International metrology standards for reflective LCDs

by Jürgen Laur

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At a first glance it seems quite strange that still (after 30 years) and with commercial instrumentation available since the early 1980s, there is no international standard for measurement and evaluation of the visual performance of reflective LCDs. Only recently the WG2 of the IEC TC110 started working toward that objective. The strangeness might be somewhat reduced by the fact that the lack of an international standard used to be compensated by recommendation of a Japanese industry standard for reflective LCDs (JEITA ED-2523-2001, *Measuring Methods for Matrix Reflective LCD modules*, former EIAJ ED-2523), a national standard that has been reflecting the features and limitations of a measuring approach and apparatus using directional illumination and providing high contrast values.

Could it ever be possible that commercial interests have been preventing the generation of an international standard for measurement and evaluation of reflective LCDs up to now?

The early days of LCDs

The 1970s were an important period for the proliferation of electro-optical displays in general and above all for LCDs. After the invention of the TN-cell in 1970, patent application and licensing of the technology to interested companies in Japan, the amazing career of that type of display started and companies all over the globe got involved in LCD research and development.

It soon became obvious that a special feature of TN-LCDs was the variation of contrast with viewing direction and its dependence on a variety of cell and material parameters. For systematic experimental optimization of TN-LCD performance it became indispensable to accurately characterize the electro-optical properties of LCDs, especially the variation of contrast with viewing direction.

Those days, the polarization microscope in the *conoscopic mode of observation* used to be the most widespread instrument for analysis of the variation of transmittance and contrast versus viewing-direction [1,2]. This approach provided direct observation of the *direction image*, but quantitative measurements were cumbersome to carry out and required special modifications of the microscope [1, 2].

In 1977, Kurt Fahrenschon, at that time working for the company Braun [3], suggested to the Institute for Electromagnetic Theory and Metrology of the University of Karlsruhe, then headed by Professor Dieter Mlynski, to get involved in the development of an apparatus that would be able to perform the required characterization of TN-LCDs. Since most LCDs of those days were operated in the reflective mode, it became necessary to implement an illumination device that provided isotropic illumination during scanning of the viewing cone of the display under test.

The resulting apparatus was then used by Kurt Fahrenschon in his laboratory and results of his evaluations were published as a paper in the journal *Displays* in 1979 [4]. The instrument that was initially focused on measuring the directional contrast distribution, quite similar to that of Barna [5], soon was equipped with a range of extra features and thus became the first computer-controlled apparatus for automated measurement of the complete set of electro-optical characteristics of LCDs in the early 1980s. Since 1985 this instrument has been manufactured and marketed by autronic GmbH in Karlsruhe, Germany, and since 1993 by autronic-Melchers GmbH.

Manufacturing of LCDs and the related research and development activities started to flourish in Japan in the late 1970s. In order to support the domestic LCD research, Canon developed and manufactured a measuring system for LCDs which was based on a bulky thermal chamber. The display(s) under test inside the chamber could be translated with motors that were located outside the chamber at room temperature via shafts and isolated feed-throughs to transmit the motion. The orientation of the illumination incident on the DUT and the reception of light from the DUT (reflected or transmitted), both realized with fiber optic cables, could be adjusted via external motors as well.

After Canon had discontinued the manufacturing of these LCD measurement systems, the company Otsuka Electronics (Osaka) introduced their version of an LCD evaluation system, which was based on a thermal chamber as the main component in 1988.

LCDs have evolved since the 1970s [6,7]. After their debut in pocket calculators and wristwatches they first created a visual interface basis for portable computers and in a next wave they conquered the desktop in offices as computer monitors. LCDs helped mobile telephones to offer video and TV contents in truly handheld devices and the latest wave of success brings large-area LCDs into the living room for home-theater purposes.

Two approaches for evaluation of reflective LCDs

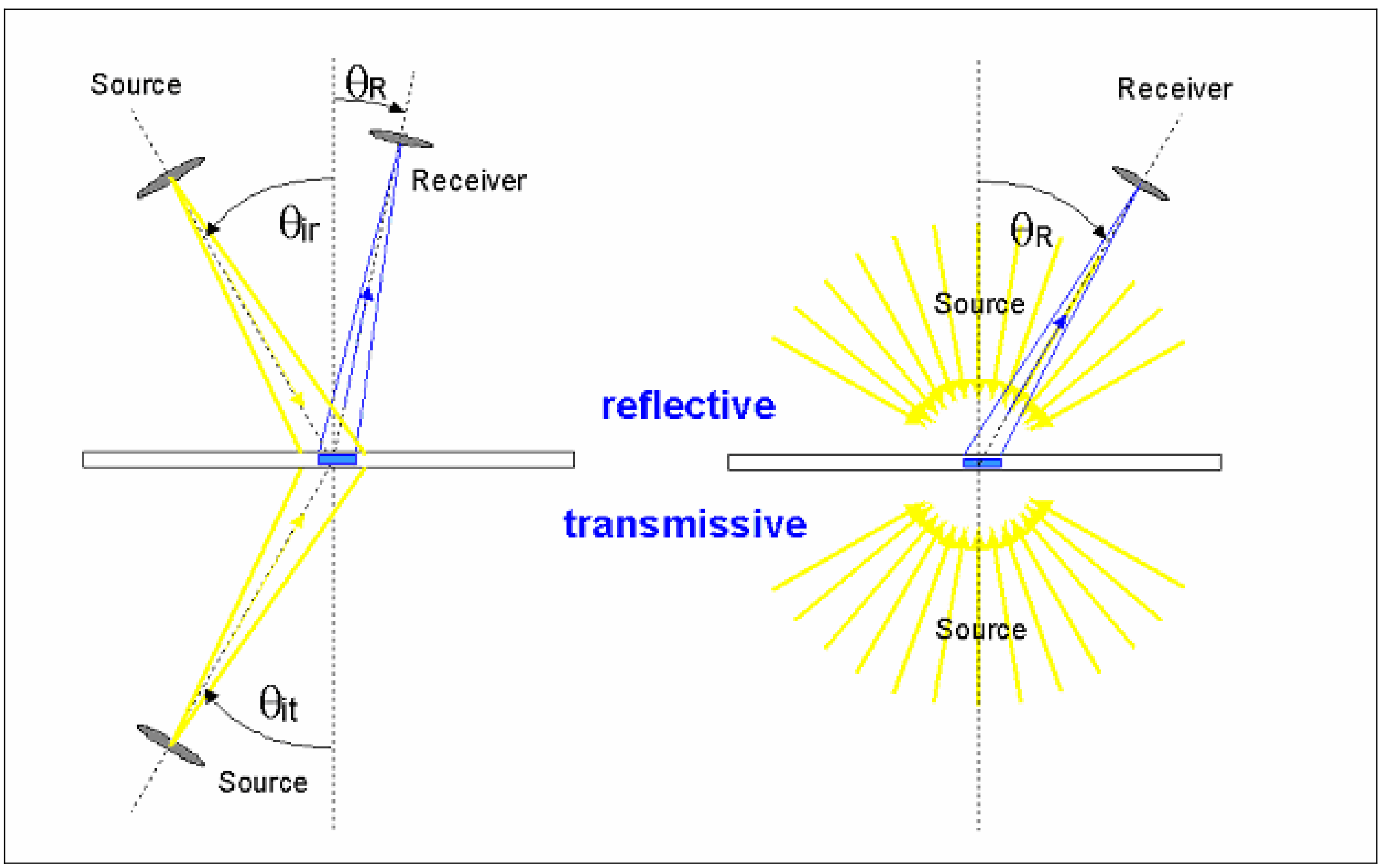

Figure 1: Two arrangements for measuring the electro-optical performance of LCDs. Directional illumination (DI, left) and multi-directional diffuse illumination (MI, right) for transmissive and reflective mode of LCD operation.

<table>
<tr><td colspan="2">Directional illumination (DI) source at direction θ_i</td><td colspan="2">Multi-directional light incidence (MI) (diffuse)</td></tr>
<tr><td colspan="2">$\theta_{ir} + \theta_R = 30°$ ($\theta_{ir} \neq \theta_R$)</td><td colspan="2">e.g. $\theta_{max} = 70°$</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>$\theta_{it} = \theta_R$</td><td colspan="2">Transmissive</td><td></td></tr>
<tr><td>scanning of VC not possible</td><td colspan="2"></td><td>scanning of VC possible</td></tr>
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Table 1: Angular conditions for source and receiver in the two measuring arrangements.

From the very first days of LCD metrology two distinctly different approaches have been practiced, the first one using a directional illumination of the DUT, the second one with a multi-directional illumination of the display under test as illustrated in *Figure 1*. In the transmissive mode of LCD operation the light incidence is in line with the direction of the receiver in the DI-approach and there is no difference between the results obtained with both methods. In the reflective mode of operation however, the difference becomes pronounced as analyzed and described in detail in [9] and [10].

This difference can be illustrated by comparing the luminance contrast of a reflective STN-LCD obtained with both approaches.

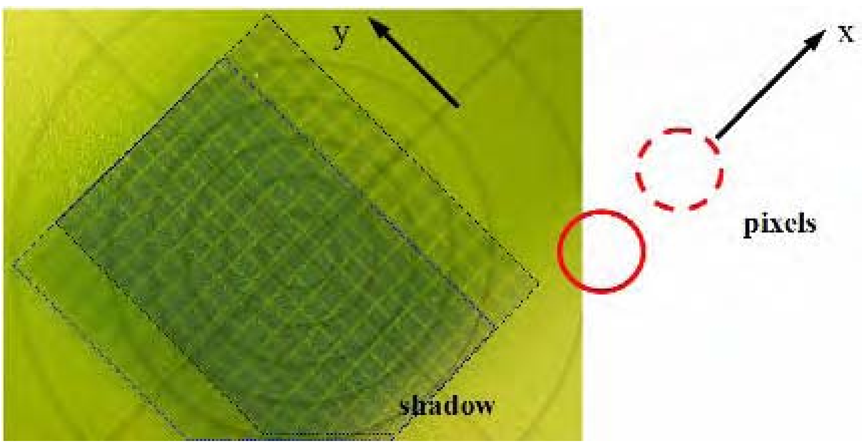


Figure 2: Activated pixels of an STN-LCD under directional illumination as "seen" by the receiver. The solid red circle indicates the field of measurement (FoM) for the normal receiver direction. The dashed red circle represents an FoM that is outside the core shadow where a lower contrast will be measured. This dislocation of the FoM with increasing receiver inclination is caused by the parallax induced by the LCD front-glass. The dashed areas mark the regions of the activated pixels and of the pixel shadow cast on the reflector.

Evaluation of the contrast of a reflective STN-LCD in the two arrangements shown in *Figure 1* yields the following values:

- setup 1 (directional illumination) $C_R = 12$
- setup 2 (multi-directional diffuse illumination) $C_R = 3$

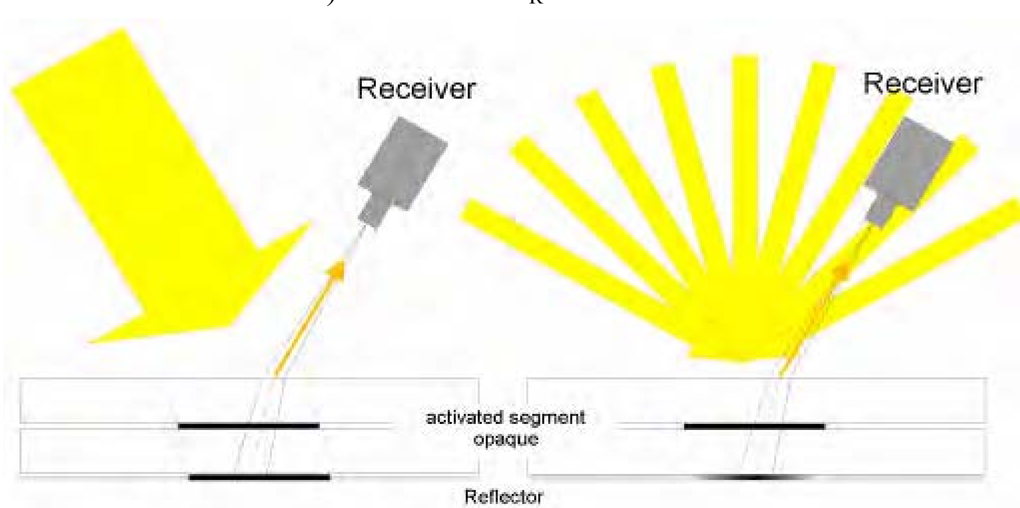


Figure 3: Formation of shadow on the reflector. Directional illumination produces a distinct deep shadow (left) while multi-directional diffuse illumination produces a week penumbra (right).

This difference of contrast values is caused by the nature of the shadows produced on the reflector of the LCD by the two illuminations schemes. The directed illumination produces a well-defined dark shadow while only a weak shadow without distinct boundaries is produced under multi-directional illumination. Since the reflector element that is located behind the field of measurement acts as "reflective light source" the contrast measured under directed illumination is higher than the contrast measured under multi-directional diffuse illumination. In other words, the light is modulated twice (on its way to the reflector and on its way to the receiver) by the activated LCD layer in the setup with directed illumination and thus the contrast becomes more pronounced. The effect of these shadows on the visual performance of reflective LCDs has been analyzed in detail by Berman in 1980 [8].

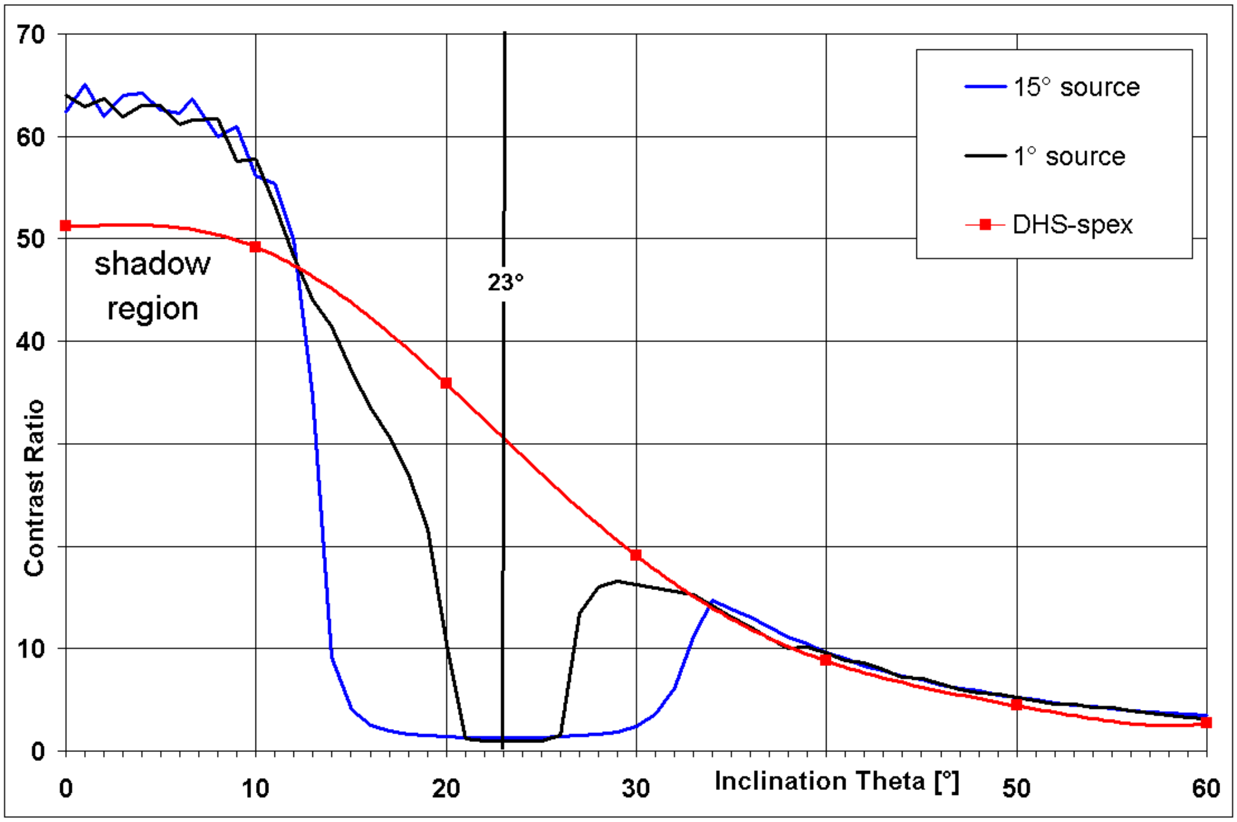


Figure 4: Contrast (luminance ratio) vs. angle of inclination of a reflective TN-LCD measured under directional illumination (1° and 15° source) and multi-directional diffuse illumination (spex: specular components excluded). Data and illustration from [9].

Figure 4 summarizes and illustrates the effect of two different illumination schemes on the contrast of a reflective LCD. A directional source illuminates the DUT from an angle of 23° (inclination from normal) with two different apertures (1° and 15° measured from the DUT). Multi-directional diffuse illumination without specular components (spex) is provided by a diffusing hemisphere (DHS). The contrast at the specular direction is dominated by surface reflections and is thus close to 1 (i.e. no contrast). With increasing angular distance from the specular direction the contrast increases and it assumes a maximum at the normal viewing direction ($\theta = 0°$). At this direction of the receiver the field of measurement is completely within the shadow cast by the activated (dark) segments.

The contrast measured under multi-directional diffuse illumination does not have a singularity at the specular direction, but due to the less pronounced shadow on the reflector the maximum of the contrast at $\theta = 0°$ is not as high as under directional illumination.

One question that might arise here is: under which conditions is the LCD observed in actual practical application situations? Only under a clear sky the special condition of purely directional illumination is approximated; in all other situations, especially indoors, there will be a mixture of directed and diffuse illumination components.

It can be concluded that the first setup for measuring the contrast of reflective LCDs under directional illumination represents a very special idealized situation, but produces high contrast values at large angular distances to the direction of light incidence (e.g. ≥30°) while the arrangement with multi-directional diffuse illumination represents a more realistic "worst case scenario" that naturally produces lower contrast values. Unfortunately, most manufacturers of LCDs do not specify in their data-sheets under which conditions the specified contrast has been measured, leaving the customer with a considerable uncertainty about the actual performance of the product.

While the approach with multi-directional diffuse illumination has been explicitly designed for evaluation of the electro-optical properties versus viewing-direction, which has shown to be an essential rating and characteristic for LCDs over 30 years, these variations cannot be measured under directed illumination [9, 10].

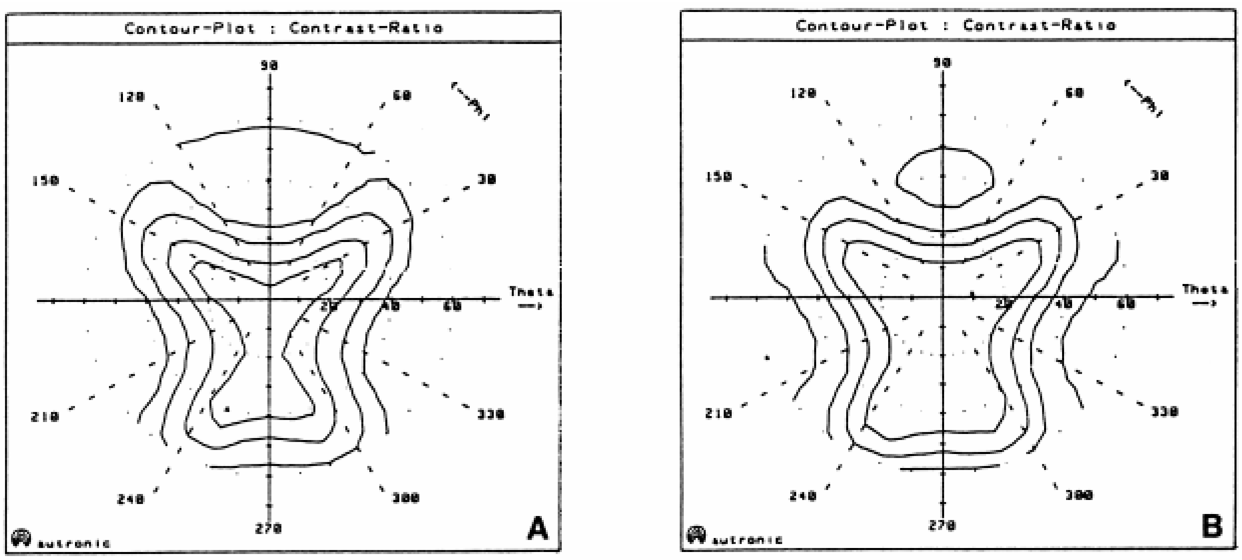


Figure 5: Contrast of a TN-LCD measured in transmissive mode of operation (left) and under multi-directional diffuse illumination (right). The intrinsic directional characteristics of the contrast of the LCD which is obvious in the transmissive mode can only be reproduced under multi-directional diffuse illumination in the reflective mode of operation [from 10].

The first TN-LCDs were small (some cm^2) and their electrodes were patterned in 7-segment layout for the display of numbers, sometimes with additional fixed symbols. In order to measure the contrast of such displays versus viewing direction the field of measurement had to be in the range of 0.1 mm and the positioning mechanism had to ensure that the location of that spot does not change with direction of observation. The realization of a mechanism with a tolerance of the intersection of all axes in the range of 50 µm was quite a challenge for the mechanical workshop. Moreover, there is a basic complication given by the parallax induced by the front glass of the LCD effecting a shift of the field of measurement with angle of inclination. Either this field has to be small enough to remain within the segment/symbol to be measured for all angles of inclination or the parallax-induced shift has to be compensated by a motorized XY-translation stage.

The optical appearance of the TN-effect us usually *achromatic* (i.e. not involving colors) and thus photometric detectors (*luminance meters*) were sufficient for characterization of their visual performance. Since most of the TN-LCDs were operated in the reflective mode, a special illumination device had to assure the illumination to be isotropic for measurements as a function of viewing direction. The realization of this device with a section of an integrating sphere (*diffusing hemisphere*) also was provided with a slit through the north-pole that has two functions: (1) making observation of the device under measurement possible; and (2) effectively suppressing specular surface reflections [9, 10].

Confusion on reflective contrast

Measurement and evaluation of the optical properties of reflective objects is not an easy task since the measured quantities are always comprising the effect of object, illumination and light measuring device and of the details of the geometry of the arrangement of all components [9]. Even though it was (and still is) not easy to make such measurements reproducible, no international standard has been created to provide assistance to those who have to carry out such measurements in their laboratories and to customers who have to make purchasing decisions based on e.g. contrast specifications provided in data-sheets.

Is it just a naive idea that an international standard could provide assistance in that case and remove confusion?

Why do we need standards?

In order to answer the question on the purpose of standards we first consider their nature: what is a standard supposed to be?

- A concrete example of an item or a specification against which all others may be measured (e.g. *International Prototype Kilogram and Meter*).
- Definitions of mechanical, electrical, data and other interfaces.
- Definitions of terminology, letter symbols, measurement and evaluation methods, etc.
- An agreed basis for communication of technical data.
- A well-defined basis for understanding between communicating parties in industry, commerce and daily life.

In the official words of the ISO (International Standards Organization) and the IEC (International Electrotechnical Commission) the objective and purpose of standards and the corresponding requirements are defined as listed below.

ISO / IEC Directives, Part 3: Drafting and Presentation of International Standards

The objective of a Standard is to define clear and unambiguous provisions in order to facilitate international trade and communication.

To achieve this objective, the Standard shall be as complete as necessary; consistent, clear and concise; and comprehensible to qualified persons who have not participated in its preparation.

According to these objectives an international standard for measurement and evaluation of LCDs in the reflective mode of operation would have been dearly required from the moment it became obvious that two measurement methods are actually practiced and that they produce very different results. An international standard would have been helpful in this case to establish a common base of communication and to remove the existing confusion.

This necessity has been recognized in 1995 by the *Presidents Advisory Committee for Future Technologies* of the IEC and standardization of measuring methods for reflective LCDs was advised as an important and urgent task to be completed (*see following page*).

INTERNATIONAL ELECTROTECHNICAL COMMISSION

TECHNICAL COMMITTEE NO. 47: SEMICONDUCTOR DEVICE

SUB - COMMITTEE NO. 47C:
OPTOELECTRONIC DISPLAY AND IMAGING DEVICES

PROPOSAL ON FPD BY PACT
~ COMMENTS OF SECRETARY/SC47C ~

1. Progress

Nov.1995 PACT (President's Advisory Committee of future Technology) submitted comments and recommendations on standardization of FPD.(See attached) The contents of the recommendations as follows:

Recommendations

1. A number of subjects in FPDs have been identified which are important and require standardization urgently. The IEC should start standardization of these subjects.
2. The first important and urgent is **reflective LCDs**.

Figure 6: Facsimile of the recommendation of the Presidents Advisory Committee for Future Technologies of the IEC to standardize metrology methods for reflective LCDs. In 1995 the TC110 was not yet established and the TC47/SC47C was responsible for "opto-electronic display devices".

A new work item of IEC TC110 WG2: Measurement Methods for reflective LCDs

This "new work item" is intended to include all possible setups, approaches and devices for measuring reflective LCDs as long as the details of the arrangements are sufficiently well characterized to assure the required reproducibility of the measurement setup, procedure and results.

The most comprehensive approach for evaluation of the reflective properties is based on the "*bi-directional reflectance distribution function, BRDF*" which had been introduced into the field of electronic display metrology in 1997 by Kelley and Becker [12, 13]. From BRDF data basically all special characteristics can be derived, but measurement of the BRDF requires some quite instrumental efforts.

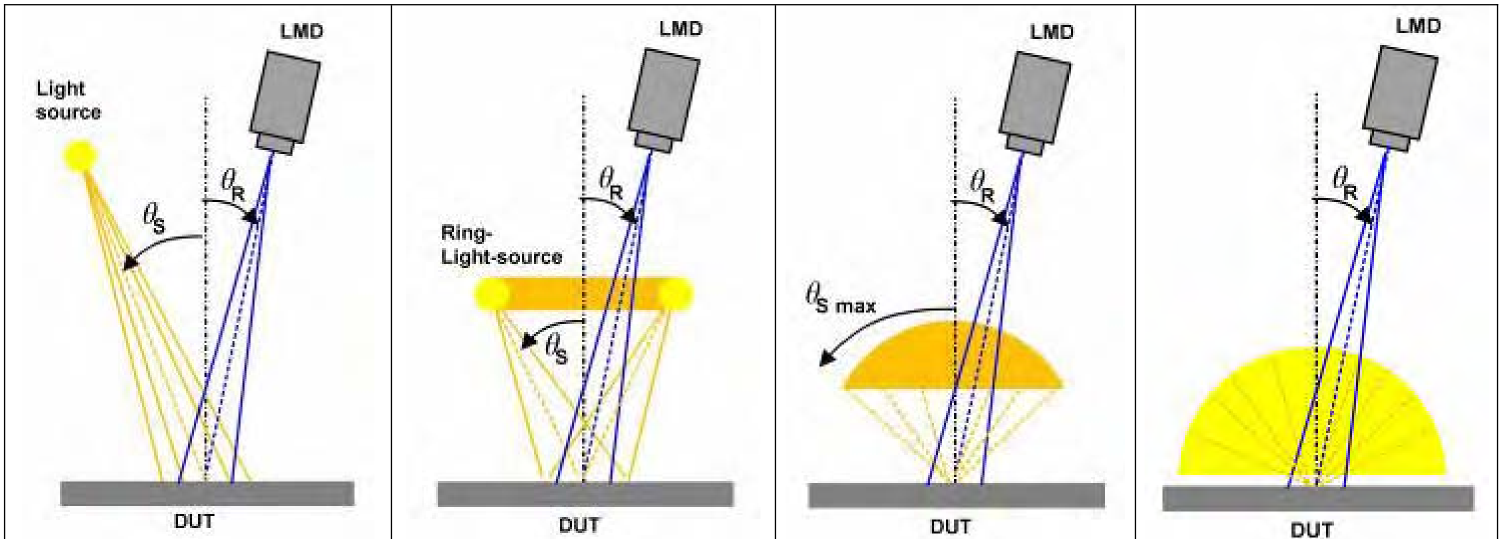
In order to limit the instrumental efforts, the new metrology standard under discussion introduces four standard measuring arrangements with different illumination schemes [11]:

- directional illumination,
- ring-light illumination,
- conical illumination,
- hemispherical illumination.

The first category comprises the DI approach described above, the ring-light illumination has been included for completeness (even though its practical value seems quite limited), the conical illumination scheme represents a practical realization of a multi-directional diffuse illumination with the maximum inclination of light incidence between 70° and 80° while the perfect hemispherical illumination can probably only be realized with integrating spheres which however are less compatible with the kinematics of directional scanning of the viewing cone.

In acknowledgement of the difficulties involved in all reflective measurements it must be emphasized here that measurement and evaluation of reflective LCDs as a function of the viewing direction is not trivial but possible. It is also no exotic or esoteric art, since it has been practiced, analyzed and improved since 1978. An excellent analysis of the sensitivities of reflection metrology with respect to various details of the geometry of the arrangement used for the measurements has been carried out and published by Ed Kelley [14]. This report again confirms the necessity of assessment and reporting of the details of the measurement setup to make the results comparable.

The proposal for this standard which is currently under discussion in the WG2 of the IEC TC110 seems explicitly intended to avoid any kind of privilege for existing measuring systems and devices in order not to distort fair technical and commercial competition. The proposal definitely is supposed to support all approaches, setups and instruments as long as they are specified sufficiently to allow reproducibility of the measurements.



Directional illumination	*Ring light illumination*	*Conical illumination*	*Hemispherical illumination*

Figure 6: Illustration of the four basic illumination schemes introduced in the proposal for the metrology standard for reflective LCDs, IEC 61747-6-2 under discussion. Only the arrangement with hemispherical illumination can be used for directional scanning of the viewing cone of the DUT.

Status and outlook

The new work item IEC 61747-6-2 "Measuring methods for liquid crystal display modules – reflective type" was proposed in December 2004 and the voting was closed in April 2005 with a positive result. Later in 2005 a first draft document was presented to the working group members. A committee draft was then circulated to the member states in January 2007 and received quite some comments from Japan and Germany indicating that there is still a lot of work to do in order to transform that CD into an international standard.

The status of the document as per July 2007 was CDM (committee draft for discussion at the next meeting) and the publication as an international standard is currently scheduled for December 2009. This period of time could be used beneficially in order to bring the working document into a good shape with consistent content and to adjust it for harmonization with other metrology standards (e.g. for PDPs and OLEDs) and with the measuring methods for transmissive LCDs.

May the wisdom be with the members of the working group and the decision-makers in the background to keep commercial privileges and industrial protection out of international standards in general and especially out of that for measurement of reflective LCDs.

References

[1] A. R. Kmetz, *Characterization and Optimization of Twisted Nematic Displays for Multiplexing*, SID'78 Digest, pp. 70-71

[2] P. Andrew Penz, *A figure of merit characterizing the anisotropic viewing properties of the twisted nematic LCD*, SID'78 Digest, pp. 68-69

[3] K. Fahrenschon, et. al., *Deformation of a pretilted nematic liquid crystal layer in an electric field*, Appl. Phys. B, 11, 1(1976), pp. 67-74

[4] R. Cremers et al., *A new method for characterization and evaluation of the optical appearance of reflective TN-LCDs*, Displays 1979 p. 12

[5] G. G. Barna, *Apparatus for optical characterization of displays*, Rev. Scientific Instruments, 47, 10(1976), pp. 1258-1260

[6] J. A. Castellano, *Liquid Gold, The Story of Liquid Crystal Displays and the Creation of an Industry*, 2005 World Scientific Publishing Co. Pte. Ltd.

[7] H. Kawamoto, *The History of Liquid-Crystal Displays*, Proc. IEEE, Vol. 90, No. 4, April 2002

[8] A. L. Berman, et. al, *The role of shadows in the viewability of TN-LCDs*, The Physics and Chemistry of Liquid Crystal Devices, Editor G. Sprokel, Plenum Press New York 1980

[9] M. E. Becker, J. Laur, J. Neumeier, *Electro-optical Characterization of Reflective LCDs*, SID 2001 Digest, pp. 322-325

[10] M. E. Becker, J. Neumeier, *Electro-Optical Properties of Reflective Positive-Contrast LCDs: How to Obtain Meaningful Measuring Results*, Proc. 11th IDRC 1991, p. 195-198

[11] M. E. Becker, *Standards and Metrology for Reflective LCDs*, SID'02 Digest, pp. 136-139

[12] E. F. Kelley, G. R. Jones, *Utilizing the BRDF to predict reflections from FPDs*, SID '97 Digest, pp. 831-848

[13] M. E. Becker, *Evaluation and Characterization of Display Reflectance*, SID '97 Digest, pp. 827-830

[14] E. F. Kelley, *Sensitivity of Display Reflection Measurements to Apparatus Geometry*, SID'02 Digest, pp. 140-143