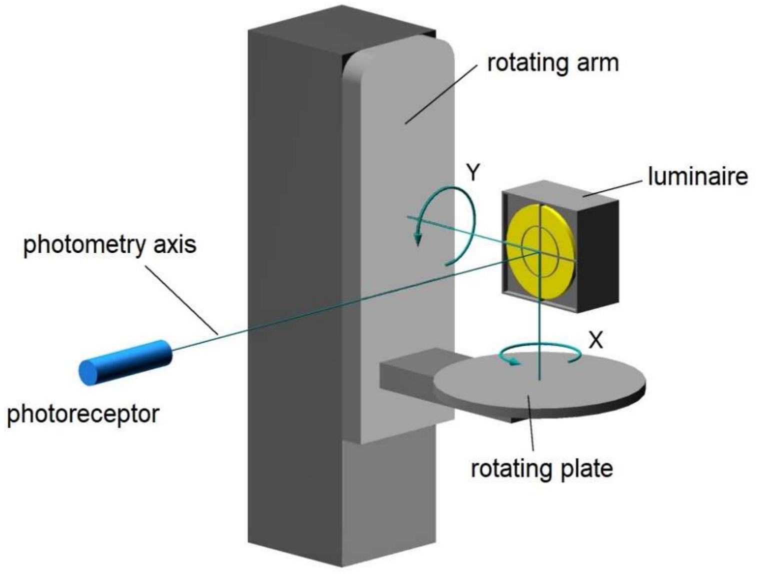
Maritime Traffic Technology

Technical Information

Goniophotometry



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Content

1 Summary

A goniophotometer is a device to measure the angular luminous intensity distribution of light sources and luminaires. The special requirements of marine signal lights concerning the luminous intensity distribution, especially very small sector angles, make it necessary to have a separate measurement standard. This was done by IALA since 1977 and the current document is R0203 Marine Signal Lights - Part 3 - Measurement.

For the review of R0203 and the transformation to a guideline, the German practice in goniophotometry is summarized in this document. It might be useful when updating the IALA documents. The focus of the document is set on the specific characteristics of goniophotometry for marine signal lights and presumes standard features of light measurement.

2 Measurement of Luminous Intensity

The luminous intensity I is defined by the density of luminous flux $d\Phi$ with respect to the solid angle $d\Omega$ in a specified direction.

$$I = \frac{d\Phi}{d\Omega} \approx \frac{\Delta\Phi}{\Delta\Omega}$$

In practice the solid angle $\Delta\Omega$ is presented by the ratio of a small area ΔA with its normal pointing to the light source and the square distance R^2 between the area and the light source (Figure 1).

$$\Delta\Omega \approx \frac{\Delta A}{R^2}$$

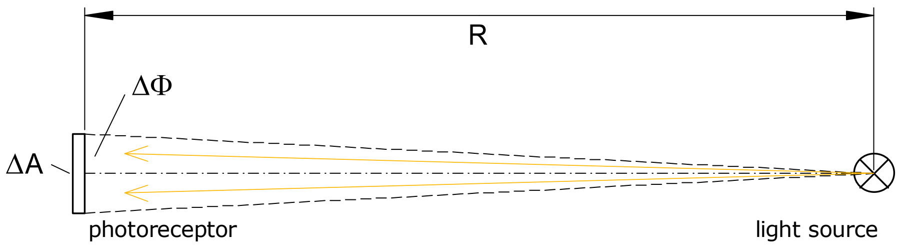

Figure 1: Luminous flux and solid angle

The luminous intensity becomes then:

$$I = \frac{\Delta\Phi}{\Delta A} * R^2.$$

The ratio $\frac{\Delta\Phi}{\Delta A}$ is defined as the illuminance E at the surface ΔA and the quantity E can be measured by a luxmeter directly. The result is the photometric distance law.

$$I = E * R^2$$

The measurement of luminous intensity is based on measurement of illuminance and distance.

3 Angular Distribution

3.1 Recommended Geometry

The luminous intensity of a luminaire depends on the direction of interest, which is normally described by two angles. For marine signal lights, the preferred angles are defined in CIE Publication No 43 Photometry of Floodlights. They are named X / Y in the original CIE paper and ϕ / Θ in IALA R0203.

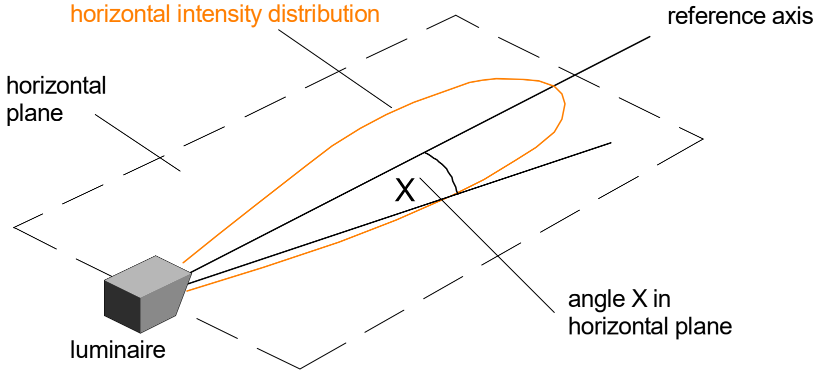

Figure 2: Horizontal angle X

With the use of X and Y from CIE No 43, there is only one horizontal plane and for each angle X in this horizontal plane there is a vertical plane (Figure 3). The reference axis may be chosen arbitrarily, but it is recommended to put it in the horizontal plane and for pencil beam light in the direction of maximum intensity. X is in the range of -180° to +180° and for Y it is -90° to +90°.

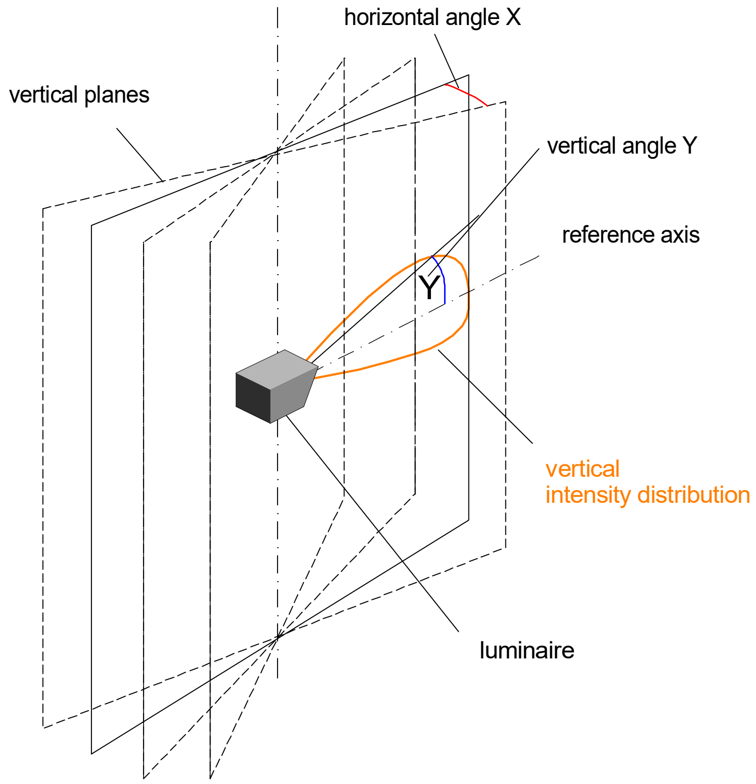

Figure 3: Vertical angle Y

The angles X and Y can easily be realized with a goniophotometer type A (CIE No 43) or type 1 (CIE No 70), see Figure 4. With this equipment the luminous intensity distribution $I = I(X, Y)$ is measured.

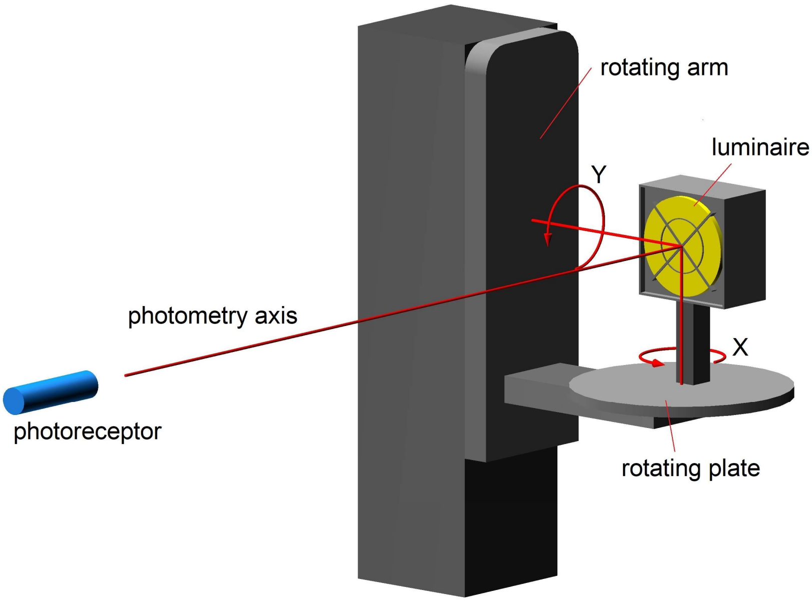

Figure 4: Goniophotometer type A (or type 1 CIE Pub No. 70)

3.2 Horizontal Distribution

In this case the vertical angle is $Y = 0$ and the measured values are $I = I(X, 0)$ for a series of horizontal angles $X_i = [X_1 \cdots X_N]$.

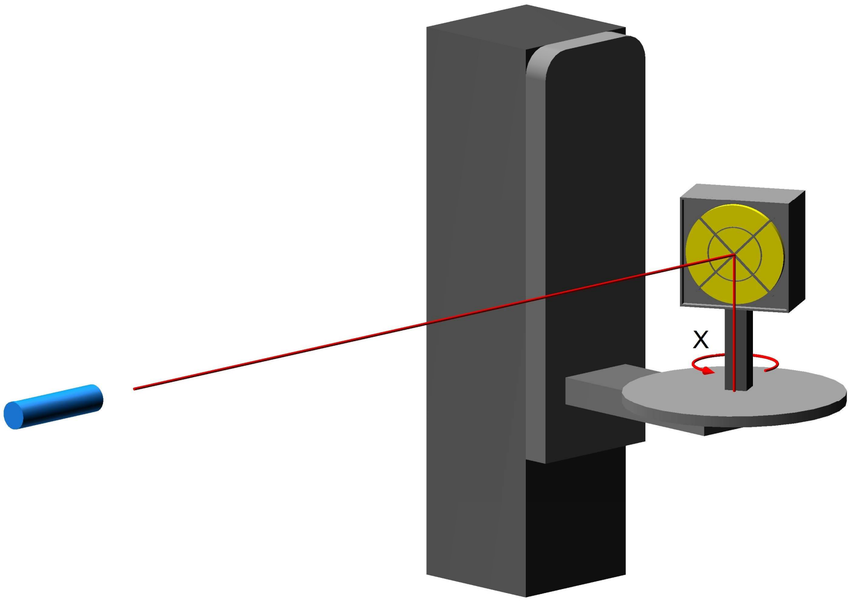

Figure 5: Goniophotometer measuring horizontal distribution

3.3 Vertical Distribution

For a fixed horizontal angle $X = X_f$ the measured values are $I = I\left(X_f, Y\right)$ for a series of vertical angles $Y_i = [Y_1 \cdots Y_N]$.

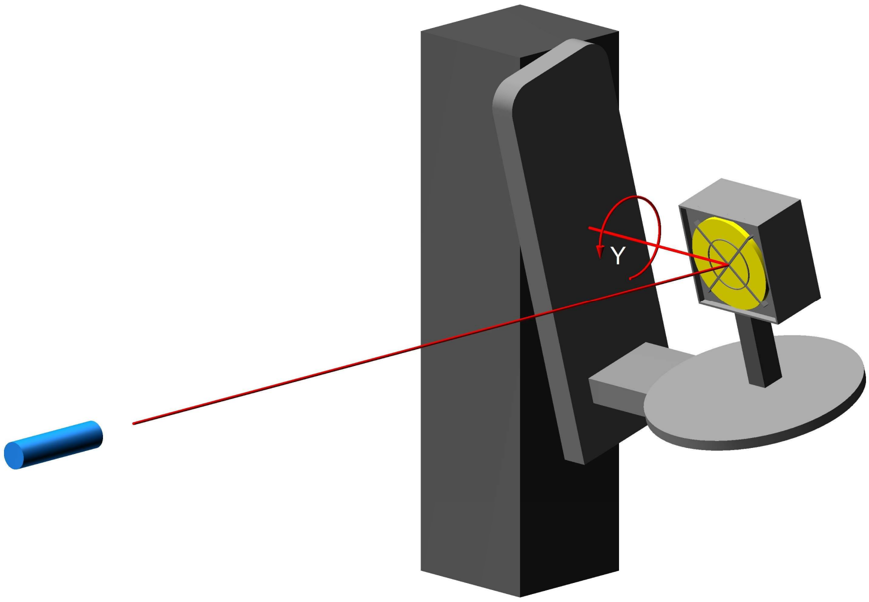

Figure 6: Goniophotometer measuring vertical distribution

3.4 Distribution on a Conical Surface

For some applications, it is necessary to measure the luminous intensity on a conical surface. This will be done for a fixed vertical angle $Y = Y_f \neq 0$ and rotating with X (Figure 7). The measured values are then $I = I(X, Y_f)$ for a series of $X_i = [X_1 \cdots X_N]$.

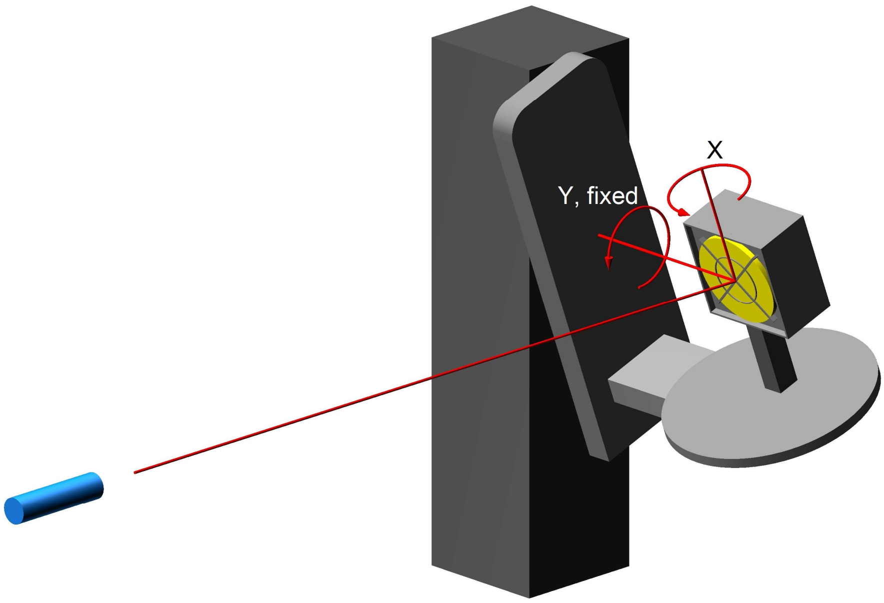

Figure 7: Goniophotometer measuring distribution in cones

3.5 Luminous Flux Dependence on Rotation Angle

Especially when a luminaire is rotated with a vertical angle Y, the luminous efficacy can change significantly due to thermal effects in the lantern. These effects were greatest for discharge lamps, where the discharge arc is influenced by gravity. For incandescent and LED lamps the effect is less but can be measured.

As a consequence, for the measurement of illumination luminaires (e.g. street and room illumination) the luminaire is fixed and the photorecepter is moved. In most cases this leads to the use of a different kind of goniometer called 'mirror-goniophotometer'.

The use of a 'type-A-goniophotometer' for marine signal lights is resonable, because

- for buoy lanterns the vertical tilting is exactly what happens on a buoy,
- for stationary lights only small vertical angles need to be measured and the intensity dependence on tilting will be small either.

4 Measurement Equipment

The measurement is usually done in a long chamber ('light range') with black walls. The equipment consists of:

- a goniometer with the test luminaire attached,
- a light chamber with dark walls,
- several stray light shades,
- a photoreceptor,
- a photometer,
- a controller for goniometer,
- a computer.

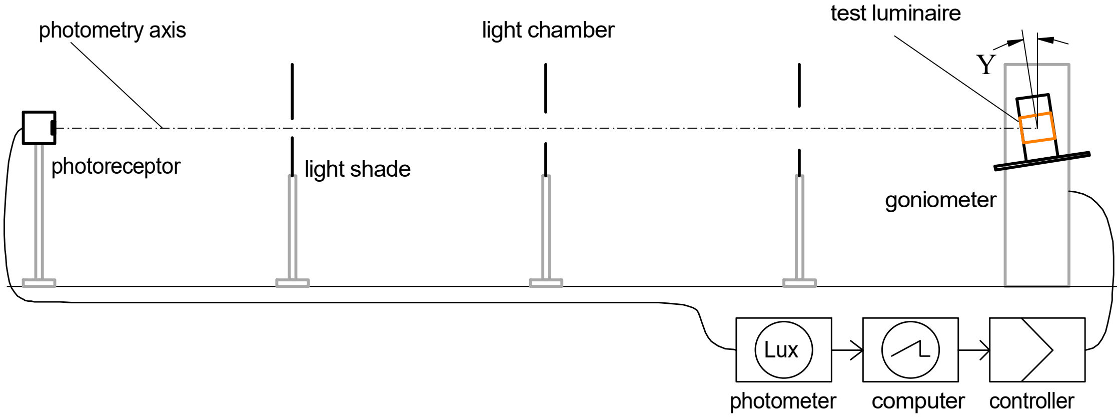

Figure 8: Measurement equipment

5 Measurement Procedure

The sequence to get the luminous intensity values $I = I(X, Y)$ for the selected angles X_i, Y_j with $i = 1 \cdots M$ and $j = 1 \cdots N$ will be:

- the computer gives the next pair of angles X_i, Y_j to controller,
- the controller moves the goniometer to the new position,
- the photometer waits for a constant value at the photoreceptor output and gives the value $I(X_i, Y_j)$ to the computer,
- computer collects the new data sets X_i, Y_j, $I(X_i, Y_j)$
- and initiates the next movement of the goniometer until all angles have been run through.

When the intensity distribution is needed for a plane only, the movement is restricted to one angle only and the result is a horizontal distribution $I(X_i)$ or a vertical distribution $I(Y_j)$.

6 Measurement Precision

The luminous intensity is not measured directly, but is calculated from measured values for the illuminance E and the distance R according to the photometric distance law $I = E * R^2$.

The calculation of error propagation is usually done by adding the relative errors of each influence parameter (see European Standard EN 13032-1 [9]).

<u>Example:</u>

$$f_{sum} = f_1 + f_2 + \cdots + f_n$$

where f_i is the relative error of a single parameter.

The precision of the illuminance E depends on the photometer and should be found in the photometer datasheet. The preferred values are listed in EN 13032-1 and give a total error $f_E = f_{sum}$ for the relative precision of the measured illuminance.

However, the influence of the distance R on the precision of I may be the major part. This can be shown by a calculation of the error propagation. Additionally, the distance R often is ambiguous.

For the photometric distance law error propagation leads to

$$I = E * R^2 \qquad \Longrightarrow \qquad \frac{\Delta I}{I} = \frac{\partial I}{\partial E} * \Delta E + \frac{\partial I}{\partial R} * \Delta R \qquad \Rightarrow \qquad \frac{\Delta I}{I} = \frac{\Delta E}{E} + 2 * \frac{\Delta R}{R}\,.$$

The relative error of the distance measurement has double influence on the intensity measurement compared with the relative illuminance error.

$$\frac{\Delta I}{I} = f_E + 2 * \frac{\Delta R}{R}$$

As shown in the paper 'Minimum Photometric Distance' [2], the required distance R is linked to the required angular sensitivity of distribution measurement. The need to measure the angular distribution with a very small resolution of about 0.1° or even less, leads to large distances R.

A second aspect, which has to be considered especially for marine signal lights, is the use of sophisticated optical devices (e. g. projectors, drum lenses). For these luminaires the reference position for light emission <u>is not the light source</u> and the precision of R depends on an estimation for a light emission reference or datum. According to the size of an optic (up to 1 or 2 metres), the uncertainty ΔR can be in the same range.

The same will be true for the angles X and Y. The rotation of the luminaire may cause that the reference position for light emission, which should be centered at the photometry axis, draws aside and produces an error ΔX or ΔY.

7 Distance References

7.1 Infinite Distance

From geometry, the required measurement distance should be as large as possible. At a short distance the light source axial extension will give an uncertainty ΔR_L for the measurement distance R. The lateral extension of the photoreceptor and the light source will give an uncertainty $\Delta\alpha$ for the angles ΔX or ΔY (Figure 9).

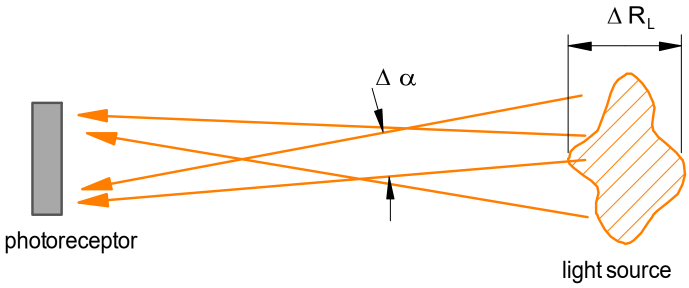

Figure 9: Short measurement distance

The geometrical aim is to keep the relative error as small as possible. This is usually done by increasing the measurement distance (Figure 10).

$$R \to \infty \qquad \Longrightarrow \qquad \frac{\Delta R}{R} \to 0 \text{ and } \Delta\alpha \to 0$$

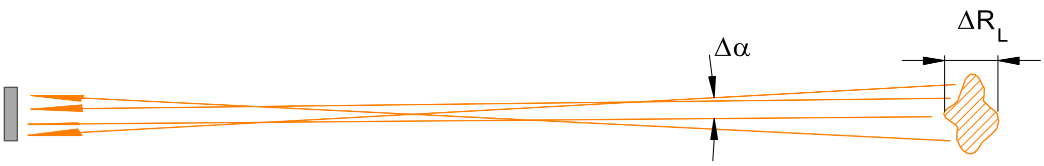

Figure 10: Increased measurement distance

The mathematical ideal is an infinite distance. In practice the costs for a large photometric chamber and the loss of sensitivity in measuring the illuminance have to be taken into account.

7.2 Photometer Reference

The photometer is a luxmeter, which measures the illuminance at a specific area. The calibration process of a luxmeter defines the position of the area exactly.

There are two main types of photoreceptor:

- optical window type,
- diffusion disc type.

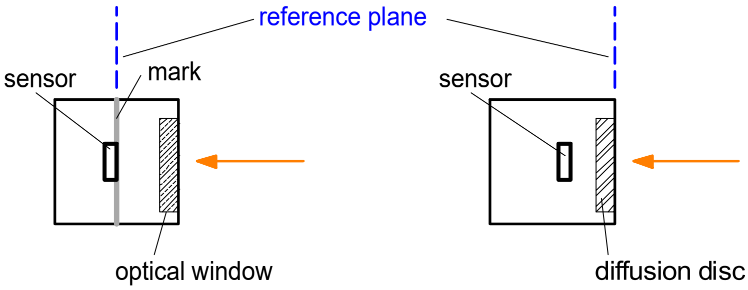

Figure 11: Reference plane

For the optical window type, the light enters the sensor through an optical window, which leaves the light nearly unchanged (Figure 11, left). The reference plane is usually the surface of the sensor and is marked on the housing of the sensor (e. g. white ring).

In the diffusion disc type luxmeter the light is scattered in the diffusion disc, which makes the measurement more robust for small angle errors. The calibration is done with the outer surface of the diffusion disc as the reference plane (Figure 11, right).

In both cases the reference plane to measure the photometric distance has a precision of about 1 mm.

7.3 Luminaire Reference

7.3.1 Theoretical Background

Marine Signal Lights consist of a variety of different optics. Looking at the precision of luminous intensity measurement, there is a strong dependency on the type of optic and its geometry.

The theory behind can be found in 'Optics, Klein / Furtak' [4][5].

Some other examples for the background theory have already been published for IALA in [2][3].

The effect of the optic on the precision of luminous intensity measurement is described for 'paraxial optics' in the first step. After that, the results are extended to larger optics and linked to some typical marine luminaires.

7.3.2 Paraxial Optics

The influence of the optic on the reference plane for photometry can be explained with a simple paraxial model. 'Paraxial' means that only the light rays near the optical axis are considered.

For signal lights, the optic is used to collect the emitted light rays of a light source into a narrow beam of light to increase the luminous intensity.

The most simple device is a spherical converging lens (Figure 12). On the right side the light source emits light. Some light rays are collected and refracted by the lens to produce a narrow beam on the left side.

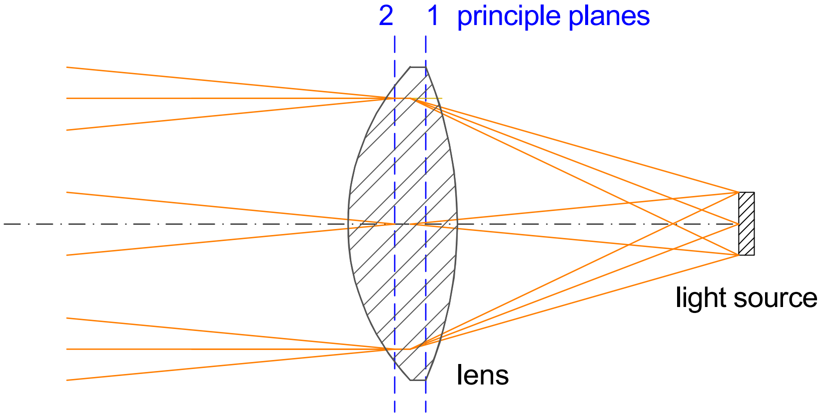

Figure 12: Converging lens

The paraxial theory says that for an observer on the left side, the reference plane to describe light emittance is the second principle plane of the lens (both principle planes are shown in Figure 12). This means that the light seems to be emitted from this plane.

Usually the plane is located inside the lens and is nearby the lens aperture (for some optical instruments, they may be outside the lens).

To measure the luminous intensity distribution for the converging lens, it is necessary to adjust the second principal plane of the lens into the rotating axis of the goniometer and measure the photometric distance R from principal plane to the photoreceptor (Figure 13).

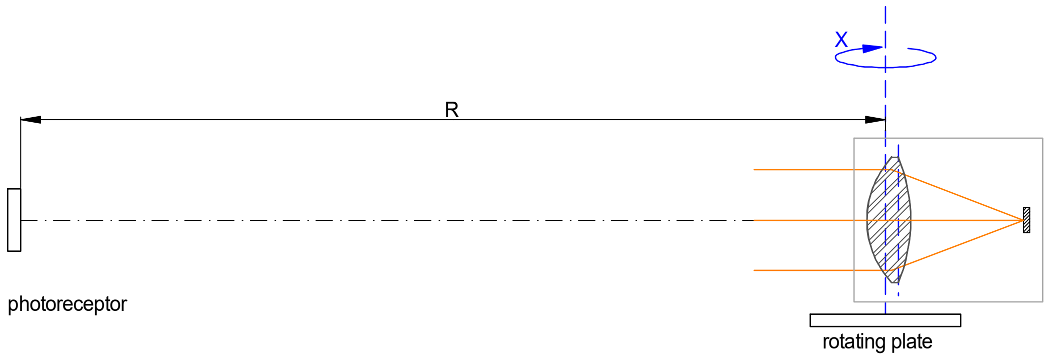

Figure 13: Setup of converging lens on goniometer

7.3.3 Large Optics

For marine signal lights, the lenses usually have a large diameter, so that a simple definition of the principal planes is not given. The principal plane may even become an elliptical, parabolic or hyperbolic surface. This will produce a systematic error on the estimation of the reference position for light emission and in consequence for the photometric distance.

Especially when measuring lights for type approval, there are no further information about the optic and the principal planes.

In many situations it can be assumed that the reference position of light emission is inside the lens. This results in a systematic error ΔR_L for the location of the principal plane, which is the thickness of the lens (example with fresnel lens: Figure 14).

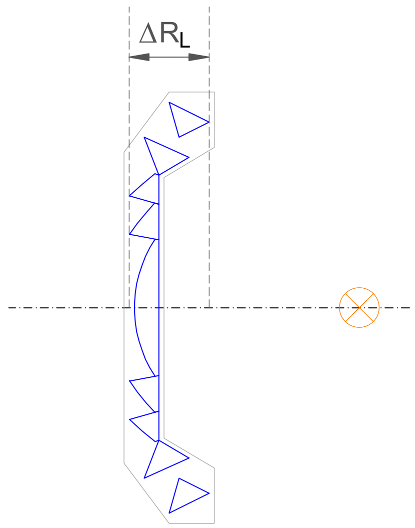

Figure 14: Pencil beam fresnel lens

8 Systematic Errors

The uncertainty for finding the reference position of light emission induces two errors on luminous intensity measurement.

- Error in estimating the photometric distance
- Error in estimating the distribution angles X, Y

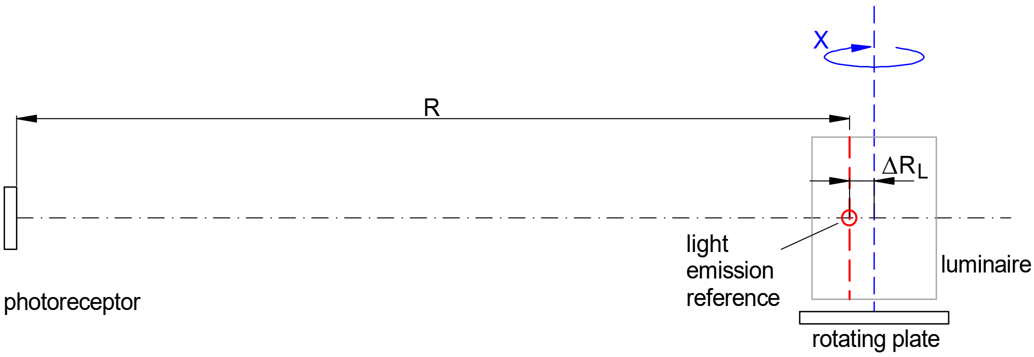

Figure 15: Unknown luminaire on a goniophotometer

When the luminaire is set on the rotating plate of a goniophotometer, the light emission reference may not exactly match the rotating axis, but is an offset ΔR_L apart. The reference plane of the photoreceptor is defined by calibration very precisely and can be ignored. The distance measurement device will have a relative precision f_R, then the overall uncertainty of the distance will be: $\frac{\Delta R_{total}}{R} = f_R + \frac{\Delta R_L}{R}$.

However, when the luminaire is rotated by the goniometer, some systematic errors are added.

This can be shown by triangle calculation (Figure 16).

1: centre of rotation

2: light emission reference

3: photoreceptor

L: distance photoreceptor - light emission reference

R: distance photoreceptor - centre of rotation

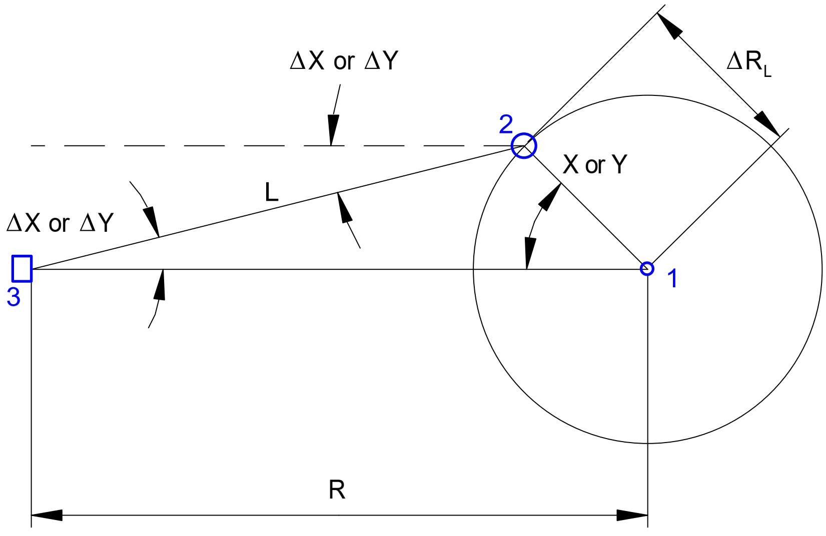

Figure 16: Evasion of a non-centered light emission reference on a goniometer

8.1 Distance

From cosine rule (for X angle, Figure 16):

$$L^2 = R^2 + {\Delta R_L}^2 - 2 * R * \Delta R_L * \cos X$$

Both the angle and the distance error depend on the rotating angle X or Y. As the equation is used to estimate the small systematic error only, it is acceptable to make some simplifications.

The distance between photoreceptor and light emission reference varies between $L = R - \Delta R_L$ for $X = 0°$ and $L = \sqrt{R^2 + \Delta R_L{}^2} < R + \Delta R_L$ for $X = 90°$.

For simplicity, the distance ΔR_L between the light emission reference and the centre of rotation is a useful estimation for the absolute error.

Remarks:

- It can be assumed that, when the light emission reference is rotated by an angle larger than 90°, it will not produce light on the photoreceptor.
- When a drum lens is rotated in the horizon (X), the light emission reference remains on the photometry axis and does not move with the lens.

8.2 Angle

From sine rule (for X angle, Figure 16):

$$\frac{\sin \Delta X}{\Delta R_L} = \frac{\sin X}{L}$$

The systematic error ΔX for the angle depends on the rotation angle X.

$$\Delta X = \sin^{-1}\left(\frac{\Delta R_L}{L} * \sin X\right)$$

For a rough estimation of the error ΔX it can be assumed that $L \approx R$.

The systematic error is then

$$\Delta X = sin^{-1}\left(\frac{\Delta R_L}{R} * sin\, X\right).$$

The same discussion is valid for the vertical angle Y and the result is

$$\Delta Y = sin^{-1}\left(\frac{\Delta R_L}{R} * sin\, Y\right).$$

8.2.1 Omnidirectional Lights

For omnidirectional light the horizontal measurement will cover $-180° < X \leq +180°$ and the maximum error occurs when $X = \pm 90°$ ($\sin 90° = 1$), which leads to

$$\Delta X = \sin^{-1}\frac{\Delta R_L}{R} \text{ or}$$

$$\Delta X \approx \frac{\Delta R_L}{R} \text{ in radians for } \Delta R_L \ll R.$$

8.2.2 Pencil Beam Lights

Pencil beam lights are usually measured within a small horizontal or vertical sector, symmetrically around the photometry axis ($X_1 = -X_N$ or $Y_1 = -Y_N$). When the maximum angle is $X_{max} = \max(|X_1|, |X_N|)$ or $Y_{max} = \max(|Y_1|, |Y_N|)$ and still $\Delta R_L \ll R$ ($L \approx R$), the systematic angular error becomes

$$\Delta X = \sin^{-1}\left(\frac{\Delta R_L}{R} * \sin X_{max}\right) \text{ or}$$

$$\Delta Y = \sin^{-1}\left(\frac{\Delta R_L}{R} * \sin Y_{max}\right).$$

When the maximum angle is less then 10° the calculation can be simplified to

$$\Delta X \approx \frac{\Delta R_L}{R} * X_{max} \text{ and } \Delta Y \approx \frac{\Delta R_L}{R} * Y_{max} \quad \text{(in radian)}.$$

8.2.3 Classical Drum Lens

For a drum lens the light emission reference is different in the horizontal and the vertical plane.

In the vertical plan the drum lens works as a large converging lens. The light emission reference is 'nearby' the intersection of the lens and the vertical plane (Figure 17).

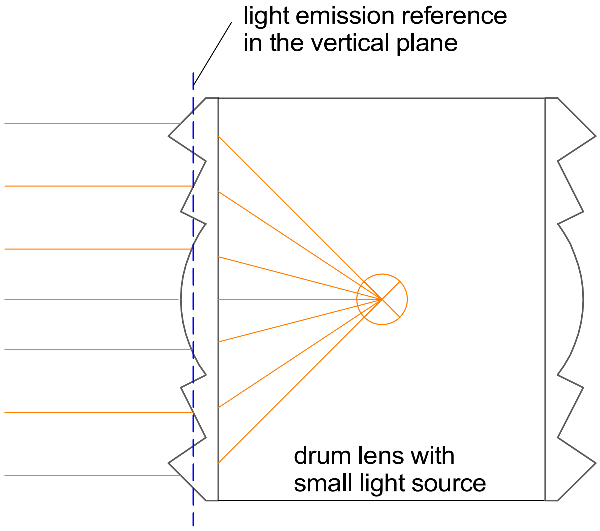

Figure 17: Light emission reference for a drum lens in a vertical plane

In the horizontal plane the optics does not refract the rays and therefor the light emission reference is the light source.

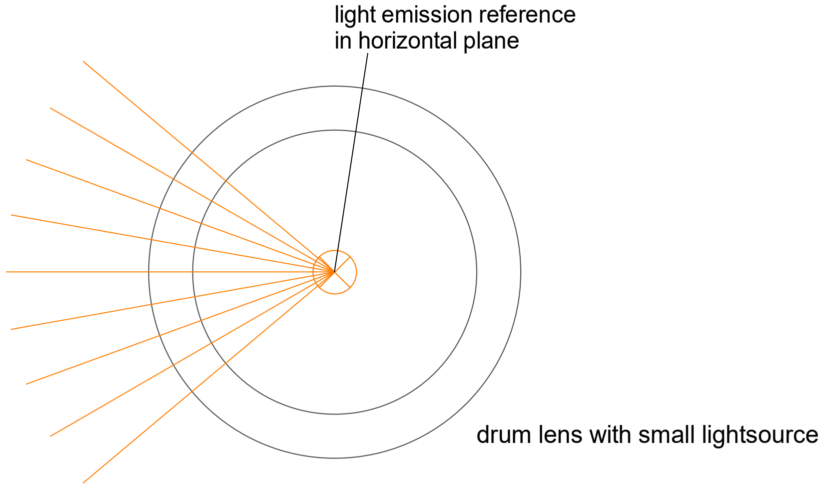

Figure 18: Light emission reference for a drum lens in the horizontal plane (plan view)

Usually a drum lens is set on the goniometer with the light source in the centre of rotation.

As a first consequence, there will be a systematic error ΔR_L for the photometric distance which is approx. half the diameter D of the drum lens ($\Delta R_L \approx D/2$). For example, a drum lems with diameter of 500 mm will produce a systematic error of 250 mm.

A second consequence is that the light emission reference leaves the photometry axis when rotated in the vertical plane (Figure 19).

The 500 mm drum lens has a systematic error $\Delta R_L = 250\ mm$. When it is measured in the vertical plane with a photometric distance of $R = 20\ m$ and a maximum angle of 10°, the maximum systematic error for the vertical angle becomes (see chapter 8.2): $\Delta Y = sin^{-1}\left(\frac{\Delta R_L}{R} * sin\, Y\right) = \sin^{-1}\left(\frac{0.25}{20} * \sin 10°\right) = 0.12°$.

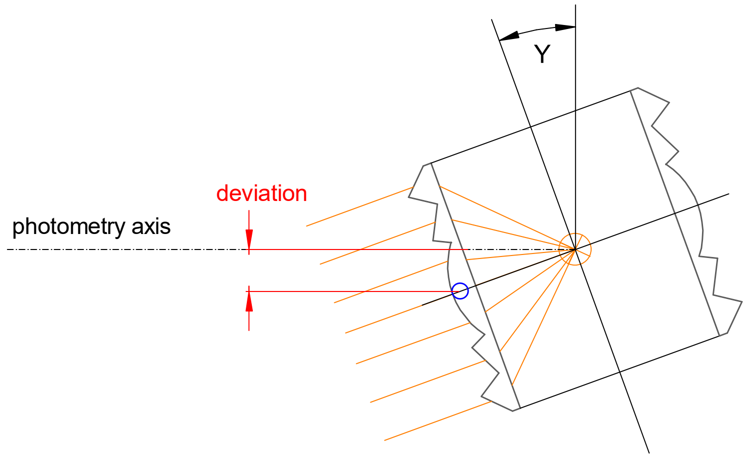

Figure 19: Systematic angular error for drum lens on goniometer

9 Required Photometric Distance

9.1 Theoretical Requirement

As shown in the document 'Minimum Photometric Distance' [2] the required photometric distance depends on the required angular resolution and the size of the optics (Figure 20). The luminous intensity measurement requires the measurement of all parallel rays (violet lines) emitted from the optics ($R \to \infty$). In practice ($R \ll \infty$), the rays pointing to the photoreceptor are measured (blue lines).

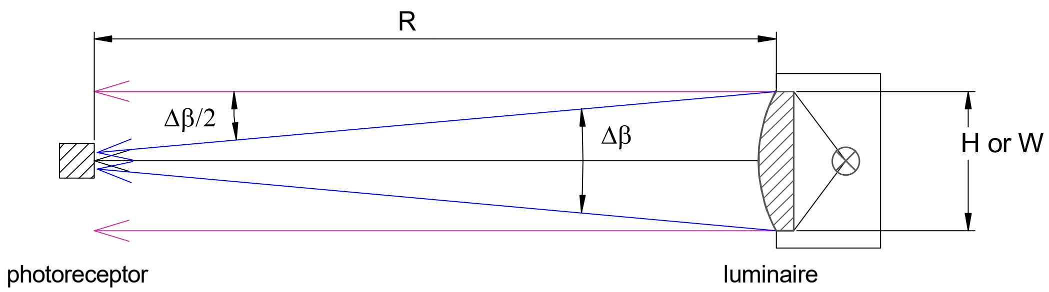

Figure 20: Size of optics

As a consequence the measured intensity distribution will be blurred over an angle $\Delta\beta$. When the required angular resolution of the measurement is ε, the blur $\Delta\beta$ should be less than ε.

$$\Delta\beta < \varepsilon$$

With $\tan\frac{\Delta\beta}{2} = \frac{H}{2*R}$ and assumming that the height H of the optics is $H \ll 2 * R$, the requirement becomes:

$$\Delta\beta = \frac{H}{R} < \varepsilon \text{ (in radians).}$$

When the required angular resolution ε is given, the recommended minimum photometric distance R_{min} is:

$$R_{min} = \frac{H}{\varepsilon} \text{ (in radians).}$$

The same calculation may be done with the width of the optics W and if it differs from the height H, the major value for R_{min} should be used ($R_{min} = W/\varepsilon$).

Further information can be found in [2].

9.2 Practical Test

Additionally the required photometric distance depends on the optical setup of the luminaire. As a 'worst case szenario' the optics of the luminaire might produced an image of the light source at the distance S.

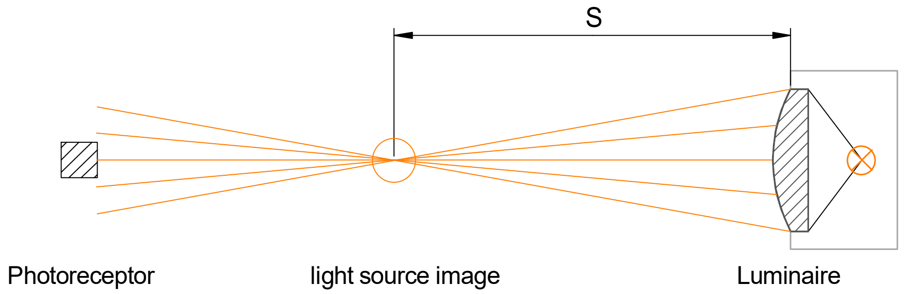

Figure 21: Real image of the light source

Normally, the optical apparatus should not be aligned this way. In a photometric laboratory for product testing, it is not the task to modify the optical alignment, but keep the apparatus as it is and measure. The German experience is that there are luminaires, which produce a real image of the light source.

This image causes a severe deviation from the photometric distance law and the illuminance may be factors higher at the position S (Figure 22).

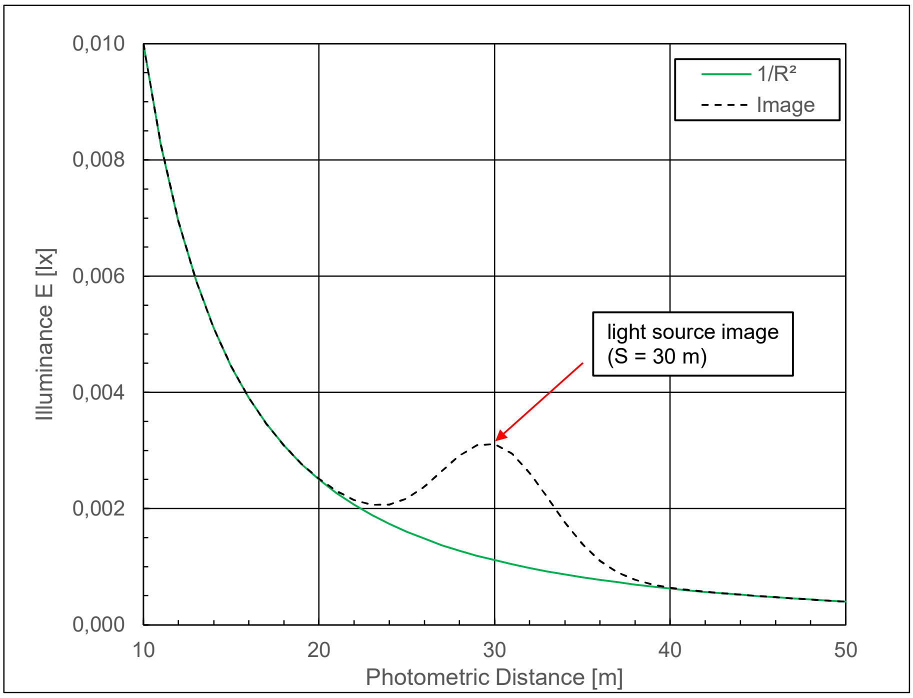

Figure 22: Light source image spoils photometric distance law

The photoreceptor should be placed far away from the image: $R \gg S$. Often, the image can be easily found by holding a projection screen in the photometry axis and moving along it.

Further improvement can be done by testing the 'photometric distance law' with a measurement of $E = E(R)$ and increasing the distance until the required precision ist reached (see Chinese paper on measurement [6], chapter 3.2.3 (3)).

10 Use of Stray Light Shutters

To avoid that stray light will be measured by the photoreceptor, shutters should be installed. The shutter is usually a baffle, painted in black matt colour with a circular hole.

The centre of the hole is set in the photometry axis.

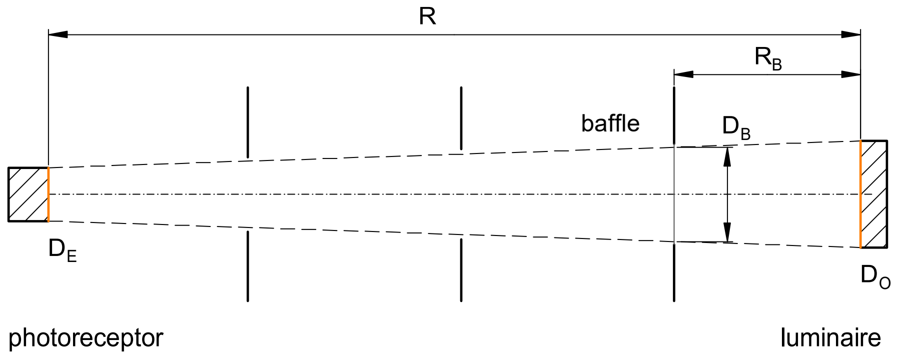

Figure 23: Arrangement of stray light shutters

The minimum diameter of the baffle hole can be calculated with intercept theorem.

$$D_{B,min} = D_O - \frac{R_B}{R} * (D_O - D_E)$$

with D_O Diameter surrounding the entire light emission surface

D_E Diameter of photoreceptor sensor area

R_B Distance light emission reference - baffle

R Distance light emission reference - photoreceptor

The real diameter should be 10 % to 20% larger than the calculated value $D_{B,min}$. Adjustable iris diaphragms are preferred.

The walls, the ceiling and the floor of the light channel should be painted in black matt colour to reduce the light passing outside the shutters.

11 Standard Procedures

11.1 Pencil Beam Lights

This type of light is usually used for a leading light and has a very narrow luminous intensity distribution. The measurement is done in the horizontal plane and in one vertical plane. Both should intersect in the luminaire axis, which points to the direction of maximum intensity. The centre of rotation is set to the second principal plane of the lens. If the principal plane is not specified by the manufacturer, it can be set to the outer vertex of the lens (Figure 24).

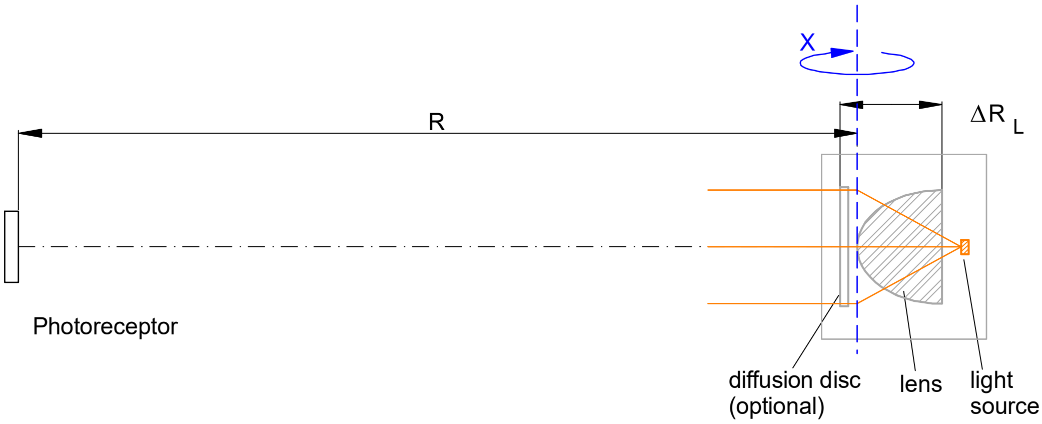

Figure 24: Pencil beam light

As a rough estimation for the systematic error ΔR_L of the light emission reference the thickness of the lens including an optional diffusion disc can be chosen. The photometric distance is typically larger than 30 m and should be confirmed with the tools of chapter 9.

	Angular Interval	Typical Values	Angular resolution
Horizontal ($Y = 0°$)	$[-X_{max} \cdots + X_{max}]$	$X_{max} = 5° \; or \; 10°$	$0.02° \cdots 0.1°$
Vertical ($X = 0°$)	$[-Y_{max} \cdots + Y_{max}]$	$Y_{max} = 5° \; or \; 10°$	$0.02° \cdots 0.1°$

Table 1: Measurement range for pencil beam lights

11.2 Simple Omnidirectional Light

A simple omnidirectional light is used for buoy lanterns or low range lights. It may be represented by a drum lens with a single light source or a 'radial drum LED layout' (Figure 25). The centre of the light is set to the centre of rotation.

Although the main amount of light measured will be from the LED pointing directly to the photoreceptor, there will be some light from the marginal rays. So the systematic error ΔR_L will be about half the diameter of the LED arrangement.

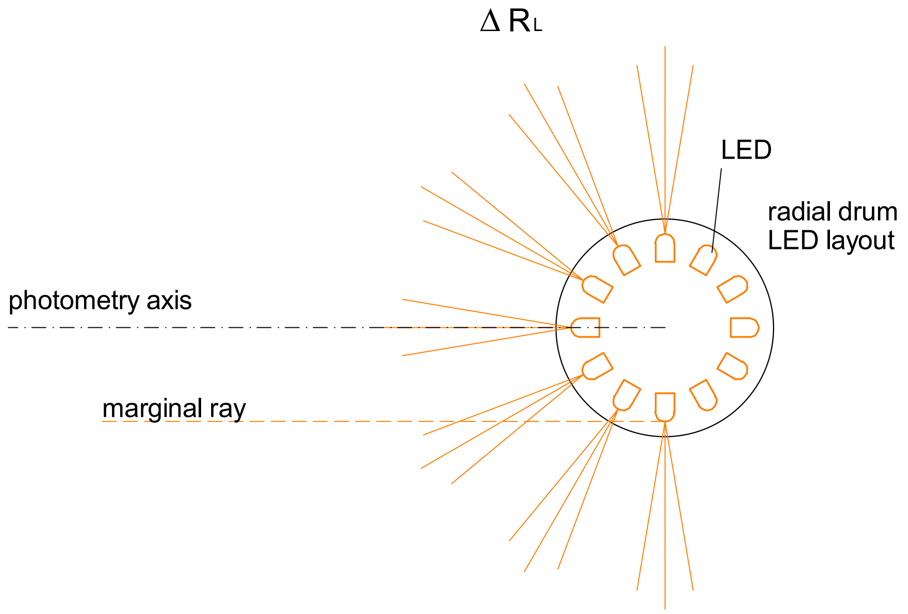

Figure 25: Plan view at a 'radial drum LED layout' luminaire

For omnidirectional lights usually the horizontal and three vertical distributions ($X_f = -120°, 0°, +120°$) are measured. In many cases a photometric distance of about 10 m is sufficient.

	Angular Interval	Typical Values	Angular resolution
Horizontal ($Y = 0°$)	$[-180° \cdots +180°]$	–	$0.5° \cdots 2.0°$
Vertical ($X_f = -120°$)	$[-Y_{max} \cdots +Y_{max}]$	$Y_{max} = 20° \cdots 45°$	$0.5° \cdots 2.0°$
Vertical ($X_f = 0°$)	$[-Y_{max} \cdots +Y_{max}]$	$Y_{max} = 20° \cdots 45°$	$0.5° \cdots 2.0°$
Vertical ($X_f = +120°$)	$[-Y_{max} \cdots +Y_{max}]$	$Y_{max} = 20° \cdots 45°$	$0.5° \cdots 2.0°$

Table 2: Measurement range for simple omnidirectional lights

11.3 Classical Drum Lens

The classical drum lens is typically used in lighthouses. It has a single light source or an equivalent LED module. The horizontal distribution may contain the entire horizon or be limited to a sector. With the use of filters the drum lens can show different coloured sectors (Figure 26).

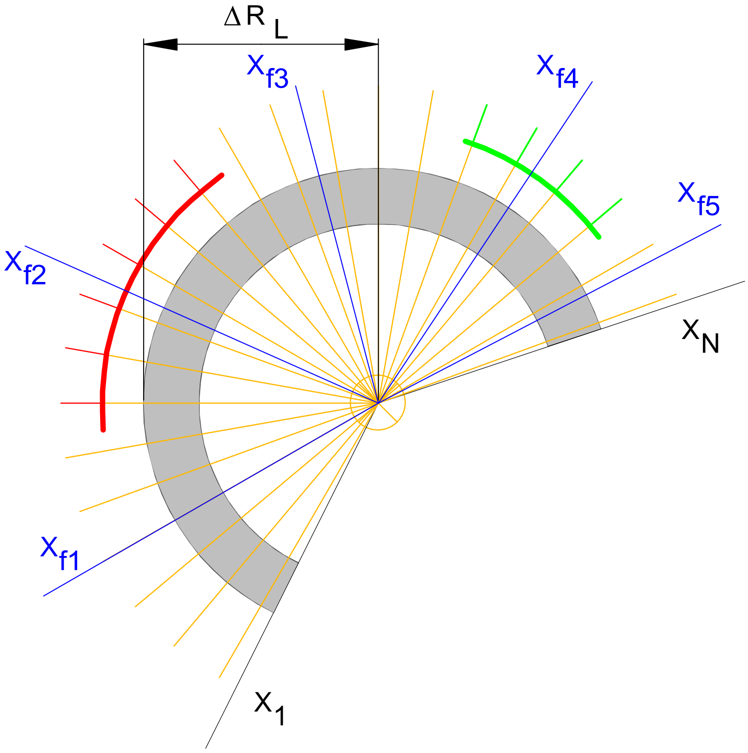

Figure 26: Classical drum lens with filters, plan view

The horizontal distribution is measured for all sectors and usually covers the range at the edge, where the luminous intensity drops. The vertical distribution is measured either at three different horizontal angles or in the centre of the coloured sectors.

The systematic error ΔR_L will be half the diameter of the lens. The photometric distance is typically larger than 20 m and should be confirmed with the tools of chapter 9.

	Angular Interval	Typical Values	Angular resolution
Horizontal ($Y = 0°$)	$[X_1 \cdots X_N]$	$\pm 20° \cdots \pm 180°$	$0.5° \cdots 2.0°$
Vertical three positions or in each sector X_{fi}	$[-Y_{max} \cdots + Y_{max}]$	$Y_{max} = 4° \cdots 10°$	$0.02° \cdots 0.5°$

Table 3: Measurement range for classical drum lens

When necessary the sector boundaries are measured separately with a higher angular resolution to find the angle of uncertainty. In this case the luxmeter is replaced by a spectroradiometer to investigate the shift of colour.

11.4 Projector sector lights

A projector sector light has two optical components: projection and condensor lens [7]. The light emission reference is at the projection lens and therefor the centre of rotation should be placed there. The thickness of the projection lens is an acceptable estimation for the systematic error ΔR_L.

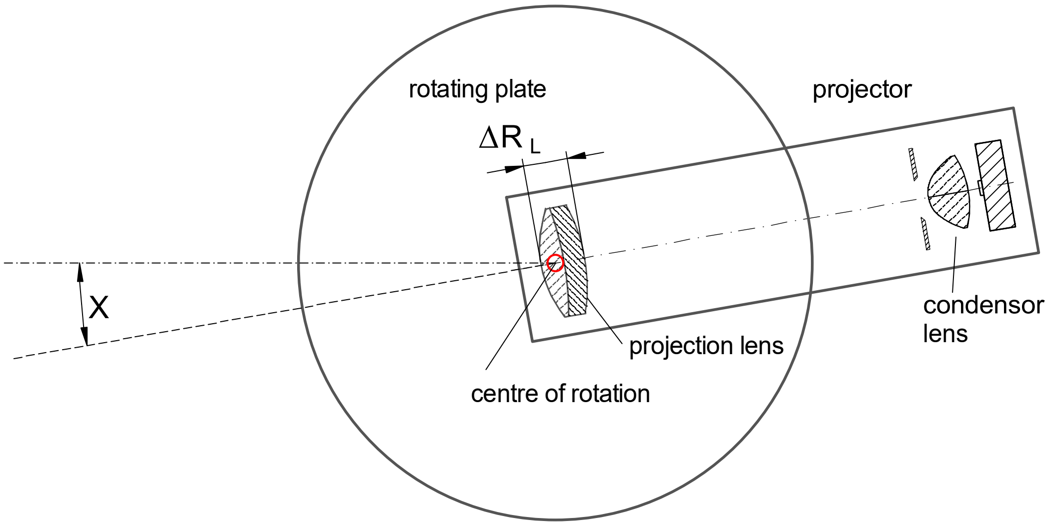

Figure 27: Projector set on the goniometer, plan view

The horizontal distribution measurement should cover all sectors. In each sector the vertical distribution is measured. The measurement needs a very small angular resolution and a photometric distance of 50 metres or more. The German laboratory uses a folding mirror and attains 100 metres.

	Angular Interval	Typical Values	Angular resolution
Horizontal ($Y = 0°$)	$[-X_{max} \cdots +X_{max}]$	$X_{max} = 3° \cdots 10°$	$0.01° \cdots 0.05°$
Vertical in each sector X_{fi}	$[-Y_{max} \cdots + Y_{max}]$	$Y_{max} = 3° \cdots 10°$	$0.01° \cdots 0.05°$

Table 4: Measurement range for projectors

Care should be taken, when measuring a fixed arrangement of several projectors. Normally the central projector is in the centre of rotation, so that the outer projectors produce an additional systematic error ΔA (Figure 28). This error has to be considered when calculating the overall error for the distance and the angle.

An alternative is to measure each projector individually and shift the 'active' projector into the centre of rotation (Figure 29). The horizontal luminous intensity distribution will be the sum of the individual measurements. As long as the sectors do not overlap, the vertical distribution for a single horizontal angle X_f is the distribution measured for the related projector.

When necessary the sector boundaries are measured separately with a higher angular resolution to find the angle of uncertainty. In this case the luxmeter is replaced by a spectrometer to investigate the shift of colour.

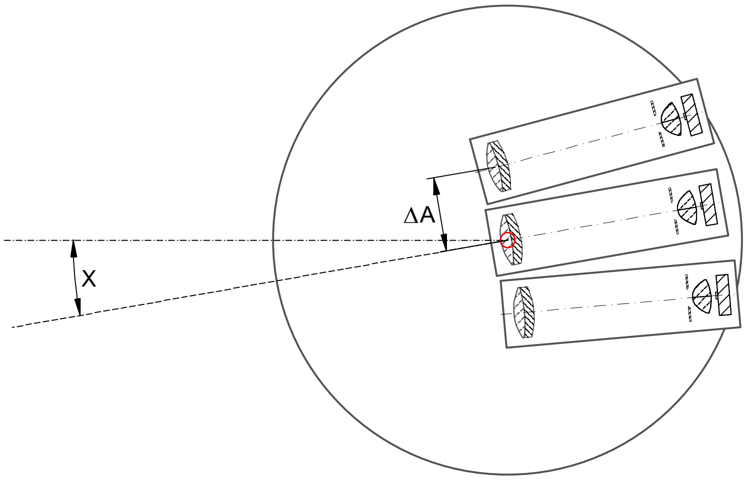

Figure 28: Measuring an arrangement of projectors

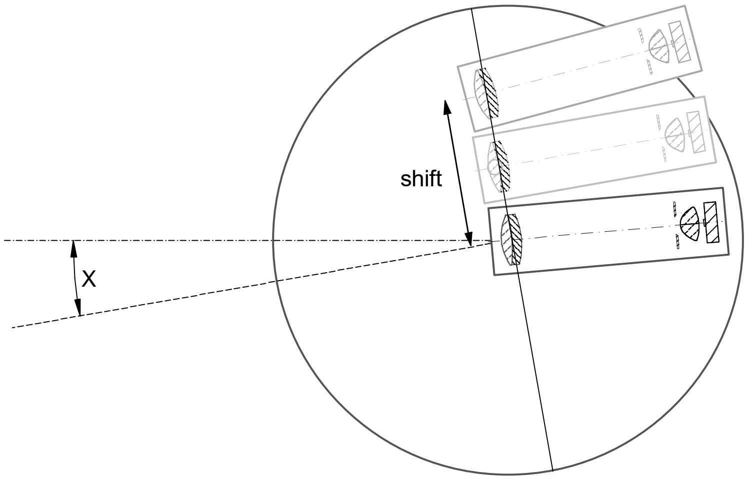

Figure 29: Shifting the active projector to the centre of rotation

11.5 Traffic signals and aeronautical approach lighting

For these lights, the luminous intensity distribution is measured by varying both the horizontal and vertical angle. So the measurement is not restricted to some selected planes.

	Angular Interval	Typical Values	Angular resolution
Horizontal ($Y = 0°$)	$[-X_{max} \cdots +X_{max}]$	$X_{max} = 10° \cdots 30°$	$0.2° \cdots 1°$
for each X_i	$[-Y_{max} \cdots + Y_{max}]$	$Y_{max} = 10° \cdots 30°$	$0.2° \cdots 1°$

Table 5: Measurement range traffic signals

Other features are similar to those for pencil beam lights (11.1).

11.6 Aeronautical obstacle lights

Most aeronautical obstacle lights have the same optical design as simple omnidirectional lights, but the specifications (e.g. ICAO) lead to a different measurement procedure. For some specified vertical angles Y_{spec} the luminous intensity is defined and is measured for all horizontal angles.

This leads to a measurement on conical surfaces (3.4).

	Angular Interval	Typical Values	Angular resolution
for each Y_{spec}	$X = [-180° \cdots + 180°]$	-	$0.5° \cdots 2°$

Table 6: Measurement range traffic signals

Other features are similar to those for simple omnidirectional lights (11.2).

12 Miscellaneous

12.1 Measurement of Flashing Lights on Goniometer

The measurement of flashing lights on a goniophotometer should be avoided. However, there are high intensity (aeronautical) lights, which are specified in flashing mode only and cannot be set to fixed light, because the thermal design does not support it.

In these situations the measuring of flashing lights is accepted for type approval measurements. Therefor the measurement procedure (chapter 5) is changed in the way that after moving to the required angles (X/Y), several flashes are measured and from these the calculated effective luminous intensity $I_{eff}(X,Y)$ is collected.

12.2 Use of spectroradiometer

All measurements can be done with a spectroradiometer instead of a luxmeter. The use of a spectroradiometer requires more measuring time and and has less sensitivity. Therefor the standard procedures are all based on high precision luxmeters with partial filtering. The spectroradiometer is mainly used for the measurement of the luminous flux, the colour, the luminous intensity at fixed angles or the colour shift at sector boundaries.

However, when confirmation is needed the measurements are repeated with a spectroradiometer.

12.3 XY-Planes versus System B

The preferred goniometer for marine signal lights (type A - CIE 43 or type 1 - CIE 70) can use either the angles X, Y (CIE 43) or B planes. The system X, Y gives a very simple presentation of the horizontal and vertical distribution. The B-plane-system is more complex.

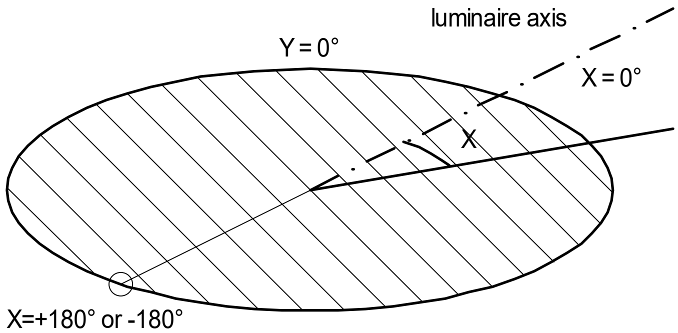

Figure 30: Horizontal plane in system X, Y

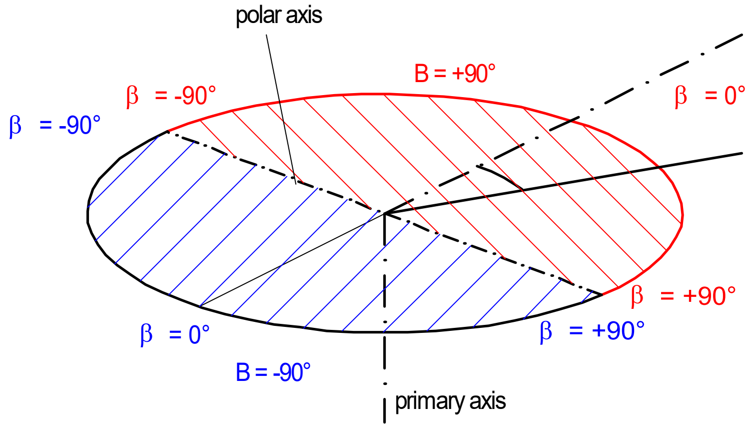

Figure 31: Horizontal plane in B-system

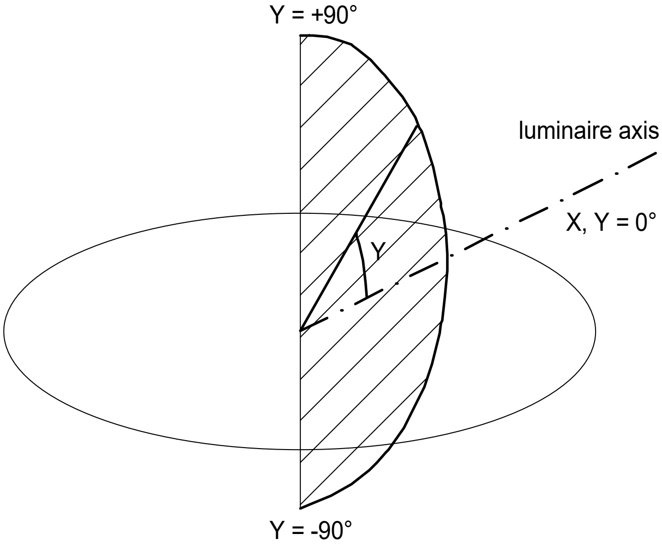

Figure 32: Vertical plane in system X, Y

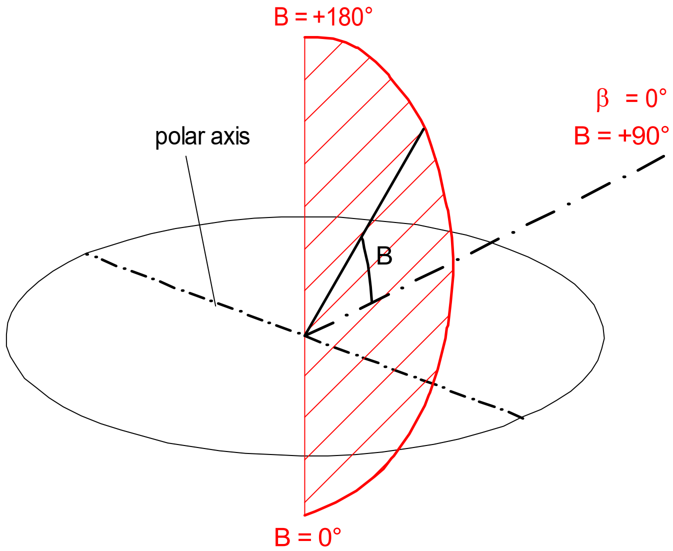

Figure 33: Vertical plane in B-system

13 References

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