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Combinational Smoke Detector

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Combinational Smoke Detector

A Major Qualifying Project to be submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

Project Number:
MQP WJL – 0801

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Abstract

The focus of this project was to design and create a combinational smoke detector to sense different fire characteristics. Research was completed on the background of detectors and different thresholds of characteristic signatures from a fire that could be identified. Fire signatures identified for the detector were smoke, carbon monoxide and heat. Individual sensors that could recognize these signatures were used in the design of a smoke detector that could reduce the number of false alarms caused by nuisance sources by looking for a combination of signals to indicate alarm.
Acknowledgements

First and foremost for this project I would like to thank the two advisors, Professor Wenjing Lou and Professor Brian Meacham, for presenting me with this great opportunity. Professor Lou was willing to experience the connection between electrical and computer engineering and fire protection engineering, and I thank her for that. Professor Meacham has a great deal of knowledge in the fire protection field and I am thankful that he was able to present me with this project and help me through the many steps along the way.

There was also a great deal of help from the Fire Lab Manager, Randy Harris. Mr. Harris helped coordinate numerous fire tests with me and showed me how to stay safe when working with fire. Randy always seemed to be able to make time for me in his lab and I am extremely grateful for that.

I would also like to thank Don Brighenti for inviting me to SimplexGrinnell and being able to talk with me about different types of detectors and where the smoke detector industry is headed. Don also presented me with a great deal of information on fire characteristics which was extremely helpful in the threshold decision process.

A great deal of thanks can also go to Tom Angelotti, the electrical and computer engineering shop manager and electrical technician. Mr. Angelotti made this project a lot easier for me by always getting me parts when I needed them and by letting me solder in his shop for numerous hours at a time.

A special thanks to all of you.

Keith Flanders

Worcester Polytechnic Institute
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Executive Summary

Smoke detectors have become common in households across the United States since the 1970’s when they were first recognized as being highly important in saving lives. Since the introduction of smoke detectors into homes, fire related deaths have dropped by nearly 50%. There are also new studies out that show 65% of fire deaths occur in homes that either don’t have a smoke detector or the smoke detector was not operating. This goes to show how important smoke detectors can be in saving lives.

The purpose of this project was to investigate, design, and create a way to detect a fire while reducing the number of false alarms that occur. This project focused on the characteristics of fire signatures and how they could be used to detect only a fire. Research and interviews were completed to determine what the most common smoke characteristics were and how they could be detected.

It was determined that when detecting a fire with just the technology of smoke obscuration sensors it was very sensitive to false alarms. However, if smoke obscuration was measured in conjunction with signals caused by temperature and carbon monoxide then it may be possible to limit the number of false alarms.

Research was conducted that found thresholds for each of these fire characteristics and then they were implemented into a design for a combinational smoke detector. The smoke

1 (Smoke Alarms)
2 (Ahrens, Reports and Statistics, 2007)
detector was designed and fabricated for testing to see if indeed a combination of these three fire characteristics could decrease the number of false alarms.
1. Introduction

Smoke detectors are a vital commodity in every occupied building in the world. Smoke detectors help to detect and indicate a threat to nearby inhabitants in the event of a fire. Smoke detectors allow people to become aware of their surroundings and alert them to seek safety. In an applications guide by System Sensor it states,

Studies have shown that in the United States the use of early warning fire and smoke detection systems has resulted in a significant reduction overall in fire deaths.\(^3\)

As a result, it is extremely important that smoke detectors remain a reliable product around the world. There is little or no room at all when it comes to efficient fire detection and saving the lives of many civilians. The National Fire Protection Association has estimated that nearly 890 lives could be saved each year if all homes had working smoking alarms.\(^4\) Smoke detectors play an important role in saving lives and are the first defense in helping to identifying a fire.

1.1. Problems

One concern with smoke detectors is the potential for smoke false alarms, which may cause people to disable or ignore the detector. All too often it is seen that detectors are either ignored as an annoyance, out of service due to poor maintenance, or disconnected from the

\(^3\) (System Sensor 2002)  
\(^4\) (Ahrens, 2007)
power source. The problem which this particular project is focused upon relates to the reliability of smoke detectors in identifying real fires. The goal of this project is to design and test a detector which can more reliably identify an actual fire and discriminate false or nuisance signals.

### 1.2. Needs

The goal of smoke detector technology today is to reduce the number of false alarms while keeping or increasing the accuracy of the original detector. There are several methods which are being tested to help improve the quality of detectors throughout the world. One of these new technologies incorporates other sensors to help identify a fire more precisely and accurately. To help create a device using multiple sensors many tests would have to be completed to determine actual fire characteristics and identify how each sensor individually responds to different fires. Making a detector which uses multiple signals to recognize a fire could be essential to saving more lives in the future.

### 2. Background

#### 2.1. Smoke Detectors

The common smoke detector used today detects a fire using either photoelectric or ionization methods, both of which are viable options for detecting smoke in the surrounding areas. However, they have different operating characteristics and different vulnerabilities which may lead to delayed detection and false alarms.

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\(^5\) (Proulx, 2000)
The effectiveness for a common smoke detector primarily depends upon the mode of combustion of a fire. The mode of combustion is the difference between a smoldering fire and flaming fire. A smoldering fire is typically characterized by visible smoke which can make a detector go into alarm. While a flaming fire does not necessarily produce an inordinate amount of visible smoke but rather releases large numbers of small smoke particles which can be used to set off a smoke detector.\(^6\) Both types of fire are dangerous and any detector should be able to recognize the threat early in the fire growth stage.

One problem with smoke detectors is that they sometimes indicate a fire when there is not one present. This creates problems the more frequently that it happens because the people that hear the alarm are more likely to ignore it. The need for smoke detectors that have fewer false alarms is clearly present. If there are fewer false alarms, then every time an alarm goes off, the more people will be likely to think of it as an emergency situation.

2.1.1. Ionization

An ionization smoke detector uses a radioactive material called Americium-241 to help detect the presence of smoke in the air. The Americium-241 releases alpha particles which ionize the air in the smoke chamber of the detector. The alpha particles cause the oxygen and nitrogen to ionize and create an electric current in the device. However, when smoke enters the chamber, the amount of ionized air is decreased, thus reducing the amount of electric flow in the circuit. This electric flow is monitored and when it becomes too low it can set off an alarm.\(^7\)

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\(^6\) (Geiman, Gottuk and Milke 2006)
\(^7\) (Baker & Adams, 1993)
Using the ionization method for a smoke detector is optimal when it may be more likely to have a flaming fire. The tiny particles from a flaming fire may not be able to be seen with the naked eye, but the characteristics of the ionization smoke detector allow it to sense a change in chemical composition of the air. This is an advantage in the case of a flaming fire, but also triggers an inordinate amount of false alarms because it is not able to sense a difference in particles in the air.

2.1.2. Photoelectric

Photoelectric detectors function by identifying the scattering of a light source due to smoke particles. This essentially follows the Mie Scattering Theory. The most common technique used is to have a light source radiating in one direction and a light sensing device set up to cross the path of the light source but not detecting the light. Once smoke enters the path of the light source, the smoke particles scatter the light into the direction of the sensor. The angle of refraction depends on various factors such as incident wavelength, particle diameter, and refraction index. This concept can be seen in the picture below, where the smoke particles reflect the incident light and send a signal to the sensing device.

---

8 (French, 2009)
9 (Dungan, 2008)
These detectors are most effective for smoldering fires where there is a lot of visible smoke. They are not the best option in the case of a flaming fire where not much smoke would be produced. This fact is important since it has been reported that the majority of fire-related deaths occurs with what started as a smoldering fire.\textsuperscript{11} Although a flaming fire may produce more heat, most fire deaths are to do the inhalation of smoke or becoming lost because of smoke obscuration.

**2.1.3. Photoelectric vs. Ionization**

The current trend of smoke detector use in the industry is headed in the direction of photoelectric detectors. In some tests, these detectors have been seen to indicate an alarm by as much as 20 minutes before an ionization detector did. While the maximum delay for a photoelectric detector compared to an ionization detector is approximately 30 seconds.\textsuperscript{12} Studies have shown that ionization detectors are to be more vulnerable to false alarms.\textsuperscript{13} These detectors

\textsuperscript{10} (Marshall)
\textsuperscript{11} (Mother Earth News 1983)
\textsuperscript{12} (Mother Earth News 1983)
\textsuperscript{13} (Ahrens, Home Smoke Alarms - The Data as Context for Decision, 2008)
can be easily set off by smoke produced from activities such as cooking when there may not actually be a fire. Photoelectric smoke detectors are built with a smoke chamber which improves the inflow of smoke and keeps other gases out which do not indicate a fire.\footnote{(Panasonic 2003)} Another reason for the movement away from the ionization detectors is that they contain small amounts of radioactive material, americium. Although almost harmless when inside the smoke detector, it can pose a threat in the event of a fire or when the detector needs to be disposed of.

\subsection*{2.2. Heat Detectors}

Another method in which to detect a fire is by the heat resulting from the combustion process. Heat detectors can be designed in a couple of ways. One apparatus is to have a fixed temperature detector that would go off at a predetermined maximum temperature. Another design of a smoke detector monitors the rate at which the temperature in the air is rising. Each kind of heat detector has particular situations where it may work better than the other.\footnote{(Dungan, 2008)}

Despite being extremely accurate in distinguishing a fire from a nuisance alarm, heat detectors are not considered a life safety device because they are not always reliable for a quick response in the event of an emergency.\footnote{(FireNet 2008)} Many times there may be a fire where the actual temperature at the ceiling does not reach the expected level until the fire has become too dangerous to even escape from. For this reason, the concept of making a combinational smoke detector...
and heat detector has been developed and more research is ongoing to make it an even more reliable device.\textsuperscript{17}

\subsection*{2.2.1. Fixed Temperature}

A fixed temperature heat detector can be made in multiple ways. One option can be accomplished by having a piece of metal which would link together once heated to a particular temperature. This mechanical design is useful for its simplicity but can only be used once as it would be damaged once linked together. Another way to create a fixed temperature detector is by using a thermistor or thermocouple. These devices have different electrical identities depending on the temperature that they are exposed to. Using simple electronics a threshold temperature could easily be detected.\textsuperscript{18}

Fixed temperature heat detectors are most common in residential settings where it may not be uncommon for the temperature to change often. In areas, such as near doors and ovens, where it is expected to change temperature a fixed heat detector may be of great use. Also, these areas may not be the best situation for a smoke detector since often there are numerous particles flying through the air, whether it is dust or smoke from cooking.

\subsection*{2.2.2. Rate of Rise Temperature}

To design a rate of rise temperature detector a thermistor or thermocouple could be utilized once again. The difference for this detector is that it would need monitoring circuitry to

\textsuperscript{17} (Brighenti, 2008)  
\textsuperscript{18} (Dungan, 2008)
detect the change in temperature over a certain amount of time. This is more complex and would require more power to carry out the necessary activities.

Rate of rise temperature detectors have primarily been used in applications where it is known to be a constant and steady temperature. These detectors are extremely effective for cold storage facilities where the temperature may always relatively low so that a fixed heat detector may be set too high to work. In this case, a rate of rise heat detector would be vastly useful in detecting a fire.

2.3. Carbon Monoxide Sensors

Another method recently being developed for use in a smoke detector is a carbon monoxide (CO) sensor. Carbon monoxide is a colorless, odorless, and tasteless gas which can only be detected by a sensor.\textsuperscript{19} This gas can be useful in a smoke detector because it is produced when materials have incomplete combustion, which is quite common for fires in a residential setting. Incomplete combustion generally is produced by a solid material being burned with a lack of oxygen.\textsuperscript{20} Carbon monoxide, along with being a fire signature, is also dangerous to humans by itself. This gas can cause problems to the human nervous system and heart with either a low exposure for a long period or high exposure for a short period of time. Carbon monoxide poisoning can even lead to death. Results have shown that over 40,000 people per year suffer from carbon monoxide poisoning in the United States.\textsuperscript{21} There are many different types of CO

\textsuperscript{19} (Carbon Monoxide Kills 2008)
\textsuperscript{20} (International Society for Complexity, Information, and Design 2008)
\textsuperscript{21} (Carbon Monoxide Poisoning 2008)
detectors which can be chosen from. The three main types of CO sensors are biomimetic, electrochemical, and semiconductor.

2.3.1. Biomimetic

The biomimetic sensor is a material that darkens in the presence of CO. This could be used with a light sensor to produce a signal when there is CO. This sensor is more commonly used as a signal for people to see than used in a sensing device. The biomimetic sensor is a material which will only react to carbon monoxide and not produce false alarms. Although, once it has detected carbon monoxide once it would not be able to be reused again because cannot be used multiple times.\(^\text{22}\)

2.3.2. Electrochemical

The electrochemical sensor is designed to create a current when in the presence of CO. The chemical inside (acid electrolyte solution) of the sensor reacts with the carbon monoxide and produce a current which then can be read by an electronic circuit. The electrochemical sensor is the most widely used sensor in CO detectors today because it is the most accurate and is also not prone to false alarms from other gases.\(^\text{23}\)

2.3.3. Semiconductor

The semiconductor sensor changes resistance with the amount of CO present which in turn could be measured by an electric circuit to detect a hazard. This is also a useful sensor for

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\(^{22}\) (Black, 2008)  
\(^{23}\) (Black, 2008)
detecting carbon monoxide and depending upon their availability could also be a viable option for a carbon monoxide sensor.\(^{24}\)

### 2.4. Combinational Detectors

In today’s market, there are detectors which both have a smoke detector and carbon monoxide detector built into one, but they function separately. The problem with this device is that carbon monoxide is less dense than air and because of this it is more likely to settle closer to the ground. This could pose a problem since it is intended to be on the ceiling with the smoke detector. Another error presented by the CO detectors is their allowances to false alarms. Such actions such as smoking a cigarette produce carbon monoxide but the detectors must not be so sensitive as to pick up this amount of the gas. However, it is obvious that multi-criterion devices need to be researched and it is known that “development is underway by some manufacturers to incorporate gas sensors such as CO or CO2 to improve the performance of smoke detectors”\(^{25}\).

There are also combinational heat and smoke detectors, as well as ionization and photoelectric detectors in one device. These detectors are advances from a single sensor detector, but there is still room for improvement. There is introductory technology where the use of multiple sensors in conjunction with each other is being made, however not many devices are currently available.

\(^{24}\) (Black, 2008)  
\(^{25}\) (Moore 2008)
2.5. Summary

In order to create a more reliable smoke detector, it should not be overly susceptible to nuisance signals. These nuisance signals include occurrences like smoking a cigarette, burning food, or dusting. It would be ideal to create a detector which distinguishes the characteristics between a real fire and these nuisance signals. Using multiple sensors such as the smoke detector, heat detector, and carbon monoxide detector it may be possible to create a device which eliminates all the current problems given by current technology. For this reason, this project was formed to help find different ways of detecting a fire more accurately and reliably.

3. Research Objective

The objective of this project is to determine if using the fire signatures of carbon monoxide, temperature, and smoke obscuration in combination inside of a detector is a viable idea that could be manufactured. A threshold at which each fire characteristic and combination thereof is to be determined and built into a circuit that produces warnings for each level reached. These combinations of thresholds should effectively reduce or eliminate the number of false alarms created by smoke detectors. The research and experiments from this project should increase the knowledge towards creating more effective and reliable smoke detectors in the future.

4. Thresholds

An important aspect of designing the combinational smoke detector is determining the points at which the device should go into alarm. The common thresholds used in current
detectors are obviously not applicable because those cause false alarms and long activation times which are trying to be prevented. For this reason research had to be done to help discover which levels of temperature, smoke obscuration, and carbon monoxide would be acceptable to initialize an alarm when either working together or separately.

The research for each threshold began by first identifying what the current levels for each threshold were in the market. This was determined by a few different methods of examination. Initially, a number of generic smoke, heat, and carbon monoxide sensors were looked at to see what the common alarm indicating levels were. From this it was found that smoke detectors generally had a level of approximately three percent obscuration per foot to be set into an alarm mode. Also, when looking into heat detectors it was established that most fixed heat detectors were either rated for 135°F or 165°F when put into a residential setting. In the case of a carbon monoxide sensor, there are no detectors which only use carbon monoxide to sense a fire. However, there are carbon monoxide detectors which look to identify the gas no matter what the source. These detectors are usually designed to sound an alarm after a certain amount of time to an exposure of carbon monoxide depending on the level. This is because some cases of carbon monoxide poisoning can happen over a long period of time with discrete amounts of the gas present.

Besides looking at how detectors are made by other manufacturers it is also possible to seek out certain standards and specifications which must be followed when designing a detector or sensor. There are standards written by approval companies that manufacturers go to help ensure the safety of their product. These standards can include design requirements for each
smoke detectors, heat detectors, and carbon monoxide detectors if the appropriate sets of standards are inquired.

The most used standard for smoke detectors is called *Smoke Detectors for Fire Alarm Signaling Systems (UL 268)*\(^{26}\) written by Underwriters Laboratories Inc. (UL). This standard goes into great detail about how smoke detectors will be tested, which in turn provides information on how detectors can be made and specifications should be followed when designing the detectors. The standard also explains different tests which a smoke detector should be able to pass in order to become a device listed for use. One requirement to meet in this standard is that a detector “shall not alarm prior to an obscuration level of 0.5 percent per foot (1.65 percent/m), or less”. This standard also has many approval tests that a detector must pass in order for it to be accepted by UL.

There is also standard for heat detectors. This is called *Heat Detectors for Fire Protective Signaling Systems (ANSI/UL 521)*\(^{27}\) and is approved by the American National Standards Institute (ANSI) and Underwriters Laboratories. This standard states that a heat detector with a temperature range of 134 °F to 174 °F is of an ordinary temperature range which is often used for residential applications. The standard says that if the ceiling temperature is not projected to rise above 100 °F then a heat detector within the range of 135 °F to 165 °F should be installed.

Another standard which deals with carbon monoxide is called *Standard for Single and Multiple Station Carbon Monoxide Alarms (ANSI/UL 2034)*\(^{28}\) and is also approved by ANSI and

\(^{26}\) (Smoke Detectors for Fire Alarm Signaling Systems, 2006)
\(^{27}\) (Heat Detectors for Fire Protective Signaling Systems, 2002)
\(^{28}\) (Standard for Single and Multiple Station Carbon Monoxide Alarms, 2005)
UL. This document explains the different parameters for a CO detector to activate in great detail. The standard states to follow a graph when determining CO level thresholds for certain lengths of time. However, it can be more easily seen in the chart below which is also in the standard.

<table>
<thead>
<tr>
<th>Concentration, ppm</th>
<th>Maximum response time, minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>90</td>
</tr>
<tr>
<td>200</td>
<td>35</td>
</tr>
<tr>
<td>400</td>
<td>15</td>
</tr>
</tbody>
</table>

**Figure 2 - Carbon Monoxide Alarm Thresholds**

This chart identifies common thresholds and how long they should recorded for before an alarm is signaled. The chart also gives minimum values for when the alarm should not be going into alarm mode. These values could be useful if the detector being made included a separate CO warning system, but the project is more focused on smoke detection. This information can still be useful in determining what thresholds to use in the combinational smoke detector being made.

A large portion of information for this process was found in a report by Hughes Associates called *Evaluation of CO/Photoelectric Detectors*. In this report many nuisance fire tests were conducted to help determine if it would be sensible to combine data from smoke obscuration and carbon monoxide to identify a fire. Information that was used from the report:

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29 (Hughes Associates, Inc., 2008)
included carbon monoxide, smoke obscuration, and temperature levels for all the fires and nuisance sources which were tested. This was extremely important information to the project because the report gave numerical values to the characteristics a nuisance source outputs. To determine the final thresholds these three characteristics were compared side by side which can be seen in the chart below.

<table>
<thead>
<tr>
<th>Test</th>
<th>Peak Obscuration (% Obscuration / Foot)</th>
<th>Peak Temperature (°C)</th>
<th>Peak CO (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shower Steam A</td>
<td>4.9</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>Shower Steam B</td>
<td>4.75</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>Microwave Popcorn 1</td>
<td>5.5</td>
<td>22.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Microwave Popcorn 2</td>
<td>3.3</td>
<td>22</td>
<td>6</td>
</tr>
<tr>
<td>Toasting Bread 1</td>
<td>10</td>
<td>27</td>
<td>16</td>
</tr>
<tr>
<td>Toasting Bread 2</td>
<td>25.5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Cooking Scenario 1</td>
<td>3</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>Cooking Scenario 2</td>
<td>2.3</td>
<td>26.3</td>
<td>2</td>
</tr>
<tr>
<td>Dust 1</td>
<td>3.2</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Dust 2</td>
<td>1.9</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Aerosol 1</td>
<td>2.2</td>
<td>19.5</td>
<td>0</td>
</tr>
<tr>
<td>Aerosol 2</td>
<td>1.45</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Aerosol 3</td>
<td>2</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>Generator</td>
<td>0</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>Trash Fire</td>
<td>4.5</td>
<td>35</td>
<td>60</td>
</tr>
</tbody>
</table>
Comparison from this chart allowed for the results of different nuisance sources to be recognized and gave great insight for which levels of each sensor might produce a false alarm. These results allowed for the final thresholds to be determined along with all the other information gathered earlier. The thresholds were finalized to be as seen below:

- Single Sensor
  - Smoke Obscuration
    - 4% obscuration per foot
  - Temperature
    - 135 °F
  - Carbon Monoxide
    - 100 parts per million
- Two in Combination
  - Smoke Obscuration and Temperature
    - 2% obscuration per foot and 120 °F
  - Smoke Obscuration and Carbon Monoxide
    - 2% obscuration per foot and 30 parts per million
  - Carbon Monoxide and Temperature
    - 120 °F and 30 parts per million
- All Three Together
  - 1.5% obscuration per foot, 105 °F, and 15 parts per million

These threshold levels for each fire characteristic can be used in creating a more reliable smoke detector that will have fewer nuisance alarms. From these findings, it seems possible to take three different sensors and have them work together in one device to try to avoid anymore

\[30\text{ Hughes Associates, Inc., 2008}\]
false alarms while still having the same effectiveness as an ionization or photoelectric smoke detector.

5. Device Design

The importance of the device design relied on a number of factors. From the beginning, a budget had been placed on the project which would be a main factor in numerous decisions. The concept of the project also required that a device be made which could replace a common smoke detector, except with the added benefit of being more reliable. This device in essence had to be designed like a regular smoke detector with the additional elements of improving the technology inside.

5.1. Price

Although this device is used for life safety a key aspect is that the product must still be in a price range which would be acceptable to all households. An economical device would help increase the number in detectors in homes and also be in fair competition with less complex detectors that may not be as efficient in detecting smoke from a fire.

A typical price for a smoke detector is in the range from as low as six dollars but also be as high as 50 dollars. This price range includes both kinds of smoke detectors, ionization and photoelectric. It is also possible to have a detector which utilizes both detection methods for more safety in the same price range. The price may also become higher if other technologies are desired such as a voice announcing that there is an alarm rather than just a simple high pitched beeping.
There are also devices which have a combination of a smoke detector and a carbon monoxide sensor that work separately from each other but are in the same unit. These devices are generally priced around fifty dollars and look similar to a normal smoke detector.\(^{31}\)

With the pricing information provided from other producers, it is apparent that the product being made in this project would have to have a retail value between fifty to eighty dollars. This would suggest that the total material cost to build the device would have to be approximately ten to sixteen dollars. This would allow for the cost of labor and equipment, as well as leaving a large sum for profit.

\subsection*{5.2. Size}

Most smoke detectors and carbon monoxide have a standard shape and size. Looking at most standard detectors the size of the device should be no more than three inches in depth and six inches in length.\(^{32}\) This is a normal size for a smoke detector that is easy to handle and also not too intrusive to the home décor.

The box size in this project was six inches in width by three inches in depth. This may be a little bigger and not the actual shape of a final product, but it sufficed while completing tests and experiments on the different sensors of the device. To actually market the combinational smoke detector a smaller and more aesthetically appealing device may be needed to be developed.

\begin{flushright}
\scalebox{.75}{\textit{\footnotesize 31 (Home Depot)  
32 (Smoke \\& Fire Alarms / Smoke Detectors, 2008)}}
\end{flushright}

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5.3. Box Design

A more complex design to allow proper smoke flow through the device to the sensors was not looked into. The main focus on the design of the box was to make sure that a sufficient amount of space was allowing smoke particles to enter the device. There was a metal guard placed between the outside and the inside of the box to prevent large particles from entering the device and disturbing the circuitry. The design only allows for tiny smoke particles to affect the circuit which is necessary to prevent false alarms from big particles making it through or other outside sources getting into the box.

Another component of the design which was followed was the placement of the thermocouple. It was important to make sure that any heat from a fire would affect the output of the thermocouple because fast detection was a need in the project. A final design for the box can be seen in the picture below:
5.4. Sensors

The sensor selection process began by first determining the most applicable methods to identify smoke from a real fire and not from a nuisance source. There are already numerous detectors available to help signal in case of a fire, but there is still much improvement needed for their reliability and activation times. With these advancements in smoke detectors many more lives could be saved due to the enhanced credibility of the detectors. For this reason the decision to use three different detectors as one device was chosen.

First the choice of which type of smoke obscuration detector use would have to be decided. This the most common way to identify a fire in its early stages before it becomes too dangerous. The main two choices for this type of smoke detection are an ionization detector or a photoelectric detector. They both have their advantages and disadvantages as discussed earlier, however it is apparent that the photoelectric detector would be the best choice for this project for
a couple of reasons. One major factor is that is known to have fewer false alarms than an ionization detector. This device is being designed to have fewer false alarms than any smoke detector, so it would not be a relatively smart decision to utilize a sensor which already has a lot of false alarms in the first place. There is also the motivation to stay environmentally healthy in today’s society which would not be possible with the ionization detectors because of the radioactive material that is used in them to detect smoke. A photoelectric detector is the best choice for a smoke obscuration sensor when considering the previous cases.

To design the photoelectric detector portion of these device two key elements had to be selected. These would be the light emitting diode (LED) and photodiode which would be used to create a light source and then measure the amount refracted by smoke inside the chamber. It was recommended by Don Brighenti from Tyco Safety Products\textsuperscript{33} to use a light source which would be infrared since it had worked best for their designs in the past. Using an infrared sensing photodiode also limited the amount of outside light that would affect the output. The focal point of this part of the circuit was to find a light which emitted a large peak at a certain frequency and make sure that the photodiode being used recognized only the light from that frequency range. Therefore, the LED would produce a light source which then gets refracted by smoke particles inside the chamber towards the photodiode. The photodiode sees the extra light signals and increases in current output. This makes for an effective and sensitive smoke detector.

\textsuperscript{33} (Brighenti, 2008)
The next part of the sensor selection was to find a device which could act as a heat detector. It had been determined that the use of a fixed temperature heat detector would be sufficient since the use of this smoke detector was being designed to be used in residential settings. The use of a rate of rate detector would only seem applicable in an area were the temperatures are normally cold and might not get hot enough to set off a fixed temperature detector if it was rated at too high of a temperature.

The heat detector had a couple of ways that it could be made through different circuitry. The two different options to choose from for this device would be either a thermistor or a thermocouple. The thermistor is a component which changes its overall electrical resistance with the change in temperature. This is convenient but not the best option since a voltage would have to be supplied to the component to keep track of its changes, which would mean less battery life for the overall device. The best option to use as a temperature sensor in this device would be a thermocouple.

A thermocouple is made by soldering two different metals wires together which provides a potential difference that can be measured. This difference in voltage changes with a variation in the temperature making it very easy to know the temperature. A Type K thermocouple was
provided as the best available thermocouple. This thermocouple used the potential difference between a nickel-chromium wire and a nickel-aluminum wire to sense a change in temperature. The Type K thermocouple has a very wide temperature range (-328 °F to 2282 °F) which would be suitable for this project.\textsuperscript{34}

The last sensor which needed to be chosen for project was the carbon monoxide sensor. The requirements for this sensor were that it had to exclusively react to carbon monoxide and no other gasses and it also had to have acceptable reproducibility. These characteristics were hard to find among carbon monoxide sensors that would also be in the price range of the circuit.

Considering these sensor characteristics and the price range it was clear that an electrochemical sensor would make the most sense. The new task was to find a company which sold these sensors independently and at a reasonable price for such a small quantity. Many retailers were looked into including companies like Alphasense\textsuperscript{35} and AppliedSensor\textsuperscript{36} who have similar sensors to what was needed in the project but were not able to offer a product which would be economical. The final sensor which was chosen was found at Figaro USA\textsuperscript{37}. This sensor can be seen in the picture below:

\textsuperscript{34} (Type K Reference Tables)
\textsuperscript{35} (Alphasense)
\textsuperscript{36} (AppliedSensor, 2009)
\textsuperscript{37} (Figaro)
It can be seen that this sensor has the characteristics which were desired for the problems faced in this project. In the graph below it shows that this particular sensor which was used is barely affected by other common gases but still has a large change in current output for different amounts of carbon monoxide.

**Figure 7 - Sensor Sensitivity to Various Gases**

38 (Figaro, 2007)

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The next graph depicts the repeatability and accuracy of the sensor. Each time the sensor is subjected to a carbon monoxide source the output clearly goes to a particular level and stays there until the source is taken away. It can also be seen that the output is approximately doubled when the carbon monoxide source is doubled in potency.

![Graph showing sensor repeatability and accuracy](image)

Figure 8 - Sensor Repeatability and Accuracy

5.5. Circuit

The initial design of the circuit began by building a circuit which would provide an output for each sensor. This process was extremely easy for the thermocouple being used as it produced its own voltage corresponding to a particular temperature. That made this particular sensor simple and was ready for use immediately. The voltage created by the thermocouple was put through a voltage follower circuit so that the thermocouple would not be affected by other
voltages when its output was used later in the circuit. This voltage follower was made by using an operational amplifier (op-amp) where the output of the thermocouple was connected to the positive input of the op-amp and the negative input is connected to the output. The operational amplifier that was used for this particular circuit and many more was a LM 358.

Figure 9 - Operational Amplifier (LM 358)\textsuperscript{41}

Tests were easily conducted on the thermocouple because all that needed to be done was to have another thermocouple next to it that produced results per degree Celsius. Recording the results through a cone calorimeter and into a computer program called LabView it was easy to see that the sensor worked as it had been projected to do so. These recordings can be seen below where the first graph displays the output voltage of the thermocouple in the device and the temperature recorded by the other thermocouple. The data from each thermocouple are near mirrors of each other except that the temperature measuring thermocouple took more time to

\textsuperscript{41} (Jangel Electronic)
settle back down to normal temperature than did the device thermocouple.

![Thermocouple Comparison](image)

**Figure 10 – Thermocouple Comparison**

The two data sets were then analyzed using a comparison of zero, average, and peak values. From the results of the two thermocouples, a third figure was able to be made which tells the temperature levels per voltage output of the device. Examining these results, it was clear that the output voltage was a linear function of temperature. Using the trend line equation,

\[
y = 0.0076x - 0.1855
\]

any threshold temperature could be determined in terms of voltage output of the sensor. This is useful since any temperature level can now be determined and turned into a threshold which is monitored for an alarm condition. A graphical representation of this relationship can be seen below:
Completing the smoke obscuration circuit was much more difficult than for the thermocouple. To get the infrared LED to output a constant light source towards the photodiode, some extra circuitry had to be used. The voltage from the battery would variable dependent on use and age so it would not create a constant source for the LED which would change the output from the LED as well. To control the light from the LED a voltage regulator (lm 317) was used to provide a constant voltage.

Figure 11 - Thermocouple to Temperature Correlation

Figure 12 - Voltage Regulator (LM 317)\(^{42}\)

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\(^{42}\) (LM 317)

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This protected the light source from changing while the voltage changed and would not change the amount of light be transmitted towards the photodiode. Using two resistors and a power supply to the regulator an output voltage of 1.46 volts was created because the maximum working voltage for the LED was 1.5 volts. This voltage was then sent into a voltage follower of an operational amplifier (LM 358) so that the characteristics of other electrical elements would not change the output from the voltage regulator.

For the photodiode, a 100K ohm resistor was attached from the positive end of the device to the negative end. This allowed the current flow from the photodiode to run through the resistor and create a voltage across it when it detected infrared light. Therefore, with more infrared light absorbed by the photodiode then more current there would be produced, in turn creating a higher voltage.

Using both the infrared LED and photodiode in combination made for an effective smoke obscuration sensor. Before any smoke entered the path between the LED and photodiode the output from the photodiode would hold constant at a small value. Once smoke was began flowing through the device the output from the photodiode could be seen to be rising. This was the affect that the smoke had on refracting more light into the photodiode sensor.

One test for this can be seen below. The figure represents the output of the smoke obscuration sensor made by the LED and photodiode along with the output measured inside a cone calorimeter which has an inverted shape compared to the device’s output. However, this is the expected result from the cone calorimeter because it is measuring the amount of light being passed across the path of the smoke. As the smoke obscuration level goes up, more light will be blocked and the output will decrease in value. There was also a calibration for the cone
calorimeters smoke obscuration sensor so that the actual percentage of smoke obscuration could be determined. This was done by; first recording the cone calorimeter’s output when no blockage was present and then the output would be recorded when there was 100% obscuration. Knowing that this would have a linear relationship, the percent obscuration could be calculated for the output.

![Smoke Obscuration Comparison](image)

**Figure 13 - Smoke Obscuration Comparison**

Once again the tests seem to be mirror images of each other which are exactly what would be expected. Using this test and other similar ones, which can be found in the appendix, a correlation between the actual smoke obscuration percentage and the output from the device could be made. This correlation produces the equation:

\[ y = 0.0087x + 0.26 \]
Using this equation the same as the thermocouple equation, any threshold percentage can be calculated as an output from the devices smoke obscuration sensor. This correlation can be seen graphically in the figure below.

**Figure 14 - Device Smoke Obscuration Percentage Correlation**

The carbon monoxide sensor being used also had additional circuitry which had to be implemented for it to work properly. However, the schematic for the setup of the sensor was in the specifications sheet\(^{43}\), so that made it much easier to understand. The circuit involved a capacitor, resistor, and operational amplifier to help extract a signal from the CO sensor. The reason for this circuit was to not allow a voltage at the working end of the CO sensor because it is known to damage the sensor. This circuit can be seen in the picture below.

---

\(^{43}\) (Figaro, 2007)
The output from this circuit was also put into a voltage follower to protect the output voltage and make sure that the measuring circuit would not be affected in order to keep the signal constant. This output was also tested and recorded using the cone calorimeter. The tests for this sensor were also completed using smoke from a fire as well because the smoke that was created was a good source of carbon monoxide at lower levels which otherwise would be hard to produce. The results from these tests can be seen below.

Figure 15 - Carbon Monoxide Measuring Circuit

44 (Figaro, 2007)
Once again the output from the device and the output from the cone calorimeter are extremely similar. The cone calorimeter has a slight delay compared to the device sensor because it is required to pass through an arrangement of filters before it is actually measured. Other than this delay, the data sets close to equivalent. The CO sensor in the device takes a bit longer to determine there is no CO left in the chamber which can be seen on the back end of each spike. This is caused by the smoke still having to clear out of the chamber maybe taking longer than there was actually smoke flowing through the cone calorimeter. Also, the circuit that the CO sensor it connected to causes a slight bit of saturation. This result was expected and does not seem to affect the readings to be of much concern. However, overall they still produce the same results which can be used to make a correlation. The cone calorimeter was also calibrated before testing and is expected to be linear. Therefore, the outputs for 0 ppm of CO and 2510 ppm of CO were measured so that there could be a determination of actual CO values. The correlation for the device’s CO sensor out compared to actual CO measurements can be seen below.
The correlation equation for the CO sensor was not a perfect linear curve. It was still able to fit a quadratic curve quite nicely though so that the correlation could still be calculated. The equation for this correlation is:

\[ y = -0.0001x^2 + 0.0198x + 0.0055 \]

Now that each sensor has a correlation to their output voltages the rest of the circuit can now be built. This includes making the thresholds voltages to compare the sensors to, as well as the final stage of the circuit which is the output to the LED’s that will signal a warning for what type of combination is going into alarm. There also has to be circuits which will add the voltages together from different sensors to create the combination alarms.

One problem observed with the combination of sensors was that the CO and temperature sensors would change dramatically over hundreds of millivolts to different thresholds. While the voltage of the smoke obscuration sensor only had to change 10 to 20 millivolts before it reached its next threshold. To counteract this effect of one sensor controlling the combination, a voltage divider circuit was created that would make the other sensors smaller when combining with the...
smoke obscuration so that they would only reach thresholds on a 10-120 millivolts scale as well. This should have guaranteed accurate results from the combination thresholds as well as the singular sensor thresholds.

To help in the design of the threshold detecting circuit for this device a program called Multisim was used. This program allows for actual electronic circuit devices to be wired together and simulated as though they were real. This program was used to simulate a large number of comparators which were being used to evaluate certain thresholds. However, it was also possible to do this just for the single alarm threshold. This setup can be seen in the picture below.

![Simplified LED Circuit](image)

**Figure 18 - Simplified LED Circuit**

This simple circuit when tested in Multisim proved that the concept would actually work when built on a circuit board. The input voltage could be changed above and below the threshold set, which in turn would turn the LED on and off accordingly. This particular comparator (LM 339)
that was used allowed for signals to be evaluated within a millivolt of each other. This feature enabled the device to be sensitive to any change in the sensors. This circuit was also tested in Multisim with the actual number of comparators being used and it worked just as well, however it is not as easy to follow as this simple circuit.

Using seven comparator outputs, the circuit would be able to produce signals if a threshold was reached and go into alarm. The sensors outputs were compared to a fixed voltage produced by a voltage divider and the output of the voltage regulator from the photoelectric setup. The voltage for which the sensors should set the device into an alarm was determined from the correlation equations and the threshold levels, both were determined previously.

5.6. Testing Plan

The testing for the final device would have three experiments in a normal sized room with the smoke detector at the ceiling. The device which is made as a smoke will be place in close proximity of another smoke detector that is actually on the market. The smoke detector used was a combination of ionization and photoelectric technologies. This is the proposed best method for protection by smoke detectors currently by NFPA.\(^\text{45}\) For each experiment, the detectors will be placed on an 8 foot ceiling of a room with 3 walls and 1 open side so that the test may be viewed. Smoke would be able to escape the room once it had built up over a 1ft edge.

\(^\text{45}\) (National Fire Protection Association)
at the ceiling on the open side of a room. All materials that were being tested were inside of a pan that was placed 2 ft off the ground directly under the smoke detectors.

The experiments which were to be run included three different scenarios. The first scenario was the burning of paper products inside the pan. This test was intended to represent a trash can fire. The paper would initially be ignited by a lighter to start the combustion. The next two tests were of food products and intended to represent nuisance alarms. One test would be two pieces of bread place in a pan on a hot plate. The hot plate would be on its maximum temperature before the bread was placed on the pan. This would act as if someone was burning their bread in a toaster. The other test would be a thawed hamburger patty that was \( \frac{1}{4} \) inch thick. This was placed in an already warmed pan and hot plate as well.

5.6.1. Expectations

From the first test with the paper products acting as a trash can fire it would be expected that the device made in this project would hopefully go into alarm either before or at the same time as the generic smoke detector. The combustion of the paper products should produce enough smoke and carbon monoxide to set off a combination alarm. There may even be enough heat to cause the signal of all three sensors combined to go into alarm.

In the test with the bread on a heat pan, it may take a little while before the bread actually begins to char and create smoke. For this reason the activation times of the smoke detectors may seem delayed compared to the paper products burning. However, ideally the bread should not produce enough CO or heat to create any combination alarms, but there may eventually be enough smoke to create an alarm due to smoke obscuration. Since the main product being produced is smoke the generic smoke detector should go off before the experimental device
which has a higher threshold for smoke obscuration when not enough CO is present. There could be enough CO at some point to set off a combination alarm according to Table 1, comparing the results from the Hughes Associates report, but it is doubtful that this would be the most common scenario.

The tests that involved the hamburger patty should have similar results to the test with the bread. The difference is that there definitely should not be a combination alarm. Both of the tests from the Hughes Associates report that involved cooking a Hamburger did not record over 2 ppm of CO. The tests did not record much in means of smoke obscuration either, but still enough to set the generic detector into alarm. The best results for the experimental would be that it never goes into alarm. If the smoke obscuration in the room stays below the single sensor threshold for smoke obscuration then there should never be an alarm because not enough heat or CO will be produced to create any type of combination alarm.

6. Experimentation

The experiments for this project were completed with the scenarios that were mentioned in the experimental plan. However, since the signaling circuit of the experimental device was not completely functional it would not be certain if the warning LED’s would light up when there was an alarm. For this reason, the testing ended up getting split over two days. On the first day, there was voltmeters setup to the experimental detector to tell if the thresholds had been reached and if the device had gone into alarm. On the second day the CO and smoke obscuration sensor were hooked up to a computer so that they could be logged into LabView for analysis.
6.1. Tests

On the first day, the experiments began with the toast test. The generic smoke detector went into alarm 14 seconds after the smoking toast was placed under the smoke detectors. It was not recorded at any point that the experimental detector had gone into alarm. The smoking toast was removed 4 minutes and 44 seconds the break had been smoking under the detectors and there still had been no alarms recorded by the experimental device.

The second test of the day was a mixture of paper products inside a pan. This fire developed quickly and the generic smoke detector went into alarm at approximately 44 seconds. The experimental detector never did go into alarm once again.

On day two, the testing began with another paper products fire test. This fire grew quickly and sustained for a long period of time producing a large amount of smoke. For this test the generic smoke detector went into alarm at 25 seconds from ignition. No LED’s came on for the experimental device to indicate and alarm. However, on this day the individual sensors were being logged so those were kept track of.

The second test of day two was the hamburger patty on the hot pan. This test resulted in no flames but did produce a large amount of smoke. The generic smoke detector went off in 44 seconds from the start of cooking and results from the experimental detector were not logged correctly so no results were made from the device on this test.

6.2. Analysis

The results from the first day of testing indicate a malfunction on behalf of the experimental device. There was enough smoke being produced in both the toast test and the
paper test to probably set off the thresholds, yet there was no indication of alarm from the experimental device. The outputs from the individual sensors also showed no response to the smoke. This indicates that there was indeed a malfunction to the device during the test because the individual outputs have been known to work from previous testing.

The second day of testing provided some results that could be analyzed. From the first test, which was a paper fire test, the outputs of both the CO sensor and the smoke obscuration sensors were recorded.

![Paper Fire Test](image)

**Figure 20 - Paper Fire Test Results**

The results from the CO sensor were inconclusive so they were not provided in this report. However, the smoke obscuration results are accurate for a paper fire. There was a large amount of smoke built up around the smoke detectors and this can be seen by a jump of 450 millivolts which is nearly double the baseline value and well over any acceptable obscuration levels for breathable air. There is a sudden drop at 280 seconds which was not expected. It was
assumed that the heat from the fire affected the wiring inside the device and caused it to malfunction.

Figure 21 - Paper Fire Test

To test whether the device was indeed still working or not, the next test with the hamburger was run. During this test, it was seen that the individual sensors inside of the device had stopped working. Due to this malfunction no test results were able to be completed.
6.3. Outcome

These final tests did not produce any conclusive results to show that the device would indeed work in the event of a fire. Useful data that was concluded from these tests was the activation times of a normal smoke detector in the smoky situations that were simulated. These results can be useful in future testing of the experimental device and other smoke detectors. The experimental device still needs work to make it more consistent and reliable to work every time. The device has been seen to work correctly outside of the testing lab, but has not repeated results when in the lab. There are many possible reasons for the device to malfunction which include the possibility of loose wires inside the device, bad circuit design, or maybe some of the testing methods were not set up correctly. In order to produce more accurate results the device would have to be worked on more to be more consistent.

7. Conclusion and Recommendations for Further Research

The research for this project was carried out in a well organized and informative fashion. An abundant amount of resources were gathered and compiled to create an extensive base for which to build the project. Many fire scenarios and different methods of smoke detection were investigated and the final decision was made to attempt to make a detector utilizing carbon monoxide, temperature, and smoke obscuration. There was enough information on these three fire characteristics and the sensing technologies that formidable thresholds could be selected for them. From this, sensors were selected and tested to prove that they could work. In the final design process, an attempt was made to interconnect all of the sensors and create a device which could warn of a potential fire. In theory, the combinational smoke detector that was produced can
still be a possibility for products in the future and can be made with a few changes in the process of getting to that point.

A suggestion for better results of the experimental detector is to have a specially made box just for the project. The box design in this project seemed to work fairly well; however, better results may have been concluded if there was improved smoke flow through the chamber. There was also the opportunity for light from outside sources to penetrate inside and affect the output of the photoelectric sensor. This additional light could change smoke obscuration values based on were the detector was located.

One problem that was seen with the circuitry of the device is that it is not 100 percent efficient in its energy consumption. There were far too many components in the device which draw current and therefore are endangering the battery life of the product. The device was built just as an initial testing element, so the long life when connected to a battery was not of great concern. There are certainly multiple changes that could be made to improve the life of a battery in the device. One major change would include how voltage is distributed to the LED’s that signal the device is in alarm. Currently, the LED’s are triggered by outputs from the comparators that are in alarm which are then combined with the other outputs which may not be in alarm. This combination through 1K ohm resistors can reduce the voltage to an LED to fewer than three volts. This will light up the LED, but may do so in a very light and faded fashion. Consequently, it would be more beneficial if an on/off switch using transistors was utilized to trigger the LED’s.

If any further research is to be completed for this project, it is highly suggested that a printed circuit board be made in place of the current protoboard which the circuit is currently
built on. This advancement in the device would allow for more free space inside the device and would take care of most of the headaches that go along with a long soldering process. In building the detector, a majority of the time was spent putting the whole circuit together rather than designing it. This could have been avoided by creating a printed circuit board where all the circuitry would already be built into the board. However, for this project, it was not the best option since different sensors and different configurations were being tested before making a final product. Once a final circuit design is completed that includes more in depth sensor analysis and less power consumption it would be feasible to design it into a printed circuit board.

The sensors used in this project seem to have been reliable and effective. There were no problems discovered with the thermocouple. This sensor worked as it was expected every time it was used. The smoke obscuration sensor seemed to work fairly well too. There had been problems were the initial output would saturate down to a steady level after about 1 minute. This was never too strongly looked into since it did eventually reach a steady value and could be used from that point on. The carbon monoxide sensor was also an effective device. This sensor when used with the provided circuit worked almost all of the time. Although, it is encouraged to short out the sensor when not in use because it may be ineffective if the device is left off for a long period of time. This is believed to be caused by stray voltage interacting with the carbon monoxide sensor from the other sensors so that they could be added to each other. Overall, the sensors seemed like good choices for the design of this detector because they did give reliable outputs when working as a singular sensor.

Another recommendation for making this project successful would be to just use the carbon monoxide sensor and the smoke obscuration sensor. The thermocouple as a temperature
sensor was used primarily as a safe guard in this project in case the smoke obscuration and carbon monoxide sensors did not already detect a fire. This would limit the total number of combination to three instead of the seven needed for the three sensors. Using three combinations means that only one comparator chip would have to be used and all the wiring needed for the thermocouple could be eliminated. That leaves more room for adding circuitry on the protoboard and also saves on the power consumption from the additional chips not in use.

The design of the final device turned out not to be so effective. Although in Multisim the circuit worked and probably would have if those were the only electrical parameters. However, the adding of the circuits was not an effective way of doing so. The signals had each been passed through a 1K ohm resistor then combined. Multisim reported that the voltages would add up then divide by two to get the voltage on the other side. This was not seen as the case when the circuit was being built and thresholds had to be matched. There was also the output to the LED for a warning signal. The datasheet of the comparator recommended using a 3K ohm resistor to draw out the proper voltage and this worked in Multisim as well. When this was designed on the circuit board with many other functions going on at the same time, the output voltages didn’t add up correctly and there just was not enough power at time to light up particular LED’s if other ones were already on. The circuit also became extremely large for the board that is was built on. There may have been too many components used in the end which lead to the lack of power and lack of space. If a smaller device design could be made then that would be beneficial to a successful project.
The testing of the product probably would have gone a lot better if the final device had been completely functional. Instead scattered results came from the testing that no real conclusion can be drawn from.

The project had the potential and was on track to produce a highly effective product until the final stages of the design circuit were implemented. This slowed the project down and was never able to recover from it. It may have been a better project if one person had been working on the thresholds and sensor while another had worked on the output circuitry. Combining the two components at the end would have made for a successful project.
8. Appendix

Lab Test Results not shown in Report

11/14/08

2/6/09
Smoke Obscuration Comparison # 3

Device Smoke Obscuration Output (V)

Device Smoke Obscuration

Cone Calorimeter Smoke Obscuration

Time (S)

Device Smoke Obscuration On/off

Device Output (V)

Time (S)
9. Specifications Sheets

9.1. Carbon Monoxide Sensor
Technical Information for TGS5042

Figaro’s TGS5042 is a battery operable electrochemical sensor which offers several advantages over traditional electrochemical sensors. It is environmentally friendly, it poses no risk of electrolyte leakage, can detect concentrations as high as 1% CO, operates in a range from -4°F and +70°C, and has lower sensitivity to interstellar gases. With a long life, good long term stability, and high accuracy, this sensor is the ideal choice for CO detectors with digital display. OEM customers will find individual sensors data printed on each sensor in bar code form, enabling users to skip the costly gas calibration process and allowing for individual sensor tracking. TGS5042 utilizes a standard AA battery-sized package.

Specifications

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IMPORTANT NOTE: OPERATING CONDITIONS IN WHICH FIGARO SENSORS ARE USED WILL VARY WITH EACH CUSTOMER'S SPECIFIC APPLICATIONS. FIGARO STRONGLY RECOMMENDS CONSULTING OUR TECHNICAL STAFF BEFORE DEPLOYING FIGARO SENSORS IN YOUR APPLICATION AND, IN PARTICULAR, WHEN CUSTOMER'S TARGET CASES ARE NOT LISTED HEREIN. FIGARO CANNOT ASSUME ANY RESPONSIBILITY FOR ANY USE OF ITS SENSORS IN A PRODUCT OR APPLICATION FOR WHICH SENSOR HAS NOT BEEN SPECIFICALLY TESTED BY FIGARO.

TGS5042 is a UL recognized component in accordance with the requirements of UL2034. Please note that component recognition testing has confirmed long term stability in 12ppm of carbon monoxide. Other characteristics shown in this brochure have not been confirmed by UL as part of component recognition.

Keith Flanders
Worcester Polytechnic Institute
1. Specifications

1-1 Features

- Battery operable
- High repeatability/selectivity to carbon monoxide
- Linear relationship between CO gas concentration and sensor output
- Simple calibration
- Long life
- UL recognized component
- Meets UL2034, EN50291, and RoHS requirements

1-2 Applications

- Residential and commercial CO detectors
- CO monitors for industrial applications
- Ventilation control for indoor parking garages
- Recreational vehicle CO detectors
- Marine CO detectors
- Fire detection

1-3 Structure

Figure 1 shows the structure of TGS5042. The gas sensing layer is sandwiched between a stainless steel washer (counter electrode) and a stainless steel cap (working electrode), together with gas diffusion control stainless film and backing layers. This assembly is placed in the compartment of the stainless steel can. Water is stored in the bottom compartment and a charcoal filter is installed inside the stainless steel cap.

1-4 Basic measuring circuit

Figure 2 shows the basic measuring circuit of TGS5042. The sensor generates a minute electric current which is converted into sensor output voltage (Vout) by an op-amp/resistor (R4) combination.

Figure 2 - Basic measuring circuit (Including equivalent circuit)

Fischer recommends the following electrical parts:

R1 : 1MΩ
C1 : 22μF
IC : AD708

An additional resistor or FEF is required to prevent polarization of the sensor when circuit voltage is off.

NOTE: When voltage is applied to the sensor output terminal, the sensor may be damaged. Voltage applied to the sensor should be strictly limited to less than ±10mV.

1-5 Operating conditions & specifications (Table 1)

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model number</td>
<td>TGS 5042</td>
</tr>
<tr>
<td>Target gases</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>Typical detection range</td>
<td>0 – 10,000 ppm</td>
</tr>
<tr>
<td>Output current in CO</td>
<td>1.2–2.4mA ppm</td>
</tr>
<tr>
<td>Baseline offset (%)</td>
<td>±10ppm equivalent</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>10°C – +60°C (continuous)</td>
</tr>
<tr>
<td>Operating humidity</td>
<td>5 – 95%RH (no condensation)</td>
</tr>
<tr>
<td>Storage conditions</td>
<td>10°C – +60°C (continuous)</td>
</tr>
<tr>
<td>Weight</td>
<td>approx. 12g</td>
</tr>
<tr>
<td>Standard test conditions</td>
<td>20±2°C, 40±10%RH</td>
</tr>
</tbody>
</table>

NOTE 1: Sensor output is air under operating conditions

Table 1 - Operating conditions and specifications
1-6 Mechanical strength
The sensor shall have no abnormal findings in
its structure and shall satisfy the above electrical
specifications after the following performance tests:

Withstand force -
withstand force of 10kg (cap from metal can) along
a vertical axis.

Vibration - frequency--10-500Hz (equiv. to 10G),
duration - 6 hours, x-y-z direction

Shock - acceleration-100G, repeat 5 times.

1-7 Dimensions (see Fig. 3)

![Diagram of the sensor showing top, side, and bottom views.](image)

Note: The sensor can be supplied with leads. Please refer to the Appendix for details.

Figure 3 - Dimensions

All sensor characteristics shown in this brochure represent typical characteristics. Actual characteristics
vary from sensor to sensor and from production lot to production lot. The only characteristics warranted
are those shown in the Specification.
2. Operation Principle
The electrolyte of TGS5042 is a very low concentration of mixed/prepared alkaline electrolyte consisting of KOH, KHCO₃, and K₂CO₃. The mixed alkaline electrolyte acts as a buffer solution with a pH value maintained between 7~10. When CO passes through the backing layer and reaches to the working electrode, electrons are generated resulting from the reaction between CO and anions in the electrolyte such as OH⁻, HCO₃⁻, and CO₃²⁻ (see equations 1a~1c). By creating a short circuit between the working and counter electrodes with external wiring, electrons move to the counter electrode through the external wiring. At that point, the consumed anions in the electrolyte at the working electrode are replenished and move to the electrolyte by the reaction of CO₂, water, and electrons as shown in equations 2a~2c. The total reaction is expressed as shown in equation 3.

A linear relationship exists between the sensor’s electric current and CO concentration (see equation 4). By calibrating the sensor with a known concentration of CO gas, the output current of the sensor can then be used to quantitatively determine CO concentration.

Since, unlike conventional dry batteries, there is no consumption of active materials or of the electrodes, TGS5042 possesses excellent long-term stability for its output signal and enables maintenance-free operation. Furthermore, the sensor’s self-generating output current makes it ideal for usage in battery-operated CO detectors.

Working electrode (Anodic reaction)
\[
\begin{align*}
\text{CO} + 2\text{OH}^- & \rightarrow \text{CO}_2 + \text{H}_2\text{O} + 2\text{e}^- & (\text{equation 1a}) \\
\text{CO} + 2\text{HCO}_3^- & \rightarrow 3\text{CO}_2 + \text{H}_2\text{O} + 2\text{e}^- & (\text{equation 1b}) \\
\text{CO} + \text{CO}_3^{2-} & \rightarrow 2\text{CO}_2 + 2\text{e}^- & (\text{equation 1c})
\end{align*}
\]

Counter electrode (Cathodic reaction)
\[
\begin{align*}
1/2\text{O}_2 + \text{H}_2\text{O} + 2\text{e}^- & \rightarrow \text{OH}^- & (\text{equation 2a}) \\
1/2\text{O}_2 + 2\text{CO}_2 + \text{H}_2\text{O} + 2\text{e}^- & \rightarrow 2\text{HCO}_3^- & (\text{equation 2b}) \\
1/2\text{O}_2 + \text{CO}_2 + 2\text{e}^- & \rightarrow \text{CO}_3^{2-} & (\text{equation 2c})
\end{align*}
\]

Total reaction
\[
\text{CO} + 1/2 \text{O}_2 \rightarrow \text{CO}_2 \quad (\text{equation 3})
\]

Theoretical output current value
\[
I = \frac{F \times (A / \sigma) \times D \times C \times n}{0.000896} \quad (\text{equation 4})
\]

where:
- F: Faraday constant
- A: Surface area of diffusion film
- D: Gas diffusion co-efficient
- C: Gas concentration
- \( \sigma \): Thickness of diffusion film
- n: Number of reaction electrons

Figure 4 - Operation principle

Figure 5 - Schematic diagram of TGS5042 operating principle
3. Basic Sensitivity Characteristics

3-1. Sensitivity to various gases

Figure 6 shows the sensor's sensitivity to various gases. The Y-axis shows output current (Iout / μA) in each gas. The output current is linear to CO concentration, with a deviation of less than ±5% in the range of 0-500 ppm. Cross sensitivity data for other gases than those in Figure 6 are tabulated in Table Y.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Concentration</th>
<th>CO equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1000ppm</td>
<td>&lt;50ppm</td>
</tr>
<tr>
<td>Methane</td>
<td>Measured</td>
<td>&lt;30ppm</td>
</tr>
<tr>
<td>Butane</td>
<td>1000ppm</td>
<td>&lt;30ppm</td>
</tr>
<tr>
<td>Br2</td>
<td>Measured</td>
<td>&lt;30ppm</td>
</tr>
<tr>
<td>HMDS (Si vapor)</td>
<td>Methyl</td>
<td>&lt;30ppm</td>
</tr>
<tr>
<td>Toluene</td>
<td>Ethylene</td>
<td>&lt;30ppm</td>
</tr>
<tr>
<td>NO2</td>
<td>Hexane</td>
<td>&lt;30ppm</td>
</tr>
<tr>
<td>Benzene chloride</td>
<td>CO2</td>
<td>&lt;30ppm</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>NH3</td>
<td>200ppm</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>SO2</td>
<td>200ppm</td>
</tr>
<tr>
<td>CH3COOH</td>
<td>Ethyl acetate</td>
<td>200ppm</td>
</tr>
</tbody>
</table>

Table Y: Cross sensitivity (using charcoal filter)

Note: The figures in this table are typical values and should not be used as a basis for cross calibration. Cross sensitivity for various gases may not be linear and should not be scaled. All data based on a 4 minute exposure. For some gases, filter saturation and gas breakthrough may occur if gas is applied for a longer time period.

3-2. Temperature and humidity dependency

Figure 7a shows the temperature dependency of TGS5042 under a constant humidity of 50% RH. The Y-axis shows the ratio of output current in 400ppm of CO at various temperatures (I) to the output current in 400ppm of CO at 20°C / 50% RH (Io). Temperature dependency is based on the difference in the catalytic reaction rate on the electrodes, and it can be simply compensated by utilizing a thermistor. The data display that even at -40°C (where water in the water reservoir is frozen), the sensor has sufficient CO sensitivity. This linear relationship between I/Io and CO concentration is constant regardless of CO concentration range, according to the sensor's operating principle.

Figure 7b shows the humidity dependency of TGS5042 under constant temperatures of 20°C and 40°C. The Y-axis shows the ratio of output current in 400ppm of CO at various relative humidities (I) to the output current in 400ppm of CO at 20°C / 50% RH (Io). This data demonstrates that humidity dependency is negligible as temperature varies.
3-3 Gas response pattern

Figure 8 shows the gas response pattern of the output signal when the sensor is placed into 30, 70, 150 and 400ppm of CO and then returned to normal air. The response time to 50% of the saturated signal level is within 60 seconds, and the recovery of the signal back to 90% of the base level is within 120 seconds. This data demonstrates that TGS5042 possesses sufficient response speed for meeting UL requirements for CO detectors.

3-4 Repeatability

Figure 9 shows the pattern of the output signal when the sensor is repeatedly exposed to 400ppm of CO at a constant interval of 240 seconds. The data demonstrates extremely high reproducibility of the output signal, the deviation being less than 2.5%.

3-5 Influence of storage

Figure 10 shows the initial action of the sensor’s output current signal in fresh air. For the purpose of this test, sensors were stored for more than six months under two separate conditions between the working and counter electrodes: in short-circuited condition, and in open-circuited condition. The chart illustrates the behavior of sensor output current for each group just after installation into the operating circuit. The output current signal of sensors stored in a short-circuited condition reaches its saturated level quickly, while those stored with an open-circuit exhibit much slower behavior. For this reason, TGS5042 is shipped in a short-circuited form which should be maintained just prior to assembling the sensor into a device.
3-6 Normal operation test

Figure 11a shows the result of the "Normal Operation Test" required by UL2034, Sec. 35.3 where the sensor is exposed to 600ppm of CO for 12 hours at 20°C/40%RH. Stable output current signal can be seen throughout the exposure.

In addition, Figure 11b shows the CO sensitivity characteristics of the sensor before, during, and after the Normal Operation Test, demonstrating that TGS5042 is hardly influenced by exposure to high concentrations of CO.

3-7 Sensitivity test

Figure 12a shows the results of the "Sensitivity Test" as required by UL2034, Sec. 38. Under this test, the sensor was exposed to 30, 70, 150 and 400ppm of CO at 20°C/40%RH. The period of exposure was varied by concentration, corresponding with the maximum time in which a CO detector should generate an alarm for the subject concentration. Throughout the test exposures, TGS5042 displayed a reasonable and stable output current signal.
In addition, Figure 12b indicates the CO sensitivity characteristics of the sensor before, during, and after the Sensitivity Test, demonstrating the excellent reproducibility of TGS5042’s CO sensitivity characteristics.

4. Reliability

Tests conducted in this section demonstrate that TGS5042 can meet the requirements of various testing standards without incurring adverse long term effects from such tests.

4.1 Interference gas test

Figure 13a shows the results of testing the TGS5042 sensor for durability against various interference gases as specified by UL2034, Sec. 39. The test was conducted by exposing the sensor to each gas shown in Figure 13a (starting with CO 30ppm) for two hours, then removing the sensor to fresh air for just one hour, and followed by inserting the sensor into the next gas. This procedure was repeated for the full range of gases shown in Figure 13a.

Because the sensor is exposed to each of the test gases consecutively, to some small extent the effect of the previous test gas may affect subsequent tests for a short period. However, despite the short-term effects of such gases remaining after exposure, the sensor still shows significantly less sensitivity to each test gas when compared to 30ppm of CO, and CO sensitivity remains unaffected.

In addition, Figure 13b shows the CO sensitivity characteristics of the sensor before and after this test, further demonstrating the excellent reproducibility of the CO sensitivity characteristics of TGS5042, demonstrating its durability against the interference gases listed in the requirements of UL2034, Sec. 39.
4-2 Long-term stability

Figure 14 shows long-term stability data for TG5042. Test samples were stored in natural clean air under a short-circuit condition and measured at various intervals as dictated by the standard test conditions of UL2034, Sec. 38. The Y-axis shows the ratio of output current in 300ppm of CO at any point in time (I) over output current in 300ppm of CO on the first day of the test (I0). This chart demonstrates very stable characteristics with negligible variation of less than ±5% for more than 900 days.

4-3 Corrosion test

To demonstrate the durability of TG5042 against corrosion, samples were subjected to test conditions called for by UL2034, Sec.58-Corrosion Test. Over a three-week period, a mixture of 100ppb of H2S, 20ppb of Cl2, and 200ppb of NO2 was supplied to the sensors at a rate sufficient to achieve an air exchange rate of five times per hour. Figure 15 shows the CO sensitivity characteristics before and after exposure in the above conditions, demonstrating that TG5042 is hardly influenced by such corrosive gases. In addition, the sensor’s stainless steel housing did not show any sign of corrosion as a result of this test.

4-4 Variable ambient temperature test

To demonstrate the ability of TG5042 to withstand the effects of high and low temperature, the “Variable Ambient Temperature Test” of UL2034, Sec. 45 was conducted.

(1) Operation in high and low temperature test

Figure 16a shows the results for the “Operation in High and Low Temperature Test” of UL2034, Sec. 45.1. The sensor was exposed to environments of 0°C/15%RH and 49°C/40%RH for at least three hours each, with measurements taken before and during the exposure in accordance with the test conditions of UL2034, Sec. 38. By plotting the output current values from these test measurements atop the data taken prior to this test at a constant 50%RH (representing standard temperature dependency), it can be seen that the test data are still in line with data taken at a constant RH. The conclusion which can be drawn is that, regardless of exposure to extremes of temperature and humidity, the sensor’s output is not affected by humidity. As a result, TG5042 can meet the requirements of UL2034, Sec. 45.1 by utilizing a simple temperature compensation method.
(2) Effect of shipping and storage

To verify the effects of shipping and storage, the sensor was tested under the conditions of UL2034, Sec. 45.2. Test samples in a short-circuited condition were subjected to 70°C for 24 hours, allowed to cool to room temperature for 1 hour, subjected to -40°C for 3 hours, and then allowed to warm up to room temperature for 3 hours. Figure 16b shows the CO sensitivity characteristics before and after the test, demonstrating that TGS5042 meets the requirement of UL2034, Sec. 45.2.

4-5 Humidity test

Figure 17a shows the results of testing the sensor under UL2034, Sec. 46A. The sensor was exposed in an atmosphere of 52±3°C/95±4%RH for a period of 168 hours, returned to normal air for 2 days, then followed by 168 hours exposure at 22±3°C/10±3%RH. The data demonstrates the stable characteristics in both low and high humidity conditions.

Figure 17b shows data taken prior to the above test at a constant relative humidity of 50%. These curves represent the typical temperature dependency of the sensor. When plotting measurements taken at the environmental extremes specified on UL2034, Sec. 46A (52±3°C/95±4%RH and 22±3°C/10±3%RH) onto the temperature dependency curves, it can be seen that measurements taken at these extreme conditions still fall in line with the temperature dependency curve derived prior to testing. The conclusion which can be drawn is that, regardless of exposure to extremes of temperature and humidity, the sensor's output is not affected by humidity. As a result, TGS5042 can meet the requirements of UL2034, Sec. 46A by utilizing a simple temperature compensation method.
4-6 Stability test

(1) False alarm test

To show the sensor’s behavior under continuous low level exposure to CO, samples were tested against the procedure detailed in UL2034, Sec. 41.1(c)-Stability Test. Test samples were exposed to 30ppm of CO continuously for a period of 30 days under standard circuit conditions. Figure 18 shows the CO sensitivity characteristics before and after the exposure test, demonstrating that detectors using TGS5042 will not give a false alarm as a result of continuous low level CO exposure.

![Figure 18 - False alarm test](image)

(2) Temperature cycle test

In accordance with UL2034, Sec. 41.1(e)-Stability Test, test samples were exposed to ten cycles (≤1 hour and >15 minutes) of temperature from 0°C/100%RH to 49°C/40%RH. Figure 19 shows CO sensitivity characteristics before and after the cycle test, demonstrating that TGS5042 is hardly influenced by the extreme conditions of the temperature cycle test.

![Figure 19 - Temperature cycle test](image)

4-7 Sequential test

In UL2034, Sec. 41.3, a single lot of sample detectors are to be subjected to the following sequence of tests: Section 38, Section 41.1, Section 39, Section 45, and Section 46A. While TGS5042 meets the requirements of each of these test individually (as shown elsewhere in this brochure), this test is designed to demonstrate the sensor’s ability to withstand all of these tests when conducted in sequence. Figure 20 shows the results of sequentially testing the same lot of sensors. The good stability of the sensor’s output signal indicates that TGS5042 can satisfy the requirements of UL2034, Sec. 41.3-Sequential Test.

![Figure 20 - Sequential test](image)
4-3 Dust test
To judge the effect of dust contamination on TGS5042, approximately 2 ounces (0.06 kg) of cement dust, capable of passing through a 200 mesh screen, was circulated for 1 hour by means of a blower, enveloping the sensor in the test chamber. Air flow was maintained at an air velocity of approximately 50 fpm (0.25 m/s) at 20°C/40%RH.

Figure 21 shows the sensor’s CO sensitivity characteristics before and after the dust exposure test. This data demonstrates that the dust test of UL2034, Sec. 53 has a negligible effect on CO sensitivity.

4-9 Water loss test
For evaluating the life expectancy of TGS5042 from the viewpoint of its water reservoir (which prevents the electrolyte from drying up), the weight loss of TGS5042 was periodically measured when stored at 20°C/50%RH, 50°C/10%RH and 70°C/5%RH respectively. Figure 22 demonstrates that the sensor’s weight decreased linearly with time due to evaporation of the water. The rate of water loss under various temperature was related with the water vapor pressure at each temperature. According to calculations based on this rate of water loss and the difference in water vapor pressure in 20°C, 50°C and 70°C, the water (~4g initially) will last more than 7 years under natural residential conditions such as 20°C/40%RH.

5. Marking
The TGS5042 comes with a sticker attached to the sensor housing which contains important information. The two dimensional bar code contains information in the following 28-digit format:
Format: XXXXZZZZZZZZmmnmnmnmmnnunppppY
where: XXXX = current value (nA / ppm)
ZZZZZmmnmnmnmmnnunpppp = serial number
(for internal tracking purpose in production and testing)
The one dimensional bar code indicates the sensor’s sensitivity (slope) in numeric value as determined by measuring the sensor’s output in 300 ppm of CO.

XXXX = XXXX nA / ppm

In user readable format, the sensor’s Lot Number is printed below the two dimensional bar code (4ymmda), and the sensor’s sensitivity per ppm (nA) is printed below the one dimensional bar code. Please note that three decimal places should be added to the sensitivity reading (e.g. 1.027 should be read as 1.027 nA / ppm).
6. Notes

The following cautions regarding storage and installation of TG5042 should be observed to prevent permanent damage to the sensor:

1) Install/store indoors, avoiding dew condensation, silicone vapor, and exposure to alkaline metals (Na, Li, etc.)
2) Avoid places where vibration or mechanical shock may occur.
3) Do not store in high humidity or temperature conditions.
4) Store and ship in a short-circuited form.
5) This sensor requires the existence of oxygen in the operating environment to function properly and to exhibit the characteristics described in this brochure. The sensor will not operate properly in a zero oxygen environment.

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Keith Flanders 70 Worcester Polytechnic Institute
APPENDIX
TGS5042 Lead Configurations

Leads are connected to sensor electrodes when the sensors are shipped. There are two lead configurations available:

- A00: Stainless steel (SUS) pin version
- B00: Flexible nickel ribbon version

When ordering, please be sure to specify the lead configuration. Please refer to Figure 24 on Page 15 for sensor dimensions on each model.

TGS5042-A00
Stainless steel (SUS) pin version
The solid SUS pins of the A00 version enable the sensor to be more easily mounted and/or directly soldered onto a PCB.

Mechanical strength:
Withstand force - 6kg along a vertical axis (lead from metal can)
Vibration - frequency--10~500Hz (equiv. to 10G)
  duration--6 hours
  direction--x - y - z
Shock - acceleration of 100G, repeat 5 times

TGS5042-B00
Flexible nickel ribbon version
For applications where there is insufficient space for mounting TGS5042-A00, such as in portable CO monitors, the TGS5042-B00 is a suitable alternative. This model can also be directly soldered onto a PCB.

Mechanical strength:
Withstand force - 1.5kg along a vertical axis (metal ribbon from metal can)
Vibration - frequency--10~500Hz (equiv. to 10G)
  duration--6 hours
  direction--x - y - z
Shock - acceleration of 100G, repeat 5 times

NOTE: The nickel ribbon leads are provided for the purpose of electrical connection and should not be used for affixing the sensor to a PCB. To secure the sensor and prevent disconnection of the leads, affix the sensor to a PCB using wire, two-sided tape, or other appropriate measures. When the sensor is shipped, the working electrode and counter electrode are connected (i.e. short circuited) by a spring in order to avoid polarization of the electrodes. To measure sensor output, the spring should be removed and the sensor connected to a measuring circuit. The cutting point as indicated can be used to cut the ribbon easily.
APPENDIX (cont.)

Figure 23 - TGS5042 Dimensions (lead configurations)
9.2. Photodiode
Silicon PIN Photodiode

Description
BPV22NF(L) is a high speed and high sensitive PIN photodiode in a plastic package with a spherical side view lens. The epoxy package itself is an IR filter, spectrally matched to GaAs on GaAs and GaAlAs on GaAlAs IR emitters ($\lambda_p = 950 \text{ nm, } S_{950} = 875 \text{ nm} > 90 \%$). Lens radius and chip position are perfectly matched to the chip size, giving high sensitivity without compromising the viewing angle. In comparison with flat packages the spherical lens package achieves a sensitivity improvement of 60%.

Features
- Large radiant sensitive area ($A=7.5 \text{ mm}^2$)
- Wide viewing angle $\theta = 60^\circ$
- Improved sensitivity
- Fast response times
- Low junction capacitance
- Plastic package with universal IR filter
- Optional "L", long lead package optional available with suffix "L", e.g.: BPV23FL

Applications
Infrared remote control and free air transmission systems in combination with IR emitter diodes (TSU-, TSL-, or TS1-Series). High sensitivity detector for high data rate transmission systems. The IR filter matches perfectly to the high speed infrared emitters in the 830 nm to 880 nm wavelength range.

Absolute Maximum Ratings
$T_{a,\text{mb}} = 25 ^\circ \text{C}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Voltage</td>
<td>$T_{a,\text{mb}} = 25 ^\circ \text{C}$</td>
<td>$V_R$</td>
<td>60</td>
<td>V</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>$T_{a,\text{mb}} = 25 ^\circ \text{C}$</td>
<td>$P_V$</td>
<td>215</td>
<td>mW</td>
</tr>
<tr>
<td>Junction Temperature</td>
<td>$T_J$</td>
<td></td>
<td>100</td>
<td>°C</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>$T_{a,\text{mb}}$</td>
<td>$T_{op}$</td>
<td>-55...+100</td>
<td>°C</td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>$T_{a,\text{mb}}$</td>
<td>$T_{st}$</td>
<td>250</td>
<td>°C</td>
</tr>
<tr>
<td>Soldering Temperature</td>
<td>$t = 5 \text{ s}$</td>
<td>$T_{sd}$</td>
<td>350</td>
<td>KW</td>
</tr>
<tr>
<td>Thermal Resistance Junction/Ambient</td>
<td></td>
<td>$R_{\text{thJA}}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### BPV22NF(L)

**Vishay Telefunken**

**Basic Characteristics**

$T_{\text{amb}} = 25^\circ C$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward Voltage</td>
<td>$I_F = 50$ mA</td>
<td>$V_F$</td>
<td>1</td>
<td>1.3</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Breakdown Voltage</td>
<td>$I_R = 100$ $\mu$A, $E = 0$</td>
<td>$V_{(R)\text{B}}$</td>
<td>60</td>
<td></td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Reverse Dark Current</td>
<td>$V_R = 10$ V, $E = 0$</td>
<td>$I_{D}$</td>
<td>2</td>
<td>30</td>
<td></td>
<td>$\mu$A</td>
</tr>
<tr>
<td>Diode Capacitance</td>
<td>$C_D = \frac{1}{2\pi f C}$, $E = 0$</td>
<td>$C_D$</td>
<td>70</td>
<td></td>
<td></td>
<td>pF</td>
</tr>
<tr>
<td>Serial Resistance</td>
<td>$R_S = \frac{V_R}{I_{D}}$</td>
<td>$R_S$</td>
<td>400</td>
<td></td>
<td></td>
<td>$\Omega$</td>
</tr>
<tr>
<td>Open Circuit Voltage</td>
<td>$E_a = 1$ mW/cm$^2$, $\lambda = 950$ nm</td>
<td>$V_a$</td>
<td>370</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td>Temp. Coefficient of $V_a$</td>
<td>$E_a = 1$ mW/cm$^2$, $\lambda = 950$ nm</td>
<td>$T_{V_a}$</td>
<td>-2.6</td>
<td></td>
<td></td>
<td>mV/K</td>
</tr>
<tr>
<td>Short Circuit Current</td>
<td>$E_a = 1$ mW/cm$^2$, $\lambda = 950$ nm</td>
<td>$I_k$</td>
<td>80</td>
<td></td>
<td></td>
<td>$\mu$A</td>
</tr>
<tr>
<td>Reverse Light Current</td>
<td>$E_a = 1$ mW/cm$^2$, $\lambda = 950$ nm</td>
<td>$I_R$</td>
<td>55</td>
<td>85</td>
<td></td>
<td>$\mu$A</td>
</tr>
<tr>
<td>Temp. Coefficient of $I_R$</td>
<td>$E_a = 1$ mW/cm$^2$, $\lambda = 950$ nm</td>
<td>$T_{I_R}$</td>
<td>0.1</td>
<td></td>
<td></td>
<td>%/K</td>
</tr>
<tr>
<td>Absolute Spectral Sensitivity</td>
<td>$s(\lambda)$</td>
<td>$s(\lambda)$</td>
<td>0.57</td>
<td></td>
<td></td>
<td>A/W</td>
</tr>
<tr>
<td>Angle of Half Sensitivity</td>
<td>$\varphi$</td>
<td>$\varphi$</td>
<td>560</td>
<td></td>
<td></td>
<td>deg</td>
</tr>
<tr>
<td>Wavelength of Peak Sensitivity</td>
<td>$\lambda_p$</td>
<td>$\lambda_p$</td>
<td>940</td>
<td></td>
<td></td>
<td>nm</td>
</tr>
<tr>
<td>Range of Spectral Bandwidth</td>
<td>$\lambda_{1-2}$</td>
<td>$\lambda_{1-2}$</td>
<td>790-1050</td>
<td></td>
<td></td>
<td>nm</td>
</tr>
<tr>
<td>Quantum Efficiency</td>
<td>$\eta$</td>
<td>$\eta$</td>
<td>90</td>
<td></td>
<td></td>
<td>%</td>
</tr>
<tr>
<td>Noise Equivalent Power</td>
<td>$V_R = 10$ V, $\lambda = 950$ nm</td>
<td>$\text{NEP}$</td>
<td>$4 \times 10^{-14}$</td>
<td></td>
<td></td>
<td>W/nm</td>
</tr>
<tr>
<td>Detectivity</td>
<td>$V_R = 10$ V, $\lambda = 950$ nm</td>
<td>$D'$</td>
<td>$6 \times 10^{12}$</td>
<td></td>
<td></td>
<td>cm$^2$/Hz/W</td>
</tr>
<tr>
<td>Rise Time</td>
<td>$V_R = 10$ V, $R_C = 1$ k$\Omega$, $\lambda = 820$ nm</td>
<td>$t_r$</td>
<td>100</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Fall Time</td>
<td>$V_R = 10$ V, $R_C = 1$ k$\Omega$, $\lambda = 820$ nm</td>
<td>$t_f$</td>
<td>100</td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Cut–Off Frequency</td>
<td>$V_R = 12$ V, $R_C = 1$ k$\Omega$, $\lambda = 870$ nm</td>
<td>$f_c$</td>
<td>4</td>
<td></td>
<td></td>
<td>MHz</td>
</tr>
<tr>
<td></td>
<td>$V_R = 12$ V, $R_C = 1$ k$\Omega$, $\lambda = 950$ nm</td>
<td>$f_c$</td>
<td>1</td>
<td></td>
<td></td>
<td>MHz</td>
</tr>
</tbody>
</table>
**BPV22NF(L)**

**Vishay Telefunken**

**Typical Characteristics** *(\(T_{\text{amb}} = 25^\circ\text{C} \text{ unless otherwise specified})**

![Graph 1: Reverse Dark Current vs. Ambient Temperature](image1)

![Graph 2: Relative Reverse Light Current vs. Ambient Temperature](image2)

![Graph 3: Reverse Light Current vs. Irradiance](image3)

![Graph 4: Reverse Light Current vs. Reverse Voltage](image4)

![Graph 5: Diode Capacitance vs. Reverse Voltage](image5)

![Graph 6: Relative Spectral Sensitivity vs. Wavelength](image6)
Dimensions BPV22NFL in mm

BPV22NF(L)
Vishay Telefunken

2.54 nom.

0.75 ± 0.12

3.2 ± 0.2

6.0 ± 0.3

3.4 ± 0.1

0.4 ± 0.1

5 ± 0.3

1.1 ± 0.2

2.5 ± 0.15

10.6 ± 0.2

4.5 ± 0.2

3.15 ± 0.5
BPV22NF(L)  
Vishay Telefunken

Ozone Depleting Substances Policy Statement

It is the policy of Vishay Semiconductor GmbH to

1. Meet all present and future national and international statutory requirements.

2. Regularly and continuously improve the performance of our products, processes, distribution and operating systems with respect to their impact on the health and safety of our employees and the public, as well as their impact on the environment.

It is particular concern to control or eliminate releases of those substances into the atmosphere which are known as ozone depleting substances (ODSs).

The Montreal Protocol (1987) and its London Amendments (1990) intend to severely restrict the use of ODSs and forbid their use within the next ten years. Various national and international initiatives are pressing for an earlier ban on these substances.

Vishay Semiconductor GmbH has been able to use its policy of continuous improvements to eliminate the use of ODSs listed in the following documents:


2. Class I and II ozone depleting substances in the Clean Air Act Amendments of 1990 by the Environmental Protection Agency (EPA) in the USA


Vishay Semiconductor GmbH can certify that our semiconductors are not manufactured with ozone depleting substances and do not contain such substances.

We reserve the right to make changes to improve technical design and may do so without further notice.

Parameters can vary in different applications. All operating parameters must be validated for each customer application by the customer. Should the buyer use Vishay-Telefunken products for any unintended or unauthorized application, the buyer shall indemnify Vishay-Telefunken against all claims, costs, damages, and expenses, arising out of, directly or indirectly, any claim of personal damage, injury or death associated with such unintended or unauthorized use.

Vishay Semiconductor GmbH, P.O.B. 3535, D-74025 Heilbronn, Germany
Telephone: 49 (0)7131 67 2831, Fax number: 49 (0)7131 67 2423
9.3. Infrared LED

PLASTIC INFRARED LIGHT EMITTING DIODE

QEE113

DESCRIPTION
The QEE113 is a 940 nm GaAs LED encapsulated in a medium wide angle, plastic side socket package.

FEATURES
- \( \lambda = 940 \) nm
- Package Type = Side socket
- Chip Material = GaAs
- Matched Photosensor: QSE113
- Medium Wide Emission Angle, 50°
- Package Material: Clear Epoxy
- High Output Power
- Gray stripe on the top side
PLASTIC INFRARED LIGHT EMITTING DIODE

ABSOLUTE MAXIMUM RATINGS \( T_A = 25^\circ C \) unless otherwise specified

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Rating</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature</td>
<td>( T_{OPR} )</td>
<td>-40 to +100</td>
<td>(^\circ C)</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>( T_{STG} )</td>
<td>-40 to +100</td>
<td>(^\circ C)</td>
</tr>
<tr>
<td>Soldering Temperature (Iron)(^{(2,3,4)})</td>
<td>( T_{SOL-I} )</td>
<td>240 for 5 sec</td>
<td>(^\circ C)</td>
</tr>
<tr>
<td>Soldering Temperature (Flow)(^{(2,3)})</td>
<td>( T_{SOL-F} )</td>
<td>260 for 10 sec</td>
<td>(^\circ C)</td>
</tr>
<tr>
<td>Continuous Forward Current</td>
<td>( I_F )</td>
<td>50</td>
<td>mA</td>
</tr>
<tr>
<td>Reverse Voltage</td>
<td>( V_R )</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td>Power Dissipation(^{(1)})</td>
<td>( P_D )</td>
<td>100</td>
<td>mW</td>
</tr>
</tbody>
</table>

NOTES:
1. Derate power dissipation linearly 1.33 mW/\(^\circ C\) above 25\(^\circ C\).
2. RMA flux is recommended.
3. Methanol or isopropyl alcohols are recommended as cleaning agents.
4. Soldering iron 1/16" (1.6 mm) minimum from housing.

ELECTRICAL / OPTICAL CHARACTERISTICS \( T_A = 25^\circ C \)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Emission Wavelength</td>
<td>( I_F = 100 \text{ mA} )</td>
<td>( \lambda_{PE} )</td>
<td>—</td>
<td>940</td>
<td>—</td>
<td>nm</td>
</tr>
<tr>
<td>Emission Angle</td>
<td>( I_F = 100 \text{ mA} )</td>
<td>( \theta )</td>
<td>50</td>
<td>—</td>
<td>—</td>
<td>Deg.</td>
</tr>
<tr>
<td>Forward Voltage</td>
<td>( I_F = 100 \text{ mA}, t_p = 20 \text{ ms} )</td>
<td>( V_F )</td>
<td>—</td>
<td>—</td>
<td>1.5</td>
<td>V</td>
</tr>
<tr>
<td>Reverse Current</td>
<td>( V_R = 5 \text{ V} )</td>
<td>( I_R )</td>
<td>—</td>
<td>—</td>
<td>10</td>
<td>( \mu A )</td>
</tr>
<tr>
<td>Radiant Intensity</td>
<td>( I_F = 100 \text{ mA}, t_p = 20 \text{ ms} )</td>
<td>( I_E )</td>
<td>3</td>
<td>—</td>
<td>12</td>
<td>mW/sr</td>
</tr>
<tr>
<td>Rise Time</td>
<td>( I_F = 100 \text{ mA} )</td>
<td>( t_r )</td>
<td>—</td>
<td>1000</td>
<td>—</td>
<td>ns</td>
</tr>
<tr>
<td>Fall Time</td>
<td>( I_F = 100 \text{ mA} )</td>
<td>( t_f )</td>
<td>—</td>
<td>1000</td>
<td>—</td>
<td>ns</td>
</tr>
</tbody>
</table>
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2. A critical component in any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.
10. Bibliography

http://www.homedepot.com/webapp/wcs/stores/servlet/Search?keyword=smoke+detector&langId=-1&storeId=10051&catalogId=10053


http://www.me.utexas.edu/~ezekoye/rsch.dir/firesite/heat_detector.html


