

Guideline Document
for the Optical
Measurement of
LED Clusters

Issue 1
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Guideline Document for the Optical Measurement of LED Clusters

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ABSTRACT

This document contains recommended guidelines for the optical measurement of LED Clusters. The ‘LED Clusters’ Focused Interest Group (FIG) was set up within the National Physical Laboratory’s Optical Technology and Measurement Network to promote a better understanding of optical measurement issues in connection with LED Clusters in signaling applications. The LED Clusters FIG has developed this Guideline document to provide guidance for the measurement of the optical radiation properties (luminous intensity, colour, etc.) of LED cluster products, and is aimed at LED cluster suppliers, measurement organisations, standards authorities, and approval bodies

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Approved on behalf of the Managing Director, NPL
by Jonathan Williams, Quality of Life Division

Guideline Document for the Optical Measurement of LED Clusters

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Background to this Document

The 'LED Clusters' Focused Interest Group (FIG) was set up within the National Physical Laboratory's Optical Technology and Measurement Network (formerly the Optical Radiation Measurement Club), in December 2002.

The 'LED Clusters' FIG aims to promote a better understanding of optical measurement issues in connection with LED Clusters in signalling applications, and enjoys representation by NPL, LED manufacturers, LED cluster and signal manufacturers, optical measurement equipment manufacturers, LED cluster users, and consultancies.

This document contains recommended guidelines for the optical measurement of LED Clusters.

Initially, a round-robin test was conducted on a number of LED Cluster artefacts, and the findings were used to identify the key measurement issues which require specification or control in order to minimise measurement error and uncertainty. These measurement issues were used by the FIG to develop this Guideline Document. Reference is made to existing documents (notably CIE 127-1997 and IALA E-122 - 2001) on the subject of the optical measurement of LEDs. The recommended guidelines in this document were validated using a second series of round-robin tests.

This document is intended for download from the NPL website, and has been passed to CIE TC2-50 "Measurement of the optical properties of LED clusters and arrays".

Issue and distribution record:

<u>Issue</u>	<u>Date</u>	<u>Circulation</u>	<u>Comments</u>
Draft 1a to Draft 1d	Oct-2003 to Oct-2004	'LED Clusters' FIG	Subject headings drafted using notes from FIG meeting 16-Oct-03. CIE reference added. Draft text fitted to subject headings. Revised draft text following FIG meeting 14-Oct-2004.
Draft 2a to Draft 2e	Dec-2004 to Dec-2005	'LED Clusters' FIG	Revised draft text following comments received to end Dec-04. Revised draft text following LED Clusters FIG Meeting Jan-05. Revised draft text following input / comments received by correspondence. Revised draft text tidied up. New figures included for final circulation & review. Revised draft, incorporating comments from ZVEI.
Draft 3a	Feb-2007	'LED Clusters' FIG	Revised draft, incorporating further comments from ZVEI and updated list of referenced documents
Final draft	Apr-2007	'LED Clusters' FIG, NPL.	Proof version of Issue 1 document, incorporating final comments from LED Clusters FIG.
Issue 1	Oct-2007	'LED Clusters' FIG, NPL.	Issued document, incorporating comments from NPL May-2007

The 'LED Clusters' FIG welcomes technical input feedback on this document. Please contact:

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Appendix B Non-CIE Publications that may be relevant to the LED Clusters Guideline Document

Acknowledgements

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(i) Definitions

For the purposes of this document, an LED cluster is defined as an array of two or more surface-emitting, visible LEDs within the same assembly and intended to be viewed together, such that their appearance is substantially different from a single LED.

The definition of general optical terms used in this document shall be in accordance with CIE Publication 17.4 "International Lighting Vocabulary" / ZVEI "LED Definitions"

(ii) Scope

This document applies to the optical measurement of LED clusters^[HB1] in signalling applications^[HB2].

The LED cluster should be measured as assembled for the intended application, e.g. if applicable with the printed circuit board and heat-sink elements, enclosure, reflector, lens(es), etc.

(iii) Objectives

This document aims to provide guidance for the measurement of the optical radiation properties (luminous intensity, colour, etc) of LED cluster products, and is aimed at LED cluster suppliers, measurement organisations, standards authorities, and approval bodies.

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1. History of LED Cluster sample

1.1 Ageing history of sample

The optical properties of an LED cluster sample are known to be influenced by its ageing history, which should be specified by the manufacturer. According to the application, the LED cluster sample may be required to be measured 'as new' or following a burn-in period appropriate for the sample. If no burn-in period duration is specified, a recommended figure of 100 hours may be taken.

1.2 Thermal history of sample (e.g. 'cold start' or 'conditioned')

The recent thermal history of an LED cluster sample is known to influence the thermal conditions of a device at the start of an optical measurement session. In order to avoid effects due to any residual thermal conditions, it is recommended that immediately prior to measurement, the LED cluster sample under test is thermally conditioned without packaging in the environment in which the optical tests are to be conducted for a period of sufficient duration to allow for thermal equilibrium to be established. Under these operating conditions, the thermal history of the sample becomes unimportant. In order to determine the thermal equilibrium condition during the measurement process, the optical output of the LED cluster sample may be monitored using a suitable measurement system.

2. Environmental conditions

2.1 Ambient temperature

The ambient temperature during the measurement of the LED cluster sample should be monitored and included with the measurement results. The value of the ambient temperature that is required during measurement may be determined by the calibrated reference artefacts used, or may be set according to the application. The overall objective is to conduct the optical measurements in a meaningful ambient temperature according to the application of the LED cluster sample. In the absence of such requirements, a recommended value of $25 \pm 5 - 10^\circ\text{C}$ [HB3] shall be used [HB4], in accordance with CIE127-1997 Section 2.2.4.

2.2 Local temperature (e.g. inside enclosure)

In order to verify thermal stabilisation of the LED cluster sample, for example where there may be a very long thermal stabilisation period, it may be desirable to measure the local temperature of the LEDs. This may be achieved by direct measurement of the LED junction, or the pcb on which the LEDs are mounted, or by measurement of the air temperature inside the enclosure. However, it is recommended that only the ambient temperature is reported. This exercise may form a pilot measurement session on an LED cluster sample. Once the thermal stabilisation duration is known, this may be recorded for reference purposes in later measurements.

It should be noted that flashing LED clusters may exhibit significantly different thermal stabilisation parameters to continuously driven LED clusters. The overall objective is to achieve a meaningful stabilisation period according to the application of the LED cluster sample.

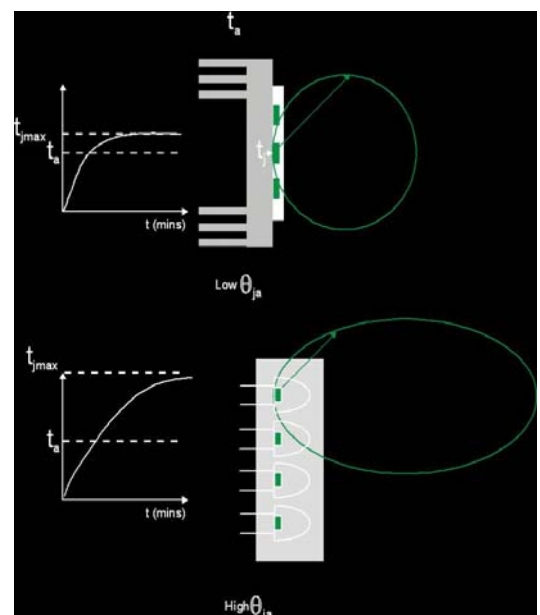


Figure 1 Temperature Stabilisation

The graphs shown on the left side of [HB5] Figure 1 illustrate [HB6] the effect of low and high thermal resistance packaging on temperature stabilisation.

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2.3 Ambient / stray light

Ambient and stray light should be minimised by the use of low reflectance darkroom surfaces and baffles where necessary. In the event that ambient light is unavoidable, this should be monitored, recorded and factored out of the measurement results.^[HB7]

3. Electrical conditions

3.1 Supply voltage / current value & stability

Measurements on LEDs are usually conducted using a DC power supply unit. However, LED clusters are generally part of a system which includes other electrical control components. Therefore, the following modes of electrical supply may all be considered appropriate for a particular LED cluster, depending on the application:

- Operation at constant current (for further information see CIE 127 Section 2.2.1),
- Operation at rated supply voltage, in which case this should be specified.
- Operation over a range of supply voltages, in which case this range should be specified by the LED cluster supplier, and special arrangements should be employed for establishing the thermal stabilisation of the LED cluster sample.

In the case of pulse-width modulated operation of LEDs, it should be noted that the optical output of the LEDs can be affected by the supply voltage. The supply voltages should therefore be quoted with the results.

4. Geometrical considerations

4.1 Definition of axis (optical / geometric).

The difficulties associated with possible discrepancies between the optical and geometric axes for LEDs (CIE 127 Section 3, Figure 3.1 provides a useful illustration) are compounded for LED clusters. The nature of LED cluster samples is such that a number of reference axes may apply. The selected reference axis should be specified by the LED cluster supplier and quoted with the results:

- The geometric axis of the LED cluster, taken by reference to a defined mechanical feature of the LED cluster or housing into which the LED cluster is fitted, and centred about the geometric centre of the LED cluster.
- The axis defined by some integral alignment feature of the LED cluster.
- The optical axis of the LED cluster, which may be defined as the axis into which the LED cluster delivers its peak value of luminous intensity.
- The optical axis of the LED cluster, which may be defined as the axis which, for a defined plane with rotational symmetry of the LED cluster^[HB8], is geometrically centred between the angles into which the LED cluster delivers a defined percentage (for example 50%) of its peak value of luminous intensity. ^[HB9]

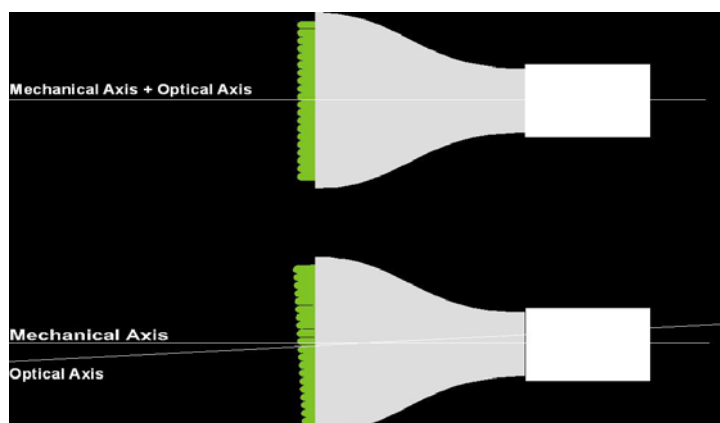


Figure 2 illustrates an example of a skewed optical axis arising from misaligned LEDs in the LED cluster.

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4.2 Definition / interpretation of lit area of LED cluster^[HB10].^[HB11]

If necessary, the boundary of an LED cluster may be defined as:

- the smallest contiguous ^[HB12]area ^[HB13]containing all the LEDs,
- the area defined by a physical boundary ^[HB14]around ^[HB15]the LED cluster, for example a mask around a pedestrian crossing indicator,
- otherwise defined by the LED cluster manufacturer.

The effects of lenses and/or diffusers ^[HB16]should be taken into account^[HB17] when defining the lit area of LED clusters.

In the case of complex LED clusters, where the cluster layout may be irregular in shape and/or population density, it may become necessary to define the boundary conditions according to the application. In such cases, it is likely that the LED cluster contains information which is intended to be visually resolved and as such the luminance of the LED cluster should be measured over a specified area (for example the critical visual angle, which is the minimum angle for visual resolution by the observer at the upper limit of viewing distance^[HB18]). Alternative boundary conditions may involve reference to the average luminance (over the whole light emitting surface) and/or the point luminance ^[HB19](at a defined location within the light emitting surface).

4.3 Colour and illuminance as a function of measurement distance, and how to establish minimum measurement distance.

The requirements for determining the minimum measurement distance for spectroradiometric measurements are dependent upon the characteristics of the LED cluster, according to whether the viewing requirements for the LED cluster are near-field or far-field. A minimum measurement distance applies, below which measurements are not valid. The minimum measurement distance may be determined according to the crossover distance^[HB20] (See Appendix B, Reference IALA E122^[HB21]). It may be desirable to conduct measurements at a distance or range of distances equivalent to those of the application^[HB22]. In any case, the measurement distance(s) should be specified with the test results.

Figure 3 shows the illuminance profiles projected ^[HB23]onto a screen at two distances from the source, from a MATLAB simulation of 2 x 2 LED array projected onto a plane at a distance of 1 m (shown left) and 10 m (shown right) and illustrate the importance of specifying the measurement distance.^[HB24]

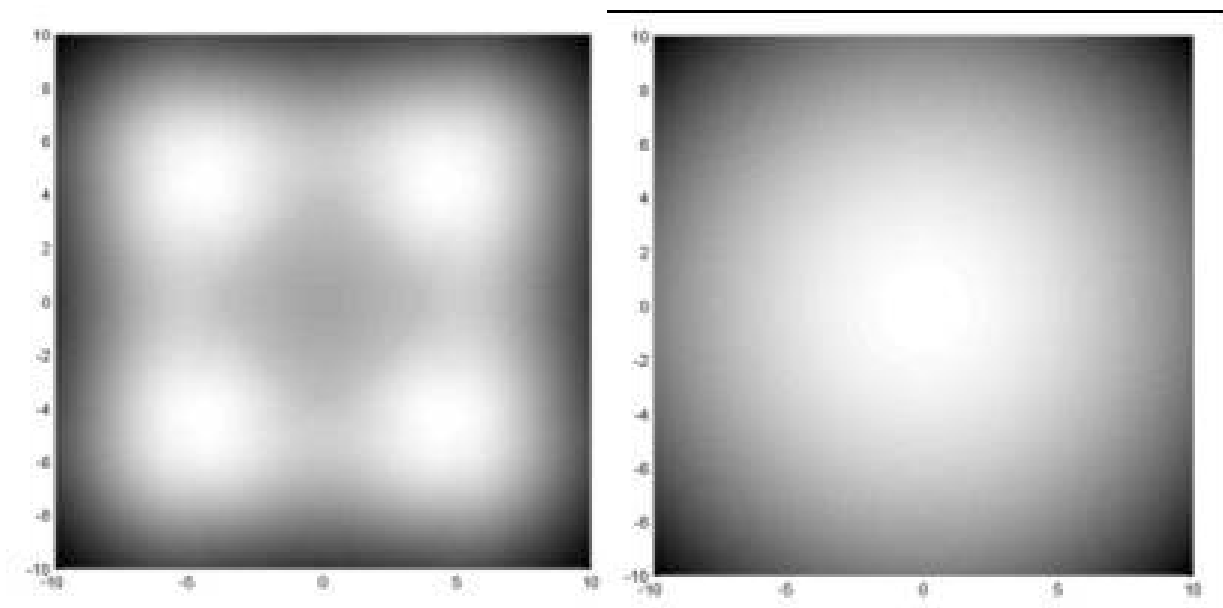


Figure 3 Illuminance profiles (simulated) from LED array at different distances.

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4.4 The use of illuminance meters to measure luminous intensity

Illuminance meters may be used to measure the luminous intensity of LED clusters, according to the inverse-square relationship between the luminous intensity of a point source and the illuminance measured at a given distance (candela = lux . distance . distance). [HB25]

Note that this technique may only be applied where the LED cluster approximates a point source to the meter, which may involve a large measurement distance. Furthermore, the use of an illuminance meter for this purpose may result in high measurement uncertainty because of limiting factors such as calibration, resolution, dynamic range and linearity (see 6.1)[HB26]

5 Measurement issues

5.1 Colour as a function of lit duration / sample temperature.

The thermal stabilisation requirements for LED clusters have been described in Section 1.2 of this document. In the case where scanning spectroradiometers are used, spectral measurements require full stabilisation, as otherwise some spectral shift may occur during the course of the measurements.

In the case of flashing lights, fast measurement devices are required, in which case such devices should be characterised with reference to a scanning spectroradiometer (CIE S/004/E-2001). If the flash rate is less than the critical flicker frequency, then the integration time must be adequate to allow averaging over a single flash.

Alternatively, it may be possible to apply theory to predict the relevant optical parameters of the flashing characteristic from the measured steady-state condition.

5.2 Colour as a function of angle off-axis (spatial distribution).

It is known that many LEDs, especially those involving phosphor emissions, exhibit different spectral properties with emission angle. In some cases, LEDs may be specified in terms of an 'average' colour[HB27] (based on partial flux, for example)[HB28]. The spectral properties of the LEDs may differ from the specified values when viewed from a particular angle. In order to measure the colour of light emitted over the functional range of emission angles, the following techniques are recommended:

- The LED cluster may be mounted on a gonio-spectroradiometer and measured using a suitably calibrated fast measurement device.
- The LED cluster may be mounted on a manual or stepping goniometer which may be adjusted to the angles of interest and the spectral properties of the LED cluster may be measured using a suitable spectroradiometer or colorimeter fixed at a suitable distance from the LED cluster (See Section 5.3).

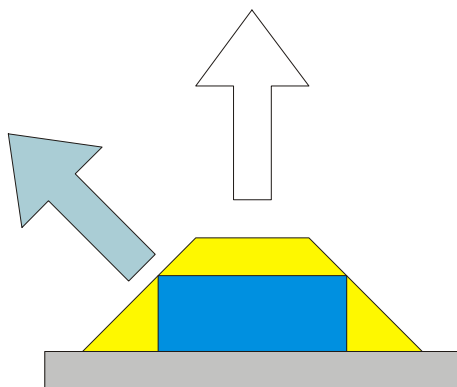


Figure 4 shows an example of a White LED comprising a phosphor coated emitter. The difference in phosphor thickness at different angles gives rise to an angular variation in chromaticity.

Figure 4 Angular variation in chromaticity with phosphor coated White LED.

Further information on the spatial distribution of LEDs can be found in CIE 127 Section 2.1.2.

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5.3 Luminous intensity / luminance as a function of lit duration / sample temperature.

The thermal stabilisation requirements for LED clusters have been described in Section 1.2 of this document, and care should be taken to ensure full stabilisation before commencing photometric measurements. In the case where the photometric quantity of an LED cluster sample is required to be known as a function of sample temperature, this requires the control of ambient temperature. If the temperature of the optical laboratory is controlled, the implications on the calibration of the optical instruments must be taken into consideration. Alternatively, if the local temperature of the sample is controlled (e.g. in an environmental cabinet) then the optical properties of any windows in the cabinet must be taken into consideration. This may be achieved by conducting the calibration measurements in the environmental cabinet. With the control of the local 'ambient' temperature, care must be taken to avoid forced cooling of the LED cluster sample, and the variation of local thermal conditions when rotating the LED cluster sample. As in the case of verification of thermal stabilisation (See Section 2.2), the measurement of the temperature of the following may be desirable: the LED junction, or the pcb on which the LEDs are mounted, or the air inside the enclosure.

5.4 Luminous intensity / luminance as a function of angle off-axis (angular distribution).

It is known that many LEDs exhibit different photometric properties with emission angle. In order to measure the luminous intensity or luminance over the functional range of emission angles, the following techniques are recommended:

- The LED cluster may be mounted on a goniophotometer and measured using a suitably calibrated detector.
- The LED cluster may be mounted on a manual or stepping goniometer (for example CIE 43 or CIE 70) which may be adjusted to the angles of interest and the photometric properties of the LED cluster may be measured using a suitable photometer or imaging photometer, fixed at a suitable distance from the LED cluster (See Section 5.3).

Further information on the spectral distribution of LEDs can be found in CIE 127 Section 2.1.1

The system or convention used for the angular measurements should be specified with the results.

5.5 Luminous intensity / luminance as a function of measurement distance, and how to establish minimum measurement distance.

The recommended method of calculating the minimum measurement distance for photometric measurements is the same as that described for 'Minimum Photometric Distance' in IALA Recommendation E-122 Section 2.4

In the case where the focal length of the optical system (LED cluster) is not known, then the crossover distance may be determined empirically, in which case the crossover distance should be quoted with the results, together with the distance at which the measurement was carried out.

5.6 Definition of measurement area for luminance measurement.

Luminance measurements of LED clusters have little meaning unless the measurement area and location is defined and reported together with the result. This is because of the pixelation of the radiating surface, as a result of which a measurement area equal to one LED separation may yield a very different luminance result from two LED separations, and even a fixed measurement area may differ considerably across the LED cluster.

Many LED clusters are mounted in enclosures which make the determination of area ambiguous. In some cases, the area of an LED cluster may be defined by a mask or other feature which provides a

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well-defined boundary to the lit area. Where no such feature exists, the lit area may be determined by the following techniques:

- Take the outermost boundary of the LEDs or lenses within the cluster and define the smallest regular polygon (e.g. circle, square, rectangle, hexagon) which just includes all the LED boundaries.
- Measure the centre-centre separation of the LEDs within the cluster and add half of this value to the smallest regular polygon which just includes all the LED boundaries.
- Measure the luminance using a spot luminance meter, in which case the spot area and location should be specified with the results. Note that the spot area may not always be easy to define, given that spot luminance meters do not always allow sharp separation of the spot and its surrounding area^[HB29].
- Measure the mean luminance of the whole LED cluster by measurement of luminous intensity divided by the lit area, in which case the method for determining the lit area should be specified with the results.

Figure 5 illustrates a possible sampling error arising when measuring the luminance of LED clusters.^[HB30]

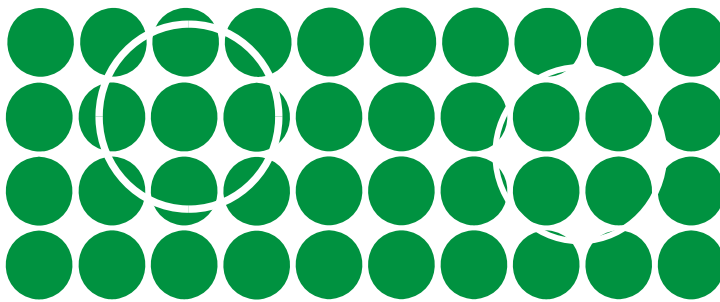


Figure 5 LED cluster luminance sampling

Luminance measurements require the use of imaging optics with the detector, or some other means of collecting radiation emitted from a given area into a specified solid angle. The solid angle used for the measurement (i.e. the acceptance angle of the imaging optics in the case of an imaging system) can have a significant influence on the measurement result. The solid angle should therefore be specified and reported with the result.

5.7 Arrangements for measurement of phantom / swamping (illuminance in the plane of the LED cluster, spectral properties of illuminant, angle of illumination, angle of measurement)

Increasingly, the optical performance of LED clusters under real lighting conditions is required to be characterised. The design of some LED cluster products is such that they may be more reflective than equivalent tungsten lamp-based products. Measurements in a darkroom laboratory are rarely indicative of the in-service optical performance^[HB31]. Generally, a measurement in the darkroom, with a correction for ambient illuminance, is required^[HB32]. The presence of finite illuminance at the surface of the LED cluster may have two performance effects:

- The reflection of coloured light from some or all of the area of the LED cluster, giving the effect of a 'phantom' display,
- In the case of clear LED clusters, the reflection of source-coloured (i.e. nominally white) light from some or all of the area of the LED cluster, giving the effect of a brighter, but generally desaturated display.

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These effects may be simulated in the optical laboratory using a light source, e.g. a heliodon, or a light source as specified in EN 12368^[HB33], but considerable care must be taken to replicate the in-service lighting conditions^[HB34]. For example, the effects of solar lighting are expected to differ considerably from artificial indoor lighting.

The following properties or consequences of the light source should be controlled:

- The illuminance at the surface of the LED cluster should be similar to the in-service value or range,
- The spectral properties of the light falling on the front surface of the LED cluster should be similar to the in-service properties,
- The geometrical arrangement of the light source should be similar to the in-service condition, and should be specified with the test results. This is particularly difficult to achieve for the simulation of daylight. In safety-critical applications, it may be necessary to supplement optical measurement data with controlled observational tests.

5.8 Special requirements for intermittent ^[HB35]flashing and / or pulsed LED Clusters^[HB36]

LED clusters may be designed for use in flashed or pulsed mode so that the duty cycle is less than 100%. Examples of such uses are warning beacons or a 'continuous' light that is pulse-width modulated to aid light output regulation. Because the output intensity and colour of an LED cluster is likely to vary with junction temperature, and as this temperature may vary considerably with duty cycle, it may be desirable to measure the LED cluster in its intended mode of operation. When using photometric or radiometric devices to measure pulsed light sources, it is important to be aware of the following:

- (i) If it is intended to record the pulse shape given by the light source, the response time of the measuring equipment should be fast enough ^[HB37]to ^[HB38]faithfully follow the pulse shape without causing distortion. As a 'rule of thumb', the response time of a photometer should be less than one tenth of the calculated time interval between the 50% intensity points of a pulse being measured. The slew rate of the photometer amplifier should be less than one tenth of the on-period of the pulse cycle.
- (ii) If the light source is intended as a 'continuous' light when viewed (e.g. the pulse repetition rate is greater than the flicker fusion frequency - approximately 20Hz to 60Hz), some form of averaging of the continuously pulsed waveform may be employed; in accordance with the Talbot-Plateau law.
- (iii) If the response time of the measurement equipment is fast enough to adequately follow the individual pulses, averaging may be carried out on the recorded waveform. However, if the response time of the measurement equipment is too slow, or if a single reading is required, then some form of electronic averaging (e.g. low-pass filter) may be employed. The introduction of filtering in the measurement process may necessitate re-calibration of the measurement system and may affect measurement uncertainty.
- (iv) For pulses slower than the flicker fusion frequency, and for warning beacons emitting occasional flashes, the effective intensity of the pulse of light may be derived from one of a number of methods, the most popular being the method of Blondel-Rey and the form-factor method of Schmidt-Clausen. Although results from different methods may vary significantly for different pulse shapes, they generally agree when the pulse is rectangular in shape. In any case, the method used for calculation of the effective intensity should be stated.

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6. Calibration issues

The calibration issues contained in this section are specific to LED clusters. General calibration requirements may be found in CIE Publications 15 & 63, and in the paper 'Calibration of Light Sources and Detectors' (T. Goodman, NPL).

6.1 Calibration of illuminance meter (if used to measure luminous intensity indirectly): Dynamic range, resolution, linearity.

Illuminance meters may be used to measure the luminous intensity of LED clusters. In this application, the illuminance meter is required to have the following properties:

- Sufficient dynamic range such that, when used at the appropriate distance (See Section 5.6), there remains sufficient dynamic range to give a useful indication ^[HB39]of the luminous intensity (Note that EN 13032 contains applicable requirements^[HB40]).
- Small linearity errors over the illuminance range of interest.
- Adequate display resolution to give meaningful results, especially in the lowest illuminance range.
- Known spectral error over the wavelength range of interest for the LED cluster, especially at the visible wavelength extremes where the percentage spectral matching error can be very large (this allows calculation of a spectral mismatch correction provided the spectral characteristics of the LED cluster are also known).
- Capability for precise alignment with the LED cluster.
- Known temperature characteristics.
- Cosine correction where appropriate.

Further information is available from the NPL website www.npl.co.uk

6.2 Calibration of tristimulus colorimeters^[HB41]

Tristimulus colorimeters meters may be used to measure the colour of light emitted by LED clusters. This type of colorimeter is required to have the following properties:

- Sufficient dynamic range such that, when used at the appropriate distance (See Section 5.6), there remains sufficient dynamic range to give a useful indication of the measured quantity.
- Small linearity errors over the range of interest.
- Adequate display resolution to give meaningful results, especially in the lowest range.
- Known spectral error ^[HB42](spectral mismatch correction at each wavelength)^[HB43] over the wavelength range of interest for the LED cluster (this allows calculation of a spectral mismatch correction provided the spectral characteristics of the LED cluster are also known).
- Capability for precise alignment with the LED cluster.
- Known temperature characteristics.
- Cosine correction, where appropriate.

6.3 Calibration of standard lamp / detector / meter: Reproducibility of lamp calibration conditions, spectral response of detector; dynamic range, resolution & linearity of meter.

The methods to be used for calibration of lamps, detectors and meters for use with LED clusters is detailed in CIE 127 Section 2.2.1.4 (temperature stabilised LED), Section 4.1 (Spectral responsivity of meter), and Section 4.2 (comparison method).

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In the case of photometric measurements, a suitable, traceably-calibrated reference source or meter can be used. In the case of spectral measurements, the calibration of the measurement system requires a suitable measurement interval and bandwidth, and the use of a traceably-calibrated reference source giving known spectral output over the wavelength range of interest. Where a reference source is used, this may be either a reference lamp (typically a tungsten lamp) or a reference LED. In the case of reference LEDs, these should be of the same type and colour as those in the LED cluster sample.

6.4 Measurement Uncertainties

Every measurement is subject to some uncertainty. A measurement result is only complete if it is accompanied by a statement of the uncertainty in the measurement. Measurement uncertainties can arise from the measuring instrument, from the item being measured, from the environment, from the operator, and from other sources. Measurement results should always be stated together with the expanded [0]uncertainty.

Measurement uncertainties can be estimated using statistical analysis of a set of measurements, and using other kinds of information about the measurement process. The 'Guide to the expression of Uncertainty in Measurement' (GUM document) contains [HB44]established rules for how to calculate an overall estimate of uncertainty from these individual pieces of information. [HB45]

The use of good practice - such as traceable calibration, careful calculation, good record keeping, and checking - can reduce measurement errors and uncertainties.

Only when the fitness of the model (relationship between the measurand and the input quantities) has been established, then the measurement uncertainty may be evaluated and stated. [HB46]

6.5 Traceability of Calibration.

Traceability in measurement is the concept of establishing a valid calibration of a measuring instrument or measurement standard, by step-by-step comparison with higher level standards up a traceability chain to an accepted or specified standard. In general the concept of traceability implies eventual reference to an appropriate national or international standard.

The National Physical Laboratory is the United Kingdom's national standards laboratory. It operates at the heart of the National Measurement System (NMS), which is the infrastructure designed to ensure accuracy and consistency in every physical measurement made in the UK. Chains of traceability link UK companies' measurements directly to national standards held at NPL.

For the majority of industrial applications, companies can establish a link to national measurement standards through the calibration and testing services offered by UKAS-accredited laboratories, which are in turn traceable to a National Measurement Institute (e.g. NPL)[HB47]. However, for challenging or novel measurements to the highest standards of accuracy, which are not catered for by UKAS-accredited laboratories, NPL can often provide a traceable measurement solution directly to industry.

The United Kingdom Accreditation Service (UKAS) is the sole national body recognised by government for the accreditation of testing and calibration laboratories, certification and inspection bodies. A not-for-profit company, UKAS operates under a Memorandum of Understanding with the government through the Department of Trade and Industry.

UKAS accreditation demonstrates the integrity and competence of organisations providing calibration, testing and inspection and certification services.

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7. Other issues

7.1 LED safety considerations.

Optical radiation can cause both short and long term damage to eyes and skin, depending on the spectral characteristics and power of the radiation. A number of international standards have been produced that specify exposure limits and hazard assessment methods for sources of optical radiation, all of which are based on the ICNIRP (2002) Guidelines for photobiological safety. Optical radiation can cause both short and long term damage to eyes and skin, depending on the spectral characteristics and power of the radiation.

A number of international standards have been produced that specify exposure limits and hazard assessment methods for sources of optical radiation, all of which are based on the Physical Agents Directive, which comes into force in 2010, sets out requirements for employers to assess the levels of exposure for workers exposed to artificial sources of optical radiation and to take measures to ensure that specified exposure limits (once again based on the ICNIRP guidelines) are not exceeded. All of these documents, particularly CIE S009, may be useful in classifying the safety of LED cluster products.

8. Reporting

The information to be included when reporting optical measurement results may be^[HB48] specified with the customer order^[HB49]. As a minimum, the following information is recommended for general reporting purposes:

- Description of LED cluster sample, including a description of its assembly, any identification markings and ageing history.
- Description of the thermal conditioning,
- Description of the environmental and electrical conditions in which the optical measurements were conducted,
- Identification or definition of the measurement axis and lit area of the LED cluster sample, including any special considerations or assumptions made.
- Identification of any special considerations in respect of flashing LEDs, for example duty cycle, or method for evaluating effective intensity.
- The format used for the presentation of measurement data, including the system of co-ordinates for any goniometric measurements.
- A description of the measurement method, including a description of the equipment used, all relevant calibration references, the identification of the operator, the date and the location of test.
- The results of the measurements including estimates of uncertainties, and details of any error correction (e.g spectral correction, ambient light correction, etc).

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Appendix A CIE Publications that may be relevant to The LED Clusters Guideline Document
David Gibbs, NPL, 05/02/2004, Supplemented by Hugh Barton 11/03/2004.

Recommendations	
17.4	International lighting vocabulary, 4 th ed. (joint publication IEC/CIE). 1987 Section 845-01 - Radiation, quantities and units Section 845-02 - Vision, colour rendering Section 845-03 – Colorimetry Section 845-05 – Radiometric, photometric and colorimetric measurements, physical detectors Section 845-07 – Light Sources Section 845-11 – Visual signalling
39.2	Recommendations for surface colours for visual signalling, 2 nd ed. 1983 Section 3 – Specification of Ordinary Colours
Technical Reports	
13.3	Method of measuring and specifying colour rendering of light sources, 1995 6 Calculation of colour rendering indices
15:2004	Colorimetry, 2 nd ed., 1986
18.2	The basis of physical photometry, 2 nd ed., 1983
38	Radiometric and photometric characteristics of materials and their measurement, 1977
43	Photometry of floodlights, 1979 Section 3 – Definitions Section 5 - Laboratory equipment Section 6 - Conditions for measurement Section 7 – Procedure Section 8 – Presentation of results
48	Light signals for road traffic control, 1980 Section 3 – Colorimetric and Photometric requirements
49	Guide on the emergency lighting of building interiors, 1981 Section 4 – Escape lighting
53	Methods of characterising the performance of radiometers and photometers, 1982 Section 2 Definitions Section 3 Specific errors for which a recommended quantitative assessment is available Section 4 Specific errors for which a recommended quantitative assessment is not yet available
59	Polarisation: Definitions and nomenclature, instrument polarisation, 1984 Part 2 Instrument polarisation (doesn't reference LEDs)
63	The spectroradiometric measurement of light sources, 1984 Part 1 The spectroradiometer and its method of use Part 2 Procedure for the measurement of various types of lamps (tungsten & fluorescent only, but methods may be applicable)
64	Determination of the spectral responsivity of optical radiation detectors, 1983 Section 1 Determination of the relative spectral responsivity function Section 2 The absolute calibration Section 2.3 Calibration by means of standard sources
69	Methods of characterising illuminance meters and luminance meters: Performance, characteristics and specifications, 1987
70	The measurement of absolute luminous intensity distributions, 1987 Section 1 Terminology (1.7 Photometric centre) Section 2 Principles of Luminous intensity measurements (2.1 Photometric distance law) Section 3 Types of photometer heads Section 4 Measuring planes Section 5 Goniophotometer with facility for turning the light source Section 6 Goniophotometer with moving photometer head Section 7 Goniophotometer with rotating mirror Section 10 General Measuring conditions Section 11 Correction of measurement results Section 14 Calibration Section 15 Error sources and measurement accuracy

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74	Roadsigns, 1988
79	A guide for the design of road traffic lights, 1988 Section 3.4 Measurement of optical characteristics (contains references to other CIE publications)
84	Measurement of luminous flux, 1989 Section 3 Methods of measurement Section 4 Calculation of luminous flux from luminous intensity distribution Section 5 Calculation of luminous flux from the illuminance distribution Section 6 Measurement with an integrating sphere Section 8 General measurement conditions
86	CIE 1988 2° spectral luminous efficiency function for photopic vision, 1990
102	Recommended file format for electronic transfer of luminaire photometric data, 1993 Section 2 CIE Recommended file format
104	Daytime running lights (DRL), 1993 Section 2.4 Detection and luminous intensity
105	Spectroradiometry of pulsed optical radiation sources, 1993 Section 2.1 Basic elements of any spectroradiometer system Section 2.2 Spectroradiometer characteristics Section 2.3 Measurement of sources Section 3 Measurement uncertainty
107	Review of the official recommendations of the colours of signal lights, 1994
111	Variable message signs, 1994 Section 10 Evaluation and testing of the optical characteristics of non-continuous variable message sign characteristics (includes guidelines for luminance, luminance ratio, test area, uniformity & colour).
114/6	Photometry of thermally sensitive lamps (deals with fluorescent lamps). Section 4 Laboratory requirements for tests Section 6 Photometric methods and practical test procedures
121	Photometry and goniophotometry of luminaries, 1996
127	Measurement of LEDs, 1997
134/3	CIE TC 6-38 Report: Recommendation on photobiological safety of lamps. A review of standards Includes: Laser hazards, occupational exposure limits, lamp safety groups, evaluation criteria
135/2	Colour rendering, closing remarks (colour rendering)
138/1	Blue-light photochemical retinal hazard (threshold limits, optical radiation sources - note excludes LEDs, BLH measurement)
149	The Use of Tungsten Filament Lamps as Secondary Standard Sources Section 2 Applications Section 4 Spectral characteristics Section 8 Operation and control of lamps
Standards and Draft Standards	
ISO 10526/CIE S005	CIE standard illuminants for colorimetry, 1999 Section 7 Practical applications of CIE standard illuminants
ISO 10527/CIE S002	Colorimetric observers, 1991 Section 7 Practical applications of colour matching functions
CIE S004-2001	Colours of light signals, 2001 Recommended colour specifications for colours of signal lights for different transport modes.
ISO 16508/CIE S006	Road traffic light – 200 mm roundel signals photometric properties, 1999 Section 5 Test methods
CIE S009:2002	Photobiological safety of lamps and lamp systems, 2002 Section 5 Measurement of lamps and lamp systems (measurement conditions, procedure, analysis)
DS010.2:2001	Photometry – The CIE system of physical photometry 2001
Symposium proceedings	
2001 Gaithersburg, USA	LED Measurement – Standard methods for specifying and measuring LED and LED cluster characteristics

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Appendix B Non-CIE Publications that may be relevant to The LED Clusters Guideline Document

Documents	
EN 12368:2000	Traffic Control Equipment – Signal Heads
EN 13032-1	Light and Lighting. Measurement and Presentation of Photometric Data of Lamps and Luminaires. Part 1 – Measurement and File Format.
EN 13032-2	Light and Lighting. Measurement and Presentation of Photometric Data of Lamps and Luminaires. Part 2 – Presentation of Data for Indoor and Outdoor Work Places.
IALA E-122	Recommendation on the Photometry of Marine Aids to Navigation Signal Lights, June-2001
SAE J1889	Surface Vehicle Recommended Practice, LED Lighting Devices, Rev. Jun-1999
ZVEI	Beigriffe für LED / LED Definitions, Version 2.11.1
ISO/TAG4	BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML Guide to the Uncertainty of Measurement (GUM). ISBM 92-67-10188-9, 1995.

Papers	
Photometry from the Right Distance, J. G. Holmes, Lighting Res. Technol. 22(4) 183-187 (1990)	
Calibration of Light Sources and Detectors, Teresa Goodman, NPL	

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