Advances in Flat Panel Display Technology and Applicability to ATCS On-Board Terminals

CHUCK J. KARBOWSKI, GIDEON BEN-YAACOV, AND DAVID BLASS

The introduction of Advanced Train Control Systems (ATCS) to the railroad industry changed the way operational information is communicated to locomotive crews. Voice communication can now be supplemented and may eventually be replaced by data communication via intelligent display terminals. Flat panel display screens are well suited for locomotive display terminals; the screens are compact and have the potential of being able to sustain reliable operation in harsh environments such as those found on board locomotives. In choosing flat panel display screens for locomotive applications, a number of factors must be considered: how the various flat screen display technologies operate, what their technical features are, and how they respond to harsh environmental conditions. Although no perfect display screen exists for locomotive ATCS applications, a comparison of strengths and weaknesses of the various technologies currently available points toward the electroluminescent and the thin film transistor displays as being the most appropriate.

Cathode ray tubes (CRTs) and flat panel display screens are the two types of display screens commonly used with display terminals to provide the operator-interface medium.

CRTs, which have been used in process industries for more than 25 years, have a wide range of commercial, industrial, and military applications. On the commercial side, CRT displays dominate the personal computer market. On the industrial side, CRTs dominate the industrial work station market. On the military side, CRTs provide operator interfaces. Presently CRTs are the only display type that can provide color at reasonable cost. But CRTs are bulky, susceptible to vibration, shock, and electromagnetic interference, and they require a moderate amount of power. If CRTs are to be used in ruggedized environments, they have to be packaged in such a way that they can withstand the harsh environments. Because CRT screens are bulky and fragile, they are not suitable for locomotive Advanced Train Control Systems (ATCS) applications.

Flat panel displays, on the other hand, are light weight, ruggedized, reliable, and compact; therefore, they can be mounted in tight spaces (i.e., locomotives). Flat panel monochrome displays are becoming popular in industrial and military applications because of technological advances in their production. Color flat panel displays are also becoming available at a reasonable cost.

A flat panel display screen that can meet all the environmental and visual requirements for a locomotive ATCS application does not exist. Each of the available display technologies has some limitations with its environmental and visual specifications. Nevertheless, flat panel display screens are considered the most suitable display screens for locomotive ATCS applications because they are ruggedized and compact.

Depending on the environmental and visual specification requirements considered by a railroad to be the most important, a compatible display technology can be identified. Such a display technology will have superior capabilities with those features considered most important, but also may have limitations in areas considered less important.

A review of the various types of flat panel display technologies, with detailed feature comparisons, is given below. The environmental characteristics of each display technology are then compared to the applicable specification requirements (ATCS Specification 110, Environmental Requirements). Key features of each flat panel display technology are outlined and each display technology ranked against the others. Finally, the display technology that the authors consider the most appropriate to support the visual and environmental requirements of ATCS locomotive applications is presented.

TECHNOLOGY REVIEW

Liquid Crystal Display

The operational theory of liquid crystal displays (LCDs) can be described as a shutter mechanism that blocks the transmission of light. The blockage of light produces a pixel whose contrast is determined by the difference between the blocked area of the pixel and the illumination (either reflected or transmitted) from a light source. The light blockage is achieved by a liquid material that is able to bend or twist light. This liquid crystal is sandwiched between two sheets of glass. Polarizers, which are oriented along each axis where the light is blocked, are placed on each layer of glass. When the two polarizers are placed on top of each other, no light can pass through the glass. When the liquid crystal is placed between the two polarizers, the twisting or bending of the light allows it to orient with the rear polarizer, so that a portion of the light can be reflected or transmitted back out. When a relatively low current is passed through the liquid crystal, the material twists again, taking the transmitted light out of orientation with the rear polarizer. This effectively blocks that area, producing the image of a black or dark pixel on a light background.

C. J. Karbowski and G. Ben-Yaacov, Automated Monitoring and Control International, Inc., 11819 Miami Street, Omaha, Nebr. 68164. D. Blass, Emerald Computers, Inc., 16100 S.W. 72nd, Portland, Oreg. 97224.

The grid of the display is scanned row by row. As each row is scanned, those pixels to be oriented are addressed and charged. The scanning panel then moves to the next row, and so on. The pixels can only "twist" when energized. This takes place during the scanning. Once the signal is removed, the crystalline material "relaxes" back to its original state.

The display must maximize the contrast of the pixel, so ample time must be given to allow the display to twist completely. Lengthening the time each row is given to twist the shutter will increase contrast of the pixel, but decrease the video refresh rate of the display. Either the display must be slowed well below the standard 60 Hz frame rate or a decreased level of contrast must be tolerated. All LCDs have had their driving schemes modified to optimize this conflicting issue.

Types of LCDs

There are four types of LCDs. Each successive display described is technologically advanced over the others. The major differences between the LCDs depend on the nature of the liquid crystalline material and the application of polarizers.

1. *Standard twist* (twisted nematic, TN). This is the original LCD technology. The distinguishing characteristic of the standard twist is that the twisting material orients at either 0° or 90°, and none other. TN is employed today in either low-information-content displays (such as digital wrist watches) or fixed legend displays, but rarely in any display that has a significant volume of information to convey. It will not be discussed further in this paper.
2. *Supertwist* (supertwisted nematic, STN). The supertwist advancement produces a liquid crystal capable of rotating 180° to 240°. This tighter rotation makes a darker pixel and increases contrast. In addition to the highly twisting nature of STN, the crystalline material also produces a birefringence effect. Simply put, birefringence allows the orientation of polarizers to transmit various frequencies of light that can produce colors. This effect permits different potential colors for both the pixel and the background, increasing contrast and flexibility.
3. *Double supertwist* (DST). This advancement lays two supertwist displays on top of each other. One layer is active, meaning that the drive mechanisms for the pixels are present. Through the birefringence effect, the second passive layer is used to cancel out interfering colors, producing a display that appears black on white. Because of the high cost of the double layering of the liquid crystal material and glass, a second method of DST, called double film supertwist, was developed. Rather than completely duplicating a layer of liquid crystal and glass, the compensating role of the second layer is performed by using a layer of specialized polarizers. The double film LCD has the same basic characteristics as the double layer, but costs substantially less.
4. *Active matrix* (thin film transistor, TFT). Active matrix displays have the same basic display characteristics as double supertwist displays. The key improvement is the elimination of (a) the row/column scan and (b) the opposing timing issues of time-to-scan versus the full rotation to the pixel. The essential principle of TFT is putting a drive transistor behind each of the pixels on the display. This allows the pixel to be turned on, and left on, until the data signal turns it off. This produces a display with high contrast, full viewing angle, and video resolution comparable to CRTs.

Backlights

Viewability in variable lighting conditions has always been a problem with LCDs. To solve this, backlights were added so the display could be viewed under night or low-light conditions. Three types of backlights are used with LCDs.

1. *Electroluminescent* (EL). An EL backlight is essentially a large area of phosphor material sandwiched between two sheets of mylar. When direct current is sent though the material, the phosphor glows. The backlight is very thin, but suffers from a short lifespan (2,000 to 5,000 hr) because of erosion of the phosphor. Additionally, an EL backlight does not emit sufficient light to be used at night.
2. *Cold cathode.* This method of backlighting consists of a fluorescent tube positioned behind the display. Fluorescent lighting yields one of the most efficient light sources. The cold cathode produces a higher light output for its power draw than nearly any other light mechanism.
3. *Hot cathode.* This technique is similar to cold cathode in that a fluorescent light source is used. It is much brighter than the cold cathode backlight, and draws more power. The hot cathode backlight is required for active matrix LCDs, which utilize the transmissive type of polarizer. The thin film transistors cut the light transmission by up to 40 percent, so the light source must be very bright.

Polarizers

All LCDs have at least two polarizers to produce the pixel image. Because LCDs work on the principle of light either passing through or being blocked by the display, the polarizers play an important role in maximizing the readability of the display.

1. *Transmissive.* This rear polarizer allows light to pass from the back of the display, through the display, and out the front. It is designed to operate best with overhead projectors and active matrix-types of displays.
2. *Reflective.* This polarizer reflects the ambient light that passes through the display and back out the front of the display. It reflects the maximum amount of light back through the display, making it the best polarizer for displays that are not backlit.
3. *Transflective.* The transflective polarizer not only reflects light like a reflective polarizer, but will also allow the passage of light from the back of the display. It offers the effectiveness of both functions of the polarizer (i.e., it will reflect less light than the reflective type and transmit less light than the transmissive polarizer).

Electroluminescent Display

EL displays work on the principle of sending a discharge of energy through a phosphor material, which produces light. EL is structured much like a sandwich of material deposited

on glass. The glass is placed at the front of the display and is viewed through, followed by the first conductor. Because the first conductor (the column conductor) is in front of the active material, it must be transparent. This material, indium tin oxide (ITO), is transparent. It is also relatively resistive and is used on the column conductor (the shortest axis). Behind the ITO row conductor is a dielectric barrier, followed by the active material, zinc sulfide doped with manganese (ZnM). This material, when energized, produces the amber color of EL. Behind the phosphor layer is another dielectric layer, followed by the row conductor. Because the row conductor is behind the layering, aluminum is used, which, although it is not transparent, has low resistance.

Through a row/column scan method similar to the other display types, each pixel can be addressed. One-third of the total voltage required to energize (light) the pixel is sent down the column, and the other two-thirds is sent across the row conductor. At the intersection (the pixel), the combined voltage creates a sufficient electrical charge to burst through the dielectric layer. This capacitive discharge causes an "electron avalanche" through the manganese phosphor, creating light. Because the pixel is essentially a capacitor and the column electrode is a resistor, this RC (resistor/capacitor) network creates a timing constant. In other words, there is a predetermined time for the signals to travel the display. This time constant prevents EL displays from being very tall (beyond 5 to 6 in.) without the implementation of costly and complex production techniques.

Types of EL Displays

There are two versions of EL displays, alternating current-driven thin film EL and direct current-driven, thick film EL. Both work on the same basic principle of operation.

1. *Alternating current thin film EL* (ACTFEL). Thin film makes EL displays truly solid state, not mere "material between glass." The films are deposited on the glass in a vacuum chamber using the same method used for making semiconductors.
2. *Direct current thick film EL* (DCEL). Instead of using the thin film process of depositing the phosphor material on the glass, a thick film paste is deposited on the glass with a silk-screening method. Also, a DC drive scheme is used, which has a lower cost than AC.

Like LCD (and plasma displays), EL displays are scanned row by row. Because the thin film display is quick to respond to the signal, pixel scanning occurs at regular video rates. In essence, an EL display has all the visual characteristics of a typical monochrome CRT.

PLASMA DISPLAYS

Plasma displays are flat neon tubes. The principle is similar to that used in standard neon signs. Neon gas is held within a vessel. A high-voltage current is passed from a cathode through the gas to an anode. The resulting excitation of gas molecules produces red light. Like EL displays, the row-by-row control of plasma displays is sufficiently fast to maintain standard video refresh rates.

Types of Plasma Displays

There are three types of plasma displays: DC, AC refresh, and AC memory. These three display types are differentiated by the electronic driving scheme of the display. By theory of operation, however, all three display types are the same.

1. *DC plasma.* DC plasma uses a DC drive scheme. The display state is always lit, even in a pixel "off" state. The lighting of a pixel is accomplished by turning it on even higher than the background. The nature of the background generates a steady glow over the entire surface of the display, resulting in a lower contrast level.
2. *AC refresh.* By means of an AC drive, individual pixels are scanned and refreshed in a fashion similar to an EL display. With this method, the background is turned "off" when a pixel is not lit. The scan refreshing method (turning a pixel on quickly and then leaving it to scan the rest of the panel), however, produces less light than the AC memory type.
3. *AC memory.* This type of plasma uses the same AC drive scheme as AC refresh, but includes a memory function. Simply put, true memory drive occurs when a pixel is turned on and remains on until a control signal turns it off. Smaller plasma displays use true memory, but in the large-area displays this method is modified somewhat. AC memory addresses every other row on every other frame. This leaves the pixels on twice as long as any other type of display. The longer the display is on, the brighter the display appears.

VISUAL CHARACTERISTICS

Feature Comparison

This section will itemize the main features and criteria for choosing the optimal display for locomotive ATCS application. To select the best display for the ATCS application, particular attention must be paid to the visual characteristics of the display, environmental specifications, and the latest state-of-the-art characteristics of various display types.

Visual characteristics are very important. The visual characteristics of the display are what the engineman and other railroad personnel will see. The combined total of all of the visual features will cause each railroad to select the display they "like." This subjective decision often has no engineering or mechanical merit. The railroad will simply select the display they personally prefer. Despite the biased nature of the decision, the criteria themselves are based on the very objective characteristics of the display. Viewing angle, color, contrast, and adjustments for low and high ambient light conditions are the main points of comparison.

Sunlight Readability

The definition of "sunlight readability" used by the U.S. Air Force is, "a readable display which exhibits a 3:1 contrast

ratio, filtered, in a 10,000-candlepower ambient light." The various types of displays are ranked below according to their sunlight readability.

STN—Excellent. The STN version of LCD is rated excellent in sunlight. The STN technology is available with either the reflective or transflective polarizer. The transflective type of polarizer is the optimum polarizer for both sunlight and backlit applications (see the polarizer section above). A reflective polarizer will maximize the readability in full sunlight, but it will not support a backlight, making the display useless in low to no light. Although the transflective display does lower the reflective qualities of the polarizer, it is still excellent for the sunlight readability requirements.

DST—Excellent. (Same as STN.) Reflective polarizers would render the backlight useless, so a transflective polarizer is the only reasonable choice.

TFT—Fair. This display depends entirely on a bright backlight and does not use any reflective/transflective polarizers. Only with the use of external sun shades would this display be usable in bright light.

EL—Poor to fair. This display produces the same light output as a monochrome CRT. Generally, an EL display is washed out by ambient light in the 5,000–candlepower range, which is far below minimum "sunlight readable" specs. Generally, it is used outdoors only with the benefit of shades or cowling. Also, sunlight readability can be enhanced with a circular polarizing filter.

Plasma—Poor to fair. Plasma displays generally have the same specifications as EL displays or CRTs. The display produces its own light, but not enough to hold up in sunlight. AC plasma is brighter, and is rated fair, but would still be found to be unacceptable for locomotive applications.

Low Light Conditions

STN—Fair to very good. With the use of a backlight, STN is fair to very good, depending on the type of backlight chosen. An EL backlight, because of its low light output, makes for an adequate lighting mechanism. However, it is not preferred. The cold cathode backlight does produce enough light to make a good display in low lighting.

DST—Good to very good. With a cold cathode backlight, the display has good to very good low light characteristics.

TFT—Excellent. The TFT is generally provided with the hot cathode backlight scheme. It therefore produces an excellent light source for low light conditions. The backlight can be adjusted downward in case the backlight is too severe. Given its bright light output and its adjustability, TFT produces the best display for lower light conditions.

EL—Very good to excellent. EL is very good to excellent in low light conditions. It produces a very bright display and can be easily seen in low light. The main drawback of EL is the lack of downward adjustability. There is no standard light adjustment offered by any of the EL manufacturers. The display brightness can be lowered by altering the high-voltage converter on the display, but tampering with display components is potentially a violation of the display's warranty and is not recommended (although not discouraged) by EL manufacturers. (The main reason for the lack of manufacturer support of brightness control is that EL emits uneven lumination across the panel when panel voltage is lowered.)

Plasma—Very good to excellent. As with EL, this light-emitting display technology does a very good job in low to no light conditions. Unlike EL, plasma can be lowered in brightness, and it will track in a uniform manner. The major drawback to the plasma display is the neon color red, which becomes, over viewing time, increasingly hard for the eye to tolerate. Low ambient light exacerbates the problem.

Color

STN—Good. The color of the STN is generally offered in blue on white. These colors, developed in the birefringence, are a good color combination. Blue is pleasing to the eye, but it does not offer the same contrast as the DST LCD. Typically, because of the lower refresh rate and the backlight, the blue color can appear to be washed out and not as saturated as would be desired.

DST—Very good. Often thought to be the best monochrome LCD color combination, DST is neither as dark as black nor as saturated as desired. The black-on-white display, even though slightly pale or washed out, does offer the highest contrast ratio of all of the monochrome LCDs. It does rate better overall in color over the STN, but is best categorized as very good.

TFT—Excellent. As a full-color display, the TFT's color is perfect. The display produces a range of colors similar to the saturation levels of a color CRT.

EL—Excellent. From the color standpoint, EL is excellent. The amber color emitted from the display is, physiologically, the second easiest color for the eye to see.

Plasma—Fair. The neon red color of plasma is rated fair. The eye tolerates the color red least of all, and the red color of a plasma display is a contributing factor to eye fatigue. The problem increases in low lighting conditions.

Contrast

STN—Good. The contrast between the pixel and the background of an STN display is no better than good, and that is only in the best conditions. When set to the maximum orientation, the display contrast is good, but can change when the display is viewed off axis. Also, the contrast setting reorients the display in a vertical adjustment (i.e, up and down). If the display is being used at different viewing heights, the contrast will be different for each viewing height. Also, the contrast is affected by variations in the ambient light or by variations in temperature.

DST—Good. The contrast of the DST is generally good, but, as in the case of the STN display, contrast is variable and is only good in a correctly adjusted position. Viewing angle and adjustments can vary the contrast to an unacceptable position. Correctly adjusted, a black-on-white display does offer good contrast. Also, the contrast is affected by variations in ambient light or by variations in temperature.

TFT—Excellent. Again, the display excels in all of the visual characteristics, including contrast.

EL—Excellent. The amber-on-black display of EL is excellent. But the excellent rating of the EL is only achieved with the use of a contrast enhancement filter. (A filter typically is a user option and is not supplied by the manufacturer.) A circular polarizer or neutral density filter satisfies the requirement. Without the filter, the contrast of the EL is fair to poor. However, the filter alters the light output affecting sunlight readability.

Plasma—Fair to excellent. The contrast of plasma varies, depending on the type of plasma technology chosen. The DC plasma display offers the poorest contrast ratio. The background of the display is constantly lit, and the lit pixel is simply driven harder. Both of the AC-driven displays have the background turned off, and it is considered black. The AC memory model has a greater contrast ratio because the pixels are brighter against the black background. The plasma panel's contrast ratio ranks DC fair; AC refresh, very good; and AC memory, excellent.

Viewing Angle

STN—Fair. The viewing angle of the STN is considered fair. Rated as 30° from perpendicular, this is adequate for most single-user applications.

DST—Poor. The viewing angle is poor. Rated at 15° from perpendicular, it has the lowest viewing angle of any of the display technologies.

TFT—Good. This LCD is better than the other LCD types, but its viewing angle is only 45° from perpendicular.

EL—Excellent. The viewing angle of the EL is greater than 80° from perpendicular. It is equal to or greater than that of TFT.

Plasma—Good to excellent. As with contrast, the viewing angle of plasma varies with the three types of plasma displays. DC plasma has vertical ribs that keep the gas discharge in a confined area. When viewed from the side, these ribs will eventually block the view of the pixel. This occurs at about 45° to 60° from perpendicular. Both the AC-drive plasmas share the same viewing angle as EL and TFT. A unique phenomenon, ionization of the neon gas, can cause the brightness and color of the plasma display to change, especially in the AC memory panel. For this reason, AC memory plasma panels fall slightly behind the other two technologies.

Image Quality

STN—Fair to good. The STN display suffers from a variety of display deficiencies. Individually, they are not severe, but when averaged together, the overall rating is only acceptable. The image quality is good only when the display is properly adjusted to the ambient light conditions and viewing angle of the operator. The pixels are well formed and focused. Off-angle viewing will wash out the pixel color and reduce contrast. There is a perceptible screen flicker from both the 60 Hz fluorescent backlight and from the scanning of the display. Also, temperature has an effect on the image quality. At colder temperatures, display response slows. At higher temperatures, the pixels orient to all on.

DST—Good. DST improves the color and contrast of the LCD over that of the STN, but suffers from a much narrower viewing angle. If properly adjusted for the current conditions, it appears better than STN, with a sharp, clear, black pixel. It will, however, fall out of adjustment more easily, and the effects of the misadjusted display are more pronounced. This display reacts to temperature the way STN displays do.

TFT—Excellent. TFT is superior in color and crispness of the display, as well as in viewing angle and contrast. This display reacts to temperature the way STN displays do.

EL—Excellent. As a monochrome monitor, EL offers an excellent display. The pixels are uniformly shaped, focused, and have an excellent contrast ratio and viewing angle.

Plasma—Good. Plasma receives a lower score because the pixels are fuzzy and generally out of focus. This is caused by the ionization of the gas that is not contained, producing more of a flaring dot without uniform edges. The color is a serious weakness for long-term viewing potential.

Gray Scale Ability

STN—Good. STN has the capability to be dithered. This is a gray scale technique that uses the refresh rate to change the intensity of the pixel. Instead of turning on a pixel the full number of frames per second, it can be controlled to turn the pixel on less often, producing a dimmer, lighter pixel. STN can produce eight levels of gray scale effectively.

DST—Very good. Using the same dithering technique as STN, DST has a more dynamic range because the pixels are darker to begin with. The display can generate 16 levels of gray scale with dithering. It should be noted that it is not necessarily easy to distinguish contiguous gray scale levels from each other.

TFT—Excellent. Even in the current limited models, TFT displays can produce 16 colors. Color-generation range will increase to 256 colors within the next 12 months. Because gray scaling is a monochrome technique intended to substitute monochrome shading for color, the TFT, being a color display, is clearly the superior display for color representation.

EL—Good. The EL display can produce gray scale through either dithering or with pattern gray scale. Because the display is fast, the dithering process can clearly be witnessed, and can be distracting. Pattern gray scale (also known as hatching) is fine for large-area graphics, but is not acceptable for text, because it turns off pixels in the character cell. True gray scale EL is relatively new. The technique of voltage modulation (16 levels of drive voltage for 16 levels of brightness) does not produce an acceptable range of definition. The lower levels are too dim, and there is very poor definition between consecutive levels. Even the newer voltage modulation/pulse width modulation (voltage plus variable signal duration) EL displays are better, but EL, in general, cannot produce 16 recognizable levels of light between threshold (the lowest level of pixel turn-on) and full pixel brightness.

Plasma—Fair to good. Generally, plasma follows the same results as EL. It can be patterned or dithered with the same limitations. Only one model of DC plasma is offered with true 16-level gray scale. Because of an increase in the dynamic range of the display, plasma is marginally better than EL, but

it, too, has a difficult time producing discernable, contiguous levels.

Size

STN/DST—Good. Both display types are available in the proper visual display size (10.5 in. diagonally). The models do have a relatively wide package in relation to the width of the active area. This extra width is wasted space. The depth of the displays is acceptable at approximately 1.25 in. The EL backlight models are incredibly thin, which makes a very thin and attractive display head, but the EL backlight method is not recommended because of its low light output, its lack of adjustability, and the rapid aging of the EL film.

TFT—Very good. The size of the TFT package is also 10.5 in. diagonally. The overall package has less wasted space than the STN/DST. TFT has the same depth concerns as STN/DST because of the backlight requirement. It is not offered with EL backlighting because of insufficient light output from the EL film. The hot cathode backlight provides the same packaging as the cold cathode type.

EL—Excellent. In the past, EL manufacturers have suffered from an inability to produce cost-effective displays larger than 9 in. diagonally. New gray scale models are now available with a display size of 10.4 in. diagonally. With the fact that the package is only 1.4 in. deep (including the power converter), the depth of the EL display is excellent.

Plasma—Very good. Plasma displays are available in large display sizes (10.5, 14, 17, and even 26 in. diagonally) and can produce high-resolution displays (up to 1,024 x 800). In spite of that, plasma suffers from two problems. The "dead" margin around the display is large in proportion to the active area. Plasma also requires a large power converter that must be placed somewhere in the terminal or on the back of the display. This adds considerable depth to the package.

ENVIRONMENTAL SPECIFICATION

The various types of displays have different strengths in terms of the environmental factors of locomotive ATCS application: temperature, humidity, shock and vibration, electromagnetic interference, power consumption and, of course, cost.

Temperature

STN/DST—Fair to good. LCDs have the narrowest temperature range, typically 0°C to 50°C and often 0°C to 40°C. The key to the display is the "liquid" crystal. The crystalline material loses its primary properties at temperature extremes. At less than 0°C, the material becomes thick and viscous before it freezes completely. At low temperatures, the display will draw an increasing amount of power to rotate the thickening crystal. Once it freezes, the display will not operate until it thaws. Also, the display becomes increasingly slow at low temperatures. High temperatures affect LCD differently. The liquid crystal will orient the pixels to an "all on" orientation, rendering the screen black. This condition will reverse, but only after the display cools down. Additionally, the display polarizers can be jeopardized if exposed to excessive temperatures and humidity. New, extended-temperature liquid crystal material and panels are making an entrance into the market.

TFT—Fair. TFT has the same problems with temperature as standard LCD models. There is a published warning regarding the operation of the panel at high temperatures (50°C). The warning states that operation at 50°C be less than 12 hr in duration for a 24-hr period. At this writing, there is insufficient data to predict extended temperature models.

EL—Very good to excellent. EL, as a display technology, is relatively unaffected by temperature. EL displays can actually operate from −55°C to +125°C, with only a slight brightness output change (±30 percent). The only true limitation to an EL application is the commercially available and specified integrated circuits (ICs) that make up the components of the panel itself. The component manufacturers rate them only at 0°C to 50°C. Though they have a relatively narrow range, the ICs have been tested and actually function without any problems from −20°C to 70°C. Below −30°C, most of the ICs fail to operate properly.

Plasma—Good. Plasma has a broader temperature range than LCD, but a narrower range than EL. Neon gas used in the display will not ionize or turn on below −5°C. The gas, too, can be affected by long-term exposure to very cold temperatures.

Humidity

STN/DST—Fair. LCD panels are rated at 85 percent humidity at 40°C. Because of the railroad industry environmental specifications, this is considered only fair. In many geographic regions, an 85 percent relative outdoor humidity will be exceeded during several months of the year. The polarizers of the display are generally most vulnerable. In excessive heat and humidity, the polarizers can peel off completely.

TFT—Fair. The preliminary TFT specification clearly spells out the warning that the absolute humidity must be lower than 85 percent relative humidity (RH) at 40°C.

EL—Excellent. EL is rated at 95 percent RH at 40°C. This is the highest humidity rating of any of the technologies.

Plasma—Fair. As with the LCD, plasma display manufacturers rate their panel at 85 percent RH. This seems low, because there are no apparent technical limitations of the technology to warrant such a specification.

Shock and Vibration

STN/DST—Fair. LCD models have low shock and vibration specs. Typically, they range from 3 *g* to about 20 *g* of shock. Vibration durability, too, is less than the other technologies'. The physical package of the LCD, made up primarily of plastic, is responsible.

TFT—Poor. Again, this type of LCD fares poorly in the shock and vibration specs. The shock specification is 3 *g* and vibration is significantly less than even the STN/DST models. Here, not only does the plastic package lend itself to the weak specification, but actually the entire TFT technology appears to be relatively delicate.

EL—Excellent. EL has a shock and vibration specification that is up to five times that of plasma or LCD. It is rated at

100 *g* of shock and a 3 *g* peak-to-peak vibration spec. Only the EL display has the integrity to withstand the shock and vibration specification established by the railroads.

Plasma—Good. Although more durable than LCDs, plasma displays' shock and vibration specs are much lower than those of EL. Plasma panels tend to average 10 *g* to 30 *g* shock and 0.5 *g* to 1.5 *g* vibration in specification.

Electromagnetic Interference

STN/DST—Excellent. The STN and the DST displays are rated as excellent for their low levels of reactivated electromagnetic interference (EMI). This can be attributed to the use of a nonemissive technology that utilizes low power and low scan rates.

TFT—Very good. The TFT display is rated very good for its low level of radiated EMI. It is not quite as good as the STN and the DST displays because its clock rates are much higher.

EL—Fair to good. The EL display is rated as fair to good because of its high clock rate and high-voltage operation.

Plasma—Fair. The plasma display is rated as only fair as it radiates even more than the EL because it, too, has a high clock rate and high-voltage operation.

Power

STN/DST—Excellent. The primary "claim to fame" for LCD is the extremely low power consumption of the display. LCD runs less than 5 W total, even with a cold cathode backlight on. The display itself draws even less power. This is pertinent for determining the packaging needed to meet the temperature specifications.

TFT—Good. The display portion of the TFT has the same very low power draw as the other LCD types, but the most voracious power draw within TFT is the hot cathode backlight. This type of backlight draws much more power than the cold cathode type, and the draw is actually slightly higher than that of EL displays. A TFT display will consume 18 W of power with the backlight on.

EL—Good. EL draws about 15 W in a typical mode. This represents a lower overall draw than that of plasma displays, but approximately three times more than that of a STN/DST LCD.

Plasma—Poor. Plasma can draw nearly 40 W of power. The display draws power linearly, so the more pixels lit, the higher the draw. In a typical screen, plasma will draw about 30 W. The worstcase power draw tops out at 50 W.

Cost

STN—Excellent. The STN is the lowest-priced flat panel display on the market today.

DST—Very good. The DST is only slightly higher in cost than the STN display.

TFT—Poor. The TFT is the highest-priced flat panel display on the market today. This can be attributed to its low production volume and the fact that it is not a mature technology.

EL—Good. EL displays cost about one-tenth of the price of TFT displays and about twice the price of the STN/DST displays.

Plasma—Fair to good. Plasma is generally priced equal to or marginally higher than the EL displays after factoring in the cost for the power converter.

CONCLUSIONS

A display that meets all the environmental and visual requirements for a locomotive ATCS application does not exist. Each of the display technologies has some limitations, yet in spite of these limitations, flat panel displays are considered the most suitable display screens because they are ruggedized and compact. A summary of all the visual characteristics, environmental specifications, and cost factors for flat panel displays is provided in bar chart format in Figures 1, 2, and 3.

The STN and DST LCDs are marginally qualified for use in locomotives. These displays, which can be read in sunlight, are rated only as poor to good for almost all of the other criteria. The temperature range is too narrow, the maximum humidity is too low, and the shock and vibration tolerance is

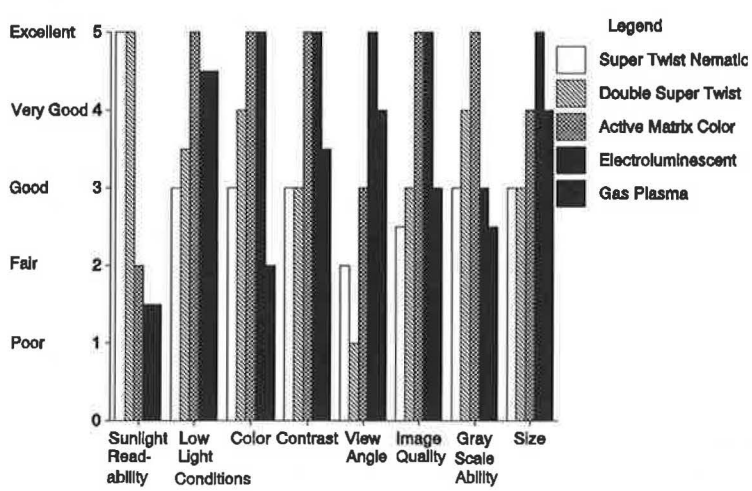

FIGURE 1 Visual features.

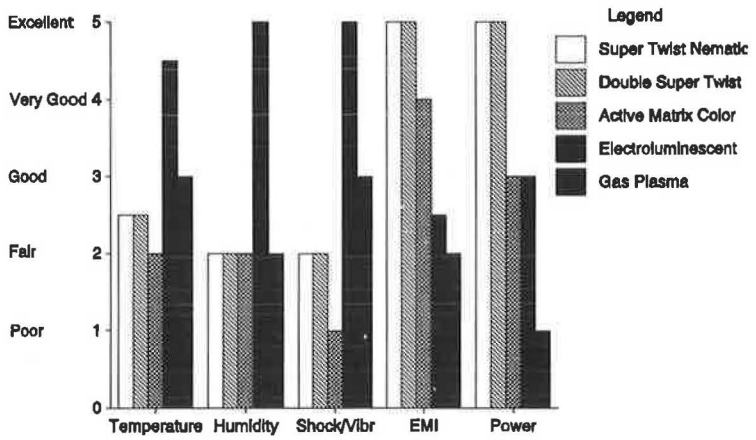

FIGURE 2 Environmental specifications.

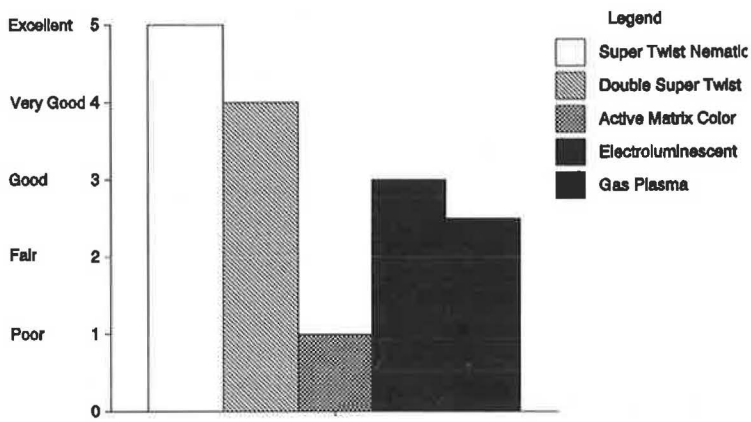

FIGURE 3 Cost.

below railroad industry specification requirements. The display does, however, meet sunlight readability requirements. If sunlight readability is given a higher weight than temperature, humidity, and shock and vibration, then these displays could be considered if properly packaged to reduce the effects from the environmental conditions found in a locomotive application. Also, these displays are only available as monochrome.

The TFT LCD dominates all visual specifications except sunlight readability and viewing angle. It is currently the only flat panel display that provides multicolor, and it produces a range of colors similar to the saturation levels of a color CRT. Simply put, it is beautiful. However, once one looks past the visual features and reviews the environmental specifications, it falls short of the mark. Much can be done in the packaging to support this display for shock and vibration, but the temperature and humidity problems are difficult to take care of. However, this display has been recently introduced into the flat panel display market, and as improvements are made in the ruggedization of this display it will become much easier to integrate into the harsh environment found in the railroad industry.

The EL technology is the most rugged of all the flat panel displays. Its shortcomings for EMI are manageable by using good packaging techniques and by selecting the right clock frequency. Other than EMI, it dominates all the remaining environmental specifications. Besides its high environmental ratings, it has received good to excellent ratings on its visual features. It does very well on the visual characteristics except that it only received a poor to fair rating for sunlight readability. The largest drawback to the EL technology is that it is not currently available in multicolor. Development is under way, but there is still difficulty in increasing the efficiency of the blue phosphor. Once this is accomplished, the EL technology will be able to provide a multicolor solution.

Finally, the plasma display's downfalls are its red color, sunlight readability, and the fact that it is completely overshadowed by the EL technology. There is simply no reason to use this display because the EL display is more rugged, provides better visual characteristics, and is priced lower.

In summary, the two top candidates for an ATCS-compatible flat panel display are the EL and the TFT. Both the displays have very good to excellent visual characteristics. The EL is the most rugged of the two, but it is not available in multicolor. On the other hand, the TFT is multicolor, but it is not nearly as rugged. As far as cost is concerned, the TFT is very expensive in comparison with the EL. All things considered, the choice comes down to the weight assigned to the multicolor capabilities, the environmental parameters, and cost differentials between these two flat panel displays.