, the termination of fire must be reliably indicated notwithstanding the failure of one or more of fire detector pick-up units $D$. This requires a parallel connection of the detection elements, as distinguished from a series con-
nection. This parallel connection of the fire detection pick-up units also imposes the restriction that the units must be tested individually, as distinguished from a simulta-
aneous testing of the units as was possible in the circuit of Fig. 1.

The negatively directed square-shaped impulses de-
veloped across output load resistor 27 of band pass amplifier tube $T_4$ are differ-
entiated principally by capacitor $C_3$ and resistor $R_5$ so that both positive and negative impulses of short duration and constant amplitude appear across resistor $R_5$. Resistor $R_1$ and capacitor $R_2$ comprise a high-
frequency filter whereby any components exceeding the upper frequency range of the band pass amplifier tube and reaching this point of the circuit are further attenuated. The component values for the filter section are selected so as not to substantially affect the wave shape of the differentiated positive impulses appearing across resistor $R_5$ at a rate of approximately 5 to 10 per second.

The positive impulses developed by differentiation in capacitor $C_3$ and resistor $R_5$ are transmitted by tube $T_4$ so as to charge integrating capacitor $C_9$. The negative impulses generated by differentiation do not affect the integration produced by capacitor $C_9$ because of the high back resistance of tube $T_4$ to negative impulses.

The charging time constant for capacitor $C_9$ is smaller than its discharge time constant. Therefore, the greater the number of impulses applied to capacitor $C_9$ within a given time interval, the greater the value of positive potential integrated thereacross. When at least five im-
ulses per second are applied to capacitor $C_9$, the inte-
grated potential applied to resistor $R_6$ through resistor $R_4$ is sufficiently large to break down thyatron type gas tube $T_3$.

The anode $A_1$ to cathode $C_9$ breakdown potential for tube $T_3$ is provided by the alternating potential output of secondary winding 106. A negative bias is applied to cathode $C_9$ and control grid $G_3$ through quick-
heating diode $T_4$ by secondary winding 109 during the filament warm-up period for rectifier tube $T_{19}$ and gas tube $T_3$. This bias arrangement prevents the operation of fire indicator lamp $FI$ by an impulse developed in the primary winding of output transformer 105 due to break-
down of tube $T_3$ during the filament warm-up period. After filament $F_{11}$ of full-wave rectifier tube $T_{19}$ reaches its operating temperature, the positive impulses at cathode $C_{19}$ are filtered by the $T$ section comprising re-
sistors 100 and 102 and capacitor 101. Potentiometer 99 is connected directly across the positive terminal of the power supply and ground so that the movable tap thereof can be adjusted to provide a direct voltage bias to gas tube $T_3$ whereby the required integration must occur in capacitor $C_9$ before tube $T_3$ is broken down.

Electrostatic shields 104, 107 and 108 prevent the de-
velopment of an alternating potential across the lower tapped portion of potentiometer 99 by secondary wind-
ings 104 and 106. Inasmuch as the potentiometer 99 supplies the negative bias to tube $T_3$ after the filament warm-up period, any appreciable alternat-
ing potential appearing across this portion of the poten-
tiometer would tend to fire tube $T_3$ falsely.

Gas diode $T_{19}$ provides conventional voltage regulation for the power supply, and the filter section compris-
ing resistor $R_9$ and capacitor $C_4$ provides additional filter-
ing for the current supplied to photographic cells $P_1$ to $P_6$. A tap on secondary winding 109 supplies the appro-
priate filament potential for the tubes having fila-
ments. If tubes are selected for use in this circuit having different filament values, the necessary voltage taps must be made to secondary winding 109.

The detection and the supervision of fire by the circuit of Fig. 4 is as follows. Test switch $TS$ should be posi-
tioned at operate position $O$ before the application of the operating potentials to the circuit. With such a posi-
tioning all of the energizing circuits for test elements $L$ will be opened. Therefore, photoconductive cells $P_1$ will be subjected only to the radiation, including possible flame radiation, within the vehicle compartments under fire supervision and not filtered by window 120 of the housing shown in Fig. 5. Window 120 is preferably in-

corporated in the housing so as to minimize the intensity of the ambient light components which impinge upon the enclosed photoconductive cell. These components are objectionable in that they tend to saturate the cell and thereby lower the response thereof to fluctuating components. Filter window 120 should preferably transmit near infrared active wavelengths for optimum sensitivity, inasmuch as the ratio of the intensity of the fluctuating to the ambient components is the highest in this portion of the spectrum.

When the appropriate alternating-current potential is applied to the input terminals of primary winding 110 from the aircraft power distribution system, temporary negative bias is immediately applied through switching diode T15 to the control space path of tube T15 by secondary winding 109 so as to prevent possible breakdown of tube T15 in response to the potential from secondary winding 106. The filaments of the various tubes of the circuit having heaters are thereafter warmed up in a conventional manner by the output potential applied to the tapped portion of secondary 109. When filament F, of full wave rectifier tube TR is sufficiently heated, a direct-current potential appears across potentiometer 99 and a portion thereof is applied as a permanent negative bias to the control space path of tube T15. Positive operating potentials are also supplied at this time to anodes A1 and A2 through load resistor 89, to anode A3 through load resistor 15, to anode A4 through load resistor 27, and to anode A5 through load resistor 31. The highly filtered direct current output of the power supply appearing at the right terminal of resistor 98 is applied to photoconductive cells P through their respective load and isolating resistors. A direct-current bias cutting off is also applied at this time to the cathode of limiter tubes T8 by the voltage divider network comprising resistors 32 and 34.

The electrical impedance of photoconductive cells P, to P9 varies in response to the cell-responsive radiant energy impinging upon the active areas of the respective cells. These cells translate the intensity of this energy to a fluctuating electrical current having a corresponding fluctuating amplitude. The frequency components of this complex electrical wave form, including any direct-current components, are applied to input terminals A, B, and C of capacitors 81, 82 and 83, which prevents the transmission of the direct-current components to the control space paths of mixer tubes T15, T15, and T15. The alternating-current components of the applied input signals are transmitted to the grids of mixer tubes T15, T15, and T15 and are mixed in a conventional manner wherein the resulting output appears across load resistors 89. The signal components developed across load resistor 89 are coupled to the input of the band pass amplifier comprising tubes T15 and T15 by serially-connected capacitor 87 and resistor 88. Inasmuch as the band pass amplifier comprising tubes T15 and T15 selectively transmits a limited range of frequency components, and, relatively speaking, attenuates all components outside of this limited range, the output signal appearing across load resistor 27 of the output of the band pass amplifier contains, for all practical purposes, components within the range of 5 to 25 cycles per second only.

These components are further transmitted to the input of limiter tube T15 by coupling capacitor 28. Limiter tube T15 translates these alternating-current components to negatively-directed square wave impulses of constant amplitude in a manner hereinbefore described in conjunction with the circuit of Fig. 1.

These negatively-directed square wave impulses are differentiated by the network comprising capacitor 33 and resistor 35 whereby sharply peaked positive and negative impulses of substantially the same wave form appear across resistor 35. The RC network comprising resistor 91 and capacitor 92 attenuates any components generated at a rate exceeding approximately ten positive impulses per second. This operation serves as an additional check upon the upper frequency attenuation of the band pass amplifier. Notwithstanding the attenuation in the range of 10 to 25 positive impulses per second, this impulse rate can still produce sufficient integrated potential across capacitor 93 to operate tube T15.

The positive impulses generated by differentiation are transmitted through diode T14 without substantial attenuation and charge integrating capacitor 93. The negative impulses generated by differentiation are, for all practical purposes, fully attenuated by the reverse impedance of diode T14 and, therefore, do not affect the integrated potential which appears across capacitor 93. The charging time constant for resistor 94 and latching capacitor 95, the combination of which directly shunts integrating capacitor 93, is relatively short and, therefore, capacitor 95 charges in a relatively negligible time to a constant potential determined by the values of resistors 94 and 96. If five or more positive impulses are integrated by capacitor 93 within an interval of one second, sufficient potential is developed across capacitor 95 and resistor 96 to break down gas tube T15. This breakdown potential must be maintained for a period of several cycles so as to operate gas tube T15 in a continuous period inasmuch as the tube is extinguished during each cycle and must be broken down before each succeeding cycle.

Inasmuch as frequency components within the range of 5 to 25 cycles per second are unique to fire flame for the reasons hereinbefore explained, appreciable signal will appear at the output of limiter tube T15 only when fire flame impinges upon one or more of the photoconductive cells P. This limiter output is differentiated and integrated so as to break down gas tube T15 and thereby operate fire indicator FI in response to the detection of fire; whereas, a detected fire should terminate for one reason or another, the output from limiter tube T15 would disappear and within a relatively short period of time the integrated charge upon capacitor 93 would be dissipated and, therefore, a breakdown potential would no longer be applied to the control space path of tube T15. As a consequence, fire indicator FI will be returned to its deenergized condition in response to the termination of the fire.

Certain characteristics of fire complicate the attainment of the indication of a termination of a fire by the fire detection apparatus and method of this invention. It has been found that in almost every fire there are periods during which the frequency components within the range of 5 to 25 cycles per second, as well as other ranges, are negligible in amplitude. This characteristic of fire introduced no serious problems in the operation of the embodiment of this invention shown in Fig. 1 inasmuch as that embodiment was required to operate an alarm only in response to the detection of fire. Once the alarm was operated, the alarm circuit was permanently established and the alarm would continue to operate notwithstanding the fact that the fire had become extinguished for one reason or another. In the embodiment shown in Fig. 4, however, fire indicator FI is not locked in after the operation thereof in response to fire and therefore, during a period in which the fire components between 5 and 25 cycles per second are negligible, it is quite possible that the integrated potential across capacitor 93 will be discharged sufficiently to prevent a breakdown in the circuit. Consequently, fire indicator FI will be deenergized, giving a false indication of the termination of the fire. Latching capacitor 95 has been added to the circuit to overcome this objection. Specifically, capacitor 95 is charged during each breakdown alternation of tube T15 by probe current from the control current generator so that probe current maintains a sufficient charge upon capacitor 95 to keep tube T15 broken down during the interval wherein less than normal potential is integrated in capaci-
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The fire apparatus of Fig. 4 is preferably tested prior to the use of the aircraft in which the apparatus is installed, so that the pilot will know definitely that the apparatus is capable of performing its detection and supervision functions. In particular, test switch TS is successively positioned at the nine test positions before flight whereby the test lamps are successively energized by current flow from secondary winding 112 through interrupter INT. Interrupter INT modulates the energy supplied to the test lamps at a frequency of approximately 10 cycles per second, whereby the light emanating from the energized test lamps L is also modulated at a corresponding frequency. When the modulated light energy from a particular lamp L impinges upon its associated photoconductive cell P, a signal is transmitted through the circuitry in the same manner as that created by impinging flame radiation. Inasmuch as the fundamental frequency of this signal is 10 cycles per second, sufficient integration will occur in integrating capacitor 93 to break down gas tube Ts and thereby energize fire indicator FI.

If this procedure is repeated throughout all nine test positions, the proper operability of each of the fire detector pick-up units can be ascertained. If for any reason fire indicator FI is not operated in response to the positioning of test switch TS at each of its test positions, repair and maintenance procedures should preferably be initiated before operation of the aircraft.

A suggested installation of a commercial embodiment of the apparatus of Fig. 4 in a reciprocating engine aircraft is shown in Fig. 7. Fire detector units D are located within the engine nacelle so as to fully supervise both the propeller and the accessory sections thereby uniting units are individually cabled to an amplifier unit AU which houses the circuit apparatus. Amplifier unit AU is preferably located outside the aircraft zones which are primarily subject to fire. Test switch TS is preferably located on the instrument panel for operative convenience. Fire indicator FI is also mounted on the instrument panel so that the pilot may readily be informed of the occurrence of a fire or the results of a testing operation.

A suggested installation of the fire detection apparatus of Fig. 4 in a jet type aircraft is shown in Fig. 6. Generally speaking, the installation of the amplifier unit AU, test switch TS, and fire indicator FI is the same as that herebefore described with respect to the reciprocating engine type of aircraft. Fire detector units D are disposed in the air space between the shroud and the skin of the aircraft, and the flame sensor appearing outside the walls of the accessory section 126, compressor section 127, burner tubes 128, turbine 129, tail comb 130, and tail pipe 131 is immediately detected.

A third embodiment of this invention which is particularly adapted to supervise the continuation of intentional fires, is shown in Fig. 8. The type of output function provided by this circuit, generally speaking, is the reverse of that provided by the circuits of Figs. 1 and 4. That is, the circuit provides a null response during a fire and a control function in response to the extinguishment of a fire. For the sake of example, photoconductive cell 1 is shown coupled by pipe 132 to a fragmentary portion of the shroud assembly of the jet aircraft shown in Fig. 6, whereby the continued presence of a flame within burner 123 is supervised by the circuit of Fig. 8. During the operation of the jet aircraft, flame should be continuously present within the burner. The appearance of an intentional flame would immediately inform the operator of the unwanted extinguishment of such a flame or to initiate some particular control function in response to the extinguishment of such flame. It should be understood, however, that this embodiment of the invention is equally adaptable to the supervision of intentional fires within all types of combustive a combustion chambers so that a change in output function will occur in response to the extinguishment of a flame.

Tubes Tz and Ts and their associated components comprise a band pass amplifier which is identical in structure to the band pass amplifier of the circuits of Figs. 1 and 4. The circuit components of Figs. 1 and 8 which perform corresponding functions are referenced by the same characters and a detailed description of the operation thereof may be had by reference to the descriptive portions of the circuit of Fig. 1.

The alternating-current output of the band pass amplifier developed across load resistor 27 in response to the detection of fire flame by photoconductive cell 1 is coupled to the control grid of cathode Cz of space path of tube Tz through serially-connected capacitor 134 and resistors 136 and 137. Diode Ts shunts to ground the positive feedback circuit of the amplifier developed across load resistor 27 wherein only a negative potential appears across resistors 136 and 137 with respect to ground. Capacitor 138 shunts resistor 137 so that a relatively smooth direct-current potential is applied to the control space path of tube Tz whenever an alternating-current signal is developed across resistor 27.

The anode-cathode space paths of tubes Ts and Tz are connected in series with respect to one another through resistor 139. An alternating-current potential is applied to the anode-cathode space path of tube Tz through the winding of relay RR by the portion of the secondary winding of transformer 146 between conductors 141 and 143. An alternating-current potential is applied to the anode-cathode space path of tube Ts through resistor 139 by the portion of the secondary winding of transformer 146 between conductors 143 and 144. Overcurrent A22 so that the value of negative bias applied to the control space path of tube Tz is determined by the current flow in the anode-cathode space path of tube Tz. In particular, if appreciable current flows in the anode-cathode space path of tube Tz, a sufficient voltage drop will be deliverably located between anode-cathode space path current flow of tube Tz so that relay RR will release its contact, thereby completing the energizing circuit for output lamp LL. If, however, a suffi-
cient negative potential is applied to the control space path of tube T2 to limit the voltage drop across resistor 139, tube T3 will conduct appreciable current in its anode-cathode space path and relay RR will be operated, thereby opening the energizing circuit for output lamp LL. Capacitor 140 shunts the winding of relay RR so that a relatively smooth operate current is applied to relay RR, thus preventing possible relay chatter.

Conductor 142 applies an alternating potential to the anode of half-wave rectifier tube T9 whereby a positive potential with respect to ground is developed at the cathode C9. Capacitor 146 is connected in parallel with the cathode of tube T9 in a manner similar to the connection thereof to the junction of resistors 133 and 27. Voltage regulator gas diode T13 and its limiting resistor 133 provide conventional filtering and voltage regulation action so that a relatively smooth and constant direct-current potential is applied to the junction of resistors 12 and 18.

The detailed operation of the circuit of Fig. 8 in response to a supervised fire within burner 128 is as follows. When the appropriate primary potential is applied to winding 147 of transformer 146, the filament F1, F2, F3, F4, F5, and F6 are heated in the conventional manner by winding 145. An alternating-current potential is applied to the anode-cathode space path of tube T9 through the winding of relay RR by the portions of the secondary winding of transformer 146 between conductors 141 and 143. An alternating-current potential is applied to the anode-cathode space path of tube T3 through resistor 139 by the portion of the secondary winding of transformer 146 between conductors 143 and 144. A positive potential is applied to photoconductive cell 11 through resistors 7, 12 and 133 from the cathode of half-wave rectifier tube T10. A positive potential is also applied to the anodes A1 and A2 through their respective load resistors 18 and 27.

The fluctuating flame radiation within burner 128 causes a corresponding fluctuation in the impedance of photoconductive cell 1 whereby a complex alternating-current wave form having components principally in the band-pass range of the amplifier comprising tubes T11 and T12 is developed across load resistor 27. The positive alternations of this complex wave form are shorted to ground by the low impedance presented thereto by diode T11. The negative alternations of this complex wave form are not affected by the high reverse resistance of diode T11 and therefore a negative potential is developed across resistor 137 in a manner already explained. This negative potential reduces the potential drop across resistor 139 so that appreciable current flow occurs in the anode-cathode space path of tube T9, thereby causing relay RR to operate. The operation of relay RR opens the energizing circuit for output lamp LL. Consequently, lamp LL is deenergized in response to the continued supervision of fire flame by photoconductive cell 1. If for any reason the flame within burner 128 should become extinguished, the alternating-current output would not appear across load resistor 27 of the band pass amplifier, and, therefore, the negative bias developed during the supervision of flame across resistor 137 would disappear and tube T9 would conduct appreciable current, thereby applying a substantial negative bias to the control space path of tube T9. This negative bias reduces the current flow through the winding of relay RR to a value less than the relay release value. Consequently, relay RR releases its contact and the break contacts are closed, completing the energizing circuit for output lamp LL. The operation of output lamp LL therefore indicates that the flame within burner 128 has become extinguished. It should be understood that other control circuits may be operated by additional contacts on relay RR so as to provide any desired output function having to do with supervision of a fire flame within a supervised chamber or in response to the continued existence of said flame.

As in the case of the embodiment of this invention shown in Fig. 4, the circuit of Fig. 8 is affected by the existence of flame periods during which the frequency components within the selected range of the band pass amplifier are negligible in amplitude. During these periods the negative potential applied to the control space path of tube T9 will be diminished in amplitude because of the reduced output across resistor 27. This reduced potential will have a tendency to cut off the anode-cathode current flow in tube T9 so that relay RR will release its contact and close the energizing circuit for output lamp LL, thereby rendering a false flame termination indication. However, inasmuch as the release current value for conventional relays is much less than the operate current value, an appreciable reduction in the current flow through the winding of relay RR is required before the relay will actually release its contact. This difference between the operate and release values for relay RR provides for a mode of operation which is analogous to the operation of the circuit shown in Fig. 4 of the invention.

That is, notwithstanding an appreciable reduction in the output signal across resistor 27 during the aforementioned periods, relay RR will remain operated because of its relatively low release current value. If a device having different operate and release current values is utilized to control the operation of the output circuit, specific latching components should preferably be incorporated in the modified arrangement.

The circuit of Fig. 8 is relatively simple in the number of components required to provide the desired functions because, generally speaking, the complex discriminator circuits shown in Figs. 1 and 4 are omitted. The discriminator circuits were necessary in the embodiment shown in Figs. 1 and 4 so as to fully assure that the fire apparatus will not operate in response to low-frequency lighting transients. Such assurance, however, is not necessary in the embodiment shown in Fig. 8 inasmuch as low-frequency transients, occurring after the supervision has been extinguished, will have only a momentary effect upon the operation of relay RR, which effect can only open the energizing circuit for output lamp LL for a relatively short time interval. After the transient has disappeared, and if no flame is being supervised, relay RR will again release its contact and permit the operation of output lamp LL. If it is desired to eliminate this momentary opening, a discriminating circuit should be added.

In view of the foregoing detailed structural and operational description, it should be obvious to anyone skilled in the art to which this invention pertains that the frequency response of the fire apparatus need not necessarily be limited to the range of 5 to 25 cycles per second. Generally speaking, with respect to the attainment of the objects of this invention, the lower frequency limit need only be capable of attenuating the non-flame low-frequency transients and/or steady radiation components to which the apparatus will be actually subjected. This can be readily accomplished by a band pass amplifier or a discriminator circuit, or preferably by utilizing both of these components as was done in the circuits of Figs. 1 and 4. Other apparatus will, of course, operate satisfactorily. Likewise, the upper frequency limit of the apparatus is defined by the non-flame high-frequency fluctuating components actually present in a particular installation. For a particular installation and purpose it might even be desirable to construct apparatus which is responsive only to components of a single modulating frequency.

It should also be understood that the novel contributions of this invention to the fire detection and supervision art is broader than that of the particular apparatus disclosed herein. From the broadest aspect, what is disclosed is a novel and basic method for producing fire responses, namely, the translation of the intensity of the fluctuating radiation components of fire into a complex alternating-current wave form of corresponding intensity and utilizing the frequency components of this wave form unique to
fire to produce an output function. This method may be practiced preferably by apparatus of the general construction shown in the drawings. However, it would also be possible to practice the novel method of this invention by utilizing non-equivalent apparatus. For example, a digital computing arrangement could be utilized to count modulated radiation components within a supervised area, and the count for a certain time interval was within the unique range for fire flame, the presence of fire would be indicated.

What is claimed is:

1. In combination, means for detecting the presence of fire flame within a supervised volume, means for developing an output in response to detected modulated components of said fire flame within specified upper and lower modulation frequency limits in the audio to sub-audio range, and means for operating an alarm in response to the output of said second means.

2. In combination, means for detecting fire flame, means for developing an electrical potential whose amplitude substantially corresponds to the intensity of the flame radiant energy received by said detecting means, and means responsive to specified audio and sub-audio frequency components of said potential within a relatively narrow range.

3. In combination, means for detecting radiant energy emanating from fire flame, means for developing an electrical potential whose amplitude is determined by the fluctuating intensity of the radiant energy detected by said first means, means for discriminating against the alternating-current components of said electrical potential having sub-audio frequencies equal to or less than the maximum frequency of the intensity of the transient light to which said detecting means is subjected, means for discriminating against the alternating-current components of said electrical potential having frequencies within the audio and sub-audio range equal to or greater than the lowest frequency of the intensity of the artificial lighting to which said detecting means is subjected, and means responsive to the alternating-current components of said electrical potential having frequencies between said upper and lower discrimination limits.

4. In combination, means for detecting the radiant energy from fire flame, means for developing an electrical potential whose amplitude is determined by the intensity of the radiant energy detected by said first means, means for producing an output determined by the alternating-current frequency components of said potential within specified lower and upper frequency limits in an audio and sub-audio range when measured over a specified time limit, and means responsive to said transmitted alternating-current potential components.

5. The combination of claim 4 wherein said specified time limit is one second and said lower and upper frequency limits are approximately five and at least ten cycles per second, respectively.

6. Fire detection apparatus, comprising one or more light-responsive elements, means for translating the fluctuating light energy impinging upon said elements from fire to fluctuating electrical currents, means for generating a specified operative output potential in response to a selected band of current components of said translating means within the audio and sub-audio frequency range, said current components being generated by the low-frequency flickering of the fire flame which impinges upon one or more of said light-responsive elements, and means for actuating a fire alarm in response to the generation of said output potential.

7. The combination of claim 6 including a trouble alarm, means for transmitting a trouble-supervising signal throughout said light-responsive elements, translating means, potential generating means and fire alarm actuating means, and means for actuating said trouble alarm in response to the incomplete transmission of said trouble-supervising signal.

8. Fire detection apparatus, comprising one or more light-responsive elements, means for generating an electrical output determined by amplitude of light impinging upon one or more said light-responsive elements, a band pass amplifier with limits in the audio and sub-audio range connected to said generating means and being selectively responsive to a portion of the alternating-current components of the electrical output generated by the fluctuating light from fire flame impinging upon one or more said fire-detecting elements, and means for operating a fire alarm in response to the output of said band pass amplifier.

9. The combination of claim 8 including a trouble alarm, means for transmitting a trouble-supervising signal throughout said light-responsive elements, band pass amplifier and fire alarm operating means, and means for operating said trouble alarm in response to the interrupted transmission of said trouble-supervising signal.

10. Fire-responsive apparatus, comprising one or more light-responsive elements, means for generating an electrical output determined by the amplitude of the light impinging upon one or more of said light-responsive elements, a band pass amplifier connected to said generating means and being selectively responsive to specified frequency ranges of the alternating-current components of the electrical output generated through light fluctuations of fire flame impinging upon detecting elements, fire apparatus, and means including a discrimination network for operating said fire apparatus when the output of said band pass amplifier continues for a specified time interval.

11. The combination of claim 10 including a trouble alarm, means for transmitting a trouble-supervising signal throughout said light-responsive elements, band pass amplifier and means for operating the fire apparatus, and means for operating said trouble alarm when the transmission of said trouble-supervising signal is interrupted.

12. Fire-responsive apparatus, comprising means for generating an amplitude-modulated electrical output responsive to the fluctuating intensity of the radiant energy emanating from fire flame, means for selectively transmitting specified low-frequency components of said electrical output within the audio and sub-audio range, means for discriminating against said selectively transmitted components unless a given minimum number thereof are transmitted within a specified time interval, fire apparatus, and means for actuating said fire apparatus when the selectively transmitted components exceed said minimum value.

13. The combination of claim 12 including trouble means, means for transmitting a supervising signal throughout a portion of said fire-responsive apparatus, and means for operating said trouble means when the complete transmission of said supervising signal is interrupted.

14. Fire detection apparatus, comprising one or more photosensitive cells, means for energizing said cells whereby an electrical output is generated dependent upon the intensity of the radiant energy emanated from fire flame within a supervised volume, means for amplifying the alternating-current frequency components of said electrical output generated by fire flame within a frequency range having a lower limit of approximately five cycles per second and an upper limit of not less than ten cycles per second, means responsive to the occurrence within a time interval of one second of a specified number of electrical impulses from said amplifying means, and output means operated by said responsive means.

15. Fire apparatus comprising a plurality of photosensitive networks connected in parallel with respect to one another so as to generate individual output signals in response to the intensity of the radiant energy impinging upon each network, a band pass amplifier selectively transmitting a range of frequency components unique to fire flame, a mixing network interconnecting said plurality
of photoresponsive networks and the input of said band pass amplifier whereby the input signal applied to said band pass amplifier is responsive to the output of all of said photoresponsive networks, an output network, a discriminating network interconnecting said output network and said band pass amplifier whereby said output network is operated only in response to the continued detection of fire flame by one or more of said photoresponsive elements for greater than a specified time interval, and a latching network for maintaining said output network operated during the fire periods wherein the amplitude of said selectively transmitted frequency components would be otherwise incapable of operating said output network.

16. The combination of claim 15 including a plurality of test lamps individually coupled to different ones of said photoresponsive networks, an energy source modulated at a frequency within the range of said band pass amplifier, and a test switch capable of individually interconnecting said test lamps and said modulated energy source whereby a fire can be simulated by said lamps so as to test the operability of the fire apparatus.

17. Fire apparatus comprising a plurality of photoelectric fire detection units, a band pass amplifier selectively responsive to a frequency range of approximately five to twenty-five cycles per second, a signal mixing network interconnecting said photoelectric cells and said band pass amplifier so as to combine the individual outputs of said photoelectric cells into a single resulting signal which is applied to the input of said band pass amplifier, a limiter network connected to the output of said band pass amplifier and translating the output of said amplifier to signals having a square wave form, a differentiating network connected to said limiter network and translating said square wave form signals into sharply peaked signals, an integrating network for generating a potential the magnitude of which is determined by the rate at which specified impulses of said sharply peaked signals are applied thereto, an output network connected to said integrating network and being operated whenever said generated potential exceeds a specified value, and a latching network connected to said output network and maintaining said output network operated during the fire periods wherein the amplitude of said selectively transmitted frequencies is insufficient to maintain the potential generated by said integrating network at a value greater than said specified value.

18. The combination of claim 17 including a plurality of test lamps individually coupled to different ones of said photoelectric fire detection units, an energy source modulated at a frequency within the range of said band pass amplifier, and switching means capable of individually interconnecting said test lamps and said modulated energy source whereby a fire can be simulated by said lamps so as to test the operability of the fire apparatus.

19. Fire apparatus for aircraft comprising a plurality of photoelectric fire detection units positioned within the compartment of said aircraft primarily subject to fire, a band pass amplifier for selectively amplifying a range of frequencies generated by said detection units within specified upper and lower limits, the values of said upper and lower limits being determined so that said amplifier will attenuate the modulating frequencies of the non-flame radiation components to which said photoelectric detection units are responsive, and an output network operated in response to the output of said band pass amplifier.

20. The combination of claim 19 including latching means for maintaining said output network operated during the fire periods wherein the amplitude of said selectively amplified frequency components would otherwise be incapable of operating said output network.

21. The combination of claim 19 including a plurality of test lamps individually coupled to different ones of said photoelectric fire detection units, an energy source modulated at a frequency within the range of said band pass amplifier, and switching means capable of individually interconnecting said test lamps and said modulated energy source whereby a fire can be simulated by said lamps so as to test the operability of the fire apparatus.

22. Fire apparatus comprising a photoelectric cell optically coupled to a combustion chamber so as to supervise the fire flame therein, a band pass amplifier for selectively amplifying the currents generated by said photoelectric cell within a range of frequencies having specified upper and lower limits, the values of said upper and lower limits being determined so that said amplifier will attenuate the frequency components generated by non-flame radiation impinging upon said photoelectric cell, means for translating the output of said band pass amplifier into a relatively smooth direct-current potential, and means for operating a relay-controlled output circuit in response to the intensity of said direct-current potential.

23. In combination, means for detecting the radiant energy from fire flame, means for developing an electrical potential whose amplitude is determined by the intensity of the radiant energy detected by said first means, means for producing an output determined by the alternating-current frequency components of said detected radiant energy, means for limiting the alternating-current frequency components of said detected radiant energy, means for discriminating against said selectively transmitted components unless a given minimum number thereof are transmitted within a specified time interval, fire apparatus, and means for actuating said fire apparatus when the selectively transmitted components exceed said minimum value, the frequency of said specified components being within a range of approximately five to twenty-five cycles per second.

24. Fire-responsive apparatus, comprising means for generating an amplitude-modulated electrical output responsive to the fluctuating intensity of the radiant energy emanating from fire flame, means for selectively transmitting specified low-frequency components of said electrical output within the audio and sub-audio range, and means for discriminating against said selectively transmitted components unless a given minimum number thereof are transmitted within a specified time interval, fire apparatus, and means for actuating said fire apparatus when the selectively transmitted components exceed said minimum value, the frequency of said specified components being within a range of approximately five to twenty-five cycles per second.

25. The combination of claim 1 wherein said upper and lower modulation frequency limits are approximately twenty-five and five cycles per second respectively.

26. The combination of claim 2 wherein said last-named means comprise a band-pass amplifier tuned to a frequency between five and twenty-five cycles per second.

27. The combination of claim 22 wherein said band-pass amplifier is tuned to a frequency between five and twenty-five cycles per second.

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