Department of Electronics and Electrical Engineering

EE396 Design Lab

Smoke Detector

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under the guidance of

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1 Acknowledgement

I am thankful to my instructor, Dr. Mahima, who regularly took updates on our project and guided us throughout the making of this project. We wouldn't have completed this project without her patience and support. I express my heartfelt gratitude to Dr. Rishikesh Kulkarni and K. Narsimha Reddy for helping us navigate through our challenges.

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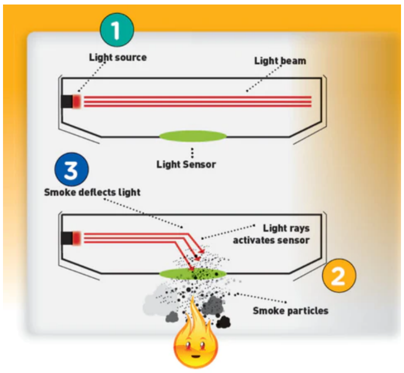
2 Abstract

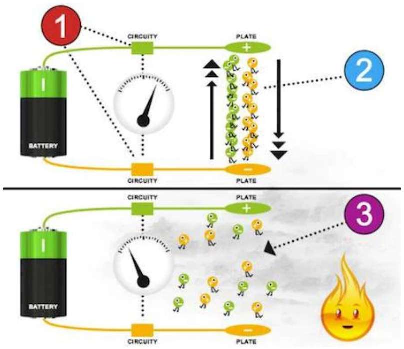
Fires are a serious risk to everyone's safety, especially in the transportation industry, where they can result in catastrophic accidents. A train fire can have severe consequences - threatening the lives of passengers and staff, resulting in property damage, and disrupting the railway network. Railways have recently developed and implemented point-based fire detection systems to enhance safety procedures and lessen fire damage.

So far, ionization smoke detectors have been widely used in various sites. The principle behind the working of these detectors is the formation of a conducting medium in between two electrically charged plates due to the ionisation of air by radiations from a radioactive material, Americium. The current flow decreases as smoke enters the chamber because the ions adhere to the smoke particles. The amount of smoke can be compared to the reduction in current in the medium. An alarm is triggered by thresholding this reduction via the micro-controller chip. These detectors are limited to identifying only fast flaming fires and hence, are rendered less effective in railways which demand an early warning for smouldering fires.

In an attempt to improve the performance of the smoke detectors and make them adaptable to the conditions of the train (exposure to high temperatures and dust), we have designed a prototype of a fire detecting system that is sensitive to heat and light. The model is intended to be cost effective and highly sensitive. Appropriate measures have been taken to differentiate dust and smoke via signal processing. The complete list of references, datasheets can be found on Github[4].



(a) Photoelectric



(b) Ionisation

Figure 1: Principle behind the 2 smoke detectors

(a) Photoelectric Detector

(b) Ionisation Detector

Figure 2: Smoke Detectors

[4]github.com/JahnaviB08/Smoke-Detector-References

3 Introduction

In the railway industry, covering every square inch of a train's numerous compartments and a vast network of tracks with sensors can be challenging and expensive. The new technology used in smoke detection has the capacity to cover larger areas with fewer sensors and more efficiency. Heat and smoke-detecting sensors are used in point-based fire detection systems. They provide a significant improvement over bulky, outdated, unreliable, and slower systems that relied on human detection by passengers or crew. Point-based fire detection systems are designed to identify flames and send a warning when these systems are triggered before they cause too much damage, enabling prompt action by the authorities.

Another advantage of these devices is their ability to differentiate between false alarms versus actual fire. Traditional smoke detectors are prone to false alarms that could be caused by disturbances like steam or dust. On the other hand, photoelectric smoke detectors using laser technology are designed to identify particular flames. They can distinguish between smoke and other particles in the air that can cause false alarms because of their sensitivity and the signal processing used.

This report discusses the development and design of the final model of the smoke detector.

4 Model Design

4.1 Experimenting with the model

A cuboidal box with two holes on opposite faces is designed to enclose the smoke detector. A light source is placed in one of the holes, with the light being incident directly on the other hole. A light detector comprising a light-dependent resistor (LDR), acting as the light-sensitive component, is placed so that no light falls on it ideally.

When smoke enters the chamber, it scatters light, and this light falls on the LDR. The LDR and a resistor act as a voltage-divider circuit of a 5V DC source. The resistance of the LDR drops when light falls on it, and the microcontroller registers the value. Initially, an LED light source was used, but we replaced it with a laser diode because the scattering was high without smoke. The value came out to be very small. In order to amplify our output, we cascaded it with an instrumentation amplifier. One of the input terminals of the amplifier was the output of the LDR-detector circuit and the other terminal was the threshold value which was determined by pattern recognition and averaging the output signal.

However, the light detector was found to work only in extremely limited conditions in which the light was concentrated on the LDR surface. This could not be achieved solely by the light scattered by smoke.

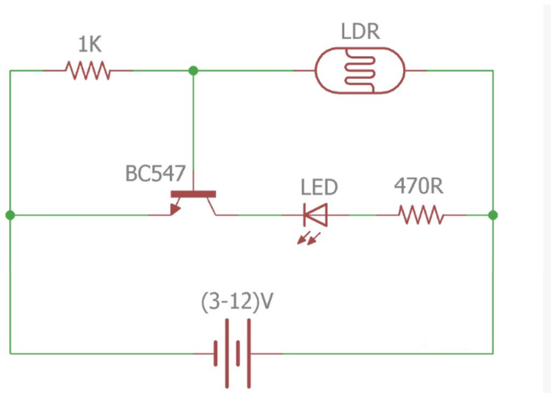


Figure 3: Light detecting circuit with LDR

4.2 Designing the photoelectric smoke detector

To overcome the challenges that we faced in the previous designs, we use a more sensitive photodetector, a photodiode. We shall describe the final setup in this section.

In a photoelectric smoke detector, a light source (laser or LED) emits light into an enclosure to keep out ambient light while allowing smoke to enter. Any smoke particles entering the chamber will scatter the light and trigger the photodiode. The basic design of a laser smoke detector includes a laser source, a detector, and a signal processing circuit. The setup of our detector is as follows :

1. **Laser Source:** The first step is to select a laser source that emits light in the visible or near-infrared region. A semiconductor laser, such as a diode laser, is a good choice due to its compact size, low power consumption, and long lifetime. We have used a 650nm (red laser) 6mm 5V DC 5mW Laser Diode Module. Laser technology gives a fast response detection with high sensitivity.

2. **Optics:** The laser beam needs to be collimated and focused onto the detection area. A combination of lenses and mirrors can be used to achieve this.

3. **Smoke Detection Area:** After the laser beam enters the detection area, smoke particles scatter it. The scattered light is picked up by a photodetector, a photodiode. The photodiode is operated in photoconductive mode, generating a reverse current. To get an amplified voltage output, a transimpedance amplifier is cascaded with a photodiode. It is positioned so that when there is no smoke, no light shines on it.

4. **Signal processing:** The photodetector's output signal needs to be processed to establish whether smoke is present. Techniques for digital or analog signal processing can be used to accomplish this. An Arduino UNO microcontroller for analog to digital conversion.

   A moving average filter is employed by continuously taking the average of 5 samples. This smoothens the signal. To highlight the change in signal, the difference between the present and the moving average of the past five samples is plotted.

5. **Alarm Trigger:** If smoke is found, the signal sees a noticeable spike, and an alarm signal will be activated. We use a buzzer to implicate an alarm system.

6. **Power Supply:** A power source is necessary for the laser smoke detector to function. The laser and signal processing hardware is powered by a low-voltage DC power supply (of 5V). We use the 5V pin of the Arduino as the dc source.

7. **Enclosure:** The laser smoke detector is kept in an appropriate enclosure that shields it from external elements like moisture and dust. A closed box is used as the enclosure. The surface of this box is made entirely black to reduce internal reflections of light.

Testing is necessary to ensure the laser smoke detector satisfies the necessary sensitivity and reliability standards after being built and put together. The resulting waveform was rather noisy, and the change in the signal due to smoke was hardly visible. We use two detectors exposed to the same environment without smoke to overcome this problem. The operation of the smoke detector after integrating all these parts has been discussed above and will be elaborated on in the next section.

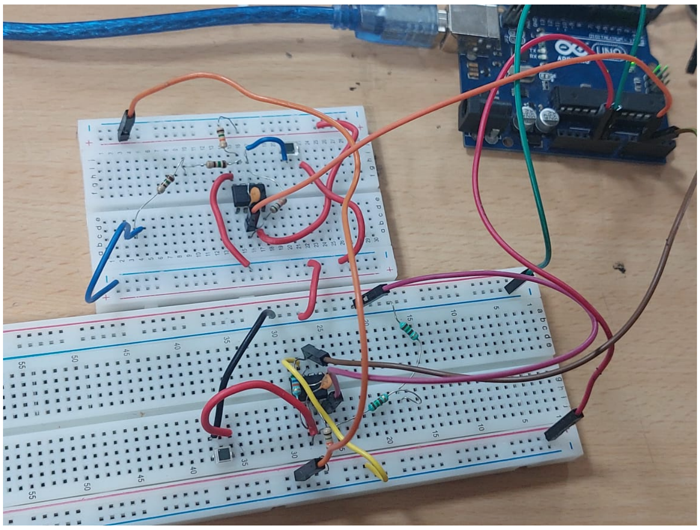


Figure 4: Two Detector Setup

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4.3 Designing a multi-criteria detector

To make a multi-criteria sensor (heat and smoke) of enhanced sensitivity we use a temperature-sensitive circuit comprising of:

1. **Infrared light source:** The infrared LED emits infrared rays that can detect the heat. It is designed such that it conducts once heat is detected. In a fire detector, an infrared LED (Light Emitting Diode) detects the presence of flames by sensing the infrared radiation emitted by them.

2. **BJT:** The BJT acts as a switch that allows the current to flow through it when triggered by the infrared radiation detected by the IR LED. The transistor turns on whenever it gets the base voltage of 0.7V through the resistor. As the circuit senses the fire, it decreases the resistance at the base. Due to this, the voltage across the base terminal increases or becomes equal to 0.7V, turning the transistor ON. The Led starts glowing to indicate the fire. When there is no fire, the led turns Off as the voltage across the base terminal falls below 0.7V, so the transistor turns off.

3. **Alarm (Buzzer or LED):** This system is integrated with the alarm circuit. Current flows through the alarm once the BJT closes the circuit.

5 Component and Cost Analysis

5.1 What does the setup consist of?

1. **Laser source:** 650nm 6mm 5V DC 5mW Mini Laser Dot Diode Module made of copper plastic.
2. **Photodiode:** Photodiode BPW 34 is suitable for applications from 400nm to 1100nm of incident light. Dark current is 2nA. The rise and fall time is 100ns and the diode capacitance is 70pF. The reverse breakdown voltage is 32V.
3. **Resistors and capacitors:** 15k, 300, 56k, 47 Ω resistors. Capacitor of value: 1pF
4. **Operational Amplifier:** UA741 - Input bias current: 200nA, 2MΩ input resistance. Gain product bandwidth 1MHz.

   Ideal op-amp(OPA320AIDBVR): Input bias current: 0.9pF, Gain Bandwidth Product: 10MHz.
5. **Arduino UNO:** 8-bit AVR RISC-based microcontroller which operates on 2.7 to 5.5V.
6. **Breadboard and jumper wires:** Breadboard (comprising 400 tie points) and male to male jumper wires have been utilised.
7. **Buzzer and led:** The buzzer is operated at 5V DC(the range of its operating voltage is 4-8V DC) with rated current <30mA.
8. **Bipolar Junction Transistor:** BC547 has $V_{ce} = 5$V when the BJT is on and the collector current is 2mA.
9. **Infrared LED:** Diameter = 5mm, wavelength = 940nm IR Receiver LED Diode Lights Clear Infrared DC 1.2V, min forward current = 100mA, max power dissipation 200mW.
10. **LDR (Light Dependent Resistor):** The dark resistance of LDR is 1MΩ and when the LDR is exposed to light of 1000 lux brightness, the resistance typically reduces to 400Ω.

5.2 Cost Analysis

Table 1: Cost Analysis of Components used in our design

Component	**Number of Units**	**Cost per Unit**	**Total Cost (in INR)**
Opamp	2	12	24
Breadboard	2	60	120
Jumper Wires	15	1.67	25
Resistors	8	1.9	15
Capacitors	2	1	2
Photodiode	2	1	208
Laser source	1	17	17
Buzzer	1	10	10
LED	2	1.5	3
Arduino UNO	1	625	625
Infrared led	1	13	13
BJT	1	10	10
LDR	1	5	5
Total cost			**1077**

6 Operation

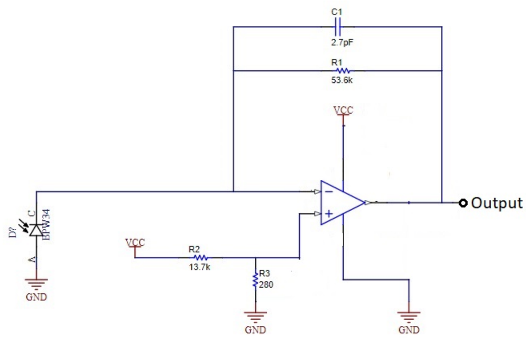

Figure 5: Circuit diagram of the transimpedance amplifier.

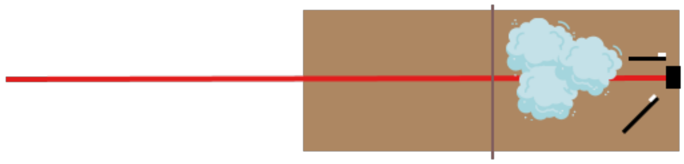

Figure 6: Top view of the setup: The red light represents the laser light. It is scattered by smoke. Two detectors are placed - one at an angle with respect to the incident light and the other against the light source. There is a barrier window in the middle to restrict the smoke in one area

6.1 Working Principle

A laser smoke detector is a device that scans the air for smoke particles using a laser beam. The smoke detector's laser beam typically operates in the visible or near-infrared range of the electromagnetic spectrum. The detecting region, often a tiny chamber or tube containing the air to be monitored, is where the laser beam is focused. A combination of mirrors collates the laser beam and focuses it onto the detection region.

The fundamental idea behind it is based on how smoke particles scatter light. The laser beam is focused on the detection area, where smoke vapors disperse it. The light falls on one of the detectors. The photodetector then picks up the scattered light and turns it into an electrical current. The photodetectors are cascaded with transimpedance amplifiers that convert the photodiode currents to amplified voltages. The difference in the output voltages is taken and plotted. This method cancels the noise. The setup is so that only one of the detectors would be exposed to light if there is any smoke. We use a barrier to isolate the other detector from light.

The circuitry for signal processing then evaluates the signal to see if smoke is present. To evaluate whether smoke is present, the signal processing circuitry has employed a range of analog or digital signal processing techniques: threshold detection and moving average filter.

If smoke is detected, the circuitry triggers an alarm signal. The alarm signal can be used to activate an audio or visual alarm.

The heat-sensitive part of the smoke detector exploits the following operation—fire releases infrared radiations, which are detected by the infrared light from the IR LED. This results in the IR LED conducting, resulting in the BJT transistor conducting. This causes current to flow through the circuit, thus forward-biasing the buzzer. The alarm circuit is triggered.

7 Observations

1. Noisy graph

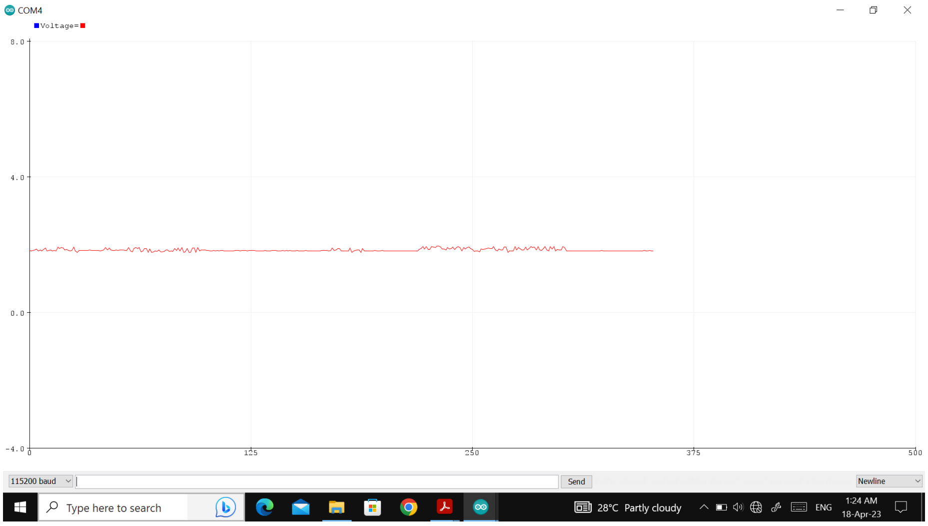

Figure 7: This waveform represents the output voltage signal of the trans-impedance amplifier of the smoke detector that contains a single photodiode. When light falls on the photodiode, a small peak in voltage must be present. We tried to note the change by shining light on the photodiode. The peak was visible when the light was directly falling on it. But when little light was falling on the detector the peak was hardly visible. The above graph has been plotted in presence of smoke and the peak can hardly be differentiated from the noise.(This happens since the scattered light is of low intensity.)

2. Moving average filter graph

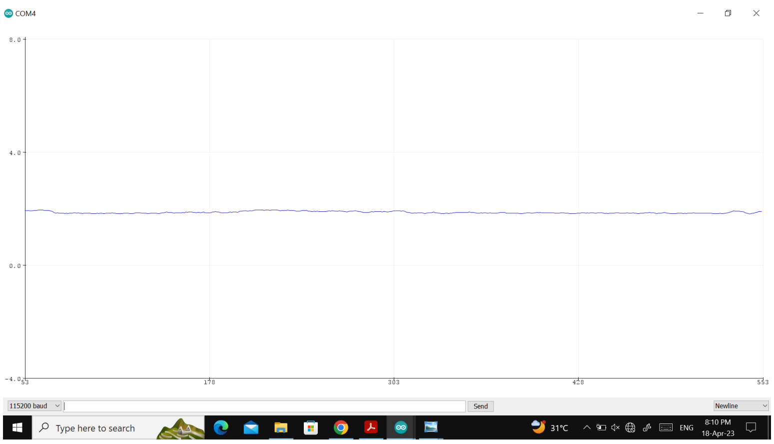

Figure 8: To smoothen the noisy signal of the first graph, we use a moving average filter that continuously evaluates the average of 5 samples. Since the change in the output signal is in the order of millivolts, the change is still not evident. This graph has been taken in the presence of smoke too.

3. Difference of the two detector outputs graph

Figure 9: The difference between the present value and the moving average of the past 5 samples is taken and plotted. Whenever the light shines on the detector a positive difference is seen and seen as a spike in the graph. When the light is removed, there is a negative dip in the signal because the present value drops and this is negative with respect to the past 5 samples. While the noise has reduced considerably, the setup is not sensitive to less intensity of light. The peak has been obtained when we were experimenting with exposing the detector to light and then removing it. This graph was not taken in the presence of smoke since we wanted to study the behavior of the circuit in the presence and absence of light. When little light was made to fall on the detector(this mimics the smoke condition), no significant change in the signal was found.

4. Two detectors

Figure 10: The outputs of 2 detectors are taken. Their difference is plotted. This facilitates the cancellation of noise. This is a much cleaner signal that is sensitive to little light. The peaks are visible when we were experimenting with the light. When light is incident on the first detector, the peak is positive and negative when light falls on the second detector. Small peaks for lesser intensity light and longer peaks for more intensity. This graph has not been taken in the presence of smoke. We tried to vary the light intensity falling on the detector so as to check if it would respond to less light.

8 Performance Analysis

Obscuration refers to the degree to which smoke, dust, or other airborne particles can block or obscure the passage of light through a given area. In the context of smoke detectors, obscuration is used to measure the concentration of smoke particles in the air that can trigger the alarm. The detector measures the amount of light scattered, known as the obscuration level. The smoke detector triggers an alarm if the obscuration level exceeds a certain threshold.

Lesser the time taken to detect smoke, better the detector. The size of the smoke detector is predominantly the size of the enclosure. The photoelectric detector is observed to have an obscuration of 0.7 to 13% obs/m, while the ionization detector had 2.6 to 5% obs/m of obscuration.

In our setup, the threshold was set to be 0.1 V of the difference in the output voltage of the two photodiodes. Since they are exposed to the same environment, the signals are of almost the same value. So if it exceeds 0.1V, the detector has detected the scattered light. This thresholding was possible because of using two detectors. When a single detector was used, the noise dominated the signal, making it difficult to specify a particular value. The time it takes for a photoelectric smoke detector to detect smoke can vary depending on several factors, such as the density of the smoke, the distance between the smoke and the detector, and the sensitivity setting of the detector. However, photoelectric smoke detectors are generally designed to detect smoke quickly and efficiently. The performance may dampen if the dust particles settle inside the enclosure. A filter could be included, or regular cleanup needs to be ensured to prevent this.

9 Future Scope

The detector's performance can be enhanced by incorporating changes in the present setup. The sensitivity can be improved using a better op-amp (OPA320) with a lesser bias current (in the order of picoamperes). Blue light could be used instead of red light laser to induce more significant scattering. Machine learning models could be exploited to improve output signal processing. This would enable a clearer spike to be visible in the presence of smoke in the chamber. The components could be soldered to a PCB board to prevent loose connections.

A filter could be placed to distinguish between smoke and dust particles so that it is small enough for only the smoke particles to enter. The size of the smoke detector can be reduced so that they occupy less space in trains. A configuration of relay systems could be integrated with the smoke detectors to notify the driver and the control station of the presence of smoke in the compartment. Wireless communication methods could be adopted to carry out the same. As we have seen, an ionization smoke detector identifies fast-flaming fires quickly, and a photoelectric smoke detector can identify smoldering fires quickly.

A conjunction of ionization and photoelectric detectors is recommendable to get the best of both. However, only separate units of the two have been made so far.

10 Epilogue

Pinnacle smoke detectors are the most successful in incorporating laser technology in their synthesis. They detect both fast and smoldering fires quickly. However, they are very expensive. This project aims to offer a cost-effective solution for the railways.

Presently, Indian trains have ionization smoke detectors that can only detect large fires. The environment that a detector is exposed to in trains is harsh. High temperatures and constant exposure to dust particles hinder the performance of typical smoke detectors. Since photoelectric smoke detectors use a focused beam of laser light, reflections are minimized in the chamber. This means that gradual dust accumulation is less of a problem.

In order to improve the ability of photoelectric detectors to detect fast-flaming fires, engineers focused on two goals: boosting the signal and reducing noise, that is, increasing the signal-to-noise ratio. Reducing noise helps reduce the probability of a false alarm.

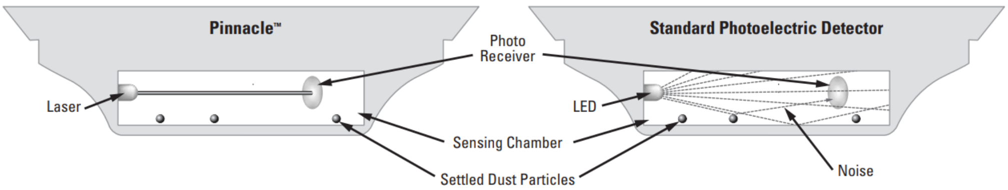

Figure 11: Pinnacle photoelectric smoke detector.

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