IALA GUIDELINE

G1049
THE USE OF MODERN LIGHT SOURCES IN TRADITIONAL LIGHTHOUSE OPTICS

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1. INTRODUCTION

1.1. SCOPE AND PURPOSE

Many lighthouse services are removing or decommissioning traditional optics and installing new, smaller, self-contained devices. There are good economic reasons for doing this, but sometimes there is a need to retain large traditional optics. In this case, the choice of light source is important.

The purpose of this Guideline is to provide the IALA membership with guidance on methods of using modern light sources in traditional optic systems.

1.2. REASONS FOR RETAINING TRADITIONAL OPTIC SYSTEMS

There is a tendency in lighthouse services, when modernizing lighthouses, to replace large, traditional optics (Figure 1) with smaller, more modern, self-contained beacons (Figure 2). This is reasonable given the cost of modernizing an old optic compared with the cost of an easily installed modern equivalent. However, there are some reasons why traditional optics may be retained in service.

1.2.1. ROTATING OPTICS WITH COMPLEX CHARACTERS

Some modern self-contained rotating beacons have a hexagonal or octagonal lens geometry which is satisfactory for simple (e.g., single flash) characters but not for more complex group flashes. Fast rotational speeds are usually required for anything greater than a single flash character which has the effect of reducing effective intensity and can produce a shorter than satisfactory flash duration (see Figure 3 and Figure 4).

1.2.2. FUTURE CHANGES

As new light sources become available, it is often desirable to replace existing light sources with modern, more efficient ones. A large optic with separate components is usually more easily modified than a small self-contained one. This is especially true when the range of light must be increased by installing a larger, more powerful lamp (see Table 1). There is also a trend towards reducing the range of lights and modern low power sources can be used in traditional lens to provide a light of the required range while meeting the requirement of low energy consumption.

1.2.3. CONSERVATION AND HERITAGE

There has been more pressure on lighthouse services in recent years from conservationist lobbies to retain original equipment in working order. At the same time there is the need to provide an efficient service without tending to obsolete and labour intensive equipment. A compromise can often be reached by retaining important features of an optic and running them efficiently.

If retention of a traditional optic is desirable, the choice of light source is important. The purpose of this document is to show the effects of various modern light sources in traditional optics and compare them to more traditional light sources, including mantles and older filament lamps.

Optics are grouped into two broad categories, fixed and rotating. Fixed optics require the light source to be switched on and off to produce a character, and rotating optics require a constantly burning light source.

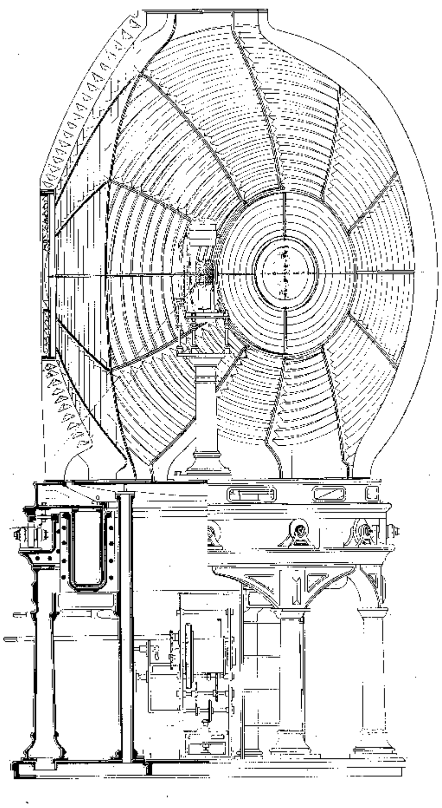

Figure 1 Trevose Head 1st order rotating optic

This is a typical traditional lighthouse optic dating from about 1900. Total height is approximately 4.5m.

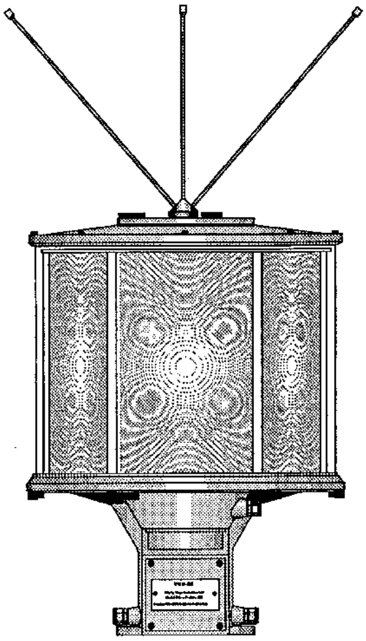

Figure 2 Modern rotating beacon with six equal and symmetrical lens panels

This beacon is approximately 0.7m high not including the bird spikes. A typical lens arrangement is shown in Figure 4. *(Courtesy Vega Industries)*

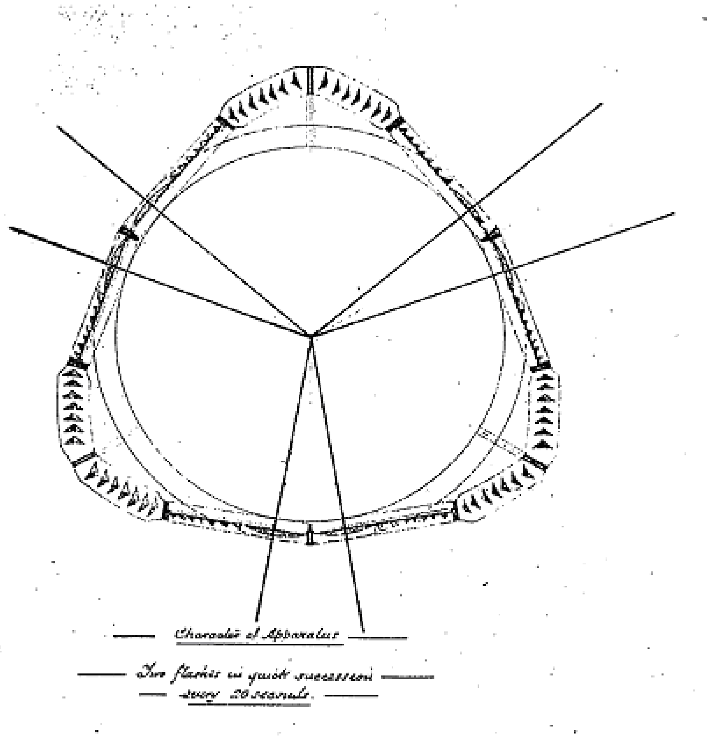

Figure 3 Keeping complex characters (Beachy Head)

First order lens arrangement at Beachy Head giving Fl (2) 20s. A rotational speed of 1RPM is required to achieve this character.

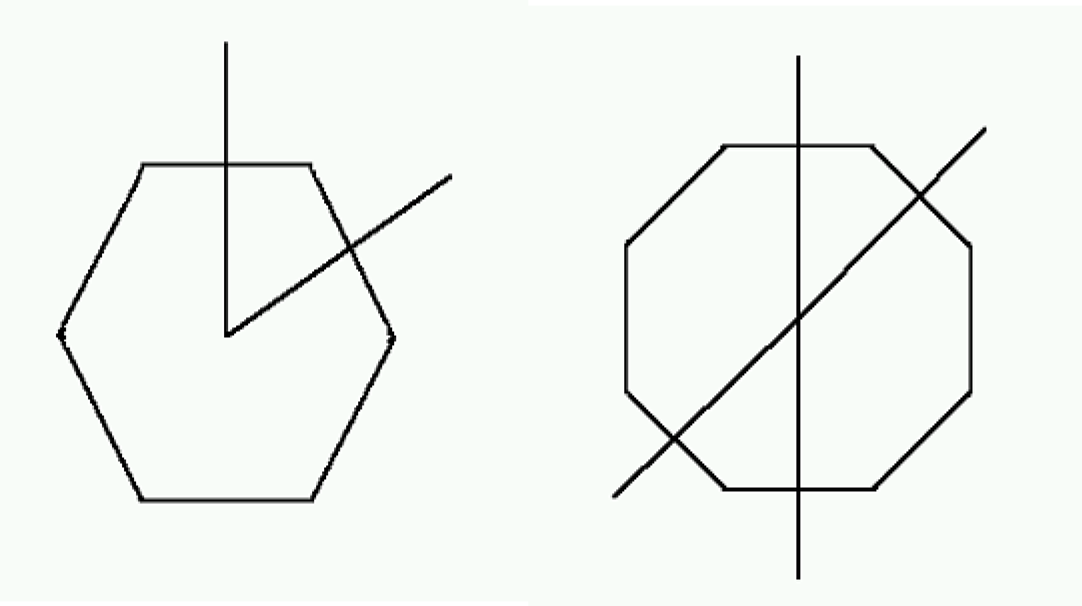

Figure 4 Keeping complex character (eighth and six panel rotating beacons)

Typical lens arrangement of eight and six panel rotating beacons. To give a character of Fl (2) 20s conforming with IALA recommendations rotational speeds of 1.5 RPM and 3 RPM respectively are required.

Table 1 Flexibility Measured results of Beachy Head

Lamp Type	Peak Intensity (cd)	Effective Intensity (cd)	Nominal Range (nautical miles)	Flash Duration (seconds)		Vertical Divergence (degrees)	
				10%	50%	10%	50%
1000W GE MBI	3,040,000	1,580,000	27	0.54	0.20	>6.0	4.1
400W GE MBI	1,350,000	697,000	25	0.35	0.18	4.8	2.2
35W Philips Master colour	315,000	151,000	21	0.34	0.15	1.7	1.0

1st order rotating optic with 1000W, 400W and 35W lamps. Medium to high nominal ranges can be achieved by selecting the appropriate light source.

2. ORIGINAL LIGHT SOURCES AND THEIR SUCCESSORS

The original light sources used in traditional optics varied from large paraffin vapour burning (PVB) mantles to Argand lamps and smaller acetylene mantles. In general, the size of the light source was much greater than modern electric light sources. They required a fair amount of attention in the way of maintenance and fuel management. Light output often varied and there was the ever present danger of fire. Some later acetylene systems were quite reliable and, in many instances, unattended operation became possible.

When lighthouses were first electrified, special lighthouse lamps were produced which had tungsten filament arrangements that tried to mimic the original light sources. Compared to their forerunners, they had high luminance, relatively consistent luminous flux, were relatively safe in operation and needed no trimming or priming. Because of their high luminance these lamps produced high intensities and, because of their filament geometry, good performances. In rotating optics this meant high nominal ranges and reasonable flash profiles. However, they usually required large amounts of electrical power and, because of their size and fragility, were difficult to transport and handle. Many lighthouse lamps are now obsolete due to high manufacturing costs and limited demand.

3. MODERN LIGHT SOURCES ADVANTAGES AND DISADVANTAGES

Modern light sources come in many shapes and sizes and although there are common standards, there are product differences between manufacturers. Two types of modern lamp commonly used are metal halide and tungsten halogen lamps. Light emitting diodes (LEDs) are increasingly used as light sources.

3.1. METAL HALIDE LAMPS

Metal halide lamps are used in rotating optics where a continuous light source is required. These lamps have very high efficacies, up to 120 lumens per watt, they also provide a very white light, and lamp life is up to 20,000 hours. Light colour correlated temperature (CCT) ranges from 3000 °K to 6000 °K, and lamps from tens of watts to several kilowatts are readily available. The smaller sized lamps are relatively rugged compared to specialized lighthouse lamps, and the single ended versions have simple plug-in bases. However, there are some disadvantages with metal halide lamps. They cannot be switched on and off rapidly to provide a character because they need time to warm up and cool down; this largely precludes their use in fixed optics. Their spectral content is low in red colour which means their use with red filters is inefficient. They require an AC supply which is carefully controlled and includes high voltage starting arrangements. Small sized lamps, although producing high luminance, have a small light source area resulting in narrow divergence in large optics. Larger metal halide lamps usually have a tall thin light source area which produces short flash durations in large optics and large, often unwanted, vertical divergences (see Table 1 and Figure 7). Some larger metal halide lamps are available with a phosphorescent coated envelope. The light source is usually larger than the original light source, but the luminance is quite low producing much lower intensities than the clear envelope versions (Table 2).

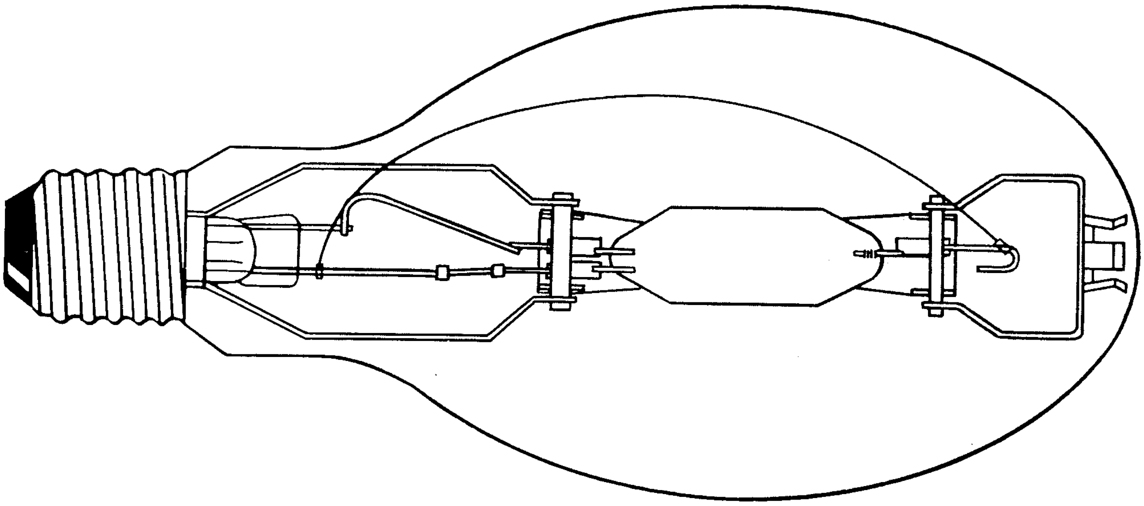

Figure 5 400W metal halide lamp showing the arc tube arrangement

This lamp is available in clear and coated envelope versions. *(Courtesy GE Lighting)*

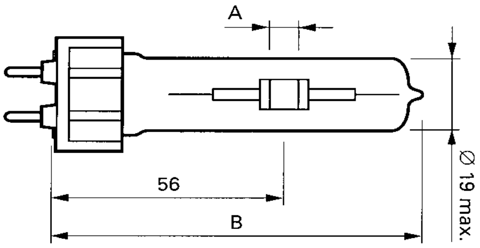

Figure 6 Low power metal halide lamp showing arc tube position

These lamps are available in 35W, 70W and 150W ratings, arc tube size varies accordingly. *(Courtesy Philips Lighting)*

***Note:* Drawings not to scale**

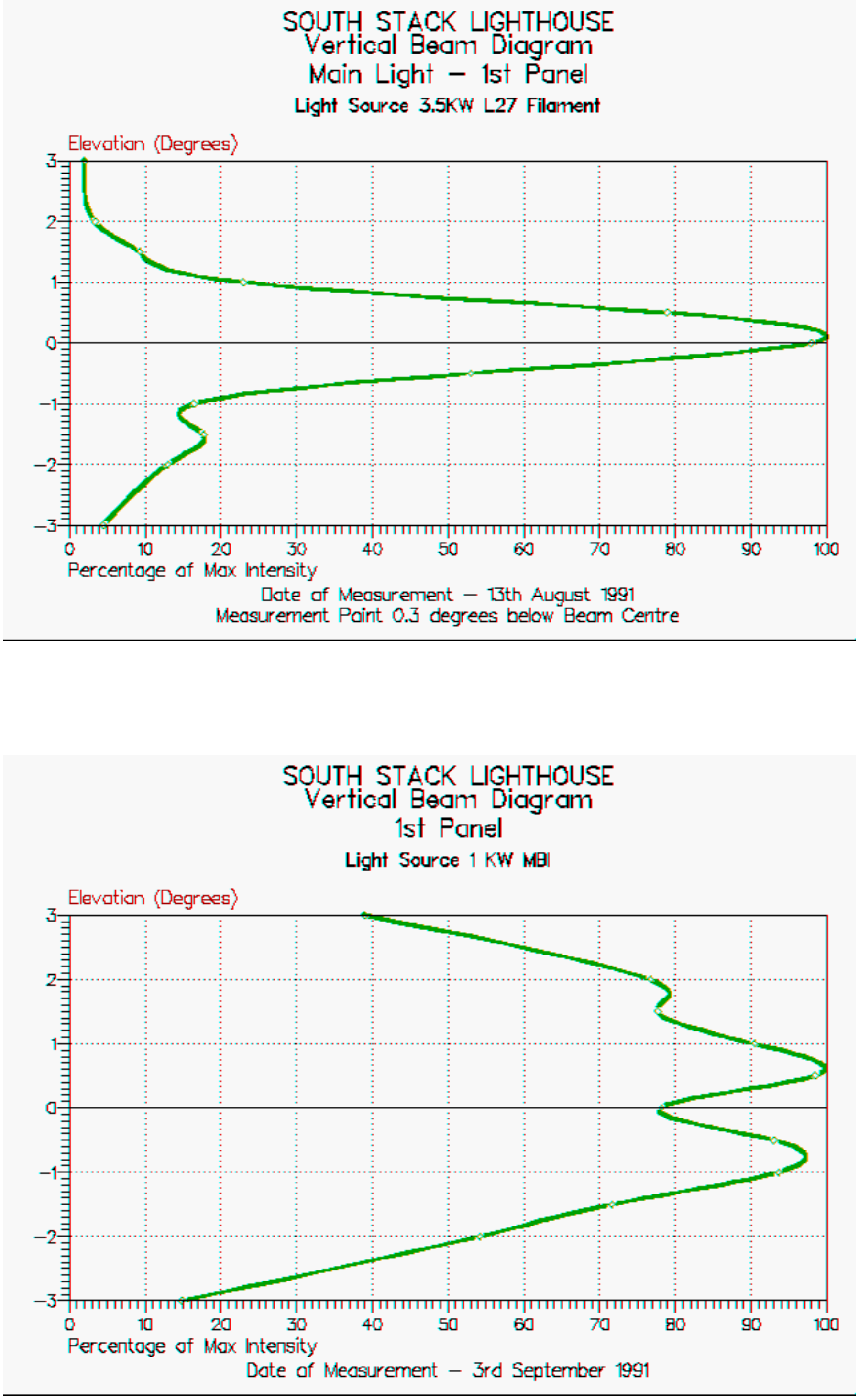

Figure 7 Two vertical beam diagrams of South Stack

1st order lens showing the difference in vertical divergence between a 3.5kW L27 filament lamp and a 1kW metal halide. The tall arc tube of the metal halide lamp produces a large vertical divergence. The upper and lower lobes of the lower plot are caused by the effect of the tall light source on the upper and lower reflecting elements.

3.2. TUNGSTEN HALOGEN LAMPS

Tungsten halogen lamps are widely used today and are consequently cheap and readily available. They have the same ease of operation as the lighthouse lamp but have smaller size, longer life (up to 2000 hours), greater ruggedness and efficacies up to 50% higher than a comparable tungsten filament lamp. However, they have the problem of small light source area. In the case of low voltage capsule lamps, the filament size is very small indeed and may lack symmetry. Another problem that can occur when flashing some tungsten halogen lamps is that the halogen cycle may be interrupted causing envelope blackening and shortening of life. This only seems to occur with some lamps and even then, only with some characters.

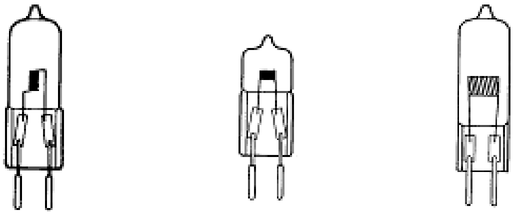

Figure 8 Tungsten halogen capsule lamps with different filament arrangements.

(Courtesy: GE Lighting)

***Note:* Drawings not to scale**

3.3. LIGHT EMITTING DIODES

High power LEDs are becoming increasingly available and provide benefits of low energy consumption with high output efficiency, particularly for coloured lights.

3.3.1. PACKAGE CONSIDERATIONS

There are different types of packaging construction:

1 One or several led chip with different implantation (panel, line, ring, ...) and different colours

Figure 9 Example of LEDs implantation

(Source: Phillips Lumileds Lighting Company)

2 Optic depend on the expected radiation pattern

Figure 10 Example of LEDs optic: batwing and side-emitting Luxéon emitter

(Source: Phillips Lumileds Lighting Company)

3 Heat dissipation or not packaging

Figure 11 Example of LED heat dissipation package: side-emitting Luxéon emitter

(Source: Phillips Lumileds Lighting Company)

When using LEDs in traditional optic systems, the following points must be considered:

- LED junction temperature must be below the manufacturer's critical limit to achieve a lifetime.
- Temperature increase with focus of suns radiation through Fresnel optic must be above specified LED storage temperature (with storage temperature of 105°C for Luxéon LED, this is essentially a problem for rotating beacons with cut glass optics).
- Colour must be within IALA recommended regions specification over the whole temperature range.
- Reference luminous intensity and reference supply voltage must be measured for the worst conditions of use (high ambient temperature, maximal current and important duty cycle).
- Luminous source must be large enough to have correct divergence.
- Luminous source must be as small as possible and located at the correct focal distance to have main intensity in the axis of the optic.
- Horizontal radiation pattern must be regular to avoid variations of intensity in different directions of observation of the light.

Junction temperature can be calculated with a direct measurement near the LED on the heat sink and with manufacturer's information of the thermal resistance of the junction/board.

A high power LED chip is fixed to a metal heat-sink slug, which provides the primary thermal path. A high temperature plastic lens is attached to the plastic case, and the gap between the power LED chip and the lens is filled with a silicone encapsulant. Silicon encapsulant is more resistant to yellowing/browning due to UV exposure and high levels of blue light emission.

High power LED technology is dependent on:

- adequate heat dissipation; and
- a choice of materials with a wider utilization temperature range and higher levels of resistance of near-UV energy.

3.3.2. LIFETIME

Lifetime and flux of small-signal LEDs are extremely dependent on operation conditions.

For high power LED 1W with a 350 mA current above 90°C temperature junction, flux decrease is nearly 30% after more than 50 000 hours.

3.3.3. COLOUR, FLUX, FORWARD VOLTAGE

Colour, flux and forward voltage are variable and depend on the method of manufacturing. All characteristics are not always available, and one or two characteristics must be primary for selection of LEDs.

When the temperature junction increases, the dominant wavelength increases, and flux and forward voltages decrease. Variations are more important for amber and red (AlInGaP technology) than white and green (InGaN technology). Temperature junction is dependent on current, ambient temperature, heat sink and duty cycle (e.g., rhythmic character).

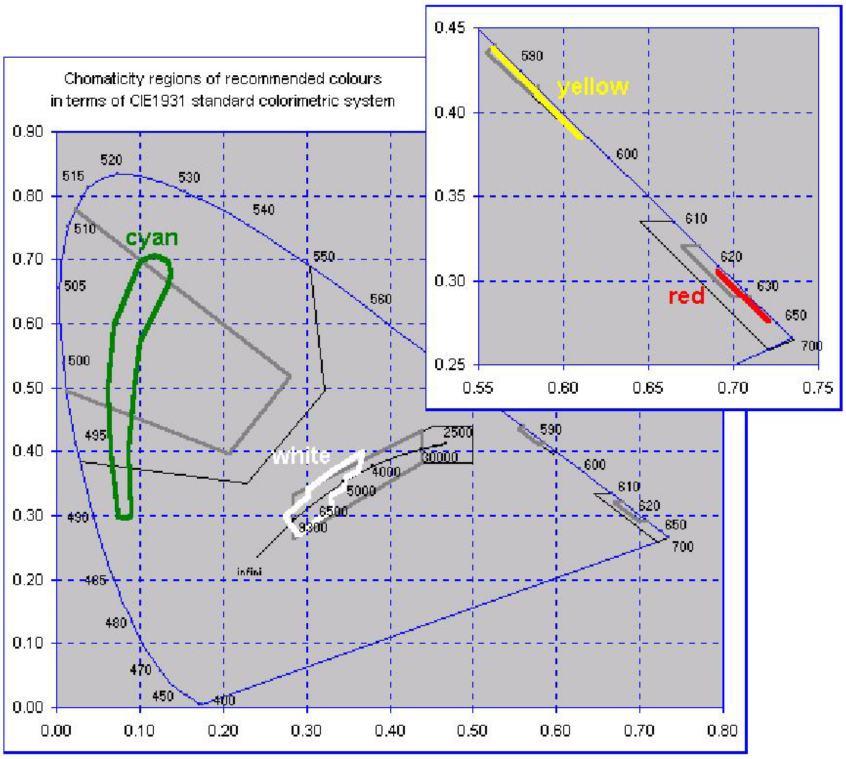

Figure 12 Colours of high power LED

3.3.4. RADIATION PATTERN

There are a lot of distinct radiation patterns, depend on manufacturer and type of LED. For example, Luxéon production family presents three distinct radiation patterns - batwing, lambertian and side emitting.

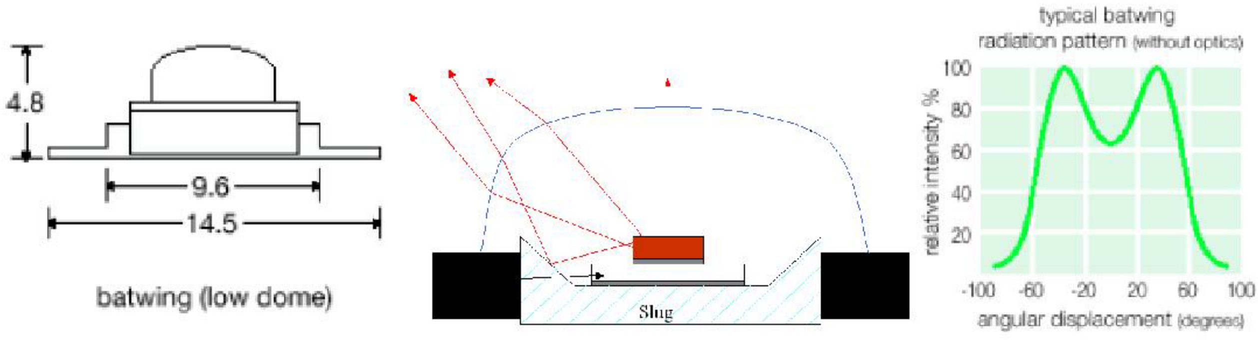

Figure 13 Typical batwing radiation pattern

(Source: Lumileds Lighting LLC)

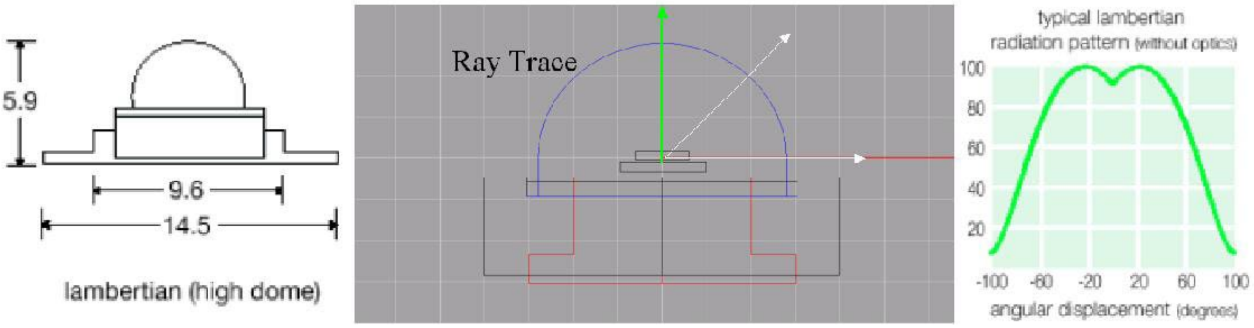

Figure 14 Typical lambertian radiation pattern

(Source: Lumileds Lighting LLC)

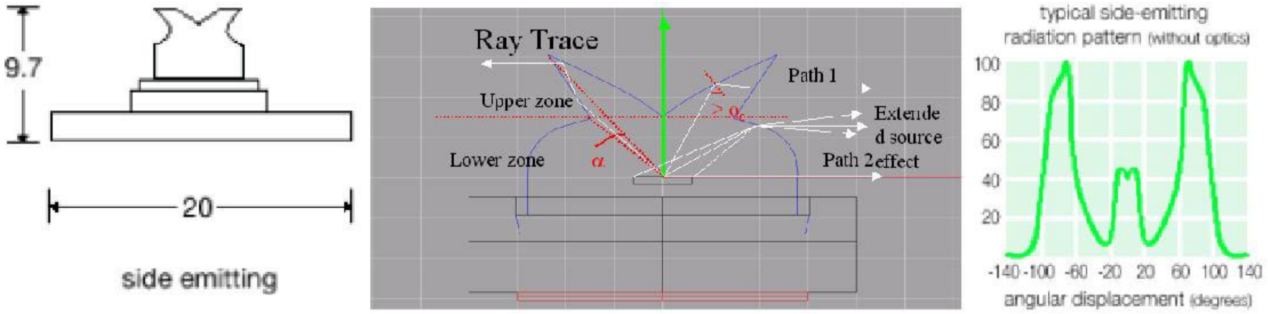

Figure 15 Typical side-emitting radiation pattern

(Source: Lumileds Lighting LLC)

It should be noted that side emitting diodes typically radiate maximum light at an angle of 10 degrees above the horizon. When correctly installed at the focal point in large lens systems, the light slightly above the horizon is collected by the lens and directed into a horizontal beam, giving a satisfactory performance. Care must be taken when using side emitting diodes in small lens systems because of the non-horizontal beam from the diode.

3.4. GENERAL DISADVANTAGES WITH SMALL LIGHT SOURCES

Large rotating lens systems were designed to collect light form a large source such as a paraffin wick or paraffin vapour burner (PVB) and form the light into a parallel pencil beam using a combination of refractor and reflecting elements.

Any small light source in a large lens can produce poorer than expected results because the lens was designed to focus a large light source.

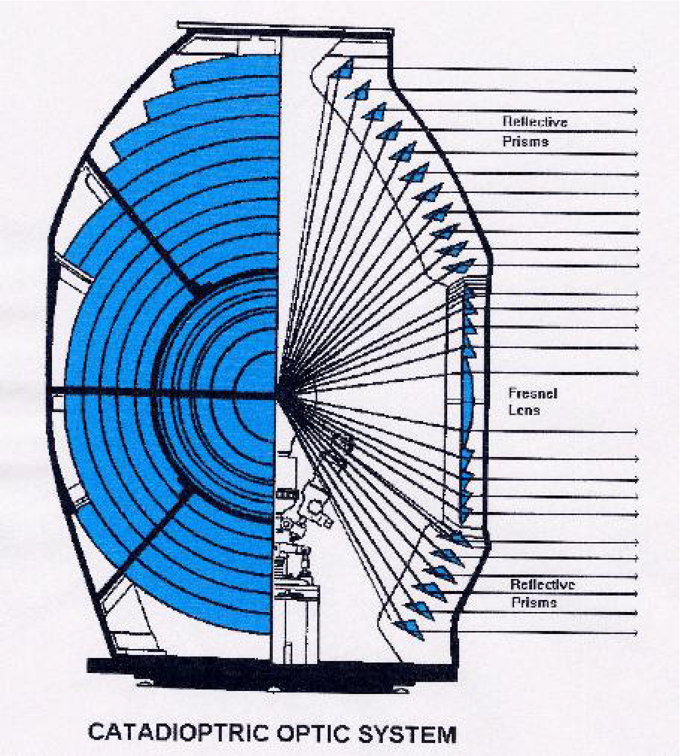

Figure 16 Catadioptric optic system

If lens tolerance is poor, a greater than expected, or unevenly distributed vertical divergence is usually the result. In the case of a traditional rotating optic with several lens panels, there can be large differences in performance between lens panels when the optic is fitted with a small light source. Whatever the type of optic, the correct positioning of the light source within it is important to ensure optimum performance. A maximum and consistent intensity is required throughout the arc of operation of the optic and at the horizon. With the narrow vertical divergences resulting from small light sources in large optics, correct positioning becomes more critical. A vertical positioning error of a few millimetres with a filament that is itself only a few millimetres tall can result in only a small percentage of the beam centre maximum being directed towards the horizon. Modern lamps, not designed specifically for AtoN use, may have considerable manufacturing tolerances and require careful and regular adjustment to ensure correct focusing.

4. OPTIC PERFORMANCE WITH DIFFERENT LIGHT SOURCES

During the 1990s, in order to reduce energy requirements for potential use of solar power, some small, low power lamps were tested by Trinity House Lighthouse Service in large optics to see how they performed. In many cases the small size of the light source has caused problems of poor performance including short flash duration and low intensity. Various techniques such as envelope etching, reeded diffusion and lamp clusters were tested to enhance the performance of these low power light sources in order to optimize their use within traditional optics.

Table 2 Measured results of Lynmouth Foreland

Lamp Type	**Peak Intensity (cd)**	**Flash Duration (seconds)**	
		10%	50%
100mm Paraffin Vapour Burner	110,000	0.35	0.29
1000W MBI clear envelope clear arc tube	2,330,000	0.16	0.07
1000W Kolorarc coated envelope	142,000	0.75	0.62
400W MBI clear envelope etched arc tube	1,130,000	0.16	0.07
35W Powerstar clear envelope	305,000	0.13	0.06
35W Powerstar etched envelope	160,000	0.18	0.08

1st order rotating optic comparing various light sources. It can be seen that the original PVB gave a fairly low intensity light but with a reasonable flash duration. The coated envelope lamp is a much larger light source than the PVB hence the greater flash length, but the intensity is comparable. By contrast, the clear envelope metal halide lamps give a high intensity, but their small light source area gives a much shorter flash duration.

Table 3 Measured results of South Stack

Light Source	**Peak Intensity (cd)**	**Effective Intensity (cd)**		**Flash Duration (secs)**		**Vertical Divergence (degrees)**	
		Blondel-Rey (BS942)	Schmidt-Clausen (IALA)	10 %	50 %	10 %	50 %
3.5 kW L27 Tungsten Filament	3,890,000	3,080,000	2,000,000	0.57	0.32	3.75	1.25
1000 W MBI Metal Halide with etched arc tube	2,940,000	1,960,000	1,370,000	0.45	0.20	>6.0	5.0

1st order rotating optic comparing L27 3500 W filament lamp with 1000 W metal halide.

Table 4 Measured results of Farne Islands

Light Source	**Red Filter Trans (%)**	**Peak Intensity (cd)**	**Effective Intensity (cd)**		**Flash Duration (secs)**		**Vertical Divergence (degrees)**	
			Blondel-Rey (BS942)	Schmidt-Clausen (IALA)	90%	50%	10%	50%
GNUK25 Acetylene Mantle	22	572	515	494	0.90	1.50	>6.0	2.5
50W Osram Halostar	19	2,030	1,770	1,650	0.69	0.88	>4.0	1.5

3rd order fixed optic white sector comparing GNUK25 acetylene mantle and 12V 50W tungsten halogen lamp. A single halogen lamp gives a better performance than the acetylene mantle in this 500mm focal distance lens. However, note the lower figures for red filter transmittance and vertical divergence.

5. USING MODERN LIGHT SOURCES EFFECTIVELY

5.1. METAL HALIDE LAMPS

Adequate provision for warm up and cool down times of metal halide lamps should be allowed for in any lamp changing or switching arrangements. Warm up times vary between two and ten minutes depending on the size of lamp, cool down times can be as much as twenty minutes before re-strike is possible. Hot re-strike facilities are available on some lamp control equipment which enables a lamp to be reignited within a few seconds after switch off and usually involves placing a very high voltage across the lamp terminals. This is not recommended for single ended lamps, usually used in lighthouse applications, because of the possibility of arcing across the small physical distance between lamp terminals on the lamp cap. Hot re-striking also shortens the life of the lamp.

Most metal halide lamp controllers are designed to run from a high voltage AC supply, the simpler designs incorporate a ballast choke to limit lamp current and supply the lamps with a voltage between 80VAC and 240VAC depending on lamp type. If low power battery operation is required, a conversion from low voltage DC to high voltage AC is necessary. Given losses in DC to AC conversion and further lamp control gear losses, the efficiency of the lighting system will be reduced. Typically, fifty or sixty watts of DC power is required to run a 35W lamp. In a solar powered application this waste of power cannot usually be tolerated and a more efficient method of running a metal halide lamp is required. There are several electronic lamp control systems now available that improve system efficiency, typically delivers 35 W to the lamp for an electrical power input of less than 38W.

Metal halide lamps are useful in rotating optics where the light source is constantly lit. Their warm up and cool down time requirements usually preclude them from being flashed on and off to produce a character in a fixed lens. Another consideration is the spectral content of these lamps, which contains very little red. It is usually fixed optics that are fitted with coloured sectors because of the sharp sector cut produced by, for instance, a drum lens and a large percentage of sectors used in lighthouses (in the UK and Ireland at least) are red. If there is a requirement for a metal halide lamp to be used in conjunction with red filter material, great care should be taken in choosing the material. Standard filter materials, may result in a colour with a chromaticity outside the IALA preferred or general region. In addition, the transmittance may be as low as 8%, resulting in a lower than expected red light intensity.

5.2. TUNGSTEN HALOGEN LAMPS

In general, tungsten halogen lamps lend themselves quite well to being switched on and off to provide a character for use in aid to navigation. However, problems can sometimes occur when the halogen cycle is interrupted due to envelope wall temperatures being too low. This results in the tungsten from the filament being deposited on the inside of the envelope causing it to go black. A shortening of lamp life is inevitable. This phenomenon seems to occur with certain types of lamp, usually those with a larger envelope, and only then with certain flash characters. A cure for this problem depends very much on the circumstances but changing the character or lamp voltage is sometimes effective. The addition or removal of simmering current can also have an effect. Most low power capsule lamps do not suffer these potentially disastrous effects.

A small capsule lamp with a filament area of a few square millimetres, although of high luminance, can produce a poor performance in a large fixed optic because of poor lens manufacturing tolerances and difficulty in positioning the lamp correctly. One technique that can improve performance is that of placing several lamps close together to form a cluster. Grouping lamps together increases the overall width of the light source that eases focussing problems and illuminates the lens more effectively. In some cases, a cluster of three lamps in a first order optic gave significantly more than three times the intensity of a single lamp of the same type (Figure 17 and Table 5). However, this is not always the case, optics must be individually assessed as to which size of light source is most suitable. One experiment in a first order lens was carried out where a cluster of eight lamps was compared with a cluster of four. The eight lamp cluster gave less intensity than the four lamp clusters because the lamps were further apart; therefore the overall luminance of the light source was lower.

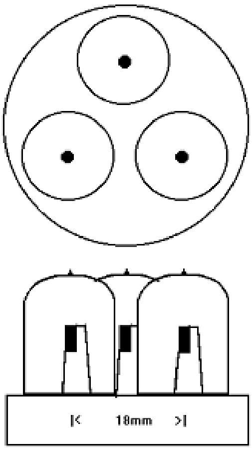

Figure 17 Schematic of a cluster of three halogen axial filament capsule lamps

Three 100W Osram Halostar lamps were used in the first order fixed lens at Flat Holm.

Table 5   Measured results of the white sector of Flat Holm

Light Source	**Peak Intensity (cd)**	**Effective Intensity (cd)**		**Flash Duration (secs)**		**Vertical Divergence (degrees)**	
		Blondel-Rey (BS942)	Schmidt-Clausen (IALA)	90%	50%	10%	50%
1.5kW L26 Tungsten Filament	29,100	24,900	24,100	0.60	0.97	4.0	1.9
Single 100W Halostar	3,650	2,860	2,920	0.36	0.79	3.0	1.1
Cluster of 3 x 100W Halostar	21,000	16,000	17,100	0.32	0.83	3.2	1.0

1st order fixed lens. A cluster of three 100W halogen lamps gives more than five times the intensity of a single 100W lamp of the same type and is comparable to a 1.5kW lighthouse lamp.

Table 6   Measured results of the white sector of North Foreland

Light Source	**Peak Intensity (cd)**	**Effective Intensity (cd)**		**Flash Duration (secs)**		**Vertical Divergence (degrees)**	
		Blondel-Rey (BS942)	Schmidt-Clausen (IALA)	90%	50%	10%	50%
3kW EC111A Tungsten Filament	75,900	62,100	61,900	0.45	0.85	2.9	1.3
Cluster of 4 x 500W M40	89,800	78,300	72,500	0.68	0.86	4.0	1.5

1st order fixed lens. A cluster of four 500W halogen lamps gives a slightly greater intensity to that of a (now obsolete) 3kW lighthouse lamp.

5.3.   METHODS OF INCREASING THE EFFECTIVE SIZE OF A LIGHT SOURCE

The effect of increasing the size of a light source by using a cluster of lamps works well in some large, fixed optics. In large rotating optics, however, the use of lamp clusters can cause problems. This is because a fixed drum or beehive optic produces a fan beam with the character generated by flashing the light source on and off. A lens panel in a rotating optic produces a pencil beam, several of which are rotated about an axis to generate a character. When a cluster containing several light sources in different positions is placed at, or near, the focal centre of a rotating optic apparatus, the result is the production of more than one pencil beam. When the optic is rotated, the observer sees several flashes close together instead of a single flash.

How then, apart from using low luminance coated envelope lamps, can a single light source be increased in size and remain suitable for use in a rotating optic?

5.3.1.   ETCHED ARC TUBE

With larger metal halide lamps, which have a vertical arc tube, it is possible to have the arc tube etched during the manufacture of the lamp. Some manufacturers are willing to do this, usually at a cost. The effect of etching is to diffuse the light emanating from the arc, which runs between the electrodes at each end of the vertical arc tube.

The original Thorn 1000 W and 400 W MBI lamps used by the General Lighthouse Authorities had their arc tubes etched during manufacture but these lamps are now obsolete. However, this means that the manufacturer must produce, what is in effect, a special lamp. The result of arc tube etching is to increase horizontal divergence by approximately half at 50% of peak intensity. At 10 % of peak there is about a doubling in divergence. The drawback to arc tube etching, indeed any type of diffusion, is the reduction of light source luminance resulting in a proportional reduction in peak intensity. A good analogy to light diffusion is spreading margarine on bread, the further you spread it, the thinner it gets! This was used successfully for many years.

5.3.2. ETCHED ENVELOPE

With smaller lamps, it is possible to etch the lamp envelope, usually by sand blasting, to diffuse light emanating from the filament or arc tube. The advantage of this technique is that you have the availability of an “off the shelf” lamp which is then modified after purchase. The degree of etching depends on the thickness of the envelope and how much diffusion is required. The amount of diffusion will also depend on the size of the envelope. If envelope etching is undertaken, the process should be carefully investigated and controlled. Once again the etching and subsequent diffusion will lead to a reduction in luminance and peak intensity. Diffusion occurs in all directions so both flash duration and vertical divergence will be increased. Care must be taken when handling the light sources after etching has been carried out because greasy fingers may affect the etched surface. Indeed, the envelopes of most modern light sources, whether etched or not, should not be handled at all.

5.3.3. EXTERNAL DIFFUSERS

An external diffuser may be fitted around the light source in order to produce diffusion. Several types of diffuser are available, for instance, those used with portable butane gas lamps, although any cylinder of suitably abraded or patterned glass or plastic will do. Care should be taken when choosing diffuser material to ensure it can withstand the temperatures it is likely to encounter from radiation, convection, conduction etc. One factor often overlooked is the effect of sunlight focused to a point by the lens or lenses of the optic. Another problem with plastics is their degradation due to ultra-violet radiation. This may come from the sun or the light source, although most lamp manufacturers are now coating lamp envelopes with UV block filtering.

External diffusers made from reeded or fluted material can be very useful because they have the property of producing directional diffusion. The diffusing effect can be observed by looking through vertically reeded glass. The observer sees several images side by side, which produces a horizontal blurring of the object being viewed. Therefore, if the horizontally reeded glass is placed in front of a light source, it will appear wider but not taller. This is useful if only the flash duration of a rotating optic needs to be increased and not the vertical divergence. Referring to our margarine spreading analogy, if the margarine is spread in a thin line across the middle of the bread instead of over the whole slice, it will be thicker. By the same token, when light is diffused over an elliptical pattern instead of a circular pattern, with the major axis of the ellipse the same as the diameter of the circle, the luminance will be greater. The results of various diffusion techniques are shown in 0. The amount of diffusion provided by a reeded diffuser depends on the profile of the reeding, and the distance from the diffuser to the light source in proportion to the focal distance of the lens. Details of a reeded diffuser and the results of using it in a first order rotating optic are show in Figure 18 and Table 8.

Table 7 Measured results of Sark

Light Source	**Peak Intensity (cd)**	**Effective Intensity (cd)**		**Flash Duration (secs)**		**Vertical Divergence (degrees)**	
		Blondel-Rey (BS942)	Schmidt-Clausen (IALA)	10%	50%	10%	50%
100W Clear Envelope	1,030,000	812,000	669,000	0.35	0.13	1.0	0.6
100W Etched Envelope	232,000	187,000	138,000	0.63	0.24	2.8	1.2
100W with Lumagaz Etched Diffuser	59,000	52,200	45,700	1.16	0.75	>>4.0	>1.7
100W with Reeded Acrylic Diffuser	457,000	428,000	353,000	2.24	0.68	1.1	0.7
100W with Plastic Pudding Bowl Diffuser	118,000	103,000	80,800	1.00	0.30	Not Measured	

2nd order rotating optic with a 10.3V 100W twin filament lamp and various diffusers.

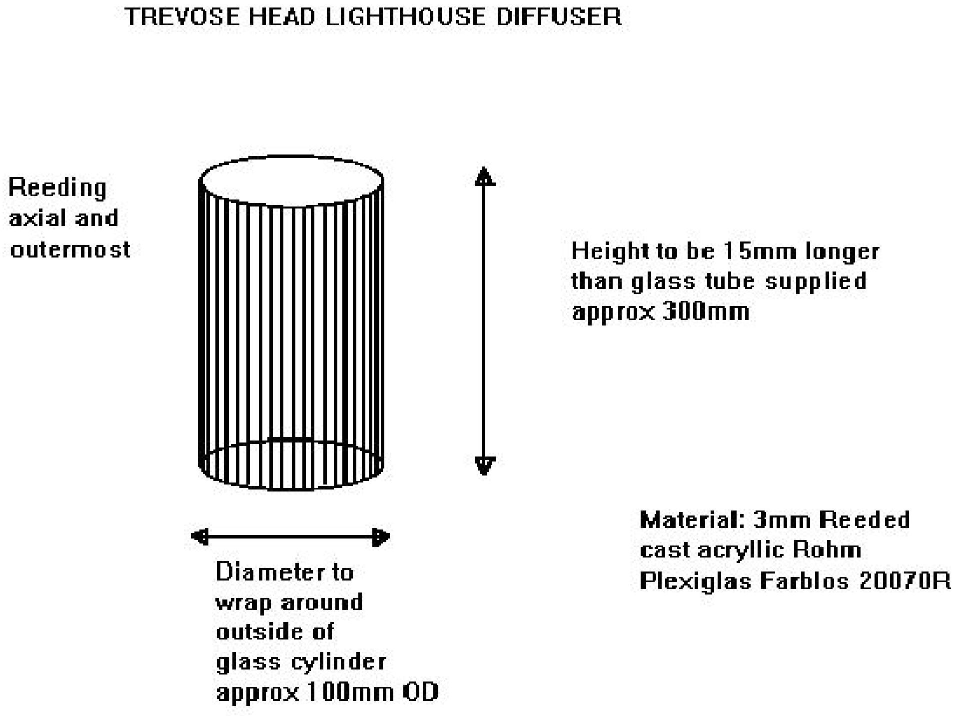

Figure 18 Details of reeded diffuser used at Trevose Head to increase flash duration

The light source installed during automation was a 35W metal halide, but the observed flash duration was considered too short. When the diffuser was installed, the lamp was changed to a 70 W metal halide to preserve the published nominal range. Flash duration was tripled.

Table 8 Measured results of Trevose Head

Light Source	Peak Intensity (cd)	Effective Intensity (cd)		Flash Duration (secs)		Vertical Divergence (degrees)	
		Blondel-Rey (BS942)	Schmidt-Clausen (IALA)	10%	50%	10%	50%
35W Philips CDM-T metal halide	1,270,000	475,000	238,000	0.09	0.04	1.1	0.7
70W Osram HQI-T metal halide	1,840,000	780,000	406,000	0.11	0.04	1.9	0.7
70W Osram with Reeded Diffuser	285,000	285,000	204,000	0.26	0.12	1.9	0.7

1st order rotating optic with a 35W Philips CDM-T, an Osram HQI-T and the reeded diffuser detailed in Figure 18.

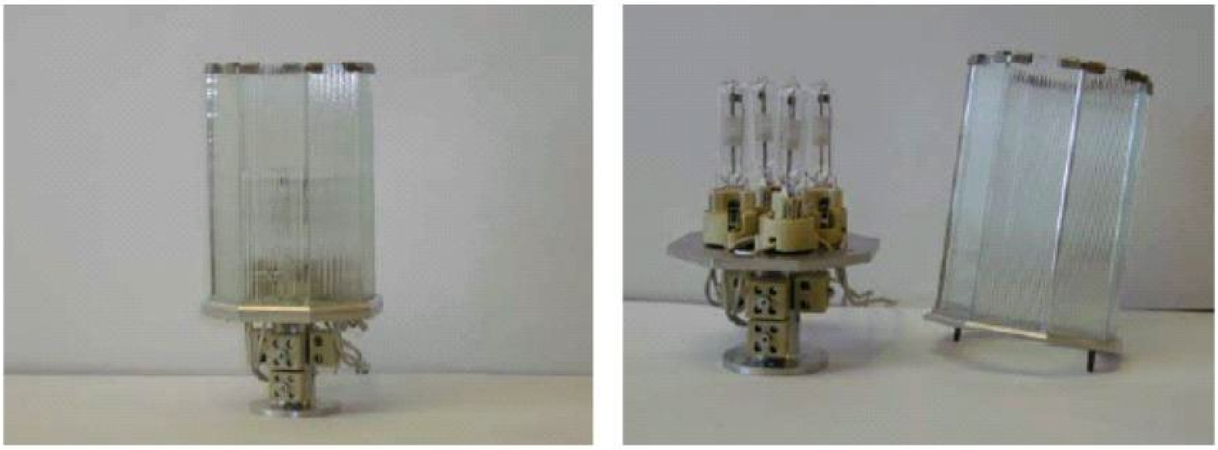

Figure 19 Experimental diffused cluster of four 150W CDM-T lamps

5.4. CLUSTERS OF LEDs

Clusters of LEDs can be formed to replace a lamp and lens system, reducing the energy consumption particularly for coloured lights, while increasing the lifetime of a light apparatus. This can be particularly useful for floating aids where extended unattended life and low energy consumption are essential. Many manufacturers provide lanterns in this configuration.

However, care must be exercised when replacing lamps with LED clusters in traditional lens systems. The angular distribution of light output from lensed LEDs may be significantly different from that of a bare lamp. The light output from the LED cluster is not from a point source and cannot therefore be correctly focused by the lens.

Figure 20 Lensed LED (right) cluster - generally not suitable as a light source in traditional lens systems

5.5. HIGH POWER LEDs

5.5.1. USE OF HIGH POWER LEDS IN OMNI-DIRECTIONAL AND RANGE LIGHTS

The objective is to replace incandescent lamps with various LED arrangements in omni-directional lanterns and range lanterns.

An incandescent lamp can be replaced with one LED luminous source in Fresnel optic with focal length smaller or equal to 0.15 m. These new types of luminous source use one or several high power LED in different configuration.

Figure 21 Examples of optics where a LED luminous source can be put

Because the luminance of LEDs is currently low, they can only effectively replace low power incandescent lamps in Fresnel optics (for example halogen lamp of <20 W can be replaced with LEDs). The luminous intensity of LEDs for coloured lights provides an energy efficiency improvement (power consumption divides by 20 in the best configuration with lifetime of 50,000 hours at 30 % of flux reduction).

The problem is to concentrate light in a small luminous source (to avoid a more important divergence), without exceeding high temperature junction (to protect LED and maintain an important lifetime).

One side-emitting LED for fixed support (the MonoDEL)

Two side-emitting LED for buoy (the biDE, Source: CETMEF))

Cluster of LEDs (the MaxiHALO-60)

Cluster of LEDs (the MLL 18W, Source : MSM)

Figure 22 Examples of LED luminous source

Table 9 Range of a 1 LED luminous source (MonoLED)

RANGE (duty cycle 50% - Ambient temperature : 24°C)				
Optic	Colour	Nominal Range Nautical mile	Vertical divergence	Equivalent lamp
Optic pressed glass 0,045 focal length	White	3,5 nm	~ 5° at 50% > 10° at 10%	Halogen 5W/12V
	Red			Halogen 20W/12V
	Green			Halogen 20W/12V
Optic PMMA (acrylic) 0,055 focal length	White	4 nm	~ 3° at 50% ~ 7° at 10%	Halogen 5W/12V
	Red			Halogen 20W/12V
	Green			Halogen 20W/12V
Optic PMMA (acrylic) 0,0775 focal length	White	4,5 nm	~ 1.5° at 50% ~ 5° at 10%	
	Red			Halogen 20W/12V
	Green			Halogen 20W/12V

(Source: CETMEF)

Table 10 Range of a 2 LEDs luminous source (BiLED)

RANGE (duty cycle 50% - Ambient temperature : 24°C)				
Optic	Colour	Nominal Range Nautical mile	Vertical divergence	Equivalent lamp
Optic pressed glass 0,045 focal length	White	3,5 nm	> 10° at 50% > 20° at 10%	Halogen 5W/12V
	Red			Halogen 20W/12V
	Green			Halogen 20W/12V
Optic PMMA 0,055 focal length	White	3,5 nm	> 10° at 50% > 20° at 10%	Halogen 5W/12V
	Red			Halogen 20W/12V
	Green			Halogen 20W/12V

(Source: CETMEF)

6. MEASURING PERFORMANCE

Throughout the various tests and measurements carried out over the last few decades, it has become clear that calculated figures for optic performance can be very unreliable. Indeed, optics which are physically very similar often produce quite different results. This is especially the case when light sources are used that are much smaller than that for which the optic was designed. For this reason, photometric measurements of optics with intended light sources give confidence in achieving a desired performance. However, due to the large size and complexity of traditional optics, it is difficult to remove them and re-install them on a measurement range.

When carrying out field measurements, problems can occur, including finding a suitable measurement site, atmospheric conditions such as poor visibility, precipitation and scintillation. The accuracy of most field measurements is often no better than plus or minus 10% and is dependent on conditions and the number of measurements taken. Nevertheless, if all that is required is a nominal range figure to the nearest nautical mile, this is considered to be accurate enough and is certainly more likely to be right than the calculated figure. Further information on measurement techniques can be found in IALA Recommendation *R0122, The Photometry of Marine Aids to Navigation Signal Lights.*

There have been occasions when the measured output of a light has been so poor that the results have not been believed. Usually the poor performance is due to poorly maintained or incorrectly installed equipment, the most likely causes being an incorrectly positioned light source or low lamp voltage. It is prudent to measure all major navigational aids, either on a light range or in the field, to ascertain the performance of lights before and after installation or modification.

7. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

8. ABBREVIATIONS

AC	Alternating current
AlInGaP	Aluminium, Indium, Gallium and phosphorous
BiLED	Bicolour LED
CCT	Colour Correlated Temperature
CETMEF	Centre d’Etudes Techniques Maritimes et Fluviales
Fl	Flashing
InGaN	Indium Gallium Nitride
LED	Light-emitting diode
PVB	Paraffin vapour burning
RPM	Revolutions per minute
UV	Ultraviolet (light) (10 – 380 nm)
V	volt(s)
W	watt
cd	candela(s)
kW	kilowatt(s)
m	metre
mA	milliamp
mm	millimetre
°C	degrees Centigrade
°K	degrees Kelvin

9. REFERENCES

[1] Ian Tutt, *The Use of Modern Light Sources in Traditional Lighthouse Optics (New Lamps for Old),* Development Department, Trinity House Lighthouse Service, United Kingdom.

[2] IALA ENG Committee, *Single High Power LED in Traditional Optic,* Xavier Kergadallan, Centre d’Etudes Techniques Maritimes et Fluviales, October 2005.