Proof of Concept of a Proximity Detector Circuit for Portable Electric Radiant Heaters

Mark Gill, Electrical Engineer
U.S. Consumer Product Safety Commission
Directorate for Engineering Sciences
4330 East West Highway
Bethesda, MD 20814, USA
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U.S. CONSUMER PRODUCT SAFETY COMMISSION
30 East West Highway, Bethesda, MD 20814

Abstract

An experimental proximity detector circuit, using an infrared (IR) radiation detector, specifically a thermopile detector, was designed and tested in an attempt to deactivate portable radiant electric heaters that are located too close to combustible objects. The sensor was evaluated with three different heaters using a 12-inch x 12-inch target placed in front of the heaters. Testing confirmed the circuit could detect the target and deactivate the heaters in less than 60 seconds with the target placed at distances of nine, six, and three inches in front of the heaters' front grills.

Introduction

The U.S. Consumer Product Safety Commission (CPSC) staff reports that from 2009 to 2011, electric heaters were associated with an estimated 1,100 fire incidents per year, resulting in average yearly estimates of 50 deaths, 130 injuries, and $50.4 million of property loss.[1] The National Fire Protection Association (NFPA) estimates that from 2006 to 2010, approximately 27 percent of fires for portable or stationary electric space heaters were caused by heaters that were placed too close to combustible materials.[2] Because forced-air and convective heaters usually do not significantly raise the surface temperatures of nearby combustible objects, it is possible that a portion of the reported fires were caused by radiant electric heaters. Therefore, a means to detect nearby combustible objects in the radiant path of such heaters could reduce the likelihood of such events, resulting in a reduction of deaths, injuries, and property loss.

At least one heater currently available to consumers incorporates a proximity detector using IR-emitting diodes to illuminate nearby objects and a semiconductor sensor to detect them. In contrast, the research effort covered in this paper was directed toward creating a proximity detector circuit using the heater's own IR radiation, which coincidentally heats nearby objects, and a thermopile detector to detect them. Advantages of this approach are that the IR radiation produced by a heater's heating elements is inherently more reliable than that generated by an electronic source; offers a greater variety of IR wavelengths to explore; and requires no additional circuitry to generate the IR radiation. A possible disadvantage of this approach is that it does require a nearby flammable object to become heated before being detected. This introduces a delay in the time of detection between the moment an object is placed in front of the heater and the point at which it becomes sufficiently heated to be detected.

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[1] Consumer Product Safety Commission, "*2009–2011 Residential Fire Loss Estimates*" (Bethesda, MD., July, 2013), p.18–21.

[2] National Fire Protection Association, *Home Fires Involving Heating Equipment*, (September, 2012), p. 46.

Experimental Proximity Detector Circuit

Proximity Detection and Remote Sensing

Proximity detection is a specialized application of the scientific analysis technique known as "remote sensing." In remote sensing, information is gathered about an object without coming into physical contact with it. Information may be gathered for later analysis, such as the use of radio telescopes in astronomy, or immediate use, such as Doppler radar systems for weather forecasting, or ultrasonic sensors in intruder detection systems.

In attempting to apply remote sensing to radiant electric heaters for proximity detection, infrared (IR) sensors known as "thermopile detectors" were selected. Thermopile detectors consist of thermocouples connected in series and/or parallel to convert incoming IR radiation into an electrical signal. Reasons favoring the choice of thermopile detectors over other remote sensing detectors include their wide range of IR detector characteristics, low cost, and simple implementation with electronic circuits. Such implementation can be seen in the availability of low-cost, handheld IR thermometers. Band-pass filtering available in some thermopile detectors permits the attenuation of background IR sources present in the various locations where portable electric heaters may be used. This would improve the selectivity of the proximity detector and reduce incidents of false triggering.

Thermopile Sensor Selection and Proximity Sensor Circuit Design

The IR band of the spectrum is continuous, but it is divided into groupings of wavelengths to facilitate reference to regions of interest for specific properties and applications. The boundaries for classifying IR radiation vary slightly in scientific literature. For this paper, IR radiation will be categorized as near infrared (NIR, 1–2μm), shortwave infrared (SWIR, 2–3μm), mid-wave infrared (MWIR, 3–5μm), long-wave infrared (LWIR, 8–12μm), very long-wave infrared (VLWIR, 12–25μm) and far infrared (FIR, >25μm).[3] The indoor environment may have IR sources such as fire places, wood stoves, heaters, hot appliances, sunlight, and remote controls. The glass used in most windows will transmit some of the sun's NIR and SWIR radiation into a room but will typically block MWIR and LWIR wavelengths.[4]

In view of the background IR radiation that may be present in a room, a thermopile detector with an optical band-pass window in the LWIR range was selected. To gather as much IR radiation from the target, and thereby, maximize the effectiveness of the proximity detector, a thermopile detector with a 120°, approximately conical field of view (see Figure 1) was

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[3] Sanjay Krishna, "The Infrared Retina," J. Phys. D: Appl. Phys., Vol. 42 (2009) 234005 (6pp), p. 1.

[4] "IR Spectral Bands and Performance," FLIR Systems Inc., http://gs.flir.com/surveillance-products/surveillance-technology/imaging-technotes/IR_Spectral_Bands, 2013.

selected; although designs with a detector having a smaller field of view are possible. To limit the effects of background IR radiation, the detector also had a band-pass for IR radiation in the region of 8−14 μm.

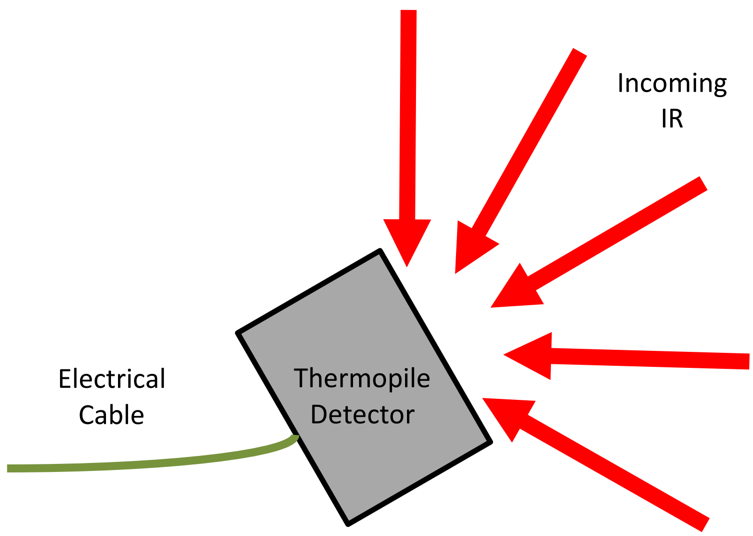

Figure 1 - Overall planar view of thermopile detector showing the 120° field of view for IR radiation.

For the design of the proximity detector circuit, the preference would have been to use a reference design circuit from a detector manufacturer. However, such circuits are typically not provided, due to the range of applications for the detectors. Therefore, it was decided to use a circuit with limited complexity to demonstrate proof of concept. Circuitry to account for varying emissivities (the ability of an object to radiate energy as compared to that from an ideal "black body") of combustible objects (*e.g.*, paper, wood, fiberboard, cloth) was not deemed necessary because the emissivities for these materials typically lie in the narrow range from 0.85 – 0.95 in the LWIR range.[5] Additionally, circuitry to compensate for variations in the temperature of the thermopile detector was not implemented. Noting these design boundaries, the circuit shown in Figure 2 was designed, although other approaches are possible.

[5] "ThermaCAM™ EX320 User's Manual," FLIR Systems, Publ. No. 1558146, Rev. a155, February 2006.

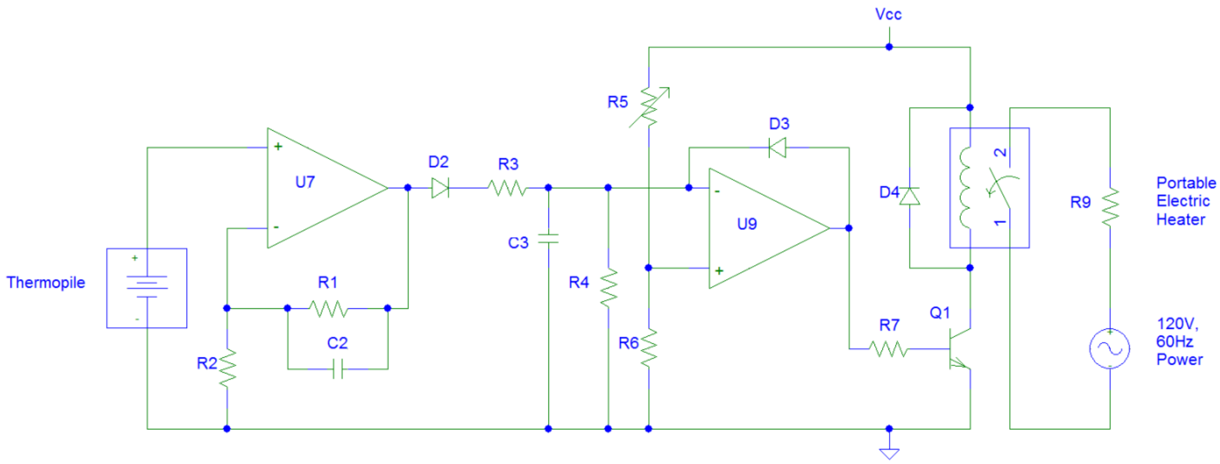

Figure 2 – Proximity sensor circuit electrical schematic.

The high-level design of the proximity detector circuit is broken into three parts: amplification of the thermopile detector voltage to create a relative IR signal voltage (U7); latching the amplified signal at a selectable voltage level (U9); and deactivation of the portable heater with a transistor-driven relay (Q1). For convenience, the detector circuit was powered by a variable electronic direct current (d.c.) power supply that was readily available, although a simpler d.c. power supply would have been sufficient. The heater was powered by 120V, 60Hz power from a wall receptacle routed through the relay in the proximity detector circuit.

Test Setup and Method

To trigger the proximity detector circuit, as well as to gather some crude information about the heating effects created by a radiant heater on a combustible surface, a 12-inch-square target containing an array of Type K thermocouples was created, with the target size chosen to be roughly the same as a small pillow. Because the circuit amplifies the voltage created by the thermopile detector, the amplified voltage provides a collective, relative level of the IR radiation from the target, as well as the room and other nearby objects and is measured at the output of operational amplifier U7 in the circuit with a digital voltmeter.

The test setup diagrammed in Figure 3 was used for the evaluation:

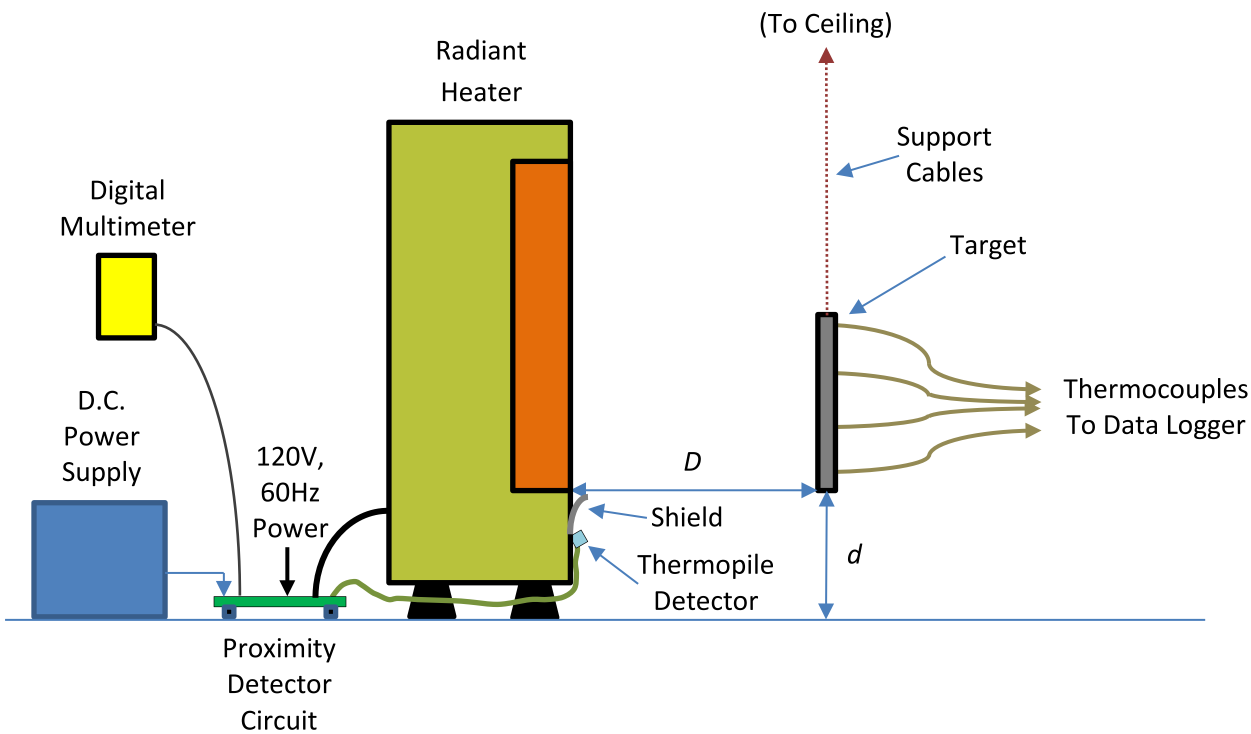

Figure 3 – Overall view of the test set up and components.

The test heater was located a distance, *D*, from the suspended target. The thermopile detector was mounted on the front of the heater, just below the heater's grill, and the center axis of the field of view was set at an angle of 45° above the horizontal. A small, shiny, foil shield was placed between the detector and the front grill to prevent the heating elements from directly radiating onto the thermopile detector. A short electrical cable, which was run under the heater, connected the thermopile detector to the proximity detector circuit. The circuit was supplied with 120V, 60Hz and variable d.c. power. The plug to the heater was connected to the proximity detector circuit for power to be disconnected. The distance, *d*, from the bottom edge of the target to the supporting surface, was set equal to the distance from the bottom edge of the heater's front grill to the supporting surface.

Sixteen thermocouples were embedded within the target and spaced on a 3.5-inch square grid (see Photo 1). A paper backing was added to the target with a layer of bubble wrap to reduce air circulation within the target. The front of the target was covered with a single layer of thin, black cloth (see Photo 2); although any color of cloth would have sufficed because cloth color does not have an effect on its emissivity of IR. The thermocouples were inserted though the rear of the target, such that the junction of each thermocouple was in contact with the rear side of the cloth on the target's front. Distances from the target to the thermopile detector of nine, six, and three inches were selected to represent the distances a flammable object could be located from a heater.

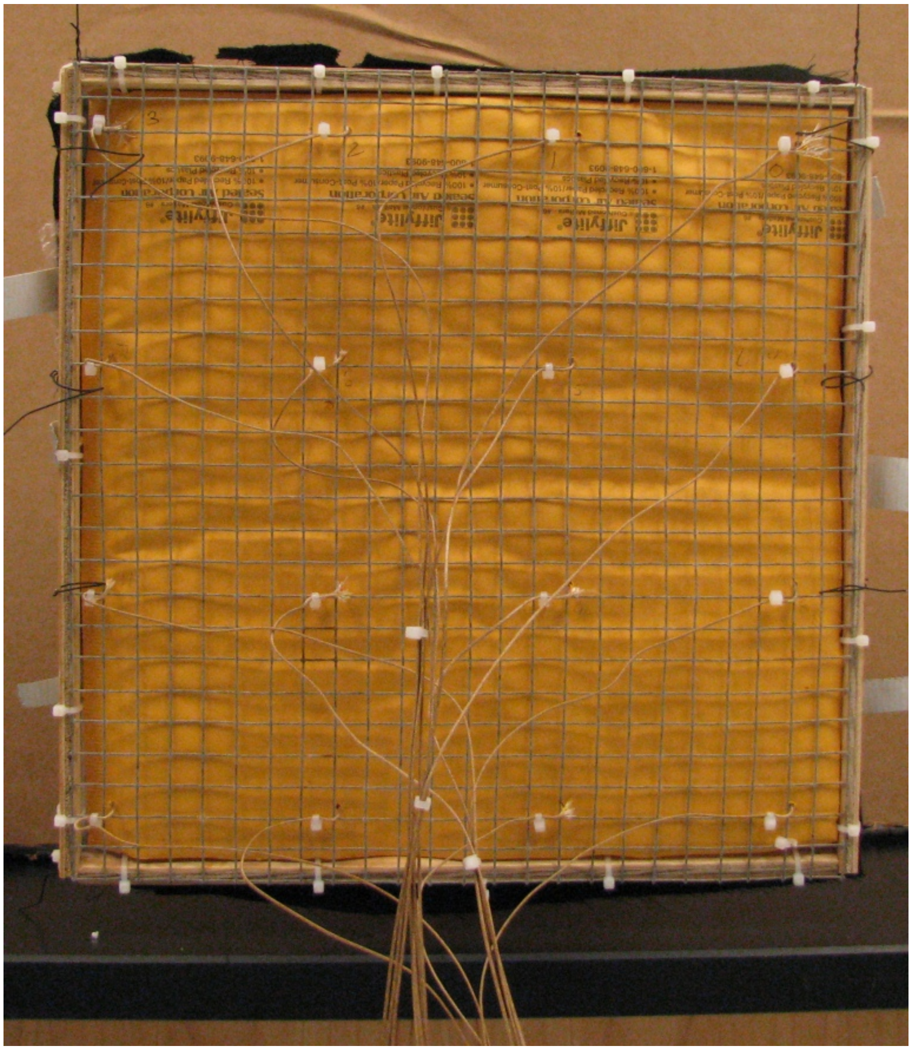

Photo 1 - Rear view of the target, showing the entry points for thermocouples. The presence of the cardboard surface behind the target was for photographic purposes only.

Photo 2 - Front view of the target, showing the cloth covering. Thermocouple junctions are in contact with the back side of the cloth.

The following test procedure was then followed:

Step 1 With the heater activated, a dull-painted, 3-inch x 3-inch x 3/8-inch piece of aluminum block, which had been heated to 38°C (approximately 38°C), was quickly placed ½-inch in the front of the thermopile detector, completely obscuring the detector's field of view, and an IR radiation measurement was made. This reading represents a room at an ambient temperature of 38°C, or a warm hand placed in front of the thermopile detector. The trip level for the proximity detector was then set 0.05 volts above this IR radiation level.

Step 2 With nothing in front of the heater, the heater was activated and an IR radiation measurement was immediately taken.

Step 3 With the heater placed at distances *D* equal to nine, six, and three inches from the target and the heater set at 1500W, an observation was made about whether the heater was deactivated by the proximity detector circuit at each distance.

Step 4 With the heater placed at distances *D* equal to nine, six, and three inches from the target, the heater set at 1500W, the proximity detector shutoff circuitry bypassed, and the target heated by the radiant heater for 10 minutes, IR radiation readings from the proximity detector were recorded for each distance.

To maintain anonymity with respect to the three 1500W portable electric radiant heaters used in the research, they are described generally as follows:

Heater A Tower with fan and two vertical quartz heating elements, metal enclosure.
Overall dimensions (h x w x d) – 22 in. x 10 in. x 8 in.
Front grill dimensions (h x w) – 14 in. x 10 in.

Heater B Tower on casters, no fan, with four horizontal quartz heating elements, metal enclosure.
Overall dimensions – 24 in. x 16 in. x 6 in.
Front grill dimensions – 15 in. x 12 in.

Heater C Tower with fan and two vertical quartz heating elements, plastic enclosure.
Overall dimensions – 23 in. x 12 in. x 8 in.
Front grill dimensions – 16 in. x 10 in.
Note: The front grill slopes upward at an angle of approximately 20° from the vertical.

Results and Discussion

For each of the three heaters, and at each of the three distances, the proximity detector circuit was able to detect the target and to deactivate the heater in less than 60 seconds when the heater was activated from a cold start. The closer the heater was placed to the target, the quicker the circuit deactivated the heater.

The range of maximum target temperatures, median temperature, and average temperature are shown below in Table 1 and are intended only to provide different ways to broadly describe the temperature characteristics of the well-heated target.

Heater	Heater on D = 9 inches			Heater on D = 6 inches			Heater on D = 3 inches		
	Range (°C)	Median (°C)	Mean (°C)	Range (°C)	Median (°C)	Mean (°C)	Range (°C)	Median (°C)	Mean (°C)
A	60 - 100	88	83	67 - 124	107	101	78 - 162	127	126
B	48 - 82	67	68	54 - 105	83	83	60 - 144	99	108
C	54 - 109	93	86	55 - 133	111	102	60 - 154	124	117

Table 1 – Temperature range, median and mean temperatures of the 16 thermocouples on the target at 10 minutes.

Table 2 summarizes the IR signal voltage levels generated by the proximity detector circuit. Note that these voltages do not correspond to any safety requirements but are intended only to understand the functionality of the detector circuit relative to each of the three radiant heaters.

Heater	Heater on, at start of test	(1) 38°C object in front of sensor	(2) Heater on D = 9 inches	Heater on D = 6 inches	(3) Heater on D = 3 inches	(4) Voltage Difference at D = 9 inches (column 2 - column 1)	Voltage Difference at D = 3 inches (column 3 - column 1)
	IR (V)	IR (V)	IR (V)	IR (V)	IR (V)	IR (V)	IR (V)
A	6.46	6.91	7.63	8.54	9.47	0.72	2.57
B	6.60	6.76	7.35	8.30	9.22	0.59	2.37
C	6.63	7.23	8.87	9.96	10.37	1.64	3.14

Table 2 – Maximum IR radiation readings (Volts) measured at 10 minutes.

Reviewing Table 2, it is clear that as the distance between the target and the front grill of the heater is decreased, the IR radiation reading expectedly increases. Column 4 indicates that a substantial signal difference can be generated by the proximity detector circuit even at the greatest distance of nine inches from the target, implying that better circuit designs may be able to generate even larger signal differences, which could possibly allow consistent detection of the target at distances beyond nine inches. Differences in the IR radiation voltages measured for the three heaters is attributed to high frequency noise present within the test environment, as well as differences in heater construction, sensor mounting, and routing of electrical cables.

An implication of this testing is that although the proximity detector circuit was able to detect a relatively small 12-inch x 12-inch target and deactivate the heaters, many flammable objects, such as sofas, beds, and curtains are considerably larger, would generate an even larger signal voltage, and would result in quicker heater shut-down times.

An additional test was conducted on heater A, where the distance between the grill and the target was two inches. The experimental mounting of the sensor on the heater necessarily forced the thermopile detector to be located approximately one inch from the target. At this distance the IR radiation reading was 8.6V. This suggests that a production-level heater, with proper mechanical integration of a thermopile detector into the heater, may be able to detect the target when it is located within one inch of a heater's front grill. The lower reading of 8.6V was expected, as compared to the measurement of 9.47V at three inches, because the target, as seen from the position of the thermopile detector, geometrically appears much smaller, and therefore, gathers less IR radiation.

Closer detection distances are probably not possible with the thermopile detector mounted on the front of a heater, due to the fixed position of such a sensor and its reduced ability to "see" the target as the target increasingly moves out of the thermopile detector's 120° field of view, and thus, is unable to gather sufficient IR radiation from the target. However, closer detection distances may be possible if the sensor is mounted inside the heater's middle section, "looking" through the front of the heater (see Figure 4 below).

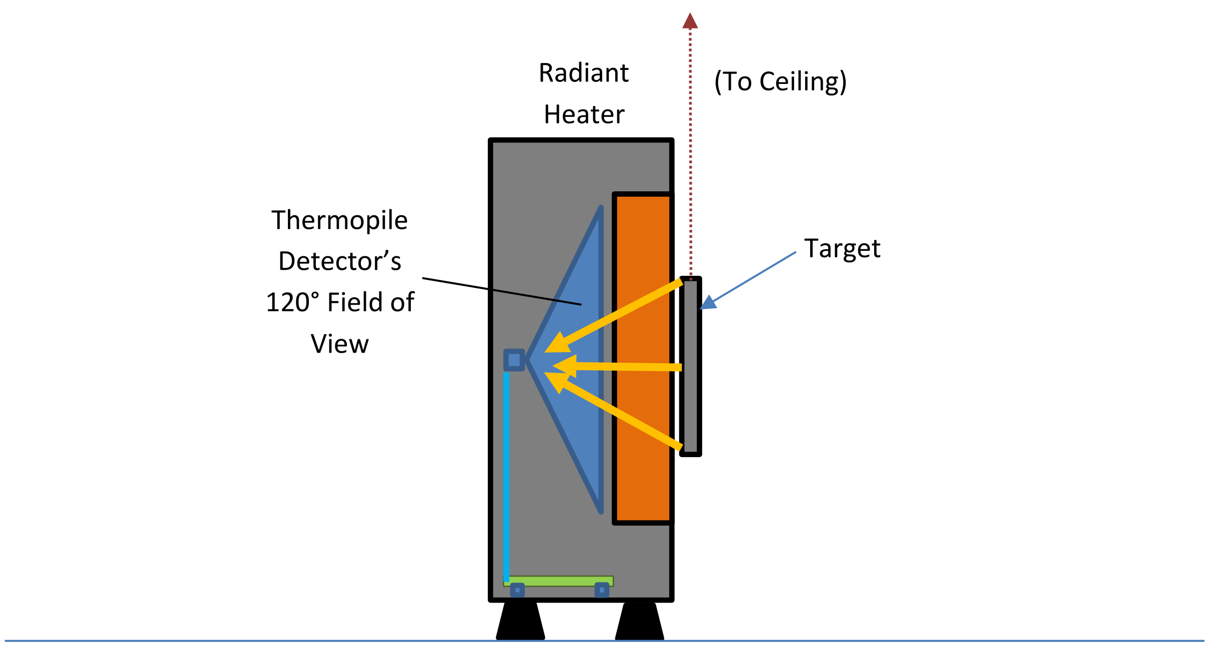

Figure 4 – Possible front-facing implementation of a thermopile detector within a portable radiant heater.

Another test was conducted with each of the heaters already in a hot condition and the target then placed quickly in front of the detector. For all heaters, the proximity detector circuit sensed the target and deactivated the heaters within ten seconds at all distances.

A final test was conducted with the proximity detector circuit mounted on heater A and heater C energized and placed at a distance of 10 feet in front of heater A. The distance between the two heaters was then decreased. Heater A eventually detected heater C at a distance of approximately five feet. Although this positioning of heaters is an unlikely scenario, it does suggest that the proximity detector circuit has a level of immunity against nuisance tripping due to other heaters being located nearby.

Conclusions

This research effort demonstrated that a proximity detector circuit using a thermopile detector could successfully sense a small target placed in front of a heater, shutting down three heaters (when tested individually) with differing mechanical constructions, heating element configurations, and IR radiation patterns. An additional test on one heater suggested that such a circuit may be able to shut down a heater when placed as close as one inch from the target. Nuisance tripping from nearby people and other radiant heaters in the area does not appear to be likely. Finally, larger combustible items, such as sofas, beds and curtains located in front of a heater would cause the proximity detector circuit to shut the heater down sooner because larger, heated objects produce more IR radiation than the 12-inch x 12-inch target used in this research effort.

Therefore, it is believed that such a circuit may be able to shut down a portable radiant heater located in close proximity to combustible objects. In view of these test results, a reasonable next step would be to gather feedback from various interested parties on this research effort to identify concerns that would need to be addressed for this proximity detector circuit to be a viable heater fire mitigation strategy.