SOCIETY FOR INFORMATION DISPLAY

APPLICATIONS SEMINARS

MAY 18-20, 1999
TUESDAY-THURSDAY
SAN JOSE CONVENTION CENTER
SAN JOSE, CALIFORNIA

SEMIANALYSE

APPLICATIONS

SID

APPLICATIONS SEMINARS

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APPLICATIONS SEMINAR

A-4:

Flat-Panel Display Measurements and Standards

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Summary

Display metrology as applied to flat-panel displays (FPDs) will be discussed. Topics include the importance of proper set-up, expected measurement uncertainty *vs.* repeatability, and problems in making accurate light measurements. The role played by measurement diagnostics is considered, and encouragement is given to employ such diagnostics routinely. A review of the status of international display standards will be provided.

***Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, U.S. Department of Commerce.**

Flat Panel Display Measurements and Standards

Because of the explosive growth of the demand for electronic displays and competition within the display industry, there is an increasing need for well-defined display metrology. Good metrology is needed to level the playing field, so to speak, not only within a particular display technology, but also across technologies. For example, we want to be able to compare the contrast of one display with the contrast of another display in a meaningful way and not wonder how the measurement was made. The parameters that characterize the display should not depend upon who measures the display (to within the limits of the uncertainty of the measurements). Those who incorporate displays into their equipment need to be able to specify what they want in such a manner that there will be no argument as to whether a display meets the specifications or not. Nobody wants surprises, and companies that do a good job of manufacturing should have the metrological backing to prove the quality of their products. All these concerns require unambiguous metrology. In this seminar, we discuss several aspects of display metrology. We then provide a list of many of the associated standards activities for your further reference.

Display Metrology

Characterization of the display depends upon how the display is configured. How the display is configured depends upon the task for which it is to be used. How well the measurements are made depends upon how well the measurements *can* be made in addition to the methods, equipment, and skills employed. Good metrology depends upon a realistic expectation of the instrumentation performance, a sensitivity to diagnostics, and an understanding of the limits of the measurement apparatus.

Display Standards

Display standards can contain several categories of specifications. They can specify what to measure, how to measure, how to check or correct the measurement, and the compliance limits of acceptability of a measurement result. Many standards concern themselves with having displays meet a certain minimum of performance. These are performance or compliance standards, and they often must deal with ergonomic and psychophysical results to set the criteria of acceptance. Often standards avoid a thorough discussion of how to measure parameters and how to establish a confidence in the measurement result. In the following pages we provide a partial listing and contact information for display standards and related activities.

A final note: The Video Electronics Standards Association (VESA) has undertaken a project to compile a comprehensive document to address the needs of the specification of quality display metrology. The VESA Flat Panel Display Measurements Standard (FPDM) document attempts to fill the gaps where other standards may have less to say. Much of the document specifies how to make measurements and how to diagnose the measurements you make. All of the material of this seminar plus a great deal more is contained within the FPDM. It contains numerous diagnostics in the Metrology Section. The Technical Discussion Section contains tutorial information on photometry, colorimetry, and other topics.

Disclaimer:

Certain commercial equipment, instruments, materials, systems, and trade names are identified in this paper in order to specify or identify technologies adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the systems or products identified are necessarily the best available for the purpose.

ANSI — American National Standards Institute

http://www.ansi.org/

ANSI HFES-100

Human Factors and Ergonomics Society (HFES)

Robert J. Beaton, Ph.D., CPE, Director, Displays and Controls Laboratory, Human Factors Engineering Center, 549 Whittemore Hall, Virginia Tech, Blacksburg, VA 24061-0118 USA, Phone: 540-231-8748, Fax: 540-231-3322, Email: bobb@vt.edu, Web: Office: http://bobb.dcl.vt.edu, Lab: http://www.dcl.vt.edu

ANSI Projection Standards IT7.227 and IT7.228

Photographic and Imaging Manufacturers Association, Inc. (PIMA) IT-7 Committee

Leon Shapiro, Chairman, NIDL, (609) 734-2527, lshapiro@sarnoff.com

Some other standards that may be of interest:

ANSI/SAE ARP 1782 Photometric and Colorimetric Measurement Procedures for Airborne Direct View CRT Displays

ANSI/SAE ARP 4102 Flight Deck Panels, Controls, and Displays (core document)

ANSI/SAE ARP 4102/7 Electronic Displays

ANSI/SAE ARP 4102/8 Flight Deck, Head-Up Displays

ANSI/SAE ARP 4032 Human Engineering Considerations in the Application of Color to Electronic Aircraft Displays

ANSI/SAE AS 8034 (R1989) Minimum Performance Standard for Airborne Multipurpose Electronic Displays

ANSI/SAE ARP 1068A Flight Deck Instrumentation, Display Criteria, and Associated Controls for Transport Aircraft

SAE ARP 1068B Flight Deck Instrumentation, Display Criteria and Associated Controls

ANSI/SAE ARP 1874 Design Objectives for CRT Displays for Part 25 (Transport) Aircraft

ANSI/SAE ARP 4067 Design Objectives for CRT Displays for Part 23 Aircraft

ANSI/SAE ARP 571C Flight Deck Controls and Displays for Communication and Navigation Equipment for Transport Aircraft

ANSI/SAE ARP 4155 Human Interface Design Methodology for Integrated Display Symbology

Publications of interest:

ANSI/NCSL Z540-2-1997 *U.S. Guide to the Expression of Uncertainty in Measurement*, (American National Standards Institute/National Conference of Standards Laboratories), first edition, October 9, 1997.

ASTM — American Society for Testing and Materials

http://www.ansi.org/

Publications of interest:

ASTM Standards on Color and Appearance Measurement, Fifth edition, 1996. Sponsored by Committee E-12 on Appearance. This is a wonderful reference to have.

E284-95a Standard Terminology of Appearance

E1392-90 Standard Practice for Angle Resolved Optical Scatter measurements on Specular or Diffuse Surfaces.

There are some newer versions available:

ASTM E1455-96a Obtaining Colorimetric Data from a Visual Display Unit Using Tristimulus Colorimeters

ASTM E1336-96 Obtaining Colorimetric Data From a Visual Display Unit by Spectroradiometry

ASTM E1682-96 Modeling the Colorimetric Unit Properties of a Visual Display

CIE — Commission Internationale de l'Eclairage

(International Commission on Illumination)

http://www.cie.co.at/cie/

TC2-42 Colorimetry of Displays

CIE Division 2 Web: http://nml.csir.co.za/~cie2

Dr. Andrew R. Hanson, Chair, also liaison officer to IEC/TC 100/PT 61966

Publications of interest:

CIE Publication No. 69, Methods of Characterizing Illuminance and Luminance Meters

CIE Publication 17.4, International Lighting Vocabulary (1989)

CIE Publication No. 44, Absolute Methods for Reflection Measurement

CIE Publication No. 46, A Review of Publications on Properties and Reflection Values of Material Reflection Standards

CORM — Council for Optical Radiation Measurements

http://www.corm.org

EIA — Electronic Industries Association

Bernie Aronson, Director of Technical Programs Components Group, Email: baronson@eia.org

http://www.eia.org/eng/default.htm

EIA JT-6 Committee on Color CRTs

Harry Swank, Chair, Thomson Consumer Electronics

1002 New Holland Ave., Lancaster, PA 17601

Phone: 717-295-2858, Fax: 717-295-6092, Email: swankh@tce.com

EIA JT-31 Committee on Optical Characteristics of Display Devices

George Ehemann, Chair, Thomson Consumer Electronics, 1002 New Holland Ave., Lancaster, PA 17601, Phone: 717-295-6216, Fax: 717-295-6092, Email: ehemanng@tce.com (Note:

Standards previously within the purview of the inactive JT-20 committee have been transferred to JT-31).

Here are some older CRT documents:
EIA TEP105 Series, Industrial Cathode-Ray Tubes Test Methods (Feb., 1981)
TEP116-C Optical Characteristics of Cathode Ray Tube Screens (Feb., 1993)
EIA TEB25 A Survey Of Data-Display CRT Resolution Measurement Techniques (June, 1985)
EIA TEP192 Glossary of Cathode-Ray Tube Terms and Definitions (Sept., 1984)
EIA TEB27 Relating Display Resolution and Addressability (Sept., 1988)
EIA TEB 24 Effect of Pulse Shape in Raster Dot Alpha-Numeric CRT Presentation on Spot Luminance and Luminance Distribution

EIAJ — Electronic Industries Association of Japan

www.eiaj.or.jp

Measuring Methods for Matrix Liquid Crystal Display Modules
See: www.eiaj.or.jp

IEC — International Electrotechnical Committee

http://www.iec.ch/

IEC/TC 100 Audio, Video and Multimedia Systems and Equipment
SC100C Audio, Video and Multimedia Subsystems and Equipment
WG6 Video imaging equipment and systems

PT 61947 Electronic Projection
Leon Shapiro, Leader, NIDL, (609) 734 – 2527, lshapiro@sarnoff.com

PT 61966 Colour Measurement and Management in Multimedia Systems and Equipment
Hiroaki Ikeda, Convener/Project leader, Chiba University
Email: ikeda@hike.te.chiba-u.ac.jp, Web: http://w3.hike.te.chiba-u.ac.jp/IEC/100/PT61966

IEEE — Institute of Electrical and Electronics Engineers

www.ieee.org
IEEE 1140-1994 IEEE Standard for the Measurement of Electric and Magnetic Fields from Video Display Terminals (VDT) from 5 Hz to 400 kHz

ISO — International Organization for Standardization

United States Technical Advisory Group to the ISO Subcommittee for Ergonomics of Human System Interaction, Jim Williams, Chair US TAG to ISO/TC159/SC4, Bellcore, Piscataway, NJ, phone 732-699-5491, fax 732-336-2605, ergojim@earthlink.net
http://www.iso.ch/
If it is difficult to connect to above site, try: http://133.82.181.177/ikeda/ISO/home.html

ISO documents are ordered through the member bodies for each participating country. For example, in the USA people would use ANSI (American National Standards Institute), 11

West 42nd Street, 13th floor, New York, N.Y. 10036, Telephone: + 1 212 642 49 00, Telefax: + 1 212 398 00 23, Internet: info@ansi.org.

ISO 13406 Part 2: "Ergonomic Requirements for the Use of Flat Panel Displays," ISO/TC 159/SC 4/WG 2, to be published (becoming a DIS at the time of this writing).

ISO 9241 series: Ergonomic requirements for office work with visual display terminals (VDTs). Contact ISO: www.iso.ch/infoe/guide.html for specific ordering information. Here are the three of interest to display metrologists (TC 159 / SC 4):

ISO 9241 Part 3 – Visual display requirements

ISO 9241 Part 7 – Requirements for display with reflection

ISO 9241 Part 8 – Requirements for displayed colours.

The following may be of some interest:

ISO 8341:1989 Photography, Slide projectors and filmstrip projectors -- Illumination test

ISO 9767:1990 Photography, Overhead projectors -- Methods for measuring and reporting performance characteristics

ISO 11314:1995 Photography, Projectors -- Image size/projection distance calculations

ISO 2910:1990 Cinematography, Screen luminance for the projection of motion-picture prints in indoor theatres and review rooms

ISO 12608:1996 Cinematography, Room and surround conditions for evaluating television display from telecine reproduction

Publication of interest:

ISO *Guide to the Expression of Uncertainty in Measurement,* (International Organization for Standardization), 1995.

NIDL — National Information Display Laboratory

NIDL Publication No. 171795-036, Display Monitor Measurement Methods
Under discussion by EIA Committee JT-20.

Part 1: Monochrome CRT Monitor Performance, Draft Version 2.0, July 12, 1995. NIDL Publication No. 171795-037, Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20.

Part 2: Color CRT Monitor Performance, Draft Version 2.0, July 12, 1995.

SAE — Society of Automotive Engineers

400 Commonwealth Dr., Warrendale, PA 15096-0001
http://www.sae.org/PRODSERV/STANDARD/standard.htm

ARP4260 — Photometric and Colorimetric Measurement Procedures for Airborne Flat Panel Displays.
Subcommittee of the SAE A-20 Aircraft Lighting Committee
http://www.sae.org/PRODSERV/STANDARD/standard.htm

SMPTE — Society of Motion Picture and Television Engineers

595 W. Hartsdale Ave., White Plains, NY 10607-1824 U.S.A,
tel: +1 914 761 1100 / fax: +1 914 761 3115, e-mail: smpte@smpte.org

Web: http://www.smpte.org/

SMPTE Standard 170M-1994 "Television – Composite Analog Video Signal – NTSC for Studio Applications"

Other SMPTE standards that may be of interest:
SMPTE RP 12-1997 Screen Luminance for Drive-In Theaters
SMPTE RP 185-1995 Classification of Projection Depth of Focus
SMPTE RP 167-1995 Alignment of NTSC Color Picture Monitors
SMPTE RP 145-1994 SMPTE C Color Monitor Colorimetry
SMPTE RP 166-1995 Critical Viewing Conditions for Evaluation of Color Television Pictures
SMPTE RP 27.1-1989 Specification for Operational Alignment Test Pattern for Television
SMPTE RP 38.1-1989 Specifications for Deflection Linearity Test Pattern for Television
SMPTE RP 27.5-1989 Specifications for Mid-Frequency Response Test Patterns for Television
SMPTE RP 133-1991 Specifications for Medical Diagnostic Imaging Test Patterns for Television Monitors and Hard Copy Recording Cameras
SMPTE RP 94-1993 Gain Determination of Front Projection Screens
SMPTE RP 95-1994 Installation of Gain Screens
SMPTE 196M-1995 Motion -Picture Film -Indoor Theater and Review Room Projection - Screen Luminance and Viewing Conditions
SMPTE RP 98-1995 Measurement of Screen Luminance in Theaters
SMPTE RP 51-1995 Screen Luminance and Viewing Conditions for 8-mm Review Rooms
SMPTE RP 59-1995 Color and Luminance of Review Room Screens for Viewing Motion-Picture Materials Intended for Slides or Film Strips

VESA — Video Electronics Standards Association

www.vesa.org

FPDM — Flat Panel Display Measurements Standard
Edward F. Kelley, Chair, NIST, Tech. A53, Gaithersburg, MD 20899, USA
Phone: 301-975-3842, Fax: 301-926-3534, Email: kelley@eeel.nist.gov
Michael D. Grote, Vice Chair, NIDL (National Information Display Laboratory)
Phone: 609-734-2506, Email: mgrote@sarnoff.com

VESA has been working on several FPD interface standards that may be of interest.

Other Publications of Interest:

Günter Wyszecki and W. S. Stiles, *Color Science: Concepts and Methods, Quantitative Data and Formulae*, 2nd Edition (1982, John Wiley & Sons). This is a classic reference work packed with information.

Peter A. Keller, *Electronic Display Measurement: Concepts, Techniques, and Instrumentation* (John Wiley & Sons in association with the Society for Information Display, 1997).

Flat-Panel Displays and CRTs (Van Nostrand Reinhold, New York, 1985) Lawrence T. Tannas, Jr., editor,

Yoshihiro Ohno, *Photometric Calibrations*, NIST Special Publication 250-37, U.S. Department of Commerce, National Institute of Standards and Technology, July 1997. This publication

contains the details on how calibrations are made in photometry and describes the subtleties in the use of the instrumentation with a complete uncertainty analysis.

Barry N. Taylor and Chris E. Kuyatt, *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, 1994 Edition.

Barry N. Taylor, *Guide for the Use of the International System of Units (SI)*, NIST Special Publication 811, 1995 Edition.

Some Abbreviations & Acronyms Associated with Display Industry:

Some web sites for finding acronyms:

http://www.onelook.com/
http://www.mtnds.com/af/
http://www.ict.etsi.fr/abrev.htm
http://www.techweb.com/encyclopedia/
http://www.ucc.ie/info/net/acronyms/acro.html
http://www.sematech.org/member/division/its/acronyms/acr_menu.htm
http://userpage.fu-berlin.de/~oheiabbd/veramain-e.cgi
http://www.sbri.com/a.htm

To find a national laboratory in most countries see: http://www.nist.gov/oiaa/national.htm

ACATS .....Advisory Committee on Advanced Television Service (advisory committee created by the FCC in 1987)
AEA .....American Electronics Association
ALARA.....as low as reasonably achievable
AMLCD .....active matrix liquid crystal display
ANSI .....American National Standards Institute
ARPA.....Advanced Research Projects Agency (formerly DARPA)
ASTM .....American Society for Testing and Materials
ASS .....Swedish Nation Board of Occupational Safety and health
ATSC .....Advanced Television Systems Committee
ATTC .....Advanced Television Test Center (created by broadcasting companies and industry organizations in1988 to test proponent advanced television transmission systems. Alexandria, VA)
ATV .....advanced television
B-ISDN .....Broadband Integrated Services Digital Networks
BIPM.....Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
BRDF .....bidirectional reflectance distribution function
BSDF .....bidirectional scattering distribution function
BTDF .....bidirectional transmittance distribution function
CATV.....cable TV
CCD .....charge coupled device
CCIR .....International Radio Consultative Committee (an organ of the International Telecommunication Union charged with studying technical and operating questions relating to radio services, including broadcasting, and issuing recommendations on the questions)

CCITT.....International Telephone and Telegraph Consultative Committee (an organ of the International Telecommunications Union charged with studying and issuing recommendations on technical, operating and tariff questions relating to telecommunications services other than radio communications services)
CCPR .....Consultatif Comité de Photométric et Radiométrie (Consultative Committee of Photometry and Radiometry)
CCT.....correlated color temperature
CD .....committee draft
CEN.....Comité Européen de Normalisation (European Standards Committee)
CENELEC...European Committee for Electrotechnical Standardization
CGPM .....Conférence Générale des Poids et Mesures (General Conference of Weights and Measures)
CIE .....Commission Internationale de l'Eclairage (International Commission on Illumination)
CIPM.....Comité International des Poids et Mesures (International Committee for Weights and Measures)
COHRS .....Committee on High Resolution Systems
CORM.....Council for Optical Radiation Measurements
CSF .....contrast sensitivity function
CSL .....Computer Standards Laboratory
DAB .....digital audio broadcasting
DARPA.....Defense Advanced Research Projects Agency
DIN .....Deutsches Institut für Normung (German Institute for Standardization)
DIS .....draft international standard
DPI .....dots per inch
DSRC .....David Sarnoff Research Center
DUT .....display under test
EC .....European Community
EEC.....European Economic Community (often use EC above as substitute)
EFTA.....European Free Trade Association
EIA.....Electronic Industries Association
EIAJ .....Electronic Industries Association of Japan
EL.....electroluminescent display
ESF.....edge spread function
FED .....field emission display
FCC.....Federal Communications Commission
FPD .....flat panel display
FPDM.....Flat Panel Display Measurements Standard (VESA)
HDTV .....high definition television
HRI.....high resolution imaging
HRIS .....high resolution information systems
IEEE.....Institute of Electronics and Electrical Engineers
IEC.....International Electrotechnical Commission
ISO .....International Organization for Standardization
IS&T .....Society for Imaging Science and Technology
ITU.....International Telecommunication Union (a specialized United Nations agency)

JND .....just noticeable difference
JT.....joint technical committee
LCD.....liquid-crystal display
LMD.....light measuring device (in VESA FPDM)
LSF.....line spread function
MAC .....Multiple Analog Component (the family of standards proposed by the EC for television transmission in EC member countries)
MPCD .....mean perceptible color difference
MPR .....Swedish National Board for Measurement and Testing
MTF .....modulation transfer function
MUSE .....Multiple Sub-Nyquist Sampling Encoding System (Japanese HDTV system)
NAB .....National Association of Broadcasters
NIDL.....National Information Display Laboratory (at DSRC)
NIST.....National Institute of Standards and Technology (USA)
NPL.....National Physical Laboratory (UK)
NRC .....National Research Council (Canada)
NRLM.....National Research Laboratory of Metrology (Japan)
NTIA.....National Telecommunications and Information Administration
NTSC .....National Television System Committee
OSTP.....Office of Science and Technology Policy (part of the Executive Office of the President)
OTF .....optical transfer function
PIMA.....Photographic and Imaging Manufacturers Association
PD .....plasma display
PSF.....point spread function
PT.....project team
PTB .....Physikalisch-Technische Bundesanstalt (Federal Physical Technical Institute [Germany])
SAE.....Society of Automotive Engineers
SI.....Systéme International d'Unités (International System of Units)
SID .....Society for Information Display
SMPTE.....Society of Motion Picture and Television Engineers
SPIE .....International Society for Optical Engineering (Society of Photo-Optical Instrumentation Engineers)
SSI.....Swedish National Institute of Radiation Protection
STN.....super twisted nematic (liquid crystal)
TAG .....technical advisory group
TC .....technical committee
TEPAC.....Tube Engineering Panel Advisory Council (for EIA)
TEB.....TEPAC Engineering Bulletin
TEP .....Tube Engineering Panel
TFT .....thin film transistor
TN .....twisted nematic (liquid crystal)
USDC.....United Sates Display Consortium
USNC.....US National Committee of the IEC
VESA .....Video Electronics Standards Association (vee'-suh)

VDT .....video display terminal
VDU.....video display unit
WG.....working group

Other Websites of Interest:

http://www.osa.org/	Optical Society of America
http://www.spie.org/	International Society for Optical Engineering
http://optics.org/	Photonics Resource Center (SPIE)
http://www.imaging.org/	Society for Imaging Science and Technology (IS&T)
http://www.sid.org/	Society for Information Display
http://www.ieee.org/	Institute of Electrical and Electronic Engineers
http://www.nist.gov/	National Institute of Standards and Technology
http://physics.nist.gov/Divisions/Div844/div844.html	Optical Technology Division, NIST
http://www.boulder.nist.gov:/div815/	Optoelectronics Division, NIST
http://www.eeel.nist.gov/811/eitg/eit_docs/fpdlab.html	FPD Lab, NIST

Flat Panel Display Measurements and Standards

SID99 Applications Seminar

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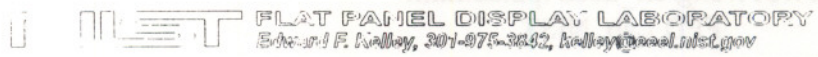


FPD Measurements and Standards

- **Display Metrology**
  - *Task Dependent Setup*
  - *Measurement Expectations*
  - *Measurements and Diagnostics*
  - *Tips & Things*
- **Display Standards**
  - *Partial Listing & Contact Information*
  - *VESA FPDM*

Where possible the information contained in this seminar is linked to the FPDM via brackets and section number, e.g., [FPDM A102] .

Task-Dependent Setup

- **Proper setup depends upon display task.**
  - *How will the display be used?*
  - *What environment (ambient, surround)?*
  - *Are there manufacturing setup specifications?*
  - *Gray scales near black and near white are often useful, but may not be sufficient. [FPDM 301-3A]*
  - *Might also try a face instead of a scene.*

*This image was provided courtesy of Autodesk, Inc. © 1996 Autodesk, Inc.

Task-Dependent Setup, Cont.

- **Setup conditions should remain fixed.**

  During series of measurements the task-specific setup conditions should not be changed to improve any single measurement, unless the task calls for such changes. [FPDM 301-2E, 305-3]

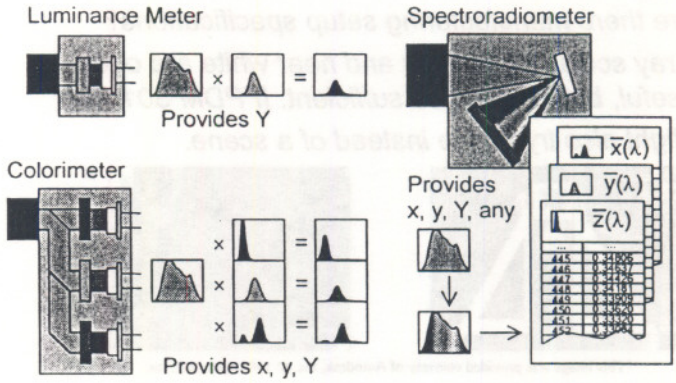
- **Warm-up time may be needed.**

  During the warm-up of the display is a good time to examine the display for defects and problems. Try out many different patterns and images suitable to the intended display task. [FPDM 301-2D]

Measurement Expectations

Devices

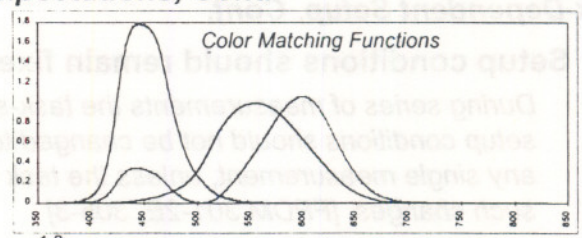
Colorimeter, spectroradiometer, luminance meter, illuminance meter, 2D array devices…[FPDM A103]

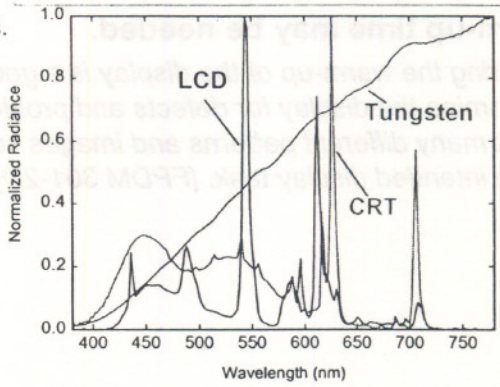


Measurement Expectations, Cont.

Devices, Cont.

Small errors in the color matching functions can affect narrow-band source measurements more than broad-band source measurements.



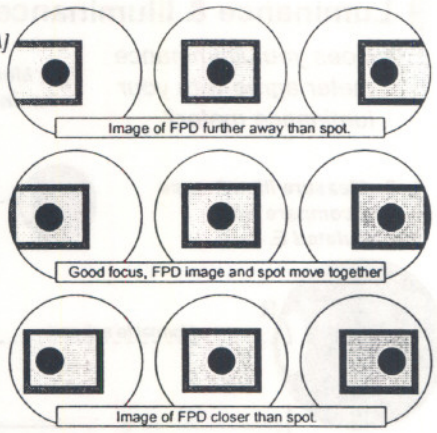


Measurement Expectations, Cont.

Viewport Device Focusing

Focus on object being measured. [FPDM A103-3A]

Use parallax method if uncertain: Focus eyepiece on spot. Then move your eye slightly back and forth (by slightly rotating your head) and see if the image and the measurement spot stay together. Change the focus of the main instrument lens until they appear to move together.

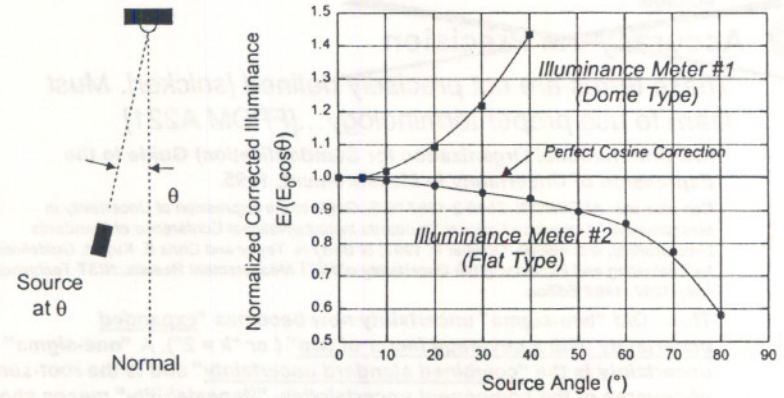


Measurement Expectations, Cont.

Illuminance Meter — Cosine Corrected?

For small source at θ, illuminance goes as cosθ.

If illuminance meter is cosine corrected, E/cosθ should be constant. Should know if it is not.

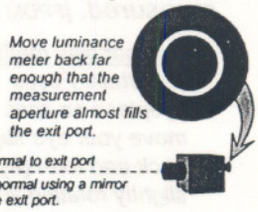


Example ONLY! Don't lift these data and use elsewhere.

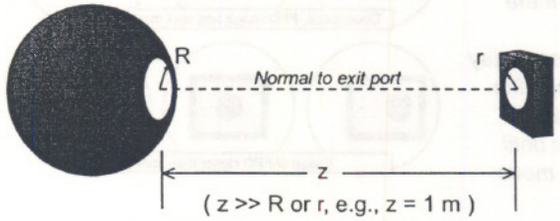
Measurement Expectations, Cont.

Luminance & Illuminance Meter Comparison

- *Does your illuminance meter agree with your luminance meter?*
- ***1. Measure luminance***



- ***2. Measure illuminance and compare with calculated E.***



(z >> R or r, e.g., z = 1 m)

Exit port area $A = \pi R^2$ assuming it is round.

$$E = \frac{A\,L}{(z^2 + R^2 + r^2)} \quad [\text{in lx}]$$

- *Reflections from surrounding objects must be carefully eliminated.*
- *Accurate measurement of exit port area is VERY important.*

Measurement Expectations, Cont.

Colorimetry vs. Electronics:

We are NOT measuring voltages. Colorimetry (and photometry) is not as precise—it is more like trying to measure an electric field than a voltage.

~~Accuracy vs. Precision~~

These terms are not precisely defined [snicker]. Must learn to use proper terminology…[FPDM A221]

ISO (International Organization for Standardization) Guide to the Expression of Uncertainty in Measurement, 1995.

Can also see: ANSI/NCSL Z540-2-1997 "U.S. Guide to the Expression of Uncertainty in Measurement," (American National Standards Institute/National Conference of Standards Laboratories), first edition, October 9, 1997; or Barry N. Taylor and Chris E. Kuyatt, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, NIST Technical Note 1297, 1994 Edition.

Thus: Old "two-sigma" uncertainty now becomes "expanded uncertainty with a coverage factor of two" (or "k = 2"). A "one-sigma" uncertainty is the "combined standard uncertainty" and is the root-sum-of-squares of the component uncertainties. "Repeatability" means shot-to-shot precision. "Reproducibility" means configuration-to-configuration precision.

Measurement Expectations, Cont.

- **Measurement Uncertainty vs. Repeatability**
  - ***Photometry:***
    - *No reliable standard sources exist to enable 0.1 % or less calibration uncertainty ("uncertainty" assumes ±).*
      National Lab (e.g. NIST) can do about 0.8 % (k=2) uncertainty.
      Secondary calibration might be 2 % (k=2).
      Delivered instrument guarantees 4 % or so (k=2) for long term.
    - *Thus, a 4 % measurement uncertainty might be expected when comparing luminance (illuminance) results with others.*
    - *The luminance (illuminance) repeatability can be smaller than 1/10 the measurement uncertainty (≤ 0.5 % often 0.1 %).*

Measurement Expectations, Cont.

Measurement Uncertainty vs. Repeatability, Cont.

- ***Colorimetry:***
  - *Chromaticity coordinates are based on ratios of tristimulus values. If detector is linear and has the proper spectral response, the chromaticity-coordinate measurements can be less uncertain than the luminance measurement*
  - *A ±0.005 measurement uncertainty might be expected when comparing chromaticity coordinate results (tungsten-halogen source may do better).*
  - *The chromaticity coordinate repeatability will probably be about ±0.002 or less.*

Measurement Expectations, Cont.

- **How Many Measurements Are Needed?**
  - *Try it and see!*

    Take seven measurements of a white screen, calculate the mean and standard deviation. If the standard deviation is about the same size as the repeatability, one measurement should be adequate. As long as the uncertainty of measurement is much greater than the repeatability, we can feel comfortable with making single measurements. [FPDM 301-2K]
  - *Repeat whenever there is a question.*

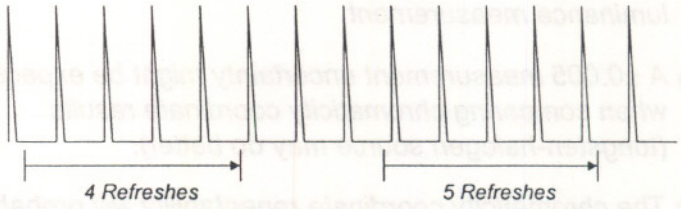
    If you wonder about any other color or level, repeat the above with the new color.
  - *Watch for short integration times.*

    When a short measurement time interval is used with a pulsed (scanned) light source (some displays) you don't always capture the same number of frames unless the detector is synchronized with the display. (See next slide for an example.)

Measurement Expectations, Cont.

- **Short Integration Times — Possible Errors from Refresh of Screen**

  If screen refreshes (as with a CRT) and it is bright so that the detector uses a short integration time can get measurement errors from the light of ±1 frame. Average many measurements or use good (and calibrated) neutral density filter to reduce luminance.

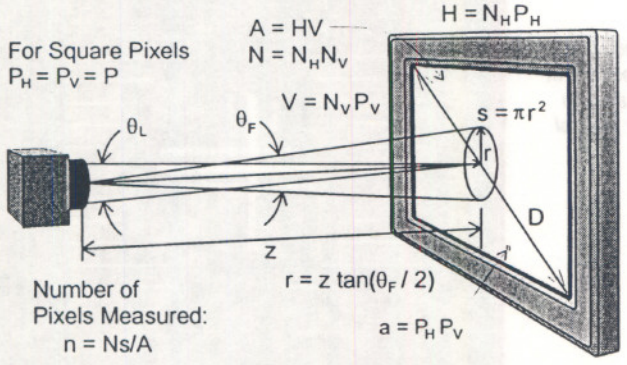


Same measurement window in both cases, but depending upon when the measurement is made, up to a 20% (or 25%) deviation can be seen in this case.

Measurement Expectations, Cont.

Subtense of Detector & Region Measured

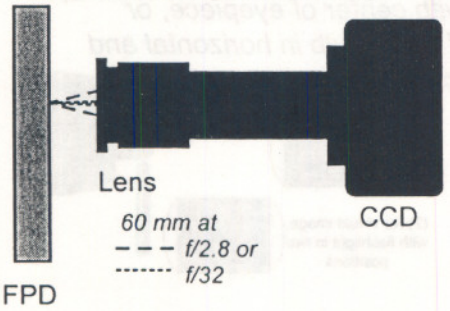
Be aware of rays of light contributing to the signal. Some displays have a viewing-angle sensitivity, and we can inadvertently measure what our eyes don't see. [FPDM A102-1]

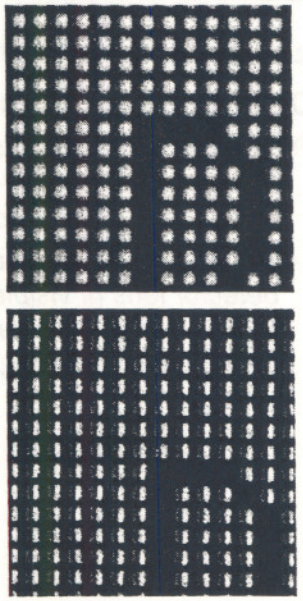


Measurement Expectations, Cont.

Subtense of Lens a Factor

Top photo at f/2.8 gathers light from many directions. Bottom photo at f/32 is more the way the eye sees things. (Lens f# = f/D=focal-length/diameter: At f/2.8 f=60 mm lens has D=21 mm whereas at f/32 D=1.9 mm.) Diagram is approximately to scale. We must be concerned about just what the detector is seeing and measuring.

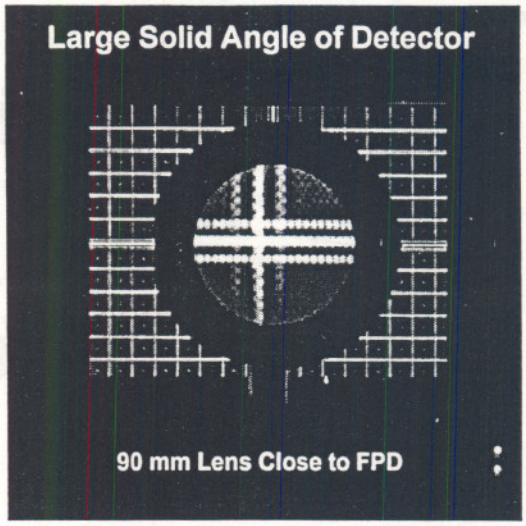




Measurement Expectations, Cont.

Subtense of Lens a Factor , Cont.

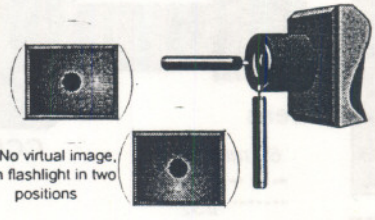
Note how much lighter the black pixels are at the top compared to the bottom or central regions.



Measurement Expectations, Cont.

- **Determination of Screen Normal**
  - *±1° is sloppy — that is about the angular width of your thumbnail with an out-stretched arm, twice the angular width of the sun or moon. Try for ±0.3° (or better).*
  - *Methods to find normal: (1) aligning virtual image of detector lens (if visible) with center of eyepiece, or (2) centering reflection of small bulb in horizontal and vertical (if not visible), etc.*

(1) Visible virtual image of detector



(2) No virtual image, with flashlight in two positions

  - *Note: Not all screens should be measured at normal. It depends upon design and task.*

Measurements and Diagnostics

- Veiling Glare
- Small Area Measurements
- Linearity Diagnostics Using NDFs
- Color Diagnostics Using IFs
- Temporal Diagnostics
- Array Detector Problems
- Projection Display Measurements
- Reflection Measurements

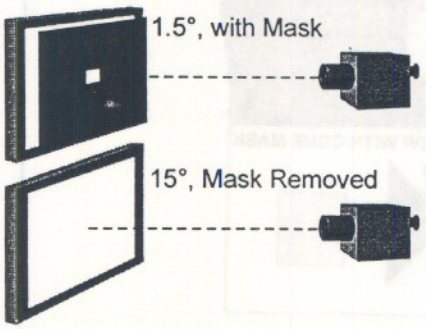
Measurements and Diagnostics, Cont.

Veiling Glare

- **Veiling Glare Can Affect Simple Measurements**

  Comparison of two identical luminances having different angular sizes.

  Same screen with & without mask (1.5° or 15° angular diameter of white area from lens of detector)



Increase with larger white area:

4.8 % — Instrument #1

0.4 % — Instrument #2

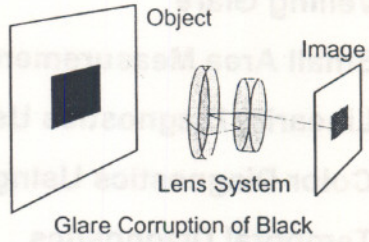
1.3 % — Instrument #3

Measurements and Diagnostics, Cont.

Veiling Glare, Cont.

- **Veiling glare corrupts black & mixes colors.**

Any pattern can be significantly corrupted by veiling glare in the instrument — reflections and scattering of light from other parts of the pattern into the region being measured. Full-screen luminances of colors can be affected, but when multiple colors are present, mixing can occur.



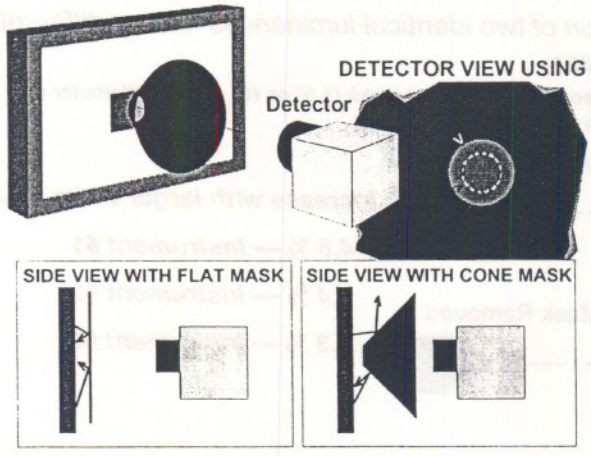
Glare Corruption of Black

- **Eye sees high contrast, instrument measures low contrast—trust your eye.**

Measurements and Diagnostics, Cont.

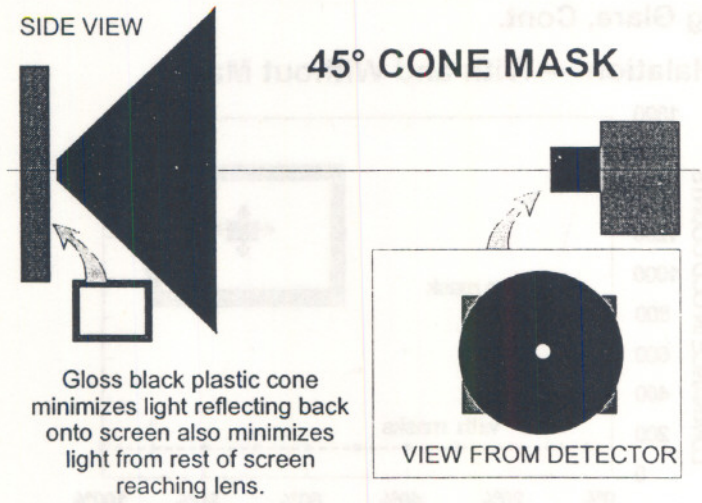
Veiling Glare, Cont.

- **Use of Masks — Flat and Cone**



Measurements and Diagnostics, Cont.

Veiling Glare, Cont.



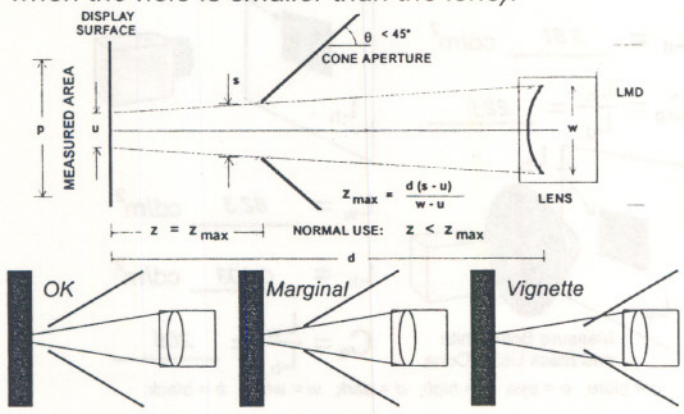
Gloss black plastic cone minimizes light reflecting back onto screen also minimizes light from rest of screen reaching lens.

Measurements and Diagnostics, Cont.

Veiling Glare, Cont.

- **Avoid Vignette (vin-yet´) from Mask**

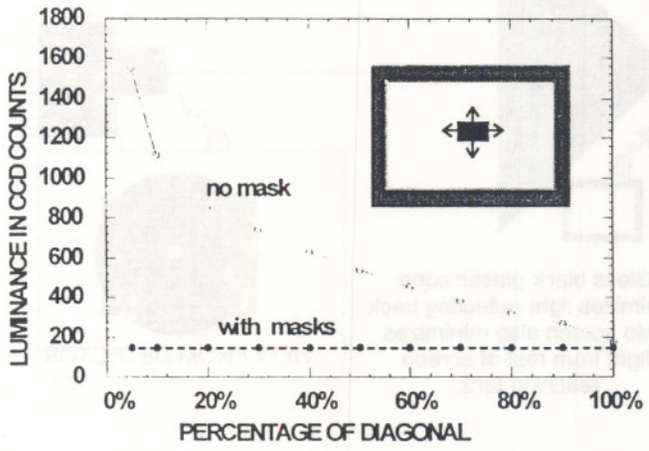
  Keep in mind that if the mask is too close to the lens it can interfere with the measurement (especially when the hole is smaller than the lens).



Measurements and Diagnostics, Cont.

Veiling Glare, Cont.

- Halation — With and Without Masks



Measurements and Diagnostics, Cont.

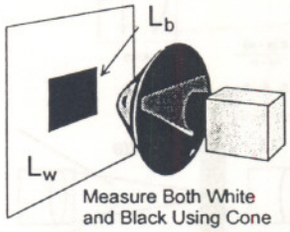
Veiling Glare, Cont.

- Example Using Cone Mask

L_h = *87.3* cd/m^2

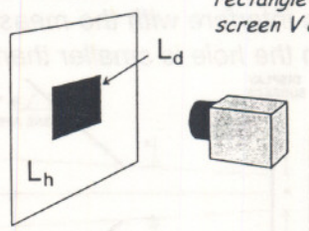
L_d = *3.81* cd/m^2

$C_g = \frac{L_h}{L_d}$ = *22.9*



Measure Both White and Black Using Cone

Used small rectangle 5% screen V & H



L_w = *82.3* cd/m^2

L_b = *0.403* cd/m^2

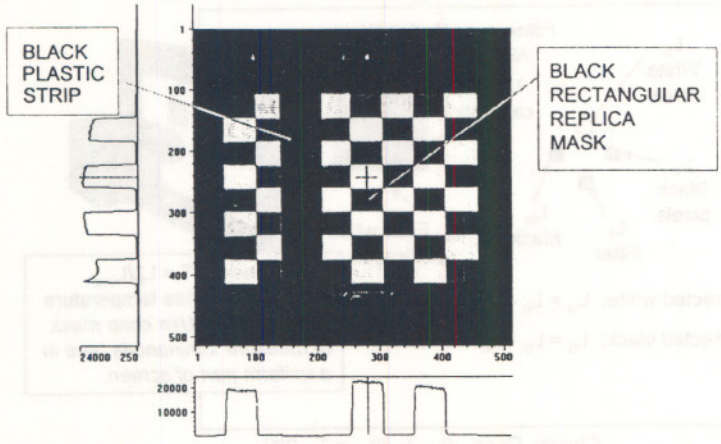
$C_e = \frac{L_w}{L_b}$ = *205*

g = glare, e = eye, h = high, d = dark, w = white, b = black

Measurements and Diagnostics, Cont.

Small Area Measurements

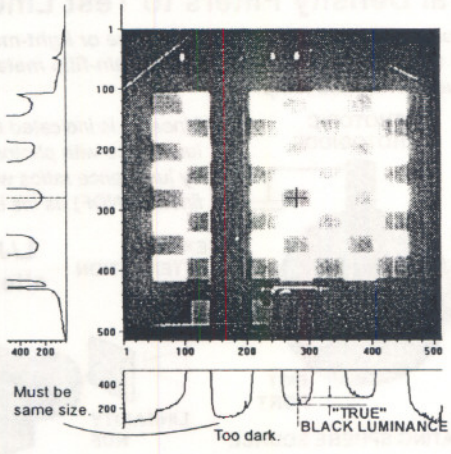
- **Replica Masks**



Measurements and Diagnostics, Cont.

Small Area Measurements, Cont.

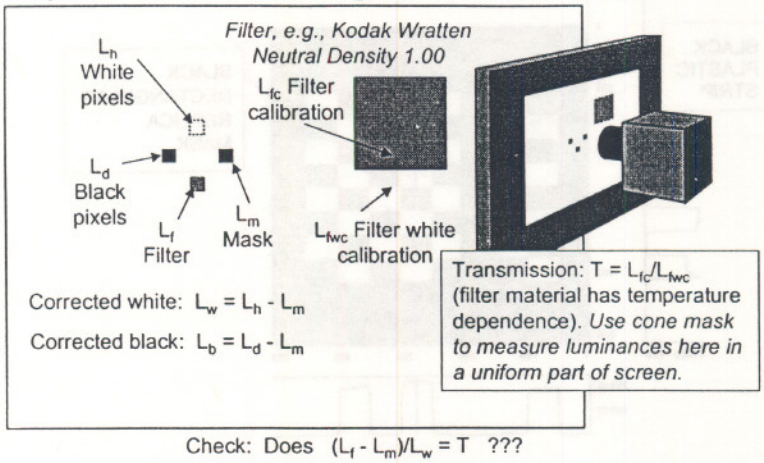
- **Replicas, Same Size As Black Region**
  - *Replica masks must be close to (±10 %) the size of the black area to be measured.*
  - *It is often a good idea to check your measurements using a NDF (neutral density filter) replica mask (at same T).*



Measurements and Diagnostics, Cont.

Small Area Measurements, Cont.

Replica Mask with Diagnostic Filter Mask



Check: Does $(L_f - L_m)/L_w = T$???

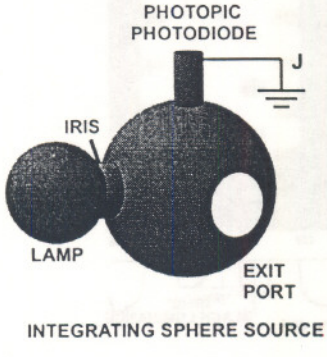
If so, measurement is probably good. (At least a lot better than if we didn't do anything!)

Measurements and Diagnostics, Cont.

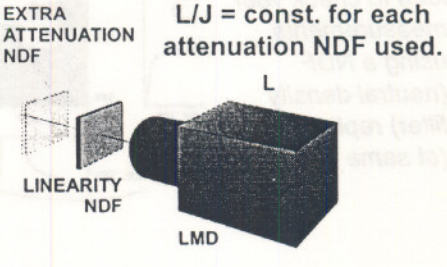
Linearity Diagnostics Using NDFs

Neutral Density Filters to Test Linearity

The color of the light should not change or light-measuring device (LMD) will report non-linearities. Use thin-film metallic NDFs and an aperture-controlled lamp.



Linearity is indicated by ratio of luminance with photodiode output (also by luminance ratios with and without the linearity NDF) as iris is adjusted.

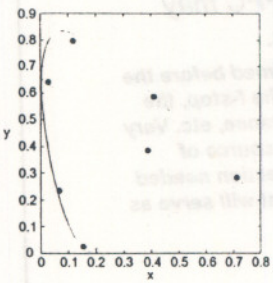


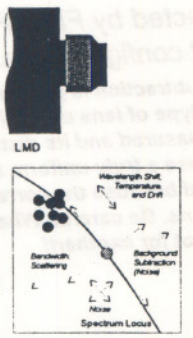
Measurements and Diagnostics, Cont.

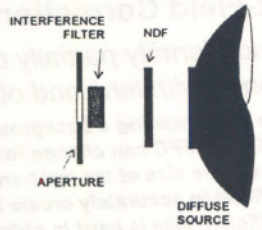
Color Diagnostics Using IFs

Interference Filters Test Color Measurement

Assuming white point calibration is accurate, the nearness of the (x,y) of narrow-band interference filters to the spectrum locus provides an indication of instrument's accuracy within the spectrum locus.





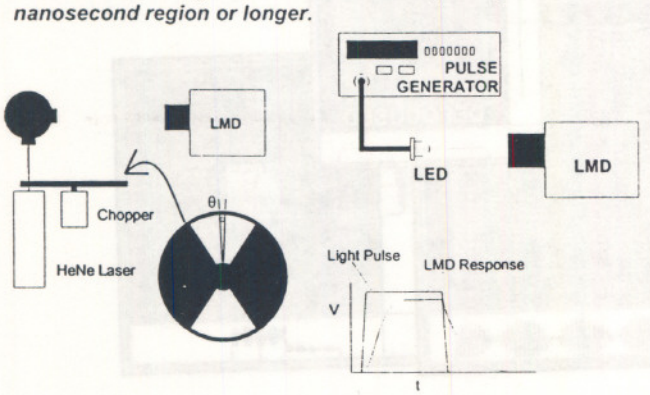


Measurements and Diagnostics, Cont.

Temporal Diagnostics

Response-Time Measurement

Use chopper and laser into inexpensive integrating sphere for submillisecond region. Use fast LED and pulse generator for ten nanosecond region or longer.



Measurements and Diagnostics, Cont.

Array Detector Problems

- **Photopic Response**

  Sensitivity to IR can seriously corrupt what was intended to be a luminance measurement.

- **Flat-Field Correction**

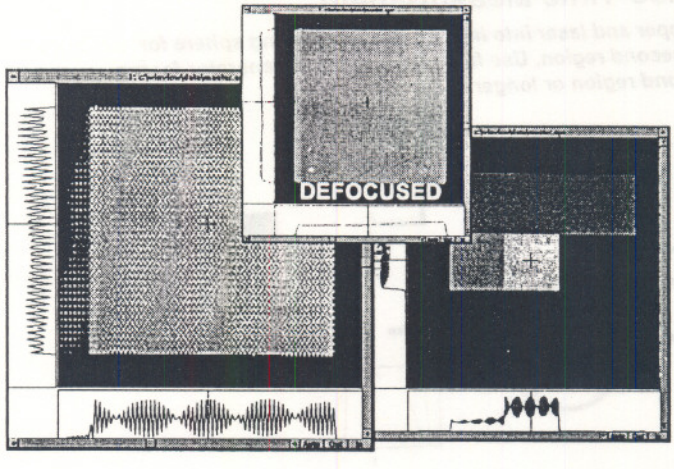
  Nonuniformity partially corrected by FFC. FFC may change with lens and object configurations.

  We are assuming a background subtraction is performed before the FFC. The FFC can change for the type of lens used, the f-stop, the focus, the size of the light-area measured and its distance, etc. Very difficult to accurately create because a truly uniform source of sufficient size is hard to obtain and because the correction needed can change so much with conditions. Be careful. What will serve as a FFC for one configuration may not for another!!

Measurements and Diagnostics, Cont.

Array Detector Problems, Cont.

- **Spatial Aliasing (Moiré Patterns)**

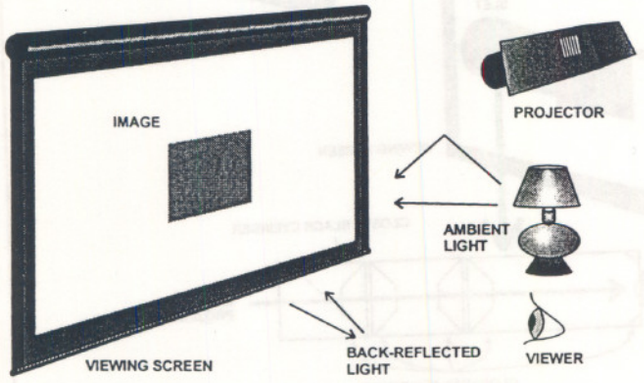


Measurements and Diagnostics, Cont.

Projection Display Measurements

Accounting for Stray Light

Projector should not be blamed for the less than perfect viewing conditions of the screen and room.

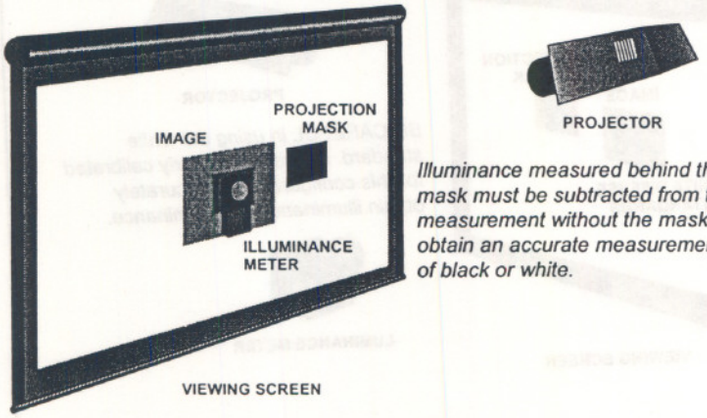


Measurements and Diagnostics, Cont.

Projection Display Measurements, Cont.

Accounting for Stray Light in Room

Use a projection mask (wider than the lens diameter) placed from 35 cm to 60 cm from the screen. Objects in room and room walls reflect light from the white screen back into black area. This can be a serious corruption of the black even in a darkroom and even using a black screen!



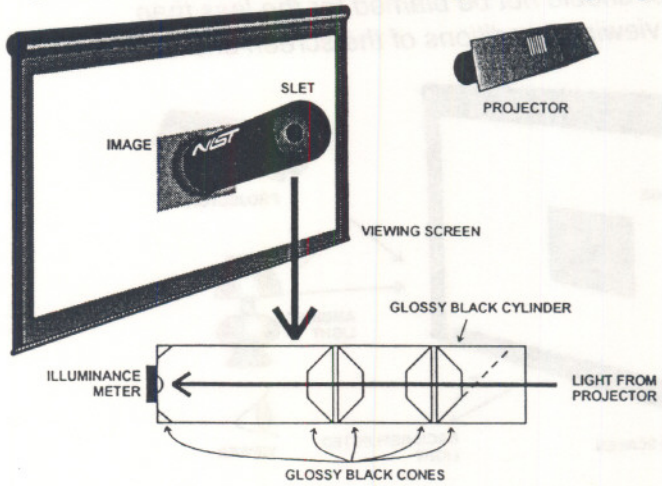
Illuminance measured behind the mask must be subtracted from the measurement without the mask to obtain an accurate measurement of black or white.

Measurements and Diagnostics, Cont.

Projection Display Measurements, Cont.

Stray-Light Elimination Tube

Can permit accurate measurements even in high-ambient lighting.

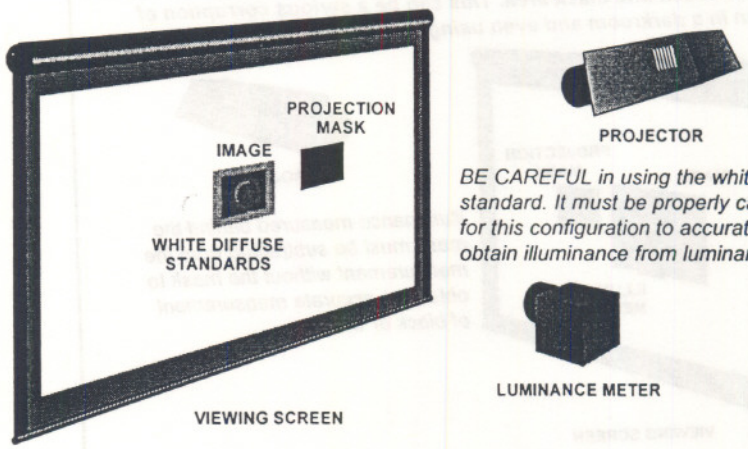


Measurements and Diagnostics, Cont.

Projection Display Measurements, Cont.

Making Luminance Measurements

Screen gain is very directional. Can avoid screen effects by using calibrated diffuse white standard and converting to illuminance.



BE CAREFUL in using the white standard. It must be properly calibrated for this configuration to accurately obtain illuminance from luminance.

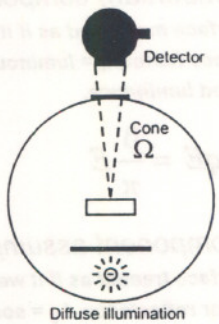
Measurements and Diagnostics, Cont.

Reflection Terminology

Reflectance Factor, R:

Ratio of the reflected flux from the material within a specified cone to the flux that would be reflected from a perfect (reflecting) diffuser (perfectly white Lambertian surface) under the same specified illumination:

$$R = \left(\frac{\Phi_{material}}{\Phi_{perfect\ diffuser}} \right)_{Cone} \Bigg|_{\substack{\text{For Specified} \\ \text{Illumination} \\ \text{Conditions}}}$$



Cone shown: Ω = 0.0379 sr for 12.6° apex (6.3° inclination angle from normal)

Example only, many other configurations possible.

Special cases:

Luminance Factor β: $\Omega \to 0, \quad R \to \beta$

Reflectance ρ: $\Omega \to 2\pi, \quad R \to \rho$

Reference: CIE Publication #46 & #44

Measurements and Diagnostics, Cont.

Reflection Terminology, Cont.

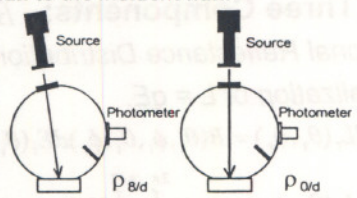
Reflectance, Reflection Factor ρ :

Ratio of the (entire, Ω = 2π) reflected flux to the incident flux:

$$\rho = \frac{\Phi_r}{\Phi_i}$$

Note notation: source/detector

Specify angle or use "d" for diffuse.

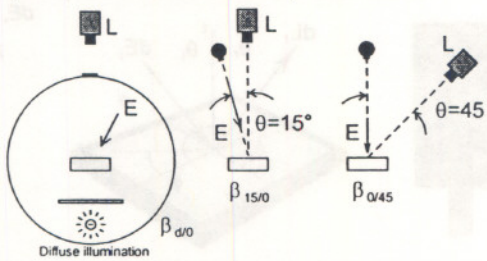


Luminance Factor β :

Ratio of the luminance of the object to that of the luminance of a perfect reflecting diffuser (perfectly white Lambertian materiel) for identical illumination conditions:

$$\beta = \frac{L}{E / \pi}$$

Note: luminous coefficient: $q = \beta / \pi$



Measurements and Diagnostics, Cont.

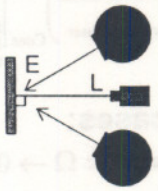
Reflection Measurements

- **Oversimplification — Possible Ambiguity**
  - *Diffuse (Lambertian) component assumption:*

    Display surface measured as if it were black matte paint.

    β = luminance factor, q = luminous coefficient, E = illuminance, L = observed luminance.

$$L = qE = \frac{\beta}{\pi}E$$

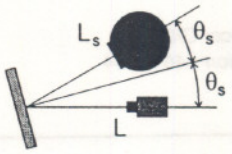


  - *Specular component assumption:*

    Display surface treated as if it were a mirror.

    ρ_s = specular reflectance, L_s = source luminance

$$L = \rho_s L_s$$



Measurements and Diagnostics, Cont.

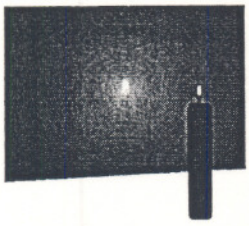
Reflection Measurements, Cont.

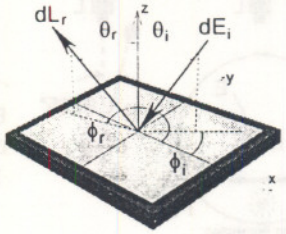
- **BRDF — Three Components:** $B = D + S + H$
  - *Bidirectional Reflectance Distribution Function*
  - *A generalization of L = qE.*

$$dL_r(\theta_r,\phi_r) = B(\theta_i,\phi_i,\theta_r,\phi_r)dE_i(\theta_i,\phi_i)$$

$$L_r(\theta_r,\phi_r) = qE + \rho_s L_s(\theta_r,\phi_r \pm \pi) + \int_0^{2\pi}\int_0^{\pi/2} H(\theta_i,\phi_i,\theta_r,\phi_r)L_i(\theta_i,\phi_i)\cos(\theta_i)d\Omega.$$

dE, element of illuminance



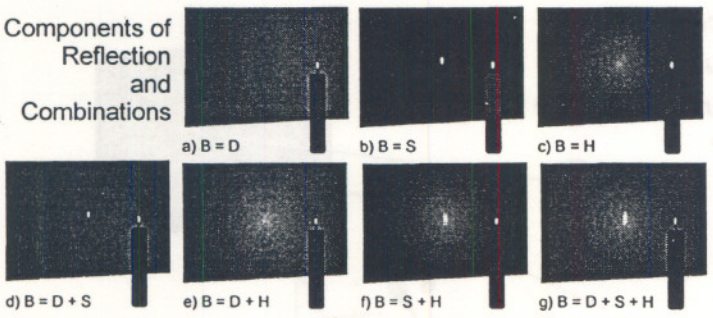


Measurements and Diagnostics, Cont.
Reflection Measurements, Cont.

- **Specular, Lambertian (Diffuse), Haze**

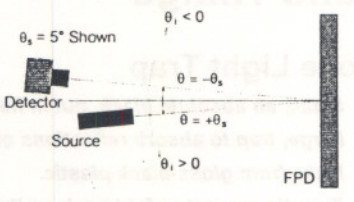
  Most think in terms of specular (mirror like) and diffuse (Lambertian) and lump haze in with both. Here we are separating out the three.

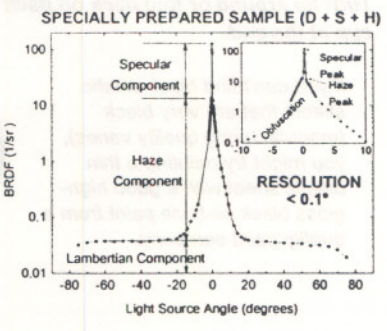
Components of Reflection and Combinations



Measurements and Diagnostics, Cont.
Reflection Measurements, Cont.

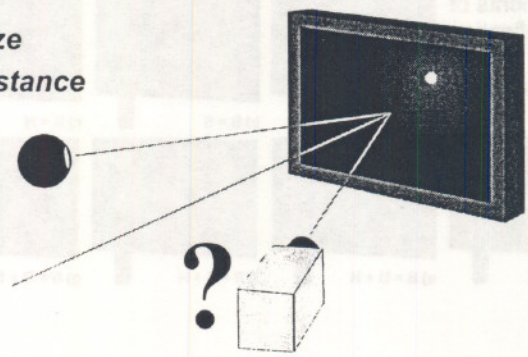
- **Simple BRDF**
  - *Extremes:*
    - ***Lambertian (flat)***
    - ***Specular (spike)***
    - ***Haze is in between.***
  - *Haze characteristics:*
    - ***Proportional to illuminance***
    - ***Directed in specular direction***





Measurements and Diagnostics, Cont.
Reflection Measurements, Cont.

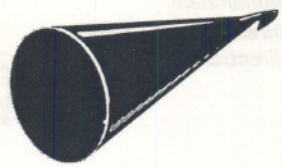
- **With Haze, Measurements Can Be Sensitive to the Geometry of the Apparatus...**
  - *LMD distance*
  - *Lens diameter*
  - *Focus*
  - *Source size*
  - *Source distance*
  - *...?*



Tips and Things

- **Cone Light Trap**
  - ***Small, an absolute black, put in field of view.***
  - ***Large, trap to absorb reflections off screen.***
  - ***Make from gloss-black plastic.***
  - ***Turn tip around or fold back on itself so there won't be a reflective cup at the end.***

If you can't find black plastic sheets that are very black (manufacturing quality varies), you might try painting a thin plastic sheet with a good high-gloss black oil-base paint from a quality paint company.



Tips and Things, Cont.

White Reflectance Standard

- ***Get the kind that can be refurbished in your lab (e.g., 220 to 240 grit water-proof emery paper using circular motion under running water).***
- ***Make sure it is sufficiently thick (some need to be 10 mm depth or more, whatever the manufacturer states is necessary). A 50 mm diameter disk may be required.***
- ***Over 99% reflectance (e.g. $\rho_{6/d}$), quasi-Lambertian... BUT watch out!!! ... What kind of reflectance is this 99% value???***

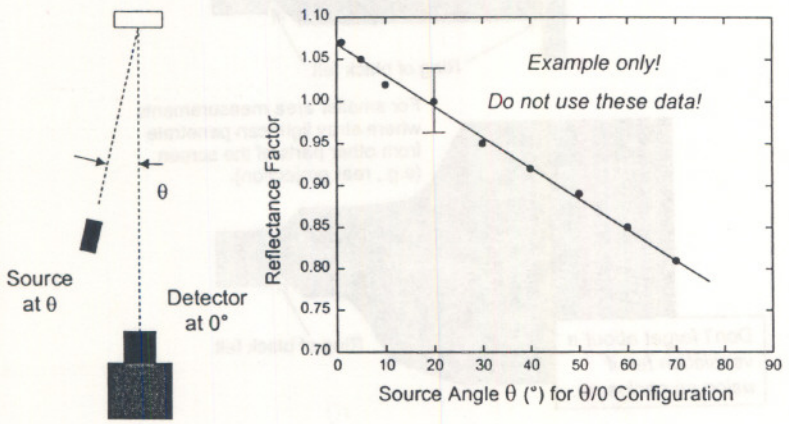
CAUTION: ***These may not be Lambertian.*** *The reflectance (e.g., of 0.99) is obtained under specific conditions of illumination and reflected-light measurement (e.g., $\rho_{6/d}$ illumination 6° from normal and measurement of diffuse reflected flux in a hemisphere). The reflectance will not necessarily be the same for all angles and all configurations!!! If you need to use it for a certain configuration (other than the configuration for which it was calibrated) then it must be calibrated for that special configuration. We cannot necessarily use the 99% value for just any configuration we want (blindly hoping that it will be OK). An illuminance meter might be better.*

Tips and Things, Cont.

Reflectance Factor of White Standard Example

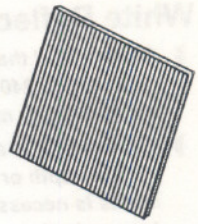
Example ONLY; don't use these results for your own purposes!!!

This shows that you cannot plop one of these in your apparatus, measure its luminance, assume a reflectance factor of 0.99 and calculate the illuminance—it just isn't that simple.

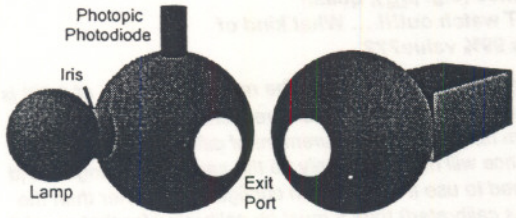


Tips and Things, Cont.

- **Ronchi Ruling**
  - *Equal thickness black and clear grille.*
  - *High-magnification distance calibration*



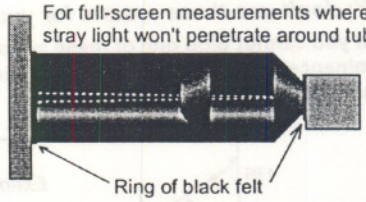
- **Integrating Sphere Light Source**
  - *Well designed, provides 1% nonuniformity.*
  - *Variable aperture source, no color shift.*
  - *Photodiode current monitors luminance.*

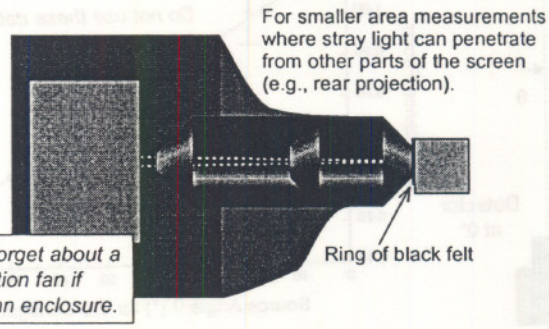


Focus on exit port. Keep things away from exit port or can change luminance. Tungsten halogen source can be well-regulated. Cover exit port when not in use!

Tips and Things, Cont.

- **Portable Darkroom Using SLET**





Don't forget about a ventilation fan if using an enclosure.

Tips and Things, Cont.

- **Intuition (Gut Feelings!)?**

  If you have a gut feeling that something is wrong, it probably is.
  On the other hand, if everything seems perfect, it probably isn't.

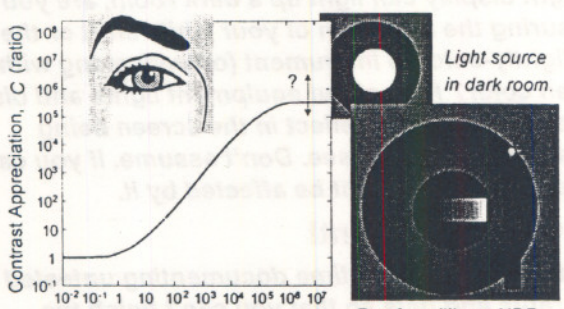
Metrology is more an attitude than procedures.

An attitude of skepticism.

(Even cynicism.)

Tips and Things, Cont.

- **Trust your eye, look at what your instrument is seeing.**



Light source in dark room.

Proof: multilayer NDF, <u>then</u> add highlight.

What contrast can the eye appreciate? (Depends upon image.)

100:1 300:1 500:1 1000:1 10^4:1 10^5:1 10^6:1 10^7:1 ...?

Tips and Things, Cont.

- Diagnostics?

  Always think in terms of diagnostics: Are you getting what you think you're getting? If you aren't sure, can you think up a way to test it out?

- Whom do you trust?

  Don't trust anything or anyone (as much as possible), always try to verify things you are tempted to assume, prove to yourself that everything is working properly and that you are not making inappropriate assumptions.

Tips and Things, Cont.

- Look for problems, be suspicious.

  A bright display can light up a dark room, are you measuring the reflection of your white shirt or the side of a lightly-colored instrument (or wall) along with the screen color? How about equipment lights and displays in the room, do they reflect in the screen being measured? Look and see. Don't assume. If you can see it, the instrument might be affected by it.

- Don't Over Document!

  Don't spend so much time documenting untested apparatus and data so that you can't finish the measurement—it's like polishing garbage. Take the time to document thoroughly after it is working properly.

Tips and Things, Cont.

- **What Is "Good Enough"?**

  We should not compromise good metrology in favor of tradition when that tradition might be based upon inadequate metrology.

  For example, people say "Why do we have to measure it so accurately when the eye can't see it?" Well, how was that "limitation" of the eye determined? If the instrumentation used to determine the "rule" is not as good as the eye, then what can't see, the eye or the instrument? If tradition states that we only need 100:1 to adequately render a scene, how was that "rule" determined. What measurements were made? Was the instrumentation capable of an accurate measurement, how do we know? How was "adequately" defined? Be a skeptic!

- **P^{12} —Lest We Forget Working at the Bench...**

  Perpetrating paperwork, poppycock, plus protocol paralyzes promising project progress producing poor products.

Partial Listing and Contact Information

- **Notation: (see acronym list in handout)**

  TC = technical committee
  SC = subcommittee
  DIS = draft international standard
  PT = project team
  WG = working group
  DS = draft standard
  CD = committee draft
  PL = project leader

- **Conformance Standards**
  - *Specification of criteria to be met*
- **Measurement Standards**
  - *Brief descriptions of procedures—most common*
  - *Detailed descriptions of procedures & diagnostics*
- **See handout for listing.**

Display Standards, Cont.

Comprehensive Document Available

- **VESA FPDM — Flat Panel Display Measurements Standard — Features:**
  - *Specification of good metrology for displays*
  - *Self-contained measurement procedures*
  - *Buffet of measurements—use what you need*
  - *Easy to use and read*
  - *Extensible—more will be added as needed*
  - *Adaptable—affords a variety of equipment*
  - *Accommodating—special needs permitted*
  - *Metrology Section, Technical Discussions Section*
  - *Available now! VESA 408-435-8225*

A reasonably priced document of close to 300 pages.