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Solid-State Lighting Program & Building Electric Appliances, Devices, and Systems Program: Displays R&D Meeting

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DOE Solid-State Lighting Program & Building Electric Appliances, Devices, and Systems Program, "Displays R&D Meeting," February 2022.

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Comments

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1 Introduction

On November 15-16, 2021, twenty subject matter experts on different aspects of display technology gathered at the invitation of the Department of Energy (DOE) Solid-State Lighting (SSL) Program and Building Electric Appliances, Devices, and Systems (BEADS) Program to help identify critical research and development (R&D) topic areas in energy-efficient display technology. This small-group discussion meeting is one forum for experts to provide technical input to the DOE SSL and BEADS Programs. The DOE SSL Program also collects inputs from stakeholders at the annual Solid-State Lighting R&D Workshop, via a Request for Information (RFI), and other means. The guidance provided by stakeholders in these various forums helps identify critical R&D areas that may be incorporated into DOE's technical roadmaps.

This year the meeting was held virtually due to travel difficulties and concerns related to the ongoing COVID-19 pandemic. The meeting commenced with "soapbox" presentations, in which each participant was invited to give a short presentation describing what they believed to be the key R&D challenges for energy-efficient displays technologies over the next three to five years. This was followed by a general discussion of the most critical technology challenges facing the displays industry today.

The meeting format provided an opportunity for experts across the research spectrum to exchange ideas and explore collaborative research concepts. Participants included invited experts in the field of displays and supporting disciplines drawn from industry, national laboratories, and government agencies.

This report summarizes the outcome of the discussions on critical technology challenges and identifies corresponding R&D tasks within the existing task structure. Outlines of the participants' soapbox presentations and related remarks are included in Appendix A: Participant Presentations.

1.1 Key Conclusions

The meeting format encouraged each attendee to participate and present his/her perspectives on critical R&D challenges for display technology. The discussions that followed the soapbox presentations offered a variety of valuable insights into a range of research topics that could advance displays technology; however, there were some recurring themes that arose during these discussions regarding research areas that could lead to significant breakthroughs in technology development and implementation. These themes are as follows and are outlined in more detail in Section 2:

- Quantifying Energy Consumption
- Display Architecture Performance and Efficiency
- Display Power Management
- Display Test Methodologies
- User Interfaces

2 Critical R&D Topic Areas

The COVID-19 pandemic has increased the energy consumption of displays with extended use of televisions and monitors with work from home conditions. Considering the potential jump in electricity load with increased displays usage in homes and buildings, this area represents a growing opportunity to embed energy saving designs.

2.1 Quantifying Energy Consumption

The energy consumption of displays and other consumer electronics has been studied and well quantified in U.S. homes for more than a decade. One participant presented on one such consumer electronics study, showing that consumer electronics devices in homes account for 12% of residential electricity use and 4.5% of total U.S. electricity consumption. More specifically, the electricity used by display products is responsible for 4.6% of the total household electricity consumption, with televisions (TVs) consuming the largest portion of display-related power in homes with an annual electricity consumption of 54 terawatt-hours (TWh). While the energy consumption of displays in homes has been well studied, participants state that equivalent studies of displays electricity consumption in commercial buildings in not well understood and quantified. Participants agreed there is an opportunity to support similar studies understanding the electricity consumption of displays in commercial settings. This would inform DOE as to where the research focus and education should be targeted to reduce the power consumption responsible for miscellaneous electric loads (MELs) in buildings.

2.2 Display Architecture Performance and Efficiency

Participants discussed several leading display architectures and their advantages and tradeoffs, in terms of performance features, energy efficiency, manufacturability, and cost. These displays architectures can be divided into transmissive and emissive architectures. Liquid crystal displays (LCDs) are the dominant display platform technology and consist of a light emitting diode (LED) backlight and a liquid crystal polarizing cell which modulates the light and contains color filters to create the red, green, and blue pixels from the white light source. The LCD's transmissive architecture results in only 5-10% of the generated light being seen by the observer, since most of the light emitted by the white LED is absorbed in the LCD cell. The LCD display architecture has continued to dominate market share due to its low cost, driven by overinvestment and intense competition.

Though LCDs are the predominant technology, further innovations to this display architecture have kept improving its performance and energy savings over time. Participants noted that mini-LED displays have emerged as an improved LCD product by replacing conventional LED backlight modules with smaller mini-LEDs that provide a higher dynamic range, wider color gamut, and lower power consumption in a thinner product. Participants also expressed that the use of quantum dots (QDs) as a red and green color conversion media in place of the LCD color filters can reduce the absorption losses when combined with a blue LED backplane. This can lead to a 30% efficiency improvement over the LCD color filters and is applicable to several display architectures including mini-LED LCDs, micro-LED displays, and organic light emitting diode (OLED) displays. Participants identified R&D needs to advance the performance of QD color converters, including improved close packing of the QDs in the color converters through optimizing QD materials, QD ink properties, and improving the deposition process. Furthermore, improved stability of the QD materials to high temperatures and high optical fluxes will provide longer life color converter layers.

An emissive display architecture, where the pixels intrinsically generate the color, can lead to much higher efficiencies by eliminating the lossy polarizers and color filters present in the LCD optical stack. There are two primary SSL technologies for producing emissive displays today: OLEDs and micro-LEDs. (Electroluminescent quantum dots represents another emerging technology for emissive displays but is currently less mature.) Currently, OLED TV display panels are more costly than LCDs; however, OLEDs provide premium performance due to higher contrast ratio, wider color gamut, and faster response times. The higher OLED display cost is largely driven by higher capital costs in manufacturing, which should reduce as volumes grow. For example, OLED cell phone displays fabricated on rigid glass substrates have reached approximate cost parity to LCDs in this high volume application. Additionally, OLED display power consumption remains ~10% higher than LCDs, despite LCD's large optical stack losses, but new approaches such as removing the color filters are decreasing OLED display power consumption. Because the backlight LEDs in the LCD displays are so efficient, they compensate for the losses in the color filters and polarizer cell. The blue OLED emitter currently used in the display has very low efficiency compared to LEDs. Furthermore, OLED TV displays currently use a white OLED source stack that requires color filters and a circular polarizer, which in turn adds more losses, and ultimately brings down the overall system efficiency compared to LCDs.

Participants identified a few development areas to improve OLED display efficiency. These include improving outcoupling enhancement from the OLED emitters to eliminate crosstalk and light scatter between pixels. Novel designs with micro-optic patterns formed on the encapsulation glass have shown increased brightness in mobile phone OLED displays and are a potential direction for larger OLED displays. Also, using red, green, and blue (RGB) side-by-side OLED emitter configurations will be more efficient than using white OLEDs with color filters (to create the RGB pixels) for TVs. Finally, the backplane efficiency depends on the number of OLED stacks so moving to architectures that stack more OLED emitters can improve efficiency.

Micro-LED displays are another emerging emissive display technology that shows promise of superior performance features such as brightness, high dynamic range, color gamut, along with form factor flexibility, and higher energy efficiency (low power consumption). The benefits of micro-LED display technology include: 90% lower power consumption, 40% larger color gamut, 10 times higher brightness, and the ability to realize seamless tiling of panels to create display sizes greater than 100 inches. While there is great promise in the performance characteristics of micro-LED displays, participants discussed several key technical challenges to address including fabrication of efficient micro-LED devices, mass transfer of the devices to the system backplane, and the driver technology to control a vastly increased number of pixels. Addressing these challenges requires further development of the technology and supply chain. While display applications are currently driving the R&D for mini- and micro-LEDs, these small LED device form factors are also being considered for illumination applications because of their ability to offer improved directional lighting and new lighting functions using adaptive pixels for wayfinding, emergency lighting, and information display. Critical to implementation in either lighting or displays, the micro-LED performance needs to improve to meet the applications requirements and enable greater energy savings.

Another area discussed by participants is how the required color gamut impacts the efficiency of the display. Increasing color gamut of LCD displays requires much more power than for emissive displays such as OLED or micro-LED displays. A better understanding of color linking visual performance to display power consumption could be very beneficial to saving energy. There is an opportunity to optimize the size of color gamut while minimizing power consumption by fine-tuning the color system design.

Participants acknowledged that all the various display architectures still have room for improvement. Emissive architectures have the potential to be the most energy efficient if the noted technical challenges can be overcome. These include more efficient blue OLED emitter materials and OLED outcoupling enhancement; more efficient and stable QD color converters; and improved micro-LED devices efficiency, transfer processes and backplane designs. In the meantime, LCD displays continue to improve their performance and reduce power consumption to remain the dominant display architecture in the midst of emerging display technologies. Overcoming the stated technical challenges with cost-effectiveness will be crucial for these emerging display technologies to supplant LCDs while providing the best performance features and lowest power consumption.

2.3 Display Power Management

The power management of a display depends on several factors including the efficiency of the power supply and the operation control schemes. Participants identified opportunities for improving display power supply efficiency performance over a broad power load operating range. Innovative circuit topologies, such as a multiplexing-based power supply architecture, can improve the display efficiency. Implementing a GaN-based primary switch can improve the efficiency of the power supply by reducing the conduction losses due to lower on-resistance in the device, and the high switching speeds in GaN devices leads to lower switching losses as well. Adding a multiplexing stage to the power supply to achieve single stage multiple output conversion will improve efficiency over the more conventional two-stage power supply approach. The two-stage power supply typically has an overall power supply efficiency of around 77%, whereas the multiplexing single-stage architecture with wide bandgap semiconductor components can achieve efficiencies of 90% across a power load range from 10% to 100%. Participants agreed that further development of innovative power supply architectures can lead to further power supply improvements, both in terms of efficiency and functionality

Beyond lowering power consumption through display backlight improvements, reduced optical stack losses, and increased power supply efficiency, managing the display power through the optimization of control schemes is a viable energy efficiency opportunity. The power draw of displays depends, in part, on default and user-selected display settings, particularly the brightness level. Electricity savings from screen state modes such as auto power down (APD) or automatic brightness control (ABC) – where the display dims brightness in relation to the room illuminance level – has led to electricity savings in displays such as monitors and TVs. Further implementation of these features into more display applications from thermostats to appliance display screens will accumulate further electricity savings over time without requiring any major technology changes. Participants indicated that least 10-15% power savings is achievable with ABC schemes when implemented into displays. Many display applications can realize further energy savings by employing these controls schemes. A 30-50% power savings is possible as more consumer electronic display models adopt the state-of-the-art technology used in high-end products such as premium TVs. Participants also suggested future policy should incentivize the use of easy-to-find brightness controls (found in mobile phones) in larger display form factors and make the ABC on/off switch harder to access, as to keep energy savings features from being easily turned off.

2.4 Display Test Methodologies

Current display test methods do not measure the display under a range of realistic operating modes and do not consider the uniformity of the display as part of the efficiency criteria. There is an opportunity to develop better methodologies to measure display energy consumption by creating a level playing field across different display architectures to ensure the products with the best operational efficiency are being identified. Considering the uniformity of the screen brightness is important to objectively compare energy consumption of different technologies. For example, LCD TVs are brighter in the center and dimmer on the edges, whereas OLED TVs have uniform brightness across the whole screen area. Since the current test methods only measure the center of the screen, LCDs displays can meet Energy Star Displays Specification requirements at lower power levels than if the entire screen area was considered, while OLED screens effectively do not get credited for their better brightness uniformity.

Participants examined a new measurement approach using a camera photometer to measure the average luminance across the whole screen while playing a dynamic video clip to determine both the luminance and power simultaneously. This method provides a more realistic view of the screen performance and the ability to access the actual efficiency of the display. This new methodology measures the display at three picture settings – a default setting, the brightest setting, and a high dynamic range (HDR 10) setting. Another feature that is critical to monitor is the power consumption of TVs with “smart wake” features. Many TVs consume more than 12 W power on standby (for an average of 19 hours a day) while waiting for the wake command. New test methods are being implemented in the coming Energy Star Displays Specification Version 9.0 to address some of the deficiencies of the current Energy Star Displays Specification. Using screen averaged dynamic luminance is important since the current “Power/Area” metric encourages dimming in default mode and the minimum luminance requirements are fraught with inaccuracies and non-representative metrics of real-use modes.

Finally, the participants discussed the challenges with developing a representative test to evaluate ABC features in displays. The high level of spatial and spectral uncertainty in a real-world setting makes it difficult to develop a representative test since the characteristics of the room environment and the location of users relative to the TV sensor (that controls ABC) vary in real world use cases. Additionally, the spatial and angular response of the TV's ABC sensor differs from spatial and angular response of the luminance meter. This becomes challenging in the typical room configuration where the ABC sensor (located in the TV) is detecting light coming from the ceiling, so the angular response curve impacts the resulting illuminance detection, whereas the luminance meter is measuring normal to the TV (a different geometry). The fact that the sensor is located in the TV, makes it not well positioned for the task at hand. It is not the ambient light seen by the ABC sensor that should determine brightness needs, but rather the ambient light seen by the viewer.

2.5 User Interfaces

The user interface (UI) is important for display power management since it indicates the power state (on/off/sleep) and can control how to wake or put the device to sleep (e.g., including voice or presence detection or timers). The UI also plays a role in how we interact with the display devices; the UI should convey the method of interaction in a simple way (e.g., is it touch- or voice-operated? What language does the device understand?). Furthermore, the UI can be a display that informs the user about the system status of an appliance or MEL (e.g., a copier, an air purifier, a microwave oven, etc.) and provides the user with a means of controlling it. Participants discussed how to expand the boundaries of the analysis for display power consumption. A poorly designed display interface hinders users from achieving their desired level of service, and thereby wastes energy when the user settles for “good enough” instead of their ideal point. For example, users can tolerate overbright displays if it is difficult to find how to adjust the brightness, though higher brightness consumes more power. Thoughtfully designed interfaces will guide users to their desired outcome, prevent frustration, and result in energy savings. Participants agreed that improving the design of user interfaces can enable further energy savings opportunities beyond what is currently achieved. Research is needed to standardize methods to measure quality of user interfaces, develop better metrics of usability and identify best practices for common tasks with user interfaces. Furthermore, facilitating audio-only modes on displays when video is not required, and using limited areas of the display when communicating information that does not require the whole area of the display can reduce power consumption while still meeting the functionality requirements of the use-mode.

Appendix A: Participant Presentations

Bob O'Brien, DSCC: Display Technology Review

Bob O'Brien, President of Display Supply Chain Consultants (DSCC), started the discussion with an overview of the display market in large area applications such TVs, monitors, laptops, and tablets. LCD technology dominates the market in these large area applications due to its low cost, driven by overinvestment and intense competition. He went to discuss other display architectures and their advantages and tradeoffs. OLED panels have much higher price, but with premium performance due to higher contrast ratio, wider color gamut and faster response times. The higher cost is largely driven by higher capital costs in manufacturing. Mini-LED displays have emerged as an improved LCD product by replacing conventional LED backlight modules with smaller mini-LEDs to that provide a higher dynamic range, wider color gamut, and lower power consumption in a thinner product. O'Brien finished by discussing some future trends including hybrid QD – OLED displays, which combine the benefits of the two architectures, as well as the emerging micro-LED displays, which have potential for superior performance features though require further development of the technology and supply chain.

Bryan Urban, Fraunhofer USA: Energy Used by Displays in Homes

Bryan Urban, Senior Engineer at Fraunhofer USA, discussed the results of a study his team performed evaluating the electricity use of consumer electronics in U.S. homes. Consumer electronics in homes accounts for 12% of residential electricity use and 4.5% of the total U.S. electricity consumption. Urban focused his talk on the electricity used by display products, which use 4.6% of the total household electricity. TVs consume the largest portion of display-related power in homes with an annual electricity consumption of 54 TWh. In 2020, 285 million TVs were plugged in at U.S. homes and used for an average usage of 5.8 hours per day. The daily usage time jumped ~50% compared to 2017, likely due to the increased time at home with the COVID-19 pandemic. 90% of the TVs employed LCD technology and had an average on-state power consumption of 81 Watts (W). Average power draw declined steadily over the past 15 years for TVs of all sizes due to a combination of performance feature improvements such as LED backlights, ABC, and zoned dimming. Urban finished by highlighting the electricity consumption of monitors and laptop displays. 70 million monitors (94% LCD) were in use in 2020 for a daily average of 9.5 hours and an average power draw of 25 W. 123 million laptops were operating an average of 9 hours a day with a power draw of 3.4W.

Dan Baldwicz, Energy Solutions: Display Power Review

Dan Baldwicz, Senior Engineer at Energy Solutions, and his team performed an analysis investigating the power consumption of small electronic screens and specifically how much power draw occurs while these screens are inactive. Inactive power of electronic devices, such as TVs and monitors, is not a function of screen area, resolution, or technology type; a standby power ceiling of less than 0.2 W for a sleeping display across multiple device types is achievable for these display devices with connectivity and other functionality. Baldwicz stated that meeting an inactive power of less than 0.1 W should be viable for smaller, lower resolution screens, which have lower power overhead requirements. He went on to discuss the electricity savings from screen state modes such as APD or ABC. The further implementation of these modes into display applications from thermostats to monitors will accumulate further electricity savings over time without requiring any major technology changes. Baldwicz estimated that at least 10-15% power savings is achievable with ABC when implemented. He concluded by indicating that many display applications can employ more efficient technology and that an a 30-50% power savings is possible as more consumer electronic displays adopt the existing state-of-the-art technology used in high-end products such as premium TVs.

Gregg Hardy, Pacific Crest Labs: TV Efficiency: Methods, Metrics, and Findings

Gregg Hardy, Principal at Pacific Crest Labs, discussed a new approach to measuring televisions utilizing a camera photometer to measure the average luminance across the whole screen while playing a dynamic video clip so luminance and power can be measured simultaneously. This method can provide a more realistic view of the TV performance and the ability to assess the actual efficiency of the TV. The new methodology measures the TV at three picture settings – the default setting, the brightest setting, and the high dynamic range (HDR 10) setting. Considering the uniformity of the screen brightness is important to objectively compare energy consumption of different technologies. For example, LCD TVs are brighter in the center and dimmer on the edges, whereas OLED TVs have uniform brightness across the whole screen area. Since the current test methods only measure the center of the screen, LCDs displays can meet Energy Star Displays Specification requirements at lower power levels than if the entire screen area was considered, while OLED screens effectively do not get credited for their better brightness uniformity. Also, monitoring the power consumption of TVs with smart wake features is critical since many sets consume more than 12 W while on standby an average of 19 hours a day. These new test methods are being implemented in the coming Energy Star Displays Specification Version 9.0. Using screen averaged dynamic luminance is important since the current "Power/Area" metric encourages dimming in default mode and the minimum luminance requirements are fraught with inaccuracies and non-representative metrics of real-use modes. Hardy also discussed the challenges with developing a representative test to evaluate automatic brightness control (ABC). The high level of spatial and spectral uncertainty in a real-world setting makes it difficult to develop a representative test since the characteristics of the room environment and the location of users relative to the TV sensor (that controls ABC) vary in real world use cases. Additionally, the spatial and angular response of the TV's ABC sensor differs from spatial and angular response of the luminance meter. This becomes challenging in the typical room configuration where the ABC sensor (located in the TV) is detecting light coming from the ceiling, so the angular response curve impacts the resulting illuminance detection, whereas the luminance meter is measuring normal to the TV (a different geometry). The fact that the sensor is located in the TV, makes it not well positioned for the task at hand. It is not the ambient light seen by the ABC sensor that should determine brightness needs, but instead the ambient light seen by the viewer.

Stefan Peana, Dell Technologies: Display Power Trends

Stefan Peana, Chief Technologist for Displays at Dell Technologies, presented on the impact of display architectures on power consumption in notebook computers. Currently, 30-40% of a notebook computer's power is consumed by the display. Year-over-year display efficiency improvements of approximately 3% can be attributed to light source efficiency improvements from the LED backlights. Peana discussed the tradeoffs and benefits of both transmissive and self-emissive display architectures. LCD (transmissive) displays are a mature technology; the newer transmissive technologies using QD enhanced color filters or mini-LED backlight displays are a technical evolution that leverages LCD maturity. OLED is an emissive display technology that provides flexible form factors and large printing format benefit. Micro-LEDs are another emerging emissive display technology that shows promise of higher performance, flexibility, and low power consumption. He then compared the power consumption of these technology architectures in a 15.6" ultra-high definition (UHD) monitor form factor. The display with QD color conversion has a lower power consumption than conventional LCDs due to the more efficient conversion using QD color filters. Moving to a micro-LED emissive display shows an even greater reduction in power consumption. OLED emissive displays, on the other hand, have higher power consumption due to the very inefficient blue OLED source. Peana closed with recommendations for improving power savings in different R&D areas including R&D on QD color filter uniformity, leakage, reliability, and deposition process; research on higher efficiency micro-LED chip assembly process and interconnect technology for micro-LED display; and development of a high-speed micro-LED integrated driver and controller.

Charles Li, PlayNitride: MicroLED Display for Smart Life

Charles Li, the CEO at PlayNitride, discussed the benefits of micro-LED display technology which includes 90% lower power consumption, 40% larger color gamut, 10 times higher brightness and seamless tiling to create display sizes greater than 100 inches. He highlighted the impact of display backplane choice on power consumption for micro-LED displays by comparing their findings on printed circuit board (PCB) used for tiling large displays and thin film transistor (TFT) backplanes used in consumer electronics. The TFT backplane is not as power efficient since too much power is consumed by the backplane (the transistors). Li indicated that the PCB backplanes are preferable to allow the use of a matrix form factor where an array of micro-LEDs are attached to a package substrate and then these matrix tiles are reflowed onto the PCB substrate. Li finished by discussing cost reduction strategies for micro-LED displays including reducing micro-LED chip size (50% to 80%), increasing yield to 99.9% or higher, and lower-cost repair technology (mass repair technology).

Mike Hack, Universal Display Corporation: Further Energy Savings from Phosphorescent OLED Displays

Mike Hack, Vice President of Business Development at Universal Display Corporation, addressed trends in OLED technology for displays. He began by discussing what limits the efficiency of today's OLED displays. Outcoupling enhancement from OLEDs needs to improve in order to eliminate crosstalk and light scatter between pixels. Outcoupling enhancement techniques developed for OLED lighting are not generally applicable to OLED displays. This is because strong scattering layers can cause pixel crosstalk, reduce display sharpness, or act as diffuse reflector for ambient light, reducing contrast. Also, the scattering surface may impact the polarization state of reflected light, thus reducing the efficiency of the circular polarizers. Novel designs with micro-optic patterns formed on the encapsulation glass have shown increased brightness in mobile phone OLED displays. Hack then reviewed how the light generation efficiency depends on the required color gamut. Increasing color gamut of an LCD display requires much more power than for OLED displays. He believed that a better understanding of color linking visual performance to display power consumption could be very beneficial to saving energy. There is an opportunity to optimize the size of color gamut while minimizing power consumption by tweaking the color system design. Finally, he discussed how the combined frontplane and backplane efficiency depends on the number of OLED stacks; 50% of the power can be lost in the backplane with a single stack, whereas stacking more OLED emitters can improve efficiency.

Ray Ma, Nanosys: High Efficiency Displays Enabled by QD Technology

Ray Ma, Senior Director at Nanosys, began by comparing the different display architectures and technologies. LCDs have lower power consumption than OLED displays (~10% lower), even though only 10% of the generated light is emitted from the LCD displays. The backlight LEDs are so efficient that they compensate for the losses in the LCD color filters and polarizer cells when compared to OLED displays. OLED displays also use color filters and a circular polarizer, but the blue OLED emitter has very low efficiency bringing down the overall system efficiency. He then discussed how implementing mini-LED backlights can improve LCD efficiency since they have the ability for more localized dimming (less pixels need to be on at the same time or on at full power). Ma finished by examining the use of QD color conversion to replace the absorptive LCD color filters to provide another efficiency improvement (~30%) for multiple display architectures like mini-LED LCDs or OLED displays. R&D needs include improved close packing of the QDs for color converters to be equivalent to that in the QD backlight conversion films. This close packing can be improved by optimizing the QD materials, QD ink materials, and improvement of the deposition process. Combining OLEDs with QD color converters though has a trade-off in that the blue OLED emitter is much less efficient. The red/green QD color converter combined with a blue OLED pump will lag in efficiency relative to RGB OLED architectures. In general, RGB side-by-side configurations are more efficient than white light generation followed by color filters (true for OLEDs, micro-LEDs, or electroluminescent QD technologies).

Po-Chieh Hung, International Commission on Illumination: Display as Tunable-White Lighting Source

Po-Chieh Hung, Director of Division 8 of the International Commission on Illumination, considered the performance of a display as a tunable-white light source. Over time, the display color gamut continues to grow wider through changing the emitters to have narrower spectral peaks. Hung analyzed three different color gamut specifications (sRGB, DCI-P3, Rec. 2020) in terms of lighting performance such as color rendering index (CRI) and luminous efficacy of radiation (LER). The very narrow nature of the red, green, and blue peaks for the Rec. 2020 specification results in especially poor color rendering, particularly in the red tones. He then mentioned a possible negative impact to vision via the metamerism effect when using displays as a tunable white source. The metamerism effect will depend on the observer's field-of-view and how we see the "white" illumination. The ability to use displays as a light source will have limitations due to narrow spectral peaks, which lead to a lower CRI and metamerism with varying fields of view. These limitations will have to be augmented with other light sources to provide the best visual performance for the occupants in the room.

David Chen, Power Integrations: Novel Multiplexed Power Architecture to Improve Display Efficiency

David Chen, the Director of Applications Engineering at Power Integrations, presented on a novel multiplexed power architecture aimed at improving display efficiency. Chen began by highlighting the power supply efficiency as a function of the power load; this topology provides 90% efficiency between 10% and 100% of the display power load. He then described two key aspects of this driver architecture. First is using a GaN-based primary switch to reduce the conduction losses due to lower on-resistance in the device. The high switching speeds in GaN leads to less switching losses as well. The second key aspect is adding a multiplexing stage to the power supply to achieve single stage multiple output conversion. This single stage solution has two blocks – a flyback converter (to convert the AC main input to DC output) and the multiplexing controller which directs the energy packets to go to specific load which needs it at that moment. Chen then explained how this multiplexing architecture is more efficient than a two-stage power supply approach. Typically, the two-stage power supply uses the flyback converter as described above, and then may have a buck regulator to step down the DC voltage from 12 V down to a lower voltage required by the display. In addition, a boost stage may be needed to increase the voltage needed for the LED strings. There will be losses with each stage, so the overall power supply efficiency with this architecture is typically 77%. For the new single-stage architecture, there is only one loss stage, leading to approximately 50% loss reduction and power supply efficiencies of 90%. This allows more flexibility in designing the overall display system to meet Energy Star Display Specification requirements.

Bruce Nordman, Lawrence Berkeley National Laboratory: Displays and User Interface Standards

Bruce Nordman, a Research Scientist at Lawrence Berkeley National Laboratory, discussed display UIs for power management and functional interaction. The UI is important for display power management since it can indicate the power state (on/off/sleep), and it can control how to wake (including voice, remote, presence detection) or put the device to sleep (timer, presence, or manual). Nordman then considered how the UI plays a role in how we interact with the display devices. As technology options increase, so does the ways we can interact with devices, though the UI does not always indicate how the user should interact with it. UIs should move to convey this method of interaction in a simple way (touch, voice – what language, etc.). He finished by reviewing the research needs for display UIs which include: surveying the UI features available today (both static and dynamic operation), understanding emerging interaction models with the displays, creating persistent content streams that would sleep to manage the power state of the device, facilitating audio only modes on displays when video not required, and using limited areas of the display when communicating information that does not require the whole area of the display to be on.

Alan Meier, Lawrence Berkeley National Laboratory: Displays for MELs: User Interfaces and Energy

Alan Meier, a Senior Scientist at Lawrence Berkeley National Laboratory, addressed how we should continue to expand the boundaries of our analysis for display power consumption. He focused on two aspects to consider. First, how the display is a key component in the control of a larger energy-using device such an appliance or a MEL (e.g., a copier, an air purifier, a microwave oven, etc.) and second, how the display interacts with people to deliver a broader service that just what is being seen on that display. Display-based UI informs the user of the MEL's status and provides the user with a means of controlling it. Meier asserted that a poorly designed interface hinders users from achieving their desired level of service and thereby wastes energy, when the user settles for "good enough" instead of their ideal point. For example, users can tolerate overbright displays if it is difficult to adjust the brightness, though operating the display at higher brightness consume more power. On the other hand, a thoughtfully designed interface guides users to their desired outcome, prevents frustration, and saves energy. Small changes in the display technology – color, haptics, graphics – can greatly influence a device's total energy use. Meier concluded that we must transform the design of user interfaces from an art to a science. Research is needed to standardize methods to measure quality of user interfaces, develop better metrics of usability, and identify best practices for common tasks with user interfaces.

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