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DRAFT STANDARD FOR COLOR ACTIVE MATRIX LIQUID CRYSTAL DISPLAYS (AMLCDS) IN U.S. MILITARY AIRCRAFT

RECOMMENDED BEST PRACTICES

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13. ABSTRACT *(Maximum 200 words)*

THIS REPORT IS WRITTEN IN THE FORMAT OF A MILITARY STANDARD AS A DRAFT TO ESTABLISH THE PERFORMANCE, FORM, FIT, DESIGN, AND DEVELOPMENT REQUIREMENTS FOR A FAMILY OF COLOR ACTIVE MATRIX LIQUID CRYSTAL DISPLAY (AMLCD) MODULES TO BE PROCURED FOR MILITARY AIRBORNE COCKPIT APPLICATIONS. THIS DOCUMENT PROVIDES GUIDANCE FOR THE SELECTION, DESIGN, AND DEVELOPMENT OF AMLCD FLAT PANEL DISPLAYS FOR USE IN MILITARY AIRCRAFT COCKPITS.

14. SUBJECT TERMS
FLAT PANEL, CREW STATION, LIQUID CRYSTAL DISPLAYS, PIXEL CONFIG, VIEWING ANGLE, RESOLUTION, CONTRAST LUMINANCE, CHROMATICITY

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FOREWORD

1. This document is the second in a series of drafts which are evolving into a military standard to provide guidance in selecting, designing, or developing active matrix liquid crystal displays (AMLCD). It represents the best practices known to date and recommends a family of displays for military cockpit use. Uncertainties and considerations in this evolving field are noted. This draft standard is written primarily for sunlight-readable, bubble canopy applications. Other applications will have less severe requirements (e. g. paragraph 3.2.1.6.3 of AFGS 87213) which would affect backlight and design. This standard will be useful to procurement programs in the drafting of their performance specification, to integrators in determining if a commercial specification can meet that performance specification, and to industry in the establishment of common AMLCDs in military aircraft and common AMLCD design elements wherever possible across all civil and military avionic applications.

2. Justification for this document takes on added significance in light of the 29 Jun 94 announcement that DOD would seek Congressional approval to cease use of military specifications (MIL-SPECs) in procurements and rely instead on commercial and performance specifications and standards. The Apr 94 "Report of the Process Action Team on Military Specifications and Standards" recommendation has been endorsed by the SECDEF, who stated that "The use of military specifications and standards is [to be] authorized as a last resort, with an appropriate waiver." SECDEF has also stated that DOD will still have to develop specifications and standards for things like fighter aircraft that only DOD buys. Thus, the development of this standard is still necessary even *if* Congress approves the changes requested by SECDEF. Furthermore, there is no commercial standard for AMLCDs in any application, civil or military, making this effort all the more necessary as a dual-use activity.

3. Companies and government offices which have contributed to this document are listed in appendix B. Their participation in the workshops (Apr 93, Nov 93) and written comments on previous drafts of this standard are gratefully acknowledged.

4. The Society of Automotive Engineers (SAE) is gratefully acknowledged for permission to use the draft Aerospace Recommended Practice (ARP) 4256 definitions. The said SAE document is referenced in several portions of this document.

5. The convention for dimensions (angular, pixels, distance) is to provide horizontal first followed by vertical second: H x V, where H & V axes are located to the normal H (left-right) and V (up-down) axes of the vehicle in its normal attitude. For length dimensions the terms width (horizontal) and height (vertical) are also in use. For coordinate systems, the horizontal width axis is represented by the standard abscissa label, X, and the vertical height axis, the ordinate label, Y.

6. Normal axes of vehicle comprise the reference Cartesian coordinate system for definition of the crew station and its displays. These axes move with the vehicle but are defined for the vehicle in its normal attitude.

7. The plan for the next draft of this document is as follows. Workshops with industry and users will be held in Fall 94 and Winter 95. The revised document will be presented for final comments at the SPIE Orlando symposium 17-21 Apr 94 during the Cockpit Displays II conference on 19-20 Apr 95 and the Flat Panel Standards conference 21 Apr 95. The revised draft standard & recommended best practices document will be published in Jun 95.

1. SCOPE

1.1 Scope. This report is written in the format of a military standard in accordance with MIL-STD-962B as a draft to establish the performance, form, fit, function, design, and development requirements for a family of [monochrome and] color active matrix liquid crystal display (AMLCD) modules to be procured for military aircraft applications. This draft of the document presumes a design eye distance of approximately 610 - 760 mm (24 - 30 inches); future drafts will include design eye distances closer (head mounted) or farther (projection). Pixels on the head, panel, and wall must be integrated into a single human system interface.

1.2 Purpose. This document provides guidance for the selection, design, and development of AMLCD flat panel display heads for use in military aircraft, including flight instruments in cockpits, multi-function displays (MFD) and video monitors in cockpits and cabins, notebooks & headsets for ground crew maintenance & preflight data loading, workstations for mission planning & debriefing, and simulation and training systems.

1.3 Classification. The display module (DM) shall be classified by size and type. The different types shall be distinguished by resolution, viewing angle, gray shading, and color or monochrome type displays. These characteristics of sizes and types are described in Table 1 of this document.

2. APPLICABLE DOCUMENTS

2.1 Government Documents. The following documents of the issue listed form a part of this standard to the extent specified herein. In the event of a conflict between the documents referenced herein and the contents of this standard, the contents of this standard shall be considered a superseding requirement.

2.1.1 Handbooks

AFSC DH 1-8	26 Nov 92	Microelectronics
AFSC DH 2-2	15 Apr 86	Crew Stations and Passenger Accommodations

2.1.2 Specifications

MIL-E-5400T Amend 3	16 Nov 79 14 May 90	Electronic Equipment, Airborne, General Specification for
MIL-P-7788E Amend 1	15 May 77 16 Apr 79	Panel, Information, Integrally Illuminated
MIL-Q-9858A Amend 2	16 Dec 63 8 Mar 85	Quality Program Requirements
MIL-L-85762A	26 Aug 88	Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible

2.1.3 Standards

FED-STD-102	29 Jan 63	Preservation, Packaging, and Packing Levels
MIL-STD-130G	11 Oct 88	Identification Marking of US Military Property
MIL-STD-454M Notice 3	15 Dec 89 30 Oct 91	Standard General Requirements for Electronic Equipment
MIL-STD-461C Notice 2	4 Aug 86 15 Oct 87	Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference
MIL-STD-462 Notice 6	31 Jul 67 15 Oct 87	Electromagnetic Interference Characteristics, Measurement of
MIL-STD-470B	30 May 89	Maintainability Program for Systems and Equipment

MIL-STD-471A Notice 2	27 Mar 73 8 Dec 78	Maintainability Verification/ Demonstration/Evaluation
MIL-STD-701N	31 Jan 90	Lists of Standard Semiconductor Devices
MIL-STD-704	6 Oct 59	Electric Power, Aircraft, Characteristics of
MIL-STD-781D	17 Oct 86	Reliability Testing for Engineering Development, Qualification, and Production
MIL-STD-783D	18 Dec 84	Legends for Use in Aircrew Stations and on Airborne Equipment
MIL-STD-785B Notice 2	15 Sep 80 5 Aug 88	Reliability Program for Systems and Equipment Development and Production
MIL-STD-810E Notice 1	14 Jul 89 9 Feb 90	Environmental Test Methods and Engineering Guidelines
MIL-STD-875A	30 Apr 74	Type Designation System for Aeronautical and Support Equipment
MIL-STD-882B Notice 1	30 Mar 84 1 Jul 87	System Safety Program Requirements
MIL-STD-965A Notice 3	13 Dec 85 24 Jul 89	Parts Control Program
MIL-STD-1776A	25 Feb 94	Aircrew station and Passenger Accommodations
MIL-STD 1800 Rev A	30 Jan 87 10 Oct 90	Human Engineering Performance Requirements for Systems
MIL-STD-1818	8 May 92	Electromagnetic Effects Requirements for Systems
MIL-STD-2073-1B	21 Jun 91	DoD Materiel, Procedures for Development and Application of Packaging Requirements
MIL-STD-2165	26 Jan 85	Testability Program for Electronic Systems and Equipment
DOD-STD-2168	29 Apr 88	Defense System Software Quality Program
MIL-M-13508C Amend 1 Notice 1	19 Mar 73 27 May 83 24 Oct 88	Mirror, Front Surfaced Aluminized, for Optical Elements

MIL-O-13830A Amend 1	11 Sep 63 28 Sep 87	Optical Components for Fire Control Instruments: General Specification Governing the Manufacture, Assembly, and Inspection of
MIL-E-17555H Amend 2	15 Nov 84 2 Nov 92	Electronic and Electrical Equipment, Accessories, and Provisional Items (Repair Parts); Packaging of
MIL-C-25050A Notice 1 Amend 2	2 Dec 62 31 Dec 87 30 Mar 89	Color, Aeronautical Lights and Lighting Equipment, General Requirements for
MIL-E-55585F	21 Sep 88	Electrical Equipment and Parts, Packaging of
AFGS 87213	8 Jan 93	Displays, Airborne, Electronically/Optically Generated

2.1.4 Joint Integrated Avionics Working Group (JIAWG) Documents.

J88-G3	Reliability and Maintainability Specification
J88-G5	Integrated Logistics Support Standard

2.1.5 Other Government Documents

RADC-TR-82-189		
WL-TR-93-1176	Dec 93	Active Matrix Liquid Crystal Display Industry Survey Results

2.2 Non-Government Documents.

SAE-ARP-4256	13 Apr 94	Design Objectives for Liquid Crystal Displays for Part 25 (Transport) Aircraft (Draft 17)

3. DEFINITIONS

3.1 Acronyms.

AFLC	Air Force Logistics Command (disestablished 30 Jun 92)
AFMC	Air Force Materiel Command (established 1 Jul 92)
AFSC	Air Force Systems Command (disestablished 30 Jun 92)
AMLCD	Active Matrix Liquid Crystal Display
AN	Army Navy
ANF	Army Navy Air Force
ATI	Air Transport Indicator
BIT	Built-in Test
CVA	Central Viewing Axis
CIE	Commission Internationale de l'Eclairage
CR	Contrast Ratio
DEP	Design Eye Point
DM	Display Module
EMI	Electromagnetic Interference
EMC	Electromagnetic Compatibility
EMR	Electromagnetic Radiation
ESS	Environmental Stress Screening
FLIR	Forward Looking Infra-red
HDD	Head Down Display (mounted in instrument panel)
HDU	Host Display Unit
HEP	High Energy Particles
HLD	Head Level Display (mounted in instrument panel)
HF	High Frequency

HLS	Horizontal Line of Sight
HMD	Head Mounted Display (projection display mounted in helmet)
HUD	Head Up Display (projection display mounted on top or above instrument panel)
IAW	In accordance with
JAN	Joint Army-Navy
JIAWG	Joint Integrated Avionics Working Group
JSRC-AS	Joint Services Review Committee - Avionics Standardization
LRU	Line Replaceable Unit
MIM	Metal Insulator Metal diode
MTTR	Mean Time to Repair
MS, MIL - STD	Military Standard
NAS	National Aerospace Standard
NVG	Night Vision Goggles
NVS	Night Vision System
NVIS	Night Vision Imaging System
PCO	Procuring Contracting Officer
PPSL	Program Parts Selection List
RGB	red, green, and blue
SAE - ARP	Society of Automotive Engineers - Aerospace Recommended Practice
SEMI	Semiconductor and Electronics Manufacturing Industry
SEMATECH	Semiconductor and Electronics Technology Consortium
SOW	Statement of Work
SRU	Shop Replaceable Unit
TFT	Thin - Film - Transistor
SPIE	The International Optical Engineering Society

USDC - MAUG United States Display Consortium - Military Avionics Users' Group

UCS Uniform Chromaticity Scale

3.2 Glossary of Terms.

3.2.1 Active Matrix. Active matrix (AM) in AMLCD consists of transistors or diodes at every subpixel. Thin - film - transistors (TFT) are more commonly used than metal - insulator - metal (MIM) diodes.

3.2.2 Checkout. That step of a corrective maintenance task during which performance of an item is verified to be restored to the full specification level.

3.2.3 Central Viewing Axis. Line from DEP to center, c, of display surface.

3.2.4 Chroma. The psychometric correlate, C*, of the concept of perceived chroma which depends significantly on the viewing conditions such as the nature of the surround (Y_n, n'_n, v'_n).

Where: $u^* = 13L^* (u' - u'_n)$

$v^* = 13L^* (v' - v'_n)$

$L^* = 116 (\text{Luminance}/Y_n)^{1/3} - 16$ for Luminance > 1 fL

$L^* = 903 (\text{Luminance}/Y_n)$ for Luminance < 1 fL

Where the surround or object-color stimulus is specified as:

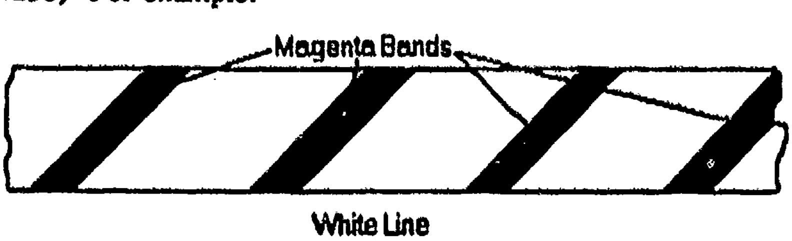
$Y_n = 100$ fL

$u'_n = 0.1978$ (D_{65})

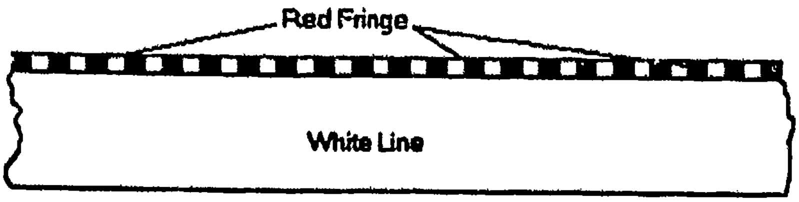
$v'_n = 0.4684$ (D_{65}) (Ref. SAE-ARP-4256)

3.2.5 Chromaticity. A measure of the hue and purity of a color; it is defined as x,y (CIE 1931), or u', v' (CIE 1976) coordinates. (Ref. SAE-ARP-4256)

3.2.6 Color Banding (Matrix). Non uniform distribution of color within a line or symbol. (Ref. SAE-ARP-4256) For example:



3.2.7 Color Fringing (Matrix). Color distortion along the edge of a line or symbol due to the interaction of line or symbol orientation with pixel pattern geometry. (Ref. SAE-ARP-4256) For example:



3.2.8 Color Group. The smallest arrangement of subpixels (defined below) addressable which is capable of portraying multicolor information. A color group comprises one subpixel in color sequential; three to four subpixels are used in spatial color simultaneous.

3.2.9 Contrast (C) $C=(L_2 - L_1)/L_1$. L_2 is the average luminance of the brighter display area and L_1 is the average luminance of the adjacent darker, or background, area and luminance is measured in specified ambient lighting conditions. (Ref. MIL-L-85762)

3.2.10 Contrast Ratio (CR). $CR = L_2/L_1$. Note: $CR = C + 1$

3.2.11 Corrective Maintenance Task. The work performed as a result of a failure for the purpose of restoring an item to a specific condition. The steps of a corrective maintenance task are: fault verification, isolation and correction, adjustment and calibration, close up, and check out. This may include the task of connecting and employing support equipment, but excludes obtaining spare resources.

3.2.12 Crosstalk. Unwanted luminance modulation in display elements which is caused by the cross coupling of electrical signals addressed to other elements or rows, columns, or blocks of other elements. (Ref. SAE-ARP-4256)

3.2.13 Defects. Pixels not operating as anticipated in design (viz, line outs, stuck on, stuck off, clusters, mura).

3.2.14 Design Eye Point (DEP). A point fixed in relation to the aircraft structure (neutral seat reference point) at which the midpoint of the pilot's eyes should be located when seated at the normal position. The DEP is the principal dimensional reference point for the location of flight deck panels, controls, displays, and external vision. (Ref. SAE-ARP-4256)

3.2.15 Display Element. The smallest addressable entity of the display. In the case of an active matrix LCD, the smallest addressable shutter of an individual color. In the case of a segmented display, any of the shapes, or symbols made up of only one individual addressable entity. (Ref. SAE-ARP-4256)

3.2.16 Display Image Resolution. Pixel dimensions of a display defined as horizontal pixels by vertical pixels. Used here to be synonymous with resolution (see below).

3.2.17 Display Module (DM). Assembly comprising all components necessary to transform an image from an electrical representation to a light representation emitted from the display. A DM typically consists of controller card, backlight assembly including heater and dimming circuitry, AMLCD optical subassembly including coatings and layers added to achieve performance standards and protective mechanical parts (See Figure 1). Case and bezel buttons are included in DM definition if pixels are imbedded into their surfaces.

3.2.18 Display Size. Dimensions of active display area defined as (a) solid angle $\Omega_{DS}= (\Theta_{DS}, \Phi_{DS})$ subtended at DEP; (b) diagonal linear length or (c) horizontal length by vertical length. Pertains to active display area. Instrument foot-print (case size) will be larger.

3.2.19 Eyebox. See viewing envelope.

3.2.20 Failed-ON. A pixel, row, or column which is failed permanently or sporadically in the "bright" or emitting state. A pixel is failed on if it, or any of its subpixels, is 30% brighter than the average of several similar adjacent pixels or subpixels in the same state.

3.2.21 Failed-OFF. A pixel, row, or column which is failed permanently or sporadically in the "dark" or non-emitting state. A pixel is failed off if it, or any of its subpixels, is 30% dimmer than the average of several similar adjacent pixels or subpixels in the same state.

3.2.22 Fault Correction. That step of a corrective maintenance task during which a failure is corrected by: (1) repairing in place; (2) removing, repairing, and replacing a failed item; or (3) removing and replacing with a like serviceable item.

3.2.23 Fault Isolation. That step of a corrective maintenance task during which testing and analysis are performed on a item to locate a failure to the level of repair action.

3.2.24 Flicker. Flicker is an undesired rapid temporal variation in display luminance of a symbol, or a group of symbols, or a luminous field. Flicker can cause fatigue and reduced crew efficiency. (Ref. SAE-ARP-4256)

3.2.25 Gray Levels. The incremental intensities of pixel or subpixel light transmission which exist between fully off (dark) and fully on (bright). May be expressed as a number of luminance levels, n, which in turn may be expressed in binary (bits) by the conversion $b = \log_2 n$. Gray levels are defined for the full operating temperature range. Note that 10 - 11 bits in a driver chip are required to provide 8 temperature-compensated bits via use of temperature-dependent look-up tables for liquid crystal displays. Gray levels may be implemented by: (1) a set of voltage levels equal in number to the number of gray scales desired, (2) on-off binary ("pi") cells with the on time corresponding to a fraction of the time, (3) two subpixels per monochrome pixel with each subpixel responding to half as many voltage levels as the full pixel, or (4) a combination of the aforementioned methods. The set of gray levels for a given display is commonly refered to as its gray scale.

3.2.26 Horizontal Line of Sight (HLS). Primary (reference) line through DEP for crew station design. (See Hdbk).

3.2.27 Host Display Unit. Flight Instrument, or LRU, in which DM is mounted for use.

3.2.28 Illuminance. A measure of ambient illumination of viewer or of display surfaces measured in lux (lx) or English (archaic) foot-candle (fc), where 1 fc = 10.763 lx.

3.2.29 Image Resolution. Portion of available image that display can present.

3.2.30 Image Retention. Image retention is an undesired afterimage (residual pattern) that persists on the display. (Ref. SAE-ARP-4256)

3.2.31 Instrument. An instrument is a display unit having a single purpose; it is a type of Line Replaceable Unit (LRU) in which a DM replaces electromechanical or CRT devices.

3.2.32 Jitter. Undesired rapid spatial movement of a displayed image, image element, or symbol that is discernible to a human eye located at the DEP. Also called swimming or breathing of symbols or image elements.

3.2.33 Line Width. Width at 50% of peak luminance of the line luminance distribution when measured from the DEP. (Ref. SAE-ARP-4256)

3.2.34 Line Replaceable Unit (LRU). Any item whose flight line removal and replacement with a like serviceable item is considered the optimum corrective method for the repair of a specific aircraft or aircraft subsystem.

3.2.35 Luminance. A measure of luminous intensity per unit area; the SI unit is the "nit" (nt). One nit is defined as one candela per square meter (cd/m^2). The English (archaic) unit is the foot-lambert (fL), where 1 fL = 3.42626 nt.

3.2.36 Maximum Maintenance Time (Mmax). Time within which 90% of all corrective maintenance tasks can be accomplished.

3.2.37 Mean Time Between Failure (MTBF). A basic measure of reliability.

3.2.38 Mean Time to Repair (MTTR). A basic measure of maintainability: The sum of corrective maintenance times at any specific level of repair, divided by the total number of failures within an item repaired at that level, during a particular interval under stated conditions.

3.2.39 Milliradian (mr). An angular measurement equal to one thousandth of a radian, where a radian is the angle subtended by a circle arc of length equal to the circle radius. 1 mr $\equiv$ [360/(2000π)] arc-deg $\cong$ 0.057297 arc-deg = 3.4378 arc-min = 206.27 arc-sec.

3.2.40 Microradian (μr). An angular measurement equal to one millionth of a radian.

3.2.41 Minimum Difference Luminance. Smallest difference in pixel or symbol light intensity discernable to a qualified, trained operator.

3.2.42 Moire'. A pattern seen when two out of phase spatially periodic patterns are superimposed. (Ref. SAE-ARP-4256)

3.2.43 Multifunction Displays. LRU display units containing DM which can display information from several different single-purpose instruments which it replaces, plus provide new integrated graphical display formats which may incorporate video modes and windows.

3.2.44 Mura. Defects that are manifested by noticeable, measurable variations across the display in gray scale structure (intensity and separation of levels). Variations may be localized or across substantial portion of surface.

3.2.45 Optical Aperture. Portion of a pixel area which transmits light, expressed as a fraction or percentage.

3.2.46 Physical Adjustment and Calibration. That step of a corrective maintenance task during which manual adjustments or calibrations are made.

3.2.47 Picture Element (Pixel). The smallest group of addressable areas (subpixels) which can provide the full capability of the display. For color displays, a pixel can provide the full color gamut, gray scale, and luminance of the display. For monochrome displays, a pixel can provide the full gray scale and luminance. For example; spatial color designs use 3 - 4 subpixels per pixel, where as sequential color designs may use a single subpixel per pixel. Similarly, spatial grayscale ("halftoning") designs use several subpixels per resolvable "spot", where as sequential grayscale designs may use a single subpixel per pixel.

3.2.48 Pixel Density. Inverse of pixel pitch (defined below).

3.2.49 Pixel Pitch. Distance from a point in one pixel to similar point in next. (May be different for horizontal, vertical, and diagonal directions). Measured horizontally as the angle, Θ_p, subtended by a pixel (defined abo ·) at the DEP (defined above). It may be expressed as distance per pixel (i.e. pixel pitch) if the viewing distance, d, is related to the linear pixel pitch, x_p, by $x_p \approx \Theta_p d$, $d >> x_p$. Similar measures, Φ_p and y_p, apply to vertical pitch. Reference units are radian/pixel and meter/pixel. Derived working units include µradian/pixel, arc-degree/pixel, arc-minute/pixel, arc-second/pixel, mm/pixel, and µm/pixel.

3.2.50 Ratcheting. Discontinuous (jerky) movement or rotation of a dynamic display feature caused by excessively large quantization steps or by long update intervals in the translation or rotation of the particular feature.

3.2.51 Resolution. The total number of pixels used to present an image via a display in a given aspect ratio (for example 4:3 or 16:9). Usually specified as an array of pixels, N_H X N_V. Standard resolutions include but are not limited to: NTSC, PAL, VGA (640 X 480), XGA (1040 X 768), super-XGA (1280 X 1024), imaging IR sensor (480 x 480 to 1280 X 480), low end HDTV (1280 X 720), and high end HDTV (1920 X 1080).

3.2.52 Roping. Periodic luminance modulation along a line producing a "rope-like" appearance. (Ref. SAE-ARP-4256)

3.2.53 Segmented Display. A display in which the individual addressable display elements (segments) are of varying shape and/or orientation such that they are dedicated to the display of a specific type or specific types of symbolic or pictorial information. (Ref. SAE-ARP-4256)

3.2.54 Semiconductor. The TFT at each subpixel is fabricated in amorphous silicon (a-Si), cadmium selenide (CdSe), polycrystalline silicon (p-Si), or single crystal silicon (x-Si). The best choice for head down display is presently a-Si, with CdSe a second choice. p-Si and x-Si are currently restricted to HMD and HUD (projection display) applications.

3.2.55 Service Limits. An end of life condition under which the unit must be removed from the aircraft.

3.2.56 Shop Replaceable Unit (SRU). A subunit of an LRU which is normally removed and replaced to effect repair of an LRU.

3.2.57 Specular Reflections. Reflections from a finite, resolvable area of a surface which continuously, over that area, follow the law of reflection (angle of light incidence equals angle of light reflection). Such reflections are exemplified by those from an ideal mirror and involve no diffusion or scattering of light. (Ref. SAE-ARP-4256)

3.2.58 Stairstepping. Undesirable discrete steps occurring along edges of a line or symbol.

3.2.59 Stroboscopic Flicker. An electronic display image can appear to flicker or jump when the image has a short rise and fall time and there is relative motion between the observer and the display. Because of the relative motion, the pulsing image is focused upon different areas of the retina. This gives the observer the impression that the image is flickering or breaking up. (Ref. SAE-ARP-4256)

3.2.60 Subpixel. The smallest independently controllable (addressable) area of a display. Some display designs, both color and monochrome, have but one subpixel per pixel. Some display designs, both color and monochrome, have several (3 - 4 in color, 2 in monochrome) subpixels per pixel.

3.2.61 Test and Access Point. Any circuit access point which is specifically designed into the SRU for functional input/output or test connection will be considered a test access point. Examples are all connectors and test jacks. In-circuit component tie points, eyelets, and solder pads are not considered test access points.

3.2.62 Viewing Envelope (eye box). The locus of all eye points in a crew station design. An eye point is a point at which all display surfaces in a crew station must comply with this standard. The locus is a volume specified by a solid angle (see Figure 3) and by a range of distances from the display surfaces. See also MIL-STD-1776A.

4. REQUIREMENTS

4.1 Display Module Definition. The term "Display Module," or "DM," shall be used to collectively refer to all types in the family of sizes, unless otherwise specified. The DM shall be an Active Matrix, Liquid Crystal Display (AMLCD). The DM is also known as a "display head" for a flight instrument (LRU).

The DM is not an entire instrument or display unit, installable as is in an aircraft cockpit. Rather, the DM hardware configuration shall include only those components which comprise the optical path. A notional schematic is provided in Figure 1. As illustrated in Figure 1, the DM shall include the heat sinks and reflectors behind the back end of the optical path, through the backlighting, diffusers, and filters (UV and IR night vision cut-off), through the glass substrate containing the liquid crystals, color filters, and thin-film heater, any antireflective and protective optical coatings or protective glass plate (the space shuttle has a heavy duty safety glass plate to prevent breakage) at the front end of the optical path, and everything in between. The DM shall contain the AMLCD row and column driver electronics, the interconnects to the rows and columns, the backlight dimming circuitry, the display direction steering components and circuitry, and the connectors required to mechanically and electrically interface the DM to a host display unit chassis and backplane. The DM shall be installable in various host display units for aircraft cockpit and other applications, and shall be capable of displaying graphics and alphanumerics. The higher performance type displays from Table 1 shall be capable of displaying either color video or monochrome sensor video.

The DM shall not include the instrument-specific controller electronics, the video/graphics processor, or the interface of the flight instrument to the avionics wiring to the instrument. These other parts will be specified case by case in each flight instrument procurement specification.

There shall be defined an interface standard between the DM driver electronics and the flight instrument display control electronics. The design of the control electronics may otherwise vary among flight instruments.

The DM shall be an SRU. The backlight within the DM should be an SRU.

The DM shall accept an electronic representation of an image in one or more standard resolutions and produce the visible representation of that image.

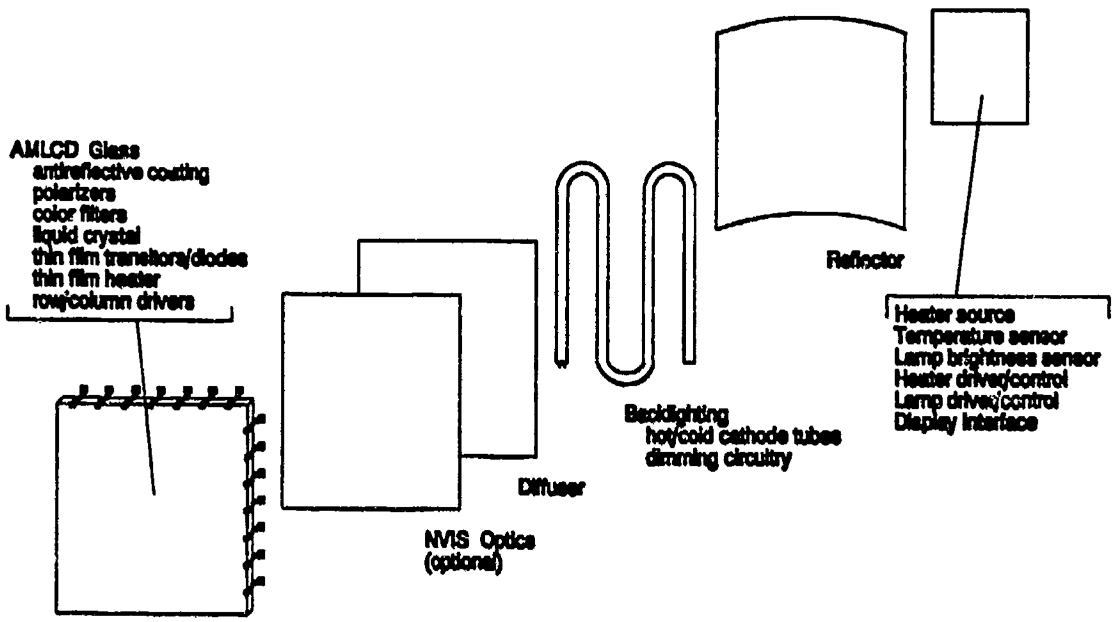


FIGURE 1. Typical Display Module Components

4.2 Characteristics.

4.2.1 Sizes and Types. There are several types of DMs specified for each of the 12 families of sizes in Table 1. The resolution, viewing angle, number of gray shades, and whether color or monochrome is supported, is specified for each type DM in every size. Each DM shall meet every characteristic designated for that size and type in Table 1. Industry, product & logistics center, and depot inputs will be used to revise Table 1. Appendix A specifies displays which have been built or are currently under development.

4.2.1.1 Size 1. Two types of displays are specified for the 50.8 x 50.8 mm (2.0 x 2.0 inch) family of DMs: monochrome and color. This size family should be used to replace gauges which contain alphanumeric and graphic information, such as speed indication and heading.

4.2.1.2 Size 2. Two types of displays are specified for the 102 x 50.8 mm (4.0 x 2.0 inch) family of DMs: monochrome and color. This size family of displays can have the same uses as Size 1 and may be suitable for a control display unit.

4.2.1.3 Size 3. Three types of displays are specified for the 102 x 102 mm (4.0 x 4.0 inch) family of DMs: one monochrome and two color. Type 2 is a lower performance color display than Type 3 and should be used for alphanumeric data, while Type 3 should be used for graphics.

TABLE 1. **Proposed Display Module Standard Sizes and Types ***

Size / Viewing Area horiz. x vert. mm (in)	Diagonal mm (in)	Type	Pixel Density, pixels/mm (pixels/inch)				Viewing Range wrt CVA, degrees		Gray Levels			Color/ Monochrome	
			3.15 (80)	4.72 (120)	6.30 (160)	TBD	±20	±60	16	64	256	color	mono
1 50.8 x 50.8 (2.0 x 2.0)	71.8 (2.83)	1			•		•			•			•
		2	•				•			•		•	
2 102 x 50.8 (4.0 x 2.0)	114 (4.47)	1			•		•			•			•
		2	•				•			•		•	
3 102 x 102 (4.0 x 4.0)	144 (5.66)	1			•		•			•			•
		2	•				•		•			•	
		3		•			•			•		•	
4 102 x 152 (4.0 x 6.0)	183 (7.21)	1			•		•			•			•
		2			•			•			•		•
		3	•				•		•			•	
		4		•			•			•		•	
		5		•				•		•		•	
5 102 x 203 (4.0 x 8.0)	227 (8.94)	1			•		•			•			•
		2			•			•			•		•
		3	•				•		•			•	
		4		•			•			•		•	
		5		•				•		•		•	
6 152 x 152 (6.0 x 6.0)	216 (8.49)	1			•		•			•			•
		2			•			•			•		•
		3	•				•		•			•	
		4		•			•			•		•	
		5		•				•		•		•	
7 152 x 203 (6.0 x 8.0)	254 (10.0)	1			•		•			•			•
		2			•			•			•		•
		3	•				•		•			•	
		4		•			•			•		•	
		5		•				•		•		•	

TABLE 1. **Proposed Display Module Standard Sizes and Types (continued)**

Size	Diagonal mm (in)	Viewing Area horiz. x vert. mm (in)	Type	Pixel Density, pixels/mm (pixels/inch)				Viewing Range wrt CVA, degrees		Gray Levels			Color/ Monochrome	
				3.15 (80)	4.72 (120)	6.30 (160)	TBD	±20	±60	16	64	256	color	mono
8	254 (10.0)	203 x 152 (8.0 x 6.0)	1			•		•			•			•
			2			•			•			•		•
			3	•				•		•			•	
			4		•			•			•		•	
			5		•				•		•		•	
9	287 (11.3)	203 x 203 (8.0 x 8.0)	1			•			•			•		•
			2	•				•		•			•	
			3		•			•			•		•	
			4				•		•		•		•	
10	325 (12.8)	254 x 203 (10.0 x 8.0)	1			•			•			•		•
			2	•				•		•			•	
			3		•				•		•		•	
			4				•		•		•		•	
11	359 (14.1)	254.0 x 254.0 (10.0 x 10.0)	1			•			•			•		•
			2	•				•		•			•	
			3		•				•		•		•	
			4				•		•		•		•	
12	432 (17.0)	338 x 269 13.3 x 10.6	1			•			•			•		•
			2	•				•		•			•	
			3		•				•		•		•	
			4				•		•		•		•	

* The types in this table may be extended and expanded to a hyperspace including contrast ratio, low/bright ambient, NVIS-compatibility, etc. in the next version of this document. The sizes shown define families and may be revised. All revisions, extensions, and expansions will be based on input received from industry, product & logistics centers, depots, and, especially, using commands.

4.2.1.4 Size 4. Five types of displays are specified for the 102 x 152 mm (4.0 x 6.0 inch) family of DMs: two monochrome and three color. Types 1 and 2 are high performance monochrome DM and should be suitable for FLIR and radar. Type 2 has a larger viewing angle than Type 1 for cross-cockpit viewing. Type 3 is a lower performance display than Types 4 and 5 and could be used for graphics and alphanumerics. Type 5 has a larger viewing angle than Type 4, for cross-cockpit viewing, however, both are high performance DMs and suitable for multifunctions, including graphically rendered imagery and video inserts/mapping, plus symbol overlays.

4.2.1.5 Size 5. The types specified for the 102 x 203 mm (4.0 x 8.0 inch) family of DMs are the same and should be suitable for the same functions as family Size 4.

4.2.1.6 Size 6. The types specified for the 152 x 152 mm (6.0 x 6.0 inch) family of DMs are the same and should be suitable for the same functions as family Size 4.

4.2.1.7 Size 7. The types specified for the 152 x 203 mm (6.0 x 8.0 inch) family of DMs are the same and should be suitable for the same functions as family Size 4.

4.2.1.8 Size 8. The types specified for the 203 x 152 mm (8.0 x 6.0 inch) family of DMs are the same and should be suitable for the same functions as family Size 4.

4.2.1.9 Size 9. Four types of displays are specified for the 203 x 203 mm (8.0 x 8.0 inch) family of DMs: one monochrome and two color. Type 1 is a medium performance monochrome DM and should be suitable for FLIR and radar. Types 2 and 3 are a high performance color displays which are both capable of multifunctions, graphics, and video; though Type 3 specifies a larger viewing angle for cross-cockpit viewing.

4.2.1.10 Size 10. The four types of displays specified for the 254 x 203 mm (10.0 x 8.0 inch) family of DMs are the same and should be suitable as the same functions as the Size 9 family; however, Types 2 and 3 both have large viewing angles and are capable of cross-cockpit viewing.

4.2.1.11 Size 11. The four types of displays specified for the 254 x 254 mm (10.0 x 10.0 inch) family of DMs are the same and should be suitable for the same functions as the Size 9 family.

4.2.1.12 Size 12. The four types of displays specified for the 338 x 269 mm (13.3 x 10.6 inch) family of DMs are the same and should be suitable for the same functions as the Size 9 family. Types 3 and 4 should, in addition, be suitable for workstation applications.

4.2.2 Performance Characteristics.

4.2.2.1 Electrical Power. The DM shall meet the digital, analog, backlight, and heater power requirements specified in Table 2.

TABLE 2. Power Parameters

Power Type	Power Levels	
Digital Voltage	Nominal: Operating: No Damage: Max Current:	+5 V +4.5 to +5.5 V -0.7 to +6.0 V TBD
Analog Voltage	Nominal: Operating: No Damage: Max Current:	+15 and -15 V +14.25 to +15.75 V -14.25 to -15.75 V -0.7 to +16 V on +15 V +0.7 to -16 V on -15 V TBD
Backlight	Voltage: Max Current:	270 Vdc TBD
Heater, Backlight	Voltage: Max Current:	TBD TBD
Heater, LCD	Voltage: Max Current:	TBD TBD

4.2.2.1.1 Power Interface. System application flight instrument LRU specification will specify a power supply to interface the DM electrical source.

4.2.2.1.2 Connectors. TBD. See notes, Section 7.4.

4.2.2.2 Thermal Dissipation and Cooling Requirements. Thermal design of the DM shall allow the unit's dissipated power (with up to 10 watts dissipated through the front glass) to be removed by the cooling system of the display unit. Touch temperature requirements of MIL-STD-1472 will not be violated.

4.2.2.3 Visual Characteristics. Display quality shall be compatible with the viewing environment of military aircraft cockpits. The DM shall, in addition, exhibit no perceptible levels of either crosstalk or optical coupling between addressed and unaddressed areas or between individual pixels. Individual pixels or patterns which exhibit time changing luminance contrast or chromaticity dependencies in the absence of intentional inputs shall be considered unacceptable.

4.2.2.3.1 Pixels.

4.2.2.3.1.1 Minimum Pixel Density. One pixel per 500 μr (103 arc sec). In a display surface at d = 610 mm (24.0 ") the minimum pixel density is 3.28 pixel/mm or 1 pixel/304 μm.

4.2.2.3.1.2 Maximum Pixel Density. One pixel per 250 μr (52 arc sec). In a display surface at d = 610 mm (24.0 ") the maximum pixel density is 6.56 pixel/mm or 1 pixel/152 μm.

4.2.2.3.1.3 Pixel Configuration. The preferred pixel configuration for multicolor displays is a color group configured in a red, green, blue, green square pattern with the two green subpixels in opposing corners of the square. In order to meet the multicolor and monochrome resolution requirements, each of the four subpixels shall be independently addressable. Other pixel configurations may be considered (such as stripe, triad, and mosaic shown in Figure 2) if it can be demonstrated that they meet the minimum multicolor and monochrome resolution requirements as specified in Table 1. The DMs shall meet the resolution requirements in Table 1.

The notation XY - nxy is introduced where:

X - pixel orientation - SQUARE (SQ), DELTA (DL), VERTICAL (V), HORIZONTAL (H),and DIAGONAL (D)
Y - pixel shape - SQUARE (SQ), DELTA (DL), RECTANGLE (R), and STRIPE (S)
n - number of subpixels per pixel - single (1), pair (2), triad (3), quad (4)
x - subpixel orientation - square (sq), vertical (v), and horizontal (h)
y - subpixel shape -square (sq), stripe (s), and diamond (d)
NOTE: For square pixels -- XY = SQ (not SQSQ)
NOTE: For delta pixels -- XY = DL (not DLDL)
NOTE: For square subpixels -- xy - sq (not sqsq)

4.2.2.3.1.4 Monochrome Pixel Configuration. Monochrome pixels usually contain one square or vertical stripe subpixel. Exception: Comanche FLIR display has square pixel comprising two vertical stripes, so that 16 gray levels per subpixel provides 256 gray levels per pixel.

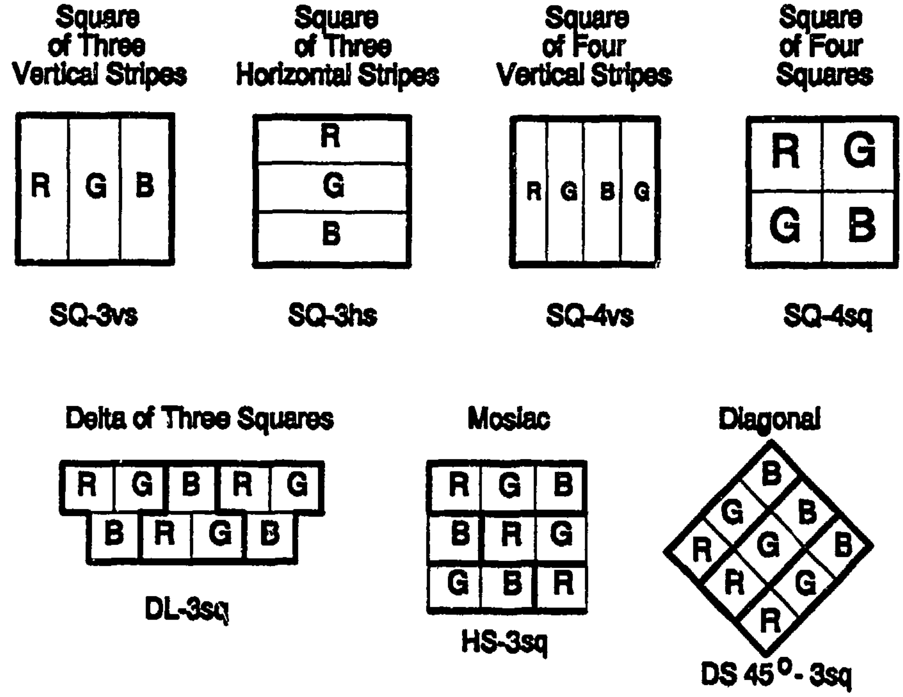


FIGURE 2. Examples of Color Pixel Configurations

4.2.2.3.1.5 Pixel Type and Semiconductor. The active matrix pixels shall be of the thin-film-transistor (TFT) design with the semiconductor material being, in preferred order, amorphous silicon (a-Si) or cadmium selenide (CdSe), polycrystalline silicon (p-Si), and single crystal silicon (x-Si). There is more experience with a-Si in aircraft displays than with any other type of semiconductor. Performance of TFT type active matrices is clearly superior to the competing metal-insulator-metal (MIM) type active matrices. Manufacturing maturity is strongly in favor of a-Si TFT AMLCD.

4.2.2.3.2 Display Legibility. Legibility shall be established by meeting the visual characteristic requirements of this specification throughout an ambient illumination range which extends from full daylight to complete darkness. The diffuse plus specular ambient environments are to be specified per MIL-L-85762A.

4.2.2.3.2.1 Full Daylight Ambient. Full daylight ambient shall be taken to be: (1) 107,640 lx (10,000 fc) direct incident external ambient illumination with 6852 nt (2,000 fL) of luminance incident at the specular angle; or (2) 86,112 lx (8,000 fc) of sunlight directly incident on the display with 1713 nt (500 fL) of luminance incident at the specular angle with respect to the test viewing angle; or (3) 21,528 lx (2,000 fc) of illumination incident on the display with 6,852 nt (2,000 fL) of luminance incident at the specular angle. The display shall be legible under all of these full daylight test conditions.

4.2.2.3.2.2 Dark Ambient. A dark ambient lighting condition is defined as when the ambient lighting over the spectral range of 380 through 930 nm is either unmeasurable (equivalent to system noise) or no greater than 1% of the value of spectral radiant energy from the test sample being measured.

4.2.2.3.3 Viewing Angle. The viewing angle requirements provided here comprise a design guideline and may be tailored for specific applications. The DM shall be readable from anywhere within a solid viewing angle bounded by an ellipse perpendicular to and centered around the horizontal line of sight (HLS), which is shown in Figure 3. The central viewing axis (CVA) of the DM is defined as a line from the center of the display surface to the DEP, the DEP is near the center of the viewing angle ellipse. The CVA and the plane containing the ellipse intersect, forming a compound angle(θ,Φ). The ellipse has a major axis in the horizontal plane, extending +θ_L degrees to the left and θ_R degrees to the right of the display CVA. The horizontal viewing angle, θ is specified as 20 degrees or 60 degrees, depending on the type of DM. These angles are specified for each DM type in Table 1. The ellipse minor axis is located in a vertical plane, extending from 20 degrees below to 20 degrees above the central viewing axis, but is truncated at 15 degrees below the central viewing axis by a chord parallel to the ellipse major axis. Compliance with this legibility requirement shall be established by demonstrating compliance with all of the DM contrast and luminance requirements of this standard, for both full daylight and dark ambient lighting viewing conditions. For reference it is noted that one requirement for cockpit layout is that, in head down displays, primary information should be placed in a 12-inch circle centered at (0°, -15°) wrt HLS; see also MIL-STD-1776A.

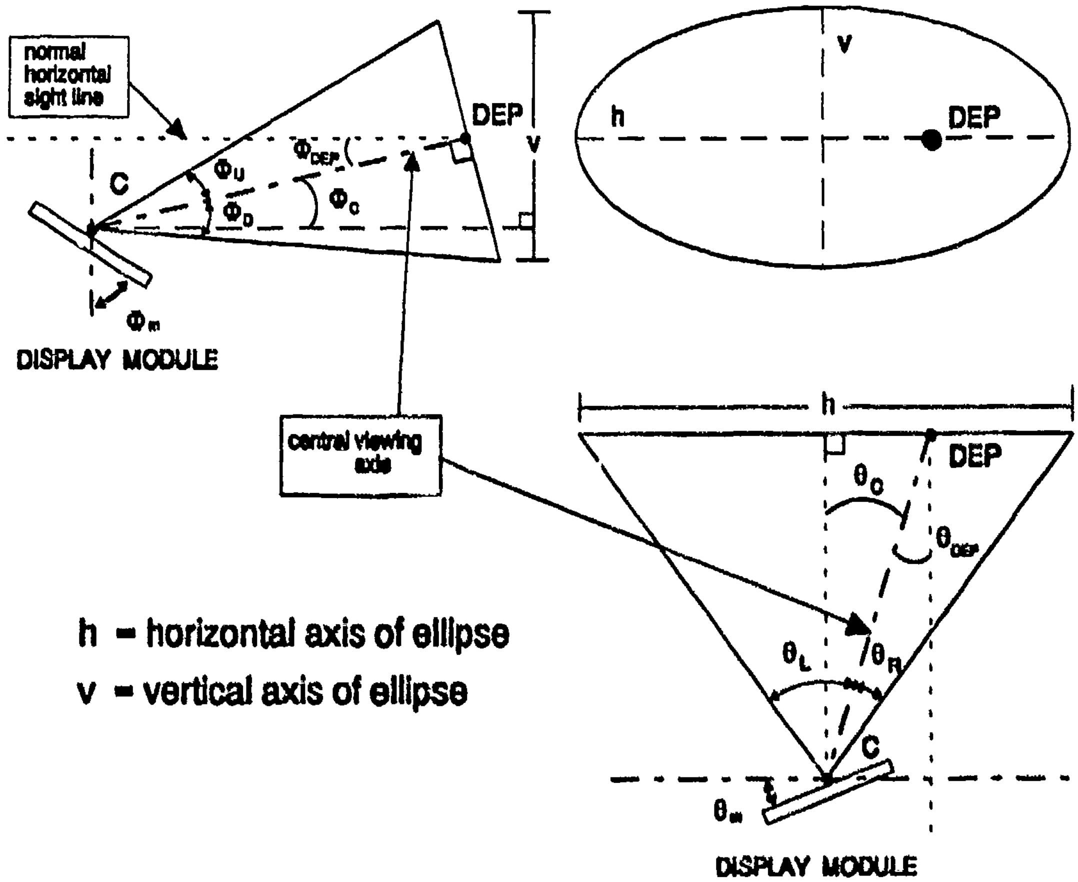


FIGURE 3. **Angle Definitions for Display Module Mounting, Viewing, Eyebox**

4.2.2.3.4 Contrast. The contrast requirements specified herein shall be consistent with the requirements for the character heights defined and verified in accordance with the guidance in MIL-STD-1800. The area-averaged contrasts of the DM green, red, and blue colors shall be sufficient to permit mixing colors to achieve the specified color palette. Minimum contrast shall be measured as in MIL-L-85762 using the following formulas:

$$C_L = \frac{L_2 - L_1}{L_1} \qquad C_I = \frac{L_2 - L_3}{L_3}$$

Where,

C_L = the ON/BACKGROUND contrast of a lighted (or activated) display image element.
C_I = the ON/OFF contrast of a display image element.
L_1 = the average background luminance of the display surface in areas adjacent to and therefore visually contrasted with activated display image elements.
L_2 = the average luminance of activated display image elements.
L_3 = the average luminance of deactivated display image elements.

4.2.2.3.4.1 Full Daylight Ambient Contrast. In full daylight ambient lighting conditions, the DM contrast for ON/OFF shall be:

a. Not less than 4.0 for white graphics and alphanumerics imagery within a symmetrically centered solid elliptical viewing angle having major and minor axes which are 75% of those of the overall solid elliptical viewing angle (i.e., major axis = ±45° for ±60° viewing angle or ±15° for ±20° viewing angle, minor axis = ±15° degrees, but truncated by a chord at -11.25°).

b. Not less than 3.0 for white graphics and alphanumerics imagery within the overall solid elliptical viewing angle (as defined above).

c. Not less than 6.0 for green monochrome video imagery within the overall solid elliptical viewing angle (as defined above).

4.2.2.3.4.2 Other than Full-Daylight-Ambient Contrast. In dark ambient lighting conditions, the DM contrast for ON/OFF shall be:

a. Not less than 20 for green monochrome video and white graphic and alphanumeric imagery, when viewed along the display central viewing axis.

b. Not less than 15 for green monochrome video and white graphic and alphanumeric imagery, within a symmetrically centered solid elliptical viewing angle having major and minor axes which are 75% of those of the overall solid elliptical viewing angle.

In a 10,763 lx (1000 fc) diffuse ambient lighting condition, the DM contrast shall be not less than 10.3 for green monochrome and white graphic and alphanumeric imagery within a symmetrically centered solid elliptical viewing angle having major and minor axes which are 75% of those of the overall solid elliptical viewing angle.

4.2.2.3.5 Luminance. The DM shall provide a minimum difference luminance (as defined in MIL-L-85762) of not less than 685 nt (200 fL) in white in full daylight ambient lighting conditions. The minimum DM luminance, besides off, shall be 0.03 nt (0.01 fL) in dark ambient. Green is

65% of white luminance value; red is 21% of white value; blue is 14% of white value. The goal for maximum luminance shall be 1200 nt (350 fL) in white in full daylight ambient lighting conditions.

4.2.2.3.5.1 Luminance Control. The DM shall be adaptable to continuous and discrete brightness controls on host equipment and shall be capable of being dimmed to luminance levels acceptable for using Night Vision Imaging System (NVIS) equipment. The DM shall be able to interface with automatic brightness controls, common brightness controls (i.e., one control for more than one DM), and dedicated brightness controls. The brightness interfaces and functions shall be supported by the host system and a single brightness interface shall be provided by the DM for the DM luminance level.

4.2.2.3.5.2 Luminance Variation. The luminance of any symbol, segment of a symbol, vector, or area, when compared to other symbols or areas of like kind and chromaticity, shall not vary by more than ±30% relative to the average across the usable area of the display, $I_{dimmest} \geq 0.54\ I_{brightest}$. That is, the average luminance is 70% of the maximum, $I_{average} \geq 0.7\ I_{brightest}$. Luminance variations which do occur shall be gradual. Background display areas, whether "off" during positive contrast image portrayals or "on" during negative contrast image portrayals, shall appear uniform with no noticeable blotches or mottling. Luminance variations shall also be not more than ±5% within an area covering a circle of 12.7 mm (0.5 inch) diameter or between adjacent pixels. Luminance uniformity shall be maintained throughout the entire range of luminance control. Luminance measurements to verify compliance with the quantitative requirements of this specification shall be required only if noticeable luminance variations, such as blotches, mottling, or excessive luminance uniformity deviations are observed.

4.2.2.3.5.3 Luminance Degradation. During the service life of the DM, luminance (for both a green monochrome DM and color DM) shall not degrade beyond the limits illustrated in Figure 4. That is, luminance would degrade by 3% or less of the original luminance for each 1,000 hours of operation.

4.2.2.3.6 Gray Levels. The number of gray levels shall be met for each DM type in the family of sizes specified in Table 1. The individual gray levels shall be separated by equally perceptible steps that are spread across the full dynamic contrast control range of the color display subpixels or monochrome display pixels. The maximum gray level shall be attained by fully activating (i.e., fully opening) a color subpixel or monochrome pixel, and the minimum gray level shall be attained by deactivating (i.e., fully closing) a color subpixel or monochrome pixel. The remaining gray levels shall be distributed between the minimum and maximum luminances the DM is able to produce in any of the three primary colors, at any highlight white absolute luminance level (i.e., backlight luminance) set by the brightness controls. The Munsell value scale (see Table 3) shall be used as the basis for establishing the display equally perceptible gray level steps. The gray levels shall be monotonic when viewed from the eyebox.

4.2.2.3.7 Color. The DM shall be capable of displaying each of the red, green, and blue (RGB) primary colors specified herein in 2 to 256 gray levels , as specified in Table 1. In addition, the DM shall be capable of displaying all of the mixed colors which result from all the possible combinations of the gray levels available for each type DM in each primary color. The DM shall be capable of displaying any of the primary and mixed colors, either alone or in spatially selectable patterns, at any designated location on the display surface. The content of the DM total color palette available under program control to display color images (i.e., characters, symbols and backgrounds) shall consist of chromaticity locations, to be selectable via software, that are capable

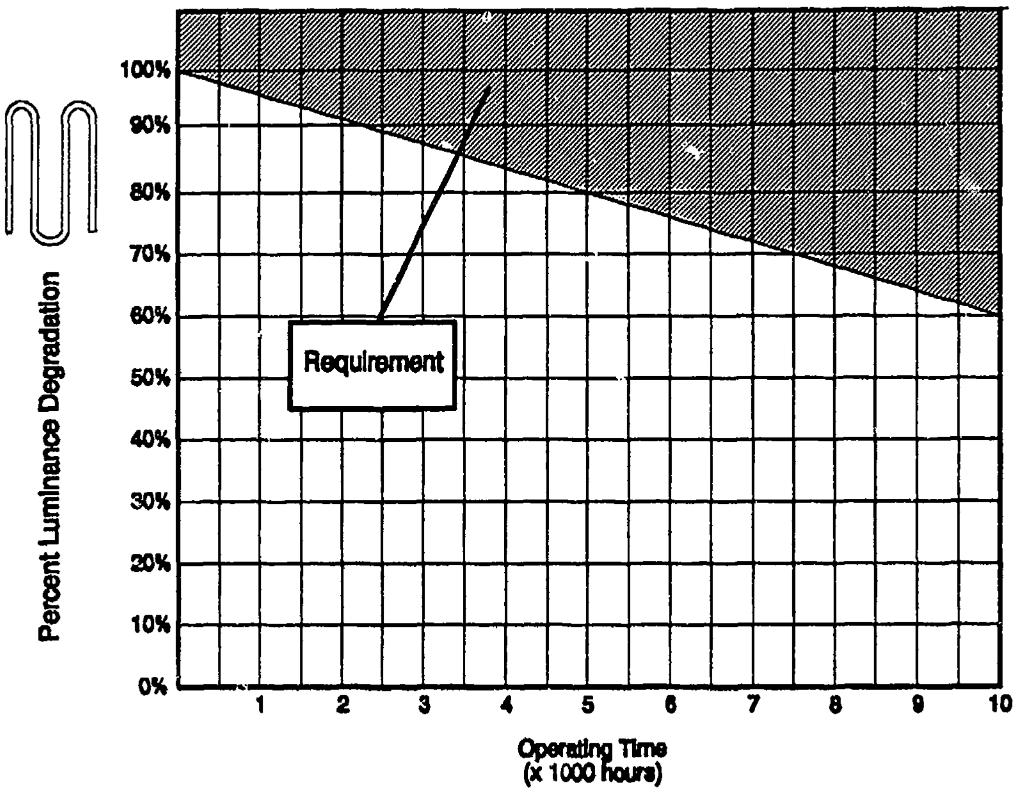


FIGURE 4. **Allowable Luminance Degradation Over Time**

of being chosen from anywhere within a triangle drawn on the 1931 CIE xy Color Mixing Chromaticity Diagram (see MIL-C-25050), which has the locations of its three vertices defined by the display RGB primary color chromaticity points as herein specified. A sketch of the 1931 CIE Chromaticity Diagram illustrating the primary and mixed colors is shown in Figure 5. The display background (off pixels) shall be black.

4.2.2.3.7.1 Chromaticity.

4.2.2.3.7.1.1 Primary Color and Reference White Chromaticities. The area-averaged chromaticities of the RGB primary color subpixels shall be selected so when each primary color, operating in dark ambient lighting conditions, is measured, mean chromaticity shall fall on or within the respective R, G, or B chromaticity diagram regions defined with the corner points specified in Table 4. These points are connected in succession on two or three sides by straight lines and on the fourth side by the spectral locus. The permissible primary color chromaticities have been determined using the 1931 CIE xy Chromaticity Mixture Diagram (Figure 5), but for convenience have also been expressed in terms of the u'v' coordinates of the 1976 CIE Uniform Chromaticity Scale (UCS) Diagram, and in terms of dominant wavelength (λ_d) and excitation purity (p_e) coordinates. The definition of the chromaticity regions is based on the requirement that the display produce a reference white at a chromaticity of x=0.3333, y=0.3333 (i.e., u'=0.2105, v'=0.4737) which is the equal energy or CIE Source E location on the xy chromaticity diagram. The reference white requirement shall be tolerated from the 5500 Kelvins correlated color temperature isothermal line on the xy chromaticity diagram to the 6500 Kelvin isothermal line, and to a distance of 0.0100 on either side of the Planckian Locus. The color uniformity requirements of this standard shall apply to both the primary colors and to the reference white color for all DMs.

TABLE 3. Munsell Value Scale

Munsell Value	Y * % Luminance	Munsell Value	Y % Luminance	Munsell Value	Y % Luminance	Munsell Value	Y % Luminance
0.0	0.000	2.6	4.964	5.2	21.62	7.8	55.63
0.1	0.120	2.7	5.332	5.3	22.58	7.9	57.35
0.2	0.237	2.8	5.720	5.4	23.57	8.0	59.10
0.3	0.352	2.9	6.128	5.5	24.58	8.1	60.88
0.4	0.467	3.0	6.555	5.6	25.62	8.2	62.71
0.5	0.581	3.1	7.002	5.7	26.69	8.3	64.57
0.6	0.699	3.2	7.471	5.8	27.78	8.4	66.46
0.7	0.819	3.3	7.960	5.9	28.90	8.5	68.40
0.8	0.943	3.4	8.471	6.0	30.05	8.6	70.37
0.9	1.074	3.5	9.003	6.1	31.23	8.7	72.38
1.0	1.210	3.6	9.557	6.2	32.43	8.8	74.44
1.1	1.353	3.7	10.134	6.3	33.66	8.9	76.53
1.2	1.505	3.8	10.734	6.4	34.92	9.0	78.66
1.3	1.667	3.9	11.355	6.5	36.20	9.1	80.84
1.4	1.838	4.0	12.001	6.6	37.52	9.2	83.07
1.5	2.021	4.1	12.66	6.7	38.86	9.3	85.33
1.6	2.216	4.2	13.35	6.8	40.23	9.4	87.65
1.7	2.422	4.3	14.07	6.9	41.63	9.5	90.01
1.8	2.642	4.4	14.81	7.0	43.06	9.6	92.42
1.9	2.877	4.5	15.57	7.1	44.52	9.7	94.88
2.0	3.126	4.6	16.37	7.2	46.02	9.8	97.39
2.1	3.391	4.7	17.18	7.3	47.54	9.9	99.95
2.2	3.671	4.8	18.02	7.4	49.09	10.0	102.57
2.3	3.968	4.9	18.88	7.5	50.68		
2.4	4.282	5.0	19.77	7.6	52.30		
2.5	4.614	5.1	20.68	7.7	53.94		

* $Y = 1.2219V - 0.23111V^2 + 0.23951V^3 - 0.021009V^4 + 0.0008404V^5$ where V = Munsell Value

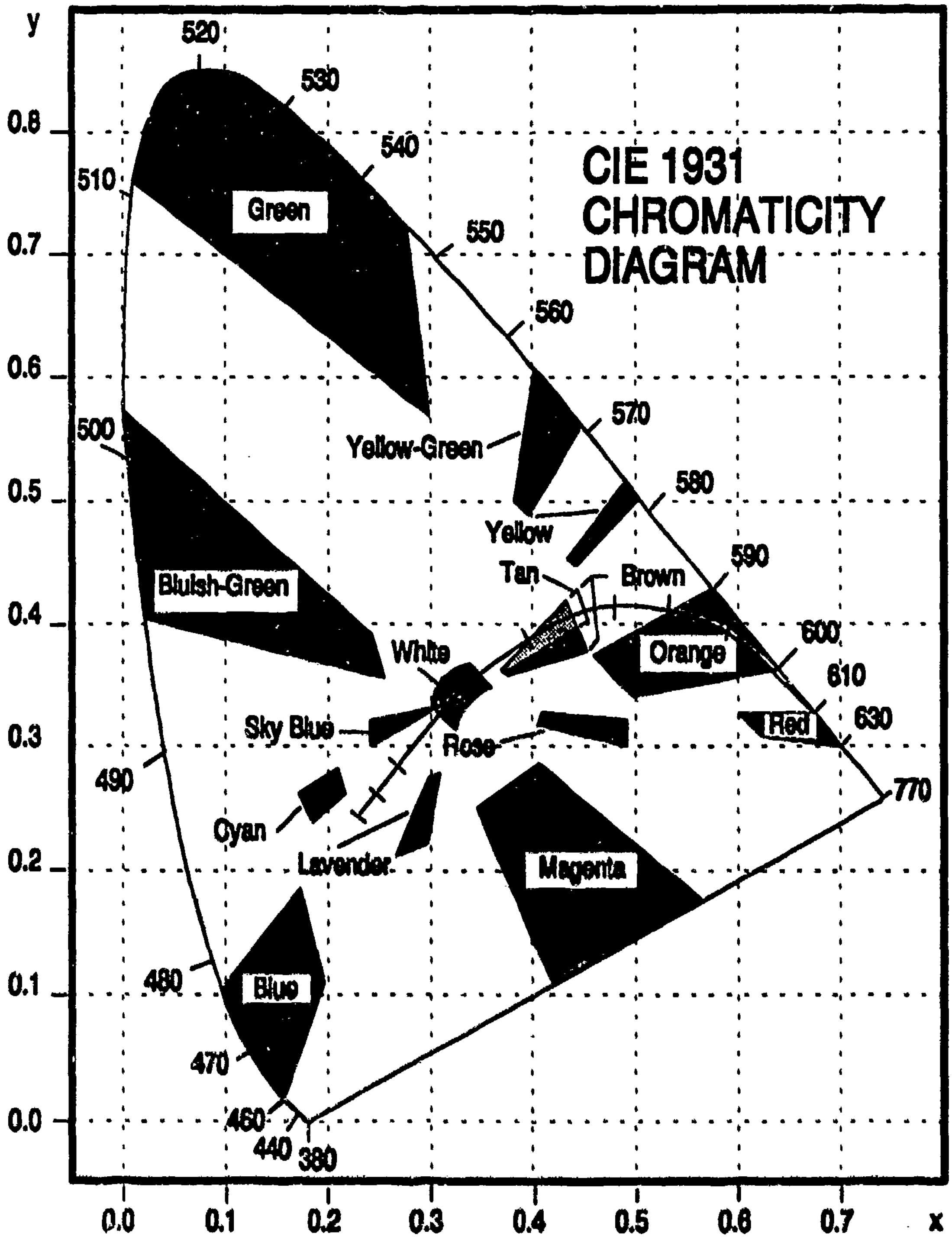


FIGURE 5. Display Module Color Palette

TABLE 4. **Red, Green, and Blue Operating Region Chromaticity Requirements**

Color Name		Dominant Wavelength	Excitation Purity *	1931 CIE xy Color Mixing Diagram Chromaticity Coordinates		1976 CIE u'v' UCS Diagram Chromaticity Coordinates	
				x	y	u'	v'
Red	1	610	1.00	0.67	0.33	0.4692	0.5296
	2	610	0.807	0.60	0.33	0.4132	0.5176
	3	630	0.832	0.65	0.30	0.4867	0.5086
	4	630	1.00	0.71	0.29	0.5566	0.5165
Green	1	546	1.00	0.27	0.72	0.0986	0.5838
	2	546	0.586	0.30	0.56	0.1311	0.5518
	3	511	1.00	0.02	0.77	0.0059	0.5670
Blue	1	477	1.00	0.10	0.10	0.1021	0.2297
	2	477	0.667	0.18	0.18	0.1500	0.3375
	3	460	0.706	0.20	0.12	0.1980	0.2673
	4	460	1.00	0.14	0.03	0.1877	0.0871

* Excitation purity calculated with respect to a reference white chromaticity at $(x_w, y_w) = (0.3333, 0.3333)$, using the equation:

$$P_e = \frac{x - x_w}{x_\lambda - x_w} \quad \text{or} \quad P_e = \frac{y - y_w}{y_\lambda - y_w}$$

where (x_λ, y_λ) are the 1931 CIE xy Chromaticity Color Mixing Diagram spectral or visual purple boundary intercepts of straight lines drawn from the point (x_w, y_w) through the specified point (x, y).

4.2.2.3.7.1.2 Display Module Mixed Color Chromaticities. Mixed color chromaticities and gray shades shall be produced by altering host system software.

4.2.2.3.7.2 Chromaticity Tolerance. Chromaticity deviations within a given DM, for any color selected from the display color palette, shall be confined to a circle on the 1976 CIE UCS u'v' chromaticity chart having a radius of 0.02 unit per color selected when measured at the central viewing angle. This color uniformity requirement shall be met for each color contained in the display color palette, for any 12.7 mm (0.500 inch) diameter circular area on the surface of the display, over the full range of brightness of the display, and throughout the useful operational life of the display. The differences between the mean chromaticities of any selected color when presented on different DMs shall be within a circle on the u'v' chart having a radius of 0.02 unit, where the center of the circle is defined by the chromaticity coordinates of the colors produced by a DM which is selected to serve as a standard. Visual comparisons using a DM selected to serve as a color comparison standard shall be conducted with the entire display surface activated for display of each color under evaluation. Chromaticity tests sensing the mean chromaticity of the entire display surface shall be required only if the visual examination indicates that a color deviation exists in one or more of the color palette chromaticities.

4.2.2.3.7.3 Chromaticity Desaturation. When exposed to ambient illumination conditions of up to 8,000 fc, the display primary color chromaticities shall not exhibit more than a 20% reduction in their color saturations, that is the purity, P, of the chromaticities shall not be reduced to less than P=0.8 with respect to the excitation purity (p_e) that is established from measurements required in Table 3. The purity of a chromaticity shall be calculated using the equations:

$$P=\frac{x-x_w}{x_c-x_w}$$

or

$$P=\frac{y-y_w}{y_c-y_w}$$

whichever gives the more accurate result, where: (x_c,y_c) are the xy chromaticity coordinates of the color under test when measured in the dark (i.e., 0.1 fc or less of illumination on display); (x_w,y_w) are the coordinates of the display reference white color; and (x,y) are the xy chromaticity coordinates of the desaturated chromaticity under the 8,000 fc high ambient test condition. The mean chromaticity measurements shall be made using a suitable spectroradiometer with the entire display surface operated at the color under test. The sunlight legibility and readability test procedures of MIL-L-85762 shall be employed subject to the following revisions:

a. The DM shall be rotated about its horizontal axis until the plane containing the center of the photometer and the diffuse source contains the display central viewing axis. The display specular source shall be located so as to be at a specular angle with respect to the photometer axis.

b. The DM shall satisfy the chromaticity desaturation requirement for test light source correlated color temperatures between 4800 and 6800 degrees Kelvin.

c. To establish the mean DM chromaticity values for each DM color, a minimum of one-third of the DM pixels shall be measured.

4.2.2.3.8 NVIS Compatibility. Several acceptable approaches for meeting the NVIS compatibility requirements of this specification are specified in the following subsections.

4.2.2.3.8.1 NVIS Radiance. The spectral radiances produced by the multicolor electronic display image and background areas shall not exceed the NVIS radiance maximums specified for Types I and II, Class A or Class B NVIS in MIL-L-85762. The NVIS Class (A or B) with which the DM shall be compatible shall be based on the application. For example, for Army and AFSOC applications, Class A applies, while for U.S. Air Force and Navy applications, Class B generally applies. The NVIS red, yellow, and green chromaticities specified in MIL-L-85762 apply to instrument, panel, indicator and other forms of aircraft interior lighting. An exception is allowed for 610 nm, fully saturated reds for use in Class A NVIS. For Class A NVIS a degraded color set using an acceptable reddish orange hue will be provided (TBD. See Section 7.6). The DM may be designed to operate in a single mode which is NVIS compatible whenever it is dimmed to appropriate night lighting levels, or, the alternative approaches specified in 4.2.2.3.8.2 and 4.2.2.3.8.3 are permissible.

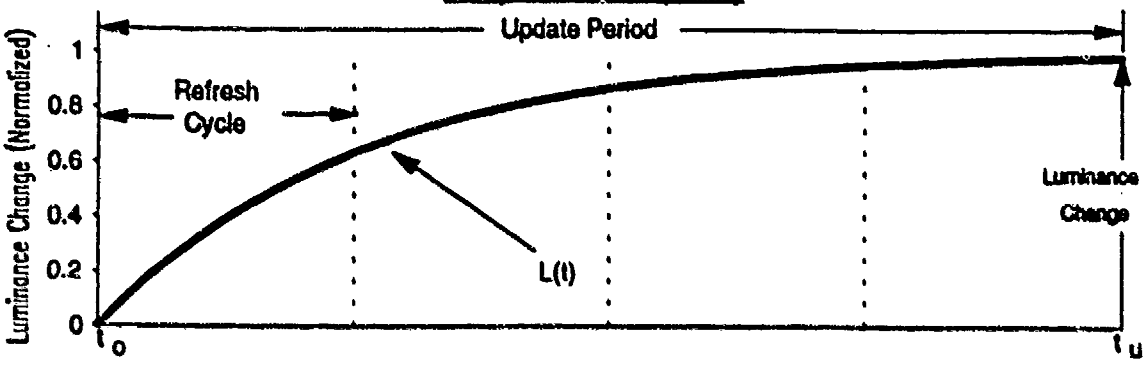
4.2.2.3.8.2 Multiple Modes (Normal/NVIS-A/NVIS-B). If a multiple mode (normal/NVIS-A/NVIS-B) approach is used, a reduced spectrum of colors or a monochrome mode is allowed when in the NVIS modes. A secondary, NVIS-compatible backlight system may be provided for use during the NVIS modes to further ensure the required performance while using NVIS equipment. While in the Class A NVIS mode, the displays shall not exceed the NVIS radiance maximums specified for Types I and II, Class A NVIS in MIL-L-85762 for multicolor electronic displays, if a multicolor Class A NVIS mode is used. If a monochrome NVIS mode is used, the displays shall not exceed the more strict Class A NVIS radiance maximums specified in MIL-L-85762 for monochrome displays. While in the Class B NVIS mode the displays shall not exceed the NVIS radiance maximums specified for Types I and II, Class B NVIS in MIL-L-85762 for multicolor electronic displays, if a multicolor Class B NVIS mode is used. If a monochrome NVIS mode is used, the displays shall not exceed the more strict Class B NVIS radiance maximums specified in MIL-L-85762 for monochrome displays.

4.2.2.3.8.3 NVIS Hardware Optional Add-on. As an alternative to the NVIS compatibility approaches specified in 3.2.1.3.8.1 and 3.2.1.3.8.2, the DM may be designed such that those hardware components which would make the DM compatible with NVIS are modularized to an extent which allows installation of the NVIS module into the basic DM as an optional hardware add-on. In this scenario, the standard DM version would be used for non-NVIS applications while the NVIS-compatible DM version would have the NVIS module added to the standard DM version for applications requiring an NVIS-compatible display. If this approach is taken, separate hardware options are permissible for Class A NVIS and Class B NVIS applications.

4.2.2.3.9 Response Time. Response time limitation shall not produce undesirable artifacts which could lead to erroneous interpretation or loss of displayed information. Such artifacts include smearing of moving images and loss of luminance. These effects may be temperature dependent and shall be evaluated over the operating temperature range. For either increasing or decreasing commanded luminance, the ratio of integrated luminance change (luminance perceived by the eye) to commanded steady state luminance, L_c, should be greater than a suggested value of 70%. Mathematically, this is described as:

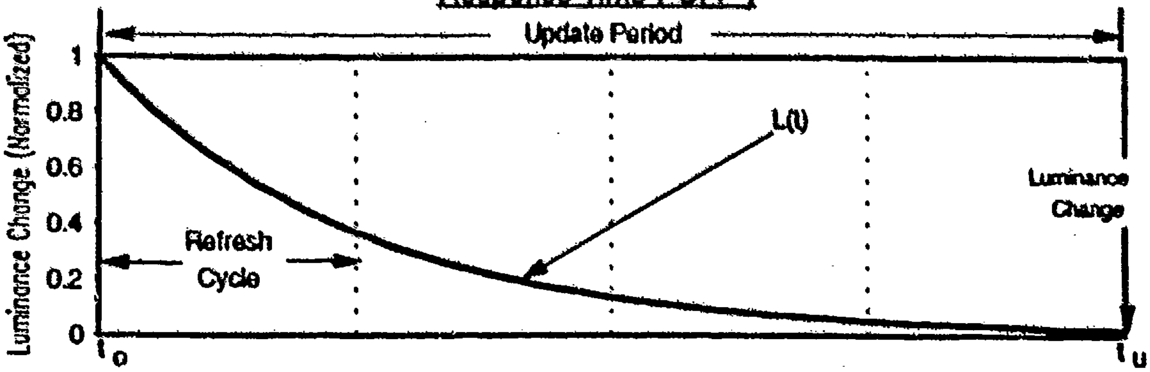
$$\text{Perceived Luminance Change ("ON")} = \frac{\int_{t_0}^{t_u} L(t)dt}{t_u(L_c - L_{t_0})} \geq 0.7$$

Response Time ("ON")



$$\text{Perceived Luminance Change ("OFF")} = 1 - \frac{\int_{t_0}^{t_u} L(t)dt}{t_u(L_c - L_{t_0})} \geq 0.7$$

Response Time ("OFF")



Where: $L(t)$ = the function luminance change with respect to time
L_c = the commanded steady state luminance
L_{t_0} = the initial steady state luminance
t_u = the data update period

FIGURE 6. Response Times

For displays with slowly changing symbol positions, t_u shall be equal to the data update period or the minimum time required for the symbol line widths to move to new pixel positions, whichever is greater. In no case shall response time cause the maximum perceived luminance of dynamic symbology to fall below 70% of the average white luminance recommended in section 4.2.2.3.5. (Ref. SAE-ARP-4256)

4.2.2.3.10 Specular Reflections. The DM shall provide an antireflective method to minimize specular reflections off all surfaces, including filters and surface treatments. Specular reflections shall not exceed 1% for a viewing angle of 30 degrees or less from the display normal. If required, antireflective methods shall be used to aid daylight readability. The DM shall meet the antireflectivity requirements specified in MIL-C-14806.

4.2.2.3.11 Symbol Motion. Display symbology that is in motion (translation and/or rotation) shall not have distracting jitter, jerkiness or ratcheting effects. Dynamic symbols shall maintain luminance, contrast, color, line width, and symbol quality characteristics independent of their rate of motion. (See Note 7.8.)

4.2.2.3.12 Display Refresh Rate. The refresh rate shall be sufficient to preclude the perception of flicker when viewing the display under any ambient illumination condition. The minimum refresh rate shall be 60 Hz. The maximum refresh rate shall be 90 Hz. Refresh refers to the full color display in color mode of color displays. Refresh refers to monochrome display in monochrome displays or in monochrome mode of color displays.

4.2.2.3.13 Display Defects.

4.2.2.3.13.1 Subpixel Defects. A subpixel shall be considered defective when it is permanently or sporadically failed-on or failed-off (see 3.2.20 and 3.2.21). No more than 0.01% of the total number of subpixels shall be defective on a DM. There shall be no full rows or columns of defective subpixels. A group of two or more adjacent color pixels containing one or more defective subpixels shall be considered a cluster defect. The ratio of display area in square centimeters (in square inches) to the number of cluster defects shall not be less than 16:1 (25:1). All production DMs shall be inspected to ensure that existing cluster defects will not affect the legibility of critical data based on standard display formats for primary flight and navigation displays. A cluster defect located in an area of critical information display is considered unacceptable and shall result in the rejection of the DM.

4.2.2.3.13.2 Surface Quality. There shall be no bubbles or scratches visible to the unaided eye. No bubbles shall develop in less than 10,000 hr of military operation. The display surface shall meet the pertinent requirements of MIL-O-13830.

4.2.2.3.13.2.1 Coating Adhesion. All coatings shall be capable of withstanding and passing Paragraph 4.4.6 tests of MIL-M-13508.

4.2.2.4 Warm-up Time - Fighter. The DM warm-up time for fighter (bubble canopy) aircraft shall be as follows:

a. The DM shall achieve 25% of specified luminance and the capability to display imagery at a 1 Hz update rate (≤ 1 second bi-level cell response time) within 30 seconds after turn on from cold soak at -54 degrees C.

b. The DM shall achieve 100% of specified luminance and the capability to display imagery at a 15 Hz update rate (≤ 66 millisecond bi-level cell response time) within 120 seconds after turn on from cold soak at -54 degrees C.

c. The DM shall achieve 100% of peak brightness and the capability to display imagery at full specification performance within 300 seconds after turn on from cold soak at -54 degrees C.

d. The DM shall achieve full specification performance within 30 seconds under standard day conditions (15 degrees C).

4.2.2.5 Warm-up Time - Transport. The warm-up time may be relaxed to be no less than more critical aircraft components, such as engine seals.

4.2.3 Physical Characteristics.

4.2.3.1 Weight. The DM weight shall be kept to a minimum and shall not exceed 0.2 g/mm^2 (0.3 $lbs/inch^2$) of viewing area.

4.2.3.2 Size. The DM outer active display dimensions shall meet the sizes specified in Table 1 and shall have somewhat larger substrate sizes such that it can be mechanically installed into the host LRU for subsequent installation in theaircraft. Minimizing DM depth shall be of primary importance to the extent necessary for ensuring a fit into available flight instrument depth.

4.2.3.3 Durability. The DM shall be designed to minimize maintenance, and shall provide protection of components from environmental contaminants, abrasion, vibration, and maintenance-induced damage.

4.2.3.4 Health and Safety. The DM shall be designed so as to preclude injury during operation and maintenance.

4.2.3.4.1 Smoke and Toxicity. No material used shall liberate gases or fumes that are detrimental to the performance of the aircraft or to the performance or health of the personnel. (Ref. SAE-ARP-4256)

4.2.3.4.2 Glass Breakage. Front glass strength shall be sufficient to withstand normal impacts that can be expected in the system environment without cracking, breaking, or loss of LCD edge seal. Display shall operate properly during and after a test in which a 1.13 kg (2.5 lb) steel ball is dropped on it five times in 1 minute from a height of 1 meter.

4.2.4 Reliability. The DM shall meet the reliability requirements specified when operated in any mode and under any combination of the loads and environmental conditions specified herein. The mean-time-between-failures goal of the DM shall not be less than 10,000 hours.

4.2.4.1 Reliability Design Guidelines. The equipment design shall be in accordance with the reliability design guidelines specified in J88-G3.

4.2.5 Maintainability. Maintainability shall be a consideration during the DM design. The DM shall be designed consistent with a two-level maintenance concept. Final maintainability will be determined by the higher level assembly design.

4.2.5.1 Maintainability Requirements.

4.2.5.1.1 Packaging. Elements within the DM form a group of functionally related elements and shall be packaged as an SRU. All functional parts of the DM shall be contained within the SRU package except for the following:

a. Connectors and EMI filters

b. Interconnecting wiring

c. Mounting provisions

4.2.5.1.2 Adjustments. The DM shall be designed such that all replacement DMs, when installed in the host display unit, shall be immediately operable at design accuracy without requirements for continuity testing or functional adjustment or calibration of the replacement DM.

4.2.5.1.3 Reversibility Restrictions. The design and construction of the DM shall incorporate features such that it is mechanically and electrically impossible to install it incorrectly. These features shall apply to attachment cables, tubes, electrical plugs, and any other such items associated with the DM installation in the host display unit. Features such as mechanically keyed mating and different size connectors shall be incorporated to eliminate any possibility of incorrect DM installation.

4.2.5.1.4 Accessibility.

4.2.5.1.4.1 Removal of Other Assemblies. The DM SRU shall be designed and constructed such that it shall be possible to remove and replace the DM with minimum removal or disconnection of any other subassemblies in the subsystem that contains it. If removal of a subsystem structure, i.e., covers, is required for access, such removal shall affect neither electrical nor mechanical alignment of the equipment nor shall the mechanical strength of the subsystem be impaired to the point that damage to the equipment, its assemblies, subassemblies, or electrical harnesses will occur during normal bench handling of the subsystems.

4.2.5.1.4.2 Test Point and Adjustment Access. The design and construction of the DM shall provide for ready access to test points and for the replacement of items during maintenance.

4.2.5.1.4.3 Testability and Integrated Diagnostics. MIL-STD-2165 and RADC-TR-82-189 shall be used for guidance in the testability design. Designs for testability and integrated diagnostics shall reflect the optimum mix of BIT and manual procedures. DM test points shall satisfy the intent of RADC-TR-82-189 and shall meet the design for testability requirements of MIL-STD-2165. The DM shall employ a backlight sensor which shall sense when the backlight has degraded below the minimum acceptable performance, or has failed completely. The backlight sensor information shall be provided to the host display unit.

4.2.5.2 Preventive Maintenance. There shall be no scheduled maintenance, including maintenance inspections and parts replacement, required for the DM.

4.2.5.3 Interchangeability. All DMs that have the same manufacturer's part number shall be directly and completely interchangeable with each other with respect to installation and performance. The DM shall not require manual harmonization or adjustment after installation.

4.2.6 Environmental Conditions. The environmental requirements are specified in Table 5; they are derived from MIL-STD-810. The DMs shall meet all requirements and shall provide required performance, life, and reliability under any combination of the service conditions and environments specified for each application. Table 5 and following subsections provide a generic set of environmental requirements that should apply to most applications. Qualifications may be by similarity where units have previously qualified to similar conditions on other programs.

4.2.7 Transportability. Preservation, packaging, and marking techniques/processes utilized shall provide a level of protection, preservation, and identification commensurate with the environments in which the equipment will be used in support of planned development test and evaluation activities established by reference to FED-STD-102.

4.3 Design and Construction. Most of the references to MIL-SPECs and MIL-STDs in Section 4.3 are guidance, to be tailored to meet requirements of specific procuring agencies.

4.3.1 Materials, Processes, and Parts. Parts and materials shall be controlled per MIL-STD-965.

4.3.1.1 Standard Parts. Whenever parts or materials are required as a design selection to satisfy this standard, Joint Army-Navy (JAN), National Aerospace Standard (NAS), Army/Navy (AN), and Military Standard (MS) parts shall be used to the maximum extent possible provided they do not compromise design integrity.

4.3.1.2 Commercial Parts. Commercial utility parts, such as nuts, bolts, and cotter pins, having suitable properties, may be used provided the parts can be replaced directly with JAN, NAS, AN, and MS parts, and providing further that the applicable assembly drawings cross reference the commercial part to the corresponding standard part number.

4.3.1.3 Nonstandard Parts or Material. When the use of nonstandard parts or material is required, parts and material shall be selected which shall not compromise design integrity and which are acceptable for aircraft use. Authority for such nonstandard parts or materials shall be requested through the Procuring Contracting Officer (PCO). Any such request must include information such as fabrication drawings or purchase control specifications. Upon approval for use, such nonstandard parts or material shall be identified on the assembly drawing parts and materials list.

4.3.1.4 Microelectronics and Semiconductors. Microelectronics and semiconductors shall be chosen in accordance with (IAW) the guidelines of MIL-H-38534, MIL-M-38510, MIL-S-19500, and MIL-STD-701. Components manufactured by a process already qualified to MIL-I-38535 specifications are considered acceptable. Previously designed systems, which are approved for use in satisfying the requirements of this specification and have nonstandard parts in their original design, shall not be subjected to parts control procedures nor listed in the Program Parts Selection List (PPSL).

TABLE 5. **MIL-STD-810 Environmental Requirements Test Methods, and Procedures**

Category	Test Method No. and Procedure	Test Conditions
High Temperature, Storage	Method 501.3 Procedure I	Ambient to +95 deg. C, 7 cycles of 24 hours
High Temperature, Operation	Method 501.3 Procedure II	Ambient to +55 deg. C, 5 cycles of 24 hours
Low Temperature	Method 502.3 Procedure II	-54 deg. C for 72 hours following temperature stabilization of the test items
Solar Radiation	Modified Method 505.3 Procedure II (8 X longer plus augmented by shock and vibration)	417 cycles (10,000 hr) of 20 hours on, 4 hours off with shock (penny drop from 1 m) and vibration (ultrasound) every 100 hr.
Humidity	Method 507.3 Procedure I	Cycle 1 (Hot Humid), 10 cycles of 24 hours
Acceleration	Method 513.4 Procedures I, II	Per tables 513.4-I and 513.4-II for higher of two levels of acceleration specified for aircraft and helicopters
Vibration	Method 514.4 Procedure I Categories 4, 5, 6	Test items shall be separated into three categories for vibration environment: Propeller Aircraft, Jet Aircraft, and Helicopter. Tests shall be conducted for each category.
Shock	Method 516.4 Procedures I, IX	Test items shall be subject to both Functional and Crash Hazard Test defined in Figure 516.4-1 for each of three orthogonal axis, with 3 shocks per axis

4.3.1.5 Repair of Printed Wiring. The repair and modification of printed wiring assemblies shall conform to contractor standard repair and modification quality procedures. The use of cuts and jumpers in the modification and repair of preproduction printed circuit assemblies shall be in accordance with MIL-C-28809, Appendix, Section 50. Cuts and jumpers on production printed wiring assemblies shall be avoided (unless the jumpers are part of the original design as allowed by MIL-C-28809), and if used, shall require prior approval of the PCO.

4.3.2 Electromagnetic Radiation. The equipment shall be designed to be electromagnetically compatible with other systems installed in military aircraft. The specific electromagnetic emission and susceptibility characteristics to which the equipment shall be designed shall be in accordance with MIL-STD-461 for Class A1b equipment. Testing shall be in accordance with MIL-STD-462. AFSC Design Handbook 1-4, Electromagnetic Compatibility, shall also be used as a design guide. Special attention shall be given to the potential problems that may occur due to multiple VHF, UHF, and HF transmitters and receivers installed on the aircraft. The frequency ranges specified in MIL-STD-461 for electromagnetic susceptibility and emission characteristics shall be broadened to include the discrete frequencies and transmission power characteristics of known aircraft emitters, such as weather radars and electronic warfare equipment, which are outside the specified frequency ranges in MIL-STD-461.

4.3.2.1 Electromagnetic Susceptibility. When installed in the host display unit the DM shall be designed to minimize susceptibility to electromagnetic radiation of the types and strengths existing in U.S. military aircraft, as specified in MIL-STD-461.

4.3.2.2 Electromagnetic Emission. When installed in the host display unit the DM shall not cause interference to any existing installed aircraft system or equipment as required in MIL-STD-461. Electromagnetic emission limits from MIL-STD-461 shall be applied to the DM when installed in the host display unit.

4.3.2.3 Electrical Bonding. Electrical bonding for current return paths and grounding shall be in accordance with MIL-STD-1818.

4.3.2.4 Shielding. The requirement for multiple shields for electromagnetic interference protection shall be held to a minimum. Shields shall not be used to contain unintentional interference, or to solve susceptibility problems. (See Note 7.8.) These problems shall be prevented by time-domain filtering or integration networks and balanced inputs. Wire shield may be used as a signal return for triaxial or coaxial cable and shall be covered by a layer of insulation. All shielded wire shall be multiple point grounded to the signal ground system or chassis. Coaxial or triaxial cables shall have the outer shield grounded at each end.

4.3.3 Identification and Marking. The DM components shall be marked IAW MIL-STD-454, Requirement 67. Abbreviations shall be in accordance with MIL-STD-783.

4.3.3.1 Name Plates. All assemblies and equipment shall be identified IAW MIL-E-5400. Name plates shall be used. Name plates shall conform to the requirements of MIL-P-15024 and shall be permanently attached.

4.3.4 Workmanship. Workmanship shall be in accordance with Requirement 9 of MIL-STD-454, MIL-STD-2000A, and of a quality to assure safety, proper operation, design reliability, and useful life requirements.

4.3.5 Safety. DM safety shall be in compliance with MIL-STD-882.

4.3.6 Human Performance/Human Engineering. The DM will meet the human engineering requirements as specified in MIL-STD-1472. Section 7.1.1 provides human factors testing considerations.

4.3.7 Green Display. Manufacturing techniques for DM shall be selected to minimize environmental impact. Design for DM shall be selected to minimize environmental impact during manufacturing, use (including storage and breakage), and final disposal (e.g. in a landfill).

5. QUALITY ASSURANCE PROVISIONS

5.1 General. The quality assurance requirements of this section shall be formally applied to the DM. The emphasis shall be on doing it right the first time, rather than inspecting quality during DM manufacture.

5.2 Responsibility for Inspection and Test. The contractor shall ensure quality through implementation of a quality effort in accordance with MIL-Q-9858. Inspection and testing shall be performed on equipment that is representative of equipment to be supplied under the contract. Inspections and tests shall be performed by using administrative and technical procedures specified in the contract. Inspections and testing shall be performed by contractor personnel at the contractor's facility or at a contractor-approved vendor facility as required by test constraints.

5.2.1 Tests and Examinations.

5.2.1.1 General. All of the requirements of Section 4 shall be verified by one or more of the verification methods described in this section. If any requirement of Section 4 is not covered by a test procedure in this section, the contractor shall submit a verification procedure using one or more of the verification methods described below.

5.2.1.2 Verification Methods. Verification shall be based on demonstration, test, analysis, or inspection, which are defined as follows:

a. Demonstration - A qualification method that is carried out by operation of the equipment and that relies on observable functional operation not requiring the use of elaborate instrumentation or special test equipment.

b. Test - a qualification method that is carried out by operation of the equipment and that relies on the collection and subsequent examination of data.

c. Analysis - a qualification method carried out by the processing of accumulated data.

d. Inspection - a qualification method carried out by visual examination.

Analysis shall be carefully documented to assure that it is specific enough to adequately describe the item in question and that all possible hazards have been addressed without omission or generalization. Analysis shall show the same or greater level of acceptability, as would be demonstrated by testing to requirements herein. Analysis shall be specific and all calculations shall be specific and logically derived from the presented data. Qualification by similarity is a special type of analysis and shall be limited to comparison with a virtually identical item that has been previously qualified by test or analysis. Qualification by similarity shall include documentation of the previous qualification and a matrix of all differences between the two articles. Each difference shall be addressed by engineering analysis.

5.2.1.2.1 Requirement Verification. The requirements of Section 4 shall be verified on both preproduction and production equipment. In the event of any failure of any the DM to pass any preproduction or production test, inspection, or other requirement verification, the contractor shall take the corrective actions herein.

5.2.1.2.1.1 Preproduction Verification. Preproduction verification shall be performed for the following categories of tests and inspections as defined in the sections listed below:

Reference Section	Verification
5.2.1.3.1.1	Acceptance Inspections
5.2.1.3.1.2	Acceptance Tests
5.2.1.3.2	Environmental Stress Screening (ESS)
5.2.1.3.3	Preproduction Qualification Tests

5.2.1.2.1.2 Production Verification. Production verification shall be performed for the classes of tests and inspections as defined in the referenced sections listed below:

Reference Section	Verification
5.2.1.3.1.1	Acceptance Inspections
5.2.1.3.1.2	Acceptance Tests
5.2.1.3.2	Environmental Stress Screening (ESS)

5.2.1.3 Test Description.

5.2.1.3.1 Acceptance Inspections and Tests.

5.2.1.3.1.1 Acceptance Inspections. Acceptance inspections shall be made on every preproduction and production DM. Demonstrations and inspections shall be performed on the equipment before acceptance to verify applicable requirements as listed in the Requirements Cross Reference in Section 5.3.

5.2.1.3.1.2 Acceptance Tests. Preproduction acceptance tests consist of functional tests to verify performance at each level of integration. Production acceptance tests shall be performed individually on all production DMs. Acceptance tests shall be performed under standard ambient conditions as defined in MIL-STD-810. All modes of operation shall be demonstrated and tested, and all input and output signals (including BIT) shall be tested and recorded. Equipment submitted for acceptance shall be operated long enough to warm up, and sufficient performance data shall be measured and recorded to verify that the equipment meets all requirements of Section 4. The results of preproduction acceptance testing shall be used to specify additional requirements for production acceptance testing. Section 5.3 provides a cross reference of requirements which shall be subject to acceptance testing.

5.2.1.3.2 Environmental Stress Screening. After each preproduction and production SRU has passed SRU acceptance testing, it shall undergo formal ESS in accordance with the applicable contract SOW, MIL-STD-781, and MIL-STD-785. This requirement does not prevent the contractor from performing informal burn-in tests before SRU acceptance, but establishes a minimum burn-in period prior to any other formal testing or use of the equipment by the Government.

5.2.1.3.3 Preproduction Qualification Tests. Preproduction qualification tests consist of the tests specified below. These tests shall be performed after ESS is successfully completed. The required tests and referenced sections are as follows:

Reference Section	Requirement
5.2.1.3.3.1	Avionics Integrity Program (AVIP)
5.2.1.3.3.2	Maintainability Tests
5.2.1.3.3.3	EMI/EMC Tests
5.2.1.3.3.4	Environmental Tests
5.2.1.3.3.5	Visual Characteristics Testing

As part of the qualification, the mass properties of the SRU shall be measured:

a. Mass (measured to within ± 0.0045 kg or ± 0.01 lbm)
b. Location of center of mass (measured on three dimensions to within ± 2.54 mm or ± 0.1 inch)
c. Magnitude of moments of inertia (measured about each mounting point)

5.2.1.3.3.1 Avionics Integrity Program (AVIP). Two DM SRUs of each type shall each be subjected to a AVIP in accordance with MIL-A-87244 and DI-GDRQ-80436. The AVIP shall be used to detect and remedy failures in preproduction SRUs. AVIP is not required for commercial off-the-shelf (COTS) hardware that is not modified or for military qualified hardware with proven reliability. Operation during AVIP testing shall simulate service use. During AVIP, SRU functions, including BIT, shall be exercised, and functional parameters shall be measured. Failure criteria of both MIL-A-87244 and MIL-STD-810 shall apply; any secondary failure that is not detected, reported, and corrected before the resumption of formal testing shall be counted as an additional failure. Any conflict between AVIP and the F-22 program will be resolved by giving the F-22 program requirements the higher priority.

5.2.1.3.3.2 Maintainability Tests. The contractor shall conduct a maintainability test of preproduction sets in accordance with MIL-STD-471, utilizing test method 9, "Test for Mean Maintenance Time and Mmax." Corrective action times and the parameters specified in Section 4.2.4 shall be used. Fault detection and isolation shall employ BIT and shall be evaluated in accordance with MIL-STD-471.

A maintainability demonstration of the DM shall be conducted in accordance with MIL-STD-471 to demonstrate that the maintainability and BIT requirements specified herein have been satisfied. The conditions of the maintainability demonstrations and tasks demonstrated shall represent that which can be expected to occur in the operational environment. For this test, a consumer's risk (β) of 20% shall be used. Task selection shall be in accordance with Appendix A of MIL-STD-471. A single simulated or induced fault or failure may be counted as a maintenance action at both the organizational and depot levels where practical. As part of the demonstration, the contractor shall demonstrate a DM fault isolation capability using system BIT.

5.2.1.3.3.3 EMI/EMC Tests. The DM shall be tested in accordance with the established test methods in MIL-STD-462 and the requirements of Section 4.3.2 herein for MIL-STD-461 Class A1b equipment.

5.2.1.3.3.4 Environmental Tests. The DM shall be tested to the environmental performance requirements specified in Section 4.2.6. Environmental testing shall be in accordance with MIL-STD-810 using the test methods and procedures defined in Table 5.

5.2.1.3.3.5 Visual Characteristics Testing. The DM shall be tested to ensure compliance with the visual characteristics requirements of this document. Visual characteristics tests and inspections shall be as specified in the various visual characteristics requirements subsections in 4.2.2.3, and in accordance with MIL-L-85762. Further, to ensure DM compatibility with NVIS equipment, the contractor shall also conduct testing with actual NVIS equipment, with Government participation.

5.3 Requirements Cross Reference. Table 6 provides a cross reference between each requirement in Section 4 and the quality assurance provisions in Section 5. For each requirement, a quality assurance provision and verification method are assigned.

TABLE 6. **Requirement and Quality Assurance Cross Reference List**

Requirement Section	Requirement	Quality Assurance Section	Quality Assurance Provision*	Verification Method#
4.2.2	Performance Characteristics	5.2.1.3.3.5	QT	T
4.2.2.1	Electrical Power			
4.2.2.1.1	Power Interface	5.2.1.3.3	QT	T
4.2.2.1.2	Connectors			
4.2.2.1.3	Abnormal Power	5.2.1.3.3	QT	T
4.2.2.1.4	Spikes	5.2.1.3.3	QT	T
4.2.2.1.5	Transient Input Voltage	5.2.1.3.3	QT	T
4.2.2.1.6	Power Transients	5.2.1.3.3	QT	T
4.2.2.2	Thermal Dissipation and Cooling Requirements	5.2.1.3.3	QT	A
4.2.2.3	Visual Characteristics	5.2.1.3.3.5	QT	T
4.2.2.3.1.1	Minimum Pixel Density	5.2.1.3.3.5	QT	T
4.2.2.3.1.2	Maximum Pixel Density	5.2.1.3.3.5	QT	T
4.2.2.3.1.3	Pixel Configuration	5.2.1.3.3.5	QT	T
4.2.2.3.2	Display Legibility	5.2.1.3.3.5	QT	T
4.2.2.3.3	Viewing Angle	5.2.1.3.3.5	QT	D
4.2.2.3.4	Contrast	5.2.1.3.3.5	QT	T
4.2.2.3.4.1	Full Daylight Ambient Contrast	5.2.1.3.3.5	QT	T
4.2.2.3.4.2	Other than Full-Daylight-Ambient Contrast	5.2.1.3.3.5	QT	T
4.2.2.3.5	Luminance	5.2.1.3.3.5	QT	T
4.2.2.3.5.1	Luminance Control	5.2.1.3.3.5	QT	T

Table 6. **Requirement and Quality Assurance Cross Reference List (continued)**

Requirement Section	Requirement	Quality Assurance Section	Quality Assurance Provision*	Verification Method#
4.2.2.3.5.2	Luminance Variation	5.2.1.3.3.5	QT	T
4.2.2.3.6	Grey Levels	5.2.1.3.3.5	QT	T
4.2.2.3.7	Color	5.2.1.3.3.5	QT	T
4.2.2.3.7.1.1	Primary Color and Reference White Chromaticities	5.2.1.3.3.5	QT	T
4.2.2.3.7.1.2	Display Module Mixed Color Chromaticities	5.2.1.3.3.5	QT	T
4.2.2.3.7.2	Chromaticity Tolerances	5.2.1.3.3.5	QT	D
4.2.2.3.7.3	Chromaticity Desaturation	5.2.1.3.3.5	QT	T
4.2.2.3.8.1	NVIS Radiation	5.2.1.3.3.5	QT	T
4.2.2.3.8.2	Multiple Modes (Normal/NVIS A/NVIS B)	5.2.1.3.3.5	QT	T
4.2.2.3.8.3	NVIS Hardware Operational Add-on	5.2.1.3.3.5	QT	D
4.2.2.3.9	Response Time and Smear	5.2.1.3.3.5	QT	D
4.2.2.3.10	Specular Reflections	5.2.1.3.3.5	QT	T
4.2.2.3.11	Symbol Motion	5.2.1.3.3.5	QT	D
4.2.2.3.12	Display Refresh Rate	5.2.1.3.3.5	QT	T
4.2.2.3.13.1	Subpixel Defects	5.2.1.3.3.5	QT	T
4.2.2.3.13.2	Surface Quality	5.2.1.3.1.1	AI	I
4.2.2.3.13.2.1	Coating Adhesion	5.2.1.3.3.5	QT	T
4.2.2.4	Warm-up Time - Fighter	5.2.1.3.3.5	QT	D
4.2.2.5	Warm-up Time - Transport	5.2.1.3.3.5	QT	D
4.2.3.1	Weight	5.2.1.3.1.1	QT	T
4.2.3.2	Size	5.2.1.3.1.1	QT	D
4.2.3.3	Durability	5.2.1.3.1.1	QT	D
4.2.3.4	Health and Safety	5.2.1.3.1.1	QT	D
4.2.3.4.1	Smoke and Toxicity			
4.2.3.4.2	Glass Breakage			T
4.2.4	Reliability	5.2.1.3.3.1	QT	T
4.2.4.1	Reliability Design Guidelines	5.2.1.3.3.1	QT	D

Table 6. **Requirement and Quality Assurance Cross Reference List (continued)**

Requirement Section	Requirement	Quality Assurance Section	Quality Assurance Provision*	Verification Method#
4.2.5	Maintainability	5.2.1.3.3.2	QT	D
4.2.5.1.1	Packaging	5.2.1.3.1.1	AI	I
4.2.5.1.2	Adjustments	5.2.1.3.3.2	QT	D
4.2.5.1.3	Reversibility Restrictions	5.2.1.3.3.2	QT	D
4.2.5.1.4.1	Removal of Other Assemblies	5.2.1.3.3.2	QT	D
4.2.5.1.4.2	Test Point and Adjustment Access	5.2.1.3.1.1	AI	I
4.2.5.1.4.3	Testability and Integrated Diagnostics	5.2.1.3.3.2	QT	T
4.2.5.3	Interchangeability	5.2.1.3.3.2	QT	D
4.2.6	Environmental Conditions	5.2.1.3.3.4	QT	T
4.2.7	Transportability	5.2.1.3.1.1	AI	I
4.3.1	Materials, Processes, and Parts	5.2.1.3.1.1	AI	I
4.3.1.1	Standard Parts	5.2.1.3.1.1	AI	I
4.3.1.2	Commercial Parts	5.2.1.3.1.1	AI	I
4.3.1.3	Nonstandard Parts or Material	5.2.1.3.1.1	AI	I
4.3.1.4	Microelectronics and Semiconductors	5.2.1.3.1.1	AI	I
4.3.1.5	Repair of Printed Wiring	5.2.1.3.3.3	QT	T
4.3.2	Electromagnetic Radiation	5.2.1.3.3.3	QT	T
4.3.2.1	Electromagnetic Susceptibility	5.2.1.3.3.3	QT	T
4.3.2.2	Electromagnetic Emission	5.2.1.3.3.3	AI	I
4.3.2.3	Electrical Bonding	5.2.1.3.3.3	AI	I
4.3.2.4	Shielding	5.2.1.3.1.1	AI	I
4.3.3	Identification and Marketing	5.2.1.3.1.1	AI	I
4.3.3.1	Name Plates	5.2.1.3.1.2	AI	I
4.3.4	Workmanship	5.2.1.3.1.2	AT	D
4.3.5	Safety	5.2.1.3.1.2	AT	D

*	AI	Acceptance Inspection	AT	Acceptance Test	QT	Qualification Test
#	A	Analysis	D	Demonstration	I	Inspection
	SFT	Safety of Flight Test	T	Test		

6. PREPARATION FOR DELIVERY

6.1 General. The equipment shall be preserved, packaged, and marked for shipment as specified in the contract and in accordance with MIL-STD-2073-1. Characteristics and considerations related to packaging, handling, and transportability, including induced environments, size, hazardous materials, weight, environmental control features, fragility, and the like, shall be considered during the initial design of equipment. In this regard, MIL-STD-2073-1 shall be used as a guide in the formulation of specific packaging for equipment deliveries.

7. NOTES

7.1 Display Module Implementation Considerations. Suitability of a DM to a specific task is not specified in the standard. The characteristics described under Section 4.2.2.3 apply to the family of displays delineated in Table 1, which should satisfy a broad range of needs in the military cockpit. Displays should be selected while considering the environment in which the operator will view the display. The many qualities of displays, such as luminance, contrast, resolution, character size, and viewing angle, interact with the operator in different environments. This interdependence can be seen when ambient illumination reflected from internal and external display surfaces adds to the luminance emitted from the display background and reduces contrast. These reflections will also reduce the saturated appearance of colors, which affects perceived color quality. The difference between external and internal illumination also affects the time required for the eye to adapt to a change in light intensity. Suitability of a display to a specific task and environment can only be finalized by rigorous testing, to ensure flight safety is not compromised. Further guidance for cockpit lighting luminance design may be found in MIL-L-85762A and AFGS-87213.

7.1.1 Human Factors Testing. Because AMLCD technology is evolving, human performance requirements for its use in the cockpit are not fully established. Research to establish these requirements is often sparse, scattered, and in some cases incomplete or contradictory. General human performance principles have been developed for other technologies such as CRTs. However, their application in the AMLCD environment may not be appropriate. For example, extensive research has been conducted on many aspects of the impact of display luminance on human performance. However, AMLCDs typically maintain much higher luminance contrast and chromatic contrast than color CRTs because of their relatively low reflectance of ambient illumination. In addition, the human responds to the total display within the operational environment, not to individual independent characteristics. Most of the experimentation to date has focused on human performance response to individual characteristics. Therefore, the interrelationships among these characteristics must be addressed. For example, luminance levels interact with the other characteristics of the display, such as color, contrast, and viewing angles. A well controlled parametric test program of AMLCD is recommended.

Prior to testing, the human factors professional must work with the engineers and/or manufacturer to define the user population (age, sex, physical characteristics, experience on similar equipment operation, etc.) and the operational environment (cockpit configuration, physical dimensions, range of ambient conditions, etc.) It is essential that all the characteristics that could impact human performance be identified. Those for which there is inadequate data or for which there is a requirement to determine interrelationships will become candidates for testing.

Testing can be conducted under four conditions: (1) the use of mockups for performance testing, (2) the testing of prototype systems under conditions that approximate their operational use, (3) the testing of operational systems under operational conditions (operational testing), and (4) performance measurement in equipment and system simulators.

7.2 Luminance. It is important to distinguish between luminance and brightness. Luminance is a measure of light energy based upon the relative sensitivity of the eye. Brightness is a subjective attribute of light sensation. Several factors must be considered in establishing requirements and measuring luminance. This document is consistent with the methodology established in MIL-L-85762A referred to as "minimum difference luminance" (para 3.10.2.2.3). Minimum difference luminance accounts for ambient illuminance of the display and is selected to provide the developer and manufacturer with more freedom in design. Minimum difference luminance does not account for illuminance on the operator's face. Illuminance on the operator's face may cause the eyes to adjust to conditions much brighter than the display and therefore cause the operator to become less able to perceive the display.

7.3 Input Signal Characteristics. The input signals to the DM, especially those containing the visual display information (i.e., pixel grey shade voltage level), will eventually have to specified. Also, the luminance control input signal from the manual luminance control device, as well as any automatic brightness controls, if used, will eventually have to be specified.

7.4 Connectors. Connectors are in the standard as a TBD. The manufacturers and integrators of the AMLCD glass and systems should produce a common connector to be used for all DMs.

7.5 Electrical Interface. Electrical interface to DM are in the standard as a TBD. Manufacturers of displays (DM) and flight instruments (LRU) are asked to suggest any widely applicable DM interface they have developed as a potential standard.

7.6 NVIS Class A. A table specifying wavelength characteristics which must be met for Class A NVIS must be provided in Section 4.2.2.3.8.1 and is currently set as TBD. Industry must provide their capabilities when dealing with NVIS Class A for 610 nm fully saturated red hues.

7.7 Warm-up Requirements. A study should be undertaken to identify possible revisions in acceptable warm-up requirements.

7.8 Changes Suggested at USDC Military Avionics Users Group (MAUG) in Jun 94. Need to define grey scale nonlinearities versus viewing angle (family of curves). Need to define chromaticity versus viewing angle, or color shift (family of curves). Make display table (standard sizes) based on function rather than display size; may not need 256 grey levels for small displays (no maps). Isocontrast curves for viewing angle (talk to Honeywell Space Shuttle program). Display uniformity uniformity depends on number of grey levels required; single digit number for 256 grey levels. Refresh rate of 250 Hz may be required due to vibration breaking up image (F-16). May need to synchronize refresh rate with backlight frequency. Provide polar coordinate transformation for viewing cone figure.

APPENDIX A

CURRENT AMLCDS

Table A-1 summarizes all the data which could be obtained on the AMLCDs which have been built, are being designed or proposed for current and future platforms, such as the F-22, F-18, and C-141. This table specifies, where available, size, viewing angle, gray shades, luminance, and whether it displays monochrome or color information for each AMLCD. Display size is the active image area. The convention adopted here for all dimensions (angles, pixels, distance) is to give horizontal (width) first followed by vertical (height). Viewing angle is relative to normal at center point of display, with the convention that left and down are negative. Unless stated otherwise: pixels are square; mono pixels are not subdivided into subpixels; and color pixels are subdivided into four square subpixels (RGBG). All displays have active matrix implemented in the form of thin-film transistors (TFT), rather than metal-insulator-metal (MIM) diodes, fabricated in amorphous silicon (a-Si). Exceptions: RAH-66, EH-101, C-130 displays are also available in cadmium selenide (CdSe) TFT.

TABLE A-1. **Current AMLCD Display Module Sizes and Characteristics**

Display Size **mm** **(in.)** *horiz. x vert.*	**Platform**	**Resolution** **pixels** *horiz. x vert.*	**Viewing Angle** **degrees** *left, right* *down, up*	**Gray Levels**	**Color/ Mono**	**Minimum Luminance** **nt** **(fL)**
343 x 224 (13.5 x 8.8)	Lamps II	1280 x 1024			color	
292 x 218 (11.5 x 8.6)	Air Force 1					
275 x 206 (10.82 x 8.12)	EH-101	768 x 576			color	
261 x 261 (10.3 x 10.3)	experimental	1024 x 1024			color	
211 x 158 (8.31 x 6.24)	terminal	640 x 480	-45, +45 -30, +10	256	color	0 - 172 (0 -50)
211 x 157 (8.3 x 6.2)	portable workstation	640 x 480 and 1024 x 768		64	color	

TABLE A-1. **Current AMLCD Display Module Sizes and Characteristics (continued)**

Display Size mm (in.) *horiz. x vert.*	Platform	Resolution pixels *horiz. x vert.*	Viewing Angle degrees *left, right* *down, up*	Gray Levels	Color/ Mono	Minimum Luminance nt (fL)
203 x 152 (8.0 x 6.0) Map Figures Charts	RAH-66* B-52 B-1 V-22 E-2C AH-64 Flightline Maintenance Field Comm. Suitcase	640 x 480		256	color SQ-4vs	634 (185)
203 x 152 (8.0 x 6.0) FLIR/ LLTV	RAH-66* UH-1N SH-60 B-52 B-1 V-22 EH-101 Army trucks	1280 x 480	-28.2, +7.7 -10.5,+12.7	256	mono VS-1vs	634 (185)
198 x 198 (7.8 x 7.8)	F-22* EF-111	640 x 640	-25, +25 -0, +15	16	color	0.3 - 685 (0.1 - 200)
198 x 158 (7.81 x 6.23)	SH-60 LAMPS II	640 x 512			color	
196 x 145 (7.7 x 5.7)	P-3C U-IV	640 x 400	-60, +60 -20, +20	2	mono	0.34 - 856 (0.1 -250)
196 x 146 (7.66 x 5.74)	EH-101	768 x 576	-50, +50 -20, +20	16	color	0.17 - 445 (0.05-130)
170 x 170 (6.71 x 6.71)	Space Shuttle* EC-3A	1152 x 960 video mode 770 x 576 graphics	-60, +60 -10, +45	56	color	0.17 - 343 (0.05-100)
170 x 170 (6.7 x 6.7)	B-777	1152 x 1152 graphics + video bus	-55, +55 -5, +30	56	color DL-3sq	0.17 - 343 (0.05-100)
159 x 159 (6.25 x 6.25)	YF-22 F-22* F-18 E/F Tiger Rafaele	512 x 512	-25, +25 -0, +15	16	color	0.3 - 685 (0.1 - 200)

TABLE A-1. **Current AMLCD Display Module Sizes and Characteristics (continued)**

Display Size mm (in.) *horiz. x vert.*	Platform	Resolution pixels *horiz. x vert.*	Viewing Angle degrees *left, right* *down, up*	Gray Levels	Color/ Mono	Minimum Luminance nt (fL)
159 x 159 (6.25 x 6.25)	F/A-18E/F	512 x 512	-15, +15 -5, +35	32	color	0.17 - 685 (0.05-200)
155 x 206 (6.1 x 8.1)	C-141* C-130 P-3 B-727 C-5 KC-135 KC-10	480 x 640 and 512 x 640	-60, +60 -5, +35	8 to 64 and 525 raster	color	0.3 - 685 (0.1 -200)
152 x 203 (6.0 x 8.0)	C-130 RAMTIP C-130J	480 x 640		32	color	548 (160)
152 x 152 (6.0 x 6.0)	YF-23* Tank F-16 FMS T-38	480 x 480		64	color	
152 x 76 (6.0 x 3.0)	C-130				color	
127 x 127 (5 x 5)	F-4, F-5 T-45 Migs, Kfir helicopters				color	
127 x 102 (5 x 4)	YF-22				mono	
126 x 99.1 (4.95 x 3.9)	F/A-18E/F* EF-111	767 x 605	-15, +15 -10, +40	32	mono	685 (200)
121 x 121 (4.75 x 4.75)	F-5	875 x 525		video, 10	mono	0.34 - 856 (0.1 -250)
121 x 25 (4.75 x 1.0)	F-117A				mono	
114 x 99 (4.5 x 3.5) HSI/ADI/radio	C-130H	410 x 328	-45, +45 -10, +30**	16	color DL-3vs	
114 x 88.9 (4.5 x 3.5)	F/A-18E/F			32	mono	
114 x 88.9 (4.5 x 3.5)	CL-415				color DL-3vs	206 (60)

TABLE A-1. **Current AMLCD Display Module Sizes and Characteristics (continued)**

Display Size **mm** **(in.)** *horiz. x vert.*	**Platform**	**Resolution** **pixels** *horiz. x vert.*	**Viewing Angle** **degrees** *left, right* *down, up*	**Gray Levels**	**Color/ Mono**	**Minimum Luminance** **nt** **(fL)**
102 x 152 (4.0 x 6.0)	YF-22				mono	
102 x 102 (4.0 x 4.0)	F-16C/D* C-130A	482 x 482	-25, +25 -10, +30	32 and 64	color DL-3sq	617 (180)
99.1 x 99.1 (3.9 x 3.9)	F-15	512 x 512		525 raster +graphics	color	
99 x 99 (3.9 x 3.9)	CH-46E	640 480			color	
99.1 x 73.7 (3.9 x 2.9)	F-22	320 x 240	-25, +25 -0, +15	bi-level dot matrix	color	685 (200)
90 x 170 (3.5 x 6.7)	RAH-66	288 x 544			mono	
86.4 x 73.7 (3.4 x 2.9)	Tiger					
86.1 x 73.4 (3.39 x 2.89)	F-15E* SH-60 KC-135 EC-3A	414 x 468			color DL-3sq	
76.7 x 57.7 (3.02 x 2.27)	C-130J	480 x 360			mono	
75 x 75 (3.0 3.0)	4ATI	480 x 480	-45, +45 0, +35	16	color RGWB	0.3 - 343 (0.1 - 100)
63.5 x 88.9? (2.5 x 3.5?)	C-141				mono	548 (160)
57.6 x 57.6 (2.27 x 2.27)	3ATI	480 x 480	-45, +45 0, +35	16	color RGWB	0.3 - 343 (0.1 - 100)
50.8 x 50.8 (2.0 x 2.0)	C-130H	164 x 164	±60		color	
50 x 25 (2 x 1) ?	F-15 FMS				mono	

* Data gathered for this aircraft; data for other systems in this row may differ.

** Center of viewing cone can be steered electronically ±10° vertically, from (-20, + 20) to (0, + 40).

? Incomplete data on size.

PRIMER ON ACTIVE MATRIX LIQUID CRYSTAL DISPLAYS (AMLCD)

A liquid crystal display (LCD) converts electrical signals into images. The key principle is optical rotation. Light is plane polarized by a polarization layer before passing through the liquid crystal (LC) layer and then analyzed by a second polarization layer oriented perpendicular to the first. Molecules of LC material twist in proportion to the applied electric field, and this molecular twist rotates the plane allowing some light to pass through both polarizers. The portion of light passing through the LCD at any given point is, thus, determined by the locally applied electric signal. This proportionality provides a grayscale capability. Typically, 20V or less causes an LCD cell to turn completely on.

The use of liquid crystal material as a display medium began in 1971. Since that time several methods have been developed for sending signals to LCDs. These methods are called "addressing" schemes and include three of importance here: direct, multiplex, and active matrix.

Direct addressing schemes are used to drive simple alphanumeric characters on watches and calculators. Entire figures or segments of figures are controlled by a single signal. This scheme is still used if a fixed figure is to be shown in a fixed location on the display. Dedicated alphanumeric displays, such as the Up Front Control Display, may use direct addressing.

Multiplex and active matrix addressing both send a separate signal to each picture element (pixel) in a dot matrix used for a computer or television screen. The active display area is divided into a grid of "wires" by horizontal lines on the front plate and vertical lines on the back plate. The line intersections define the matrix and coincide with pixels. The signals for a given row are applied simultaneously, requiring M leads from the display if there are M dots in a row. If there are N rows some N additional leads are required to activate each given row when its turn comes to receive its M signals. Thus, M + N leads are required. Multiplex and active matrix addressing differ in terms of charge storage. No charge is stored at each pixel in multiplex addressing and the LC molecules begin to relax as soon as the locally applied electric field is removed. For this reason multiplex addressed displays cannot operate at real-time video frame rates if they are too large (>2" X 2"). New "active-addressing" schemes (AALCD) extends multiplex addressing to larger size displays (5" X 5") via frequent refresh of selected pixels in proportion to their commanded grey level.

The multiplexing technique works adequately for small displays, but even there the image is far less crisp than on a cathode ray tube (CRT). (Almost all present-day displays in TVs and computer monitors are CRTs.) Charge from one pixel location permeates adjacent pixels -- even pixels that are supposed to be off get slightly turned on. The result is lower contrast: instead of crisp black and white, the image appears in barely distinguishable shades of gray. By the mid-1970's multiplexed LCDs had become dominant in portable displays of low and medium information content and are referred to as "STNs" after the type of LC used. Current manufacturing capacity is a 10" diagonal. Prototypes up to 14" diagonal have been demonstrated in research facilities for non-video use.

The size limitation on multiplex addressed displays results from the fact that they must be refreshed. The electrical signal conveyance capability (bandwidth) of the electronics imposes a size limit of about 10" X 10". At 160 dots/inch (1600 X 2 leads) for multiplex addressed screens in video applications a structured, 8-bit signal enables a 256-level grayscale but requires 20.48 Mb/ frame at 60 frames/ sec, or 1.23 Gbps bandwidth. A fiber optic has the capacity to deliver 1.23 Gbps to the display controller board where demultiplexing leaves a still high 768 Kbps to be fed to each column driver. Each column driver must then, in turn, put out 96,000 structured analog signals/ sec. This bandwidth problem can be overcome by storing charge at each pixel.

Active matrix (AM) addressing involves storing charge at each pixel. Charge is stored in a semiconductor switch: either a metal-insulator-metal (MIM) diode or a thin-film-transistor (TFT). The latter is preferred. The TFT can transfer and store enough voltage to quickly switch a liquid crystal pixel from light to dark, resulting in a sharp image with no blurring or fading. With the TFT active matrix the electric charge used to switch one pixel no longer spills over into neighboring ones. As a result, the contrast between completely on and off pixels can approach 100:1, versus 6:1 in a multiplexed LCD. And because the TFTs are deposited on a transparent glass substrate, the display can be lit from behind, further enhancing its viewability. Red, green, and blue filters can be placed at each subpixel to form a color display. Because of its high contrast capability, an active matrix display can produce full color images that look as good or better than those produced by CRTs.

An AMLCD is then a large integrated circuit (IC). The manufacturing technology is a combination of LCD and IC equipment and processes.

AMLCDs will go through several generations as the quality of the semiconductor circuit material improves. Usually this material is silicon (Si) with some use of alternatives such as cadmium selenide (CdSe). Achieving a large area layer of Si suitable for TFT circuits in display-sized areas was a technical challenge that had to be overcome. AMLCDs for pocket televisions and laptop computer displays are currently in production using first-generation, or amorphous silicon (a-Si) technology. Most manufacturing investment is presently going into a-Si production capacity. Polycrystalline silicon (polysilicon or p-Si) and single crystal silicon (x-Si) offer improved capabilities but are more difficult to form over large surface areas.

Polysilicon initial OEM shipments in 1990 (Japan) began the second-generation of AMLCDs. Polysilicon technology is under development in the US (Sarnoff, Xerox, OIS), France (Thompson CSF/ Sextant), and Japan (NEC, Sharp, Toshiba, etc.). Single-crystal technology is being explored by Kopin in the US.

Displays fabricated in p-Si are superior to those fabricated in a-Si with respect to most physical properties (drive current, electron mobility, stability, response uniformity, light sensitivity, connector interface size, and radiation hardness). The a-Si is superior to p-Si only in leakage current (p-Si is too high), which gives a-Si displays the edge for static (nonvideo) displays. Additional advantages of p-Si (over a-Si) are: (1) the active matrix can be formed at high temperature (625°C) enabling the use of additional integrated circuit manufacturing processes, (2) a high performance transistor can be provided because of the higher electron mobility in p-Si, (3) PMOS and NMOS TFTs are all CMOS circuitry design establishing commonality and compatibility with microchip designs, (4) TFTs like those used at each pixel can also be used to fabricate the display drivers on the glass substrate at the boundary of the active display area, and (5) the potential to integrate the system on the glass. Also, p-Si TFTs require less area than a-Si TFTs and, thus permit more light/ pixel through, which means that p-Si and x-Si displays will require less backlight intensity and, thereby, consume significantly less power. Some technologists favor a-Si for direct view displays and p-Si for projection.

A manufacturing challenge is presented by the p-Si technology. It presently costs 4 - 5 times as much to produce a given AMLCD in p-Si compared to a-Si. One must either use a higher cost optical substrate (quartz) to withstand the high-temperature processes of current p-Si fabrication technology, develop a low-temperature (less than softening point of glass) p-Si fabrication technology;or use the circuit transfer technology discussed below for x-Si. The p-Si technology is presently being expanded with ARPA funding under contracts managed by the Wright Laboratory Cockpit Avionics Office and Manufacturing Technology Directorate (AF MANTECH).

Single crystal silicon is superior to p-Si in its physical properties. The electron mobility is highest in the x-Si form of Si providing the greatest display speed and size at the minimum input power. Manufacturing techniques are just being worked out and demonstrated for x-Si displays. An additional advantage of x-Si over p-Si is that it can be processed at yet higher temperatures, enabling more standard IC manufacturing processes for microchips to be used on macrochips (i.e. AMLCDs). These higher temperature processes are above the melting of the glass substrate normally used for a-Si and p-Si AMLCDs. Thus, the x-Si process development involves either a different substrate, such as a high temperature transparent plastic (e.g. Lexan polycarbonate resin), or a transfer process to move the completed x-Si circuit from the fabrication substrate/ carrier (e.g. SiO_2) to the display substrate (i.e. glass). The latter technique was pioneered under ARPA contracts managed by the Cockpit Avionics Office and is now being used to develop 1280 X 1024 pixel displays in a 1.3" X 0.9" format.

The evolution of AMLCD manufacturing as each generation emerges from research to applications will take many years. Several generations of AMLCD technology are anticipated -- a-Si for direct view displays, p-Si for direct view and projection displays, x-Si for HMD/ virtual-reality systems, and tiling for large area (200 - 300 sq. in.) displays built as a mosaic of smaller panels. One manufacturer (Litton, Canada) is developing CdSe based instead of Si based AMLCD technology.

Military AMLCDs differ from commercial AMLCDs in several regards. First, they have a heater and, often a night vision filter and an anti-reflection filter. Second, the LC and other materials must be tailored to military environmental requirements. Third, wide range (>4000:1) dimming electronics is required. The remaining parts are mostly common with commercial aviation and automotive displays. It is important to note that the highest value added item, the active glass sandwich (i.e. the unfilled liquid crystal cell), may be common to more general commercial applications, such as computer screens, if the viewing area is the same.

A flat panel user guide from Stanford Resources provides an in-depth resource on AMLCD and other flat information display technologies.

APPENDIX C

LIST OF PARTICIPATING ORGANIZATIONS

TABLE C-1. Government Participants

Name of Participant and Organization	Date(s) of Meeting(s) Attended	Type of Meeting
Mr. James Barnaba ASC Subsystems SPO	7-8 Apr 1993	Gov. & Ind.
Mr. James Byrd ASC Display Engineering	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Mr. James Thorndike ASC Subsystems SPO	7-8 Apr 1993	Gov. & Ind.
Mr. Marvin Most ASC F-16 SPO	7-8 Apr 1993	Gov. & Ind.
Ms. Lea Gordon ASC F-22 SPO	7-8 Apr 1993	Gov. & Ind.
Capt Ken Millard ASC F-22 SPO	7-8 Apr 1993	Gov. & Ind.
Capt Christine Cartaya ASC F-22 SPO	7-8 Apr 1993	Gov. & Ind.
Mr. Wayne Martin AL/CFA	4 Nov 1993	Gov. & ARINC
Mr. Dave Post AL/CFHV	4 Nov 1993	Gov. & ARINC
Mr. Sherman Morton WR-ALC F-15 HSI AMLCD Redesign	7-8 Apr 1993	Gov. & Ind.
Mr. Robert Zwitch WR-ALC E-3 Display Trade Study	7-8 Apr 1993	Gov. & Ind.
Dr. Darrel Hopper WL/AAA-2	7-8 Apr 1993 4 Nov 1993 18-19 Nov 1993	Gov. & Ind. Gov. & ARINC Ind. & CAO
Capt William Dolezal WL/AAA-2	7-8 Apr 1993 4 Nov 1993	Gov. & Ind. Gov. & ARINC
Mr. Bill Hale WL/AAA-2	4 Nov 1993 18-19 Nov 1993	Gov. & ARINC Ind. & CAO
Mr. Joseph Ghrayeb WL/AAA-2	4 Nov 1993	Gov. & ARINC

TABLE C-1. Government Participants (continued)

Name of Participant and Organization	Date(s) of Meeting(s) Attended	Type of Meeting
Mı. ˀobert Michaels WL/AAA-2	4 Nov 1993	Gov. & ARINC
Mr. Gurdial Saini WL/AAA-2	4 Nov 1993	Gov. & ARINC
Capt Allen Revels WL/DOL (AAA-2)	4 Nov 199	Gov. & ARINC
Mr. Walter Melnick WL/FIPC	7-8 Apr 1993	Gov. & Ind.
Mr. Anthony Bumbalough WL/MTEA	4 Nov 199	Gov. & ARINC
Mr. Frank Bick AMSAT-R-ESC	7-8 Apr 1993 4 Nov 1993	Gov. & Ind. Gov. & ARINC
Mr. Eric Gurd US Army TACOM	4 Nov 1993	Gov. & ARINC
Ms. Laurel Elliot-Sadler Army Research Laboratory	7-8 Apr 1993	Gov. & Ind.
Mr. Tom Kelly U.S. Army	7-8 Apr 1993	Gov. & Ind.
Mr. John Parker Naval Air Systems Command	7-8 Apr 1993	Gov. & Ind.
Mr. George Burrows Naval Air Warfare Center	7-8 Apr 1993	Gov. & Ind.
Mr. James Moore Naval Air Warfare Center	7-8 Apr 1993 4 Nov 1993	Gov. & Ind. Gov. & ARINC
Mr. Charles Halsted Naval Air Warfare Center	4 Nov 1993	Gov. & ARINC
Mr. William Mulley Naval Air Warfare Center	7-8 Apr 1993	Gov. & Ind.
Ms. Sally Hanuscin Naval Aviation Depot	7-8 Apr 1993	Gov. & Ind.

TABLE C-2. **Industry Participants**

Name of Participant and Organization	Date(s) of Meeting(s) Attended	Type of Meeting
Mr. Zvi Yaniv Advanced Technology Incubator, Inc	7-8 Apr 1993	Gov. & Ind.
Mr. Bharat Vakil Allied-Signal ATA	18-19 Nov 1993	Ind. & CAO
Mr. Michael Rock Allied-Signal Aerospace Company	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Mr. John Wilson Allied-Signal Aerospace Company	7-8 Apr 1993	Gov. & Ind.
Mr. John Liccione ARINC Research Corporation	7-8 Apr 1993	Gov. & Ind.
Mr. Thom Roberts ARINC Research Corporation	4 Nov 1993 18-19 Nov 1993	Gov. & ARINC Ind. & CAO
Mr. Keith Schur ARINC Research Corporation	4 Nov 1993 18-19 Nov 1993	Gov. & ARINC Ind. & CAO
Mr. Robert Yienger ARINC Research Corporation	4 Nov 1993 18-19 Nov 1993	Gov. & ARINC Ind. & CAO
Ms. Peg Shaffer ARINC Research Corporation	18-19 Nov 1993	Ind. & CAO
Ms. Karlene Harris ARINC Research Corporation	18-19 Nov 1993	Ind. & CAO
Mr. John Rizzo Astronautics Corporation of America	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Mr. Earl Ratliff Astronautics Corporation of America	7-8 Apr 1993	Gov. & Ind.
Mr. John Rantenen Astronautics Corporation of America	7-8 Apr 1993	Gov. & Ind.
Mr. Tim Stauffer Battelle	7-8 Apr 1993	Gov. & Ind.
Mr. Jeff Melaragno Battelle	7-8 Apr 1993	Gov. & Ind.
Mr. Randall Orkis Battelle	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Mr. Paul Wren B. F.Goodrich Aerospace	7-8 Apr 1993	Gov. & Ind.

TABLE C-2. **Industry Participants (continued)**

Name of Participant and Organization	Date(s) of Meeting(s) Attended	Type of Meeting
Mr. Frederic Quan Coring, Inc.	18-19 Nov 1993	Ind. & CAO
Mr. Russell Watts Cybernet Systems Corp.	7-8 Apr 1993	Gov. & Ind.
Mr. Arnold Lagergren DTI	7-8 Apr 1993	Gov. & Ind.
Mr. Leon LeCave Display & Technologies, Inc.	7-8 Apr 1993	Gov. & Ind.
Mr. John Lapp GEC-Marcone Avionics, Ltd.	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Mr. Colin Lennon GEC-Marcone Avionics, Ltd.	18-19 Nov 1993	Ind. & CAO
Dr. John Erbacher General Research Corp.	7-8 Apr 1993	Gov. & Ind.
Mr. Mark Poling Grimes Aerospace	18-19 Nov 1993	Ind. & CAO
Mr. Ted Wood Honeywell Defense Avionics Systems Division	7-8 Apr 1993	Gov. & Ind.
Mr. Jeff Groat Honeywell (Graphics Processor Development)	7-8 Apr 1993	Gov. & Ind.
Mr. Randy Blanchard Hughes Aircraft Co.	7-8 Apr 1993	Gov. & Ind.
Mr. Russ Schwarzer Hughes Aircraft Co.	7-8 Apr 1993	Gov. & Ind.
Mr. John Fowler Hughes Aircraft Co.	7-8 Apr 1993	Gov. & Ind.
Mr. Ron Hegg Hughes Aircraft Co.	7-8 Apr 1993	Gov. & Ind.
Mr. Ian Huntley-Playle Hughes Aircraft Co.	7-8 Apr 1993	Gov. & Ind.
Hyundai - Advanced Display Technologies Mr. Scott Holmberg	7-8 Apr 1993	Gov. & Ind.

TABLE C-2. **Industry Participants (continued)**

Name of Participant and Organization	Date(s) of Meeting(s) Attended	Type of Meeting
Mr. Steve Hix In-Focus Systems	7-8 Apr 1993	Gov. & Ind.
Mr. Herb Richardson In-Focus Systems	7-8 Apr 1993	Gov. & Ind.
Mr. John Olsen IBM Corp.	7-8 Apr 1993	Gov. & Ind.
Mr. Robert Komar IBM Corp.	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Dr. Edward Feustel Institute for Defense Analyses	7-8 Apr 1993	Gov. & Ind.
Mr. Robert Ehlert Interstate Electronics Corp.	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Mr. Larry Wade JWK, Inc.	7-8 Apr 1993	Gov. & Ind.
Mr. Lynn Giroir Kaiser Electronics	7-8 Apr 1993	Gov. & Ind.
Mr. James St. Jean Kaiser Electronics	7-8 Apr 1993	Gov. & Ind.
Mr. Paul Rust Kaiser Electronics	18-19 Nov 1993	Ind. & CAO
Mr. Dean Fisher Kaiser Optical Systems	18-19 Nov 1993	Ind. & CAO
Mr. Jim McNaughton Kaiser Optical Systems	18-19 Nov 1993	Ind. & CAO
Mr. Ronald Ruta Litton Systems Canada, Ltd.	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Mr. James Walker Lockheed	7-8 Apr 1993	Gov. & Ind.
Mr. Wes Halstead Lockheed-Sanders	7-8 Apr 1993	Gov. & Ind.
Mr. Rich Hicks Lockheed-Sanders	7-8 Apr 1993	Gov. & Ind.
Mr. Gordon Neal Lockheed-Sanders	7-8 Apr 1993	Gov. & Ind.

TABLE C-2. **Industry Participants (continued)**

Name of Participant and Organization	Date(s) of Meeting(s) Attended	Type of Meeting
Mr. Theodore Zammit Magnascreen Corp.	7-8 Apr 1993	Gov. & Ind.
Mr. Frank Cupero Norton Systems	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Dr. Fang Luo Optical Imaging Systems, Inc.	7-8 Apr 1993	Gov. & Ind.
Mr. Michael Lambie Optical Imaging Systems, Inc.	7-8 Apr 1993 18-19 Nov 1993	Gov. & Ind. Ind. & CAO
Mr. Frank Bonham Optical Imaging Systems, Inc.	18-19 Nov 1993	Ind. & CAO
Mr. Scott Clark Rockwell International Corp.	7-8 Apr 1993	Gov. & Ind.
Mr. Rob McKillip Rockwell International Corp.	18-19 Nov 1993	Ind. & CAO
Mr. Gerry Kaiser Rockwell International Corp.	7-8 Apr 1993	Gov. & Ind.
Mr. Darrel Peterson Rockwell International Corp.	7-8 Apr 1993	Gov. & Ind.
Mr. Jeff Newcomb SCI	7-8 Apr 1993	Gov. & Ind.
Mr. Michael Lengyel Science Applications International Corp.	7-8 Apr 1993	Gov. & Ind.
Mr. John Binger Smiths Industries	7-8 Apr 1993	Gov. & Ind.
Mr. Kevin Kelleher Smiths Industries	7-8 Apr 1993	Gov. & Ind.
Mr. James Doubek Smiths Industries	7-8 Apr 1993	Gov. & Ind.
Mr. Phil Ernvall Smiths Industries	7-8 Apr 1993	Gov. & Ind.
Ms. Barbara McQuiston Sytronics, Inc.	7-8 Apr 1993	Gov. & Ind.
Mr. Scott Myers Sytronics, Inc.	7-8 Apr 1993	Gov. & Ind.

TABLE C-2. **Industry Participants (continued)**

Name of Participant and Organization	Date(s) of Meeting(s) Attended	Type of Meeting
Mr. Richard Groppi Tektronix, Inc.	18-19 Nov 1993	Ind. & CAO
Mr. Allen Gard Tektronix, Inc.	18-19 Nov 1993	Ind. & CAO
Mr. Peter Rothenberg Teledyne Systems Co.	7-8 Apr 1993	Gov. & Ind.
Mr. Al Riggs Teledyne Systems Co.	7-8 Apr 1993	Gov. & Ind.
Dr. Don Moon University of Dayton	7-8 Apr 1993	Gov. & Ind.
Mr. Charlie Boyd Vought Aircraft	18-19 Nov 1993	Ind. & CAO