Tyco International Ltd:
Enhanced Strobe Reflector

A Major Qualifying Project Report:
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Abstract

It is necessary to warn the hearing impaired in case of an emergency, however, each strobe light requires immense power and current. By maximizing the efficiency of the power input, it will be possible to connect more strobe lights to the fire protection system. To do this there is a need to find a working ray tracing program for testing, specify requirements for the new design, create a method of statistical analysis, and finally make a 3D model. According to the simulation results, about 40% of the power supplied to the fire alarm can be saved along with a 5% efficiency increase.

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Introduction

People who are hearing-impaired have the right to be adequately safeguarded by the fire alarm systems placed around them (Department of Justice, 2010). By attaching a strobe light to a noise producing fire alarm it gives the ability to warn those who are hearing-impaired. SimplexGrinnell, a company owned by Tyco International Ltd. makes such a fire alarm, TrueAlert®. (SimplexGrinnell, 2011) Around the world, fire alarms are geared towards saving the lives of those who are not hearing-impaired; the Americans with Disabilities Act (ADA) require that appropriate fire alarms must be located in all public buildings. (Federal Emergency Management Agency, 1999) With the needs of fire alarms including a visual warning signal, it is important to adapt the current fire alarms and make them more efficient.

To make the fire alarms acceptable world-wide, it is essential to make the strobe reflector more efficient. The current wall mount reflector used on the TrueAlert® fire alarms has not been updated or changed since 1998. While this reflector does meet all of the requirements from both Underwriters Laboratory (UL) 1971 and National Fire Protection Association (NFPA) 72; it still can be improved upon. It is our goal to design a new strobe reflector that will maximize the efficiency of the power input, while following the American requirement standards. To achieve this, we have made an objective list of what needs to be done: 1) Find a working ray tracing program for testing the current and final product, 2) Specify requirements for the new design, 3) Create a method of statistical analysis to help create a standard for all reflectors, and finally 4) Make a 3D model of our proposed design.

For each objective we will establish an organized plan in order to come up with the most appropriate design for Tyco. It is our hope that the outcome of this project will both supply Tyco with a new product, a standardized method for future reflects to be held up against, but to also be able to help more of those who are hearing-impaired. As the demands for equal rights are growing world-wide it is imperative to have equipment that can warn the masses for all emergency situations.

Background

Tyco International Ltd.

Tyco International Ltd. is a diversified global company with customers in more than 60 countries and in all 50 states. (Tyco International Ltd., 2011) They have three segments of business which include Security Solutions, Fire Protections, and Flow control. The business segment in which the strobe reflector falls under is the fire protection section. Under this segment the main focuses are: Special Hazard Fire Suppression, Water Fire Suppression, and Mechanical products. Their products range from electronic security and alarm monitoring to fire-fighting equipment and breathing apparatus'. (Tyco International Ltd., 2011) They also handle water purifications and flow control solutions.

Tyco International Ltd. was founded in 1960 by Arthur J. Rosenburg, Ph.D. who opened this company as a research laboratory to conduct experimental work for the U.S. government. (Tyco International Ltd., 2011) The focus of the company later turned into high-tech materials science and energy conversion products for the commercial sector in 1962.

TrueAlert®

A strobe light is a high powered device that puts a significant load on wires, power supplies and batteries of the fire alarm systems. The product, TrueAlert® is made with a xenon flash tube and a candela reflector available as a wall or ceiling mount, Fig.1. Currently the product measures the light in a horizontal plane from 0° to 180°. This is an arc that starts on the lefts side of the device and pivots from one end of the wall to the right side. The vertical plane also is tested by starting for the 90 ° point or also known as the center of the reflector descending down to the bottom of the floor, perpendicular to the 90°line since there is no need to test the amount of light on the ceiling. These planes create a “T” pattern by the juxtaposition of these two planes creating a horizontal and vertical arc.

Strobe lights currently require immense amount of power and current. Each strobe light requires about 24 Volts and 50 milliamps in one use. The reflector’s complexity is to steer the light into the specific areas that UL measures light intensity, Fig.2. Any of this light that is not steered into those areas does not get measure and is therefore “wasted”, according to Mr. A.J. Capowski. The more light that can be steered into those areas the higher the intensity and therefore lower the overall current draw of the appliance.

The current design was created through trial and error. After designing an initial reflector, using a point light source, the reflector was prototyped and tweaked upon the UL 1971 requirements. Tyco ran many tests to design their product. Their end result was a reflector that meets the requirements in some areas, and exceeds in others.

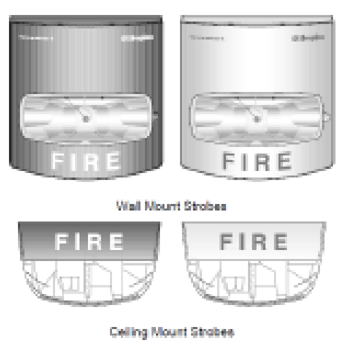

Figure 1: TrueAlert® fire alarms. For the purpose of this project, only the wall mount reflector will be redesigned.

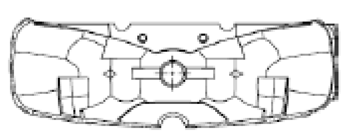

Figure 2: The current design of the reflector.

Test Requirements and Procedures

Part of this project it is required to follow the rules and regulations set forth by NFPA 72 and UL 1971. These rules and regulations must be met, as in accordance with the ADA. UL 1971 states that devices must be suitable for use in a controlled and uncontrolled environment depending on the products intent. The main purpose of the strobe reflector is that it must be able to alert occupants and or inhabitants in the protected area.

UL requirements designated to the strobe light itself states that it shall take the form of a flashing light, vibration, or air movement. The particular signaling unit must have two samples tested in the as-received condition. The minimum signal strengths shall meet a flash rate of no less than 1 Hz or no greater than 2 Hz. (Underwriters Laboratories, 2002) The candela light must be of a white light and at 0° there must have 100% dispersion at the center of the reflector.

NFPA 72 requires that the bottom of the reflector lens must not be less than 80 inches and no greater than 95 inches above the floor, from Appendix A. The purpose of this code is to provide notification of alarm, supervisory, and trouble conditions; to alert the occupants, to summon aid, and to control emergency control functions. As far as power is concerned, it is required that the secondary power supply shall have sufficient capacity to operate the system under non-alarm conditions for a minimum of 24 hours and at the end of this period it also must be capable of operating all alarm notification appliances used for evacuation or direct aid to the location of an emergency for five minutes.

According to the UL requirements, it states in (UL 27.2.2) that the test of the lens is accomplished by a low wattage laser beam that is passed through the viewing holes of the light box onto the surface of the lens to be viewed. However there needs to be a test that shows how much light is shown at different angles. To obtain this information the sample must be rotated to the desire position and aligned using the reference stationary laser beam.

Methodology

The goal of this project was to design a new strobe reflector that will maximize the efficiency of the power input, while following the American requirement standards. Within this goal, there were four objectives to be completed. The first objective was to find an easy to use ray tracing program that would allow for the analysis for the current reflector and the newly designed reflector. The second objective was to specify requirements or create standards for the current product to be held against and to give a baseline for the new reflector. The third objective was to generate a method of statistical analysis. This statistical analysis will allow for Tyco to make adjustments for their future product, based on the knowledge given in the analysis. The fourth and final objective is to make a 3D model of the new design in Pro/Engineer 2.0. Pro/Engineer is the software that is used by Tyco International Ltd. and for ease of transfer of documents; the new design would be made to accommodate their software. For each objective, we have established an organized plan that would enable us to develop recommendations and a new design based on the needs of Tyco and the requirements set by the ADA. By following our tasks and objectives it will enable us to provide the most convincing and efficient design to Tyco International Ltd.

Objective 1: Find a simple ray tracing program for analysis

To run analysis on the current product, it was necessary to find an easy to use ray tracing program. The program needs to be able to upload the design and run light tests upon it. Since we did not have access to a lab to run a real-life simulation on the current product it was impertinent to find software that could reliably show results similar to real life testing. As with using any software, it is necessary to consider the errors that come from both the software and manufacturing tolerances of the real-life products.

The ability for the ray tracing software to upload the current design was crucial. Without being able to upload the design, analysis would not have been able to run. As such, the first task was to make sure the ray tracing program would be able to upload the current design and to specify the parameters of the software. The light ray receiving board needed to be designed, a new light bulb needed to be created, and the reflectance of the design had to be set for the test to run similar to the real-life tests. With the parameters set, next it was important to show the reliability and functionality of the program.

The second task in this objective was to show the functionality of the program and to test how the software experimentation compares to the real-life results. Since there was not a lab access in which we could run our own tests, we had to rely on the ability of the software. Having received the real-life tests from Tyco, we were able to compare the two results. Except for allowing for a few manufacturing tolerances and a few software miscalculations, comparing the two results verify the software's ability.

In order to see how rays reflect and how simple shapes create certain dispersion patters, we designed four different lens types with six different variations. The first three cylinders varied from having sides at 50° to 70° in 10 degree increments; this was to see if the angle had anything to do with the distribution of light and where its light intensity is on the candela plot. More than just changing the degrees of the sides, it was decided to change the length at which the two side angles were placed from each other. These two different types of information give us the needed information to provided awareness to how the ray reflections differed between angles and lengths. On top of testing the effects of a simple cylinder with side edges we also tested a cylinder without any sides, sphere, and an ellipse.

Finding a compatible and useful ray tracing program was essential to the beginning of our project. It allowed us to begin a simple analysis on the current product while using it as a learning tool as well. This objective was not necessary for the completion of the other objectives other than the final one. With having a basic understanding of light distribution patterns, we started to brainstorm the requirements needed a new reflector design.

Objective 2: Specify requirements

Underwriters Laboratory 1971 is a code that states requirements for signaling devices for the hearing impaired. For this second objective, we researched and read the UL 1971 requirements to completely understand its restrictions and limits. The necessary stipulations can be accessed in section 26 and 27 of the UL 1971 code. Also this product shall comply with the performance and supervision requirements in the Standard for Control Units for Fire-Protective Signaling Systems in the NFPA 72 code. As such, it is important to fully understand the UL 1971 requirements and what they mean to the new reflector design.

The first task for this objective was to completely comprehend the UL requirements and how they affect our new design. The minimum signal strength shall produce a candela output in accordance with tables 27.1- 27.3 and figures 27.1- 27.3 of UL 1971, as noted in Appendix B. Table 27.1 states the required minimum percentage for the horizontal dispersion that is dependent on the degree at which the light is emitted. The second task was to recognize the candela rating percentage requirements. This provided us with crucial information, as the analysis will be based off of the candela rating percentages. The pattern that this product follows is a T shaped pattern that has its highest candela rating of 100 percent at the 0° point.

Specifying requirements and understanding the limitations helped this project move forward. This objective did not supply any analysis or any resulting product; however, it offered valuable information and useful boundaries. Further analysis is needed of the final design to be completed.

Objective 3: Develop a new method of statistical analysis

The third objective for this project is to develop a new method of statistical analysis for Tyco to use for their present and future products. In order to offer Tyco a standard which their products would be held against it was imperative to come up with a new method of statistical analysis.

This includes setting up parameters from the UL 1971 requirements that gives descriptions of the height of the reflector and the distance away from the designated object, while also providing the correct strobe light and reflective material for the new design, as our first task. Going through this process there was a need to make an efficiency equation for the current product to compare it to the simpler lens types. Creating this equation is the second task and helped us understand where the need for improvement is needed and implement criteria for the new design.

Making design limitations and an efficiency equation was important to help with the construction of the new design. By having set requirements and specifications, it was better to narrow down what needed to be completed for this project, as well as helping provide an equation that defined the success of this new design.

Objective 4: Create a new 3D model

To create a new 3D model it is necessary to brainstorm several new design ideas and make a design draft that follows the previous criteria. The 3D model will both allow for analysis to be run and for a tangible product for Tyco.

Taking the information gathered from the previous objectives makes this objective feasible. Not only was it necessary to understand the modeling software, but it was also necessary to know where to begin the new design. The first task in this objective was to understand the modeling software, Pro/Engineer, which is the modeling software that Tyco uses. After taking time to comprehend the software, with the help of a text book, (Qingan, 2005), the strategic trial and error began. Since the geometries of the design would be too complex to make an algorithm or equation, strategic trial and error was used for the construction of the new model.

Creating a 3D model of the new design was the last, but most important objective. In order to prove the validity of our design, we needed to produce a model to run analysis upon it. By using the same statistical method and efficiency equation on the new model, we were able to provide valuable results to Tyco.

Results

By using our newly designed reflector, the strobe light can be powered at 60% of the original power. Meaning that if you power one strobe light with the original reflector at 1 watt, the second strobe light with the new reflector will only have to be powered at 0.6 watts to get the same effect. While being very conscious of the UL 1971 requirements, we were able to design a new reflector that can still warn the hearing-impaired in an occupied area.

Characterization equations

There were three main characterization definitions during this project. The first definition is the efficiency of performance which is used to characterize the light reflecting and the performance of a reflector. This definition explains how much of the light is casted into the desired area, Equation 1, which is the T-shaped pattern you will see throughout the analysis of the project, Fig 3. We regard efficiency as a criterion to evaluate the performance of a reflector. However, efficiency alone is not enough because it only distinguishes between the light inside and outside the T-shape area. This is why the Conformance coefficient is needed in regards to the different light intensity requirements at different angles.

$$Efficiency = \frac{\text{Light flux in the T area[Watts]}}{\text{Ideal light flux on the semisphere}}$$

Equation 1: Efficiency of the reflector.

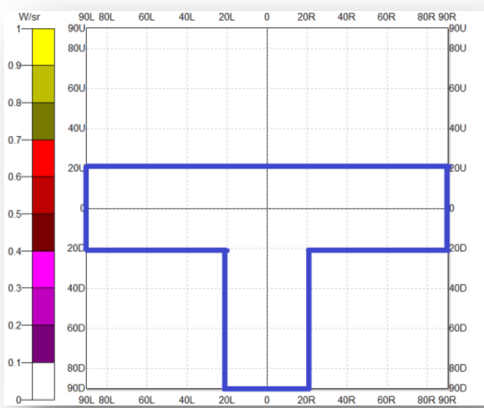

Figure 3: The “T-Shape” pattern which we have outlined to define efficiency.

As stated previously the Conformance coefficient is used to characterize the performance of a light distribution curve, rather than the reflector itself. It tells how well the curve conforms to the UL standard, Equation 2. To do so the Conformance coefficient is created to provide information that the efficiency equation lacks. This equation measures the shape of the curve regardless of the light intensity of the curve. To calculate the Conformance coefficient of a curve, there are three steps starting with obtaining the value of a curve at each measured angles from 0° to 90° in five degree increments. Secondly it is necessary to divide the values by the UL requirement percentage, which starts at 100 percent at 0° and decreases in by ten percent for every five degree increment. We call this process to be normalized and the results we get are to be named “normalized light intensity”, Equation 3. Lastly calculate the average value and the standard deviation of the normalized light intensity and calculate their ratio, then finally the Conformance coefficient of a curve is given. Conformance coefficient is actually the coefficient of variation of the normalized light intensity. It is not difficult to find the following properties, also the smaller its Conformance coefficient the, better it conforms to the UL requirements. For the curve of the same reflector the conformance coefficient keeps the same when the output power of the bulb changes. Also for the UL standard distribution curve itself, the normalized light intensity keeps the same in any direction and the Conformance coefficient is zero.

$$\textit{Conformance coefficient} = \frac{\text{Standard deviation of normalized light intensity}}{\text{Average of normalized light intensity}}$$

Equation 2: Equation for the Conformance coefficient, which indicates the similarity of the two comparing curves.

$$\textit{Normalized Light Intensity at } \alpha°[\text{candela}] = \frac{\text{Light intensity at } \alpha°[\text{candela}]}{\text{UL required percentage at } \alpha°[\%]}$$

Equation 3: The equation for the normalized light intensity, a value necessary for the calculation of Conformance coefficient.

Maximum candela is used to characterize the performance of a reflector of its distribution curve. This tells the best test a reflector or curve can pass with a certain light bulb output.

Maximum candela can be regarded as the combination of Efficiency and Conformance Coefficient, which reflects the test result of a UL standard test. An improvement in either Efficiency or Conformance Coefficient can lead to an improvement in Maximum candela. A reflector with a large Maximum candela is the ultimate goal of this project. Therefore the larger the value of the final design gives, the more successful the project is.

The new design gives off a much better result, 300 candelas compared to the current product of 180 candelas. This is done by much improvement and changes to the current product; such as more light is now casted into the T-shape area. The efficiency of the new design has only increased by five percent of the current design. However, the second aspect is the light distribution curve should be more similar to the UL standard distribution. Therefore the new design largely reduces the conformance coefficient making the new design a better performer. A rough estimate suggests that the surface parameters of the current product need to be adjusted correctly. By doing so the maximum candela could possibly improve to 250 candelas without changing the surface configuration of the current product.

Current product analysis

Software needed

In order to run analysis on the current strobe reflector and to design a new reflector for the fire alarm, it was necessary to use various software. For this project we used two different types of software. The first software that was needed is any easy to use ray tracing program. The second software used was a modeling software. Both types were needed to adequately complete the project.

Before needing the software to create a 3D model, it was necessary to find a ray tracing program. The ray tracing program needed to be able to upload the current design and simulate rays that a light source would produce. The ray tracing software uses discrete light rays to simulate real light. The number of the rays compared to the unit area of the source is the same, and each ray has the same light flux. The software calculates how many rays come into a certain area of the receiving board, add the light flux, divide it by the area, and then calculate the average light intensity in this area. If the area is small enough, it will be the light intensity of that particular spot. The 3D model of the current product was given to us as a Pro/Engineer file. Pro/Engineer is software owned by PTC and it is a parametric, feature based, solid modeling software. Since three of the four team mates had not used Pro/Engineer before it was difficult to understand the construction of the current product. With study and book reading, we were able to understand the complexities of the current product. Moving forward with our own design, we first designed our model in Unigraphics NX, a more familiar system. However, in trying to convert the file to a Pro/Engineer file, there were many faults. So that Tyco would have a tangible resulting product, we then designed the product in Pro/Engineer. This software, unlike the ray tracing program, was predetermined for our project.

Construction of a new light source

To prove that our analysis and final results are accurate, it was decided to create a new light source, instead of using a point light source, for the creation and study of the reflectors. If the light source model differs too much with the real bulb, the simulation results may deviate a lot from the real situation. So it was crucial to build a light source model similar to the real bulb as much as possible. First, we tried making the light source a cylinder that emits uniform light. The shape is the same as the xenon tube used in the current product, but the light is not uniform in the real light source. By analyzing the way the real bulb emits light, we were able to approximate where the bulb needed to be adapted for our desired effect. In comparing the results from the uniform cylinder and the point light source, it was decided that there are three locations at which there needs to be light points. When the effects of three similar light sources are added, the light distribution curve should ideally have three turning points at each side. If the turning points are well positioned, the curve will be very close to the real bulb distribution. In this way we built our light model. There are three spheres, which are light sources, and a block that absorbs light out in front, as in Fig.4. By precisely control the radius, light output and the distance of the three spheres, we are able to generate a light model that performs similar to the real light bulb. Using this light source instead of a point source allowed us to accurately compare software results between the current product and our new design.

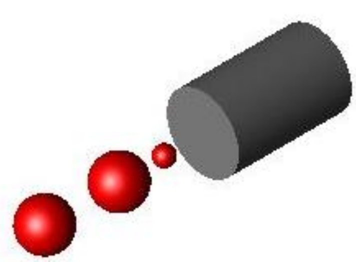

Figure 4: The diagram of the newly constructed light source. It is comprised of three point light sources and a block.

Simple lens testing

To test the software and to get a better understand of the different lens types we created several different simple lenses. We created a sphere, an ellipse, a cylinder, and a cylinder with side edges. The sphere, ellipse, and cylinder do not have variations to their tests, however the cylinder with side edges have six different variations.

The first variation we did to the cylinder with side edges was to have the edges come in at a 50° angle. To test the difference that length has on its reflectance, we had two different 50° cylinders, a short one and a long one. The difference between the 50° short and long shows that the closer the side edges are to the light source the wider the candela plot. Also, the graph shows the horizontal and vertical plane to be very similar. The 50 ° long has a high candela rating along the horizontal line in certain sections, Fig. 5, as well as a high center peak; as is needed to achieve the UL 1971 requirements. The 50° short does not have the light spread across the horizontal plane, like the 50° long cylinder. Instead, it has a high concentration of light in the center of the candela plot, Fig.6.

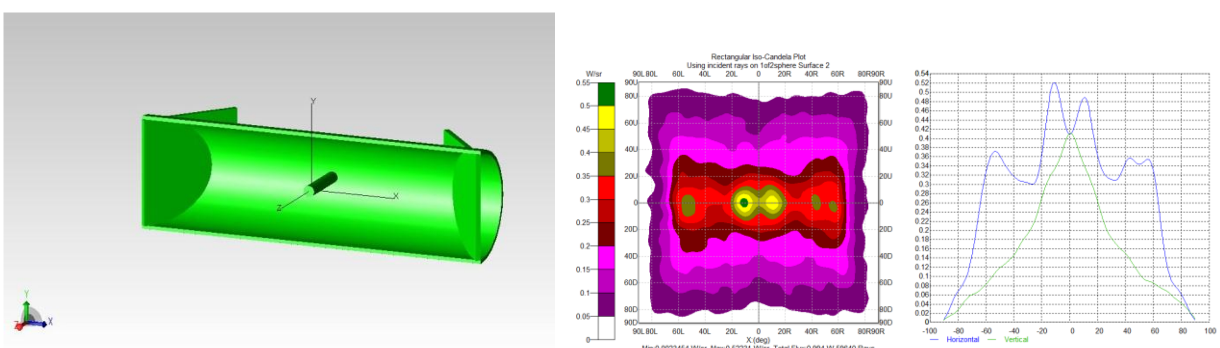

Figure 5: Cylinder with side edges, 50° long. The candela plot has high readings along the horizontal plane.

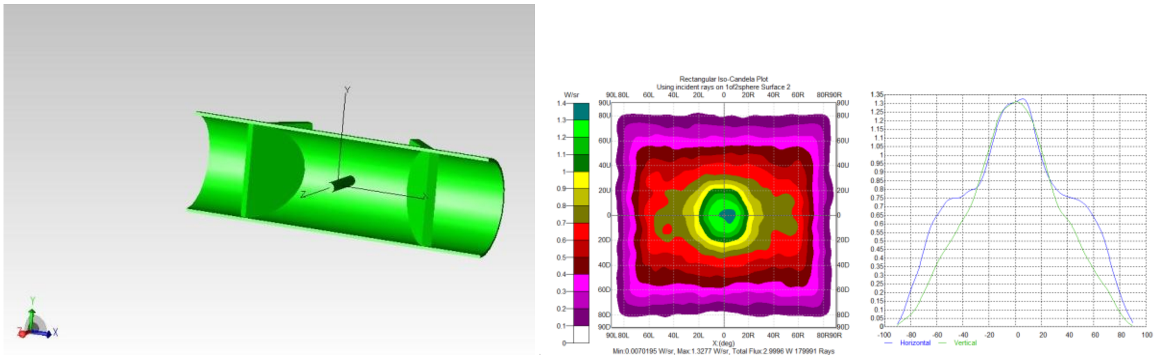

Figure 6: Cylinder with side edges, 50° short. The candela plot has a strong center peak.

The second variation to the cylinder with side that we did was 60° short and long. The 60° long shows two separate peaks in the horizontal creating an unnecessary flat area from negative 20° to 80°on the horizontal and vertical graph unlike the slight increase in the previous cylinder 50° short, Fig.7. The 60° short shows that the horizontal and vertical planes have comparable peaks however there are three separate circles giving off multiple areas of intense light, Fig.8. Despite the unnecessary area the 60° long cylinder is the closest representation of the current product in terms of a consistent horizontal light displacement from negative to positive 90°.

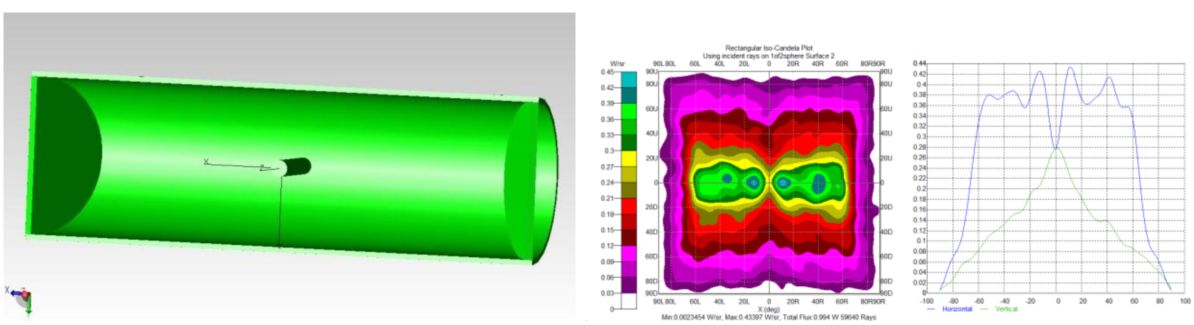

Figure 7: Cylinder with side edges, 60° long. The distribution graph is similar to the current reflector.

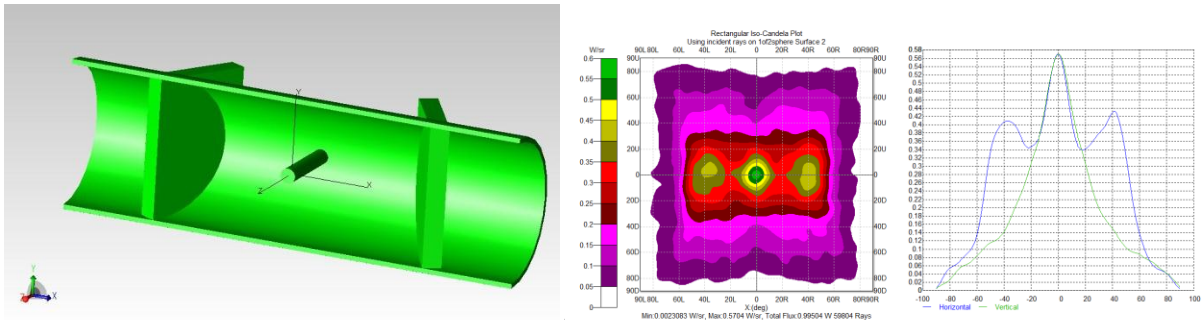

Figure 8: Cylinder with side edges, 60° short. There are three high light intensity points; it needs to be more uniform.

The last variation to the cylinder with side edges is the 70° long and short. 70° showed results that were completely different from the other two angles. 70° long and short are similar in that they both have two separate circles of light intensity however their vertical displacement is very low and therefore the horizontal displacement makes up for most of the light intensity. Both 70° cylinders do not provide much of a center peak with a high light intensity, Figs. 9 and 10. Having a high light intensity at the center peak is idea for our new design and it is extremely important for meeting UL requirements. Therefore this angle is the least effective and was not necessary for the new design.

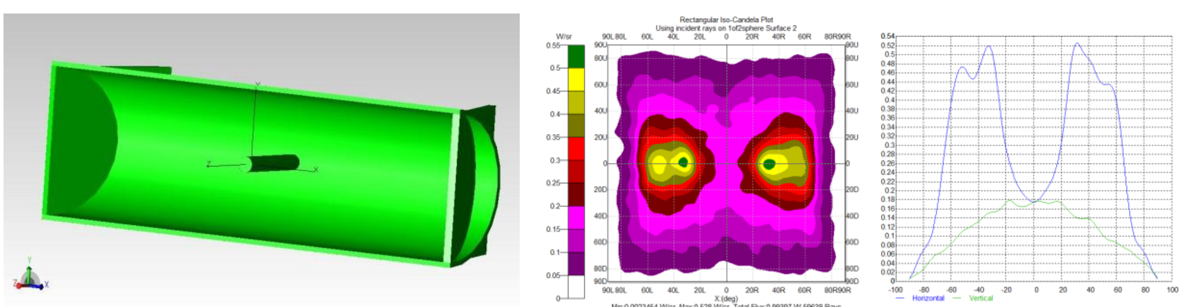

Figure 9: Cylinder with side edges, 70° long. The two peaks do not span across enough space to be important.

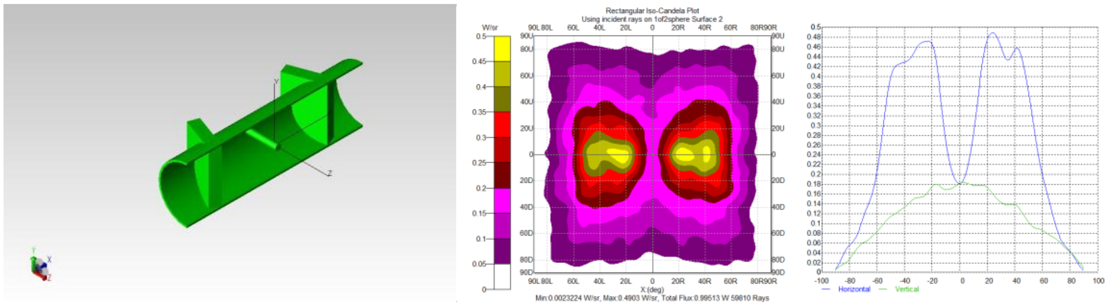

Figure 10: Cylinder with side edges, 70° short. The two areas of high light intensity are not strong enough.

Having seen how angles and length affect the areas of light intensity, we created a simple cylinder to see how light is reflected in one of its more simple forms. Fig.11 shows that the cylinder directs light across the horizontal plane at a high light intensity, without a center peak, but with a very wide distribution. One of the UL 1971 requirements states that the light must reach to the left and right 90°, which this cylinder did achieve. However, the light intensity is too large for the ends. Using the information that this cylinder gave us, we were able to modify this simple shape and form it into a better functioning reflector.

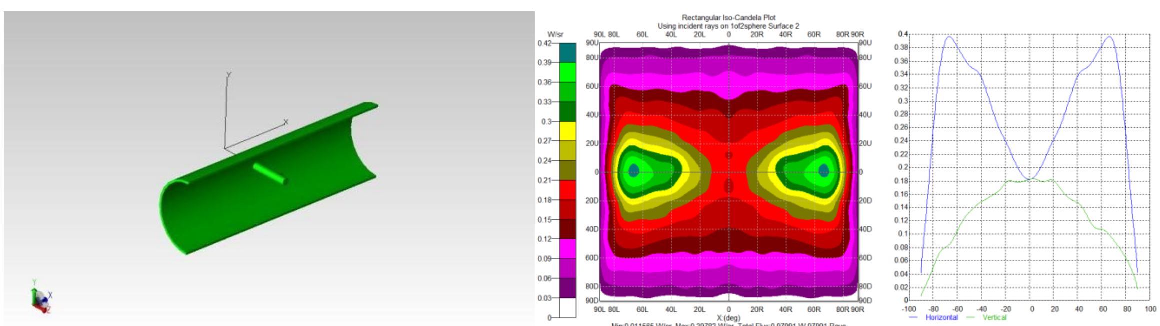

Figure 11: Cylinder. The points of high light intensity are very wide.

The next simple reflector that was tested was an ellipse reflector. We wanted to test a few simple reflectors to get a basic idea of how light reflects from simple shapes. This ellipse reflector, Fig. 12, showed interesting results. The highest points of light intensity are neither in the center nor towards the ends. Also, the light is reflected upwards and downwards too much.

This reflector provides too much light outside of the ideal T-shape. As such, this elliptical reflector was not used in our final design.

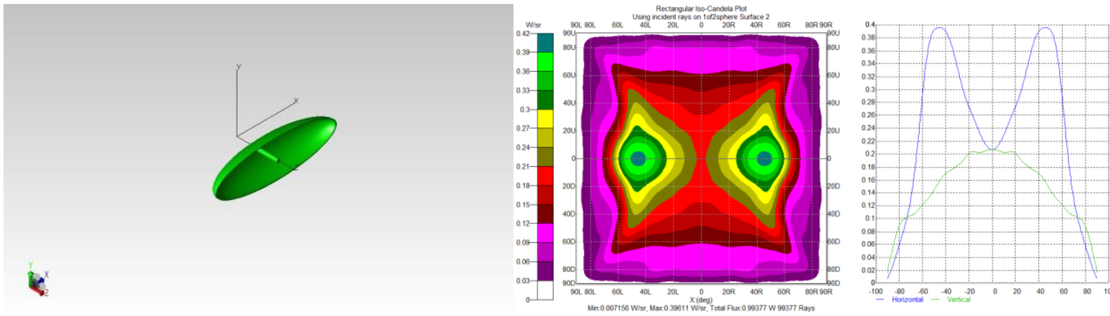

Figure 12: Ellipse. The points of highest light intensity are too tall.

The last simple reflector to be tested was a spherical reflector. Its results were just as predicted. As shown in Fig. 13, the semi sphere produced results that yielded an incredibly high light intensity in the center. Ideally, our new design will have an overall higher light intensity, not an incredibly high center peak. Therefore this type of reflector is not used in our final design.

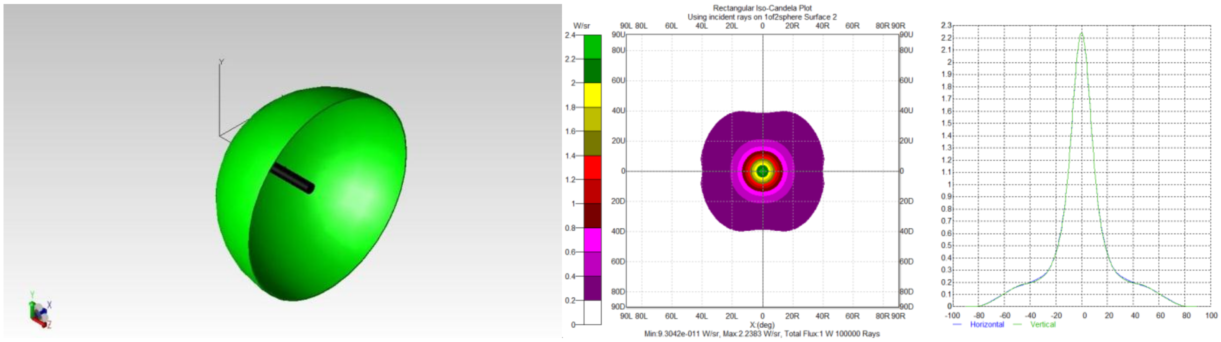

Figure 13: Semi sphere. The only place where light is reflected is in the center.

These reflectors gave us many ideas of what simple shapes to use for our reflector as well as idea for what not to use. Creating a simple basic structure with more of a cylindrical shape is the best place to start manipulation for our design. The ellipse and the sphere did not offer the desirable results we were looking for. Starting with these reflectors was a good start to the rest of the project.

Analysis of product's surfaces

The different surfaces of the current reflector contributed to where the strobe light spread its light. To better understand the current product, it was important to dissect the surfaces and find the reasoning behind each one. There are surfaces which contribute to the horizontal plane in the T-shape, and there are surfaces which contribute to the vertical plane.

Horizontal plane

There are seven main surfaces which contribute to the horizontal plane. Some contribute to the center peak, some the horizontal areas and other contribute to the expansion of light to the left and right 90°.

This curved surface, in Fig14, is similar to a spherical or parabolic surface. These surfaces in black focus the light into the center peak of the T-shape. The surface area is very large, and therefore creates a very large peak on the graph. This large peak is not necessary, it is too high. It would be better to have a smaller surface contribute to the center peak, so that the light intensity is not so high. The unexpected yellow spots in the candela plot appear because the slight inaccuracies of the light bulb position.

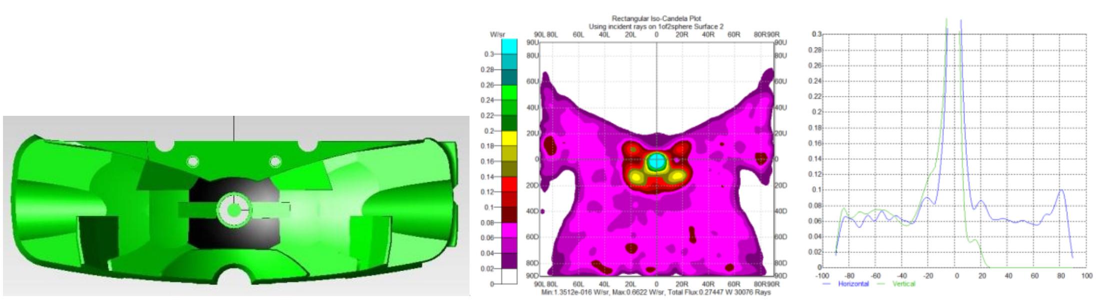

Figure 14: The black surfaces contribute to the center peak. As you can see in the graph, it is too high.

The two inclined black surfaces in Fig. 15 seem to contribute very little on both horizontal and vertical planes but they make some modification of the result of center curved surface. Notice that the majority of the candela plot is purple and pink; there are very few red areas. There is not an area in the candela plot that has a high intensity. This is due to the small surface area of the black pieces, as well as their ineffectiveness.

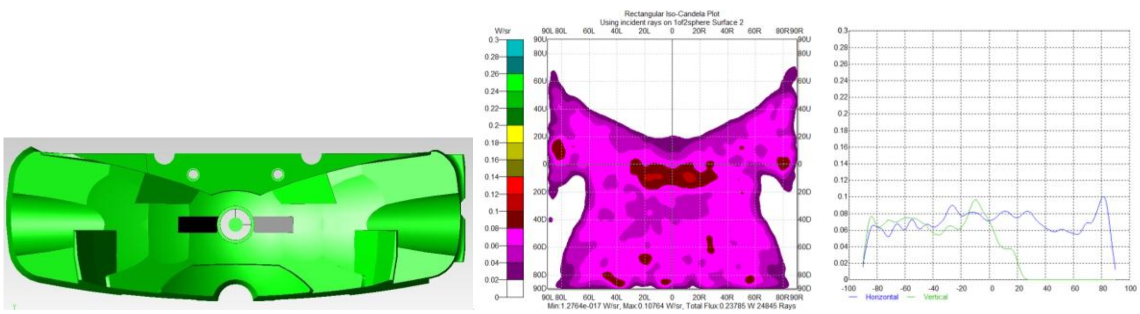

Figure 15: These black surfaces do not offer a large contribution to the light distribution.

These two 'wings" reflect light going to the outer edges of the receiving board. These pieces allow for the light to be directed to the left and right 90° area. This needs to be achieved because of the UL 1971 requirements. These two surfaces are important and necessary for the new design.

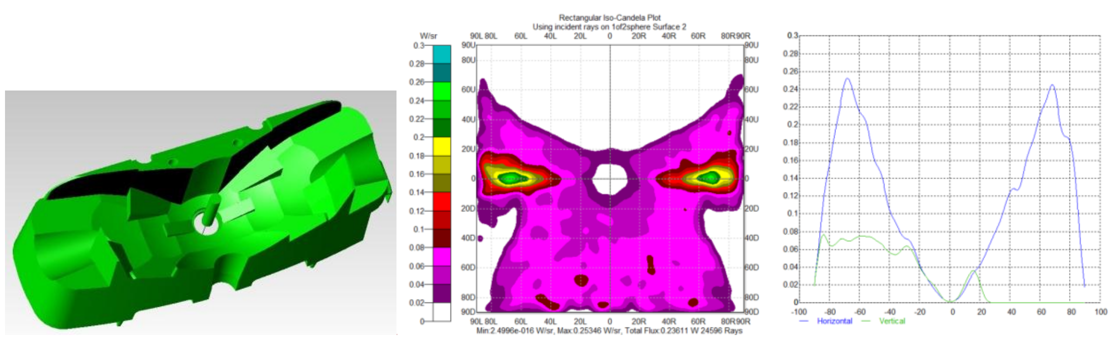

Figure 16: The black "wings" direct light to the 90° left and right.

The two parabolic surfaces in Fig. 17 have discordant focuses concentrating light into two peaks near the center of the horizontal test plane and meanwhile giving no contribution to the center. The surface area of these surfaces is very small. As the graph shows, the surfaces give high sharp peaks around ±30°. It would be more beneficial to have a larger surface that would provide a larger area of light intensity in the candela plot.

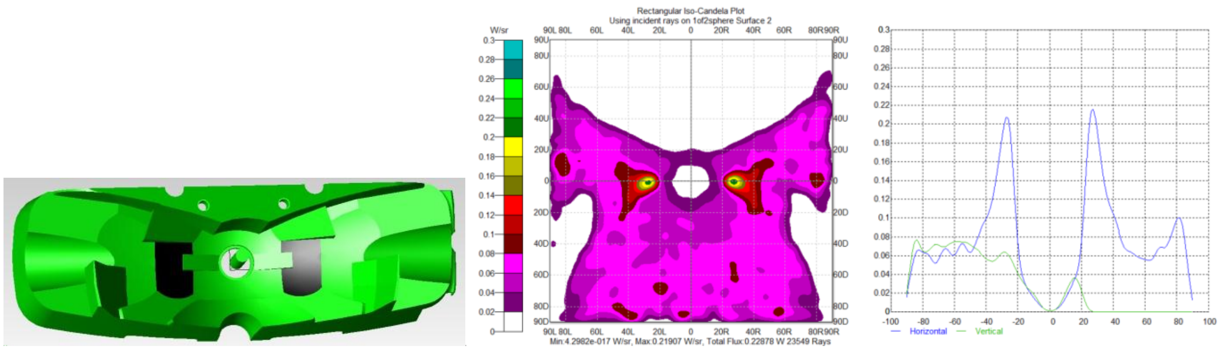

Figure 17: These black surfaces direct the light into the middle of the horizontal plane.

These two curved surfaces perpendicular to the reflecting surface limited light to the plane of less than 50 °. They work as two walls to avoid light on plane of larger than 50° but unlike the parabolic surfaces, they contribute at approximately ±40°. Since these two surfaces contain light instead of enhance it, they are a waste.

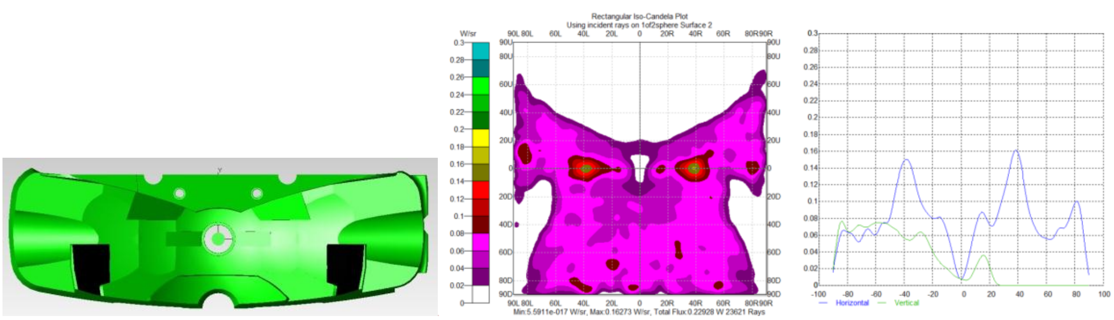

Figure 18: The black surfaces focus the light into ±40° on the horizontal plane.

These two parabolic surfaces with far focus form two small peaks at ±60°, as seen in Fig.19. As mentioned previously, the surface area of these surfaces are not large enough to obtain the desired effect. They do not supply enough light to any one area to be beneficial.

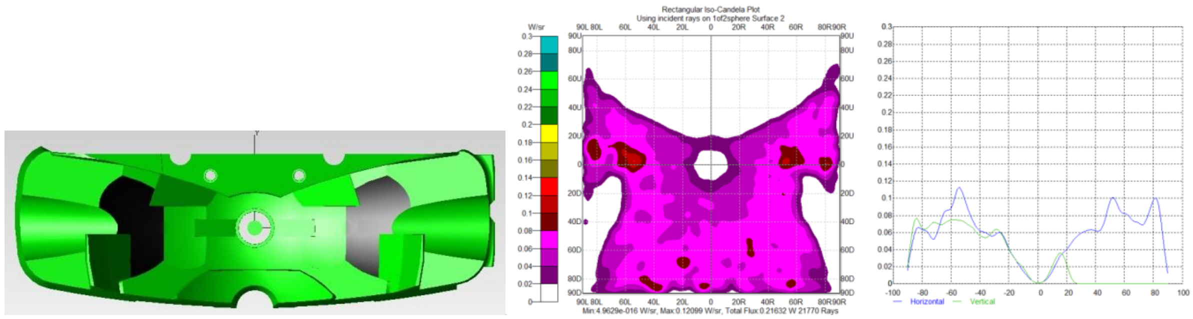

Figure 19: The black surfaces have a low light intensity around ±60°.

These two surfaces narrow the light on horizontal plane but only have little contribution around ±80 °, Fig. 20. The two highlighted surfaces are too far away from the light source to offer much guidance to the light. The light distribution graph is nearly flat, meaning it has very slight peaks and offers no great contribution to the T-shape.

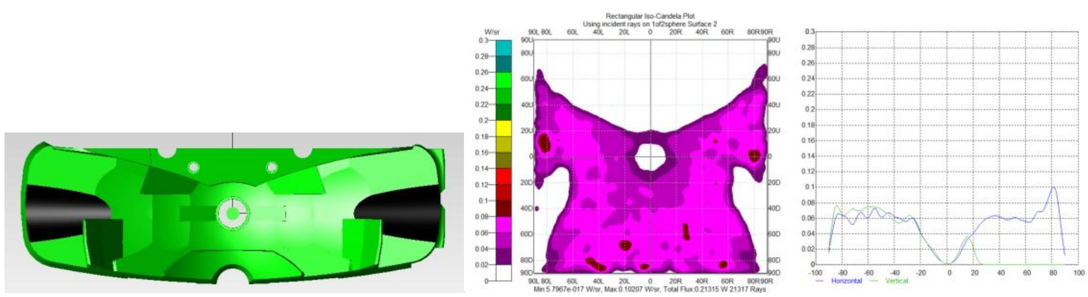

Figure 20: The black surfaces offer very little to the light distribution.

Vertical plane

The vertical plane is the bottom half of the T-shaped pattern. There are currently four surfaces that contribute to this area and to the 45° compound areas. These surfaces were necessary for the current product's achievement of the T-shape.

The first surface that contributes to the vertical plane is the bottom piece. The curved surface is a small part of parabolic surface with light bulb near its focus, so it gives relatively high light concentration a little below the center part on vertical plane. The two unexpected yellow spots are due to the fact that the light bulb is not strictly in its ideal position. The combination with this piece and the one from Fig. 14 create an incredibly high peak at the center.

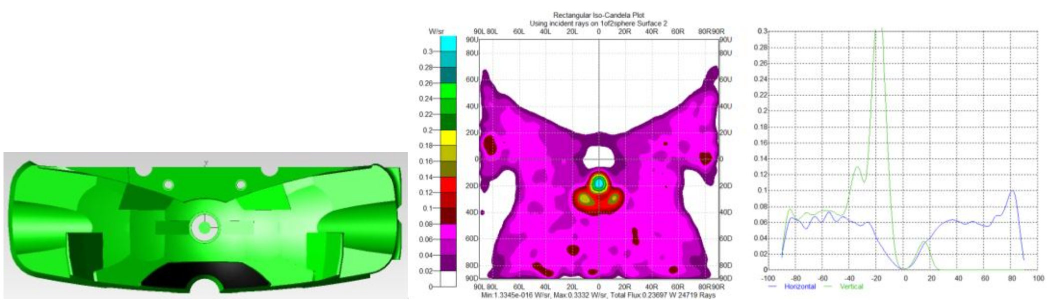

Figure 21: The black surface concentrates the light towards the center of the vertical plane.

These two inclined top surfaces contribute little on vertical test plane, Fig. 22. The surfaces concentrate a small of light into the same area as Fig. 21. The surfaces are raised from the base and do not contribute much because of this fact.

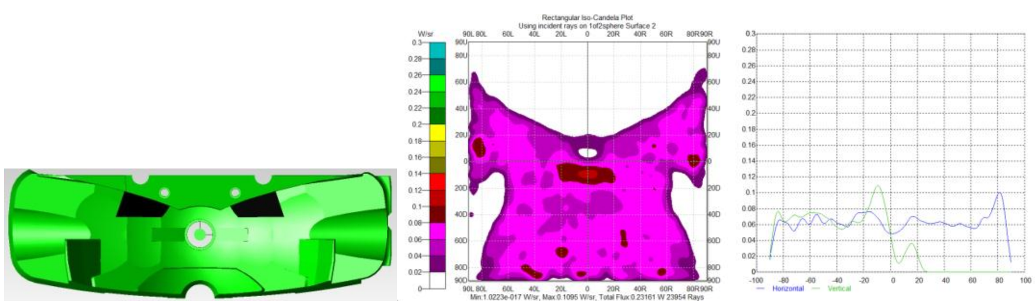

Figure 22: The black surfaces contribute very little to the vertical plane.

The small part of a spherical curved cylinder surface reflects almost all light going downward, Fig.23. Although it covers only a small part above the light bulb, its position close to the bulb makes it contribute a lot. This is the biggest contributor to the vertical plane.

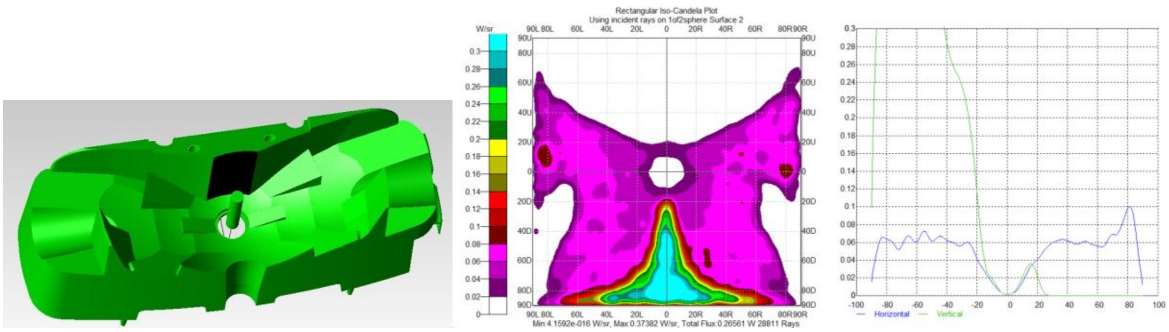

Figure 23: The small black surface is the largest contributor to the vertical plane.

These two curved surface contributes on compound 45° on both X and Y axis, Fig.24. The two spots are not in the ideal position, which implies more modification is required. The UL 1971 requires that there are two spots of low light intensity at the compound ±45°.

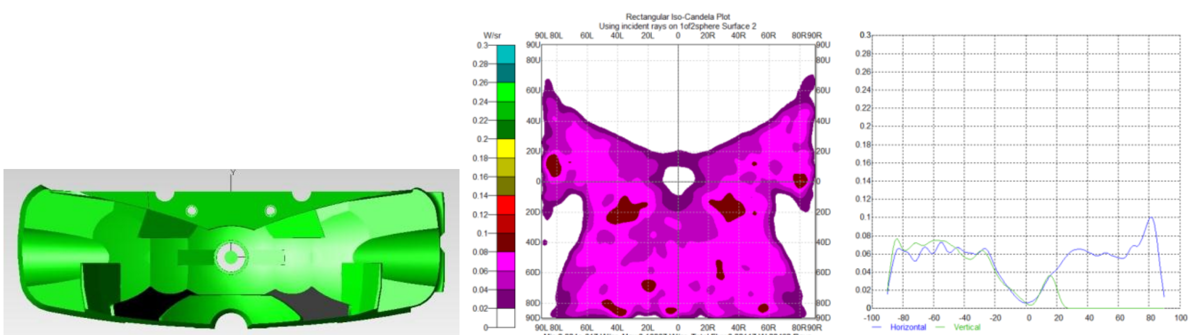

Figure 24: The two black surfaces direct the light to the ±45° compound areas.

Summary

Overall, the current design is very complex. Specific software, a new light source, simple lens testing, and surface analysis were needed for the analysis of the current product. Creating the new light source proved the ability of our software, making it easier to compare our new design results to the current products'. To gain basic optical knowledge, we tested several types of simple reflector lenses. Looking at the results from the cylinder reflectors we were able to decide a basis for our new design. From its multifaceted structure, there are many unnecessary surfaces that either contribute very little to the overall light distribution or need to be modified. The analysis of each of the surfaces allowed lots of information for the future of this project. We were able to deconstruct the useful surfaces and reject the surfaces that offered no influence to the light distribution. The information gathered from this process of the project allowed us to move onto the creation of our new design.

Construction of new design

Our design relies a lot upon trial and error, but it is not possible to design the whole reflector totally by trial and error. This is because the UL standard requires not only the luminous shape, but also the certain luminous intensity at different positions. Such a complex light distribution cannot be simply design by random trial and error.

In the design process, our trial and error was based on the conclusion we drew either from optical knowledge or the trial and error itself. Also, it is guided by a preliminary “function separation design”, which means that we separated the surfaces by their function and where they cast light. For each round of trial and error, our goal was only to generate simple reflecting patterns by one surface. By adding the surfaces together, we hoped to create a satisfying reflecting pattern. This is what we call a systematic trial and error.

The first step in designing a new reflector was to separate the “T-shape” into several different sections, or function separation. Our team separated the “T-shape” into five different sections, as seen in Fig.25. There is a center peak, a horizontal plane, left & right 90°, a vertical plane and two compound 45° areas. However, the way to separate the “T” area is not unique. The reason for the separation is that, in each section, the light distribution required by UL should be simple and easy to generate by one or a set of similar surfaces. The separation enables the designers to focus on only one part at a time, which reduces the design difficulty.

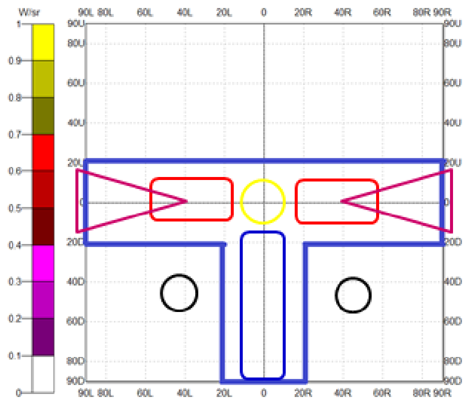

Figure 25: The "T-shape" area and the five separate areas of directed light.

The second step in our design process was to choose the shape and the position of each surface; also known as single surface design. For each section of the "T" area, we found a surface that would generate the light distribution as the UL standard requires in this area. The surface can either be designed according to optical knowledge, or it can also be design simply according to trial and error with random simple shapes; such as cylinder, elliptical surface, parabolic surface, or a spherical shape.

To specify the parameters of each surface was the third aspect to our design process. The construction of each surface may have several parameters involved. Each of those parameters may have a different impact on the light distribution in a certain manner, for example, some will control the magnitude of a peak and some will control its position. By modifying these parameters by trial and error, it's possible to reach the optimum value.

The fourth and final step to our design process was to combine the single surfaces and modify them to be harmonious with each other. When the surfaces are added together, they may harm the effect of each other. By adjusting the position and direction, the designers need to reduce the negative interactions.

Analysis of new design

The design of the new reflector follows a similar guideline as the current product. After noticing the surface contribution to the T-shape in the current reflector, the new design was broken down into five main parts that needed improving. First is the center peak, which needs the highest light concentration. The horizontal plane needs to span across a large surface with a large light intensity. The left and right 90 degree needs to be reached based upon the UL 1971 requirements. The vertical plane needs to be achieved with a large light intensity to complete the T-shape. And finally the two compound areas of low light intensity at 45 degrees. So by using what was gathered by the deconstruction of the surfaces, the ability to come up with a new design was easier. The small rectangle in the center gives a high intensity at the center peak. The wide rectangular piece gives a more intense horizontal distribution. Having only one surface contribute to the vertical plane, it is a more efficient use of space. The two set of wings on the top of the reflector distributes the light to reach 90 degrees left and right. The two flaps that attach to the beginning of the wings allow the light to be directed to the 45 degree areas. The final bottom two rectangular curves that complete the design were created to enhance the overall reflected light.

The analysis shows that the center peak in the current product is too large; therefore reducing the area of the surface in the new design gives off a smaller center peak. The horizontal plane light distribution is not enough in the current product and also the effectiveness of the reflecting surfaces are low. So enlarging these surfaces and modifying its shape in the new design makes it more effective. Lastly the vertical plane distribution of the current product is okay, but it takes too many surfaces to manage that. By reducing the number of these surfaces to only one and keeping the performance, makes the product more efficient. The light distribution of the whole reflector in the new product is more intense and concise than the current product. Therefore, the distribution curve is flatter and closer to the UL requirements. Also, the light absorbed by the reflector becomes less because in the current design a considerable portion of the light reflects more than before reaching the semi sphere, hence more light absorbed. However, in the new design that portion is largely reduced. With that being said the new design can produce a maximum of .576 watts whereas the current product can only produce .512 watts.

Recommendations

For the continuation of our project, we give several recommendations. The first being to make a model that can be manufactured and prototyped. The second suggestion is to test the prototyped model in the real-life conditions. Finally we recommend running analyzing tests on it to see if our simulation results compare to a real-life test.

The Pro/Engineer model we established is a model simply for simulation, rather than an actual model that can be manufactured. We only established those surfaces that contribute in terms of reflection. To build a manufactured model, the gap between surfaces should be filled, and the back side of the reflector should have a structure that is able to combine with the circuit board. But since the real product is not expected, it would be not necessary to build a manufacture model. The simulation model should be enough because it performs the same in the simulation as the manufacture model.

Since our design depends largely on trial and error, it cannot be proved wrong that there might be a better design, or a better configuration of the surface. By a rough estimation, it would be very hard to have a design with 400 or more maximum candela with the same bulb, but a 350 one could be possible with more tweaking.

Conclusion

Within seven weeks' time working on the Tyco Enhanced Strobe Reflector Project, our team created a design that is potentially able to largely improve the performance of the reflector and decrease the power consumption to 60% of the current product. But regrettably, we are not able to build a real model to test and verify our design because the limited time and restricted resource and equipment.

The project can roughly be divided into 3 parts: pre-design study, design process, and post-design analysis. In pre-design phase, we created the criteria for reflector performance evaluation and then analyzed the current product. In the design phase, we first studied the reflecting patterns of some simple shapes, and then established our own reflector model. In post-design phase, we made a qualitative analysis of our design.

Pre-design study is the foundation of the design process and it is critical to the whole project. A comprehensive study in pre-design phase has enabled us to fully understand the requirements of the reflector, and thus to establish a clear and practical goal. By the time this phase ended, we had been able to characterize the performance of a reflector with the aid of the simulation software, and we have also acquired a good understanding about how the current design is build, how it performs, and most importantly, how it can be improved.

The design process is the main body of the project. In this phase, we came up with the new reflector design and established a Computer Aided Design (CAD) solid model. The design of the whole reflector was unexpectedly complex. To reduce the difficulty in brainstorming and initial idea generating, we broke down the design into surfaces that will realize different functions. Afterwards, we designed those surfaces by trial and error. The iteration is also a learning process, helping us to develop an intuitive judgment about the performance of surface with different shapes. As the model was brought into completion gradually, the design process accelerates and the “trail” encounters the “error” less and less.

The post-design process is mainly focused on evaluation and theorization. The work in this phase demonstrates the improvement, explains and organizes our design process in a theoretical way. The evaluation provides a solid numerical proof of the reflector performance improvement and displays its potential to become a successful as well as beneficial product. Also, the theorization work extended the value of the project from merely generating a design or product to establishing a design theory and procedure that may guide any other reflector development, which, we believe, is the most valuable part of this project. This report shows most of the key processes of our project, through which we sincerely wish to show our project progress thoroughly

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Appendix

Appendix A

Simplex — **True*Alert*® Multi-Candela Notification Appliances**

*UL, ULC, CSFM Listed; FM Approved; MEA (NYC) Acceptance**

Visible Notification Appliances with Synchronized Flash; Non-Addressable, Smart*Sync*™ Operation Compatible

Features

Visible only (V/O) 24 VDC notification appliances with high output xenon strobe, available for wall or ceiling mount:

- Intensity is selectable as 15, 30, 75, or 110 candela with visible selection jumper secured behind strobe housing
- Operation is compatible with ADA requirements (refer to important installation information on page 3)
- Polarized input allows connection to compatible reverse polarity, supervised notification appliance circuit (NAC)
- Regulated circuit design ensures consistent flash output and provides controlled inrush current
- Rugged, high impact, flame retardant thermoplastic housings are available in red or white with clear lens
- Listed to UL 1971 and ULC S526

Strobes provide synchronized flash for use with:

- 4006, 4008, 4010, and 4100U Series fire alarm control panels with NACs selected to provide strobe synchronization or SmartSync two-wire control**
- 4009 IDNet™ NAC Extenders
- Separate strobe Synchronization Modules that are available for Class B or Class A operation
- Separate SmartSync Control Modules (SCMs) that provide Class B or Class A output from conventional NAC inputs

Strobe housings provides flexible, easy, and convenient semi-flush or surface wall mounting:

- Rear of housing does not extend into box
- Wall mount strobes easily mount to single gang, double gang, or 4-inch square outlet box
- Ceiling mount strobes mount to single gang boxes

Wall mount strobe features:

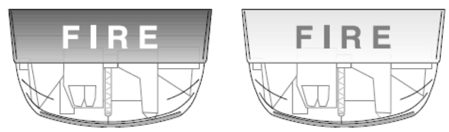
- Wiring terminals are accessible from the front of the housing providing easy access for installation, inspection, and testing
- Covers are available separately to convert housing color

Optional adapters and wire guards:

- Wall mount strobe adapters are available to cover surface mounted electrical boxes and to adapt to Simplex® 2975-9145 boxes
- UL listed red wire guards are available for wall or ceiling mount strobes*

* Refer to page 2 for guard listing. This product has been approved by the California State Fire Marshal (CSFM) pursuant to Section 13144.1 of the California Health and Safety Code. See CSFM Listing 7125-0026:316 for allowable values and/or conditions concerning material presented in this document. It is subject to re-examination, revision, and possible cancellation. Refer to page 2 for listing status of wire guards. Additional listings may be applicable; contact your local Simplex product supplier for the latest status. Listings and approvals under Simplex Time Recorder Co. are the property of Tyco Safety Products Westminster.

Wall Mount Strobes



Ceiling Mount Strobes

Description

Multi-Candela TrueAlert synchronized strobes provide convenient installation to standard electrical boxes. The enclosure designs are both impact and vandal resistant and provide a convenient strobe intensity selection. Since each model can be selected for intensity output, on-site model inventory is minimized and changes encountered during construction can be easily accommodated.

Wall mount strobe housings are a one-piece assembly (including lens) that mounts to a single or double gang, or 4" square standard electrical box. The cover can be quickly removed (a tool is required) and covers are available separately for color conversion.

Ceiling mount strobes install using standard single gang electrical boxes. Color choice is determined by model number.

Strobe Intensity Selection

During installation, a selection plug at the back of the housing determines the desired strobe intensity. An attached flag with black letters on a highly visible yellow background allows the selected intensity to be seen at the side of the strobe lens.

Strobe Application Reference

Proper selection of visible notification is dependent on occupancy, location, local codes, and proper applications of: the *National Fire Alarm Code* (NFPA 72), ANSI A117.1; the appropriate model building code: BOCA, ICBO, or SBCCI; and the application guidelines of the Americans with Disabilities Act (ADA).

** Simplex multi-candela SmartSync two-wire horn/strobe appliance operation is protected under one or more of the following U.S. Patent Numbers: 5,559,492; 5,622,427; 5,865,527; 5,886,620; 6,281,789; 6,954,137; 7,005,971; and 7,006,003.

S4906-0001-4 9/2009

Synchronized Strobes

Multiple Strobes. When multiple strobes and their reflections can be seen from one location, synchronized flashes reduce the probability of photo-sensitive reactions as well as the annoyance and possible distraction of random flashing. These multi-candela strobes are synchronized over a two-wire circuit when connected to compatible NACs, to compatible Synchronized Flash Modules, or to SmartSync Control Modules.

SmartSync Two-Wire Control

Some applications desire the audible notification appliances to be capable of being silenced before the alarm condition is reset (on-until-silenced) while the visible notification appliances are kept activated until the alarm condition is reset (on-until-reset). SmartSync operation mode provides this function using a single circuit (two-wire operation).

SmartSync Control Sources

SmartSync two-wire control is available from:

- 4006, 4008, 4100U, and 4010 Fire Alarm Control Panels (refer to individual product data sheets for more information)
- 4009 IDNet NAC Extenders (refer to data sheet S4009-0002)
- SmartSync Control Module (SCM) Model 4905-9938 (refer to data sheet S4905-0003)

Additional SmartSync compatible notification appliances include separate horns and combination horn/strobe notification appliances.

Product Selection

Multi-Candela Visible Notification Appliances (Strobes)

Model	Mounting	Housing Color	"FIRE" Lettering	Description
4906-9101	Wall	Red	White	Multi-candela strobe with intensity selectable as: 15, 30, 75, or 110 candela; synchronized flash rate; SmartSync two-wire control compatible
4906-9103	Wall	White	Red	
4906-9102	Ceiling	Red	White	
4906-9104	Ceiling	White	Red	

Wall Mount Strobe Adapters

Model	Description		Dimensions
4905-9937	Red	Surface Mount Adapter Skirt; use to cover 1-1/2" (38 mm) deep surface mounted boxes	5-3/8" H x 5-1/4" W x 1-5/8" D (136 mm x 133 mm x 41 mm) Total depth with strobe = 4-3/8" (111 mm)
4905-9940	White		
4905-9931	Red Adapter Plate for mounting to Simplex 2975-9145 box (typically for retrofit, may be mounted vertical or horizontal)		8-5/16" x 5-3/4" x 0.060" Thick (211 mm x 146 mm x 1.5 mm)
2975-9145	Red Mounting Box, requires Adapter Plate 4905-9931		7-7/8" x 5-1/8" x 2-3/4" D (200 mm x 130 mm x 70 mm)

Ceiling Mount Strobe Adapter

Model	Description	Dimensions
4905-9910	Surface Mount Adapter Plate; zinc plated; **required for mounting to handy box; not needed when using 4905-9926 guard**	4-7/8" x 3-1/8" x 0.060" D (124 mm x 79 mm x 1.5)

Synchronization Modules (refer to data sheet S4905-0003 for additional information)

Model	Description		Dimensions
4905-9914	Class B	Synchronized Flash Module; epoxy encapsulated with in/out 18 AWG (0.82 mm^2) wire leads, rated for 2 A NAC, requires 5 mA for power	1-3/8" x 2-7/16" x 13/16" (35 mm x 62 mm x 20 mm)
4905-9922	Class A		
4905-9938	SmartSync Control Module with Class B or Class A output; mounts in 4" (102 mm) square box		4" x 4-1/8" x 1-1/4" D (102 mm x 105 mm x 32 mm)

Replacement Covers and Guards

Model	Description		Dimensions
4905-9992	Red cover with white "FIRE" lettering	For Wall mount strobes	5-1/8" H x 5" W x 1-1/2" D (130 mm x 127 mm x 38 mm)
4905-9993	White cover with red "FIRE" lettering		
4905-9961*	Wall mount	Red wire guard with mounting plate, compatible with semi-flush or surface mounted boxes	6-1/16" H x 6-1/16" W x 3-1/8" D (154 mm x 154 mm x 79 mm)
4905-9926*	Ceiling mount		6-1/8" x 4-3/8" x 2-7/8" deep (156 mm x 111 mm x 73 mm)

* UL listed by Space Age Electronics Inc.

Strobe Specifications

Wall Mount or Ceiling Mount, Common Specifications

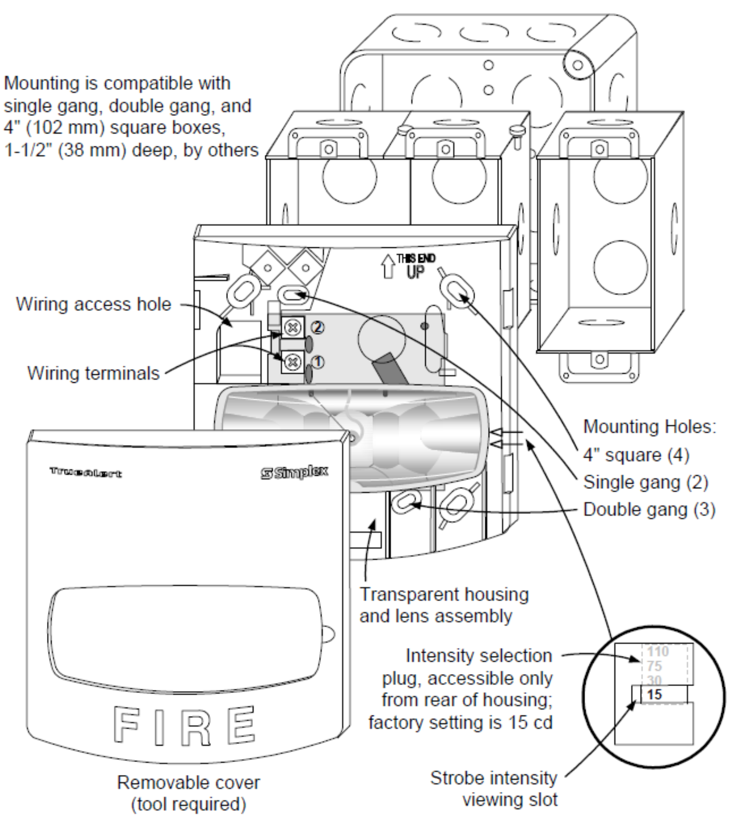
Rated Voltage Range	Regulated 24 VDC; see Note 1 below
Flash Rate	1 Hz
Synchronized NAC Loading	Up to 35 synchronized strobes maximum per NAC
Temperature Range	32° to 122° F (0° to 50° C)
Humidity Range	10% to 93%, non-condensing at 100° F (38° C)
Connections	Terminal blocks for 18 AWG to 12 AWG (0.82 mm^2 to 3.31 mm^2); two wires per terminal for in/out wiring

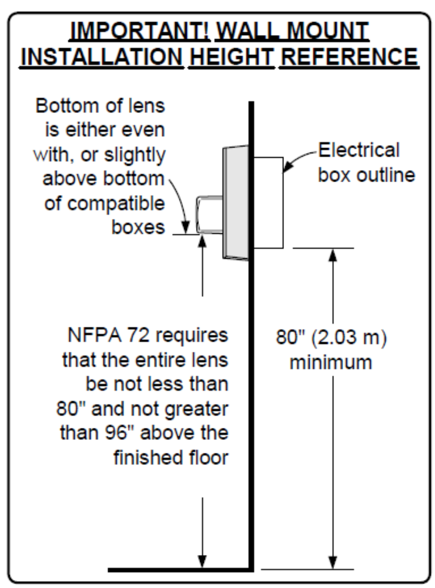
Wall Mount	Housing Dimensions (with lens)		5-1/8" H x 5" W x 2-3/4" D (130 mm x 127 mm x 70 mm)			
	Maximum RMS Current Rating per Strobe Setting (see Note 2 below)		**15 cd**	**30 cd**	**75 cd**	**110 cd**
			60 mA	**94 mA**	**186 mA**	**252 mA**
	Reference RMS Currents at other voltages	18 VDC	53 mA	84 mA	165 mA	224 mA
		24 VDC	40 mA	63 mA	124 mA	168 mA
Ceiling Mount	Housing Dimensions (with lens)		4-3/4" L x 2-5/16" W x 2-5/8" D (121 mm x 75 mm x 67 mm)			
	Maximum RMS Current Rating per Strobe Setting (see Note 2 below)		**15 cd**	**30 cd**	**75 cd**	**110 cd**
			75 mA	**125 mA**	**233 mA**	**316 mA**
	Reference RMS Currents at other voltages	18 VDC	67 mA	111 mA	207 mA	281 mA
		24 VDC	50 mA	83 mA	155 mA	211 mA

NOTES:

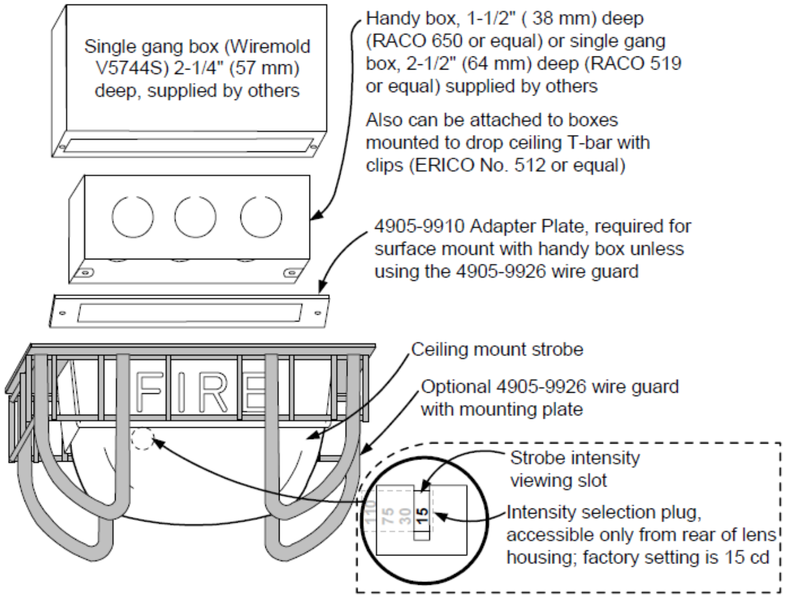
1. "Regulated 24 VDC" refers to the voltage range of 16 to 33 VDC per UL Standard 1971, *Signaling Devices for the Hearing Impaired*, changes effective May 1, 2004. This voltage range is the absolute operating range. Operation outside of this range may cause permanent damage to the strobe. Please note that 16 VDC is the lowest operating voltage that is allowed at the last appliance on the NAC under worst case conditions.
2. The maximum RMS current listed is the device nameplate rating. Strobe designs are constant wattage and the maximum RMS current rating occurs at the lowest allowable operating voltage. (RMS is root mean square and refers to the effective value of a varying current waveform.)

Installation Reference, Surface or Semi-Flush Wall Mounting

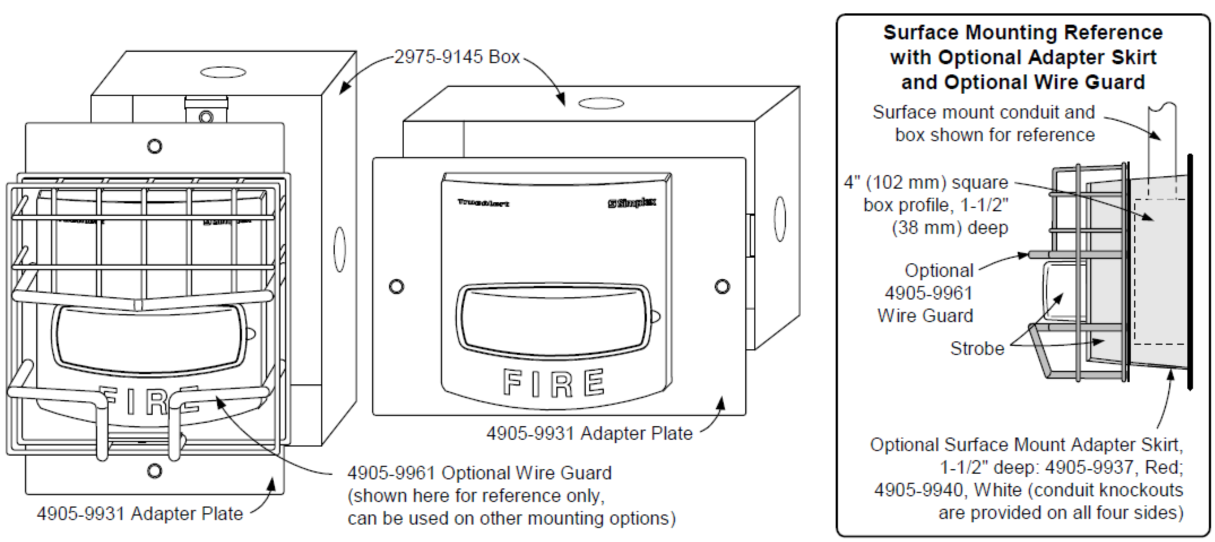




Ceiling Mount Strobe Installation Reference



Wall Mount Installation Reference; Adapter Plate, Guard, and Adapter Skirt



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Appendix B

26 Normal Operation and Electrical Supervision Tests

26.1 A system or unit shall be capable of operating for all conditions of its intended performance when used in conjunction with initiating devices, indicating devices, and power supplies to form a combination of the type indicated by the installation documentation.

26.2 To determine if a system or unit complies with the requirements in 26.1, initiating devices, signaling devices, and power supply circuits are to be connected as specified by the installation document to form a typical combination, and the system or unit is then to be operated for each condition of its intended performance.

26.3 The initiating devices (remote transmitters, remote receivers, heat detectors, thermostats, smoke detectors, and the like) used for testing are to be those specified by the installation document of the system. Substitute devices shall not be used unless they produce operation of the unit and circuit loading that has been determined to be equivalent.

26.4 Substitute load devices are considered to be those that have been determined by investigation to provide the same load conditions as those obtained with the devices intended to be used with the system in service.

26.5 During the test each power supply circuit is to provide the rated frequency and voltage.

26.6 All products shall comply with all applicable performance and supervision requirements in the National Fire Alarm Code, NFPA 72. All products intended for commercial use shall also comply with the requirements in the Standard for Control Units for Fire-Protective Signaling Systems, UL 864, and all products intended for residential use only shall also comply with the requirements in the Standard for Household Fire Warning System Units, UL 985.

26.7 There shall be a distinction among signals for units also intended to signal other than a fire condition.

27 Signal Strength and Format Test

27.1 General

27.1.1 Alarm signaling for the hearing impaired shall take the form of flashing light, vibration, or air movement. The signal shall be pulsating and shall operate at or above the signal strength rating for the device. The signal format or general plan for organization and arrangement of the signal shall conform to the manufacturer's description of the signal shown in the installation and operations manual for the device. See the Installation and Operating Instructions, General, Section 48.

27.1.2 Two samples of a single signaling unit or two samples of a system combination of units are to be tested in the as-received condition. These units or system are to be mounted, electrically connected, and operated in accordance with the installation instructions provided with the equipment. In those cases in which electrical power is not required but energy is achieved through a mechanical means such as pressurization, compression, weight loading, and the like, the system is to be prepared for normal supervisory condition in accordance with the instructions provided with the equipment.

27.1.3 The following minimum signal strengths shall be met:

a) Signaling lights shall produce a candela output in effective intensity in accordance with Tables 27.1 – 27.3 and Figures 27.1 – 27.3. The flash rate shall not be less than 1 hertz or greater than 2 hertz over the rated operating voltage range. The light output shall be white light. The measurement of light output shall be in accordance with the procedure described in 27.2.1–27.2.4.

b) A vibration unit (not worn) shall produce a radial displacement of 1/8 inch (3.2 mm) minimum. The vibration frequency shall be within a range of 60 – 120 hertz. The vibration device shall have a cross-sectional area of at least 6 square inches (38.7 cm^2) for at least one of its three dimensional planes and that plane shall have linear dimensions not less than 1-3/8 inches (34.9 mm).

c) Air movement systems shall produce a minimum air peak velocity of 270 feet (82 m) per minute at a distance of 5 feet (1.5 m). The signal shall vary from zero air movement to peak velocity at a frequency of 15 – 20 cycles per minute. The pattern shall impact a full 2-foot square (0.372-m^2) area.

Table 27.1
Required minimum percentage for horizontal dispersion

Degrees[a]	Percent of rating
0	100
5 – 25	90
30 – 45	75
50	55
55	45
60	40
65	35
70	35
75	30
80	30
85	25
90	25
Compound 45 to the right	24
Compound 45 to the left	24

[a] Tolerance of ±1 degree is permitted.

Table 27.2
Required minimum percentage for vertical dispersion

Degrees[a]	Percent of rating
0	100
5 – 30	90
35	65
40	46
45	34
50	27
55	22
60	18
65	16
70	15
75	13
80	12
85	12
90	12

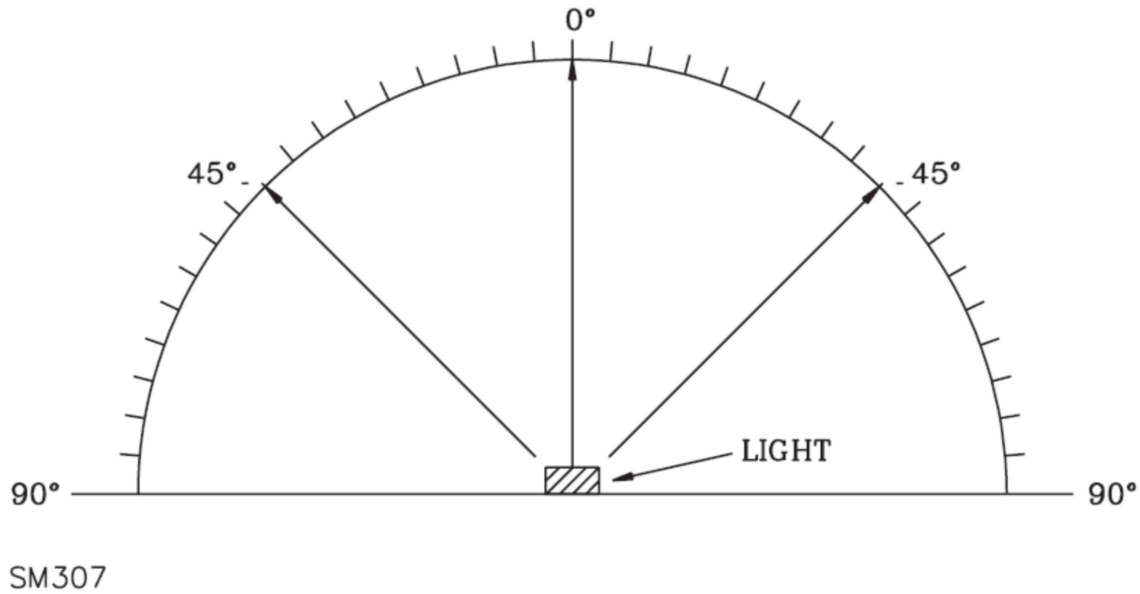
[a] Tolerance of ±1 degree is permitted.

Table 27.3
Required minimum percentage for vertical dispersion in both X and Y planes

Degrees[a]	Percent of rating
0	100
5 – 25	90
30 – 45	75
50	55
55	45
60	40
65	35
70	35
75	30
80	30
85	25
90	25

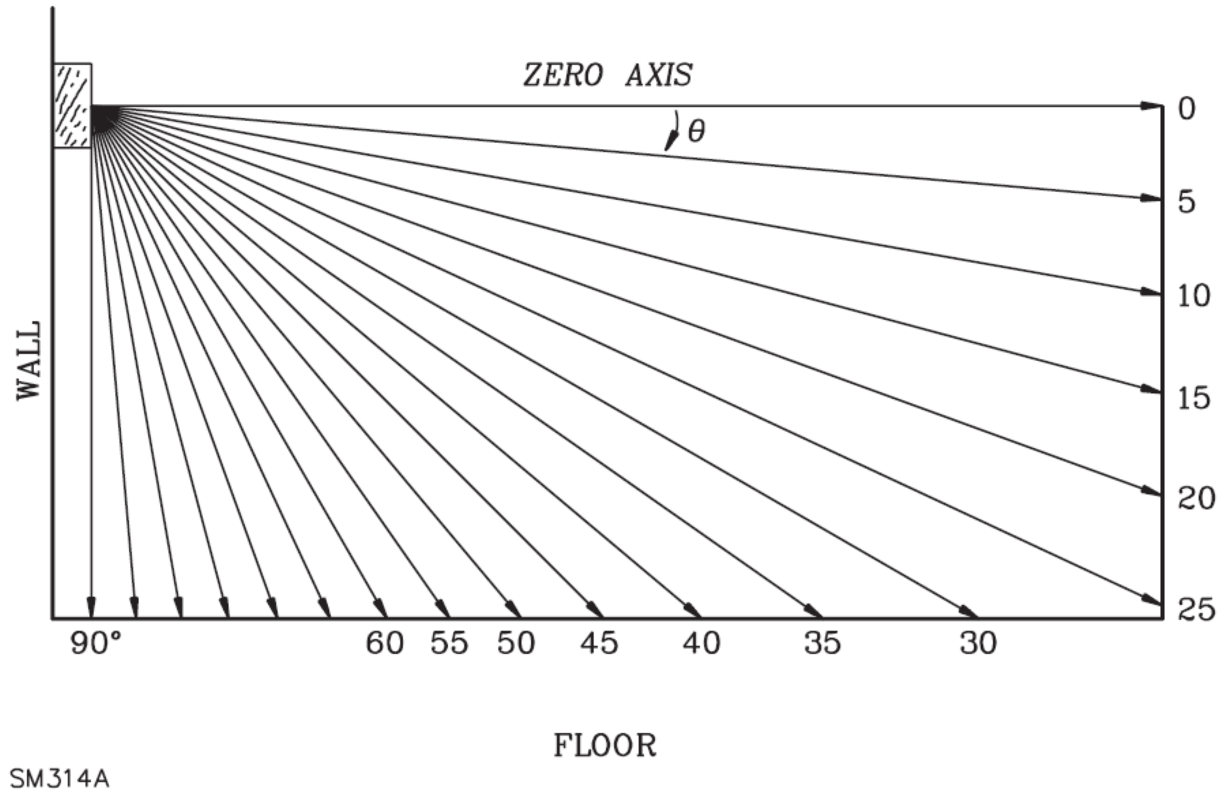
[a] Tolerance of ±1 degree is permitted.

Figure 27.1
Light output – horizontal dispersion



NOTE – Rating is on axis measurement at 0 degrees as indicated in Table 27.1.

Figure 27.2
Light output – vertical dispersion, wall to floor

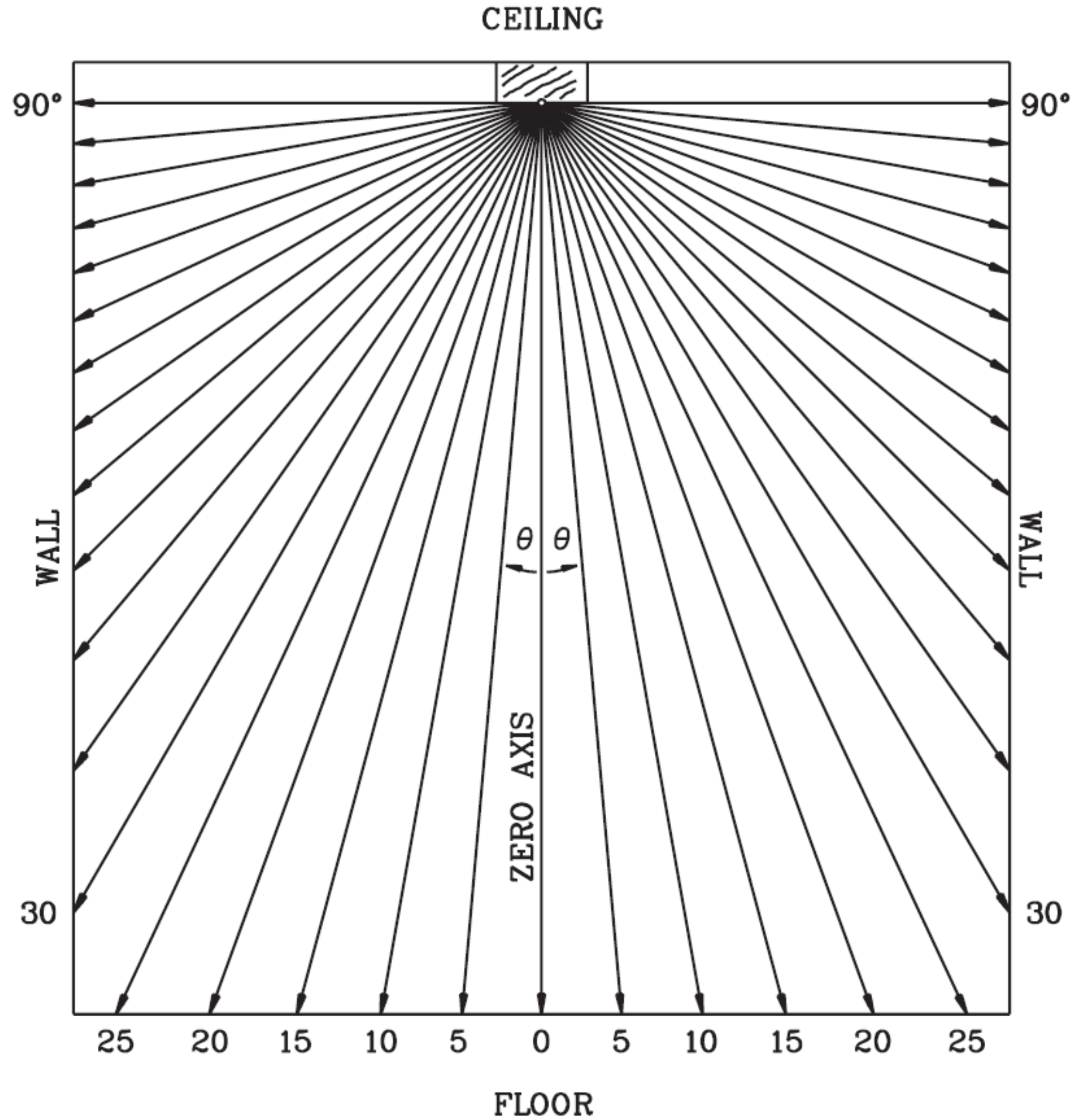


NOTES

1 Visible signaling devices used below 24 inches (0.6 m) from the ceiling shall produce light output above zero axis greater than or equal to the values noted in Table 27.2.

2 Not all 5 degree incremental measurements, above zero axis, are required. Only those light increments that produce light patterns below the 24 inch (0.6 mm) level are required. As an example, a signaling device located at a 4 foot (1.2 m) level within a room with an 8-foot (2.4-m) ceiling shall also comply with light measurements for the wall height of 4 – 6 feet (1.2 – 1.8 m).

Figure 27.3
Light output – vertical dispersion, ceiling to walls and floor



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NOTES – Vertical dispersion is measured in both the x and y planes (one set of measurements, then rotate 90 degrees and repeat measurements) as viewed from below the light looking up from the floor. Table 27.3 illustrates the minimum percent value of the on-axis rating for each 5-degree dispersion angle as illustrated in Figure 27.3.

Four additional compound angles are to be measured, one per floor quadrant, each complying with the minimum 24 percent values specified in Table 27.1.