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A Survey of Flat Panel Display Technologies

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The U.S. Army is moving towards replacing cathode-ray-tube displays with the newer flat panel technologies. This report presents the results of a survey whose objective was to identify current and emerging flat panel technologies and evaluate the potential usefulness of these technologies for near- and mid-term military panel- and head-mounted applications The survey consisted of a literature search of scientific and trade journals in the area of displays , a review of the annual programs of major display societies and associations, and interviews with flat panel technology subject matter experts. The survey identified liquid crystal, plasma, and electroluminescence as currently mature technologies and field emission as the most promising emerging technology.

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Statement of objective

The objective of this survey is to identify current and emerging flat panel display technologies and evaluate the potential usefulness of these technologies for near- and mid-term military panel-mounted and helmet-mounted applications. A comparative analysis of currently mature and most promising technologies will provide guidance for ongoing and future visual science investigations of image quality metrics.

Background

The cathode ray tube (CRT) display has been the mainstay of data and imagery presentation for decades. From the user's perspective, the attributes of low cost, dependability, and excellent image quality made the CRT a very acceptable choice. It is only due to the CRT's inherent drawbacks of weight, size (primarily depth), and power requirements that flat panel technologies have made inroads into the predominance of CRTs in the display market. However, this encroachment has been exceedingly slow, with the prospect of large, thin displays which hang like pictures on the wall having been promised for years. The process of electroluminescence (EL) was discovered in 1936. The first patent for a matrix display using EL was filed in 1953. The first commercially viable light emitting diode (LED) display was introduced in 1968. The first designs for an active matrix thin film transistor liquid crystal display (LCD) were proposed as early as 1968 at RCA Sarnoff Laboratories, Princeton, New Jersey, and Westinghouse Research Laboratories, Pittsburgh, Pennsylvania.

The first two commercially feasible flat panel technologies were LED and LC displays, both being used first in digital watches, and for LEDs, in electronic calculators. These applications are several decades old, having appeared in the early 1970s. It was not until the late 1980s that widespread use of these new display technologies began. In 1986, it was estimated that 845 million LCD units were manufactured with 59 percent of these going into watches, 15 percent into calculators, and 26 percent into various types of office equipment (Werner, 1988). Problems with operating temperature range, brightness, contrast, and color availability were limiting factors. By 1990, displays based on flat panel technologies were no longer relegated to small application niches but were expanding into those areas previously controlled exclusively by CRTs. These areas included avionics, televisions, personal computers, and automotive displays. Today, with tremendous technological strides having been made in the last eight years, there are few, if any, display applications where CRTs have an exclusive market.

Survey methodology

The survey was achieved by studying the international scientific and manufacturing flat panel communities in order to develop an in-depth understanding of the issues which are driving the development and application of flat panel technologies. A three-prong approach was employed. First, an exhaustive literature search was performed on the major scientific and trade journals which present ongoing research in the following areas: electronics, display technology, display performance, and image quality metrics. Second, the scientific meeting programs of major display societies and associations were examined for trends in display related basic and applied research, manufacturing and fabrication, and performance test and evaluation. Third, leaders in the scientific and commercial display community were interviewed for their opinions on technical and marketing trends. The literature search and inspection of display society programs were limited to the period of 1993-1996. Table 1 provides a list of sources used in this survey.

Flat panel display technologies

For the purpose of this survey, flat panel displays and their inherent technologies shall be defined as a class of displays that is based upon noncathode ray tube technologies and derives its name from the physical characteristics of the flatness of its viewing surface and its reduced depth (thin form) as compared to CRT displays. There are an ever increasing number of promising flat panel display technologies. These include liquid crystal (LC), electroluminescent (EL), light emitting diode (LED), which dominate current applications such as laptop computers, watches,

Table 1.

Source listing

Scientific and trade journals	Display association programs	Consultants
Electronic Design Electronic Products Flat Panel Display News IEEE Transactions Information Display Magazine Journal of Electronic Engineering	Institute of Electrical and Electronic Engineers (IEEE) Society of Information Display (SID) Society of Photo-Optical Instrumentation Engineers (SPIE) United States Display Consortium (USDC)	David L. Post, Armstrong Laboratory, WPAFB, Ohio Ken Werner, Editor, Information Display John L. West, Associate Director of the Liquid Crystal Institute, Kent State University, Kent, Ohio

calculators, electronic test instrumentation, and video games. There also are a number of emerging flat panel technologies such as field emission (FE), vacuum fluorescent (VF), electrophoretic (EP), electrochromic (EC), and plasma (P). Emerging technologies are defined as those which have not matured sufficiently, either for performance or manufacturing reasons, to be commercially viable. A listing of both current (mature) and emerging flat panel technologies is provided in Table 2.

In general, the various technologies differ in the physical mechanisms by which they emit or modulate light. Displays based on these technologies often are classified as emissive or nonemissive. Emissive displays present information using light inherently produced by the display's mechanism. [Note: CRT displays would fall under this group since the light energy producing the final image is a result of the electron beam exciting the phosphor crystals.] Nonemissive displays are those that present information by reflecting the ambient light (background) at the observer or by modulating the transmission of light from an external source. A classification diagram for the various flat panel technologies is provided in Figure 1.

Table 2.

Flat panel display technologies

Mature	Emerging
Liquid crystal (LC) Active matrix liquid crystal display (AMLCD) Passive matrix liquid crystal display (PMLCD)	Electrochromism Electrophorism Ferroelectric liquid crystal (FELCD)
Electroluminescence (EL)	Field effect (emission) (FE)
Light emitting diodes (LED)	Digital micromirror (DM)
Plasma (P)	
Vacuum fluorescent (VF)	

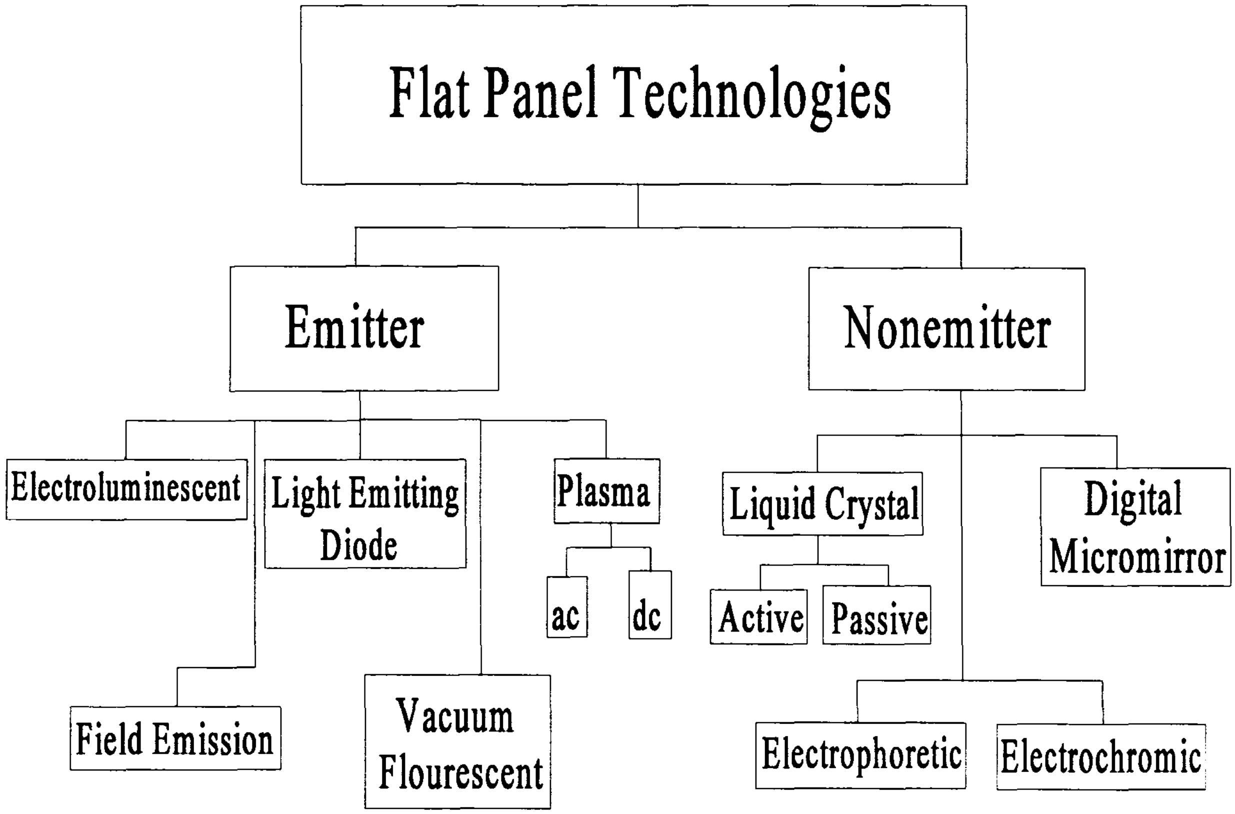

Figure 1. Classification diagram for flat panel technologies

A brief description of each of the major technologies follows:

Liquid crystal

The most widely known flat panel display technology is that of liquid crystals. LCDs are nonemissive displays. They produce images by modulating ambient light. The ambient light can be reflected light or transmitted light from a secondary, external source (e.g., a backlight). The mechanism by which modulation is achieved is the application of an electric field across a liquid crystal material which has both liquid and crystalline properties. The LC material is sandwiched between layers of glass and a set of polarizers. By applying an electric field, the LC can be caused to act as a light valve.

LCDs exist in several configurations. These include the twisted nematic (TN), the modulated twisted nematic (MTN), the optical mode interference effect (OMI), and the super twisted nematic (STN). These differ primarily by the electro-optical effect the crystal exhibits. The liquid crystal cell is constructed using two glass plates which are coated with a transparent conducting material. Between the plates, a thin layer of polyimide is applied. This layer is rubbed in one direction causing the LC molecules to align parallel to the rubbing direction. Polarizers are placed on the outside of each glass plate with the direction of polarization parallel to the rubbing direction. Application of a drive voltage affects the polarization of the LC material, and hence, the transmission/reflection characteristics of the cell.

Two active areas of research in LCDs are the development and testing of ferroelectric and the polymer dispersed (reflective cholesteric) LCDs. Ferroelectric LCDs utilize intrinsic polarization, meaning these LC molecules have a positive or negative polarity in their natural state, even without the application of an external electric field. This attribute gives FELCDs certain characteristics such as high operating speed, wide viewing angle, and inherent (no power) memory (Patel and Werner, 1992). Polymer dispersed LC technology is based on a concept called nematic curvilinear aligned phase (NCAP), in which the nematic LC material is microencapsulated in a transparent polymer. Polymer dispersed LCDs do not use polarizers and employ plastic film substrates rather than glass (Castellano, 1992). This technology does not require a backlight, is bistable, and has full gray scale memory (Yaniv, 1995).

LCDs also can be grouped according to the method by which the individual picture elements (pixels) are activated (or addressed). The two commonly used addressing modes are passive matrix and active matrix. In passive matrix LCDs (PMLCDs), pixels are defined by the intersection of a pair of vertical and horizontal electrodes. Voltages applied to any selected pair causes the LC material at the intersection to respond. Active matrix LCDs (AMLCDs) employ an array of individual pixels, each controlled by an electronic switch (Tannas, 1985). The most successful active matrix approach to addressing uses thin film transistors (TFT). In this approach, a TFT and a capacitor are used to switch each LC cell on and off.

LCDs can be monochrome or full color. Monochrome LCDs usually use a backlight consisting of one or more fluorescent lamps, a reflector, and a diffuser. Less frequently used is a backlight where the light source is an electroluminescent panel. [See following section.] Approaches to achieving color LCDs are numerous and increasing every day. One approach is similar to the additive color method employed in modern CRT displays. In this approach, pixels are composed of three or more color subpixels. By activating combinations of these subpixels and controlling the transmission through each, a relatively large color gamut can be achieved.

AMLCDs currently dominate video and multimedia applications such as laptop computers and hand held televisions. PMLCDs generally have been used in applications limited to word processing and spreadsheets, but in the past year, they have gained part of the market of AMLCDs. A potentially large and new application area for LCDs is that of portable communication devices such as cellular telephones and pagers.

Electroluminescence

Electroluminescent displays generally have a layer of phosphor material sandwiched between two layers of a transparent dielectric (insulator) material which is activated by an electric field. Pixels are formed by patterning the phosphor into dots. EL displays are either alternating current (ac) or direct current (dc) driven and also can be classified as powder or thin/thick film. The two most prevalent EL display types are direct current thick film EL (DCEL) and alternating current thin film EL (ACTFEL). Active matrix EL (AMEL), which uses active matrix addressing, can provide reasonably high luminance, contrast, and speed. All EL displays are emissive in nature (Castellano, 1992).

EL displays can be monochrome, limited color, or full color. Color is achieved either by classic filtering techniques of color-by-white or by patterned phosphors similar to those used in conventional CRTs. EL panels of uniform layers of phosphor sometimes are used as backlights for LC displays.

Light emitting diode

Light emitting diode displays are emissive displays composed of multiple LEDs arranged in various configurations which can range from a single status indicator lamp to large area x-y addressable arrays. The individual LEDs operate on the principle of semiconductor physics where electrical energy is converted into light energy by the mechanism of electroluminescence at the diode junction. Light energy is produced when this junction is forward biased by an applied voltage. The LED's light output is a relatively narrow spectral band and often is considered monochromatic (single color) and identified by a dominant wavelength. The "color" of the LED is a function of the semiconductor material, and, for the visible spectrum, includes green, yellow, red, and blue (Tannas, 1985; Castellano, 1992).

LED displays typically are monochrome, but the use of subminiature LEDs in red-blue-green (RGB) configurations can provide full color.

Field emission

Field emission displays (FEDs) are emissive displays. They consist of a matrix of miniature electron sources which emit the electrons through the process of field emission. Field emission is the emission of electrons from the surface of a metallic conductor into a vacuum under the influence of a strong electric field. Light is produced when the electrons strike a phosphor screen (Cathey, 1995; Gray, 1993). [Note: This process also is referred to as cold emission.] FEDs can be classified by their geometry: point, wedge, or thin film edge. Each geometry has its own advantages and disadvantages. FEDs are driven by addressing a matrix of row and column electrodes. Full gray scale monochrome and full color displays have been developed.

Vacuum fluorescent

Vacuum fluorescent displays (VFDs) are flat vacuum tube devices that use a filament wire, control grid structure, and phosphor-coated anode. They operate by heating the filament to emit electrons which are accelerated past the control grid and strike the phosphor anode, producing light. They are emissive displays. VFDs typically are used in small dot matrix or segmented displays. VFDs can be classified by their anode configuration: single matrix, multiple matrix, and active matrix. The single matrix configuration uses one anode and is the simplest design. The multiple matrix configuration uses multiple anodes which allows the duty cycle of the display to be increased. Active matrix configurations also have multiple anodes but have switching elements at each anode (Nakamura and Mohri, 1995).

VFDs are widely used in automotive applications. They primarily are used to present text and graphics. Monochrome and multicolor displays are available, with full color possible as more efficient blue phosphors are developed.

Plasma

Plasma (gas discharge) displays are emissive in nature and produce light when an electric field is applied across an envelope containing a gas. The gas atoms are ionized, and photons (light) are emitted when the atoms return to the ground state. A plasma display is an array of miniature gas discharge lamps, similar to florescent lamps. Images are produced by controlling the intensity and/or duration of each lamp's discharge currents.

Plasma flat panel displays can be classified by whether the applied voltages are alternating current or direct current; however, there is a hybrid ac-dc plasma display. Plasma displays also can be classified by the method used to update the information on the display. The methods are known as memory and refresh.

Initially, plasma displays were only monochrome and light emission was orange, green, yellow, or red, dependent upon gas type. Full color has been achieved by placing phosphors in the plasma panel and then exciting those phosphors with ultraviolet light from the plasma. Plasma displays are currently the only choice if the display application requires direct view, full color, large-screen, video rate capable displays.

Electrochromism

Electrochromism is a change in light absorption (color change) as a result of a reversible chemical reaction which occurs in accordance with Faraday's Law of electrolysis (Tannas, 1985) The pixels act as little batteries which are charged and discharged. These displays possess excellent color contrast between "on" and "off" pixels and do not have to be refreshed. EC displays are low power, nonemissive displays. Disadvantages include poor resolution, limited color range, high cost, and addressing problems (Warszawski, 1993).

Electrophoresis

Electrophoretic displays are passive (nonemissive) displays whose technology is based on the movement of charged particles (of one color) in a colloidal suspension (of a second color) under the influence of an electric field. The application of the electric field changes the absorption or transmission of light through the solution. Usually, color contrast is achieved through the use of dyes in the solution. When a dc field is applied to the suspended dye, the particles of the dye migrate to the surface of a transparent conductor which acts as the screen. The surface takes on the color of the particles. When the electric field is removed (or reversed), the dye particles are dispersed back into the suspendant, and the surface takes on the color of the suspendant. EP displays offer the desirable features of large area, wide viewing angle, and long memory without the need of a power supply (Castellano, 1992; Tannas, 1985; Toyama et al., 1994).

Digital micromirror

The digital micromirror device (DMD) display is a matrix where each pixel is a very small square mirror on the order of 10-20 microns. Each mirror pixel is suspended above two electrodes driven by complementary drive signals. The mirrors are suspended between posts by a very thin torsion hinge attached to opposite (diagonal) corners of the mirror. When no signal voltage is applied, the mirror is in its flat state. The application of a drive signal causes the mirror to tilt one way or the other. The mirror tilt is typically 10 degrees. These two (actually three, since the tilt can be in two directions) conditions correspond to "on" and "off" pixel states. Images are formed by using the mirrors to reflect light. DMDs are used in projection displays and offer potentially significant advantages in size, weight, and luminance capability over other types of projection systems (Critchley et al., 1995; Sampsell, 1994).

Survey results

The survey used a three-prong approach. First, a literature search was performed of the major scientific and trade journals which publish the current status of research, manufacture, and market trends in flat panel displays. Second, the scientific and technical proceedings of major display societies and associations were examined for trends in flat panel technologies. Finally, a number of leading individuals of the scientific and commercial display community were interviewed for their opinions on technical and marketing trends. The results are summarized below.

Literature search

A number of scientific and trade journals and magazines (Table 1) were reviewed for articles and advertisements relating to flat panel technology. In addition, an on-line computer search of the EI Compendex*Plus™ database was conducted. This database provides access to 2,600 journals, selected government reports, and books covering the fields of engineering. The search was performed using the keywords "flat panel" in combination with "display" and the technology specific keywords of "liquid crystal," "electroluminescence," "plasma," "electrochromism," "electrophoresis," and "field emission" in combination with "display."

The search revealed that the most commercially available flat panel display technologies are AMLCD, EL, and plasma. The technologies experiencing the most active research are LC, EL, plasma, and field emission.

LCDs, by far, continue to dominate the market. While laptop computers are the primary usage, inroads have been made into applications involving projection and low-power communication systems. Both active and passive matrix LCDs have provided improved brightness and contrast, firmly entrenching both technologies. The remaining problem area, which is being intensely researched, is that of limited viewing angle. The size of AMLCDs continues to increase. The largest currently available is 21 inches diagonally (West, 1995). The most active areas of research for LCDs are those of multidomain effects and ferroelectrics. FELCDs offer the possibility of simple construction, high resolution, and large aperture ratio (McDonnell et al., 1993). The coming year should result in additional improvements in luminance, contrast, and viewing angle.

EL displays are the fastest growing segment of the display market (Vieira, 1995). This is expected to increase further if current research can improve luminance and contrast values, with pixel blooming being the major obstacle. A new manufacturing technique known as Integral Contrast Enhancement (ICE™) has resulted in recent increases in available contrast. This technique uses a new light absorbing layer in the thin film structure which reduces reflection of both internal and ambient light. This modification is applicable to monochrome displays and can result in a 100 percent increase in both display luminance and contrast.

Plasma displays are considered the most likely candidate to provide the well publicized, promised large screen, direct view, hang on the wall display. A 40-inch display has been demonstrated and larger sizes are predicted. Currently, monochrome plasma displays have a small portion of the market for computer, medical, and military applications. Color medium-to-high resolution plasma displays are available and can provide high luminance and operate at full video rates. As of today, the best RGB group pixel pitch is 0.33 millimeters (mm); this is for a 1280 x 1024 display that compares well with a typical 0.28 mm 15-inch SVGA CRT monitor (Friedman, 1995).

As for emerging technologies, FEDs show the greatest potential for becoming a dominate technology. They have been experiencing an unprecedented development program. The most pressing problem is the development of low voltage, high resolution thin film phosphors which would be specific to FEDs. Applications already include their use in camcorder viewfinders and as miniature image sources for military helmet mounted displays.

The following summarizes current typical and maximum values for salient characteristics of both the mature and most promising of the emerging technologies. Because of the volatility of flat panel research and development, these values should only be considered as guidelines:

Active matrix liquid crystal
Resolution (H x V): 1280 x 1024 pixels
Viewing angle: 40 degrees
Speed: 10 milliseconds
Size (active area): Up to 21-inch diagonal
Luminance (typical): 250-400 fL
Gray scale: 64 levels
Contrast ratio: 40:1

Passive matrix liquid crystal
Resolution (H x V): 640 x 480
Viewing angle: 45 degrees
Speed: 150 milliseconds
Size (active area): Up to 10-inch diagonal
Luminance (typical): 50 fL
Gray scale: 16 levels
Contrast ratio: 15:1

Electroluminescent
Resolution (H x V): 1024 x 800 pixels
Viewing angle: >160 degrees
Speed: 16 milliseconds
Size (active area): Up to 17-inch diagonal
Luminance (typical): 100 fL
Gray scale: 64 levels
Contrast ratio: 100:1

Light emitting diode
Resolution (H x V): 192 x 128 pixels
Viewing angle: >170 degrees
Speed: 1 microsecond
Size (active area): Up to 10-inch diagonal
Luminance (typical):
Gray scale: 16 levels
Contrast ratio: 10:1

Plasma
Resolution (H x V): 672 x 512 pixels
Viewing angle: 140 degrees
Speed: <200 milliseconds
Size (active area): Up to 40-inch diagonal
Luminance (typical): 60 fL
Gray scale: 64 levels
Contrast ratio: 50:1

Field emission
Resolution (H x V): 640 x 480 pixels
Viewing angle: 180 degrees
Speed: Video speeds
Size (active area): 6" x 8"
Luminance (typical): 70 fL
Gray scale: 64 levels
Contrast ratio: >100:1

Vacuum fluorescent
Resolution (H x V): 128 x 32 pixels
Viewing angle: 150 degrees
Speed: 1 millisecond
Size (active area): largest is 10" x 2-1/2"
Luminance (typical): 500 fL
Gray scale: 16 levels
Contrast ratio: 180:1

Digital micromirror
Resolution (H x V): 640 x 480
Viewing angle: >160 degrees
Speed: 20 microseconds
Size (active area): 12 feet diagonal
Luminance (typical): 25 fL
Gray scale: 10 bit gray scale per color
Contrast ratio: >100:1

When the performance characteristics of the various technologies are examined, a comparison of the technologies can be made based upon the advantages and disadvantages of each. This comparison is provided in Table 3.

Table 3.

Comparison of flat panel technologies

Technology	Advantages	Disadvantages
Active LCD	1. Full color 2. Superior image quality 3. Video speed	1. Limited viewing angle 2. Requires backlighting
Passive LCD	1. Low cost 2. Simple design	1. Reduced resolution 2. Slow response
Electroluminescent	1. Very rugged 2. High resolution 3. Wide viewing angle 4. Long life	1. Full color not available 2. Inefficient drive scheme
Plasma	1. Large size 2. High luminance	1. Affected by electro-magnetic fields
Field emission	1. High luminance 2. High energy efficiency	1. Questionable reliability 2. Higher voltages required
Digital micromirror	1. High luminance for projection 2. Reduced flicker	1. Temporal artifacts 2. Artifacts, both temporal and spatial
Light emitting diode	1. Low cost	1. Lack of full color 2. High power requirement
Electrochromic	1. High contrast	1. Addressing techniques 2. Low pixel addressing speed
Electrophoretic	1. Low power requirement	1. Suspensions are complex and hard to reproduce 2. Low pixel addressing speed
Vacuum fluorescent	1. High luminance 2. Wide viewing angle	1. Limited resolution

Display society conferences

A review of the programs of Display Manufacturing Technology Conference (1996), Society for Information Display (SID) International Symposium (1993-95), and Cockpit Displays Conference of the Society of Photo-Optical Instrumentation Engineers (SPIE) AeroSense Meeting (1994-96) was conducted and presentations were classified as to flat panel technology type. The analyses for the SID and SPIE programs are presented in Tables 4 and 5. The largest percentage of papers dealt with liquid crystal research. EL and plasma were second and third, respectively. Work in the area of FEDs generally was consistent, but not significant. The areas of electrochromic and electrophoretic displays were represented, but were inconsistent and not significant.

Table 4.

Frequency of presentations at SID conferences
(Percent of total presentations)

	1993	**1994**	**1995**
Display technology	Total of 166 presentations	Total of 159 presentations	Total of 165 presentations
Liquid crystal	81 (49%)	78 (49%)	92 (56%)
Electroluminescence	14 (8%)	11 (7%)	15 (9%)
Plasma	6 (4%)	8 (5%)	9 (5%)
Field emission	3 (2%)	5 (3%)	4 (<1%)
Digital micromirror	1 (<1%)	3 (2%)	2 (<1%)
Light emitting diode	0	1 (<1%)	1 (<1%)
Electrochromic	1 (<1%)	0	0
Electrophoretic	0	1 (<1%)	0
Multiple	1 (<1%)	2 (1%)	0

Table 5.

Frequency of presentations at Cockpit Displays conferences of AeroSense meetings

	1994	1995	1996
Display technology	Total of 44 presentations	Total of 38 presentations	Total of 39 presentations*
Liquid crystal	26 (59%)	21 (55%)	15 (38%)
Electroluminescence	1 (2%)	0	1 (3%)
Plasma	1 (2%)	0	0
Field emission	1 (2%)	2 (5%)	1 (3%)
Digital micromirror	0	0	0
Light emitting diode	0	0	1 (3%)
Electrochromic	0	0	0
Electrophoretic	0	0	0
Multiple	2 (5%)	0	4 (10%)

* Scheduled April 8-12, 1996, Orlando, FL

Consultant interviews

Interviews with several subject matter experts in the display community (Table 1) resulted in a surprisingly consensus. Defining mature technologies as those which are available from a number of sources, manufactured on established production lines, have a significant market presence, and have demonstrated the capability of providing user acceptable imagery, the consultants identified the following: STN and active matrix LCD, EL, and plasma. The most promising new technology is that of field emission displays. The rapidity with which this technology has developed is considered unprecedented amongst all of the other display technologies. Identified as technologies which deserve close attention are the ferroelectric and polymer dispersed liquid crystal.

Conclusions

The advantages of reduced weight, size, and power consumption offered by displays based on flat panel technologies are extremely favorable to military applications. Aircraft cockpits, submarines, tanks, and other armored vehicles have limited space and weight allowances. In addition, system power requirements, which include displays, drive these space and weight requirements. As a result, a growing number of systems under development are using flat panel displays as the technology of choice for presenting information. Replacing traditional CRTs with flat panel displays, assuming comparable image quality and performance, makes more efficient use of the limited interior space of military vehicles (Odryna and Hashizume, 1995).

AMLCDs are the most mature flat panel technology and serve as the benchmark for comparison with other flat panel technologies. However, each technology, including AMLCD, has both advantages and disadvantages which may make it more, or less, suitable for a given application.

However, when the overall current capabilities of the various technologies are compared, there are three which can be considered mature enough to be suitable for military applications. These are: AMLCD, AMEL, and plasma. Even so, each of these have some limitations. AMLCDs are limited in display size to less than 16 inches (diagonally) and have additional limitations in speed of response and viewing angle; EL full color displays, while under development, have yet to appear on the market and pixel blooming is a limitation to increased luminance; PDPs have not been able to achieve a pixel pitch better than 0.33 mm and have the highest manufacturing cost per display area than any other display type.

New work with LC has been concentrated in ferroelectric and polymer dispersed displays. New techniques are being investigated to solve the problem of pixel blooming. Plasma displays continue to increase in size and are challenging LCDs for a larger fraction of the flat panel display market.

Of the emerging technologies, FEDs could provide the best return on investment. While the technology remains to be proven, it has undergone phenomenal growth in the last year and offers the prospect of extremely high luminance output (equal to or greater than CRTs) with wide viewing angles.

VFDs have continued to make inroads in automotive applications. Current research is in the areas of rib grid tubes and color fluorescent tubes (Nakamura and Mohri, 1995) which has improved resolution as a goal.

Very little work appears to be ongoing with LEDs. What progress has been made has been in increasing brightness and efficiency. The development of blue LEDs has opened the potential of full color capability. One promising endeavor is the development of prototype displays based on rotating LEDs. It capitalizes on the high response speed and luminous emittance of LEDs. This approach claims to provide large size (up to 60 inches), high resolution (2400 x 1800), and a 170-degree viewing angle (Gur, 1995).

In summary, a survey of flat panel technologies was performed based on the literature searches, professional society program reviews, and interviews. Employing selection criteria which include production maturity, image quality, number of manufacturers, range of applications, and market presence, AMLCD, plasma, and EL displays were identified as the predominant flat panel technologies. The FED appears to be the most promising of the emerging technologies. However, newer types of liquid crystal, specifically ferroelectric and polymer dispersed LC, are undergoing rapid spurts of research and development. For large projection displays, digital micro mirror devices are growing in capability and acceptance. The two technologies which appear to be advancing the slowest are electrochromism and electrophoresis.

References

Castellano, J. A. 1992. Handbook of display technology. San Diego: Academic Press, Inc.

Cathey, D. A. 1995. Field emission displays. Information Display. Vol 11, No. 10, pp. 16-20.

Critchley, B. R., Blaxtan, P. W., Eckersley, B., Gale, R. O., and Burton, M. 1995. Picture quality in large-screen projectors using the digital micromirror device. SID Digest, Vol. 26, pp. 524-527.

Friedman, P. S. 1995. Are plasma display panels a low-cost technology. Information Display. Vol 11, No. 10, pp. 22-29.

Gray, H. 1993. The field emitter display. Information Display. Vol 9, No. 3, pp. 9-14.

Gur, J. 1995. New display based on rotating LEDs. SID Digest. Vol. 26, pp. 459-461.

Hopper, D. G., ed. 1994. Cockpit Displays. Proceedings SPIE. Vol. 2219. Bellingham: SPIE.

Hopper, D. G., ed. 1995. Cockpit Displays II. Proceedings SPIE. Vol. 2462. Bellingham: SPIE.

McDonnell, D. G., Bannister, R. W., Graham, A., Hughes, J. R., Pedlingham, H. A., Scattergood, D. C., and Smith, C. J. T. 1993. An ultra-high-resolution ferroelectric liquid crystal video display. SID Digest. Vol 24, pp. 654-657.

Nakamura, T., and Mohri, J. 1995. New materials realize color VFD tubes, expand horizons. Journal of Electronic Engineering. Vol. 32, No. 348, pp. 23-25.

Odryna, V., and Hashizume, B. 1995. Display technology frees space in confined milieus. National Defense. Vol 80, No. 513, pp.26-7.

Patel, J., and Werner, K. 1992. Ferroelectrics ready for prime time? Information Display. Vol 8, No. 10, pp. 14-17.

Sampsell, J. B. 1994. An overview of the performance envelope of digital micromirror device based projection display systems. SID Digest. Vol. 25, pp. 669-672.

Society of Information Display. 1993. Digest of technical papers. Vol. 24. Santa Ana: Society of Information Display.

Society of Information Display. 1994. Digest of technical papers. Vol. 25. Santa Ana: Society of Information Display.

Society of Information Display. 1995. Digest of technical papers. Vol. 26. Santa Ana: Society of Information Display.

Society of Photo-Optical Instrumentation Engineers (SPIE). 1996. Advance program for Cockpit Displays III.

Tannas, L. T., ed. 1985. Flat-panel displays and CRTs. New York: Van Nostrand Reinhold.

Toyama, J., Akatsuka, T., Takano, S., Tadakuma, A., Mori, T, Suga, S., and Sano, Y. 1994. An electrophoretic matrix display with external logic and driver directly assembled to the panel. SID Digest. Vol 25, pp. 588-90.

Vieira, J. 1995. More contrast and luminance for EL. Information Display. Vol. 11, No. 2, pp. 18-20.

Warszawski, B. 1993. Matrix addressing and driving in a new electrochemical display technology. SID Digest. Vol 24, pp. 993-96.

West, J. L. 1995. Liquid crystal displays. Information Display. Vol 11, No. 12, pp. 14-17.

Werner, K. 1988. The flowering of liquid-crystal technology. Information Display. Vol. 4, No. 2, pp. 6-11.

Yaniv, Zvi. 1995. Reflective cholesteric displays. Information Display. Vol. 11, No. 10, pp. 10-14.