IALA

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SECTOR LIGHTS

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International Association of Marine Aids to Navigation and Lighthouse Authorities
Association Internationale de Signalisation Maritime

DOCUMENT REVISION

Revisions to this document are to be noted in the table prior to the issue of a revised document.

Date	Details	Approval
December 2008	Whole document general update.	Council 44
December 2015	Whole document major update and addition of section on theodolite alignment.	Council 61
July 2022	Edition 3.1 Editorial corrections.	

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1. INTRODUCTION

Sector lights have been used as a Marine Aid to Navigation (AtoN) since the 19th century. Many different methods are used to provide sector lights. In addition, there are several emerging technologies that may be used to provide sector lights.

2. BACKGROUND

A sector light is an AtoN that displays different colours and/or rhythms over designated arcs. The colour of the light provides directional information to the mariner.

A sector or a limit between two sectors may indicate a fairway, a turning point, a junction with other channels, a hazard or something else of importance for the navigator.

When a fairway is covered by a white sector, the convention for a vessel approaching the light from the seaward side must be a green sector to starboard and a red sector to port as per IALA Maritime Buoyage System colour convention for Region A; for Region B the colours are reversed. The white sector indicates safe passage; however, this does not always hold true in the entire radial length of the sector. The fairway may alternatively be marked with lighted buoys or leading lights.

When designing fairways, consideration should be given to all possible types of aids to navigation to find the best solution for the particular site.

The requirements for sector lights can be a complex task. The process should be carried out with reference to a good quality chart of the area. In many cases, good local knowledge is also required, and factors such as tidal flow, currents and background lighting may need to be considered.

A sector light may indicate one or more of the following boundaries of a navigable waterway.

- Change of course position
- Shoals, banks, etc.
- An area or position (e.g., an anchorage)
- The deepest part of a waterway
- Position checks for floating aids
- Boundaries of a navigable waterway

Some examples of sector lights applications are illustrated in Figure 1 and Figure 2.

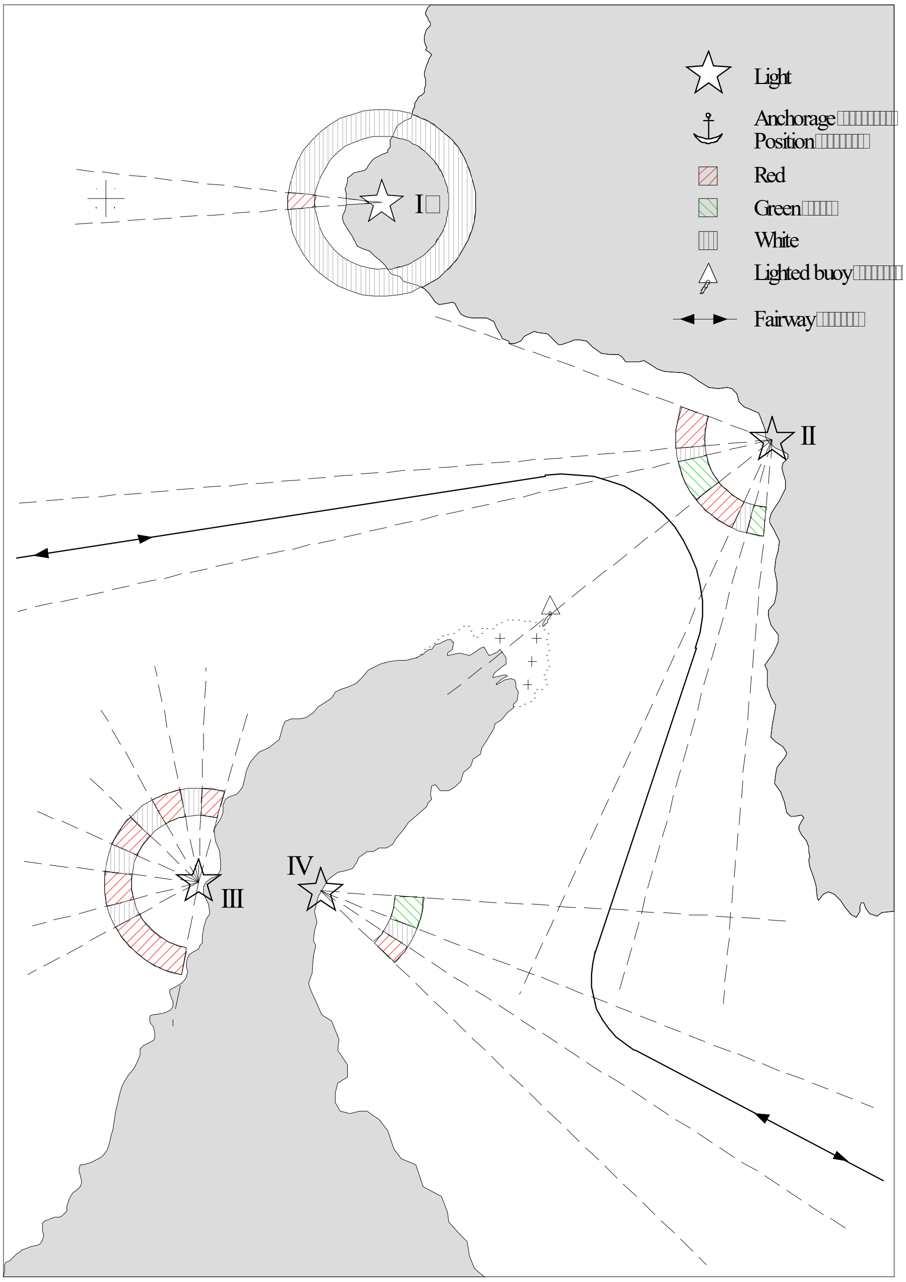


Figure 1 Several applications for sector lights.

Light I is a coastal white light with a red sector indicating a danger. In this application, high boundary accuracy is not essential.

Light II is a sector light obscured over the shore, with two white sectors indicating a safe channel. The boundary between the red and the green sector also indicates the position of a buoy.

Light III is a sector light with a red light and 4 white sectors indicating four anchorage positions. It is obscured over the shore.

Light IV is a sector light with a white sector indicating a safe channel. It is obscured over the shore.

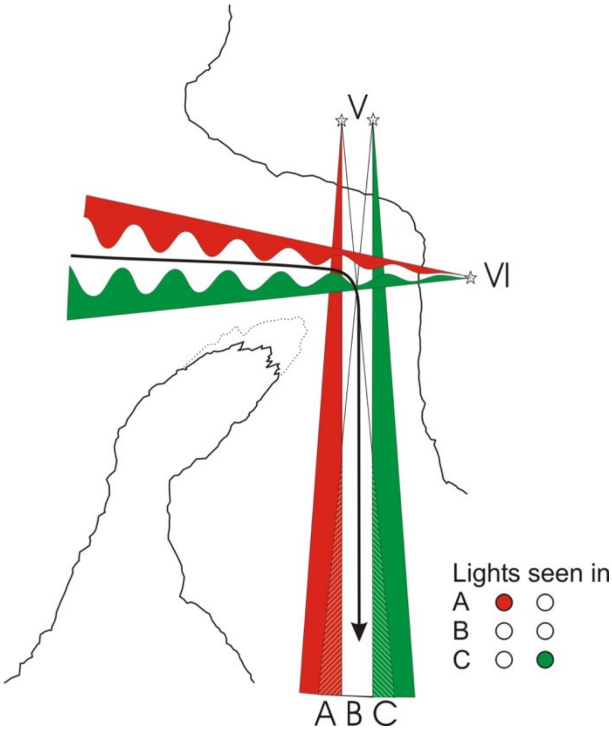


Figure 2 Multiple sectors arrangement marking a channel

Light V in Figure 2 shows two sector lights arranged to create a parallel sector light system. This arrangement has five sectors. Each sector can have its own flash character or colour.

Light VI indicates oscillating boundaries which could be made up of five or seven sectors and can be used to improve identification of the vessels lateral position.

3. PURPOSE

The purpose of this document is to provide the IALA membership with guidance on the principles of operation, practical design and installation of sector lights.

This document does not provide guidance on the nautical requirements.

4. KEY PARAMETERS OF SECTOR LIGHTS

Definitions of the main parameters are presented in section 14. A more detailed description of the relevant concepts are as follows:

- Sector width (angular subtense in horizontal plane)
- Colour
- Intensity
- Flash character
- Uniformity of intensity across the sector
- Angle of uncertainty between adjacent sectors
- Vertical divergence

Definitions of main parameters are provided in section 14; detailed descriptions of relevant concepts are provided below.

4.1. GENERAL REQUIREMENTS

A sector light should comply with the following specifications:

- The colour should be in the optimum regions of IALA Recommendation *R0200 (E-200), Part 1 - Colours* [1].
- The flash characters should conform to IALA Recommendation *R0110 (E-110) The Rhythmic Characters of Lights on AtoN* [2].
- The calculation of luminous range or intensity should be carried out according to IALA Recommendation *R0200 (E-200) Part 2 – Calculation, Definition and Notation of Luminous Range* [3].
- The measured performance should be in accordance with IALA Recommendation *R0200 (E-200) Part 3* [4].

The current IALA *NAVGUIDE* and specific IALA guidelines on Light Sources and LED Technology should be considered.

4.2. ANGLE OF UNCERTAINTY

The angle of uncertainty is the region where the colour and/or the flash rhythm change. The mariner typically sees a mixture of the two sector characters and this causes an uncertainty where the mariner is unable to distinguish between the two sectors. The understanding of this aspect is very important for the design of a sector light.

In most cases the angle of uncertainty should be as small as possible or defined by the navigational requirement.

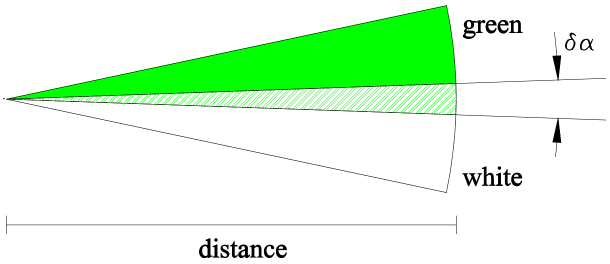


Figure 3 Angle of uncertainty

The basic mechanisms that determine the achievable minimum angle of uncertainty differ between types of Sector Lights as described below.

4.3. THE USE OF FILTERS IN SECTOR LIGHTS

In sector lights, where optical filtering of a single light source is used, the luminous intensity, and thus the range, of each sector may vary considerably due to different transmission factors of the optical filters.

The spectral characteristic of the light source has a major impact on the light output from a coloured filter. It is necessary to match the light source with a filter material having a suitable spectral transmission, thus providing a light whose chromaticity is within the IALA recommended colour region.

The transmission factor of the colour filter will determine the intensity and therefore range of coloured sector. Some typical values of transmission factors are given in the table below.

Table 1 Typical transmittance for various light sources

Colour	Light Source/(Colour Temperature)			
	Filament (3000K)	Discharge (5800K)	LED (4000K)	LED (6500K)
Red	8-25%	~13%	~10%	~8%
Green	8-25%	~22%	~17%	~20%
Yellow	50-70%	~55%	~50%	~45%

For further information on filter and transmittance, refer to the IALA Wiki.

There are a number of materials, including glass and plastic, suitable for filters. It is generally easier to get large filters in plastic rather than glass. When using plastic filters, the filter material must be ultraviolet stable and be suitably fitted to ensure that the heat generated by the lamps does not distort it.

5. TYPES OF SECTOR LIGHTS

There are two basic types of sector lights: omni-directional and directional. Omni-directional sector lights generally cover up to 360 degrees, whereas directional sector lights only cover a relatively small arc.

Many technical solutions exist for generating sectors. They may be categorized in a number of ways, one of which is by the optical method applied. The two most common technologies for the provision of sectored light signals are as follows:

- Point Light Source Sector Lights (for large sector angles or omnidirectional):
  - Single light source and filters
  - Multiple Source Sector Light (MSSL)
- Projector Sector Lights (for small sectors)

Older technologies are:

- Slot sector light
- Use of colour filters in rotating optics

New developments are:

- Rotating colour switching sector light

A comparison between the basic types of Sector Lights is made in table 2. A more detailed description of each is shown in the following sections.

Table 2 Comparison of the difference technologies of sector lights

Type	Practical Night Time Range	Precision/ Angle of uncertainty	Maximum Sector width	Typical Minimum Sector width
Point Source	Up to 20 M	Medium (0.25°-0.75°)	360°	1°
Slot	Up to 30 M	Low Boundary width is constant with range	45°	1°
Colour filters in rotating optics	Up to 20 M	1° - 20°	360°	7°
Rotating colour switching sector light	Up to 15 M	1° - 2°	360°	8°
Projected	Up to 30 M	Very High (1 minute of arc, 0.017°)	25°	0.2°

6. POINT LIGHT SOURCE SECTOR LIGHTS

6.1. SINGLE LIGHT SOURCE AND FILTERS

This type of sector light is sometimes referred to as a “traditional sector light” due to the fact that they have been in use with since the 19th century. Another name is “shadow method sector lights”, in which a coloured sector is generated by placing a piece of coloured glass or plastic (such as polycarbonate or acrylic) against the lantern house glazing or against the light itself. This casts a coloured shadow over the water at the required sector.

Figure 4 Single light source sector light with drum lens

6.1.1. PRINCIPLE OF OPERATION

Point source sector lights generally have a single light source, usually a lamp within a drum lens with one or more optical filters placed at some distance, screening the light and producing each sector in the desired colour.

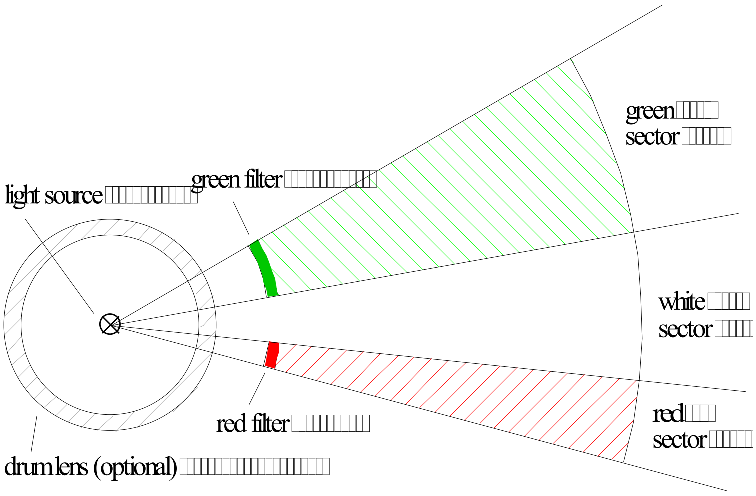


Figure 5 Basic operating principle of Point Source Sector Lights

The physical position of the optical filters used with a light source should be mechanically adjustable for proper alignment of the individual sectors and sector boundaries.

In order to ensure sufficiently small angles of uncertainty between sectors, it is important to locate the optical filters at a sufficient radial distance from the light source.

The optical filters may be located internally within the lighthouse glazing or external to a lantern.

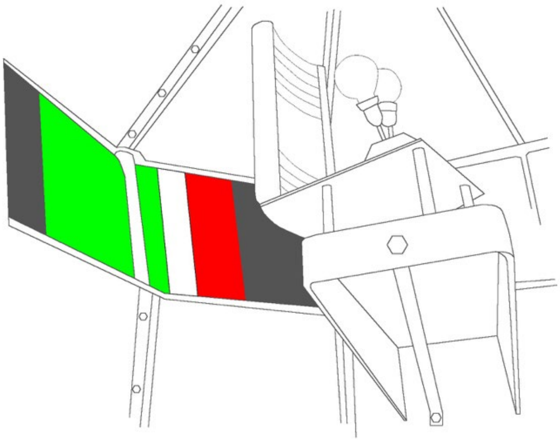


Figure 6 Internal filters in a light house

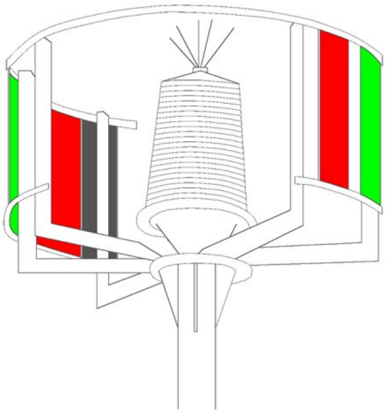


Figure 7 External filters on a small lantern

On small lantern sector lights consisting only of a lantern, the manufacturer may provide fixed internal filters. In the latter case it is not possible to adjust the sector boundary, and the angle of uncertainty is likely to be quite large.

6.1.2. THE LIGHT SOURCE

In a Point Source Sector light, the horizontal dimension of the light source has a great influence on the angles of uncertainty (see 6.1.3).

It is important to correctly focus the light source within the optical apparatus as any small misalignment can result in altering the sector boundaries. This problem can be overcome by either using a pre-focussed light source or incorporating a means of accurately aligning the light source as each new lamp is installed.

The spectral characteristics of the light source must match the desired spectrum of each coloured sector as mentioned in the section on basic principles. This means that the spectrum of the lights source contains enough red and green.

In general halogen and metal halide lamps achieve good results concerning the aspects above.

6.1.3. ANGLE OF UNCERTAINTY

The shadow method can be used where very sharp sector boundaries are not required. The angle of uncertainty maybe 0.25-0.75° and intensity may vary. As with any optical apparatus, precise positioning of the lamp is essential. The sector boundary will move if the lamp filament is moved, as it might when a lamp is replaced.

In the Point Source type of sector light, the ratio between the horizontal dimension of the light source (d) and the distance between the light source and the optical filter (D), determines the angle of uncertainty (δβ), and thus the width of the boundary region at any given distance from the sector light.

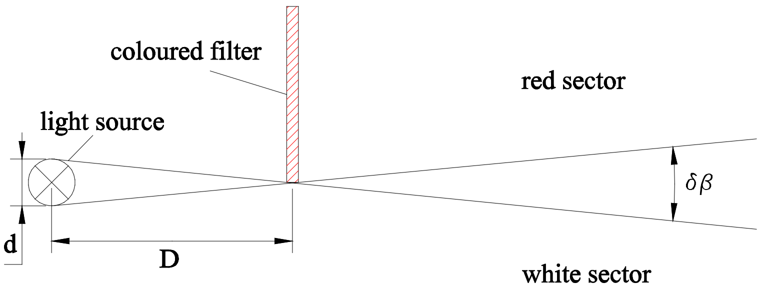


Figure 8 Factors that determine the angle of uncertainty in point source type of sector lights

The mathematical relationship between the factors is as follows:

$$\delta\beta = d/D \text{ [radians]}$$

Equation 1 Angle subtended by the light source

$$\frac{d}{D} \times 57.3 \text{ [degrees]}$$

Equation 2 Angle of uncertainty

where:

d is the Horizontal dimension (width) of light

D is the Distance from filter to light source

Error! Reference source not found. is the angle subtended by the light source width d at the edge of the filter which is distance D away from the light source. The multiplier 57.3 is an approximate conversion from radians to degrees, 360°/2*π. In this case, δβ is the angle between the light source being fully covered by the filter and being completely uncovered by the filter (see Figure 8) when viewed from a distance by an observer.

The angle of uncertainty can be reduced by decreasing the width of the light source or by increasing the radial distance to the coloured filter.

If space on the AtoN's structure is not a limiting factor, it is usually possible to achieve an angle of uncertainty of around 0.5° with this type of sector light.

Equation 1 is known to be somewhat ‘conservative’. Regarding the colour visible from a far distance, it will not change immediately, when the observer enters the sector of uncertainty defined by Equation 1.

An exact method for finding the angle of uncertainty based on the observed colour is presented in [10].

6.1.4. Filter size

When a coloured sector is required, the size of the filter should extend beyond the given sector angle.

The white sector is more intense than the coloured sector which shows a fraction (T) of the intensity of the white sector. As a result, the white light will dominate in the transition zone between the two sectors, and the resulting colour will be still in the white region (Figure 13).

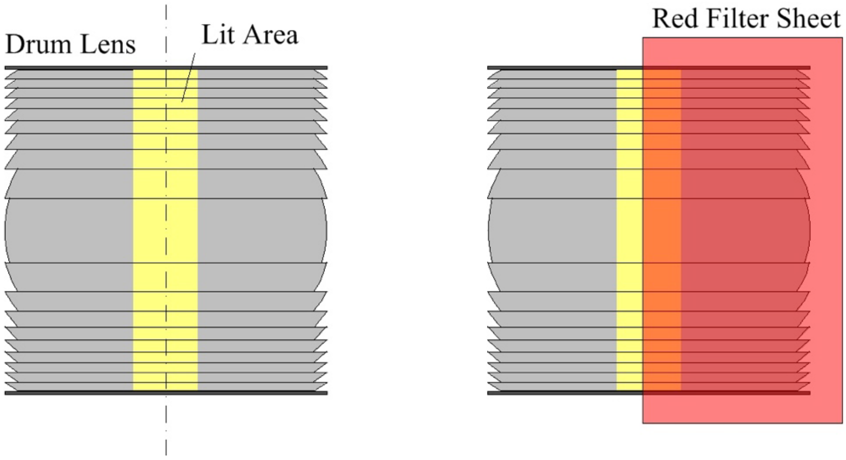


Figure 9 Observer’s View at the Assumed Nominal Sector Boundary

To avoid this, the coloured filter should be made larger by a filter offset. With this measure, the intensity of coloured and white light becomes equal at the sector boundary (Figure 10).

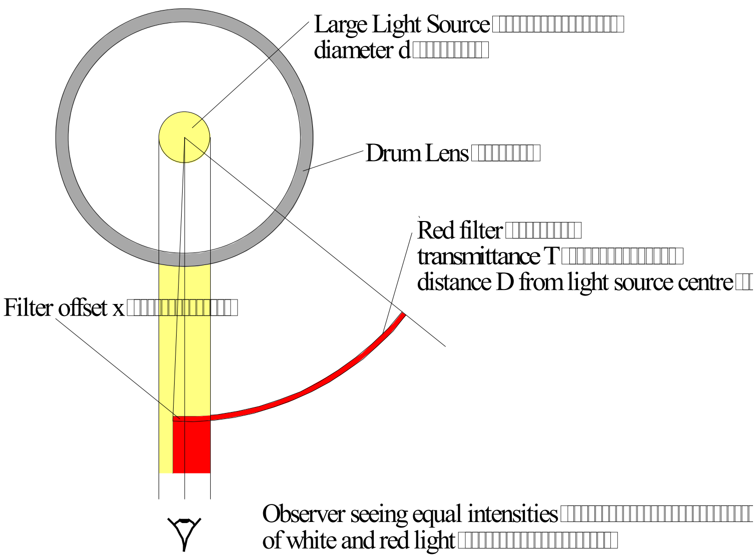


Figure 10 Plan View of the Drum Lens

The filter offset distance, the distance between the edge of the filter and the nominal sector boundary, can be determined by the following equation:

$$x = \frac{d}{2} - \frac{d * T}{1 + T}$$

Equation 3 Filter horizontal offset distance in millimetres

where:

T is the filter transmittance as a factor of one;
d is the horizontal width (or diameter) of the light source in millimetres.

The angular offset of the filter Φ, the angle between the edge of the filter and the observed sector boundary, can be determined by the following equation:

$$\Phi = \frac{x}{D} \text{ measured in radians}$$

or

$$\Phi = \frac{x}{D} \times \frac{180}{\pi} \text{ measured in degrees}$$

Equation 4 Angular offset of the filter Φ

where:

Φ is the filter horizontal angular offset of the filter edge;

x is the filter horizontal offset in millimetres;

D is the distance from the centre of the light source to the filter edge

The filter offset occurs at both edges of the filter, so the required angular width of the filter is always greater than the sector angle covered by that filter.

Therefore, for a single sheet of filter material, the width of the sheet should always be greater than the width of the sector by twice the horizontal filter offset (sector width + 2*x / sector angle +2*Φ).

Remarks: In practical terms it is often useful to use two pieces of filter material that overlap in the centre of the sector. This allows for some adjustment during the checking procedure.

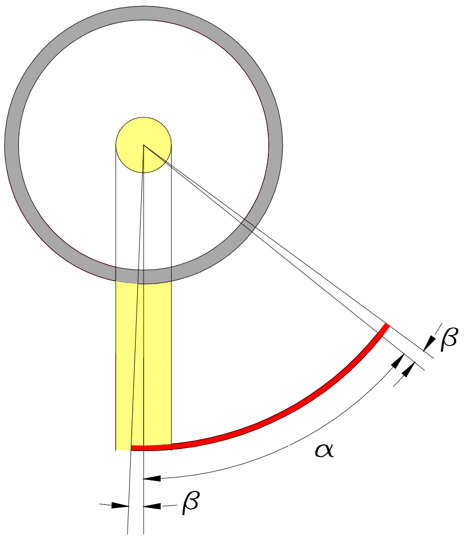


Figure 11 Filter offset applied on both sector boundaries

6.1.5. Advantages/Disadvantages

Advantages:

- Robust design
- Retrofitting with new light sources is possible
- Relatively small cost
- Low maintenance

Disadvantages:

- Possible large angle of uncertainty
- Large nominal ranges may not be achievable
- Filter degradation

6.2. SINGLE SOURCE MULTIPLE TIER SECTOR LIGHTS

In order to replicate the single point light source method with LEDs a separate tier is required for each colour. The use of opaque screens limits the output of light from each tier and thus create the sector boundary.

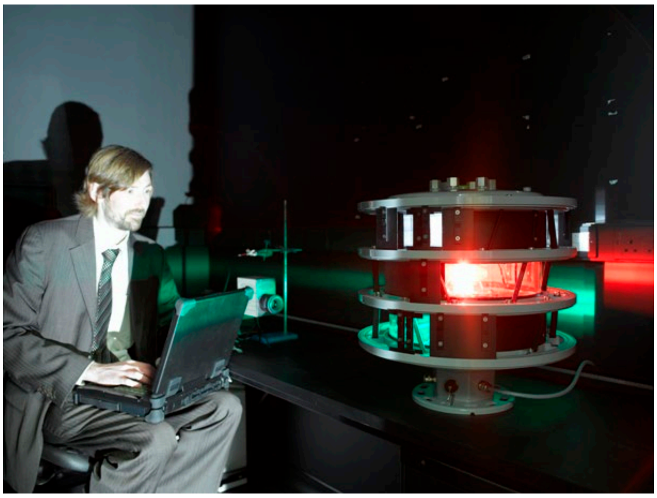


Figure 12 Example of Single source multiple tier sector light

6.2.1. Principle of Operation

Single source multiple tier sector lights generally have one LED for each colour required. A secondary lens is used to direct the light output from each individual LED in the horizontal plane. Opaque screens are used to blank each of the different colours in order to create the sectors required.

6.2.2. Light Source

This type of sector light is specifically designed for LEDs.

6.2.3. Angle of Uncertainty

The method to determine the angle of uncertainty is similar to that of the single point source sector light and similar angles of uncertainty can be expected.

6.2.4. ADVANTAGES

- Low maintenance
- Robust design
- Relatively low cost
- Different blanking screens can be used on the same base unit which allows for different applications.

6.2.5. DISADVANTAGES

- Range limitation
- Inefficient power use (blanked omni-directional)

6.3. MULTIPLE SOURCE SECTOR LIGHT (MSSL)

The principle of a point source sector light can be used with LED as the light source. However, the classical point source sector light in most applications requires a light source which radiate light omnidirectional covering 360° of the horizon.

A single LED is restricted to an angular subtense of maximum 180°. Although a single LED can produce an omnidirectional light by the use of a special optic, it is much easier to use multiple LEDs for an omni-directional LED sector light.

There are additional reasons for the developing MSSL:

- Green and red LEDs have a very saturated colour which fits perfectly into the IALA colour regions. Using optical filter with LED instead is not very efficient. Therefore, each sector has its own LED.
- To achieve large ranges / high intensities it is necessary to stack multiple LEDs in a vertical arrangement (tier arrangement).

6.3.1. PRINCIPLE OF OPERATION

MSSL produce the sector signals using several LED light sources equipped with individual lenses and beam forming screens that are distributed in horizontal plane as off-centre point sources (Figure 13).

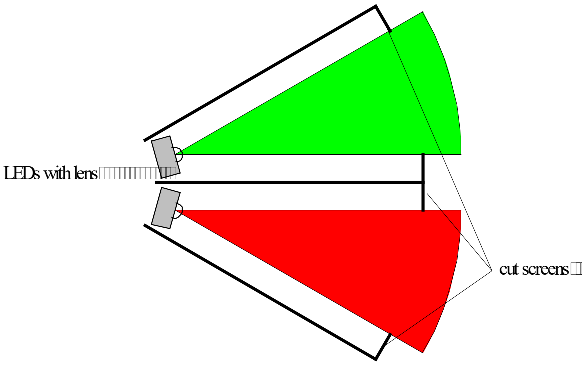


Figure 13 Principle of a multiple source sector light

In Figure 14 an arrangement with 5 sectors of the same size but different colours are shown. To increase the total intensity the horizontal arrangement is repeated in for vertical tiers (Figure 15).

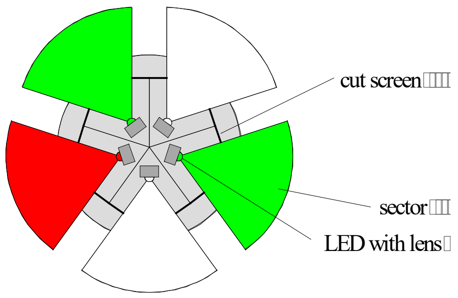


Figure 14 An omnidirectional sector light with 5 sectors

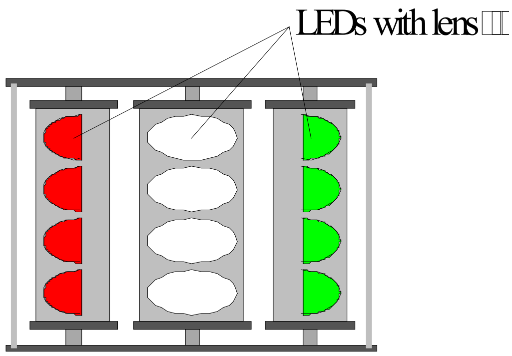


Figure 15 Example of a Multiple source LED sector light with four vertical tiers

6.3.2. Light source

Although in theory it is possible to build Multiple Source Sector Lights using incandescent light sources and filters, this technology is currently implemented using LED light sources.

Light signal modules employed inside a MSSL may be of varying complexity, ranging from a single unprotected LED/lens assembly to a fully weather proofed LED/lens module with several vertical LED arrays, redundant circuitry and low-level modulation input for control of flashing.

To achieve a small angle of uncertainty it is necessary to use LED with a small luminescent area. Many new high power LEDs (> 50 W) have a large luminescent chip and cannot be used in a MSSL.

6.3.3. Angle of Uncertainty

Depending on the light source and cut screen geometry implemented for separating the sector signals, usable segment of an MSSL starts at a distance L that is typically from tens to a couple of hundreds of meters from the AtoN position (Figure 16). A blind patch of the size of the cut screen (D, typically not exceeding 100 mm) extends to infinity, increasing the sector boundary region slightly.

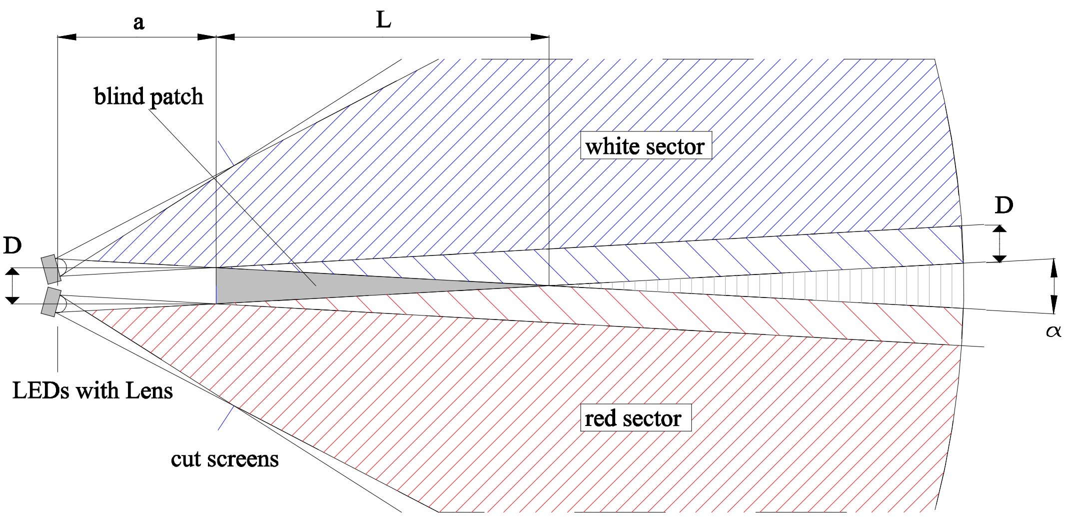


Figure 16 Multiple LED sector light with cut screens

Beginning of the usable segment of an MSSL can be estimated using the following formula:

$$L = \frac{a \times D}{d}$$

Equation 5 Distance from AtoN to beginning of usable segment of an MSSL

where:

L is the distance from the AtoN to the beginning of usable segment of an MSSL;

a is the distance from light source to cut screen;

D is the horizontal extent of the cut screen between sector light sources;

d is the horizontal dimension of the light source.

Multiple Source Sector Lights are suitable for sites where high precision of sector borders is not required. Angle of uncertainty depends on a particular implementation with typical values in the range of 0.2° to 0.6°, with longer distances from light sources to cut screens (larger enclosure diameters) providing resolution improvements.

Angle of uncertainty should be the input parameter for MSSL design for preliminary estimation of feasibility of MSSL application.

6.3.4. ADVANTAGES

- Once manufactured to site specification, installation on AtoN site requires minimum efforts.
- Sectors with widely varying luminous intensities can be implemented inside a single enclosure.
- Different sectors can utilize different rhythmic characters.
- Sectors with overlapping borders displaying alternating colour signals with isophase rhythmic character at the boundary can be created using a multi-tiered construction.
- LED modules with dual (redundant) circuitry can be employed for increased dependability.
- Power consumption of optimally combined LED arrays of different sectors is typically lower than in case of single-source-per-tier screened omnidirectional solutions.
- Distributed modular design allows to utilize existing lantern house at the AtoN site, bypassing shadowing effect of window frames.

- In case of a modular construction, light source replacement can be accomplished efficiently onsite when necessary and does not require re-adjustment of sectors.
- Modular design allows stocking of spare modules for extended life cycle support.

6.3.5. DISADVANTAGES

- Once manufactured to site specification, sector configuration cannot be altered.
- Not available off-the-shelf - engineering costs are involved in the design process of each sector light.

7. SLOT SECTOR LIGHT

7.1. PRINCIPLE OF OPERATION

Slot sector lights consist of one or more light beams directed to a focal aperture (slot) at some distance. The ratio between the focal aperture width and the distance between the light source (assuming a point source) and the slot aperture defines the horizontal angle of the sector.

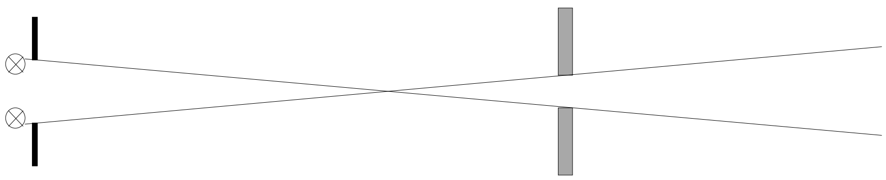


Figure 17 Basic operating principle of Slot Sector Lights

In Figure 17, there is only one sector. The principle may however be extended to a number of light sources of different colours yielding a number of sectors of different colours, and if need be different rhythmical characters

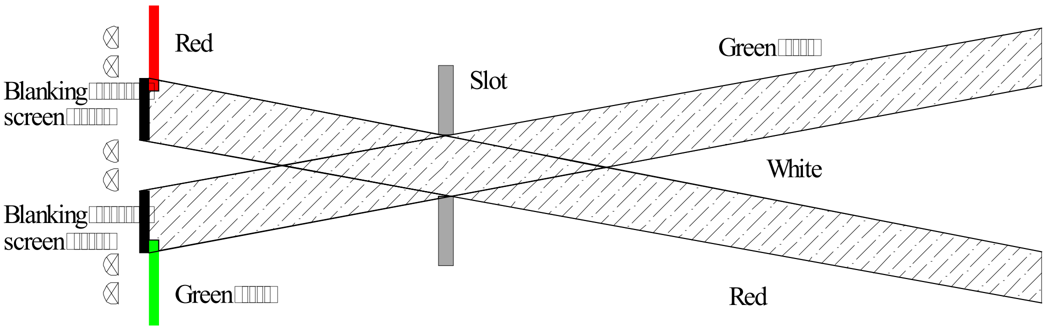


Figure 18 Light Source Array

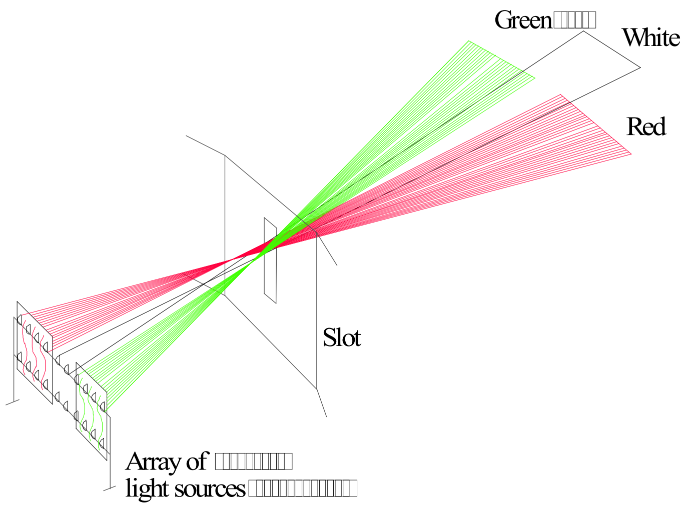


Figure 19 Basic operating principle of Slot Sector Lights (Three light sources and three sectors)

Coloured sectors are arranged with coloured glass mounted directly in channels in front of the lamp.

The boundaries are defined with baffle plates. The baffle plates are some millimetres wider than the focal apertures in the lantern house, to compensate for refraction of light around the baffle plate edge and provide the light exactly at the boundary crossing. The baffle plates are mounted in the same way as the filter glass.

Using an array of lamps as the light source, the luminous intensity in different sectors can be altered depending on the number of lamps used in that sector. The lamps can be connected in several separate groups, which are switched on in sequence, thus giving a stable power load and a character like a rotating light. With a Slot Sector Light it is possible to create very distinct boundaries and sectors if the lamps are placed a long distance from the slot.

7.2. THE LIGHT SOURCE

The light source depends on the application. Sealed beam lamps, PAR 56 200W 30V, mounted in simple stands are typically used as a light source. Systems with up to 2 x 96 lamps have been build, but smaller systems also exist with only a couple of boundaries and 3 - 6 lamps.

An advantage of such a lamp array is that a burned out lamp will not lead to a total loss of light in boundaries or sectors, but only a reduction in luminous intensity in that part of a sector as the boundary is illuminated by several overlapping lamps.

LED technology can be used in the Slot Sector Lights.

7.3. ANGLE OF UNCERTAINTY

The angle of uncertainty is about 1° or more.

7.4. ADVANTAGES/DISADVANTAGES

The slot sector light may be used in existing lighthouses but is not recommended for new installation.

7.4.1. ADVANTAGES

- Very robust design
- Easy to maintain

7.4.2. Disadvantages

- Size of lantern
- Low intensities
- Low precision

8. USE OF COLOUR FILTERS IN ROTATING OPTICS

The application of accurate coloured sectors with a classical revolving pencil beam is not easy to achieve. Therefore, it is not recommended to use this type of sector light for new installations.

However, in many situations it is advantageous to use this arrangement to support the existing optic in a lighthouse.

8.1. PRINCIPLE OF OPERATION

A Rotating Optic Sector Light consists of a central light source inside a circular arrangement of Fresnel lens panels (pencil beam projection). The Fresnel panels rotate around the light source at the rotation centre. The whole optic is surrounded by one or more filters or opaque screens.

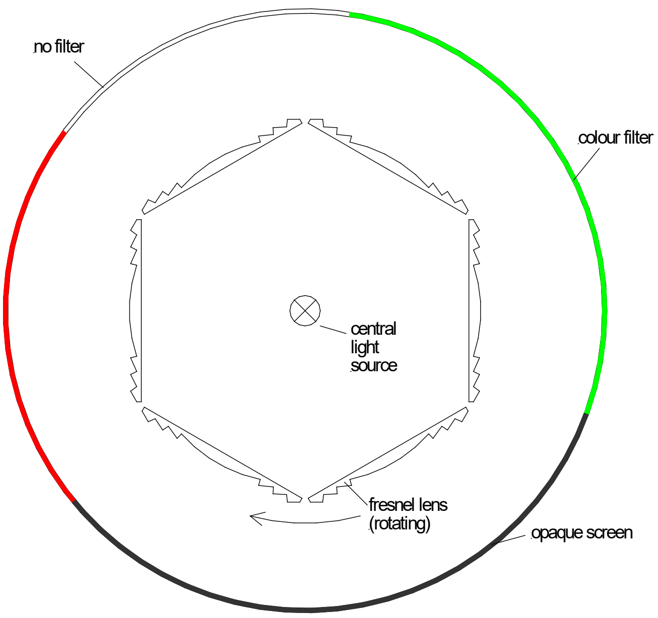


Figure 20 Rotating Fresnel Lens

8.2. THE LIGHT SOURCE

A Classical revolving pencil beam light requires a compact light source to ensure a single flash for each Fresnel lens panel. The colour is produced by filtering (see 4.3).

Preferred light sources are:

- Halogen incandescent lamps
- Metal halide lamps
- Short arc discharge lamps (e.g., xenon lamps)

LED as a light source requires more care:

- In general, it is necessary to use an arrangement with more than one LED, so the size of this arrangement should be small enough to produce a single flash for each Fresnel lens.
- The LED and the filter material have to be selected to ensure that the resultant intensity and colour are acceptable.

8.3. ANGLE OF UNCERTAINTY

The angle of uncertainty can be evaluated by the means of the paper *A Study of Filtered Sector Lights*'[10].

8.4. ADVANTAGES/DISADVANTAGES

8.4.1. ADVANTAGES

- High intensities available
- Existing optics can be used.

8.4.2. DISADVANTAGES

- Low precision, large angle of uncertainty may be several degrees
- Susceptible to false flashes
- Low colour recognition when flashes are too short.

9. ROTATING COLOUR SWITCHING SECTOR LIGHT

9.1. PRINCIPLE OF OPERATION

Rotating LED light sources can be used for producing several light beams of different colours with spatial distribution in sectors as required in particular application. Each combination of an LED and a lens produces a different beam that can be precisely controlled in time during rotation. Each sector signal is produced by the LED/lens system at a specific time when passing through the designated sector. Basic rhythmic character of such light sector system depends on selected speed of rotation.

Figure 21 shows an example with 6 lenses (2 white, 2 green, 2 red). Thus, an equipment producing 2 white beams, 2 green beams and 2 red beams is produced.

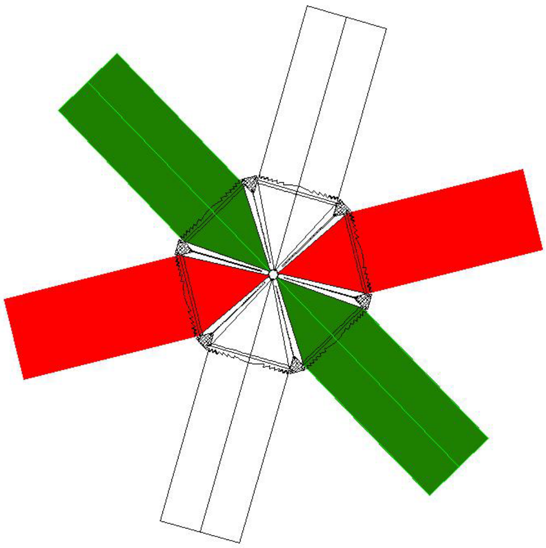


Figure 21 Top view Rotating Colour Switching Sector Light

When rotating, an electronic control detects the angular position of the optic and switches on each LED during the passage through the sector required.

For example, when the lens with white LED points into the direction of the white sector, it is programmed to switch on, providing white light only within the limits of the white sector. The same applies for green and red sectors (see Figure 22). In case of blank sectors all LEDs are switched off.

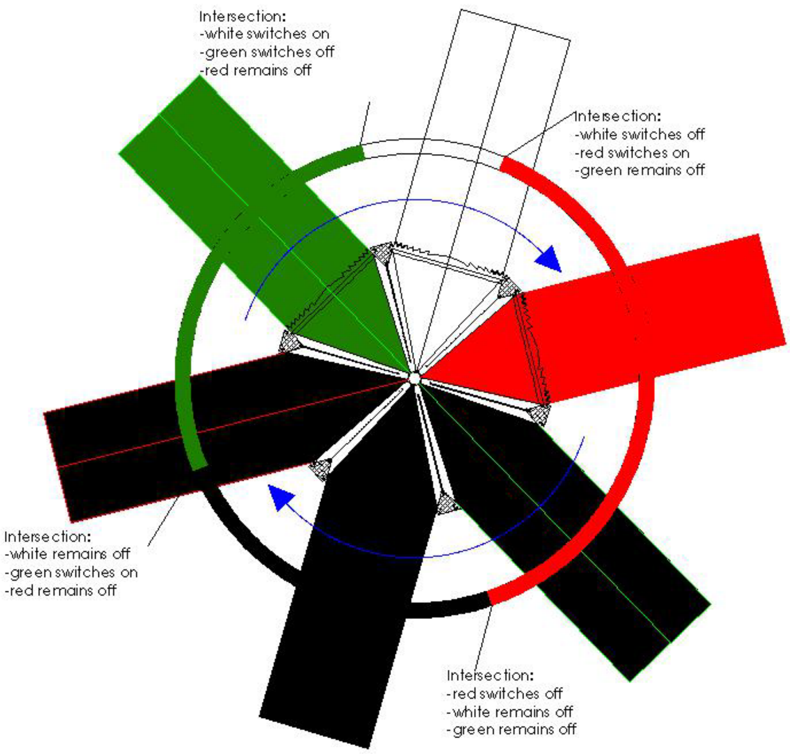


Figure 22 Example operation mode for single flashing light of 3 sectors

9.2. LIGHT SOURCE

This technology is only possible with fast switching LED.

9.3. ANGLE OF UNCERTAINTY

The angle of uncertainty depends on the horizontal divergence of the single beam with typical values of 1° to 4.7°.

9.4. ADVANTAGES

- The sector configuration is merely a matter of programming, with the possibility of any kind of configuration, from only one sector of a single colour up to complex multiple sectors of different colours.
- The modification of the width of any sectors can be done by programming without the need of physical handling or modification of the equipment.
- High luminous intensities can be achieved in comparison to sector lights which illuminate the whole sector.
- Power consumption is typically lower than in case of single-source-per-tier screened omnidirectional sector light.

9.5. DISADVANTAGES

- Low angular precision
- Mechanical moving parts
- Single point of failure in electronic control
- Only for short flashes

10. PROJECTOR SECTOR LIGHTS

Projected light is a specialized form of sector light that can generate sharply defined sector boundaries. This feature is particularly useful for applications that require one or more narrow sectors.

10.1. PRINCIPLE OF OPERATION

10.1.1. SINGLE LIGHT SOURCE

In this type of sector light, an image of the desired sectors is produced, and projected through a lens. While the image of the desired sectors may be produced in a number of ways, the most common way of producing it is by precisely machined optical filters. The principle is the same as in a slide or an overhead projector, focused at infinity. Vertical strips of coloured filter glass, optically ground and highly polished on their edges to fit closely together, are used as the 'slide' or 'film' to divide the beam into different sectors. The condenser system collects light radiating from the lamp and spreads it uniformly across the coloured filter.

An image of the filter is projected out to infinity. Sector boundaries may appear blurred within the first few hundred metres as they are out of focus, but will be very sharp at working distances.

Small changes in lamp filament position may cause minor changes in intensity within the beam, but will have no effect on the boundary positions, which are fixed by the projection (or objective) lens system.

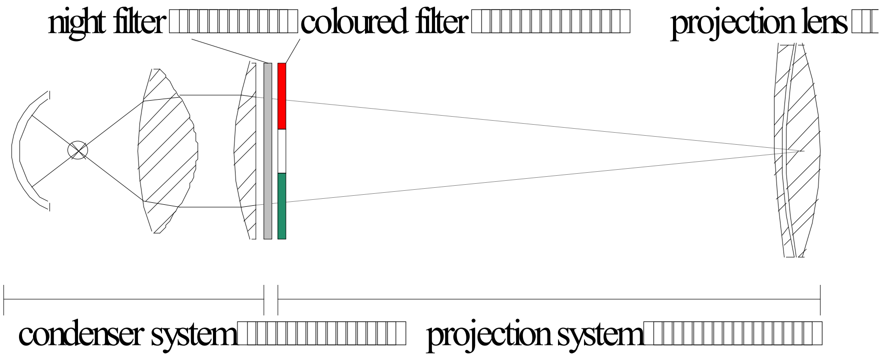


Figure 23 Basic operating principle of Projector Sector Lights

The objective lens and the filter assembly together determine the total subtense. Different objective systems are used to obtain all the different subtenses with optimal efficiency. Generally smaller subtenses require larger objective lenses and longer barrel lengths. A smaller subtense with the same size lamp would provide a greater intensity and range.

A projector Sector Light uses colour to convey information to the mariner about his angular position relative to the light. The process of 'colouring a beam involves filtering out many colours and only allowing the desired colour to pass (see 4.3).

The Sector Light is bright enough to use by day if sufficient power is available to operate the necessary size of lamp.

The size of lamp that can be fitted is limited by physical size constraints of the optical arrangement. If greater ranges are required than can be achieved with the largest lamp, then it is possible to operate two projector light units in a bi-form arrangement.

Greater range is achievable by using a smaller subtense for the projector.

10.1.2. LED PROJECTOR SECTOR LIGHTS

LED light sources are available in a range of monochromatic colours and do not need to use coloured filters. They can provide an energy efficient light source for a coloured sector light, as the light is generated directly in the desired colour and no light is wasted by absorption in sector filters. The filter cost is avoided, as are the cleaning problems often associated with filter installations. Because of the spectral characteristics of white LED lights, coloured filters should not be used with these sources.

Using an individual coloured LED projector for every sector, the resultant is a multi-beam LED Projector Sector Light (Figure 12). Single beam LED Sector Lights can be created using various methods including the use of mirrors (Figure 13).

This technology requires that the sector limits must be adjusted very carefully relative to each other.

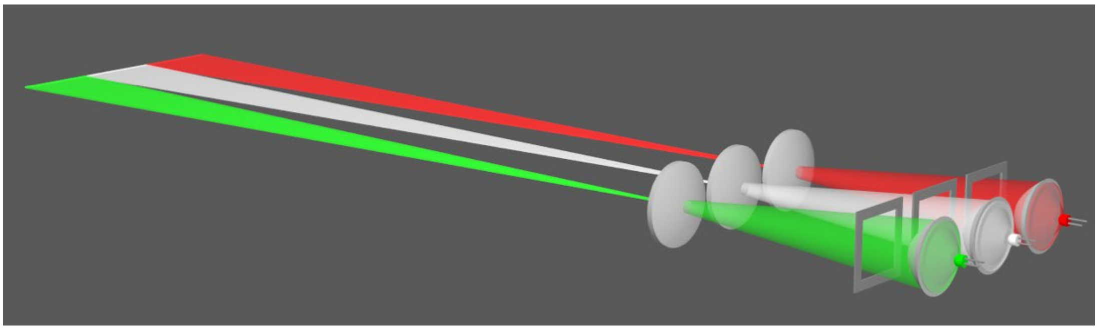


Figure 24 Multiple beam LED projector sector light

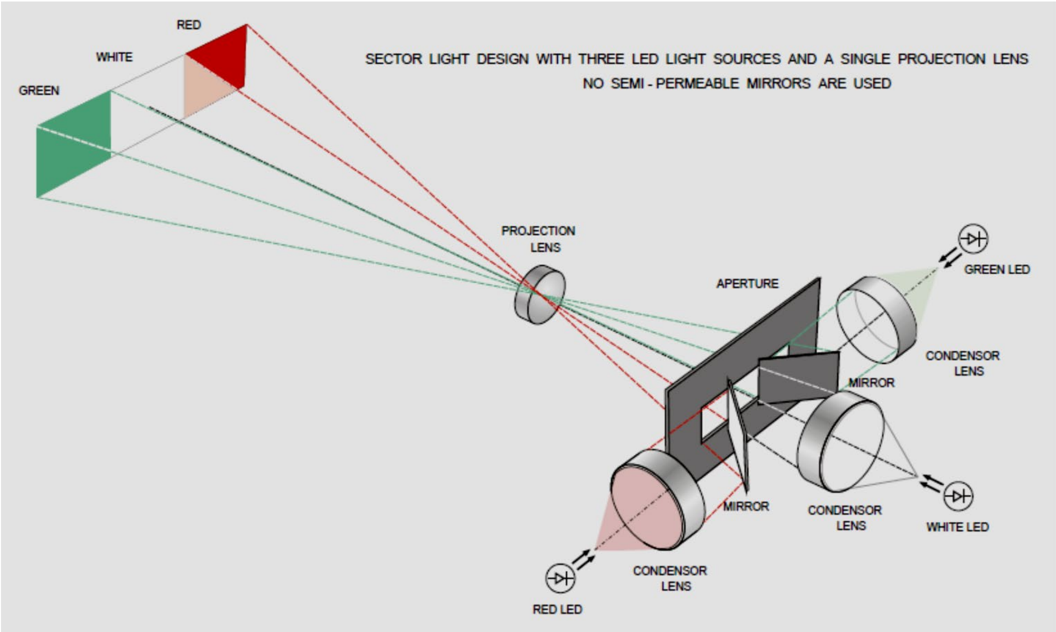


Figure 25 Single beam LED projector sector light with mirrors

10.2. ANGLE OF UNCERTAINTY

Some sector projectors can overcome boundary inaccuracies by the design of the projector optics. These projector sector lights are so precise that a complete colour change at a sector boundary occurs over an angle of less than 1 minute (0.02°) in most models. This corresponds to a lateral distance of just 1 metre at a viewing distance of 3.5 km. Nevertheless, precision of certain projectors with high intensity or wider sectors may exceed 6 minutes (0.1°).

In addition, the intensity is maintained right to the edge of the beam, and does not reduce the further the observer is away from the axis.

10.3. ADVANTAGES/DISADVANTAGE

10.3.1. ADVANTAGES

- High intensities available even for daytime use
- Small angle of uncertainty
- Compact design
- Low power consumption (LED projector)
- Power efficient day/night mode switching (LED projector)

10.3.2. DISADVANTAGES

- Supporting structure must be very robust
- Difficult to change sector size

11. GENERAL DESIGN METHODOLOGY

The following procedure shows some steps to find an appropriate design for the required sector light.

11.1. STEP 1

Determine the required sectors.

The subtense of each sector is given by the nautical requirements.

The design process for a sector light needs to consider the speed and manoeuvrability of vessels likely to be negotiating the sector, how quickly they can respond once they cross a sector boundary and the situations that may develop when other vessels are in the vicinity.

For each boundary the angle of uncertainty must be considered depending on the precision of the guidance required.

11.2. STEP 2

Determine the required luminous range (from nautical requirement), the background illumination and a typical value for the meteorological visibility.

In general, the calculation of the luminous intensity is not based on nominal range (Meteorological visibility = 10 nautical miles (M) and no background illumination). Typical values chosen for meteorological visibility in range calculations are 2 to 5 M.

11.3. STEP 3

Determine whether a night-only signal is required or a day and night signal.

11.4. STEP 4

Determine the required vertical divergence of the luminous intensity distribution. The divergence can be derived from the lowest range the light is used for navigation, the maximum and minimum bridge height, the height of the light and the tidal range (see IALA Guideline *G1065 Aids to Navigation Signal Light Beam Vertical Divergence*).

11.5. STEP 5

Calculate the required intensity for each sector with the tools of IALA Recommendation *R0200 (E-200) Marine Signal Lights, Part 2 - Calculation, Definition and Notation of Luminous Range*.

11.6. STEP 6

Determine the flash character for the sector light or each sector, bearing in mind the characters of other nearby AtoN lights.

The flash characters should comply with the nautical requirements. In many cases occulting or isophase characters are preferred to provide ample time for a mariner to recognize the transitional phases that occur at the sector boundary (longer flash length).

For renewable energy systems, the additional energy consumption arising from long flash length must be balanced against the ability of the power system to provide the required energy.

Flash characters are not suitable to use with oscillating boundaries and therefore consideration must be taken of the background lighting for the fixed sectors.

Isophase characters are suitable when using alternating flashing.

After Step 6 the optical parameters for the light are known and in the next steps the optical apparatus is chosen. However, in these steps a nautical assessment should still be considered, especially for the angle of uncertainty.

11.7. EXAMPLE 1

The nominal boundaries of a sector light are 30°, 65°, 105° and 130° (Figure 26). When the angle of uncertainty of the optical apparatus is taken into account, the safe sector should include the angle of uncertainty. This will ensure that the hazardous sector is clearly identified and when the ship is in the angle of uncertainty it will be still in the safe sector.

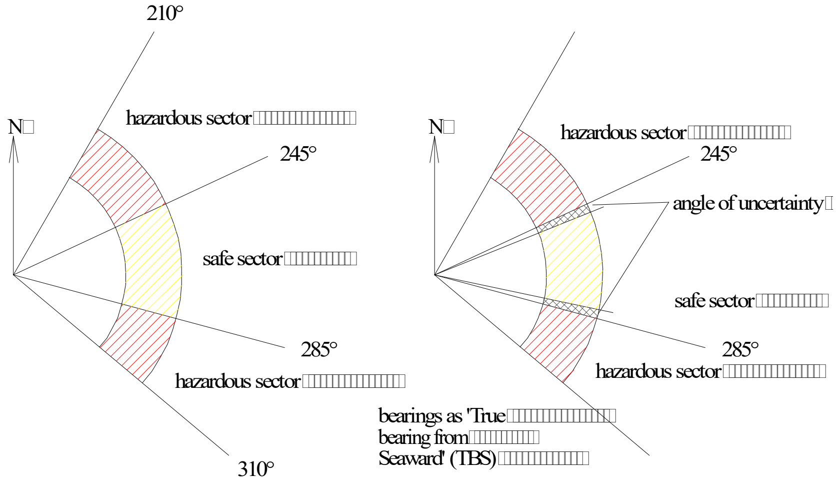


Figure 26 Reduction of the optical white sector

11.8. EXAMPLE 2

A small channel should be marked by a projector sector light. A first assessment for the safe sector will be derived from the water depth and width of the channel. A re-evaluation will then take into account the width of the vessels, their speed and manoeuvrability, and the angle of uncertainty of the optical apparatus. This will result in a smaller white sector (Figure 27).

To improve visual navigation in this case, additional sectors with alternating flashes or oscillating boundaries should be considered (see IALA Dictionary for definitions of boundary types).

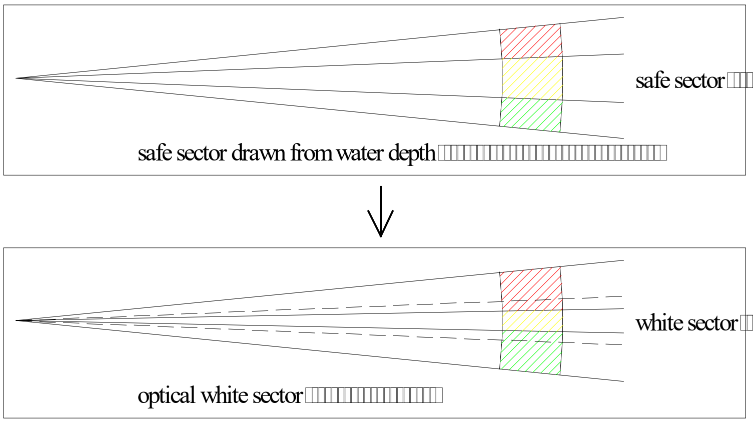


Figure 27 Re-evaluation of the white sector

11.9. STEP 7

Select the type of a sector light from the list in sections 7-11.

The preferred types are:

- point source sector lights, for large angular subtense and medium accuracy;
- projector sector light for small channels, high accuracy and high intensity; and
- rotating switching sector lights for large angular subtense and high intensity.

If the total subtense is large and the sectors need high intensity and accuracy an arrangement of multiple projector and/or point source sector lights should be considered.

11.10. STEP 8

If a daytime signal is required:

Check if the daytime range can be achieved with an acceptable effort. Check whether additional AtoN are needed for daytime (e.g., buoys to mark a single danger or the border of a channel).

The night time reduction of the intensity should be between 1% to 10% of the daytime intensity. However, each application should be considered individually by calculating daytime and night time luminous range.

The preferred methods for night time reduction are:

- pulse with modulation (PWM, LED only);
- optical grey filter; and
- combination of PWM with reduced night mode current (LED only).

Sometimes voltage reduction may be used for lights with incandescent lamps. In this case the colour of the sectors should be checked for low voltage. Whereas the green and red sectors may fulfil the IALA Recommendation on Marine Signal Lights *R0200 (E-200), Part 1 Colours*, it may not be true for the white sector.

11.11. STEP 9

Thereafter optical apparatus is selected by considering additional features as:

- Power supply
- Mechanical adaption
- Remote monitoring
- Remote control
- Maintenance

12. SPECIAL DESIGN REQUIREMENTS

Sector lights are very sensitive to small changes; therefore, special requirements are needed for the design of the lantern.

12.1. SECTOR ACCURACY

The sector borders may be moved unintentionally from the required position by:

- moving the light source;
- moving cut or filter screens; or
- rotating the lantern or the supporting structure.

Since the bearing of a sector light is critical, structures supporting sector lights must be particularly resistant to twisting to ensure that the sector lights remain accurate.

The light source has to be adjusted exactly in the focal point of the optic even when it is replaced. If a lamp changer is used, it should exactly reproduce the position for each lamp.

The elements which can cause a misalignment should be marked. The maintenance staff should be trained to take care about the precise alignment of the sector boundaries.

12.2. REFLECTIONS

Unwanted reflections may be caused by the lantern glazing, the sash bars, obstructions at the light house, etc.

These reflections may produce false flashes, wrong colour or even a wrong sector. Such anomalies can be minimized by tilting the glazing, by using curved panes or by using sector screens. The window glazing should be made of a single plate. Double-glazed windows should not be used because this will increase reflections.

Obstructions of the light path should be avoided and if they are necessary they should be covered with black matt finish.

12.3. CLEANLINESS OF OPTICAL PATH

Ice, condensed water or grime on the glazing of a lighthouse or on the optical components of a sector light may cause coloured sectors to appear white. It may also make the light faint or invisible.

The glazing of the lighthouse and the optical components of a sector light should be accessible for cleaning the surfaces. Preparations should be made to avoid ice, condensed water and grime on the lighthouse glazing. This can be done by a small roof above the glazing at the optical path of a sector light or by introducing a window defroster.

13. INSTALLATION AND VERIFICATION

Due to the significant impact of small deviations in alignment of sector lights on safety of navigation, it is important that engineering, manufacturing and installation are carried out with care.

Proper measurement, installation and verification procedures must be implemented at each stage of the deployment process.

For details on measurement see IALA-Recommendation *R0203 (E-200-3)Marine Signal Lights Part 3 – Measurement* [4].

13.1. ANGLE DEFINITION

Once the sector boundary angles have been determined, they need to be converted from the goniometer scale to a compass bearing and reciprocal compass bearing. This will enable the sectors to be checked with figures published in the Admiralty List of Lights or with the navigational requirement.

Table 3 Compass and reciprocal bearing

Compass Bearing (lighthouse)	Reciprocal bearing (ship)(TBS)	Compass Bearing (lighthouse)	Reciprocal bearing (ship)(TBS)
0	180	180	0
350	170	170	350
340	160	160	340
330	150	150	330
320	140	140	320
310	130	130	310
300	120	120	300
290	110	110	290
280	100	100	280
270	90	90	270
260	80	80	260
250	70	70	250
240	60	60	240
230	50	50	230
220	40	40	220
210	30	30	210
200	20	20	200
190	10	10	190

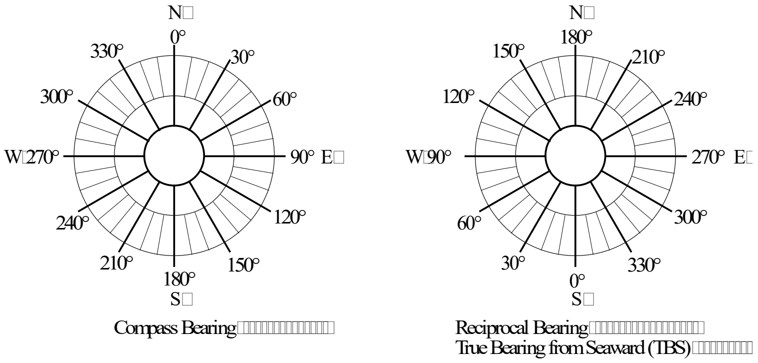


Figure 28 Compass versus reciprocal bearing

13.2. GENERAL REMARKS

The installation and verification process depends on whether a new piece of equipment is setup or, existing equipment is updated.

Many new sector lights have sectors already setup by the manufacturer in a laboratory to comply with the customer's specification. In this case the installation process is reduced to levelling and rotating the lantern into position for correct sector alignment.

On lighthouses where existing equipment is being updated with the addition of filter material a more complex process is required. In this case each sector boundary has to be adjusted individually. Some sector lights which are not set up by the manufacturer have to be set up in the same manner on site.

If replacing an existing light, mark the sector boundaries from the old light on a convenient existing structure. This can be used for confirmation after installation of the replacement light.

13.3. INSTALLATION OF NEW SECTOR LIGHT WITH FACTORY SETUP SECTORS

13.3.1. PROCEDURE WITH A DATUM ON THE LANTERN (LOW ACCURACY)

The installation of a new sector light requires the equipment to comply with the particular specification which includes the sectors and a datum. This datum could be a notable local feature (landmark) or North. The sectors should be verified by a test report from the manufacturer.

Figure 29 shows the top of a sector light with a datum showing 'North'.

Figure 30 shows a sector light with a datum for the direction of a given landmark which is on bearing 267°

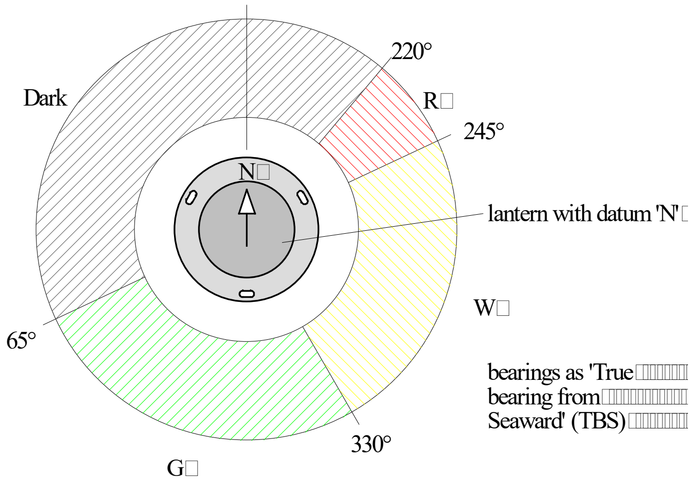


Figure 29 Sector light with datum 'North' on top of the lantern and coloured sector

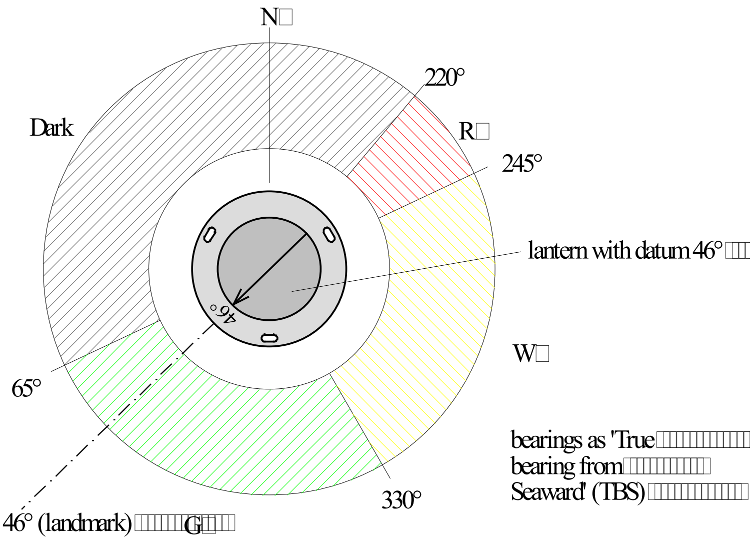


Figure 30 Sector light with datum '46°' (TBS) which points to a known landmark

Once the lantern is installed it should be levelled (Figure 31). In many cases this can be done with the help of a spirit level. The lantern should have either a fixed spirit level or a reference plane which is parallel to the horizontal central beam axis.

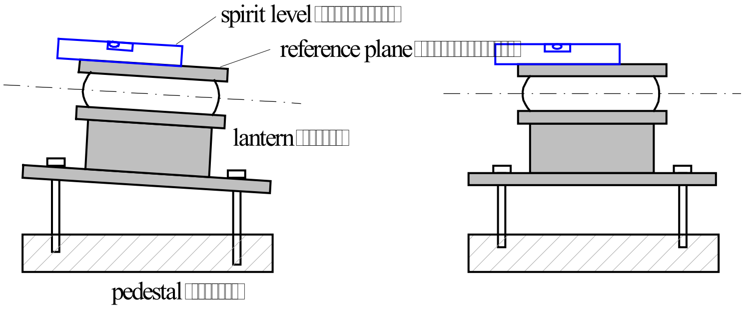


Figure 31 Levelling a lantern

Then the lantern is rotated to align with the reference point (Figure 32), so that the sectors of the lantern correspond to the required sectors of the charts (Figure 33).

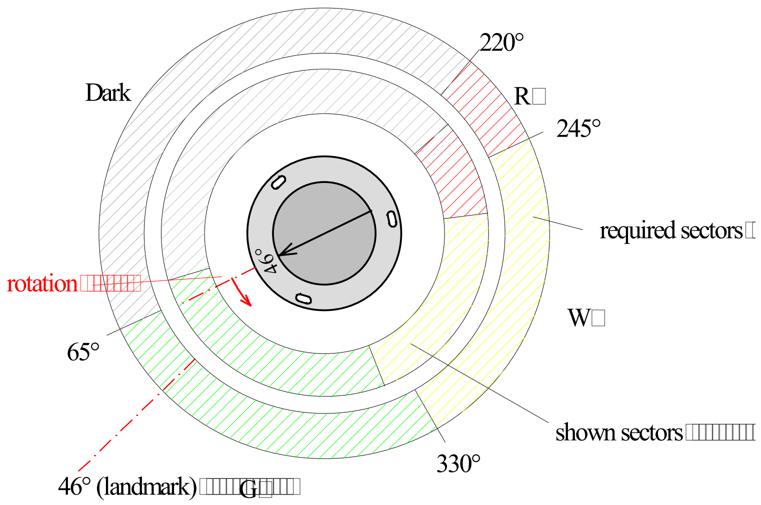


Figure 32 Rotating the lantern with a landmark at 226° as the reference point

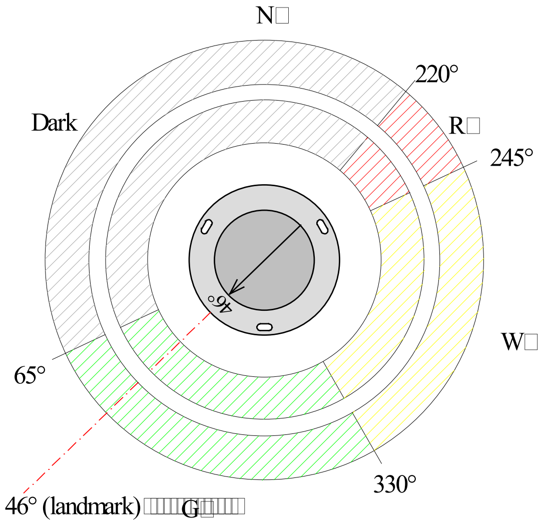


Figure 33 Alignment finished

Commissioning of the sector light should be carried out by a vessel. The task is to sail round all sectors and sector boundaries to ensure that the light complies with the navigational requirement. This requires the mariner to carefully observe the change in colour of the light at each sector boundary and recognition of colour change may best be achieved if a fixed light is exhibited from the sector light for the duration of the commissioning procedure.

Commissioning by a vessel should be carried out at the required range of the lantern and if possible at the shortest range that the light can be used.

In Figure 34 shows an example for commissioning the sectors by a vessel. The sector boundaries are crossed several times to check the correct alignment of the sector boundary. While crossing a sector it should be verified that the sector shows the right colour, flash character and intensity.

More details about commissioning can be found in section 13.5.

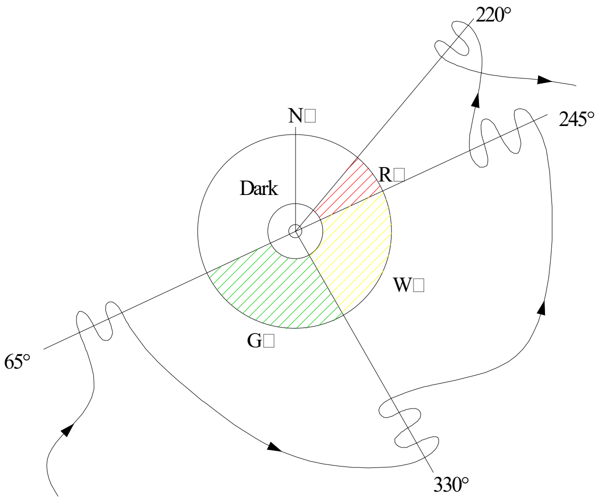


Figure 34 Commissioning the sector light by a vessel

13.3.2. USING A REGISTER PLATE

The adjustment of the sector light may be easier when using a register plate. The register plate shows a drawing of the sectors and the directions to North and the landmark used for alignment.

The register plate will be mounted permanently underneath the lantern with a gap so that the plate drawing stays visible.

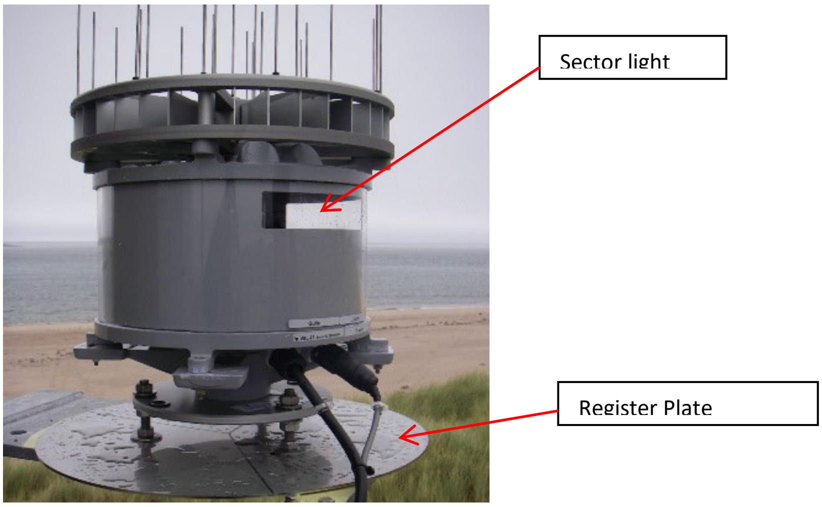


Figure 35 Sector Light mounted on a Register Plate

The design of the register plate should include slotted fixing holes to enable it to be rotated about its vertical axis so that it can be aligned with the relevant landmarks and/or references. It should also include markings pertinent to the station on which the sector light is to be fitted as follows:

- A true North mark
- A diametric line at the relative bearing of a previously agreed landmark or landmarks
- Radial lines at the relative bearings of the sector boundaries (optional with TBS)
- Colour identification of the sectors
- The thickness of the line markings on the register plate should be no more than 0.5mm.

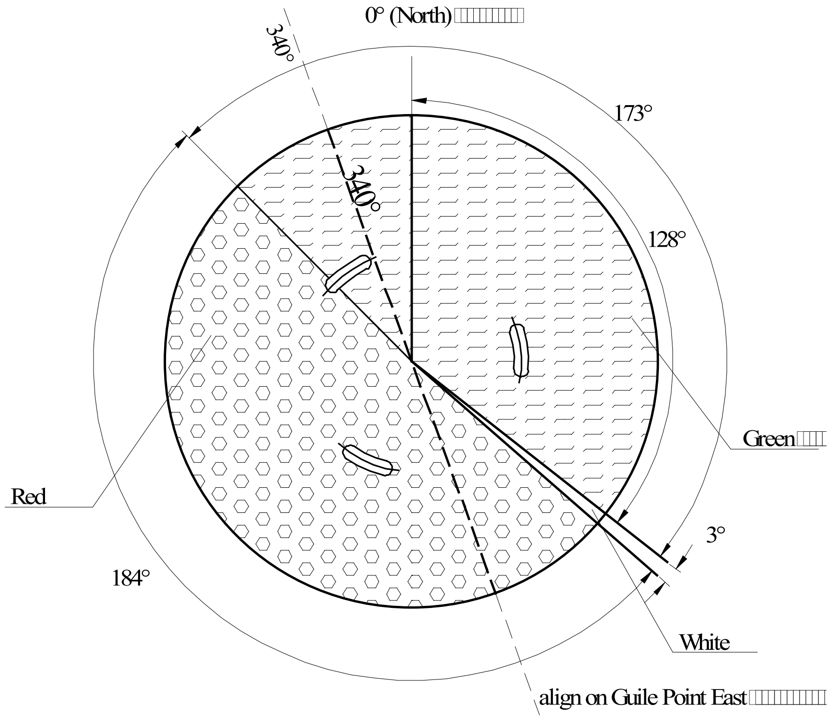


Figure 36 Example of a Register Plate

Please note that if the slotted hole for mounting is in line with the landmark bearing line, the nut and bolt may obscure the observer's view along the line (across the plate).

- place the register plate on the pedestal mounting plate, roughly aligning the true North radial mark on the register plate with true North using a magnetic compass or similar;
- using nuts and bolts, loosely secure the register plate in its approximate position on the mounting plate, bearing in mind that the plate will have to be turned to finely adjust its position;
- look along the diametric landmark bearing line marked on the register plate in the direction of its respective landmark and rotate the plate until the diametric line is aligned with the landmark;
- if there are other landmarks, check their respective lines for correct alignment and adjust to get the best compromise between all landmarks;
- tighten the nuts and bolts carefully and recheck the landmark alignments;
- mount the sector light assembly above the register plate (see Figure 37) and loosely secure (bearing in mind that the light will have to be turned to adjust its position);
- ensure the light is levelled by using the integral level or a spirit level across the top of the light assembly;
- rotate the light assembly until the true North datum mark on the sector light base (marked during the light range measurement procedure or by the manufacturer) is aligned with the true North radial mark on the register plate;
- if appropriate, ensure all other marks on the lantern perimeter are aligned with their corresponding radial marks on the register plate;
- tighten the nuts carefully and recheck the alignment with the register plate.

The installation procedure should now be complete but further adjustment or alignment may be necessary during commissioning.

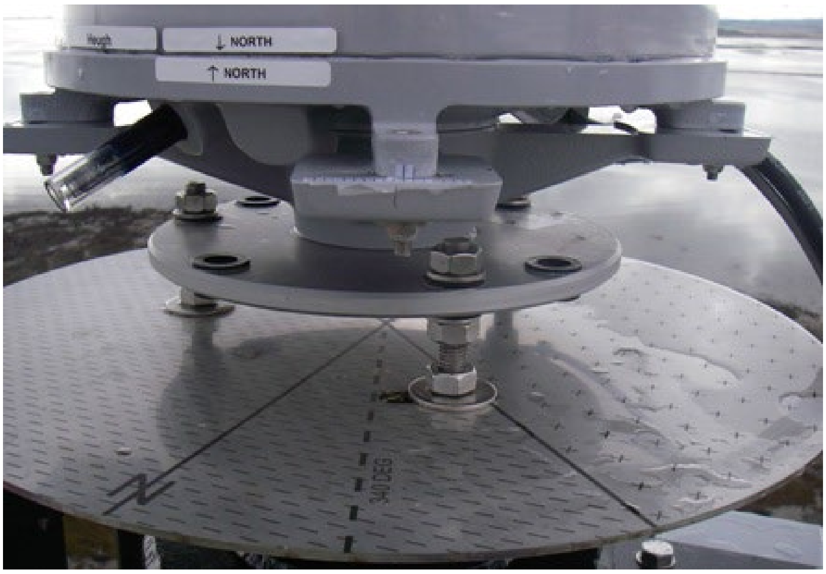


Figure 37 Close-up Sector Light Mounting on a Register Plate

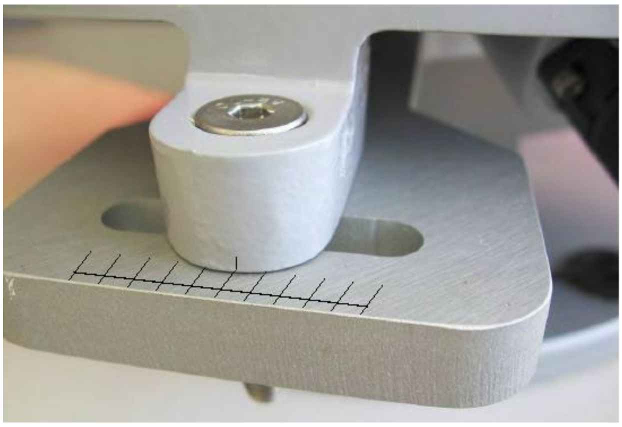


Figure 38 Graduated Scale marked on the Secondary Mounting Arrangement

13.3.3. THE USE OF SIMPLE SIGHT TO IMPROVE ACCURACY

In many cases a datum is not a very precise method for the alignment of a sector light. The accuracy can be improved by using a simple sight. It is composed of front and rear aiming pieces. There are different shapes for the aiming pieces.

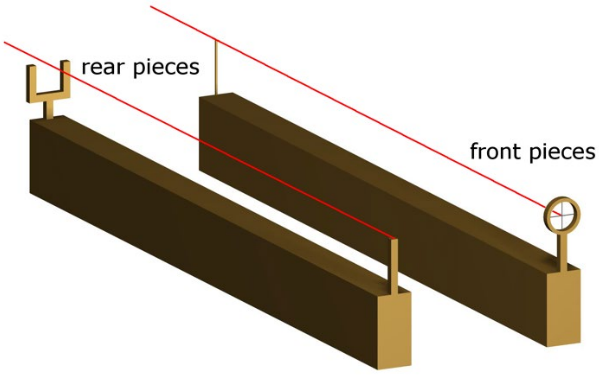


Figure 39 Two different sights

If a simple sight (alternative: iron sight) is used, the sight picture for the alignment procedure should be explained.

Some sights are called 'open' when the target has to be aligned above the sight pieces. In this case the occlusion of the target is minimized.

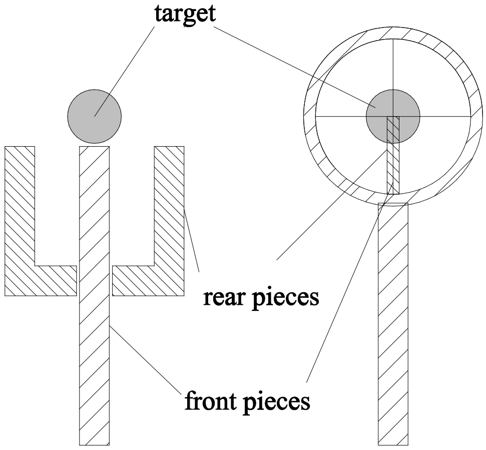


Figure 40 Sight picture for the two sight examples

The alignment procedure using a simple sight is the same as described in section 13.3.1.

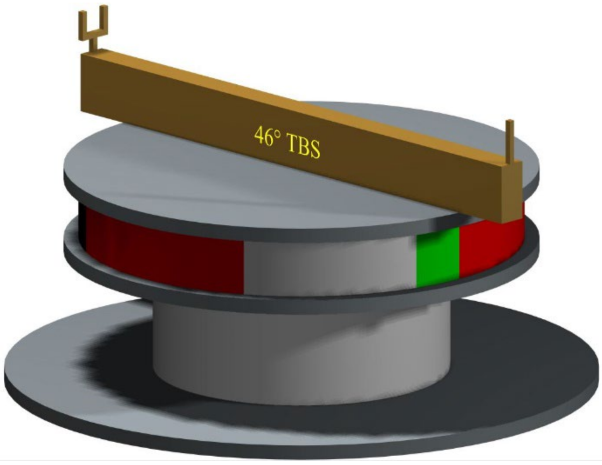


Figure 41 A simple sight mounted on a sector light

13.3.4. THE USE OF A TELESCOPIC SIGHT FOR MAXIMUM ACCURACY

The accuracy of the alignment on site can be maximized by using an optical or telescopic sight (alignment telescope). It is the preferred method for the installation of precision sector lights with small sector angles (Figure 42)

Some manufacturers use re-locatable filters or screens for the projector. The sectors can be changed in size and position. Some other projectors have fixed sectors, so there is only the need to adjust the projector on the whole.

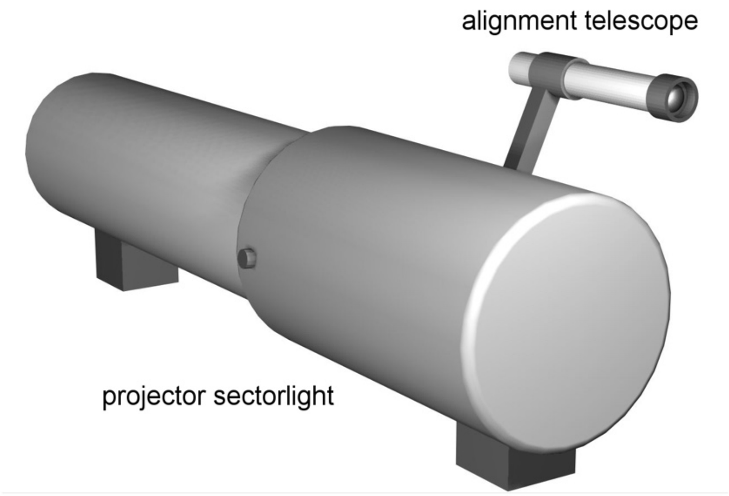


Figure 42 Precision sector light with alignment telescope

The centre of the white sector is often regarded as the optical axis of the projector. In the workshop or light laboratory, a telescope with crosshair or reticule is fitted to the projector. The telescope is adjusted so that the centre of the crosshair shows in the direction of the optical axis of the projector. This means that the optical axis of the projector and the telescope are parallel (Figure 43).

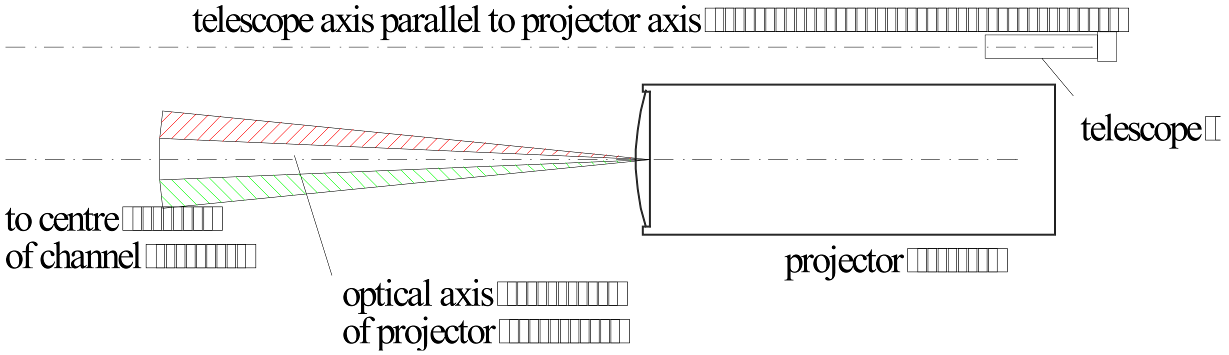


Figure 43 Projector and telescope axis

During installation, a vessel with high precision positioning equipment should align itself to the centre of the safe sector. The projector is rotated while looking through the telescope, until the vessel appears at the centre of the crosshair.

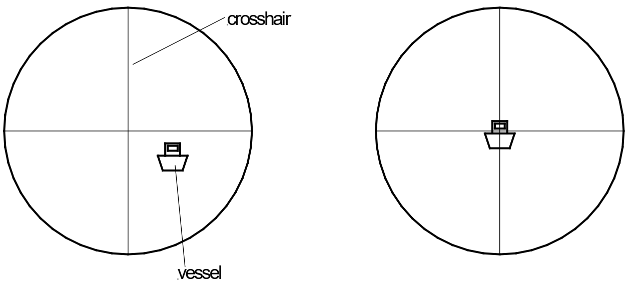


Figure 44 View through telescope

Figure 45 Sample of practical installation with fixed telescope method

Remarks:

- It is assumed that the sectors are already correctly set in a laboratory or workshop, so the adjustment with the telescope is the only task during installation.

  However, it is recommended to check all the sectors by verifying with a ship.

- The adjustment may be done both horizontally and vertically.

13.3.5. ALTERNATIVE

In some cases, it is more convenient to use a landmark to adjust the projector. The landmark however may not be on the axis of the safe channel but has an angular deviation α to the axis. In this case the telescope has to be adjusted with the angular deviation to the projector axis.

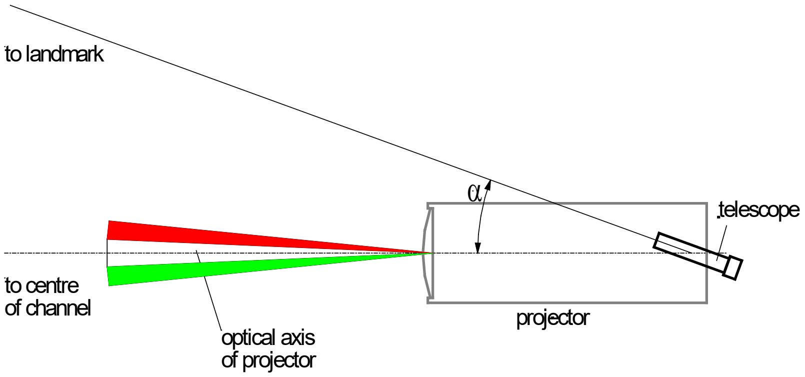


Figure 46 Adjustment to a landmark

13.3.6. ADJUSTMENT IN WORKSHOP OR LABORATORY (FACTORY SETUP)

For the preliminary adjustment of a projector sector light in a workshop or laboratory the limited viewing or measurement distance has to take be considered.

The size and location of the sectors can be measured by a goniophotometer or projected on to a screen. The projection screen should have a distance of at least 20m to the projector (Figure 47).

When X is the horizontal distance between the projector axis and the telescope or sight axis, the distance between the screen marks for the axis and the telescope should have a distance X as well. This will ensure that both axes are adjusted parallel to each other.

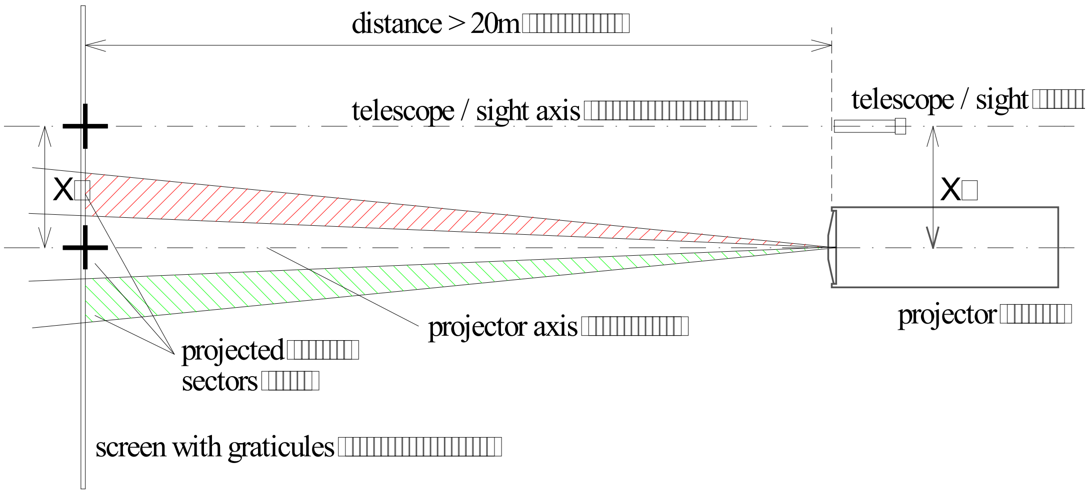


Figure 47 Horizontal alignment in a workshop

The same holds true for the vertical plane. In nearly all cases the telescope is placed a vertical distance Y above the optical axis of the projector. So the mark on the screen must have a distance Y.

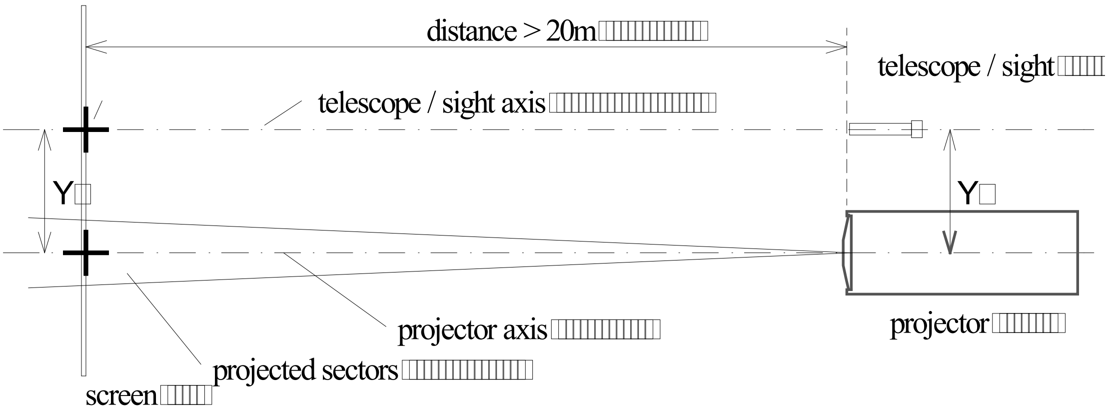


Figure 48 Vertical alignment in a workshop

13.4. INSTALLATION OF A NEW SECTOR IN EXISTING LIGHTS

A sector can be installed in an existing light by the addition of filter material or opaque screens. At first the nominal size of the filter material and screens should be calculated taking into account the height of the optic, the distance between light source and filter / screen (d) and the sector width (α).

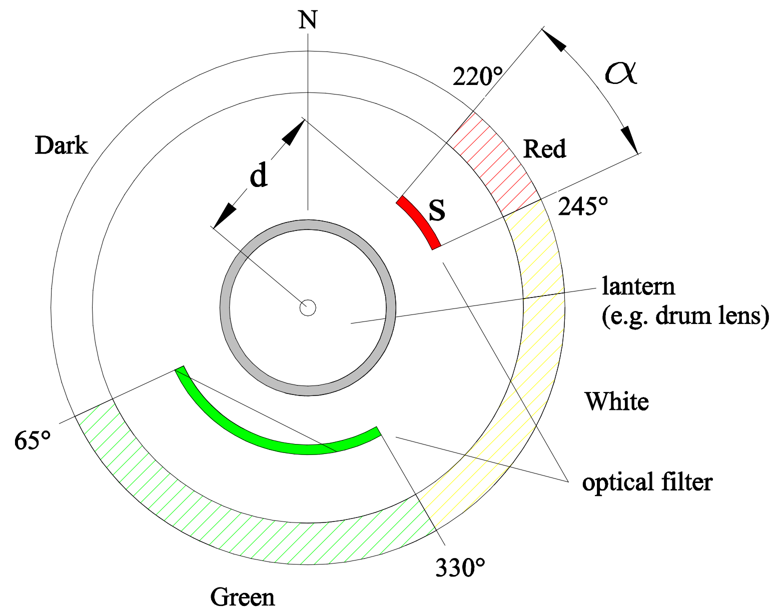


Figure 49 Installing new sectors in an existing sector

S is the horizontal length of the filter

H is the vertical height of the filter

$$S = d \times \alpha \text{ when } \alpha \text{ in radians}$$

$$S = d \times 0.01745 \times \alpha \text{ when } \alpha \text{ in degrees}$$

Equation 6 Horizontal filter length

H > height of the optic

At the boundaries between a coloured and a white sector, the actual size of the filter material / screen should be greater than the nominal size (see section 6.1.4: $S_c = S + x$).

In practical terms two pieces of filter material that overlap in the centre of the sector should be used if two boundaries need to be adjusted. This allows for some adjustment during the checking procedure (Figure 50).

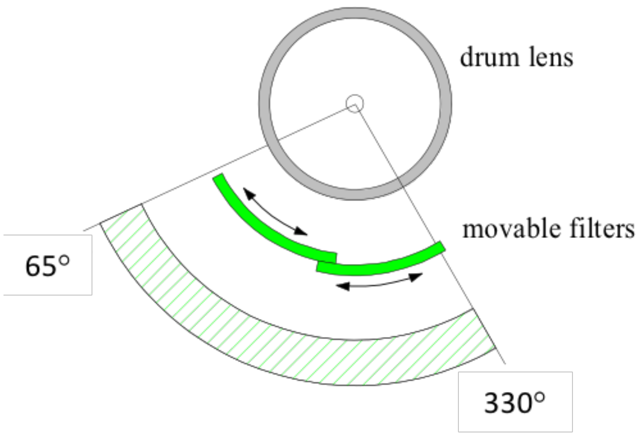


Figure 50 Overlapping filters

The filter material / screen should be installed as far from the light source as possible (normally at the inside of the glazing). It should be moveable during the installation and have a facility to lock it in place once sectors have been commissioned.

If the radius of the filter material is large, the cylindrical shape of the filter may be replaced by a set of plane filters (Figure 51).

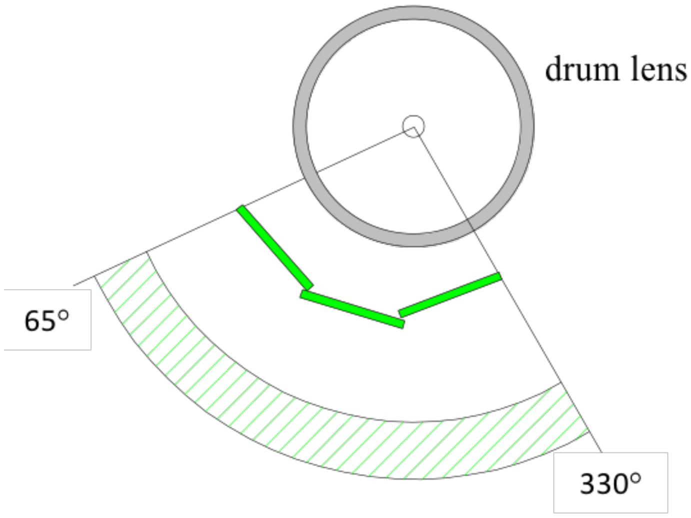


Figure 51 Plane filters

For the commissioning procedure a ship is required to adjust and verify the correct sectors. It should be noted that the sector edge may not exactly match up with the filter material / screen edge (see section 6.1.4).

13.5. COMMISSIONING

Verification of sectors should be carried out by at least two experienced observers. Testing should be conducted under good weather and water conditions, preferably in clear and transparent air.

Observations made from a long distance should be carried out in complete darkness. Prior to testing, the sector light system should be inspected to ensure that it is functioning correctly and glazing, lens, etc. are clean. It is recommended that, when the light has long eclipses, the character should be set to fixed light.

For sector boundaries with a wide angle of uncertainty, the bearing at which the change in colour is perceived in one direction may be significantly different to that in the other direction. In this case, each direction should be treated separately and a mean of several recorded bearings for each direction taken. This will result in two mean values, the mean of which can be taken as the sector boundary bearing and the difference of which can be taken as the angle of uncertainty of the sector boundary.

For example, in one direction the change of colour from red to pink may be recorded three times and the mean taken. In the other direction, the change of colour from white to pink may be recorded three times and the mean taken. The mean of these two means would be the sector boundary bearing. The difference between the two means would be the sector boundary angle of uncertainty.

Each mean sector boundary bearing should be compared with the published data for that station and reported accordingly.

It should be borne in mind that on most stand-alone sector lights there is no readily available means of adjusting a sector boundary. Therefore, if there is a significant departure from the published bearing, either the whole beacon has to be turned, which will affect all other sector boundary bearings, or the equipment will have to be returned to shore to be adjusted on a light measuring range. If necessary, the whole light assembly can be rotated to seek an all-round compromise between the errors at all sector boundary bearings.

Measurement is carried out at a number of different positions as indicated in Figure 52 presenting one of many methods to ensure that the sectors are correctly marked throughout the usable part of the sectors.

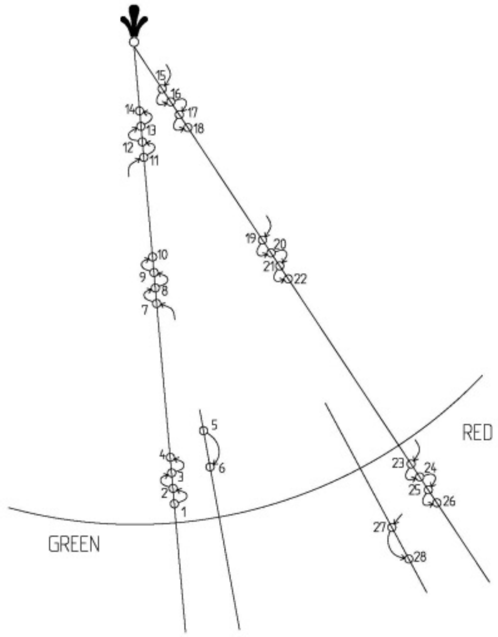
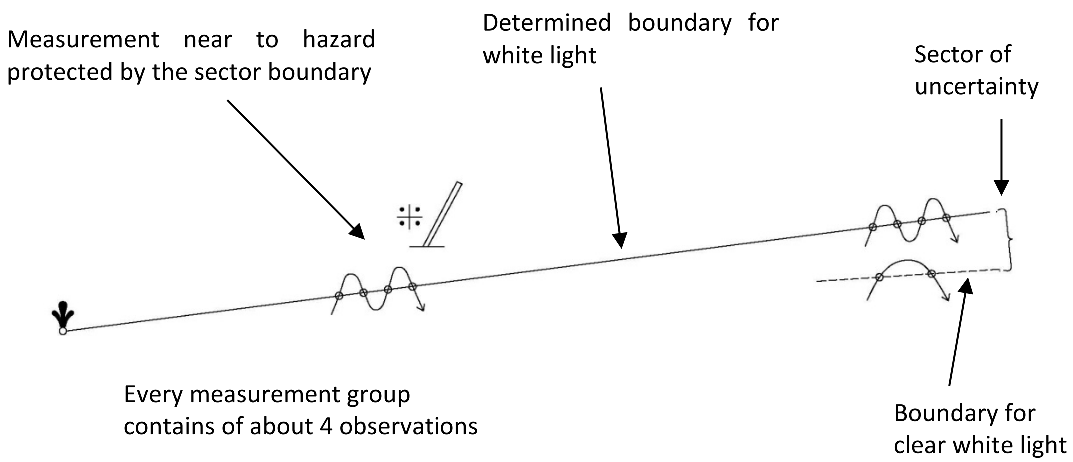


Figure 52 Sector light testing using a boat



The number of observations varies depending on the length of the border. At least 2 (normally 3-4) locations should be tested, one of which is close and one at the outer end of the sector. The spread of observations is important to determine the angle of uncertainty.

Figure 53 Sector light commissioning

However, each uncertainty contribution should be considered carefully for each station and each sector. When using an electronic chart and positioning by DGNSS, the greater the distance between light and vessel, the more accurate the bearing and consequently the lower the angular uncertainty. This increased accuracy is offset by the ability to observe a change of colour in a light when it is much smaller in the eye (smaller subtense angle) and much dimmer. In the case of white/green boundaries, there is potential for colour confusion at low levels of observer illuminance, particularly for flashing lights. At greater distances of observation therefore, the change from white to green, or vice versa, might not be easily distinguishable.

13.6. EFFECT OF COLD WEATHER CONDITIONS

In geographical areas that experience freezing temperatures the angle of uncertainty may increase substantially due to snow and ice coating or formation of mist on the optical apparatus. The light could then be interpreted as white in sectors where it under normal conditions will be seen as coloured due to scattering. Furthermore, a false light in dark sectors, originating from adjacent sectors, might be observed under these same conditions.

13.7. USE OF THEODOLITE FOR INSTALLATION, ALIGNMENT AND COMMISSIONING

13.7.1. INTRODUCTION

A theodolite is a portable precision instrument designed to measure angles in the horizontal and vertical planes. Theodolites are used mainly for surveying applications, e.g., topographic/geographic surveys and surveys for house building, bridge building, road construction, etc.

The details of theodolites vary according to their make and type. Older theodolites are typically of solely mechanical construction while newer ones can be rather complicated with digital display and data memory unit. Modern theodolites or so-called intelligent or ‘total station’ theodolites are equipped with integrated electro-optical distance measuring and computerized for saving data into an integrated register.

Basically, the theodolite consists of a movable telescope which is mounted within two perpendicular axes – the horizontal and the vertical axis.

By turning the upper part of the theodolite (around the vertical axis) it is possible to take a bearing on a specific target object and read the value on a graduated scale. Using a clamp on the horizontal scale it is possible to set the horizontal scale reading to a desired reading, e.g., when the direction is given from site A to site B. By tilting the telescope (around the horizontal axis) the vertical or the tilt angel can be determined.

The angle of each of these axes can be measured with great precision – typically to one second of arc. The scale of theodolite can be graduated in 360° or 400^g.

It is recommended to use a 360° theodolite for verification and alignment of sector light because it corresponding to the nautical measuring system within degrees (°), minutes (‘) and seconds (“). A 400^g theodolite requires a conversion factor which can lead to confusion during its use and errors in the final results.

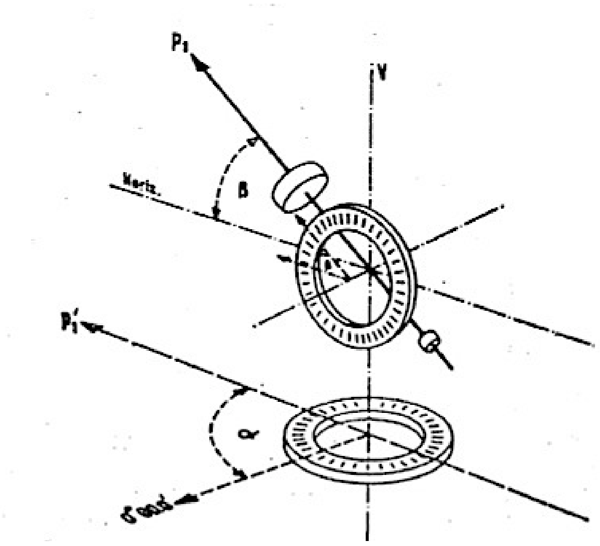


Figure 54 Theodolite rotation axis

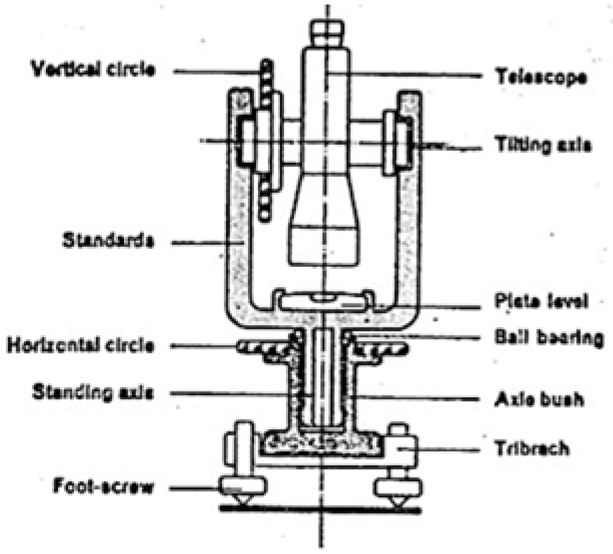


Figure 55 Theodolite basic elements

Figure 56 Simple mechanical theodolite

Figure 57 Modern theodolite mounted on a tripod

Commonly the theodolite is mounted on a tripod. The head of the tripod supports the instrument while the feet are spiked to anchor the tripod to ground.

The theodolite is a fragile and expensive instrument and should be handled with care during transport and use. The theodolite is commonly stored away in a shock proof and water tight case equipped with carrying straps. The tripod can be folded together and it is equipped with shoulder straps for easy transport.

13.7.2. PREPARATION BEFORE ALIGNMENT

13.7.2.1. Sectors and geographic position

- Sector and geographic position of the light are published in the Admiralty List of Lights or with the navigational requirement from the national maritime authority;

  Boundary angles and bearings of these from sea need to be converted to reciprocal compass bearings for use with the theodolite from the light (see Table 3).

- If the geographic position of the light is not accurate enough, it must be re-positioned before the alignment procedure.

  The position can be confirmed / approved by a portable DGPS unit or by a geodetic survey procedure including relevant geographic reference objects.

13.7.2.2. Selection of geographic reference objects

- Lists and register of geographic reference objects are available from national and local geodetic authorities.

  By studying sea chart and geographic chart and lists, relevant geographic reference objects are selected;

- Details from previously conducted alignments at the same light can provide useful information about previously used reference objects;
- Preference should be given to reference objects for the baseline in same direction as the sector being aligned;
- Only approved and confirmed reference objects are used for calculation of reference baselines;

Bear in mind when selecting reference objects that the geographic object must be clear and observable from the light being aligned.

- Consider obstacles in the sight line and the distance – not to close, but not so far away that it is difficult to see;
- Commonly lighthouses, church spires, larger building construction, etc., are suitable as a geographic reference objects;
- In remote areas reference objects are typically available in the terrain and marked with a numbered metal plate;

  In that case the reference object must be marked with a temporary pole with flag to be visible for the operator of the theodolite.
- Select at least 3 geographic reference objects – one for the reference baseline and two for verification of the baseline and position of the light.

13.7.2.3. Calculation of reference baselines

- Using identified reference objects and the position of the light, it is now possible to calculate baselines / bearings between the light and the selected reference objects.

  National geodetic authorities commonly provide a web-based service for these calculations. If not, it is possible to calculate the bearing direction.

13.7.2.4. Pre-test of the alignment procedure

- Due to the complexity of a theodolite it is essential to have a trained and experienced observer to operate the instrument and it is recommended that they be familiar with the instrument before using it in field;
- Set up the theodolite and think in the baseline and the reference baseline and the sectors being aligned.

13.7.3. FIELD ALIGNMENT OF SECTOR LIGHT

13.7.3.1. Weather forecast

- To achieve a good alignment, it is important to have a good and stable visibility;

  It is recommended the operation be carried out at night-time or in daytime in cloudy weather. Avoid sunny days and days with rain and fog / low visibility due to the difficulty in clearly observing the transition between sectors;
- Local wave height and current must also be considered when using a small boat for observation from sea.

13.7.3.2. Preparing lantern and coloured filters for aligning sectors

- Pre-installation work must be finished in good time before the alignment procedure;
- The preparation for the type the sector light. Filter sheets in required colours and size and addition fittings and fixtures must be available;
- Before the alignment procedure proceeds, filters and lantern with internal sectors must be installed and aligned by taking a coarse bearing over the lantern with the naked eye in direction to reference objects;
- For easy alignment in field calculate the width of the arc of 1°, 45’, 30’ and 15’, and then it is easy to adjust the filter sheet or the lantern during the alignment procedure.

13.7.3.3. Setting-up theodolite

- Light and lighthouses vary according geographic place, size of the building and technical equipment. It is not common to have access to place the theodolite exactly over the lantern or optic;

  At larger lighthouses it is practical and easy to set-up the theodolite at the balcony and at smaller lighthouses it is more practical to set-up the theodolite on ground in front of the lighthouse building.

- Bear in mind that the best result without errors is to set-up the theodolite in same direction/line as the aligning sector;
- Before setting-up and levelling the instrument verify that it is possible to see all selected reference objects and having unobstructed clear view over sea to follow the vessel.

13.7.3.4. Alignment procedure

- The theodolite is set-up and the horizontal circle is levelled using the spirit level bubbles and three foot screws in accordance to the manufactures' instructions;
- The horizontal graduated scale is set to the bearing calculated from the light to the 'baseline object' position by pointing the telescope to the reference objects chosen as 'baseline object';
- The telescope is then pointed to the additional reference object positions (at least two) and the bearings are read on the horizontal scale;
- Readings must be identical to the calculated bearings for each position which provides verification of the position of the light;
- It is recommended that the light exhibit a fixed light character during the alignment procedure;
- Communication between vessel and lighthouse is commonly established by VHF radio at a working channel (not channel 16);
- To avoid confusion in the communication it is recommended that a plan be agreed describing the order in which the sectors are aligned;
- The observer's location on board the vessel is agreed (e.g., starboard bridge wing) to ensure that a precise bearing is available to the observer on board;
- The observer must have normal eye vision and normal colour vision and have good authority and accuracy when reporting observations;
- The vessel is ordered to go to the first sector as agreed (e.g., white/green) and report by VHF which colour they observe (example of messages: white, white, white – CUT – green, green, green…);
- To obtain accurate observations the vessel must cross the sector in as narrow angle to the sector as possible. If crossing the sector perpendicularly the crossing will happens very fast and the observer cannot make an accurate observation;
- During the vessels passage through the sector boundary the theodolite is pointing to and following the observer on board the vessel;

  At the moment the message 'cut' is received, the reading of the theodolite is taken. Depending on the type of sector light the uncertainty can be more and less and this influences the reported observation when aligning the sectors.

- The difference between the readings and the final sector is calculated and the result is multiplied by the arc value (mm/°);

  The position of the coloured filter sheet or the lantern is moved according to the result of the calculation.

- The procedure is repeated until a satisfied result is obtained;

It is recommended to cross the sector boundary at least 3 times from each side – 3 times from white to green and 3 times from green to white, a total 6 crossings.

- At traditional point source sector lights every single sector is aligned and the coloured sheets are secured by fittings and stops.

  At modern LED sector light the cutting is factory set and it is only needed to align one of the sector boundaries and then verify the additional sectors.

13.7.3.5. Final verification of sectors from vessel

- Before leaving the light it is recommended that a vessel navigates in every single boundary shown from the light;
- For verification of safe passage in areas with shallow water and rocks, echo sounder registrations are appropriate.

13.7.3.6. Report

Finally prepare a report of the alignment and commissioning including following details:

- Name and number of light (List of Lights)
- Date and time (night, day) for the alignment including information of weather condition (visibility, sun, cloudy, rain etc.)
- List of sectors aligned
- Reference objects, position of reference objects and bearing from the aligned light to the used reference objects
- Verification of position of light
- Name of responsible operator of theodolite
- Vessel name and observers name

14. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) at http://www.iala-aism.org/wiki/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.

15. ABBREVIATIONS

AtoN	Marine Aid(s) to Navigation
DGNSS	Differential Global Navigation Satellite System
^{g}	Gradian (unit of measurement of an angle, equivalent to 1⁄400 of a circle, 9⁄10 of a degree)
LED	Light-emitting diode
M	Nautical mile
mm	millimetre
MSSL	Multiple Source Sector Light
PAR	Parabolic Aluminized Reflector lamp
PWM	Pulse Width Modulation

TBS	True Bearing from Seaward
V	Volt(s)
VHF	Very high frequency
W	Watt(s)

16. REFERENCES

[1] IALA. Recommendation R0200 (E-200) Marine Signal Lights, Part 1 - Colours

[2] IALA. Recommendation R0110 (E-110) The Rhythmic Characters of Lights on Aids to Navigation

[3] IALA. Recommendation R0200 (E-200) Marine Signal Lights, Part 2 - Calculation, Definition and Notation of Luminous Range.

[4] IALA. Recommendation R0200 (E-200) Marine Signal Lights, Part 3 - Measurement

[5] IALA. NAVGUIDE

[6] IALA. Guideline G1048 LED Technologies and their use in Signal Lights.

[7] IALA. Guideline G1043 Light Sources used in Visual Aids to Navigation

[8] IALA. Recommendation R0112 (E-112) Leading Lights, Edition 1.1 December 2005

[9] IALA. Guideline G1023 The Design of Leading Lines Edition 1.1 December 2005

[10] A Study of Filtered Sector Lights by Ian Tutt, March 2012