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Edition 1.0 2018-11

TECHNICAL REPORT

colour inside

Electronic displays –
Part 2-4: Transparent displays – Overview of application scenarios

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FOREWORD

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IEC TR 62977-2-4, which is a Technical Report, has been prepared by IEC technical committee 110: Electronic display devices.

The text of this Technical Report is based on the following documents:

Enquiry draft	Report on voting
110/972/DTR	110/988A/RVDTR

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62977 series, published under the general title *Electronic displays*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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ELECTRONIC DISPLAYS –

Part 2-4: Transparent displays – Overview of application scenarios

1 Scope

This part of IEC 62977, which is a Technical Report, provides a comprehensive overview of application scenarios for transparent displays of the two major display technologies (liquid crystal (LC) and organic light emitting diode (OLED) displays) and introduces the observation and illumination aspects that are taken into account for the establishment of appropriate measurement methods.

This document only considers direct view displays, it does not include projection displays (eye-projection and projection to screens.)

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms, definitions and abbreviated terms apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1 Terms and definitions

3.1.1
AR
augmented reality
overlay of real objects and scenes with artificial visual information

3.1.2
intended visual information
visual information to be presented intentionally

Note 1 to entry: Visual information that is not intended can sometimes be observed, for example reflection of ambient images.

3.1.3
unwanted contributions from ambient light
visual information that is unintentionally generated (by e.g. reflection of ambient light sources) and superimposed over the intended visual information, thus creating disturbing visual effects

3.1.4
on-screen contrast
contrast created by the display screen by emission or absorption (transmission), including the background light transmitted and reflected light, when measured in an ambient lighting environment

3.1.5
through-screen contrast
contrast of the object or scene behind the transparent display, mainly affected by the transmissive properties of the transparent display screen, which can also include the background reflected light and transmitted light outside the regular direction when measured in an ambient lighting environment

3.2 Abbreviated terms

AR augmented reality

CIE Commission Internationale de l'Eclairage
(International Commission on Illumination)

LC liquid crystal

LCD liquid crystal display

OLED organic light emitting diode

TBLU transparent back-light unit

TDS transparent display screen

VR virtual reality

4 Application scenarios

4.1 General

Transparent displays are considered, for example, for advertising purposes (shop-windows and showcases, also in combination with touch-screens) and for other similar applications (e.g. refrigerator doors) where real scenes and objects are overlaid with additional visual information just as in the case of augmented reality (AR). In airplanes and automobiles head-up displays are used to present visual information on top of the surrounding scenery. Those head-up displays, however, use projection optics to display visual information at a certain distance in front of the observer, so usually no refocusing is required.

Transparent displays may also be realized by a reflective or transmissive screen on which visual information is being projected, but this case is not considered in this document.

4.2 Performance aspects

Two cases have to be distinguished for the performance of transparent displays:

1) on-screen performance with visual information generated by emission (OLED display) or transmission (LC display),
2) through-screen (see-through) performance with objects or a scenery located behind the transparent display screen.

NOTE 1 RGB-LCDs with colour filters have transmittance levels in the range of 5 % up to 25 % (RWGWBW), so the objects and the scene behind the display are usually illuminated with high intensity to be sufficiently visible.

NOTE 2 Scattering of the transparent display can cause excessive haze, which reduces contrast. In addition, pixel fill-factor effects can cause blurring of objects or the scene behind the screen (blurring means spatial low-pass filtering).

On-screen performance of transparent displays is generally hampered by the mixing of the scene behind the display with the visual information content shown on the display.

Transparent display screens realized with LCDs can comprise a transparent back-light unit or, alternatively, they can simply utilize available ambient illuminance and thus do not include a back-light.

4.3 Application cases

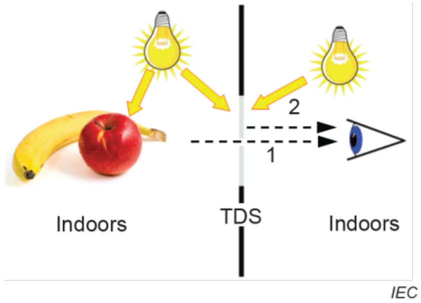
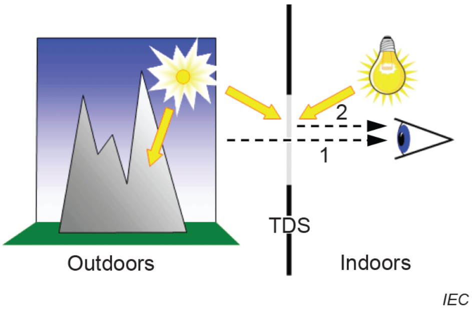
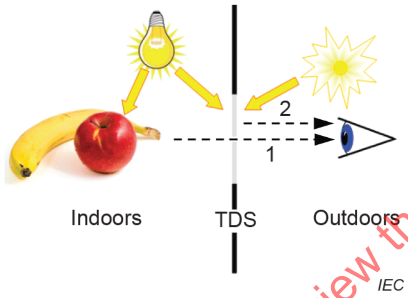
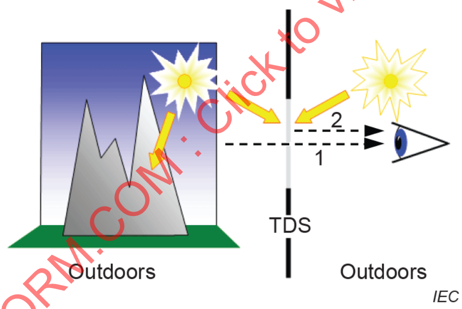
Table 1 illustrates four typical application cases for transparent displays (case 1 through 4). Each case contains two illumination sources, one on the side of the observer and one behind the transparent display screen. The light source on the side of the object or the scene provides illumination for the objects, and the scenery and light reflected by those is transmitted by the TDS and seen by the observer. At the same time, light from this source that is directly transmitted or reflected by the TDS can reduce contrast and colour saturation of the objects and the scenery behind the TDS, thus negatively affecting the intended visual information. Additionally, light reflected by the light source that is located on the side of the observer can also contribute to a deterioration of the intended visual information.

Outdoor illuminance levels are typically two orders of magnitude higher than indoor illuminance levels (Table 1, cases 3 and 4), thus possibly contributing high levels of unwanted reflected light and correspondingly a high degree of degradation of contrast and colour saturation.

The focus of the observer can be on the transparent display screen for observation of on-screen information or on the objects or scenery behind that display for observation of through-screen information.

Objects behind the TDS are illuminated by a light source, and parts of the reflected light are transmitted by the TDS (case 1) and are seen by the observer. This is the intended visual information. Light from both sources (behind and in front of the TDS) that is directly transmitted and/or reflected by the TDS is added to the intended visual information (case 2) and reduces contrast and colour saturation.

Table 1 – Application cases

1		Indoor showcase seen through a transparent display by an indoor observer (e.g. refrigerator)
2		Outdoor objects or scene seen through a transparent display by an indoor observer
3		Indoor showcase seen through a transparent display by an outdoor observer
4		Outdoor objects or scene seen through a transparent display by an outdoor observer

4.4 Intended visual information and unwanted contributions from ambient light

4.4.1 General

Visual information is provided to the observer by contrast, which is given by the difference of two adjacent areas with respect to luminance and/or chromaticity.

4.4.2 Visual information on screen

The first set of visual information is generated on a transparent display by lateral modulation of light by the processes of light emission (OLED) or absorption of transmitted light (LCD). This is the "on-screen" case.

This intended visual information can be characterized by the difference of luminance and/or chromaticity (e.g. obtained from the spectral radiance distribution) of area elements of the transparent display screen. Luminance and/or chromaticity at each location of the display surface area generally are functions of the direction of observation or measurement.

4.4.3 Visual information behind the screen

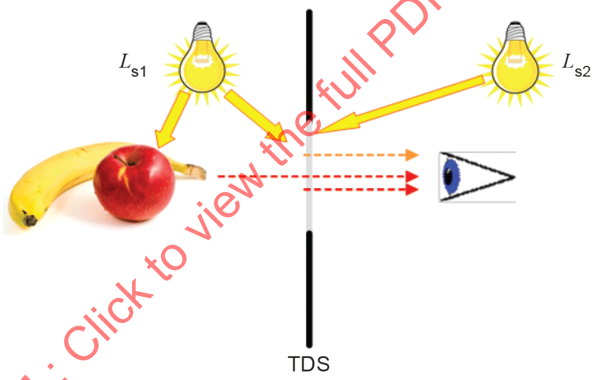
The second set of visual information is given by the scene or the object located behind the transparent display screen, i.e. at a distance that is larger than the distance between the observer and the transparent display. This is the "through-screen" case.

This second set of visual information can be characterized by the difference of luminance and/or chromaticity (e.g. obtained from the spectral radiance distribution) of surface area elements of the scene or the objects behind the transparent display screen. Luminance and/or chromaticity at each location of the scene or the objects behind the transparent display screen generally are functions of the direction of observation or measurement.

4.4.4 Intended and disturbing components of light (case 1)

Illustration and explanation of intended and disturbing light components in the case of TDS are given in Table 2.

Table 2 – Illustration and explanation of intended and disturbing light components in the case of transparent display screens (TDS)



Light reaching the observer

Intended component	Disturbing components
Image on TDS	From object/image behind TDS Scattered from L_{s1} and L_{s2} Scattered from object/image behind TDS Specular reflections from L_{s2}
Object/image behind TDS	From image on TDS Scattered from L_{s1} and L_{s2} Scattered from object/image behind TDS (blur) Specular reflections from L_{s2}

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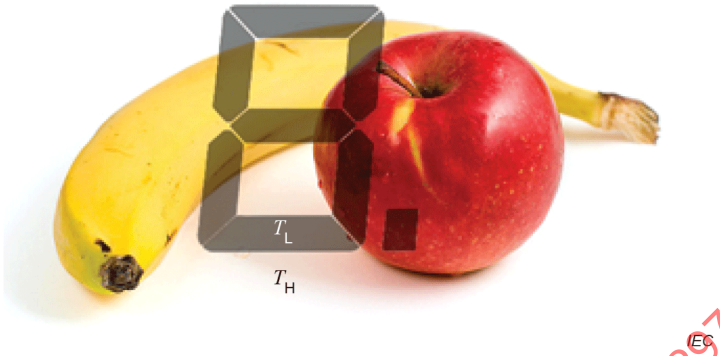
NOTE Scattered components include diffracted components.

4.4.5 Transmissive transparent display (case 2)

Two objects (i.e. a scenery) located behind and seen through a transparent display are shown in Figure 1.



NOTE The contrast of the transparent display is determined by transmittance values (high state, T_H, and low state, T_L, resulting in a contrast of T_H / T_L).

Figure 1 – Two objects (i.e. a scenery) located behind and seen through a transparent display

The scenery, i.e. the lateral variations of luminance and chromaticity, can be seen through the information shown by the transparent display as illustrated in Figure 1, Figure 2 and Figure 3. A simple segmented LC display as shown in Figure 1 does not cause diffraction of incident light.

No reflected or transmitted components of ambient light are considered here.

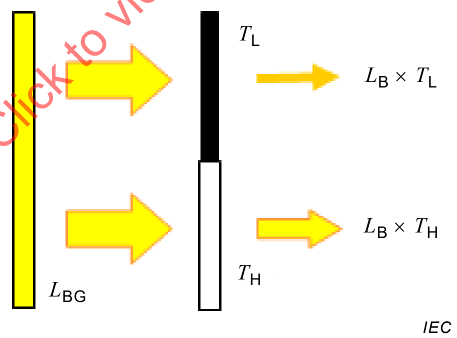


Figure 2 – On-screen contrast generated by electrically controlled transmittance, T_H and T_L

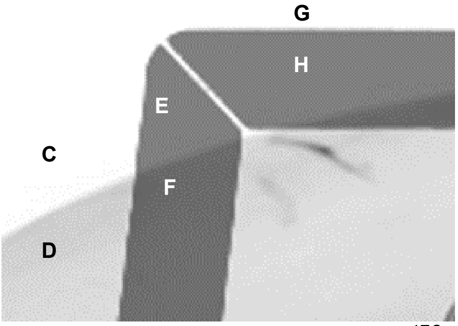


Figure 3 – Luminance image of a detail of Figure 1

The on-screen contrast of the transparent display is given by the ratio of the transmittance values T_H and T_L (shown at, for example, locations G/H and C/E). The contrast of the banana against the background is given by the ratio L_C / L_D. The contrast of the banana as seen through the activated segment of the display (T_L) is L_E / L_F = (L_C x T_L) / (L_D x T_L) = L_C / L_D. The contrast of the banana thus remains unchanged, but the involved luminance levels are both reduced by T_L.

4.4.6 Emissive transparent display (case 3)

Figure 4 – Two objects (i.e. a scenery) located behind and seen through a transparent emissive display (emission shown in green for illustration)

The contrast of the transparent emissive display is determined by the levels of emitted luminance, L_{eH} and L_{eL}, measured in front of a dark background, L_B = 0.

The scenery, i.e. the lateral variations of luminance and chromaticity, can be seen through the information shown by the transparent display as illustrated in Figure 4 and Figure 6.

No reflected or transmitted components of ambient light are considered here.

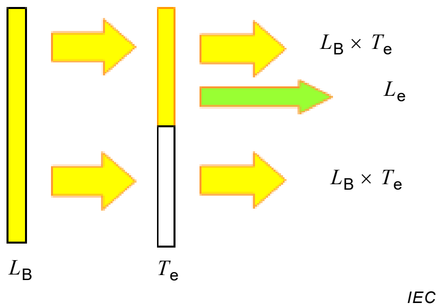


Figure 5 – Example of light which is supposed to be transmitted independently of the state of the emission, by a transmittance T_e

On-screen contrast is generated by the emission of light, L_e (shown in green, see Figure 5).

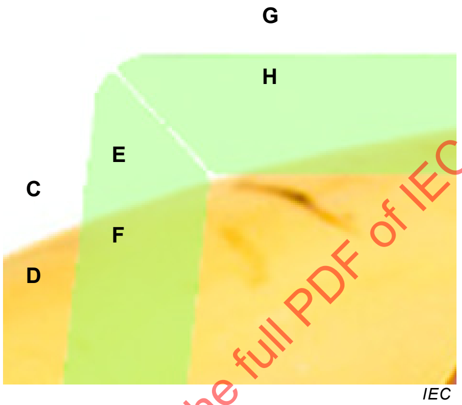


Figure 6 – Details of Figure 4

The on-screen contrast of the transparent emissive display (C_{OS}) is given by the ratio of the sum of transmitted and emitted luminance, and the transmitted luminance (shown for example at locations E/C and H/G).

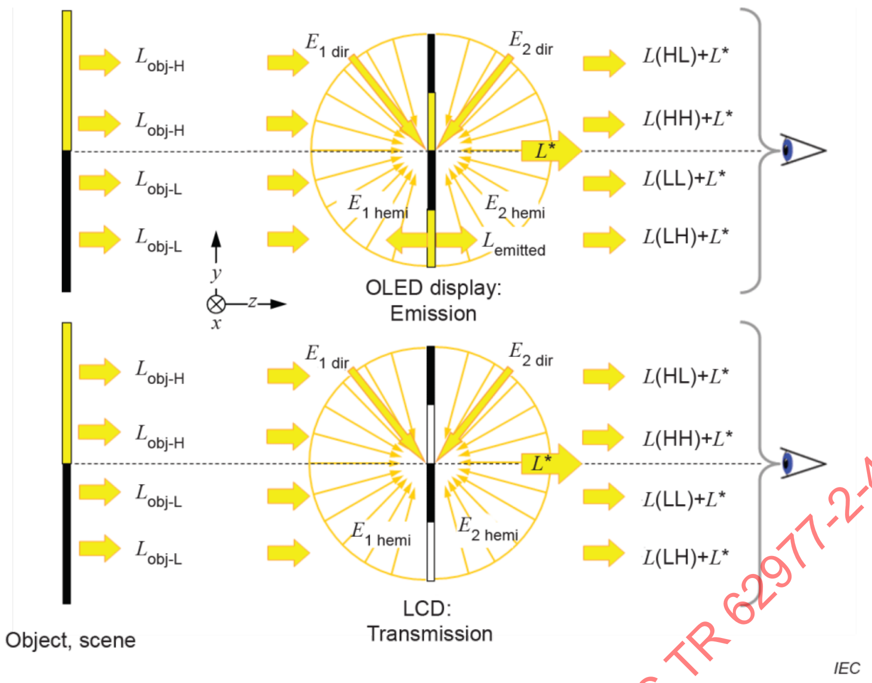
$$C_{OS} = (L_C \times T_e + L_e) / (L_C \times T_e) = (L_B \times T_e + L_e) / (L_B \times T_e) \quad (1)$$

The higher the background luminance, L_B, the lower the on-screen contrast, C_{OS}, of the emissive display. The lower the background luminance, the higher the contrast of the emissive transparent display. The contrast between locations E/C (same as H/G) is lower than the contrast between locations F/D.

5 Component specifications – For measurement

5.1 Spectral radiance

Spectral radiance (or luminance) distribution at positions x, y, z is given as a function of the local spherical coordinates θ and ϕ, ($L(\theta,\varphi,\lambda)|_{x,y,z}$). Figure 7 illustrates the possible spectral radiance (or luminance) distribution at object or display positions x, y, z as a function of the local spherical coordinates θ and φ, ($L(\theta,\varphi,\lambda)|_{x,y,z}$).



Key

$L_{\text{obj, H}}$ and $L_{\text{obj, L}}$:	Luminance of object/scene, high and low state.
$L_{\text{H, H}}$, $L_{\text{L, H}}$:	Luminance of object/scene, high state, after transmission through TDS in high/low state.
$L_{\text{L, H}}$, $L_{\text{L, L}}$:	Luminance of object/scene, low state after transmission through TDS in high/low state.
$E_{1,\text{dir}}$ and $E_{1,\text{ hemi}}$:	Illuminance from behind the TDS, directed and hemispherical component.
$E_{1,\text{dir}}$ and $E_{1,\text{hemi}}$:	Illuminance from front side of TDS, directed and hemispherical component.
L*:	Luminance resulting from all illuminance components.

NOTE The OLED display can emit light also in the direction of the object/scene.

Figure 7 – Emissive and transmissive display screen between the observer and the object/scene

The display contrast is generated by differences in emission or transmission. Ambient light incident on the display from the front and the rear side of the display (E_1, E_2) affects both the on-screen and through-screen performance. L* is the sum of all contributions arising from ambient light sources.

5.2 Object/scene

The object can be emitting, transmitting or reflecting light. The object can be planar or the object/scene can have arbitrary shapes ($L_{\text{obj}}(\theta,\varphi,\lambda)|_{x,y,z}$).

5.3 Display

The display is assumed to be planar and normal to the z-axis.

5.4 Emissive transparent display

The sum of transmitted and emitted luminance (radiance) at each location x, y is:

$$L_{\text{disp}}(\theta,\varphi,\lambda)|_{x,y,z}$$

Reflectance, R, and transmittance, T, for uniform hemispherical diffuse (diff) and directional (dir) ambient illuminance are:

$$R_{\text{diff}},\ R_{\text{dir}},\ T_{\text{diff}},\ T_{\text{dir}}$$

Ambient light can originate from the front of the display or from behind the display as illustrated in Table 1.

It is assumed that the emission of the transparent OLED display does not affect its transmissive properties.

5.5 Transmissive transparent display

The transmitted luminance (radiance) at each location x, y is:

$$L_{\text{disp}}(\theta,\varphi,\lambda)\big|_{x,y,z}$$

Reflectance, R, and transmittance, T, for uniform hemispherical diffuse (diff) and directional (dir) ambient illumination are:

$$R_{\text{diff}},\ R_{\text{dir}},\ T_{\text{diff}},\ T_{\text{dir}}$$

Ambient light can originate from the front of the display or from behind the display as illustrated in Table 1.

Transmittance in the regular direction (i.e. the same direction as the incidence of light from a directional source), preferably in the direction normal to the display surface plane, T_{reg}, is:

$$T_{\text{reg}}(\theta,\varphi,\lambda)\big|_{x,y,z}$$

Absorption (e.g. polarizing filters, colour filters in the case of LCDs, light emitting material in the case of OLED displays) as well as scattering and diffraction reduce the transmittance in the regular direction.

NOTE Diffraction in the case of LC display screens (caused by the matrix structure) and scattering in the case of OLED displays (caused by the light-emitting material) are not yet taken into account in this document. Diffracted and scattered light components can originate from any source of light located behind and in front of the transparent display and disturb the visual information intended to be presented to the observer as specified in Table 2.

5.6 Precautions during the measurements

The measurements of transmittance and reflectance are complicated by the fact that diffraction and scattering occur in the transparent display, caused by the pixel matrix of the transmissive LC display screen or by the light emitting material of the OLED display, respectively. Diffracted and scattered components of incident light can introduce severe uncertainties into the measurements.

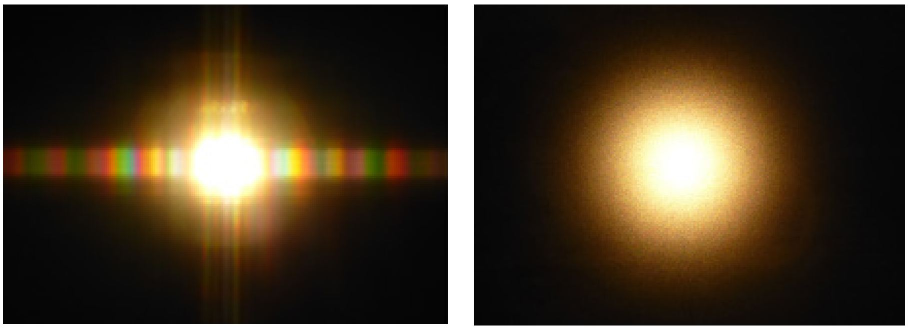


Figure 8 – Illustration of the effect of diffraction (left) and scattering (right)

Figure 8 shows a point light source (white light) seen through a diffracting LCD screen (with RGB subpixels) and through a scattering layer (e.g. light emitting material of an OLED display).

In order to make measurement results for transmittance and reflectance reproducible and significant, the solid angle of illumination of the field of measurement (measurement spot) and the aperture angle of the LMD (light measurement device) have to be controlled and specified.

More details on the measurement of hemispherical and directional transmittance levels are given in [6][1].

Figure 9, top, shows a transparent OLED display, and the bottom part shows an LCD with a transparent back-light unit (TBLU) with a transmittance that is usually smaller than one.

The object or the scene behind the transparent display is specified by the luminance (radiance) as a function of the position on the object (x, y), the viewing direction (θ, ϕ), and the wavelength of light (in the case of a spectral radiance distribution), $L(x, y, \theta, \phi, \lambda)$; a bright state, $L_{\text{obj-H}}$, and a dark state, $L_{\text{obj-L}}$ generate a dark room through-screen contrast.

The transparent display is specified by a transmittance $T(x, y, \theta, \phi, \lambda)$ and, if applicable, by an emission $L_{\text{em}}(x, y, \theta, \phi, \lambda)$. Darkroom on-screen contrast is generated by bright and dark states of transmission for LCDs, if the LCD back-light unit is turned off or if the LCD is not equipped with a back-light unit, or by emission for OLED displays.

If a back-light unit is equipped, the transparent back-light unit (TBLU) is specified by its luminance (radiance) and its transmittance. In Figure 9 the transmittance of the BLU is assumed to be one (perfect transmittance), and the radiance (luminance) is assumed to be constant (uniform) across its surface area.

1 Numbers in square brackets refer to the Bibliography.

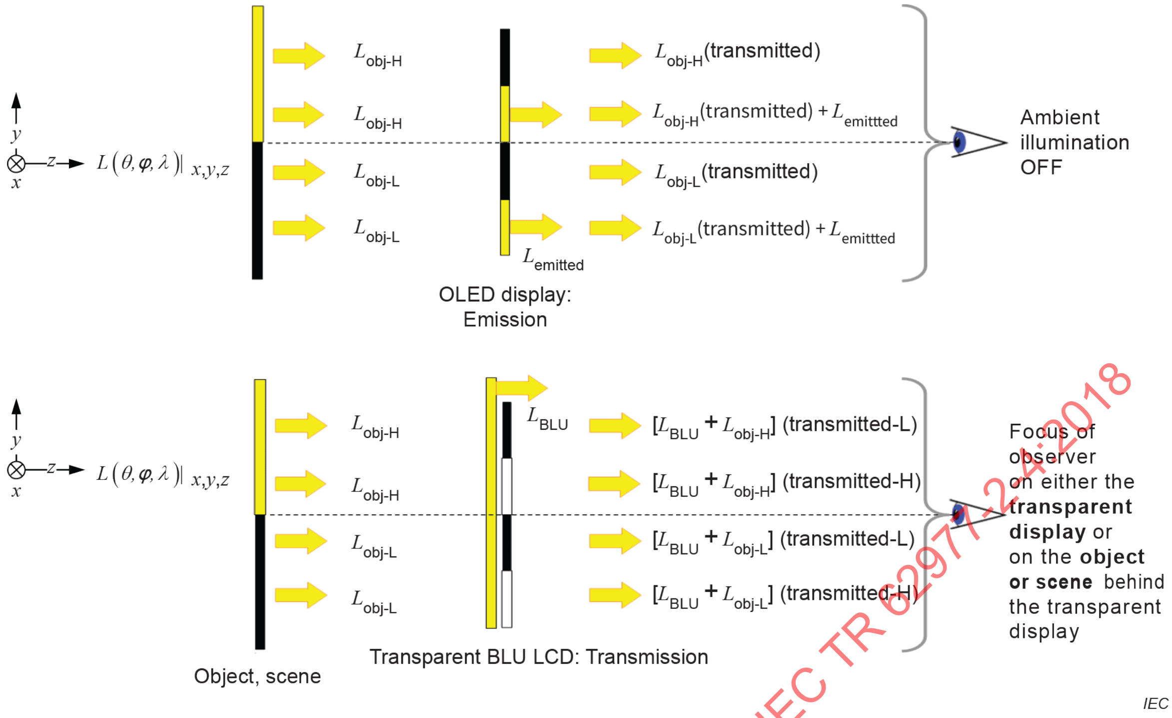


Figure 9 – Transparent display's scheme for OLED and LCD without background ambient illumination

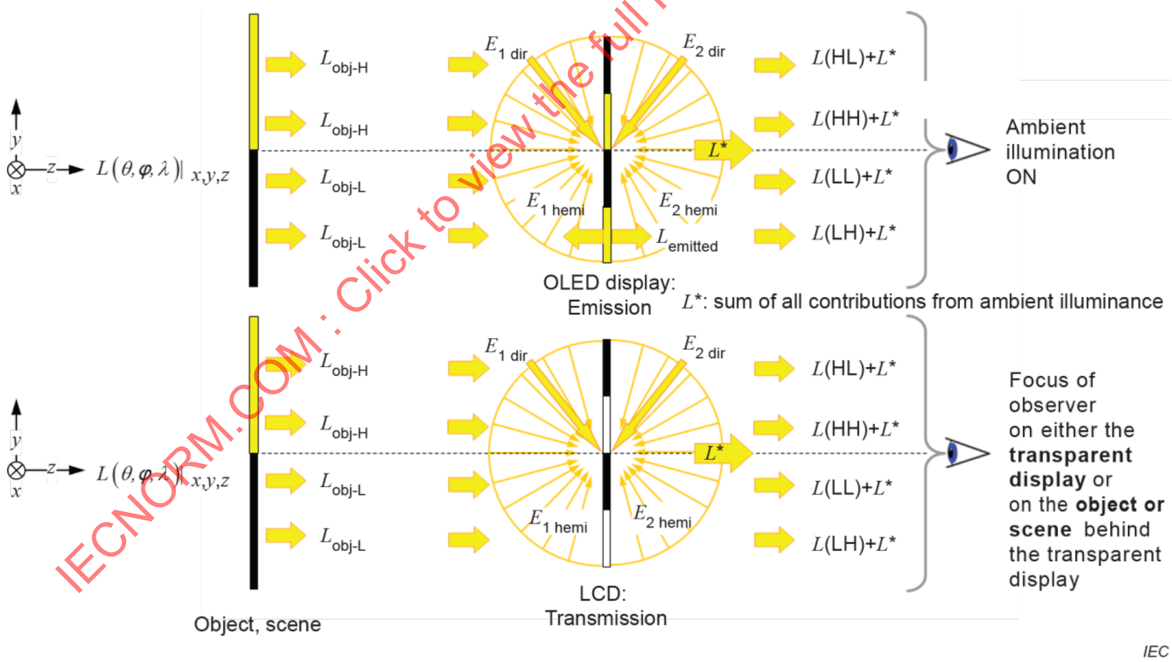


Figure 10 – Transparent display's on-screen performance affected by ambient illuminance

On-screen contrast is affected by ambient illuminance, E (irradiance), incident on the transparent display from behind or from the front as illustrated in Figure 10. Ambient illuminance may be hemispherically diffuse or directed. The level of unwanted luminance (radiance) caused by ambient illuminance is given by the (spectral) transmittance or reflectance factors of the transparent display. On-screen contrast is affected (overlay) by the luminance of the objects or scene behind the transparent display.