Professional Display Technology Overview – by Bram Desmet

The following is a very high level overview of various display technologies currently in use for professional monitoring applications. It is meant to serve as a straightforward guide to the benefits, limitations, and realities of various technologies as they exist at this moment. Display technology is evolving rapidly so it is important to keep in mind that this overview reviews these technologies as they exist at this time and therefore this overview does not reflect the state of the industry as it existed 1 year ago nor will it likely reflect the state of the industry as it will exist 1 year from now. This paper is written with readability by both a non-technical and engineering audience in mind so some of the topics covered are admittedly oversimplified (on purpose). For those looking for more technical elaboration on any of the points below we welcome you to contact us at Sales@FlandersScientific.com .

CRT Monitors

CRT technology for many serves as the reference to which all other display technologies are compared. For this reason it is important to review the pros and cons of CRT monitors before discussing other display technologies.

For decades CRT Monitors were essentially the only reference grade video monitoring devices available and as such the standards for video acquisition and post production were largely based around the characteristics of these display devices. Though CRT monitors have been the standard bearer of professional monitoring for many years they are not the perfect monitoring devices and do have many serious limitations.

The primary performance benefit of CRTs, even to this day, is the achievable black level. CRTs have very high contrast ratios because they are emissive displays (light emission occurs at the screen level), so they have the ability to emit little or essentially no light when reproducing low luminance signal information. Another benefit of CRT monitors is response time. The rise and decay time of an excited phosphor is relatively fast, which leads to minimal motion blur. There is often a tendency to overemphasize these performance benefits when comparing other display technologies to CRT monitors and doing so often neglects to properly discuss the drawbacks and real world limitations of CRTs.

Some of the most basic CRT drawbacks and limitations are:

1. Linearity: CRT monitors have difficultly achieving and maintaining linear horizontal and vertical speed of the electron beam's position and this lack of linearity leads to onscreen irregularities. In plain English, if you put something like a crosshatch on screen it is difficult for the CRT monitor to maintain proper equidistant spacing between the lines of the crosshatch. On fixed pixel structure displays this is a not an issue (i.e. a crosshatch pattern will have perfect equidistant spacing between lines).
2. Geometry: Unlike fixed pixel structure displays CRT monitors have a difficult time maintaining proper image geometry. Simply put, an image as simple as a circle is not always shown as a perfect circle on a CRT monitor. Even a properly adjusted CRT monitor rarely exhibits perfect geometry and anyone that has spent an extended period of time working with a CRT monitor can likely attest to the time spent fine tuning geometry adjustments on the display over time.
3. Convergence Errors: The guns controlling the Red/Green/Blue components of a signal are physically at a distance from each other in a CRT monitor. This means that they are all influenced differently by the deflection coils. This can result in the beams landing in the wrong places and this leads to what is commonly called a convergence error. This error could easily be 1-2mm on many CRT monitors and as

bad as 3-4mm in the corners of some displays. In plain English, this means that with something like a crosshatch pattern on screen operators would see individual Red/Green/Blue lines diverging from each other where technically a single (converged) white line should exist. Adjusting for convergence errors is a time consuming task and often requires both ancillary equipment such as a convergence gauge and a knowledgeable technician familiar with correcting for convergence errors. This problem does not occur on fixed pixel structure displays as the R/G/B sub pixels have a static location onscreen and cannot physically move.

4. Stability: CRT monitors are relatively unstable display devices. Drifts in luminance and color temperature tend to occur at a much faster rate on CRT monitors than many alternative display technologies. Regular recalibration of CRT monitors is necessary to stay within acceptable tolerances. Some facilities, especially those using aging CRT monitors, have adopted recalibration cycles of once, or even more regular than this, per month.
5. Environmental Variations: CRT monitors are greatly affected by magnetic fields. Environmental variables such as the CRT monitor's location in the world, physical positioning within a suite, and the equipment surrounding the monitor can all significantly impact the performance of the CRT display. All of these variables need to be accounted for, often manually, on CRT monitors and are particularly troublesome if the monitor needs to be moved regularly as is the case in field use applications.
6. Poor Multi-Format Support: All of the concerns listed above are amplified when the CRT is used as a Multi-Format monitoring device. CRTs in general do not switch well between SD and HD formats. Different components are physically used inside the CRT monitor when dealing with different formats. This means that individual monitor adjustments are required for these different formats and on many CRT displays this means complex manual adjustments per format to account for the variations between these differing relays and circuits. In addition to these difficulties CRT monitors are physically incapable of natively supporting certain formats (such as 24p material).
7. Fixed Color Space and Gamma: CRT monitors have a fixed color space determined by the phosphor set used (EBU, P22, SMPTE C). CRT monitors cannot accurately reproduce many defined color spaces in common use such as Rec 709 (HD) and DCI P-3. So while CRT monitors may be still be in use at many facilities as reference displays for work on HD material they are demonstrably incapable of correctly operating within the Rec 709 color space. Furthermore, CRT monitors do not have programmable or adjustable gamma making them unsuited for many workflows requiring a specific display gamma response.
8. Limited Peak White Luminance: CRT Monitors in general cannot operate well at high luminance levels required for operation in brighter environments. Moreover, many CRTs are actually incapable of maintaining industry recommended peak white luminance levels as they age. In many facilities that have traditionally used CRT monitors this has led to the in-house adoption of lower peak white luminance levels that were often a function of manufacturer's recommendations or the facility's own experience with expected longevity/stability of the monitor at a given luminance level, but these in-house standards did not necessarily have any relation to the recommended practices set forth by the industry's various technical standards organizations.
9. Curved Screen: CRT monitors do not have flat screens. The lack of a flat screen makes it inherently more difficult to display a straight image.

10. Limited Form Factor: CRT monitors come in very restricted size options. Large format CRT monitors are difficult to produce and at any size are generally much bulkier and heavier than alternative display technologies with the same screen size.
11. Environmental Health Concerns: CRT monitors have traditionally relied on large amounts of lead to shield operators from the otherwise harmful effects of the electron beam. In larger CRT monitors the amount of lead used could easily be as much as 5lbs. The concern over disposal of CRTs and their contribution to high levels of lead in landfills led many governments to adopt Lead Free Initiatives that essentially banned the sale of such CRT monitors.
12. Poor Availability: Even for facilities wanting to use CRT monitors despite some of the technical limitations listed above the general lack of availability of high quality CRT monitors has become a real world problem. Lack of availability is attributable to a combination of environmental health concerns, limited form factor, and technical limitations all of which have led to a drastic reduction in demand. The production of glass used in CRT monitors requires 24/7 operation of large glass furnaces that cannot be easily switched on/off as needed. Without sufficient consumer demand for products using such glass it has become economically unviable for the glass manufacturers to keep these facilities running on such a required non-stop basis.

Despite the limitations listed above the tendency to review other display technologies as they compare to CRT monitors is a rather natural inclination as CRT monitors are a known quantity with which a lot of operators have decades of experience.

LCD Monitors

LCD Monitor technology has undergone a rapid evolution in recent years. Early generations of LCD monitors exhibited very poor performance and were typically not suited to any critical monitoring environments. Limitations in viewing angle, contrast ratio, pixel response time, achievable color gamut, and backlight lifespan meant that early generation LCD monitors were typically reserved for less critical viewing environments where the benefits in power consumption, form factor, and cost outweighed the performance limitations. However, this began to change in the early part of the 21st Century as LCD monitor technology rapidly evolved to become suitable for more and more critical monitoring applications. The technology has advanced to the point that top-tier LCD technology is now being successfully employed by many facilities in even the most color critical of monitoring environments. However, LCD monitors, like all current monitoring technologies, do have some real world limitations and the advancement in this and competing technologies is far from over. Additionally, it is very important to note that LCD technology comes in many different variations, each with its own set of pros and cons. This can make understanding the choices available quite difficult so an overview of these variations can be useful.

In trying to understand the various LCD monitoring solutions available it is important to recognize that LCD panels are transmissive, not emissive devices. This means that the light emitted from the monitor does not come from the panel surface, but rather from a light source behind the monitor that is commonly referred to as the backlight. The LCD panel itself is a high density matrix of pixels, each of which are typically comprised of 3 sub pixels, one for Red, one for Green, and one for Blue. Each sub pixel is essentially an adjustable filter (valve) that only allows light in its portion of the visible light spectrum (Red, Green, or Blue) to pass through the screen.

Therefore, for any given LCD monitor there are two primary components that contribute to the overall performance of the display, the LCD panel itself and the backlight.

With respect to the LCD panel technology itself there are more variations than can be succinctly cited here and for our purposes it is not as important to understand precisely how the panels differ in actual design/operation as it is to understand how the most prevalent of these technologies vary in performance characteristics. Exhaustive lists of the multitude of other LCD panel technologies, and detailed explanations as to how they differ in design, can be found in other resources, but three of the most prevalent technologies are TN (Twisted Nematic), PVA (Patterned Vertical Alignment), and IPS (In Plane Switching).

TN panel technology is one of the oldest and generally has a reputation for overall poor performance. Limited viewing angles with severe off-axis color shift (the tendency of onscreen colors to look different depending on the viewer’s relative position to the screen) are hallmarks of TN panel technology. Additionally, the majority of TN panels have poor contrast ratios with sharply elevated lowlight performance. Lastly, the majority of TN panels are 6bit offering a color depth of only 262,144 colors. TN panels are generally reserved for lower end LCD monitoring solutions for non-critical viewing environments and are becoming rarer in professional use. However, many early generations of professional LCD based broadcast monitors used this technology so they are still quite prevalent in many facilities. Despite poor performance in most assessment benchmarks TN panels do excel at one thing: pixel response time. Modern LCD monitors based on TN panels can have pixel response times as fast as 2ms, which makes them popular in such applications as consumer gaming. However, with the improvement in pixel response times in other panel technologies in recent years this advantage has become marginal and for professional use is typically vastly outweighed by other performance limitations.

PVA panels, and its many closely related variations/technologies (S-PVA, M-PVA, etc.), offer marked improvement in most of the technical limitations seen with TN panels. Specifically, high-end S-PVA panels can offer dramatically improved contrast ratios with better lowlight performance, improved off-axis viewing with minimal color shift, and increased color depth (typically 8bit offering 16,777,216 colors) compared to TN panels. Despite not suffering from the same type of severe color shift problems seen on TN panels, even high-end S-PVA panels tend to exhibit a noticeable off-axis viewing limitation often referred to as black-shift. Black-shift is a sharp perceived increase in low-luminance levels onscreen when viewing the panel off-axis. When sitting directly centered in front of the monitor the lowlight levels are typically very low offering very good black level reproduction. However, some subtle luminance level differences can be difficult to differentiate on-axis, but when viewing off-axis become very noticeable as all lowlight levels become lifted. A colorist attempting to see small luminance differences in dark areas of a scene may not be able to see this unless viewing off-axis. This can cause a bit of an annoyance as the scene ends up being perceived, and sometimes graded, differently as a result of slight variations in viewing position. 3 to 5 years ago S-PVA was held in generally high esteem because unlike TN panels the image was still visible with minimal changes in color perception off-axis. However, the black-shift issue on these panels also played a large role in restricting their deployment in some more highly color critical applications.

In addition to the black-shift issue PVA panels tend to have significantly slower native pixel response times than other LCD panel technologies. To reduce motion blur artifacts and bring pixel response times within acceptable limits for professional use most PVA manufacturers devised workarounds, the most common of which is an Over

Drive Circuit (ODC). ODCs improve pixel response time by allowing the voltages that drive the open/closure of pixels to essentially overshoot what would be their intended normal voltage for any given frame by evaluating preceding and subsequent frames in the signal. This generally works very well at improving pixel response time, but has the negative side of effect of introducing an inherent processing delay within the panel driver (typically 1 frame). This processing delay adds to the total amount of delay between a monitor's receipt of a signal and onscreen display of that signal. In many applications this is of little consequence, but for a limited number of professional applications the minimal processing delay possible is essential so use of PVA based monitoring solutions is deemed unacceptable.

The same panel suppliers traditionally providing PVA type technologies are already in the process of developing and releasing both new variations and replacements for PVA panels that, among other things, address this black-shift phenomenon and pixel response time concerns. However, the availability and deployment of these newer technologies is still quite limited.

IPS panel technologies, including IPS, S-IPS, P-IPS, and H-IPS, are some of the most prevalent panels currently in use in mid-range to high-end professional broadcast LCD monitors. IPS technology aims to strike an ideal balance between off-axis viewing performance and pixel response time. Early iterations of the technology tended to suffer from a limited 'sweet spot' for monitoring, but one that was nonetheless wider than TN panels. Noticeable black-shift does not occur on IPS panels and severe color shift or image loss to the degree seen on TN panels also does not occur. However, many IPS panels have an ideal viewing angle range that is actually much smaller than the viewing angle quoted in their specifications. For virtually all LCD monitors the quoted viewing angle limits are just a quantification of the angle at which a minimum 10:1 contrast ratio is maintained, but this does a poor job of accurately quantifying the typical viewer's experience with the LCD panel in question. With older IPS technologies specifically the panel may have had a quoted viewing angle of 176° (88° left/right of center), but in reality the sweet spot where minimal color shift occurred may have been something closer to half of that, about 90°, or 45° left/right of center. On many widely used IPS panels this color shift tends to manifest itself as a purple or blue sheen over the entire screen once a certain off-axis viewing angle is reached. Newer improved generations of IPS panels employing S-IPS and H-IPS technology have greatly improved upon the off-axis viewing performance of IPS monitors. Specifically, these panels have a much wider 'sweet spot' for viewing before significant color shift occurs. Additionally in many of the best H-IPS or S-IPS panels the once ubiquitous blue/purple sheen seen as a viewer approached the quoted viewing angle limits has been replaced by a much more subtle slight white sheen that is unquestionably less noticeable and less objectionable.

IPS panels tend to have satisfactory native pixel response times and do not typically require an ODC to improve upon these pixel response times for professional use. This allows monitors that use IPS panels to have a faster video processing chain than most PVA based technologies, which helps to minimize the delay between receipt of the signal and onscreen display for the operator.

IPS panels are also widely available in 8bit (16,777,216 colors) and even 10bit (1,073,741,841 colors) varieties allowing for very accurate color reproduction with minimal banding. However, as with TN and PVA panels IPS panels are transmissive and other performance benchmarks such as color gamut and white uniformity are largely determined by the backlight used in conjunction with the LCD panel so understanding the various backlight technologies used and their characteristics is also crucial in understanding various LCD monitors as a complete device.

Backlighting technology can be broken up into two major categories, Fluorescent and LED. These major categories can then be further broken down by important subcategories such as EEFL, CCFL, White LED Edge Lit, RGB LED Edge Lit, White LED Matrix, and RGB LED Matrix.

Fluorescent backlights have historically been the most commonly used of the LCD backlighting technologies, but this is changing quickly. Fluorescent backlights are simply a series of fluorescent lamps used in conjunction with a diffuser (commonly referred to as a light guide) to as uniformly as possible create a constant light source that is then filtered by the LCD panel's various sub pixels (typically R/G/B). The fact that this light source is constantly on is the primary reason that LCD monitors have more elevated black levels than emissive displays like CRTs because the pixels simply cannot block out 100% of the backlight. The maximum native color gamut of fluorescent backlit LCD panels is largely a function of the backlight's spectral distribution, which is itself a function of the phosphors used within the fluorescent lamps.

Depending on the fluorescent backlight used an LCD display may be able to achieve only as little as 50% of NTSC color space or as much as well over 100% of NTSC color space. Color gamut coverage is typically cited for any give panel/backlight combination with wide gamut fluorescent backlights typically able to achieve around 75% of NTSC color space and so called ultra wide gamut fluorescent backlights able to achieve in excess of 100% of NTSC color space. The typical wide gamut fluorescent backlight (75% NTSC) is normally sufficient for 100% coverage of Rec 709 (HD) color space. The typical ultra-wide gamut fluorescent backlight (greater than 100% NTSC) is typically sufficient for satisfactory DCI-P3 color space emulation.

Within the fluorescent backlight category there are two distinct technologies that are widely used for professional monitors. The less prevalent of the two is EEFL (External Electrode Fluorescent Lamp), which is very similar to the more prevalent CCFL (Cold Cathode Fluorescent Lamp). EEFL is a more recent and superior technology where, as the name implies, the electrode generating the lamp's electric field sits outside of the lamp. The EEFL design aids in heat dissipation, which translates into improved white uniformity performance and improves the lamps overall efficiency and stability over time. While EEFLs are generally recognized as a superior technology to standard CCFLs they are not widely available as an integrated part of most LCD panels. All other things being equal broadcast monitor manufacturers will typically opt for EEFL over CCFL, but in practice the availability of EEFL backlit panels is quite limited and therefore units with such a backlighting system are usually only found in a handful of monitor sizes.

While there has been a rapid transition in panel suppliers' use of LED over CCFL backlights for new panel designs it should be noted that this likely has more to do with environmental concerns and the desire to have something new for marketing departments to promote rather than any major real world performance benefits. The latest generation of CCFLs and EEFLs are long lasting, well performing, and very cost effective backlighting options. However, there are two notable factors aside from marketing gimmickry that will almost certainly result in LED backlighting completely replacing fluorescent backlighting in the long run:

1. Fluorescent backlights contain a small amount of mercury. There is real environmental concern that improper disposal of fluorescent backlit displays over time could lead to the accumulation of mercury in

landfills and the environment in general. This is a valid concern, though it should be noted that there are many display recycling programs available that can safely handle the mercury in these backlights and keep them from becoming an environmental concern. Additionally, while LED backlights are generally seen as a more environmentally friendly mercury free alternative to CCFLs it has been shown that many LEDs contain measurable amounts of arsenic and lead that also suggest a need for careful disposal of those systems. Concern over regulative pressures, much like the lead free initiatives in the waning days of CRT based monitors, that may eventually lead to a ban of backlights containing mercury in some jurisdictions has likely prompted some manufacturers to pursue other backlighting options such as LED.

2. Fluorescent backlights require a substantial warm up period before they stabilize at a desired color temperature and luminance. When first turned on, especially when cold, fluorescent backlit displays are dim and the color temperature is not within acceptable limits for professional use. It typically takes such a monitor 15 minutes to warm up to acceptable levels for general professional use and up to 30 minutes from startup to really achieve an acceptably stable condition for truly color critical monitoring. For many rack mount and edit suite applications this is not a huge issue, but for field use the comparably quick (almost instant) warm up to acceptable tolerances by LED backlit displays is undeniable a significant advantage over fluorescent backlights.

LED backlights are available in many varieties, each with its own combination of limitations and benefits. Backlights can be broken up into two basic configurations: edge lit and matrix. In an edge lit system the LED backlights are at one or more of the panel's edges and a light guide is relied on for even distribution of the light. In a matrix system the LEDs are evenly arranged as a low resolution grid behind the higher resolution LCD panel. In both edge lit and matrix systems white LEDs or a combination of Red/Green/Blue LEDs can be used.

Edge lit white LED backlights are perhaps one of the most power efficient and lightweight backlighting options available. However, the majority of edge lit white LED backlights on the market have difficulty achieving a wide enough color gamut to cover 100% of the Rec 709 (HD) color space. Additionally, less advanced edge lit LED backlights may have difficulty achieving and maintaining good white uniformity performance for two reasons:

1. Light is emitted from the side(s) of the panel so the light guide system must be carefully designed to ensure even light distribution. This has improved significantly over time, but can still be difficult on larger size panels. Additionally, the best light diffusion technologies are often too cost prohibitive as the majority, though certainly not all, white edge lit LED backlight panels are geared towards lower cost monitoring options.
2. To ensure good white uniformity performance in white LED backlight systems the LEDs must be binned by suppliers in groups that match as closely as possible. White LEDs that do not match well invariably lead to poorer white uniformity performance. Finding and grouping matching white LEDs is not impossible, but as the acceptable tolerance levels between LEDs are narrowed the cost of the backlighting system tends to increase.

These factors combined mean that for professional use edge lit white LED backlights are primarily relegated to the smaller field use display market because white uniformity is inherently easier to maintain on smaller displays and because many of these field use applications are more concerned with weight, power consumption, and cost rather than color fidelity.

Edge lit RGB LED backlights can offer significant improvements in performance compared to edge lit white LED backlights. Wider color gamut is typically much easier to achieve by using a combination of Red, Green, and Blue LEDs as a backlight. Many edge lit RGB LED backlight systems can easily achieve well over 100% NTSC color space and easily outperform the majority of white LED backlight systems. Additionally, edge lit RGB LED backlight systems are not as reliant on having matching LEDs to achieve good white uniformity performance because precise control of white balance can be achieved by mixing variable amounts of the individual Red, Green, and Blue LED light output to achieve a desired white point. When combined with advanced light guide technologies RGB LED backlight systems can offer very good performance while maintaining the power consumption advantages typical of edge lit white LED systems. Though not the most widely adopted backlighting technology currently in use for professional broadcast LCD monitors, edge lit RGB LED backlight systems will likely continue to become more prevalent as global supply increases, performance continues to be improved, and costs continue to fall.

White Matrix LED backlights attempt to work around the white uniformity challenges of edge lit technologies by evenly spacing the LEDs in a low resolution grid behind the LCD panel. While this technology avoids the challenge of more complex even diffusion of light from the edge of the display it requires that greater care is taken to match the White LEDs to achieve acceptable white uniformity. This typically results in a higher product cost than edge lit systems. As white LED matrix backlights tend to be found in this higher end of the white LED backlight market the LEDs are often capable of wider achievable color gamut (greater than Rec 709) than the lower quality LEDs used in many edge lit white LED systems, but currently these systems still come well short of the achievable color gamut of most higher end RGB LED backlight technologies.

RGB Matrix LED backlight systems have proved to be one of the highest performance backlighting options available. In particular, higher end systems can employ very fine tuned zoned control of white uniformity and offer some of the widest achievable color gamut. However, the cost for such systems has also historically been much higher than competing backlight technologies and with the rapid technological improvements being employed in alternatives like edge lit RGB LEDs the cost versus real world performance benefits have become harder to justify. This technology is far from dead, but it remains to be seen if it can compete in the long run with respect to offering a performance benefit on par with its cost premium.

Matrix LED systems are also used by some manufacturers to employ zoned dimming of the backlight to achieve very high contrast ratios. Zoned dimming of backlights was designed as a consumer technology enhancement to improve contrast ratios in non-critical viewing environments, but is generally considered inappropriate for professional monitoring applications because zoned backlight dimming invariably leads to monitoring artifacts for the simple reason that the LED backlighting grid is significantly lower resolution than the LCD panel matrix. This means that with zoned dimming it is impossible to maintain stable contrast response with dynamic signal content. The reason this is important to understand with respect to professional monitoring is that the dynamic contrast ratios often quoted for such technologies are not representative of the real world static contrast ratios the technology will exhibit when operating in an appropriate (for professional use) always on backlight state.

PDP (Plasma) Displays

Plasma Display Panels (PDPs) are widely used in the large form factor professional monitoring market, especially as client monitors in postproduction environments. PDPs, much like CRTs, are emissive displays with fast pixel response times, good off-axis viewing characteristics, good color depth, and high contrast ratios. However, there are several factors that limit wider scale adoption of PDPs for professional monitoring:

1. PDPs are difficult to manufacturer in small screen sizes, especially in native HD resolutions. The smallest PDPs have traditionally been around 32” in size, with native 1920x1080 resolution displays typically only found in the 40”+ size range. For this reason PDPs are often simply too large for many monitoring applications.
2. Plasma displays are relatively inefficient in terms of power consumption. The total power draw is also variable and heavily influenced by the signal’s content with brighter scenes pulling much more power. In virtually all Plasma monitors there is a cutoff point necessary to ensure safe, reliable, and sometimes even legal operation in jurisdictions with power efficiency regulations for display devices. This results in an objectionable side effect commonly referred to as floating peak white luminance (or sometimes floating white point, though this phrase is understandably also used to refer to lack of color temperature stability). It is easiest to understand this issue with a simple example: If a typical Plasma is displaying a small white box on screen (say about 15% of the total screen size at 100IRE) with a black background this box will be displayed much brighter than a larger version of that same white box (say about 95% of the total screen size, also at 100IRE). Ideally the display should show the 100IRE white box at the same luminance regardless of how large it is in on screen, but in the example cited above a PDP may produce the small box at 35fL (just as an example), but the larger white box may be up to half as bright (around 17 fL for example). This degree of dynamically changing luminance levels not only effects the perception of image brightness, but has also been shown to effect the perception of color saturation. Facilities using PDPs attempt to deal with this is numerous ways:
    a. Often times the PDP is simply calibrated to a very low peak white luminance level (16fL-20fL for example) that allows the display to achieve much more stable luminance reproduction performance. This is a fairly effective solution to the floating peak white luminance issue and when used for monitoring of content destined for theatrical release can be not just a real world workaround, but also a technically appropriate workflow. However, for video based work these low luminance settings are well below industry defined (e.g. SMPTE) recommended practices for peak white display luminance and may result in significantly different viewing experiences than would be experienced on displays abiding by these industry standards and recommended practices.
    b. External alignment and color space management hardware and software are often used to try and improve upon the PDP’s normal display characteristics. These tools can be effective at improving upon the floating peak white luminance issue, but ultimately will also rely on lowering the overall peak white luminance (point a.) to completely address the issue as there is a physical limitation imposed by the display device and its power supply and/or power management system.
    c. Some facilities simply accept the limitation of this technology and attempt to deal with its side effects as they occur. Educating editors, colorists, and clients about this limitation ahead of time can be helpful in better managing the issue and expectations.

This floating peak white luminance issue has become more pronounced in some newer PDPs as energy efficiency regulations have forced many manufacturers to adopt even more restrictive power management systems while other manufacturers are focusing on updated PDP designs specifically for prosumer/professional use that aim to limit this problem.

3. Plasma displays require frequent calibration for accurate color temperature, color space, and gamma response reproduction. PDPs tend to be much less stable than transmissive display technologies and in more color critical environments monthly or even weekly calibration schedules are employed to manage this stability challenge, particularly with respect to white balance (color temperature).
4. As an emissive phosphor based technology Plasma displays are subject to burn-in if static content is left onscreen for extended periods of time. Several different technologies have been used by manufacturers to minimize burn-in risks, but burn-in still remains a valid concern for PDP owners and recommendations on how to avoid such burn-in should be carefully observed.
5. In lowlights Plasma displays tend to exhibit more noise than other technologies and this may be objectionable when viewing at a close distance.
6. PDPs use a heavy and glossy glass screen that makes the overall product not only heavier than alternative displays technologies, but also potentially less durable if moved often. Additionally, PDPs are prone to screen glare from ambient lighting. Careful design of the viewing environment is necessary to minimize glare.

OLED (Organic Light-Emitting Diode) Displays

OLED technology aims to combine the best aspects of CRT displays and combine them with the best aspects of fixed pixel structure flat panel displays. OLED technology affords excellent black levels/contrast ratio and fast pixel response times that cannot be matched by competing LCD technology. Unlike Plasma displays OLED panels can be extraordinarily lightweight and manufactured at much smaller screen sizes while maintaining high native resolutions. However, OLED technology has been slow to market and in both professional and consumer applications has gone through several aborted product launches. Several factors currently limit wide scale adoption of OLED monitors or are otherwise a concern in professional monitoring applications:

1. Price & Availability: OLED manufacturing is very challenging with many OLED production lines currently achieving less than a 10% production yield of usable OLED panels; this is especially true in larger screen sizes (over 3.5”). Low production yields have led to very high costs and a very limited number of available screen sizes. Price premiums for OLED based professional monitors vs similarly sized LCD based professional monitors is typically anywhere from 3 to 6 times as much.
2. Product Lifespan: OLED monitors have historically had very limited maximum lifespans. The various color channels of many OLED monitors decay at different rates, with many OLED screens having Blue Channels capable of operating only 10,000 hours. This is starting to improve with some monitors now claiming 30,000 hour estimated lifespans, but this is still half of the estimated lifespan of many top tier LCD monitors.
3. Stability: The uneven aging of the Red/Green/Blue channels on an OLED screen mean that the product is rather unstable and requires either an advanced onboard monitoring system to maintain stability over

time or very frequent traditional realignment. In either case this adds substantial cost compared to more stable display devices.

4. Limited Peak White Luminance: Most OLED screens have a hard time achieving and maintaining industry recommended peak white luminance levels with many maxing out at a peak white luminance level of about 100cd/m^2 even when new.
5. Burn-In Concerns: As with all phosphor based emissive displays burn-in is a concern on OLED monitors and proper precautions must be taken to avoid burn-in.

OLED development is currently focused on improving production yields, enhancing display stability and total lifespan, increasing maximum light output, and offering larger and higher resolution panels.

Summary

A wide variety of display technologies are currently being utilized in professional video environments. Managing and servicing aging CRT monitors, especially for multi-format monitoring, is still a day to day challenge in many facilities that have not transitioned to other technologies. LCD monitors have been successfully adopted by many facilities in an extremely wide variety of color critical monitoring applications with elevated lowlight levels still being the main challenge for most LCD monitors. For larger format monitoring, and especially as an inexpensive client monitoring option in postproduction environments, Plasma displays have been widely adopted. While certainly offering better lowlight levels than the majority of LCD monitors other PDP display characteristics have certainly limited wider scale adoption of this technology. Many facilities have adopted PDPs for client monitoring while still relying on LCD or CRT monitors as the primary edit, color correction, or QC monitors. OLED display technology is rapidly evolving and seems poised to become the preferred professional monitoring technology in the future. However, OLED monitors are currently cost prohibitive for most facilities and applications. Significant improvements in production yields and in turn sharp reductions in pricing will be needed before OLED monitors can be widely adopted. OLED monitors will also likely need to show significant improvements in stability, light output, and overall lifespan before their costs can be justified at any level. It is unrealistic to expect wide scale adoption of OLED monitors at a 300% to 600% price premium when, if calibrated properly, the main difference will be a marginal improvement of lowlight performance compared to LCD based solutions. However, if/when these issues are addressed by advancements in OLED technology in the future and if/when the price premium can truly become marginal compared to LCD monitors then wider scale adoption of OLED technology should be expected.