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Avionic Displays

Branko Livada[1)]

This paper addresses the basic functions and dimensions of principal avionic displays helping to determine the opportunities for applying different display technologies in the harsh avionic environment. The avionic displays are specified by their active area and dimensions as well as other characteristics such as luminance, resolution, viewing envelope, colour, gray scale, night vision compatibility and sun light readability. In addition, some typical requirements for avionic display properties are discussed. This paper further provides a short overview of the key technologies used in display design and their compliance with the basic requirements. The Commercial Of The Shelf - COTS components application concept was successfully applied to the AMLCD flat panel technology after resolving initial issues. The AMLCD stays a dominant technology for the application in avionic displays as well as for other military applications.

Key words **avionics, avionic display, new technologies, liquid crystals.**

Introduction

MODERN avionic systems use digital ruggedized displays [1]-[4]. Ruggedized displays technology development is linked to specific military and aerospace applications, which means that ruggedized displays are suitable for applications in demanding environmental conditions.

Avionic display applications and needs are still a leading ruggedized displays advancement source, providing new technical solutions mainly based on specific enhancement of available COTS (Commercial of The Shelf) panels.

Nowadays, this technology is fully transferable to other areas of application such as industrial displays, medical, automotive, etc., and the term ruggedized extended its meaning to “advanced”, or “customized” more often than “militarized“.

Whenever there is a need to obtain some additional display feature for specific application such as:

- Sun Readability
- High Contrast
- High Brightness
- NVIS Compatibility
- Wide temperature range & Environmental
- Improved EMI shielding
- Increased Colour Gamut
- Increased Colour Rendering Index
- Controlled Viewing Angle
- Specific Video signal Interface
- Specific communication Interface
- High Reliability and long Lifetime
- BIT (Built In Testing) and Controls
- Special Bezel Functions

one should ask for a ruggedized display solution.

Depending on the application, different levels of ruggedization and appropriate technical solutions can be applied [5]. In the present time, preferred solutions use COTS AMLCD panels adapted to work properly for specific application by adding new features using existing technological solutions [7, 8]. This process requires deep understanding of the current scientific and technological advancement. Display development means application of technological achievements through application of specific skills to implement known solutions into new products.

That adaptation process and/or ruggedization usually involve the following engineering solutions and changes:

Mechanical Design: contributes to the display functionality in all specified environmental conditions (temperature, vibration, etc.), displays mechanical interface to the user’s system, and integrates all other design solutions providing a suitable and compact mechanical design.

Electrical/Hardware Design: provides electrical power interface design (external and internal), EMI/EMC compatibility, AMLCD driving and control circuits, LED backlight driving circuits, backlight control functions (colour sensor, temperature sensor, bezel illumination sensor, etc.).

Software (Firmware) Design: involves design solutions leading to an extended range of the display microprocessor controlled functions, required video signal interface and transformation functions, Built-in Test functions (BIT), pre-programmed graphics, etc.

Optical Design**:** usually involves design changes necessary to include more reliable LED backlight and special display optical features such as: NVIS Compatibility, Sun Readability, wide viewing angle, high brightness, high contrast, etc.

All engineering solutions and changes involved are cross-dependent and lead to unique technical solutions necessary to fulfil basic requirements.

This paper discusses possibilities of display technologies and how their capabilities were used in past or will be used in near future.

1) Luxell Technolgies Ltd., Mississauga, Toronto, CANADA

Ruggedized display structure

As depicted below (see Fig.1), a ruggedized display is a complex optoelectronic system. Such a system requires a complex design. In addition, a display requirements tracking process should be applied throughout its whole life cycle (Preliminary Design, Full Development, Manufacturing, Operational use, and Disposal). The display key subsystems are described below.

Bezel – incorporates switches, pushbuttons and indicators which can be equipped with appropriate backlight including NVIS filtered backlight. In addition, ambient light sensors can be used as a part of the display brightness automatic control electronics.

Display Active Surface – displays visual information content.

Housing, Mechanical Interface – used to provide display parts integration and proper mechanical mounting in the user's system.

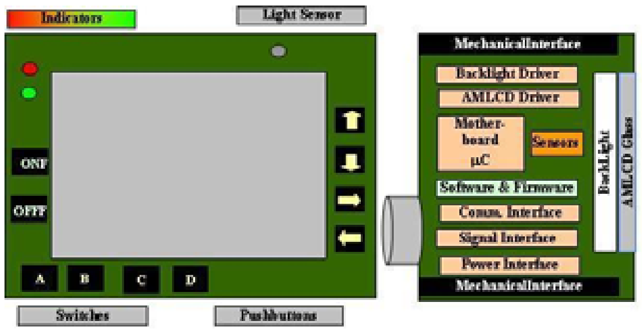
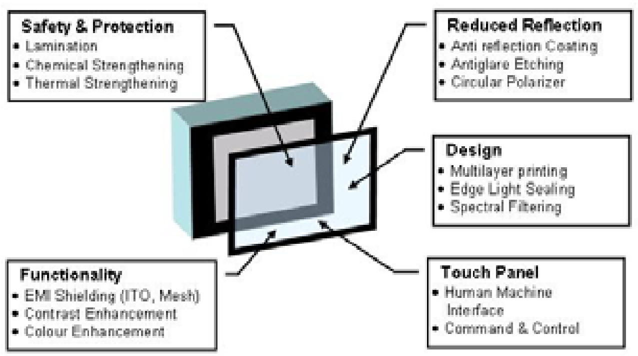
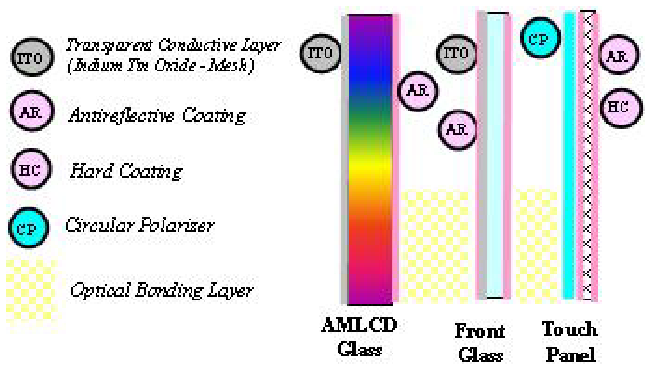


Figure 1. Ruggedized Display generalized structure



(a)



(b)

Figure 2. Front Glass: (a) functions and (b) generalized structure

Ruggedized display device – is the most important part of the display system, including integration of novel technologies into unique functionality and contributing to the display mechanical strength.

Generally speaking, this part consists of:

- Touch Panel (if required, as a part of Cover Glass)
- Front (Cover) Glass (see Fig.2) - providing antivandal protection, antireflective front surface, transparent conductive EMI layer, spectral filtering for contrast enhancement, better AMLCD Glass thermal management at elevated ambient temperatures when laminated, and/or NVIS, etc.
- Display Device (CRT, FEL, AMLCD, OLED, etc.) – electronically controlled pixel array structure.
- Display device Heather – providing low temperature operation

Backlight – is another critical subsystem (if used) consisting of two main parts

- **Optical Stack** (light collection and beam shaping optics)
- **Illumination Source** (suitable light source, CCFL, White LED, R G B LEDs)

Backlight can be designed as:

a) Bottom Illuminated (Illumination source is distributed in a matrix bellow the AMCLD active surface)

b) Side illuminated (Illumination source is located on the side and light is transferred to the AMLCD using Waveguide optics).

Backlight Driving Electronics – energy efficient driving circuits including dimming control electronics.

Display Driving Electronics – drives display pixels (light valves) according to video signal content.

Motherboard & Microcontroller – Integrates all electronics and control circuits.

Software and Firmware – application tailored embedded software and firmware controlling display functions, graphics and controls.

Communication Interface Electronics – electronic boards designed for proper communication with the user system.

Power Interface – transform external power source voltage to voltages needed for the display operation.

Signal Interface Electronics – transforms used video signal formats into the signal compatible with the AMLCD driving electronics.

Sensors – usually used to sense display temperature, illumination level or colour, and produce signals used in the display automatic control functions.

The dependability matrix between the display subsystem structure and the display features is illustrated in Table 1, showing how the required display features influence the display structure and design.

Modern avionic displays designs tend to use some of specific functions supporting flight control needs. Having in mind basic display functions, various types of displays can be used in avionic applications:

- MFD – multi-functional displays – capable of providing different pre-programmed functions and visual contents
- MMD – moving map displays – displaying digitalised maps.
- EFIS – electronic flight instrument system – providing specialized functions: EMD – engine monitoring displays, FDU – flight display unit, TWD – threat warning display.

Table 1: Display features and Components dependability matrix

Display Features ⇒ / Display Subsystems & Components ⇓	Sun Readability	High Brightness	High Contrast	NVIS Compatibility	Wide temperature range	EMI Shielding	Increased Colour Gamut	Increased Colour Rendering	Controlled Viewing Angle	Specific Video Signal Formats	High Reliability & Long Lifetime	BIT (Built In Test) and Controls	Special Bezel Functions
Bezel	■			■									■
Active Surface	■	■	■	■	■	■							
Display Device	■	■	■	■	■	■	■	■		■	■		■
Touch Panel	■		■			■					■		■
Cover Glass	■	■	■			■							
Display Surface		■	■		■	■	■	■		■			
Heater		■	■		■								
EMI Shield	■	■	■		■								
Backlight	■	■	■	■	■		■	■	■		■		
Optical Stack	■	■	■						■				
Light Source	■	■		■	■		■	■			■		
Housing					■								
Backlight Driver			■	■							■	■	
Display Driver					■					■			
Motherboard					■							■	■
Soft/Firmware							■	■		■	■	■	■
Comm. Interface					■						■	■	■
Power Interface					■						■		
Signal Interface					■					■			
Sensors	■	■	■		■							■	■

Display basic properties

The main purpose of any display is to show visual information suitable to be used with the human visual system (HVS). The HVS is a complex and highly evolved system and, to date, no display technology has been able to match its capacity. A definition of the display optical properties should provide the metrics of display conformance with the HVS-related requirements.

An amazing amount of work has been done to establish a reasonable system of parameters defining display properties and standardized measurement methods [9-17]. Nevertheless, this work has not been finished yet. In addition, specific applications need specific requirements definition and measurement methods development.

Information capacity

On the one hand, the amount of visual "information" that a display is able to convey is related to the "information content" of a display, defined through the total number of pixels, the size of the pixels (resolution) and the size of the display active area. On the other hand, there is the eye's ability to discern details - *visual* [18] and the eye-brain system perceptual capability.

The human visual system (HVS) has evolved over millions of years. The disparity between the natural world appearance perceived with the HVS and that potentially "sampled" by the year 2000 display technology is more than a factor of one million. The grand challenge for display technology is to close this fantastic 10^6 gap between devices and the human visual system [12]. On the other hand, we have airworthiness requirements providing accurate message recognition and safe, on time, reaction that set higher information caption threshold levels. In these circumstances, display technology capability is much closer to the HVS system.

The acuity of an average human eye can resolve an individual pixel of approximately one arc-minute of the visual context wide. Visual acuity determines the level of detail that an eye can absorb from the pattern of pixels present on a screen. The closer the object isviewed, the smaller the level of detail can be determined.

Brightness (Luminance)

The brightness of a viewed object is defined in a psychological sense as a level of light intensity perceived by a viewer. The key physical measure of brightness is luminance. Brightness is defined as the luminance of the brightest component (usually white colour) in the centre of the screen and is measured in candela per square metre (cd/m^2 = nit) or footlamberts (1fL=3.426 nits).

The typical display luminance varies from 100 nits in the shadowed office environment up to 1000 nits in the high ambient illumination environment.

The other important consideration for display technologies is the luminance dynamic range (dimming range), i.e. the ratio between the minimum and the maximum luminance that can be generated and allow display luminance to set a value in accordance with human eye accommodation properties. Avionic displays have a dimming range up to 1:200 in the day light operating mode and the same in the night mode. The brightness change over the dimming range should usually follow a predefined brightness control law to provide optimal visual information reception.

Contrast

Display Contrast Ratio is the ratio of the maximum luminance to the minimum luminance that can be generated in the same image. *Display Contrast* is created by the difference in luminance from two adjacent surfaces. It is related to the display image detail luminance L and the background luminance L_b (usually defined as: $(L-L_b)/L_b$)).

These parameters should be specified in a predefined illumination environment where ambient light and reflections from the screen will significantly affect the values.

A display may not be able to deliver a "pure" black because the technology applied leaks light or reflects ambient light. A good display will offer a contrast ratio that exceeds 1000:1 in the dark, and will be able to display a nearly "pure" black. From the point of view of the HVS contrast sensitivity, it is more than enough.

A contrast ratio higher than 5:1 is required as a minimum for image details detection in the high ambient light environment. In this case, black and other colours are „washed up".

Colour Properties

An average human eye can perceive millions of different colours. The 1931 Commission Internationale de l'Eclairage (CIE) developed a three dimensional colour "space" that allowed any visible colour to be mapped. Any colour could be located within the colour space and its composition from each of the three primaries (Red, Green and Blue) can also be determined.

Display colour reproduction ability depends on the purity of display primary colours. It is usually represented by a triangle in the colour space having red, green and blue colour in the corners, also known as the colour gamut. The display gamut is compared with the standard gamut (NTSC) and the gamut quality is defined as the ratio of the display gamut area and the standard gamut area in the (u', v' - CIE 1976) chromaticity chart.

Emissive colour displays usually have more pure primaries and hence a wider gamut than non-emissive ones.

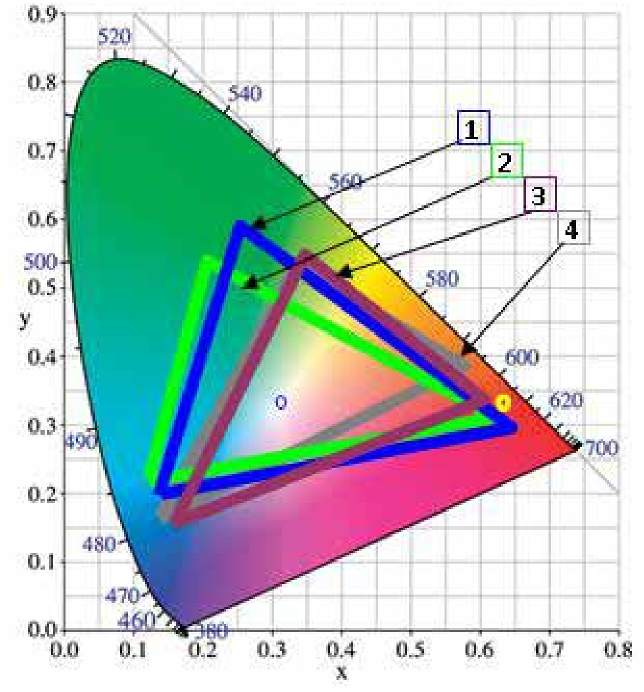


Figure 3. Display typical gamut: 1-Emissive PDP,CRT, 2-LCD +RGB backlight, 3-LCD+CCFL, 4-LCD+WLED

Resolution

The key measure for display quality, in accordance with the HVS acuity is the pixels density expressed in pixel per inch (PPI) or pixel per millimetre (PPMM). The requirements for display resolution depend on the application through the anticipated observer to display distance, where 300 PPI (12 PPMM) is a typical visual acuity limit for hand held device displays – so-called retinal displays, 170 PPI (7 PPMM) is a visual acuity limit for avionic displays and 200 PPI (8 PPMM) is a good approximation of the HVS requirement within a computer gaming display application environment.

Active Area

The Avionic Display shape is determined by the cockpit design and it is standardized [19]. The display active area should fulfill the display front surface as much as possible.

The active area is the display surface where the information content is presented. It is measured by the diagonal (usually expressed in inches or mm), and the aspect ratio (1:1, 5:4, 4:3, 16:10, 16:9). Avionic displays traditionally had 1:1 aspect ratio, and a relatively small diagonal, but nowadays, in newly designed multifunctional displays, a large active area and commercial aspect ratio is more often used. The most common sizes of avionic displays are illustrated in Fig.4.

Viewing Envelope

The angle of view is defined as the angle at which the viewer must be positioned in relation to the screen in order to clearly see the image on a display. The angular viewing envelope is the space that contains all required viewing angles.

Avionic displays should have a viewing envelope that covers at least $\pm 60^o$ horizontally and $+30^o/-20^o$ vertically, but more specific detail requirements could be set according to application.

Response-time

The time an individual pixel or cell in a display screen takes to change from the minimum to the maximum and vice versa is known as the *response time* and is measured in milliseconds (ms). The response time affects the ability to change an image rapidly on the screen.

Some typical response time values required are:

- 25ms for general computer applications,
- 12 - 15ms for TV, sports and gaming,
- 100ms in the case of avionic displays using the slow changing graphical content.

LCDs have an inherent latency time due to switching of the liquid crystal gates and this introduces a longer response time than it is required by some content types. Also, switching time highly depends on the temperature. To operate at low temperatures, LCDs require local heating.

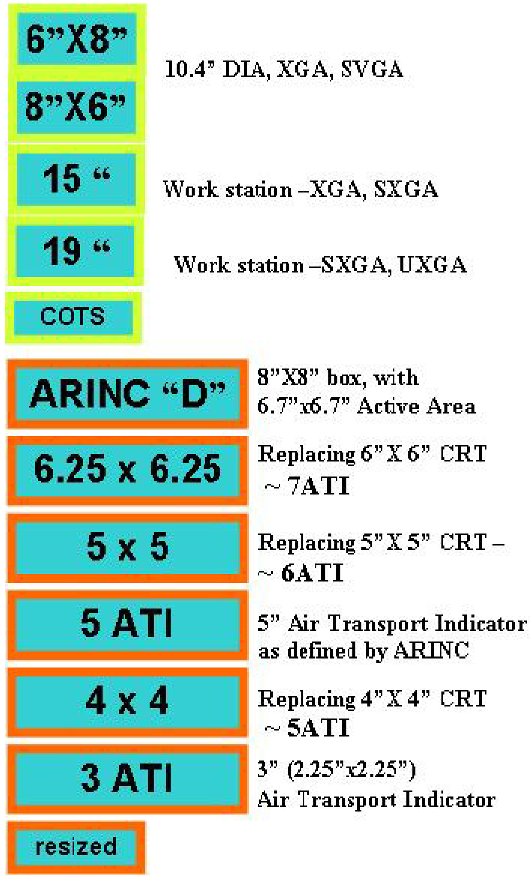


Figure 4. Avionic Display most common sizes

Sun-Readability

Readability in a high ambient lighting from as low as zero to as high as 100.000 lx of diffuse and/or collimated illumination from one or more directions is the avionic display typical requirement. The display should be mounted to minimize the impact of the ambient illumination. The display front surface should be optically enhanced to minimize diffusive and specular reflectance.

For a "mission critical" display, a high ambient illumination requirement is usually specified through the threshold contrast ratio [10], [12], in the given illumination environment. The most common definitions of the high illumination environment are presented in Table 2.

The measurement method and set-up should be clearly defined. A minimally required contrast value depends on the type of information displayed (2 - alpha numerical; 3 - graphics; 4.66 ($4\sqrt{2}$ gray levels) for a B/W image)

Table 2. High Illumination Environment definitions

	Specular (glare) Source	Diffusive (point) Source	NOTE
	[*fL*]	[*fc*]	
1	2000	10000	Fighter, bubble canopy
2	2000	8000	Helicopter
3	2000	2000	The most realistic combined reflection
4	500	10000	
5	-	8000	
6	-	10000	Without specular reflection

NVIS Compatibility

To obtain a possibility to use both the display unit and the **NVG** (**N**ight **V**ision **G**oggle) at the same time, a specific technical solution is selected. Sharing the optical spectra is achieved by using special optical filters on the NVG and the display unit. NVGs are filtered using a so-called "minus blue" filter, and the display unit is filtered to eliminate excess NIR radiation, so the display can be operated successfully using the naked eye, and without disturbing the NVG. The NVIS compatibility is illustrated in Fig.5. The NVIS compatibility requirements are defined in the standard [14].

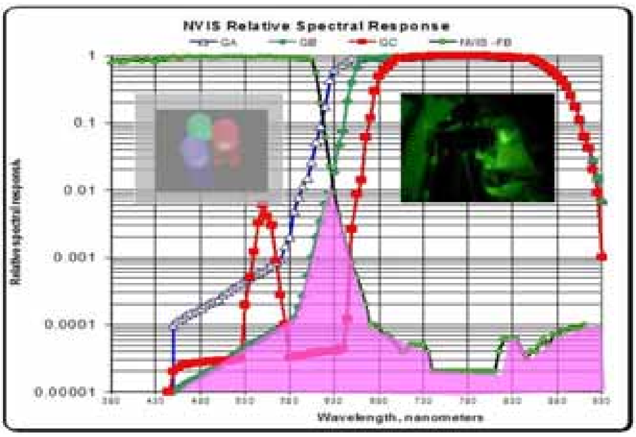


Figure 5. NVIS compatibility sharing spectrum

A display used in the NVIS compatible mode has a limited gamut – a poor red gamut corner.

Electromagnetic Compatibility

To provide proper EMC, suitable for the complex avionic EM radiation environment, display electronics is equipped with EMI filters, and the display active area is covered with a transparent conductive layer (ITO or micro mesh) connected to metal housing forming the Faraday cage.

Environmental Properties

A wide operation temperature range is the most critical environmental requirement. Operation at low temperatures (up to -40°C) could be achieved using heaters, but operation at high temperatures (up to +85°C), should be inherent to the applied display technology and the display structure.

Display Technologies

The simplified classification of the flat panel display technologies is shown in Fig.6. An emissive display is one that produces its own light; a passive display modulates light that passes through it.

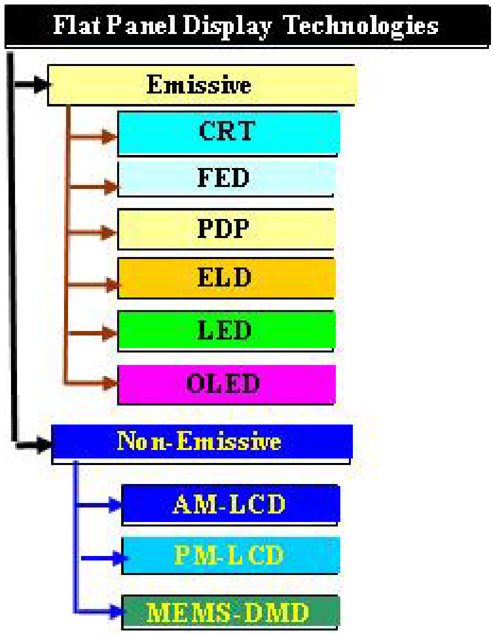


Figure 6. Flat Panel Display classification

Emissive Display Technologies

The emissive display simplified pixel structure and the operation principles are illustrated in Fig.7.

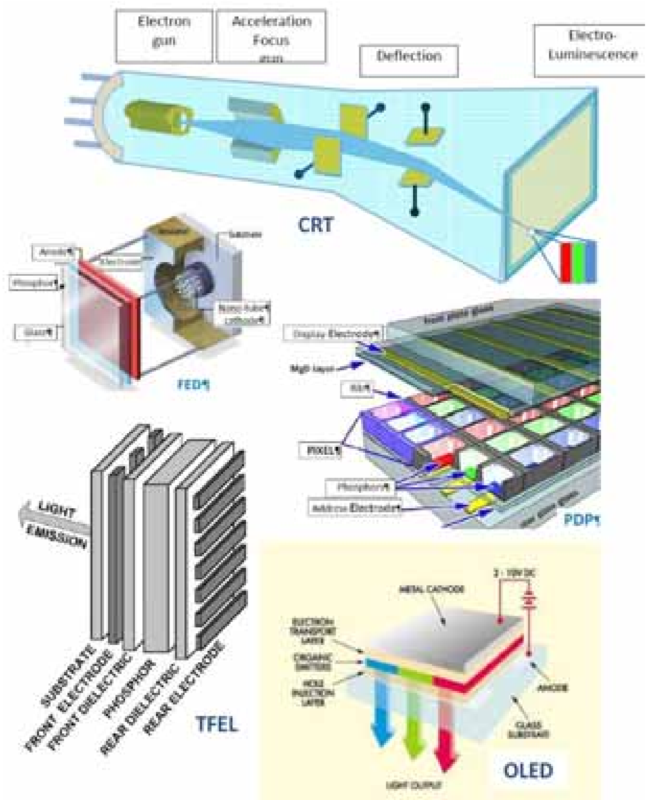


Figure 7. Emissive Displays pixel structure and operation

CRT – Cathode Ray Tube

The Cathode Ray Tube (CRT) has been the standard form of displaying an image for TV and computer terminal screens for over 80 years [18]. The colour picture is generated by tiny dots of three types of phosphorous (red, green, blue), deposited on the inside of the screen, which glow when they are hit by electrons. The electrons are generated by heating an element consisting of many tiny wires (the cathode), placed at the back of the vacuum tube, in a process known as *thermionic emission*. The flow of electrons is controlled by a magnetic field provided by copper coils wrapped around the vacuum tube. The coils direct the beam of electrons in a sweeping movement, 'drawing' one horizontal line of the image at a time (a process known as raster scanning). This takes place in the vacuum in order to avoid ionising of air during the thermionic process, which would adversely affect the operation.

FED - Field Emission Displays

Field emission devices use electrons to fire up a phosphor screen directly, in the same manner as traditional CRTs. However, with field emission devices the mechanism used to generate the electrons is completely different. It is non-thermionic and uses the physical properties of the “field emission effect” and “quantum tunnelling”, whereby a low voltage is applied to a very large number of tiny, highly pointed cathodes in order to release electrons. These cathodes can be made from a number of possible materials including carbon inks, diamond-based structures, Spindt tips (molybdenum) and carbon nanotubes. Carbon nanotubes are one of the new products emerging from the field of nanotechnology.

LED – Light Emitting Diode

The LED device is essentially a semiconductor diode, emitting light when a forward bias voltage is applied to a p-n junction. The light intensity is proportional to the bias current and the colour dependent on the material used. The p-n junction is formed in a III-V group material, such as aluminum, gallium, indium, phosphorous, antimony, or arsenic.

ELD – Electro-Luminescent Displays

A phosphorous film between glass plates emits light when an electric field is created across the film. The ELD uses a polycrystalline phosphorous (similar to LED technology, which is also an electroluminescent emitter, but uses a single crystal semi-conductor). ELDs are doped (as a semiconductor) with specific impurities to provide energy states that lie slightly below those of mobile electrons and slightly above those of electrons bound to atoms. Impurity states are used to provide initial and final states in emitting transitions. The thin film EL (TFEL) using active matrix addressing has the widest application [24].

PDP – Plasma Displays

Plasma screens are composed of millions of cells sandwiched between two panels of glass. Placed between the glass plates extending across the entire screen, there are long electrodes known as address electrodes and display electrodes which form a grid. The address electrodes are printed onto the rear glass plate. The transparent display electrodes, insulated by a dielectric material and covered by a protective magnesium oxide layer, are located above the cells along the front glass plate. The electrodes intersecting a specific cell are charged in order to excite a xenon and neon gas mixture contained within each cell. When the gas mixture is excited creating plasma, it releases ultraviolet light which then excites the **phosphorous** electrons located on the sides of the cells. When these electrons revert back to their original lower energy state, visible light is emitted. Each PDP pixel is composed of three cells containing red, green, and blue phosphorous respectively.

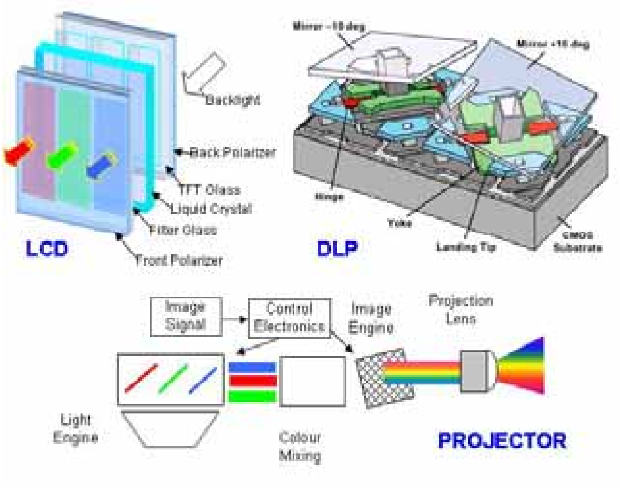


Figure 8. Non-Emissive Displays pixel structure and operation

OLED – Organic Light Emitting Diode

OLEDs use a very thin film of an organic substance that can emit red, green, blue or white light when a charge is applied. Display devices are made of layers of this organic material sandwiched between a positive (anode) layer and a negative (cathode) layer. When a charge is applied, energy passing between these two layers stimulates the organic layer into emitting light in a process called electrophosphorescence. The OLED technology has the potential for large-scale production using printing processes and it is believed it would overcome some of the limitations of LCDs [25].

These characteristics, particularly the low power consumption, made OLEDs promising for smaller display screens and they are already being used in handheld devices.

Non-Emissive Display Technologies

The non-emissive display simplified pixel structure and the operation principles are illustrated in Fig. 8.

LCD - Liquid Crystal

A liquid crystal material acts like a shutter: it blocks, dims, or passes light unobstructed, depending on the magnitude of the electric field across the material. Backlight is provided by the light source.

To form a working LCD, individual components (glass casing, liquid crystal cell, alignment layer, conductive electrodes and polarizers) are combined. Light entering the display is guided by the orientation of the liquid crystal molecules twisted by ninety degrees from the top plate to the bottom. This twist allows the incoming light to pass through the second polarizer. When voltage is applied, the liquid crystal molecules straighten out and stop redirecting light. As a result, light travels straight through and is filtered out by the second polarizer. Consequently, no light can pass through, making this region darker compared to the rest of the screen.

High-end displays today have easily 256 different levels of light or shades allowing a grey scale range in which graphics and characters can be displayed in many varying intensities [22, 23].

The AMLCD Basic Technologies defining the AMLCD panel structure and functioning, as illustrated in Fig. 9, are:

TN - Twisted Nematic
STN - Super Twisted Nematic

VA (MVA) - Vertical Alignment (Multidomain Vertical Alignment)
IPS (AFFS) - In Plane Switching (Advanced Field Fringe Switching),

The AMLCD technology comparison is presented in Table 3.

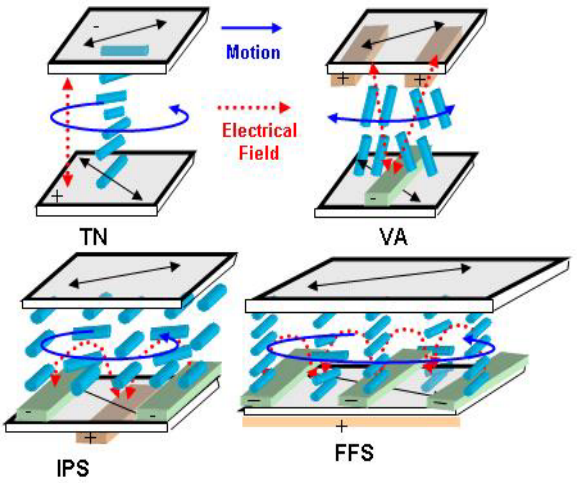


Figure 9. AMLCD pixel basic technologies

Table 3. AMLCD Technology Comparison

Benefits	AMLCD technology			
	C-TN	VA	IPS	FFS
Viewing Angle	●	✪	✪	✪
Response Time	●	✪	●	●
Contrast Ratio	∇	✪	●	●
Angular Colour uniformity	∇	✪	✪	✪
Transmission	●	✪	∇	✪
Manufacturability	✪	∇	●	✪
Power consumption	✪	✪	∇	●
✪ - excellent, ● - good, ∇ - bad				

MEMS-(DMD) – Projection Display Technologies

MEMSs (Micro Electro Mechanical Systems) are miniature devices which integrate actuators, sensors and processors to form intelligent systems. Functional optical sub-systems control light transmission or reflection. There are few emerging technologies still in development (Grating valve display, Pixtronix MEMS shutter with Field sequential RGB backlight, Mirasol displays based on bi-stable interferometric modulation). The only one having mass production and application is the digitally controlled mirror based reflective projection technology.

The DLP technology is a system that uses an optical semiconductor developed by Dr. Larry Hornbeck of Texas Instruments in 1987. This device, known as a Digital Micro-mirror Device (DMD chip), is essentially a very precise light switch that can digitally modulate light through the use of 2 million hinge-mounted microscopic mirrors arranged in a rectangular array. Combined with a digital video or graphic signal, a light source and a projection lens, the mirrors of the DMD chip can reflect an all-digital image onto any surface.

Touch-panel Technologies

Touch Panel – Screen is a position sensitive device, which could be activated using a finger or a stylus. In the same time, they are transmissive and could be overlaid to display. This allows integration of the display visual content and touch position detection into unique human machine interface capability. This capability makes them very suitable as a data input device for mobile applications. The touch technology could also be useful in all applications including some avionic displays.

In order to be considered as suitable for integration, a touch panel should have sufficiently high optical clarity, transmission and touch position sensing resolution, at least.

The major benefits of the touch technologies are:

Easy to use – what you see you touch to generate command

Flexible –One can implement different options using the same interface

Upgradeable – easy and fast changes through the software

Cost Effective – relatively cheap technical solution

Rugged and reliable – could be used in the extremely harsh environment

Regarding the promising capabilities, a lot of effort was made in the development of suitable technologies. There are some of them applicable in avionic displays:

- Resistive (RES)
- Capacitive & Projective Capacitive (CAP)
- Surface Acoustic Wave (SAW)
- Infrared Array Sensor (IR)

Table 4. Touch Screen Technology Comparison

Benefits	Touch panel technology			
	IR	RES	CAP	SAW
Vandal Resistant	✪	●	●	●
Scratch Resistant	✪	●	●	●
Not sensitive to dirt	✪	✪	●	∇
Non Sensitive to EMI	✪	✪	∇	∇
Can be FINGRER operated	✪	✪	✪	✪
Can be GLOVE operated	✪	✪	●	✪
Can be hermetically sealed	✪	✪	∇	●
Sensitivity to temperature	✪	●	✪	✪
Suit military environment	✪	●	✪	✪
Integration suitability	✪	✪	✪	∇
NVIS compatibility	∇	✪	✪	✪
✪ - excellent, ● - good, ∇ - bad				

Ruggedization Technologies

There are various ruggedization techniques applicable to enhance display properties.

Optical bonding: One of the most important ones is optical bonding that allows us to join different layers (glass, filters, or films) to enhance the display rigidity and the display front surface optical or conductive properties. The resultant assembly is very rugged, shock-, impact- and vibration-resistant, maximizing the optical properties at the same time. Two main technologies used for optical bonding are: (a) liquid bonding (using silicones, epoxies, polyurethane) – Optically Clear Adhesive (OCA) and (b) dry bonding (using a roll-on process based on the application of Pressure Sensitive Adhesive (PSA). [31, 32].

Resizing: To allow that AMLCD COTS displays could be used in displays requiring a specific shape, the resizing process was applied. This is a complex process [27-30], protected with patents. Resizing has an important role in the AMLCD technology application, mainly in cockpits, but could be used in any other application.

Environmental Strengthening: Displays should work within a wide temperature range, so additional heating used at low temperatures should be applied. There is usually no forced cooling so conductive cooling and proper thermal management should be applied as well. Displays should be capable of operating at low pressures and at high altitudes, which requires appropriate design solutions.

Electromagnetic Shielding: EMI interference could be critical in the avionic environment. The display EMI shielding is demanding but an achievable task. There are several techniques suitable and proved for EMI shielding optimization: (a) EMI filtering on the PCB; (b) proper grounding techniques; (c) transparent conductive layer over the display active surface (ITO or micro-mesh), forming a proper Faraday cage together with the metal housing.

Mechanical Strengthening: Displays should be operational in harsh conditions (vibration, shock, etc.), which requires an adequate mechanical design.

Display Technology comparison

Multifunctional and moving-map displays were the first objectives to generate new developments using any new technology available.

CRTs (Cathode Ray Tubes) in varying degrees of flatness were used for years.

Electroluminescence panels followed, introducing all solid – state compact display technology in the cockpit. The main disadvantage was a relatively low luminance level and no colour panel available in mass production. The introduction of AMLCD in avionics application in the mid-1980s [7] as a feasible technology was an example how commercial COTS components could find application in the demanding environment as avionics is.

A rough comparison of the different features of display technologies is presented in Table 5 and Table 6.

Table 5: Display Technology feature suitability comparison

Display Technology ⇓ / Display Features ⇒	Sun Readability	High Brightness	High Contrast	NVIS Compatibility	Wide temperature range	EMI Shielding	Increased Colour Gamut	Increased Colour Rendering	Controlled Viewing Angle	Specific Video Signal Formats	High Reliability & Long Lifetime	BIT (Built In Test) and Controls	Special Bezel Functions
AMLCD	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪
CRT	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪
FED	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪
LED	✪	✪	✪	✪	✪	✪	☒	☒	Ⓟ	✪	✪	✪	✪
ELD	Ⓟ	☒	✪	Ⓟ	✪	✪	☒	☒	Ⓟ	✪	✪	✪	✪
PDP	Ⓟ	☒	✪	✪	Ⓟ	✪	✪	✪	✪	✪	✪	✪	✪
OLED	Ⓟ	☒	✪	Ⓟ	☒	Ⓟ	✪	✪	✪	✪	☒	✪	✪
MEMS - DMD	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪	✪

✪ - Excellent capability
Ⓟ - Some capability
☒ - Pure or no capability

Table 6. Display Technology and basic properties comparison

Display Technology and properties comparison

Display Technology ⇓ / Display Properties ⇒	*Luminance*	*Contrast Ratio*	*Active Area*	*Resolution*	*Viewing Envelope*	*Switching Time*	*Life Time*	*Temperature Range*
AMLCD	✪	✪	✪	✪	✪	✪	✪	✪
CRT	✪	✪	✪	✪	✪	✪	✪	✪
FED	Ⓟ	✪	Ⓟ	✪	✪	✪	✪	✪
LED	✪	✪	Ⓟ	✪	✪	✪	✪	✪
ELD	Ⓟ	✪	Ⓟ	✪	✪	Ⓟ	Ⓟ	✪
PDP	Ⓟ	✪	Ⓟ	✪	✪	✪	✪	✪
OLED	Ⓟ	✪	Ⓟ	✪	Ⓟ	✪	Ⓟ	Ⓟ
MEMS - DMD	✪	✪	✪	✪	✪	✪	✪	✪

In 1990s, R&D in display devices was accelerated at an unprecedented level and long-term development road-map were set down [7, [5]. The related development were concentrated on two types of flat panels, one for primary flight instruments and the other for behind-the-cockpit displays for sensors and flight or air-traffic control needs.

The AMLCD storage, start up and operating temperatures were tricky issues. The LC materials could remain operable, although slower, down to -40°C and lower. The speed of operation can be increased with heating via a transparent Indium-Tin-Oxide (ITO) thin-film heater applied close to the AMLCD glass. In addition, the backlight acts as a heater, because of its power dissipation, increasing the AMLCD surface temperature up to 15°C in some cases.

The upper temperature is limited by the clearance point of the LC material. Above the clearance point temperature, an immediate but reversible loss of image occurs. Modern LC materials can be produced with a clearance point temperature of over 100°C without sacrificing other properties.

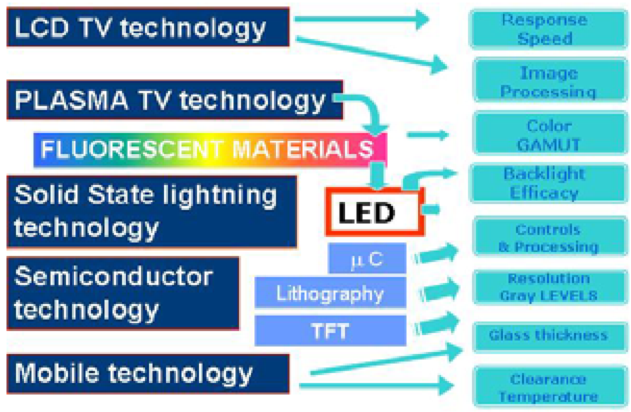


Figure 10. AMLCD Display Technology development interconnection

The back-lit AMLCD is unique in several ways, which proves to be a highly desirable attribute for the avionic use. The following objectives for primary aviation instruments are satisfied by the AMLCD: (i) low volume with low weight and power preferably without forced air cooling; (ii) a wide luminance range is easily achievable (from 0.05 fL to as high as 300 fL; (iii) colour primaries of saturated red, green and blue with at least 64 shades of gray in each primary; (iv) wide viewing angles greater than ± 60° in both horizontal and vertical direction, (v) readability in high ambient illumination with contrast ratios of at least ten to one; (vi) high uniformity without distortion with resolution through the image plane with at least 160 PPI addressable pixels density, and (vii) frame rates of at least 20 and up to 80 frames per second.

The AMLCD display technology development was supported with technology developments in other areas as illustrated in Fig.10. The semiconductor technology contributed through more capable driving circuits. LED lightning developments contribute to all solid state backlight (both R,G,B and white LED). New, more efficient LEDs contribute to lower power consumption. Solid state lightning needs forced mass production thus lowering the LED price. Plasma TV technology developments contribute to better fluorescence material contributing to higher white LED efficacy. Mobile device technology development forced lower power consumption and the application of LC materials with a higher clearance temperature.

The AMLCD market is highly dynamic, changing directions in assortment. This is the weakest point of the COTS AMLCD application in avionic displays. The monitor displays selection moved to higher diagonal sizes (19”, 22”). Laptop displays adopted mainly the wide format following HD resolution needs. Industrial and automotive displays stay relatively stable in size and resolution, and this group is the best source for the ruggedized display donor panel selection.

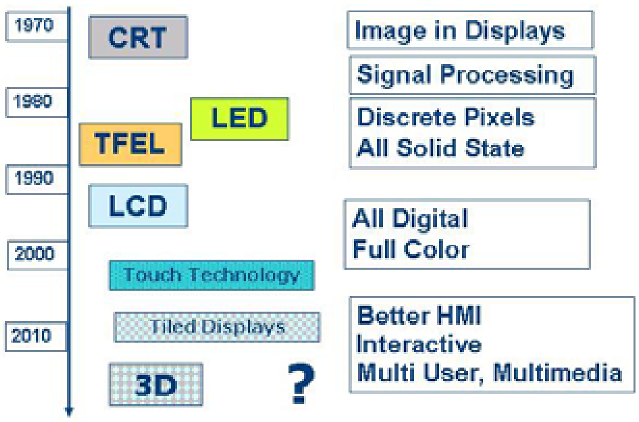


Figure 11. Avionic Display Historical Milestones

The avionic display historical development milestones illustrated in Fig.11 show that the AMLCD panel application has dominated the 21 century up to now, and will continue to do so, despite new emerging technologies.

Conclusion

CRT displays broke the ice and introduced image application in cockpits, thus increasing the display information capacity. ELD (TFEL) and LED displays find their place in some specific applications, opening the door to all solid-state displays, but the back-lit AMLCD prooves as ideal for aviation. There is no display technology that can compete with it. The development forced by TV related applications increased the LCD speed and the viewing envelope. Hand held and industrial applications forced the increase in the clearance temperature. The back-lit AMLCD creates an image transparent to the airplane, electronic and navigational sensors and the pilot. The product life is not limited to any particular size or configuration. In the near future, there is no any advanced display technology that can replace back-lit AMLCDs.

Resized AMLCD panels were used in the past and will be used in the future in all cockpit retrofit projects, but in new designs the commercially-sized big AMLCD active area will be more often used.

The AMOLED displays are a new and competitive technology with mass production for mobile device-related applications and potential mass production for TV-related applications. There are some issues in the operation temperature range, panel life time, relatively low luminance and suitability for ruggedization, thus lowering a possibility for a successful application in avionic systems.

The AMOLED technology will not be ready for mass application in avionic-suitable sizes in the next five years.

Tiled displays with a large active area (both AMLCD and projection display-based) are looking for new avionic-related applications on the ground.

Touch screens and 3D displays are in consideration [33], but more research effort is necessary regarding the influence of the human factor on the effectivity of application.

Technology is ready for new challenges, but more research regarding the influence of the Human Factor should be done before new display development directions are set.

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Avionski displeji

U radu su analizirane osnovne funkcije i dimenzije avionskih displeja, kao osnova za analizu primena različitih tehnologija displeja u teškim uslovima primene u avionu. Za definisanje avionskih displeja su važne veličina aktivne površine i dimenzije displeja ali i druge karakteristike kao što su: luminancija (sjajnost), rezolucija, vidni ugao, karakteristike boje, broj nivoa sivog, kompatibilnost za primenu pojačavača slike, čitljivost na suncu.
Diskutovane su tipične vrednosti odabranih tehničkih zahteva za avionske displeje. U članku se daje kratak pregled najvažnijih tehnologija displeja i njihova pogodnost za ispunjenje osnovnih zahteva.
Koncept primene ojačanih komercijalnih komponenti (Commercial Off The Shelf – COTS) je uspešno primenjen i u slučaju aktivnih matrica sa tečnim kristalima (AMLCD - Active Matrix Liquid Crystal Display), posle razrešenja početnih problema. AMLCD tehnologija je postala dominantna za primenu u avionici, a i u ostalim vojnim primenama.

Ključne reči: **avionika, avionski displej, nove tehnologije, tečni kristali.**

Авиационный дисплей

В статье рассматриваются основные особенности и размеры авиационных дисплеев, в качестве основы для анализа применения различных технологий отображения в трудных условиях в авиакосмической промышленности. Для определиния плоскости для отображения размеров важны размеры активной области экрана и других функций, таких как: лунинация (яркость), разрешение, угол обзора, цветовые характеристики, количество оттенков серого, совместимость приложений яркости изображения, читаемость на солнце.
Мы рассмотрим типичные значения отдельных технических требований к авиационным дисплеям. В статье приводится краткий обзор наиболее важных технологий отображения и их пригодности для удовлетворения основных потребностей.
Понятие коммерческого применения усиленных компонентов (Commercial Of The Shelf – COTS) было успешно применено в случае активной матрицы дисплея с жидкими кристаллами (AMLCD – активная матрица жидкокристаллического дисплея), после устранения начальных проблем. AMLCD технология стала доминирующей для использования в самолётах и в других военных применениях.

Ключевые слова: **бортовое оборудование, авиационный дисплей, новые технологии, жидкие кристаллы.**

Affichage d'avion

Dans ce papier on a analysé les fonctions basiques et les dimensions des affichages d'avion comme la base pour l'étude d'application de différentes technologies de l'affichage dans les conditions difficiles d'emploi chez les avions. Pour définir ces affichages les dimensions de la surface active et celle d'affichage sont très importantes ainsi que les autres caractéristiques telles que : luminance, résolution, angle de visibilité, couleurs, gamme de gris, compatibilité avec l'amplificateur d'image, lisibilité à la lumière de soleil. On a discuté les valeurs typiques des exigences techniques choisies pour les affichages d'avion. On a donné aussi un court compte rendu sur les technologies d'affichages les plus importantes et sur leur convenance pour accomplir les exigences basiques. Le concept d'emploi des composantes commerciales renforcées (Commercial Off The Shelf – COTS) a été utilisé avec succès chez les matrices actives aux cristaux liquides (AMLCD – Active Matrix Liquid Crystal Display) après la résolution des problèmes initiaux. La technologie AMLCD est devenue dominante dans l'utilisation en avionique ainsi que dans les autres applications militaires.

Mots clés: **avionique, affichage d'avion, nouvelles technologies, cristaux liquides.**