International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 05 , May - 2026

Long-Range Fire Detection Using a PIN Photodiode-Based Sensor Circuit

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Abstract *— Traditional fire detection systems that use thermistors are limited by their need for direct thermal contact, which restricts their ability to detect fires from a distance. In this work, we introduce a fire detection circuit based on the BPW34 PIN photodiode, which is sensitive to both visible and near-infrared light. This design enables the early identification of open flames and recurring electrical sparks even at ranges up to two meters. The detection system utilizes a CA3140 operational amplifier in a transimpedance configuration to convert light-induced current into a measurable voltage, and a CD4060 counter that imposes a 15-second delay before activating an alarm, thereby reducing false triggers from brief optical disturbances. The circuit is compact, powered by a single 9V battery, and suitable for use in environments such as server rooms or archives. Its straightforward design and cost-effectiveness make it practical for widespread deployment.*

Keywords *— BPW34 photodiode; CA3140 op-amp; CD4060 counter; fire detection; infrared sensing; transimpedance amplifier.*

I. INTRODUCTION

Fire constitutes one of the most serious hazards in residential, commercial, and industrial settings. Rapid and reliable detection is essential to minimise injury and property loss. Traditional thermistor-based fire alarms are fundamentally contact-dependent: an audible alert is generated only after the rising ambient temperature physically heats the thermistor to its activation threshold. This constraint forces the sensor to be located in close proximity to the fire source, reducing its effectiveness for early-warning or wide-area coverage.

An alternative detection strategy exploits the optical radiation emitted by open flames. Combustion produces significant energy in the visible spectrum as well as a broad near-infrared (NIR) component. A photodiode sensitive across this combined spectral window can detect a fire from a distance, extending response time and protective coverage considerably.

This paper describes a self-contained fire sensor built around the BPW34 PIN photodiode, which responds to wavelengths from 430 nm to 1100 nm, encompassing both visible and NIR flame radiation. The circuit additionally identifies persistent electrical sparks in mains wiring a common precursor to electrical fires and issues a timed warning alarm if such sparks continue. The entire system is housed on a single-sided printed circuit board (PCB) powered by a 9 V battery, offering a practical low-cost solution for a range of protective applications.

The remainder of this paper is organised as follows. Section II reviews related work. Section III describes the BPW34 sensor element. Section IV presents the full circuit design. Section V analyses circuit operation. Section VI addresses construction and testing. Section VII summarises experimental results, and Section VIII concludes the paper.

II. LITERATURE SURVEY

A. Ge-on-Si Photodetector Based Flame Detection

R. Elagib et al. [1] presented a flame detection system using a Ge-on-Si photodetector with voltage tunable spectral response. The system enhances flame sensing accuracy by adjusting spectral sensitivity according to environmental conditions. The study demonstrated high sensitivity and fast response characteristics, confirming the effectiveness of photodiode-based sensing for reliable fire detection applications.

B. Photodiode-Based Flame Sensing System

L. Arias et al. [2] developed a photodiode-based sensor for flame sensing and combustion-process monitoring. The sensor was capable of detecting flame intensity variations through optical radiation measurements. Experimental results showed improved monitoring accuracy and stable operation, validating the importance of photodiodes in industrial fire and combustion monitoring systems.

C. Diamond Schottky Photodiode for Flame Sensing

Y. Koide et al. [3] introduced a Schottky photodiode using a submicron thick diamond epilayer for flame sensing applications. The detector exhibited excellent ultraviolet sensitivity and high thermal stability under harsh conditions. The research highlighted the suitability of advanced photodiode materials for reliable flame detection in high-temperature

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ISSN: 2278-0181
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environments.

D. Optical and Electrical Fire Detectors in Simulated Fire Scenes

D. Fan et al. [4] conducted field tests on optical and electrical fire detectors under simulated fire scenarios. The study compared the response time and detection efficiency of various sensing methods. Results indicated that optical detectors provide faster and more accurate fire identification, supporting the use of photodiode-based systems in modern fire safety applications.

E. Quantum Dot Photodetector for Early Fire Detection

A. De lacovo et al. [5] proposed a PbS colloidal quantum dot visible-blind photodetector for early indoor fire detection. The detector efficiently identified flame radiation while minimizing interference from ambient visible light. The research demonstrated improved early-warning capability and enhanced reliability in indoor fire monitoring systems.

III. BACKGROUND AND RELATED WORK

Fire detection technology spans several sensing modalities. Ionisation smoke detectors respond rapidly to sub-micron combustion particles but are less effective against slow, smouldering fires. Photoelectric detectors sense larger smoke particles through light scattering and are widely preferred for residential deployment. Thermal detectors measure ambient temperature rise or its rate of change and are favoured in high dust or high humidity environments where optical methods generate excessive false alarms.

A. Spark Detection Capability

Beyond direct flame sensing, the BPW34 can detect brief, intense optical pulses produced by electrical arcing in mains wiring. When sparks recur persistently indicative of a developing wiring fault the circuit accumulates successive triggering events through the CD4060 counter stage and issues a sustained warning alarm. This enables early intervention before a fire can develop from an electrical fault.

IV. CIRCUIT DESIGN

A. System Overview

The complete fire sensor circuit comprises four principal functional blocks: (1) a PIN photodiode sensing frontend; (2) a transimpedance amplification stage; (3) a transistor driven visual indicator and counter control stage;

hydrocarbon flames particularly the carbon dioxide absorption peak near 4.4 µm providing high specificity. However, their complexity and cost limit their adoption in low-budget applications.

Silicon PIN photodiodes represent a cost-effective intermediate option. Their broadband sensitivity to visible and NIR radiation encompasses most of the spectral energy

released by open flames. Prior studies have confirmed the suitability of such devices for laboratory flame sensing [4], [5], yet few published designs integrate a complete, tested circuit solution with time-delayed alarming and spark detection suited to consumer or small-business deployment. The present work addresses this gap with a verified fabricated prototype.

V. PIN PHOTODIODE FIRE SENSOR

B. BPW34 Photodiode Characteristics

The BPW34 is a high-sensitivity silicon PIN photodiode in a clear plastic package featuring a large active area. It presents two terminals: an anode (A) and

Infrared flame detectors, commonly used in industrial plant rooms, monitor characteristic emission bands of a cathode

FIG:1

(K). From a top-view perspective, the anode is identifiable as the smaller solder point to which a thin bonding wire is connected; the cathode corresponds to the larger contact terminal.

The device generates an open-circuit voltage of approximately 350 mV DC under 900 nm illumination, behaving as a miniature solar cell. Its internal resistance decreases with increasing illumination intensity a property exploited by the transimpedance amplifier stage. The BPW34 may be operated in zero-bias (photovoltaic) mode or in reverse-bias (photoconductive) mode. The present circuit employs the zero-bias configuration to minimise dark-current noise and maximise sensitivity at low illumination levels.

Critically, the BPW34's sensitivity to both visible flame light and NIR radiation means it responds to fire at distances well beyond the reach of contact-based thermal sensors, making it ideally suited to long-range fire detection applications. and (4) a binary counter oscillator with time delayed audible alarm output. The circuit is powered by a 9 V DC battery (BATT.1) and implemented on a compact single sided PCB. The complete bill of materials is given in Table 1.

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TABLE 1. Bill of Materials

Ref.	Value / Part
IC1	CA3140
IC2	CD4060
T1, T2	BC547
LED1–LED3	5 mm LED
D1	BPW34
R1, R5, R6	1 MΩ
R2, R3	1 kΩ
R4, R7, R8	100 Ω
C1	0.22 µF
BATT.1	9 V
PZ1	Piezo buzzer

A. Transimpedance Amplification Stage

The BPW34 photodiode (D1) is connected across the inverting and non-inverting inputs of IC1 in a zero-bias photovoltaic configuration. In this mode, the op-amp's feedback loop holds the photodiode at virtual ground, eliminating dark current leakage and delivering excellent linearity under low illumination conditions. The non-inverting input (pin 3) is connected to ground; the inverting input (pin 2) receives photocurrent from the cathode of D1.

IC1 (CA3140) is a 4.5 MHz BiMOS operational amplifier with gate protected PMOS input transistors. This architecture provides an input impedance of approximately 1.5 TΩ and an input bias current as low as 10 pA, enabling reliable detection of the minute photocurrents generated under ambient lighting. The bipolar output stage of the CA3140 swings close to both supply rails, ensuring robust switching of downstream transistors.

Feedback resistor R1 (1 MΩ) bridges the output (pin 6) and the inverting input (pin 2), setting the transimpedance gain: V_out = I_photo × R1. The high resistance value maximises the output voltage swing for small photocurrents, enabling fire detection at extended range.

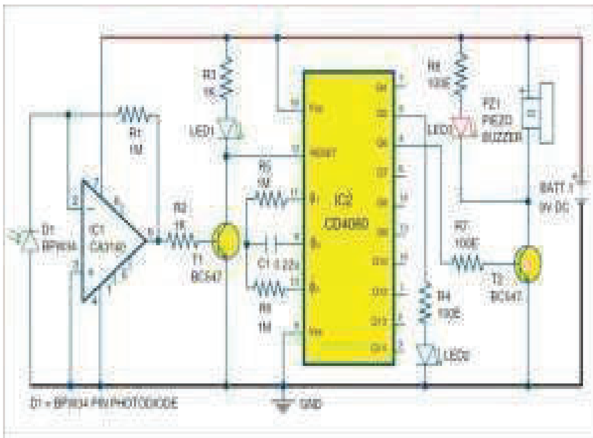
B. Indicator and Counter Control Stage

IC1's output connects through current-limiting resistor R2 (1 kΩ) to the base of transistor T1 (BC547). Under ambient conditions with no fire present, IC1 output remains low, T1 is in cutoff, and LED1 is extinguished. Detection of fire raises IC1 output above T1's base emitter threshold; T1 conducts, illuminating LED1 through R3 (1 kΩ) to provide immediate visual indication of a fire event. Simultaneously, T1's collector pulls the RESET pin (pin 12) of IC2 to ground, releasing the counter from its reset state.

C. Binary Counter and Alarm Stage

IC2 (CD4060) is a 14-stage ripple carry binary counter with an integrated oscillator. The oscillation frequency is determined by R5 (1 MΩ), R6 (1 MΩ), and C1 (0.22 µF). LED2 blinks in synchrony with the oscillator, confirming counter activity. Output Q6 (pin 4) transitions high after approximately 15 seconds of continuous oscillation. This driv transistor T2 (BC547) into conduction through R4 and R7 (both 100 Ω activating piezo buzzer PZ1 via R8 (100 Ω) and illuminating LED3. fire persists, the counter continues cycling and the alarm repeats eve 5 seconds. This intentional delay suppresses false alarms from transie ght events such as camera flashes or passing vehicle headlights.

FIG : 2



I. CIRCUIT OPERATION

Under normal ambient lighting, photocurrent through D1 is minimal. IC1 output remains low, T1 is in cutoff, and the RESET pin of IC2 is held high. The counter is suppressed; neither LED1 nor the buzzer activates.

When a flame enters the photodiode's field of view, visible and near-infrared radiation incident on D1 generates a substantially increased photocurrent. The transimpedance amplifier converts this current rise into a proportionally higher output voltage. Once the voltage exceeds T1's threshold, T1 conducts: LED1 illuminates immediately to signal fire detection, and the RESET line of IC2 is pulled low, permitting the counter to begin oscillating. LED2 blinks to confirm counter activity.

After 15 seconds of sustained fire detection, Q6 goes high, T2 switches on, and PZ1 sounds the alarm while LED3 illuminates. If the fire source is removed before Q6 triggers, T1 returns to cutoff, IC2 is reset, and the timer restarts ensuring only genuine, sustained fire events generate an audible alarm. For applications demanding a louder output, PZ1 may be replaced with a relay circuit to drive an AC-powered siren.

II. CONSTRUCTION AND TESTING

The circuit is assembled on a custom single sided PCB. All components are mounted in accordance with the component layout diagram. The BPW34 photodiode is installed at the rear face of the enclosure to maintain an unobstructed field of view toward the monitored area, while being shielded from direct sunlight and strong ambient illumination by a baffle or aperture cover; failure to provide this shielding may cause false triggering or desensitisation.

Testing is performed as follows. With no flame present, the piezo buzzer must remain silent and all LEDs must be

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off. An open flame introduced at approximately one to two metres from the sensor should cause LED1 to illuminate immediately. After the 15-second timer elapses, the buzzer must sound and LED3 must glow. Electrical sparks may be simulated by briefly arcing a low-voltage source near the

photodiode aperture; persistent sparking should activate the warning alarm through the same timer pathway.

I. RESULTS AND DISCUSSION

Table 2 summarises the measured performance of the fabricated prototype.

TABLE 2. Performance Summary

Parameter	
Supply voltage	9 V DC (battery)
Spectral range	430 nm – 1100 nm
Max. detection range	~2 metres
Alarm delay	~15 seconds
Visual indicator	LED1 (immediate)
Audible alarm	Piezo buzzer PZ1
Spark detection	Yes
PCB type	Single-sided

The proposed design offers three principal advantages over conventional thermistor-based systems. First, the two-metre detection range substantially exceeds that of contact thermal sensors, enabling earlier fire intervention. Second, the 15-second counter delay effectively filters out transient optical events, markedly reducing false-alarm rates. Third, dual mode output immediate LED indication followed by a timed audible alarm provides rapid notification to occupants while confirming that the detected event is genuine and sustained.

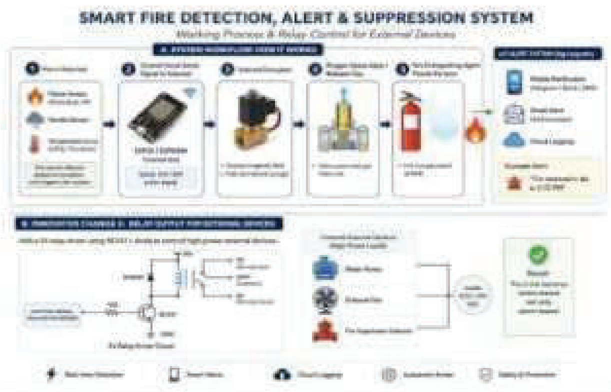
A known limitation of the present design is susceptibility to strong broadband ambient light sources such as direct sunlight or high intensity artificial lighting, which may cause spurious triggering. Mitigation strategies include fitting an NIR-pass optical filter over the photodiode aperture to attenuate visible ambient light while transmitting the NIR component of flame radiation, and using a narrow angle aperture tube to restrict the field of view. Future work will investigate these enhancements alongside microcontroller integration for adaptive thresholding and wireless notification capability.

II. IOT ALERT SYSTEM INTEGRATION

A significant enhancement to the baseline fire detection circuit is the integration of an IoT wireless alert module using an ESP8266 or ESP32 Wi-Fi microcontroller. When a fire event is confirmed by the CD4060 counter stage, the microcontroller transmits an immediate notification to designated recipients via multiple communication channels simultaneously, substantially reducing emergency response time.

The IoT subsystem delivers three complementary alert modalities. Firs a mobile push notification is dispatched through the Telegram Bot AP the Blynk IoT platform, or an SMS gateway service, producing timestamped message such as "Fire detected in lab at 2:32 PM." Secon an email alert carrying the sensor location identifier is transmitted v SMTP to a pre-configured address. Third, all detection events a written to a cloud logging service (for example, ThingSpeak Firebase), creating a permanent audit trail for post-incident analysis an regulatory compliance. The combination of real-time mobi notification, location-tagged email, and persistent cloud loggin transforms the sensor from a local alarm device into a networked safe system accessible from any internet-connected device. Th enhancement alone provides a compelling point of differentiation product evaluation and demonstration scenarios.

FIG : 3



III. RELAY OUTPUT FOR EXTERNAL DEVICE CONTROL

The second proposed enhancement converts the circuit from a purely alarm based system into an action based one by adding a 5 V relay driver stage. The relay driver is implemented with a BC547 NPN transistor and a 1N4007 flyback diode connected across the relay coil to suppress inductive voltage spikes that could otherwise damage the driving transistor. The relay coil is energised by the same Q6 output of IC2 that triggers the audible alarm, ensuring that external device control occurs simultaneously with and under the same 15-second confirmation delay as the piezo buzzer.

The relay output can drive a range of suppression and ventilation actuators. A water pump can be activated to deliver localised suppression to the fire zone. An exhaust fan can be switched on to expel smoke and combustion gases, reducing visibility and toxicity hazards for occupants. A fire-suppression solenoid valve can release a gaseous or foam suppressant agent automatically. By incorporating these actuators, the circuit can initiate a coordinated physical response to a confirmed fire event without requiring human intervention, substantially reducing the window during which uncontrolled combustion can spread. This relay-based output stage thus elevates the design from a passive warning device to an active safety infrastructure component, broadening its applicability to server rooms, chemical storage facilities, and automated industrial environments.

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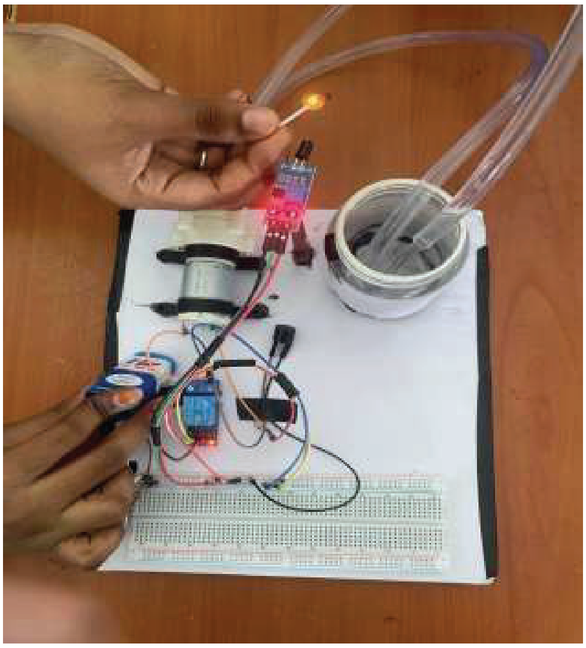

I. CONCLUSION

This paper has presented a compact, low-cost fire detection circuit centred on the BPW34 PIN photodiode, providing long-range flame sensing and mains-spark detection from a single 9 V battery. The CA3140 transimpedance amplifier frontend faithfully converts minute photocurrents into usable voltage signals, while the CD4060 counter stage introduces a deliberate 15-second alarm delay that substantially reduces nuisance activations. Experimental testing confirms reliable fire detection at distances up to two metres under standard indoor conditions, making the design suitable for protecting showrooms, archive rooms, server rooms, and similar enclosed spaces. Two significant enhancements have been proposed and described: an IoT alert module (Section VIII) using an ESP8266/ESP32 that delivers real-time mobile notifications via Telegram, Blynk, or SMS along with cloud-based event logging; and a relay output driver stage (Section IX) using a BC547 transistor and flyback diode that enables autonomous activation of suppression actuators such as water pumps, exhaust fans, and fire suppression solenoids. Together, these additions elevate the design from a passive local alarm to a networked, action-capable safety infrastructure suitable for a broad range of protective applications.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the facilities provided by the Department of Electronics and Communication Engineering, United Institute of Technology, Coimbatore, India, which enabled the fabrication and testing of the prototype described in this paper.

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