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Chair: Curtis Clark, ASC
Vice-Chair: Richard Edlund, ASC
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Introduction

ASC Motion Imaging Technology Council Chair:

Curtis Clark, ASC

The American Society of Cinematographers (ASC) Motion Imaging Technology Council (MITC – "my tech") continues its well-established 15 year tradition of proactive engagement with the motion picture and television industry by playing a significant leadership role influencing the development of key motion imaging technologies to better support our filmmaking art form and the role of the cinematographer in its creation.

The past year has been a watershed year for advancing key motion imaging technologies on several fronts. We continue to see the evolution of digital motion picture cameras incorporating high dynamic range (HDR) image capture in conjunction with significant developments in both spatial resolution (4K, 6K and 8K) and temporal resolution with higher frame rates, as well as large format sensors with wide color gamut (WCG).

HDR enables visual storytellers to expand their creative canvas in terms of increased tonal contrast with enhanced highlight and shadow detail while maintaining dramatically improved blacks that utilize brighter image display. When filmmakers shoot and master using the wide color gamut of ACES (the Academy Color Encoding System), they can creatively make the most of this additional picture information, both color and contrast, while preserving its integrity throughout the workflow.

Parallel with these camera and workflow developments are significant advances in display technologies that are essential to reproduce this expanded creative canvas for cinema exhibition and TV (both on-demand streaming and broadcast). While TV content distribution has been able to take advantage of increasingly available consumer TV displays that support ("4K") Ultra HD with both wide color gamut and HDR, including HDR10 and/or Dolby Vision for consumer TVs, Dolby Vision for Digital Cinema has been a leader in developing laser-based projection that can display the full range of HDR contrast with DCI P3 color gamut. More recently, Samsung has demonstrated their new emissive LED-based 35 foot cinema display offering 4K resolution with full HDR utilizing DCI P3 color gamut.

Together, these new developments enable significantly enhanced creative possibilities for expanding the visual story telling of filmmaking via the art of cinematography.

We will continue to proactively engage key technology developments that are influencing our motion imaging future, including virtual production techniques, along with the evolution of virtual reality (VR).

The following reports from our Committees and Working Groups cover in detail the crucial work being done by our Council to address the growing array of motion imaging technology developments that are impacting the art of filmmaking.

As always, the ASC Motion Imaging Technology Council is guided by its primary mission to engage and influence motion imaging technology developments in ways that best serve the filmmaker's creative intent and the role of the cinematographer in realizing a creative vision that best serves that creative intent. As we traverse this radical terrain of unprecedented technology transition, it is imperative that we persevere in our mission to have a path embracing the new while preserving the artistic achievements of the past that have defined the art of filmmaking.

I would very much like to thank all those who generously devote their time and expertise to support the mission of the ASC Motion Imaging Technology Council.

Secretary's Comment

ASC Motion Imaging Technology Council
Secretary & Director of Research: David Reisner,
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At the risk of repeating myself, motion picture tools and technologies have moved firmly into the digital realm and are experiencing the same type of continuous and rapid change and increased capabilities that every other digital technology shows. For ASC MITC, the past year saw an even greater interdependence in the work of our more than a dozen committees. Much of that interdependence has involved the themes of HDR and WCG - science, technologies, equipment, and workflows. (VR and Computational Cinematography are getting very close to being in that list now.) All of our committees are rising to the challenge of sharing that work, knowledge, and resources.

Once we got solidly to 4K, I had expected digital movie camera development to slow. But this past year has seen release of several 6K and a few 8K cameras, and increased performance in cameras across the board. To understand what has been happening, see our Camera Committee report. For the next element, see our Lens Committee report on the comprehensive work they are doing on both lenses and on filters. (For those of you who don't shoot pictures, the range of lens looks is wonderful. Come to one of the ASC's lens days, if you can.) The Lens and Camera Committee reports both suggest that we may finally be seeing useful movement and advances in camera metadata. In the practical world, that is a long-sought achievement and a big deal.

In the vast majority of feature movies and scripted-series television shows, the image data will promptly and repeatedly encounter the ASC CDL (ASC Color Decision List) during production and post. The DI (Digital Intermediate) Committee is exploring how well the ASC CDL works in this HDR, WCG environment and if any changes/additions are necessary. Our Motion Imaging Workflow Committee is working with the Academy's ACESnext Working Group to refine, improve, and educate about the ACES system, which is still our best channel for collecting, processing, sharing and archiving that content.

Our UHD TV, Next Generation Cinema Display, and Professional Display Committees are all actively involved in helping shape how that content is ultimately presented to provide compelling viewing experiences that do a good job representing the creative team's artistic intent. New, theater-screen sized emissive display products may be the route that gets HDR into theaters. (Note the match between the small OLED (organic light-emitting diode) and the display wall in **Fig. 1**.) We have an impressive set of work and results from our Advanced Imaging Committee that is making some real progress

FIGURE 1. View of Samsung Onyx 2K display (background) with Sony BVM-X300 (foreground) at Roundabout West in Santa Monica, California.

in establishing a scientific basis, understanding, and guidelines to support presentation of artistic intent on a wide range of displays, in a wide range of display environments, for a wide range of material, potentially originated from a single master. (As demonstrated by Chair Gary Demos in his 2018 HPA Innovation Zone demo of single master appearance compensation for bright and dim surround.) But before you get too confident, look for our upcoming article that will include the daunting list of appearance phenomena that need to be revisited/reexamined in light of modern HDR display and camera capabilities. The SSIMWave HDR Evaluation Working Group is coordinating with a commercial effort that is trying to provide an analytical measure of how those image characteristics hold up through real-world delivery chains. They are also participating very actively in the assembly of our HDR test material library, with generous and essential participation by EFILM (esp. Joachim Zell) and by Roundabout Entertainment (esp. Bryan McMahon and Jerome Dewhurst).

Our Plenoptic and Computational Imaging Committee is both helping bring the concepts and technology of more-than-planar image capture into the ASC and also helping its developers understand the needs of movies and movie-makers. To make a movie plenoptically, you probably shoot with a single perspective, one focus, and from one position, and throw the massive amount of camera data into the cloud where it can be worked on by large-scale cloud computation resources. Then during "post" that processing allows the cinematographer to pick/create actual shots. To help provide some order and to give cinematographers a means to express, communicate, and realize artistic intent, the Committee is exploring the possibility of an ASC PDL (Plenoptic Decision List).

On the computational theme, over the past year we have seen initial but real progress in the application of AI (Artificial Intelligence) – or, really, ML (Machine

Learning) - on the artistic side of movie making. There are significant benefits being realized in everything from ingest, description, and search, to localization and even a little bit of look manipulation and editing. But we are still seeing much less ML contribution to image manipulation in post and mastering than I have been calling for. If you think of this as the swell before you are hit by a huge wave, you will probably have it right.

The Joint Technology Committee on Virtual Production has continued to "spread the word" about the use of real-time computer graphics on-set during shooting. If you work in the industry, you probably know that that battle has already been won (e.g. Spielberg's *Ready Player One*). The Joint Technology Committee on Virtual Reality is still mostly doing introductory and educational work, but also doing a serious hands-on dig into the production process by designing and creating a VR test movie. We don't yet really understand how VR will be used in narrative storytelling, or how it will be produced, used, and monetized, but if you go to VR Committee meetings or visit places like the Technicolor Experience Center (the Committee's third meeting), you will see how real these new and emerging technologies are.

The ASC was formed nearly 100 years ago - in January 1919 – for cinematographers, with the participation of other industry experts, to share important information and experiences to develop and advance the industry's ability to produce exceptional imaging and tell exceptional stories. The modern ASC actively continues that tradition through the every-day work of its Members, Associates, staff, and the ASC Motion Imaging Technology Council.

Camera Committee

Chair: David Stump, ASC
Vice-Chair: Richard Edlund, ASC
Vice-Chair: Bill Bennett, ASC
Secretary: David Reisner

The ASC MITC Camera Committee engaged in a number of community activities this year.

Metadata

The interest kindled in the last few years at numerous camera manufacturers, lens companies and software companies is moving forward in renewed effort to unify metadata standards in cinematography, especially lens data, for inclusion in image files. Zeiss has very recently introduced their new ZEISS CP.3 Compact Prime lenses with eXtended Data that tracks focus information, lens distortion and lens shading characteristic information in real time for every frame. In addition, many cameras now record lens data from Cooke /i Lenses and also the ARRI LDS system. The

big news this year is that ARRI cameras now automatically record lens metadata to the camera data stream. In addition to lens data, the metadata scheme also records data such as pan tilt information on a frame by frame basis! ZEISS Compact Primes provide metadata that is included into DPX files or RAW files via either system, depending on the camera set up, and some grading tools are now giving users the ability to de-warp and control lens shading on set. The lenses are compatible with the Cooke /i system, and provide a glimpse into the future of automated real-time on-set metadata collection. The Metadata and Lens Committees are planning to co-host a meeting to demonstrate the capabilities of the system to Members, and possibly to invite the Visual Effects Society to attend as well. IMAGO (the European Federation of National Cinematographers Associations) have conducted a survey to elevate awareness in the community on the subject, and this topic needs to be brought to the forefront this year!

New and Emerging Camera Technologies
ARRI
ARRI ALEXA LF (large format) 4K ALEV III Sensor (from the ALEXA family), compatible with Full Frame Lenses, and new ARRI Signature Primes at T1.8 to support the camera. The sensor is slightly bigger than 35mm full frame at 36.70 x 25.54 mm and uses 4448 x 3096 pixels. It features the ALEXA SXT family body design, 4K ProRes recording options, ARRIRAW at 150 fps, uncompressed and unencrypted. ALEXA LF records to SxS or SXR Capture Drives depending on configuration.

ALEXA LF is Netflix/Amazon and other UHD/4K deliverable mandate compliant. It features multiple configurable monitoring outputs. An entirely new ARRI LPL Large Positive Lock mount fits large format lenses, and is LDS2, LDS, Cooke /i supported, with a larger diameter, and a shorter flange depth. The camera is compatible with S35 lenses, with a PL-to-LPL adapter that is delivered with each camera.

Canon
Canon's new C700 Large Format CMOS sensor has an active area of 38.1 x 20.1 mm covering a 43.1mm image circle and a 17:9 aspect ratio, with support for Super 35mm, Super 16mm and anamorphic. C700 FF is available in EF or PL mounts, and PL supports Cooke /i metadata.

The camera uses an external Codex CDX-36150 recorder to capture 5.9K RAW or ProRes. Wide color gamut meets BT.2020 standards, and Canon Log 3, Log 2, Log and Wide DR are all supported, as well as Cinema Gamut, DCI-P3 and Rec. 709. An internal ND filter system enables five density settings of 2, 4, 6, 8, and 10 stops.

Specifications: 5952 x 3140 - 5.9K recording, RAW/XF-AVC/ProRes, 4K DCI, "4K" UHD, 2K, HD, 17:9 aspect ratio, Canon Log 3/Canon Log 2/Canon Log/Wide DR, ISO 160 – 25600, Dual Autofocus with CFast, SD, Codex recording options.

Panasonic

Cinema VariCam Pure - S35 4K/2K camera system, dual ISO 800/5000, and built-in, uncompressed RAW up to 120 fps, utilizing Codex solid state drives.

Panavision

Millennium DXL 2 – available with VistaVision size sensor, DXL 2 uses the RED MONSTRO sensor, shoots VistaVision, 8K resolution, 60 fps max at 8K full frame, 75 fps at 8K 2.41:1, recording RED RAW with simultaneous 4K proxy (ProRes or DNx), Light Iron Color, 5 different series of Panavision large format lenses, spherical as well as anamorphic, with lens and camera metadata recorded to the data stream as well.

Red Digital Cinema

RED MONSTRO and GEMINI sensors, and the addition of ProRes and DNxHD recording codecs in addition to RED RAW, join the DSMC2 family of cameras. The WEAPON 8K S35 can shoot a maximum of 60 fps at 8K resolution. RED GEMINI features dual ISO 800/3200 in a large camera sensor (30.72 x 18mm), and captures 5K RED RAW @ 96 fps.

Sony

Sony VENICE highlights include a new Full Frame 36x24mm CMOS Sensor, an interchangeable Sensor Block – for future sensor upgrades (user serviceable). Features include 6K full frame 3:2 mode (6048 x 4032), currently 24 fps in full frame mode, 4K anamorphic 4:3 and 6:5 (4096 x 3432), and 4K Super 35 mode (windowed). VENICE offers support for FF & S35 spherical & anamorphic lenses, an 8-step mechanical built-in ND filter (8 stops ND), PL mount that is Cooke /i technology supported, and a locking E-mount.

Recording codecs/formats include X-OCN Compressed Raw onto AXS-R7 Recorder, 4K XAVC, ProRes HQ/422/LT, and MPEG HD. Recording media are SxS cards, AXS cards for RAW (external recorder).

Eastman Kodak

Yes, film… Kodak is still in business and many movies were shot primarily on film last year, including:

Dunkirk	*Roman J. Israel, Esq.*
The Post	*Murder on the Orient Express*
Phantom Thread	*The Cloverfield Paradox*
The Florida Project	*A Quiet Place*
Baby Driver	*Mission: Impossible – Fallout*
I, Tonya	*The Man with the Iron Heart*
Call Me by Your Name	*Justice League*

Battle of the Sexes	*Stories*
The Killing of a Sacred Deer	*Personal Shopper*
	The Lost City of Z
Wait for Your Laugh	*Porto*
Wonderstruck	*Beach Rats*
The Beguiled	*Most Beautiful Island*
The Only Living Boy in New York	*Suicide Squad*
	Mother!
Good Time	*Gifted*
The Ballad of Lefty Brown	*Godard Mon Amour*
The Wall	*The Mercy*
Wonder Woman	*Radegund*
The Mummy	*Shock and Awe*
The Book of Henry	*Hostiles*
The Meyerowitz	*The Florida Project*

The vast majority of movies, including those shot primarily on film, include some and often many digital shots. And essentially all movies now use digital compositing and VFX (visual effects) and go through a digital post workflow, rather than the "traditional" photochemical processes. For 100 years, film has set the benchmark for motion picture aesthetics. At this point, shooting digital and shooting film can both be used to create artistically rich movies.

Other Technologies
High Frame Rate Acquisition and Post Processing.
RealD TrueMotion

This technique was used to create the 24 fps and 60 fps release versions of Ang Lee's *Billy Lynn's Long Halftime Walk*, and the director has announced that his upcoming movie *Gemini Man* will employ the same technique.

The technique is to shoot digitally with 360° shutter at 120 fps or higher. Then post-process the images with RealD TrueMotion™ synthetic shutter software for any frame rate output (e.g., standard 24, or any high frame rate). The color and metadata are untouched during this process. During the process you select the synthetic shutter to render the motion look best suited to your scene. The process can eliminate judder in fast moving silhouetted objects moving against bright backgrounds in HDR displays. There is the option to control the speed of apparent motion (simulate over- and under-cranking), create a speed ramp in a sequence, with a simulated constant shutter angle throughout the speed change. You then output at the selected frame rate, and the output images are ready to pass into existing editing and post production workflows. The process works with ProRes, H.264, ARRIRAW, ACES (EXR), DPX, and TIFF original file types. The output format is the same as the input format, with the color, contrast, latitude, metadata, etc. unchanged.

High Dynamic Range Capture and Finishing

HDR continues to be a topic of discussion and demonstration throughout the industry. Numerous workflow

demonstrations have been given in post houses, and the acceptance of the technique is growing. HDR has become a regular deliverable on the list of deliverables for numerous studios. The topic will be covered more thoroughly elsewhere in this report.

Lens Committee

Co-Chair: Jay Holben
Co-Chair: Michael McDonough, ASC, BSC
Vice-Chair: Christopher Probst, ASC

Formed in the fall of 2016 the Lens Committee has been hard at work examining multiple issues facing cinematographers and filmmakers today with regard to cinema optics.

Comprehensive Cinema Lens Database

At the forefront of the Committee's work is the Comprehensive Cinema Lens Database (CCLDb), a project originally started by Christopher Probst, ASC, and Jay Holben. The ambitious goal of the CCLDb is to catalog detailed technical data for every cinema-style lens that has ever been used on a film or digital cinema camera in the history of motion picture production.

The database currently lists more than 2,900 cine-style optics from the evolution of cinema to today's modern optics along with as much technical information as can be gathered for each lens: Manufacturer; Original format designed for; Type (prime or zoom or specialty); Shape (spherical or anamorphic); Special identifiers: family name, model number, genealogy, attributes; Focal length; *f* or T stop calibration; Maximum aperture; Minimum aperture; Close focus distance (MOD) (imperial & metric); Manufacturer stated image circle; Year/decade of introduction; Country of origin; Number of iris blades; Number of glass elements; Number of glass groups; Number of aspherical lenses; Number of exotic glass elements; Type of focus mechanism (cam or helical); Focus rotation; Iris rotation; Zoom rotation; Front diameter; Front filter thread diameter; Length (imperial & metric); Weight (imperial & metric); Any mounts available for the lens; Intelligent electronics; Lists of films shot; and any special notes. It is a wealth of information, much of which cannot be easily found elsewhere.

Some of the more esoteric bits of technical information cataloged in the CCLDb may not be available for all lenses. For instance, not every manufacturer readily offers the number of glass elements, groups, aspheric surfaces and/or exotic glass elements in their products. To some cinematographers, however, this is pertinent and valuable information. A common theory regarding the three-dimensionality perspective of lenses, those which present the world with more depth cues,

surrounds the number of glass elements in the lens. The fewer the elements, the more dimensionality a lens has. The more elements, the flatter the lens' perspective may be. Although actual optical design theory proves this concept to be only *somewhat* valid, there are some cinematographers who seek out optics based primarily on their number of elements. For a cinematographer looking for a high-performing, low-aberrant lens, information on the number of aspheric surfaces and exotic glass elements is very key to their decision making. As noted earlier, not every lens will have this particular information listed, but the Committee endeavors to make it available for as many of the lenses in the database as possible.

The database will reside on the ASC website as a free resource for the community and will continue to be updated and refined on a constant basis.

Historical Lens Registry

A project proposed by one of the committee's founding members and co-chair currently on sabbatical, Michael McDonough, ASC, is to record actual serial numbers and locations for specific lenses utilized on historical and seminal films. The goal is to identify, by specific serial number, a lens that was utilized on a project of cinematographic significance. The project has received early support from rental houses that "open their doors" to records of films with which they have been involved. The project will seek to engage the involvement of film students and volunteers to track down the necessary archaeological data to attach to a particular optical device.

Three other projects of the Lens Committee have grown in scope and focus to merit breaking off into their own Subcommittees: Smart Lens Metadata; Filter Classification; and Focus Accuracy.

Smart Lens Metadata

Since the origin of the Lens Committee, the investigation into the protocol, potential standardization, promotion and further integration of lens metadata has been a primary goal. The original intention was to examine the various technological approaches and solutions, especially the Cooke /i and ARRI LDS systems, and to examine the potential for a uniform standard for the industry.

Internal lens metadata requires a computer chip and built-in encoders within the lens that transmit specific data to the camera: focus distance, iris setting, zoom focal length are the common pieces of information that are recorded per frame of recorded image. Further expansion on this data includes specific lens vignetting/shading and distortion data per stop, focal distance and focal length at a per-frame resolution. This expansion of the metadata, coupled with software programming in the post suite, allows visual effects artists to "dial out" the shading and distortion, completely or partially, from

the image in order to create "clean" effects and then re-apply the distortion and shading to whatever degree is artistically required. This form of extended metadata – currently available in the Zeiss CP.3 lenses and in the Cooke S7/i primes – eliminates the need to shoot distortion and shading tests in preproduction; a task that has beleaguered visual effects supervisors and camera assistants for many decades.

Since the original discussions of this subject, the industry at large has spoken and many other lens, camera and software manufacturers have adopted the Cooke /i open-license system as their metadata of choice. Aaton, Andra, Angenieux, ARRI, Atmos, Avid, Birger Engineering, Blackmagic Design, Canon, Cinematography Electronics, Cmotion, Codex, CW Sonderoptic, Element Technica, Fujufilm, Global Boom International, IB/E Optics, Mark Roberts Motion Control, Opitiek, Ovde, Panavision, Preston Cinema Systems, RED, Service Vision, Sony, The Foundry, The Pixel Farm, Transvideo, Vision Research – Ametek Materials Analysis Division and ZEISS have all signed on to become /i technology partners.

Currently the focus for the subcommittee is to investigate the needs and desires of the post production community, cinematographers, camera assistants and software designers regarding lens metadata: how they wish to utilize it, how it might best be of benefit to them, what new data can be recorded/included to be of aid. The subcommittee's secondary goal is in educating the various disciplines in the industry about the technology and its possible applications. A test and demonstration is in the works combining the resources of the ASC MITC Camera, Metadata and Lens Committees to incorporate this technology and data into real-world examples to be presented at Cine Gear 2018 in cooperation with ZEISS and Cooke. The work on this test is being completed by David Stump, ASC, Academy Award-winning visual effects supervisor Scott E. Anderson, Christopher Probst, ASC and ASC Associate Member Jay Holben.

Filter Classification Subcommittee

An intensive and exhaustive examination of lens diffusion filters has been proposed to the Lens Committee with the intention of creating a numerical classification system for each filter based on three attributes of image manipulation: resolution, halation and contrast.

By way of anecdotal research, it has been determined that most cinematographers choose their diffusion filters based on their own subjective testing and experience. Lens diffusion filters are a bit of a voodoo science and most cinematographers only have the opportunity to test a select few for a specific project and then end up employing the filters they are already familiar with on future projects. The exact mechanism of image manipulation is often not clear and selection often comes down to highly subjective "taste" for a specific project's look.

Few seem to have an intrinsic, technical understanding of what the filters are actually doing to their image and descriptors of filters often feature nebulous terms such as: silky, smooth, creamy, soft, etc. There is a phenomenal wealth of filters from which to choose and crafting a more precise calibration system that clearly identifies the nature of image manipulation will allow cinematographers to choose their filter for more accurate application to their creative needs. Further, the ability to choose an alternate filter when a desired one is unavailable is a complicated process requiring further subjective testing and a lot of guess work.

The Subcommittee will endeavor to formulate an empirical testing methodology and classification system to objectively measure the image manipulation aspects of all currently available lens diffusion filters and classify them within a numerical system (proposed to be 0-100 in each category) in an effort to provide the cinematographer more precise information to inform their selection of available filtration. A particular theoretical filter might have a 25 contrast adjustment, 60 resolution adjustment and 15 halation adjustment. If a cinematographer likes the contrast and halation factor of that filter, but is unhappy with the amount of resolution loss, they need only select another filter that has the same contrast and halation rating, but a lower resolution rating. It provides a more technically accurate system of selecting specific filters for further testing based on objective and empirical data. The data will be offered to the individual manufactures, many of whom are participants of the Subcommittee, to label/identify their filters.

Current Subcommittee members include cinematographers, representatives and technicians from Tiffen, Schneider and Formatt (three of the top diffusion filter manufacturers), lens manufacturers, rental houses and optical experts.

Focus Accuracy Subcommittee

A third Subcommittee was formed based on a proposal by Howard Preston of Preston Cinema Systems for the investigation of manufacturer methodologies for calibrating and marking focus accuracy on lenses.

As imaging technology has improved, digital cinema cameras with high resolution sensors of 4K or greater are now mainstream. Further, a recent trend for larger sensor cameras results in imagery with extremely shallow depth of field. Additionally, lens performance in sharpness and contrast have also improved greatly. All of these attributes contribute to the need for more precise control over focus to accurately and consistently achieve the requirements set by the cinematographer and director.

To achieve the high precision necessary in today's digital world a lens needs enough focus markings, typically between 20 and 40; the optomechanical design of the lens must support accurate interpolation so that an accurate distance can be determined for any focus

setting, not just on the specific engraved mark – but *between them* as well; the accuracy must be consistent over a range of temperature from -20°C to 40°C and the accuracy must be maintained over time and the heavy use found on-set.

In order for a lens to accurately reproduce focus under any condition, its tolerances must be less than the minimum depth of field that the lens is capable of reproducing. Many high-end cinema lens manufacturers utilize modulation transfer function measurements in cooperation with 20m+ optical benches to engrave accurate focus marks. This allows the high degree of precision that is required for today's super-fast lenses. The faster the lens, the more accurate the focus marks need to be. Other manufacturers of lower-priced lenses often utilize less accurate methods. The mix of methods can make integration of smart follow focus systems more than a challenge and can make repeatable, accurate focus during production equally challenging.

The Subcommittee is currently formulating a questionnaire to submit to cinematographers, camera assistants, rental houses, visual effects artists and lens service technicians to find the needs, demands and expectations of professionals in the field to further determine how refined methodologies of improved focus accuracy from the manufacturer's end might aid the industry at large.

Next Generation Cinema Display Committee

Co-Chair: Michael Karagosian
Co-Chair: Eric Rodli
Vice-Chair: Joachim Zell

In its 2015 SMPTE report, the Next Generation Cinema Display Committee first discussed the emergence of LED (light-emitting diode) displays in cinema. Two years after that report was written, in 2017, the first LED display product was introduced by Samsung to the cinema market. In early 2018, the first LED displays were installed in Los Angeles, which for the first time enables the Hollywood community to view HDR content on cinema-sized emissive displays.

Earlier work of this committee was directed to exploring the limits of HDR on projectors. Laser light sources were assumed, leading to much discussion about the pros and cons of narrow band primaries. The Committee produced the *CINEMA DISPLAY EVALUATION PLAN & TEST PROTOCOL* to examine the visual value of the limited performance parameters of projectors and projection screens for higher dynamic range display. The emergence of emissive displays dramatically changes the discussion, although the Test Content section of the document remains as relevant now as when it was written.

Emissive displays not only can deliver high peak white levels but it is also possible to achieve deep blacks by designing the display surface for a large negative reflectance value, as opposed to the positive reflectance value of a projection screen. Viewed in an auditorium, the side walls of the auditorium will tend to reflect more light than the display, further lending to the appearance of deep black in the display. When the light levels between black and peak white are managed well, the technology lends itself to cinema HDR display.

To enable future studies, the ASC has licensed a collection of professionally shot content that will be useful for evaluating cinema HDR displays. Special thanks to EFILM for its assistance in collecting and storing the materials. The first U.S. LED cinema displays were installed in the Los Angeles area early this year, providing this committee and others in MITC with the opportunity to view these materials on cinema-sized HDR-capable displays.

An area that remains difficult to study is that of display color gamuts wider than P3 (**Fig. 2**). The LED displays installed in the Los Angeles area are limited to P3. The ASC, however, has been vocal in the past about the desire of cinematographers for a gamut that extends deeper into the cyan range. The container gamuts defined by SMPTE ST 428-1 and ITU BT.2020 are large enough to do the job in distribution. However, a larger minimum display gamut than P3 has yet to be defined. If it is to be defined, cinema would be the place to begin, before the cinema HDR format is formally established.
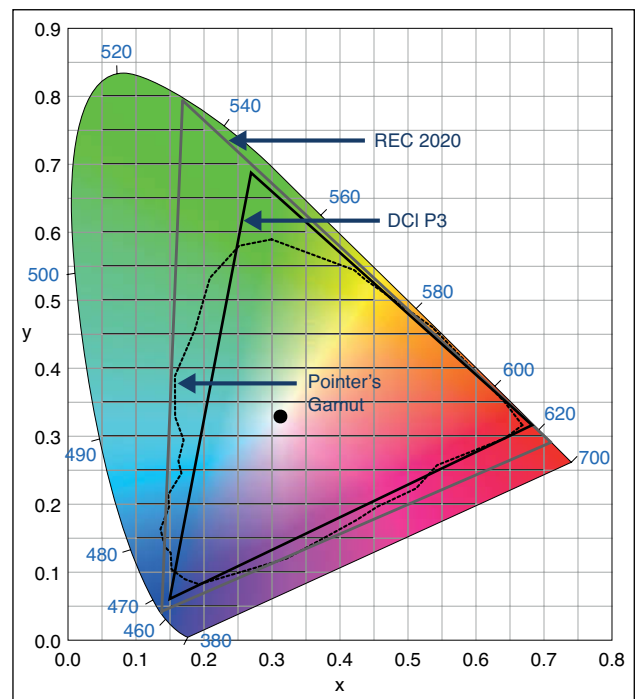

FIGURE 2. CIE Chromaticity chart. Pointer's Gamut is the gamut of real surface colors as seen by the human eye.

We expect the presence of HDR-capable cinema displays in the Los Angeles area to drive much discussion and interest in further study. The Committee exists to encourage and funnel such discussions and studies.

UHDTV Committee

Chair: Don Eklund
Vice-Chair: Bill Mandel

If you were fortunate enough to have an HDR capable television and a cable or satellite subscription that provided Olympic coverage in 4K 60 fps HDR, you will have undoubtedly recognized the significance of what is now possible in terms of picture quality delivered to the home. Like others, I grew up watching the Olympic games and have appreciated how technology is often showcased with this event. Live or documentary style programming is becoming available which covers a range of sports, concerts, food and other special interests. These programs are not without flaws. They may have exaggerated color or contrast and some angles may have lesser quality cameras or lenses, but the higher bit rates, resolution, color and bit depth afforded are often a pleasure to behold and easier on the eyes than the SD or HD over-compressed equivalent. We are also seeing some extraordinary pictures coming from user-generated content on YouTube. Both PQ and HLG encoded pictures are being uploaded, often with high quality from modest cameras.

The cinema industry has continued to take advantage of UHD/HDR, though not uniformly so. In discussion with many film makers, colorists, and post production engineers, we found a range of opinions on how to make use (or not) of the capabilities of current UHDTV's. A primary reason for this is clear: the first audience for a feature is cinema, and that generally means a mastering target suitable for projection in DCI format. It may take two weeks to prepare the first color grade of the film where the "look" for every shot is established. Re-grading the title in HDR typically comes with time and cost constraints and builds on the work previously completed for the SDR grade. Without adequate time allowed, the HDR graded result may not produce the intended impression in make-up, lighting, VFX, or simply where the viewer's attention should be focused. This can be short-cut by taking a conservative approach to the HDR grade and the result, unsurprisingly, may be quite similar to the SDR version. We were repeatedly told that if the first grade was for HDR, the final result would be significantly different. With greater latitude for both highlights and shadow detail, more textures and nuance can be included and appreciated in the HDR presentation. If production considers an HDR grade and if lighting, scene composition, camera work and monitoring are prepared accordingly, the results are often exceptional.

It is understandably difficult to disrupt and reorder workflows for the sake of a minority who are looking for HDR presentation in the home. However, HDR will not be limited to home environments for long. Video walls are starting to appear in cinema and are playing typical DCP grades, but behind closed doors at trade events we can see the same devices showing HDR grades.

It is likely that, at least in the near future, each film will make greater or lesser use of HDR features depending on how each title is envisioned by the film maker. But the existence and market-impact of HDR cannot be ignored and, for the right project, HDR can provide a differentiated experience unmatched by any previous technology.

A wide variety of UHD displays are now easily available to the consumer, ranging from modest to premium price points. And there are now many good sources for HDR content including Ultra HD Blu-ray, many OTT (over-the-top) services, traditional satellite and cable options, and gaming.

Input to the Committee is welcome, provided that it can be shared on a non-confidential basis. Contact asc-uhdtv (at) d-cinema (dot) us.

Advanced Imaging Committee

Chair: Gary Demos
Vice-Chair: Jim Fancher
Vice-Chair: Bill Mandel
Vice-Chair: Joe Kane
Secretary: David Reisner

The ACES system has been architected as a floating-point end-to-end system, with the exception of ACESproxy (ACES S-2013-001). The ACESproxy formula applies a matrix from linear scene-referred AP0 (very wide gamut as specified in SMPTE ST 2065) to AP1 (wide gamut) color primaries. Then a pure logarithmic function is applied, extending up to about ten stops above mid-grey with about eight stops below mid-grey. For 12-bits (range 256 to 3760) this is 200 steps per stop. For 10-bits (range 64 to 940) this is 50 steps per stop. The scene-referred ACES floating point maximum value is 222.875 (where 0.18 is scene mid-grey). The minimum value is .001185417. The main intended use case for ACESproxy is for on-set monitoring.

There are several weaknesses for ACESproxy if the intent is to convey scene-referred ACES according to SMPTE ST 2065 (as floating point with AP0 primaries).

■ The AP1 red primary lies slightly outside of the AP0 gamut
■ The AP1 gamut excludes large portions of cyan

- The inability to go to zero interferes with black representation
- The logarithmic slope approaching black is not optimal for thermal noise
- The use of SMPTE "legal" (aka limited) range is to some degree obsolete
- The values outside the SMPTE legal range are undefined (and thus problematic if encountered or created, such as in resizing)

Quasi-Log

It was suggested that ACEScct (ACES S-2016-001) might solve some of these weaknesses if it were to be re-cast into an integer representation using the full integer range (0 to 1023 for 10-bit, 0 to 4095 for 12-bit). ACEScct requires AP1 primaries, and is applied in floating point. ACEScc shares the same pure logarithmic characteristics as ACESproxy but using floating point. ACEScct differs from ACEScc in that the dark portion of the ACEScct curve is a slope-matched straight line going through zero down to -.006917. This solves the black representation of zero (including averaging zero in the presence of thermal noise) as well as providing better noise behavior (being a shallow-sloped straight line).

This form of log/linear hybrid is commonly called a "quasi-log" representation. Note that this is the form of BT.709 using a gamma2.2222/linear hybrid.

Color Primaries

Figure 3 shows a plot of CIE 1931 chromaticities for various relevant sets of red, green, and blue primaries including AP0 and AP1. The CIE 1931 xy chromaticities of AP0 and AP1 are shown in **Table 1**.

The AP1 to AP0 matrix (TRA2 in equation 4 in section 4.4.2 of ACEScct S-2016-001) contains the negative term -.0055258826. This negative term indicates that AP1's gamut goes slightly outside of AP0's gamut. This can also be seen by including the z component of chromaticity. Chromaticity is defined to be x = X / (X+Y+Z), y = Y/(X+Y+Z), z = Z/(X+Y+Z). This implies that x+y+z = 1.0. By also looking at the z component of chromaticity, ACES AP1 Red can be seen to have chromaticity at x = .713, y = .293, z = -.006, whereas the ACES AP0 Red has chromaticity at x=.7347, y =.2653, z = 0.0.

The issues related to AP1 can be solved by skipping the AP0 to AP1 matrix that is required by ACEScct,
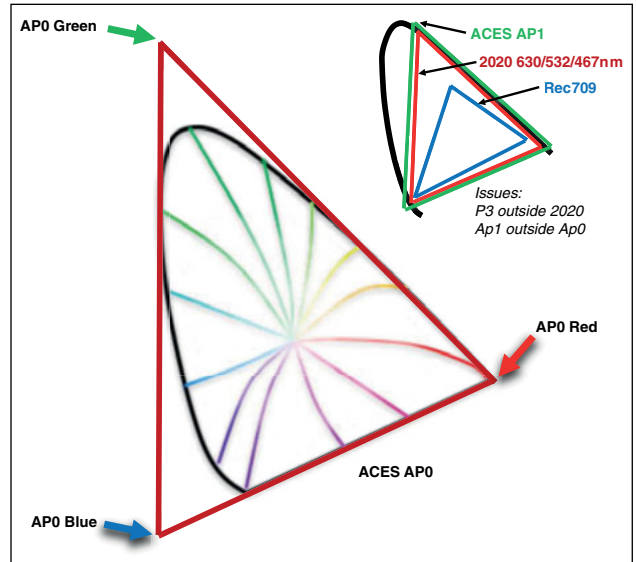

FIGURE 3. ACES AP0, ACES AP1, BT.2020, and BT.709 primaries.

and thus applying the quasi-log curve directly to ACES AP0 primaries (as defined in SMPTE ST 2065).

We have informally named this "ACES_AP0_integer" (see **Fig. 4**), although there is no formal connection yet between this work and the ACES committees. However, there is a clear relationship to ACEScct by our having adopted its quasi-log formula, although it is applied to AP0 and mapped to full-range integers. If there is a requirement to adhere to an existing formal ACES specification, then ACESproxy could be utilized instead of ACES_AP0_integer.

Undefined Brightness and Color

As we mentioned in our previous reports, there are two fundamental concerns with the PQ/2020 signal, beyond being display referred. One concern is that PQ contains brightness levels up to 10,000 nits, which will nearly always exceed a given display's capability. The behavior of the brightnesses and colors above a given display's maximum is not standardized, and will thus vary depending on the specific display make and model.

The other concern is that most HDR-capable displays have a gamut near DCI-P3 primaries (with a D65 whitepoint). The use of BT.2020 primaries includes colors outside of the P3 gamut. As with brightness, any colors outside the P3 gamut will have unstandardized behavior, which again may thus vary depending on the specific display make and model.

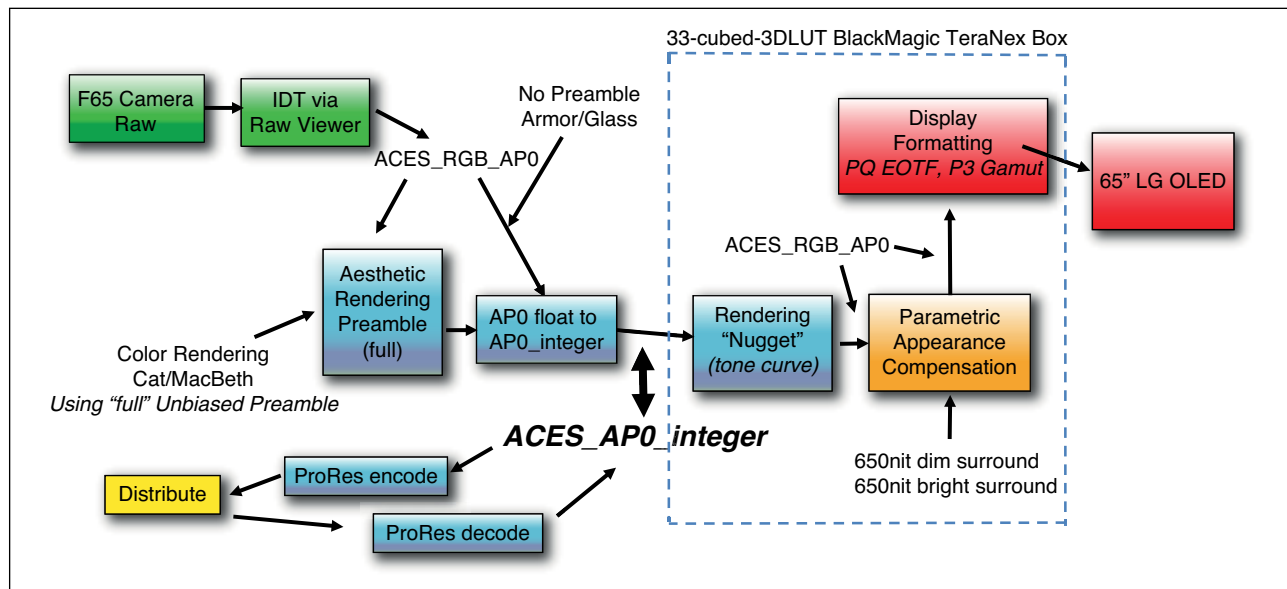| TABLE 1. CIE 1931 Chromaticities for AP0, AP1, and BT.2020 RGB primaries							
	Red		Green		Blue		White
	x	y	x	y	x	y	x	y
ACES AP0	.7347	.2653	0.0	1.0	.0001	-.0770	.32168	.33767 (D60)
ACES AP1	.713	.293	.165	.830	.128	.044	.32168	.33767 (D60)
BT.2020	.708	.292	.170	.797	.131	.046	.3127	.3290 (D65)
BT.2020 (alt.)	630nm		532nm		467nm		.3127	.3290 (D65)

FIGURE 4. ACES_AP0_integer demonstration using 3D Lookup Tables

Demonstration Configuration

We were able to address both of these issues using the LG 55C7P OLED TV using optional "Content Professional" firmware in a demonstration in the HPA Innovation Zone February 2018. The SMPTE ST 2084 PQ curve was set to specifically hard clip at 677 nits. The color of the display was set to the P3 gamut at D65 whitepoint. By setting the maximum pixel brightness to 650nits (for dim and bright ambient surround viewing), and managing the gamut reduction from AP0 gamut down to P3 gamut, the LG 55C7P OLED was fully under control. In other words, each and every pixel color and brightness was displayed as intended using appropriate brightness and surround compensation. The specific demonstration implementation is shown in **Fig. 3**. The tone curve, appearance compensation (for bright and dim surround), and display formatting for 650nit maximum brightness and P3 gamut, were all implemented using a modest 33-cubed 3D Lookup Table (LUT) with tetrahedral interpolation. The demonstration codec used was ProRes 422 10-bits.

Alternatively, the processing embodied in the 3D LUT could be replaced by directly computation algorithms. A GPU is a useful way to implement the direct computation approach, which we previously have demonstrated with the floating-point codec.

In some cases a 3D LUT will be the best approach, and in other cases the direct computation will be best.

Note that AP0 primaries are used at all major interconnection points in this demonstration configuration prior to the final display formatting into PQ/P3.

The HPA demonstration configuration provides a proof of principle, and a validation that ACES_AP0_integer performs well in this initial test configuration.

Future Work on Appearance Compensation

Parametric appearance compensation, as described above, compensates for display absolute brightness and for ambient surround brightness using a D65 whitepoint. The on-screen whitepoints and ambient surround whitepoints may often not be D65. For example, D60 is the on-screen whitepoint of ACES AP0 RGB as defined in SMPTE ST 2065. The ambient surround whitepoint may vary from night-time tungsten to daytime, and may even be a wall color behind the display. The ambient surround also may not be uniform in brightness, or even in color. For large displays, the on-screen edges of the image begin to take on the role of an ambient surround in combination with the ambient surround outside of the display.

Numerous other appearance phenomena are documented for SDR brightness. However, most of the experiments and results pre-date HDR displays and modern wide-range professional cameras.

Professional Display Committee

Chair: Jim Fancher
Vice-Chair: Gary Mandle

2017 could be called the year of the High Dynamic Range (HDR) display as many manufacturers joined Sony and Dolby in providing a professional HDR display. With HDR projection and 4K HDR consumer sets driving the shift, manufacturers delivered very solid offerings for professional applications. Our investigations into surround lighting for HDR continued with participation in several demonstrations that showed the

impact of surround lighting on perception of HDR test images. Our investigation concluded there was no one-size-fits-all solution to surround lighting and that the type of material being viewed will dictate the preferred level of surround lighting.

Motion Imaging Workflow Committee

Chair: Greg Ciaccio
Vice-Chair: Tim Kang
Vice-Chair: Chris Clark

Current Committee focus: ACESnext Working Group

For the last several years, the ASC MITC Motion Imaging Workflow Committee (Workflow) has continued to focus on helping to educate and guide industry professionals on ACES benefits parallel with efforts by the Academy of Motion Picture Arts and Sciences' Science and Technology Council (Sci-Tech Council).

The Committee is composed of key individuals in a variety of positions involved in production and post, who provide valuable real-world feedback. Frequently, prominent cinematographers attend and contribute with fresh perspectives.

Since its introduction, a significant number of productions have used ACES. A fairly comprehensive list can be found here: http://www.imdb.com/search/title?colors=aces

A clear definition of ACES is posted on the Academy's website:

"The Academy Color Encoding System (ACES) is becoming the industry standard for managing color throughout the life-cycle of a motion picture or television production. From image capture through editing, VFX, mastering, public presentation, archiving and future remastering, ACES ensures a consistent color experience that preserves the filmmaker's creative vision. In addition to the creative benefits, ACES addresses and solves a number of significant production, post-production and archiving problems that have arisen with the increasing variety of digital cameras and formats in use, as well as the surge in the number of productions that rely on worldwide collaboration using shared digital image files."

A forum has been established to enable global ACES discussion and collaboration and has been instrumental in functioning as a central repository for our industry. This forum, ACES Central, can be found here: www.acescentral.com. The ASC's site includes a link to ACES Central: https://theasc.com/asc/committees/aces

This year, within the Workflow Committee, we have created an ACESnext Working Group to work in support of the ACESnext effort being led by ACES Project Chair Annie Chang and ACES Project Vice-Chairs Rod Bogart and Joachim Zell.

Our Workflow Committee is contributing to the development of the ACESnext roadmap by gathering feedback on ACES experiences among the ASC membership. Further adoption of ACES will be hastened by improvements to the motion imaging chain (**Fig. 5**), so Member feedback is vital to ACESnext development.

Though there are multiple areas in the ACES pipeline which will be enhanced and extended, the initial work is focusing on ACES Input Transforms (IDT), as this is the first image transform in the ACES chain. ASC members participated in the ACES Implementation Assessment of Input Transforms, held in December 2017 at Panavision's rental facility in Woodland Hills, CA. The Assessment involved every digital cinema camera available at Panavision. The material was screened at EFILM in Hollywood, and the findings are being analyzed to determine specific follow-up work with the participating camera manufacturers.

The MITC ACESnext Working Group will also create ACES workflow support documentation for all ACES Logo Program tools, from image capture through delivery of finished results to help foster clear communication and to help eliminate confusion which often exists with the many options presented to users unfamiliar with manufacturer-specific terminology. Critical areas of focus will include on-set color grading, dailies color grading, finishing color grading and visual effects solutions.

With so many new imaging advances being introduced concurrently (increases in spatial resolution, dynamic range, color gamut, etc.), it is vital to faithfully process and preserve creative intent by ensuring that no bits are lost along the way. This is especially important now as interest in HDR imagery has taken center stage,
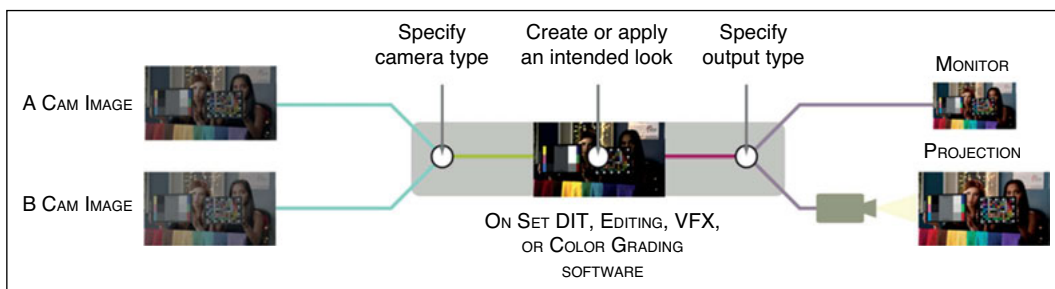

FIGURE 5. Overview, ACES camera to screen workflow

requiring a standard which can not only accommodate the extra range needed, but can more easily produce the numerous versions needed for new and legacy sets of varying brightness capabilities.

As ACES user experiences are shared within our industry, the practical benefits are being realized.

More information regarding ACES is available at http://ACESCentral.com.

Digital Intermediate Committee

Co-Chair: Joshua Pines
Co-Chair: David Reisner

The ASC CDL is used in the production and post process of the substantial majority of all feature movies and scripted series television shows. It is implemented in hundreds of products. For those reasons, we want to keep the ASC CDL very stable and only pursue changes very carefully. But to meet and support changes in encoding formats, deliverables, or predominate workflows we do need to reexamine the ASC CDL periodically. We also want to fairly and seriously consider the requests we sometimes receive for enhancements and new functions. And we occasionally consider small changes that should increase usability without damaging interoperation or history.

The DI Committee continues to evaluate if and how the ASC CDL transforms might be modified to better serve the requirements of newer production workflows - concentrating first on ACES and HDR acquisition. Although the ASC CDL is being used successfully in these areas, there could be some optimization of the underlying CDL parameters and algorithms for these specific use cases.

The preferred working colorspace of ACES is a rather particular wide gamut, and there is evidence that some newer LED lighting equipment causes issues that are exacerbated by the ASC CDL Saturation function (probably by making spikes in the light source/imager combined response more visible). The DI Committee will investigate to determine if these issues can be mitigated with new saturation coefficients tailored for this wider color gamut working space.

We will also work on the long outstanding issues of minor additions to the ASC CDL metadata to support organization of correction collections, more strongly encourage use of existing features to document viewing transforms, and on creating a SMPTE RDD.

The DI Committee is the ASC MITC's primary resource on post-production. HDR and WCG imaging are issues affecting many MITC Committees. We will continue to work with other MITC Committees on color correction strategies specifically targeting HDR

workflows, researching and documenting current HDR workflow "best practices", and recommending procedures for color grading (including surround lighting specifications) that minimize compromises or limitations on HDR and WCG mastering. We will continue to participate actively with all the Committees, providing both a deep and practical understanding and application of color science.

To get the current ASC CDL specification, send an e-mail to asc-cdl (at) theasc (dot) com; an auto-responder will send terms and instructions. For additional information about the ASC CDL or Digital Intermediate Committee, contact Joshua Pines at jzp (at) technicolor (dot) com or David Reisner at dreisner (at) d-cinema (dot) us.

Plenoptic and Computational Imaging Committee

Co-Chair: Pete Ludé
Co-Chair: David Reisner
Co-Chair: Joshua Pines

The Plenoptic and Computational Imaging Committee was formed by the ASC Motion Imaging Technology Council in 2017 in response to a liaison request from ISO/IEC JPEG Pleno Working Group. The first meeting was held in December 2017 with an enthusiastic attendance, and work by the Committee is continuing in several key areas during 2018.

Plenoptic Imaging refers to a camera system which can not only capture the intensity and color of light in a scene, but also the direction that the light rays are travelling in space. These imaging systems, also known as light field cameras, have the potential for significant impact on entertainment content production. When used to produce traditional motion pictures – that is, those intended for display on a flat projection screen or display panel – during post-production the directional information of light rays captured on-set can be used to totally reconstruct many versions of the image. For example, the cinematographer can in-effect make changes to the "camera" and image *after* the scene was shot, including the focus plane, depth of field, equivalent focal length, aperture and stereoscopic interaxial distance. Due to very recent developments in cloud data transport, storage and computation these transforms can be accomplished using complex processing techniques developed in the field of study now referred to as Computational Photography. Alternatively, a scene shot using a light field camera can (in the future), be viewed on a light field display, which would re-construct the light rays and emit them toward the viewer over a range of angles, causing the image to appear in space, similar to the famous Princess Leia

FIGURE 6. The Lytro Cinema Light Field Camera was introduced at NAB 2016, and provided a dramatic demonstration of the benefits of light field imaging. The company ceased operations in March 2018, but it is expected that developments will continue at Google (who purchased the Lytro patents) and elsewhere. *Photo courtesy Lytro, Inc.*

"hologram" scene in *Star Wars*. The result appears to be nearly science fiction: a 3D aerial image visible to the unaided eye without glasses or head tracking.

During its December 2017 meeting, the Committee heard presentations from experts in both light field cameras and displays. Buzz Hays, from Lytro Inc. in Mountain View, CA provided a detailed update on the Lytro Light Field Cinema Camera. This prototype, introduced at the NAB conference in April 2016, has a prodigious 755-megapixel image sensor operating up to 300 fps, with a dense array of microlenses and a single large taking primary lens (**Fig. 6**).

The camera was used by director of photography David Stump, ASC for the 2016 experimental short film, *Life*, providing a tantalizing preview of the benefits that such cameras will have in the future. The Lytro unit is physically very large, and the resulting image files produce up to 400 gigabytes per second of data. Separately, another prototype camera called the Lytro Immerge was developed for Virtual Reality content.

Regrettably, in March 2018, Lytro announced that they will be "winding down the company". The substantial patent portfolio and other assets, as well as a portion of the Lytro development team, were absorbed by Google, a company already well-acquainted with light field imaging and other aspects of computational photography. While the Lytro cameras are not expected to be commercialized as originally designed, the extraordinary research and development work undertaken by the company over its 12-year life will certainly contribute to the progress in plenoptic imaging.

Light Field Displays

Light field displays have also been the subject of significant research over the past ten years. Currently, several companies have plans to bring this advanced technology to market. At the December Committee meeting, Thomas Burnett, CTO of FoVI3D in Austin,
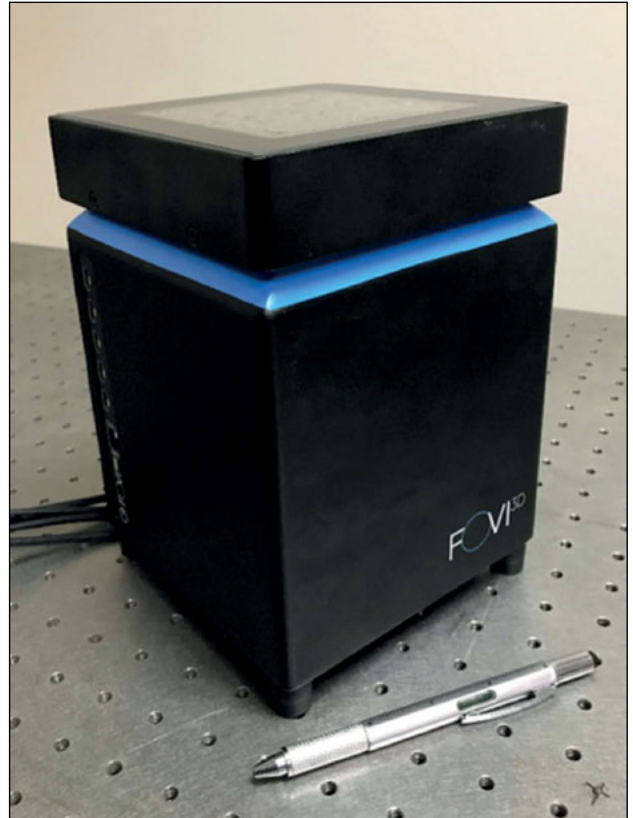

FIGURE 7 The FoVi3D DK2 provides a 9x9cm image area to create a 3D aerial image visible without glasses or head tracking. This developer's kit will be a useful starting point for system engineers and content developers gain familiarity with these novel light field displays. *Photo courtesy FoVI3D Inc.*

TX, provided a tutorial on light field display technology. The company has completed work on a development kit with a 9cm (3.5 in) square display panel incorporating an array of spatial light modulators (SLM's) and "hogel" (holographic element) optics to create 32,400 hogels, each of which emits 2,500 light rays over a 60-degree field of view (**Fig. 7**).

This very early implementation serves as a proof of concept, and a means by which system engineers and content developers can become acquainted with how light field displays might be used in the future. Another technology company, Light Field Labs, in San Jose, CA, has also announced plans to introduce an 85-in. (diagonal) light field display within the next two to three years.

Much Work Remains

These developments in both light field cameras and displays are in their early stages. However, substantial development over the past decade has brought these closer to commercial reality. Given this progress, it is now time to think about the implications in entertainment and storytelling.

Plenoptic Decision List

The Committee has started to explore the implications of an image that can be dramatically altered after the camera leaves the set. If a rack focus, zoom or dolly move can now be added during post-production, how can we preserve the creative intent of the cinematographer during the on-set capture? One potential solution is to introduce a set of metadata that precisely records the cinematographer's initial creative decisions, and bind this metadata frame-by-frame to the plenoptic digital image file. This would create an ASC Plenoptic Decision List (PDL) – analogous to the current ASC Color Decision List (CDL), which has played an important role in grading work for over a decade. The PDL could include codes to inform the light field image processor where to set focus, depth of field, viewpoint, field of view and many other parameters as the image is rendered for a 2D planer display – such as a current cinema or television. Of course, the original PDL values could be altered during post-production based on creative needs, and the source file from a light field camera could still be used to create a 3D volumetric image in a light field display. The Committee will explore these concepts and the workflow implications.

Compression and Interchange standards

While the ASC Plenoptic and Computational Imaging Committee was initially prompted by the liaison inquiry from the JPEG Pleno Working Group, the Committee has become aware of other studies and standards work from many other industry bodies and standards organizations. There is an immense challenge when ingesting light field data volumes which might reach 400 to 1,000 gigabytes per second – over three petabytes of data per hour. Several approaches are being explored by research labs to compress light field images, including the creation of a "mezzanine" format that can allow for interchange of the image in a lossless (or near-lossless) manner. For example, non-essential detail from the data source can be removed, and files might be optimized based on how people perceive the image – similar to today's video compression algorithms. Separately, there is exploration in compressive light field coding and machine learning to compress the data volume. Another approach is to borrow from the computer graphics field and transform the plenoptic camera images into a scene graph – a data structure commonly used in game engines – or reproduce the image with real-time ray tracing. Each of these approaches could introduce different discrepancies in "look" of the scene, or artifacts in the decoded plenoptic image. The Committee intends to track the work underway in research laboratories and standards development organizations, and to advocate for adopting technologies that fully preserve the artistic intent of the captured image.

In this rapidly changing world, we believe this powerful technology will almost certainly have impact on our industries. The ASC Motion Imaging Technology Council and the ASC Membership will keep actively abreast of and involved in developments and (when funding and equipment are available) testing, to help guide these new techniques toward results that will support the filmmaker's creative vision and provide satisfying audience experiences.
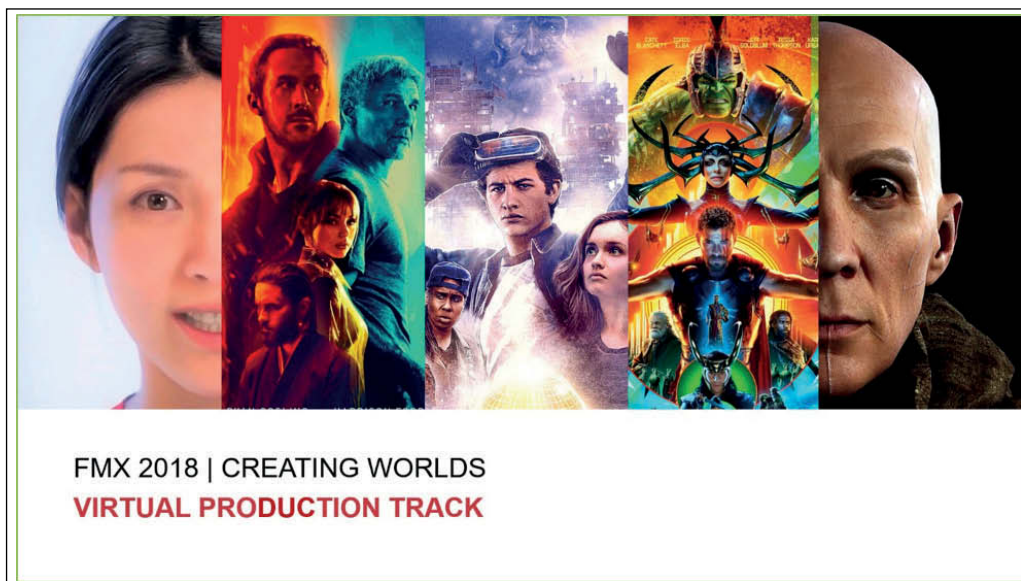

FIGURE 8. A series of seven presentations on virtual production were showcased at FMX in Stuttgart, Germany on 25 April 2018

FIGURE 9. *Carne Y Arena* was a landmark project combining virtual production with virtual reality that won another Oscar for A. Innaritu

Joint Technology Committee on Virtual Production

Chair: David Morin
Co-Chair: John Scheele

Over the period since the last SMPTE report, the Joint Committee on Virtual Production of the ASC Motion Imaging Technology Council continued its activities around the broadening use of real time computer graphics on set.

The Virtual Production Track at FMX 2018

For the seventh year in a row, Virtual Production committee chair David Morin curated the "Virtual Production Track" at FMX2018 in Stuttgart, Germany (**Fig. 8**). The track showcased seven presentations that took place on 25 April 25 2018. The presentations covered the use of previsualization and virtual production in movies such as *Blade Runner 2049*, *Ready Player One*, and *Thor: Ragnarok*, along with the demonstration of immersive game-engine based virtual production technologies for projects such as *Adam*, *Siren*, and a digital Andy Serkis. You can see more details on the program at https://fmx.de/program2018/list?t=776

Virtual Production Project of Note in 2017

Of note in 2017, director Alejandro Innaritu and cinematographer Emmanuel "Chivo" Lubezki, ASC, AMC created *Carne Y Arena* (**Fig. 9**) an immersive virtual reality installation produced using virtual production techniques. In recognition for the development of this groundbreaking and emotional experience, the Academy of Motion Pictures Art and Sciences presented a Special Award Oscar statuette to the director - another landmark pointing to the increasing use of virtual production in storytelling for all media.

Future Activities

The Virtual Production Committee has one meeting left (meeting #12) in the cycle of 12 case studies that we set out to do when we created this committee in 2010. Originally planned for 2017, meeting 12 will be scheduled at a future date, when we will reassemble presenters from previous meetings in a conference that will celebrate the transition of virtual production from the pioneering age to a more affordable toolset available to all filmmakers, thanks to investments in the field of virtual reality and new development in game engine technology.

Participation is encouraged. Those interested can contact:

David Morin, Chair, davidmorin (at) davidmorin (dot) com.

John Scheele, Co-Chair, johnscheele (at) gmail (dot) com.

Joint Technology Committee on Virtual Reality

Chair: David Morin
Vice-Chair: Michael Goi, ASC
Vice-Chair: Mike Sanders, Activision

The Joint Technology Committee on Virtual Reality (the VR Committee) was formed in 2016 with the intent of exploring the roles of the traditional crafts of cinematography, set design and visual effects in the field of virtual reality narrative content production. It was proposed and adopted that the Committee would embark on the production of a VR narrative short subject as the means of exploring its intended goals.

Michael Goi, ASC, wrote a seven-minute script entitled "Virtually Engaged" which was broken down into ten shots that would utilize VR technology to tell its story. It contains elements of location photography, sound stage photography and computer-generated environments. As part of its emphasis on telling a narrative story, the short subject will incorporate techniques that have not been thought of as part of the VR vocabulary, such as the use of close-ups for dramatic emphasis.
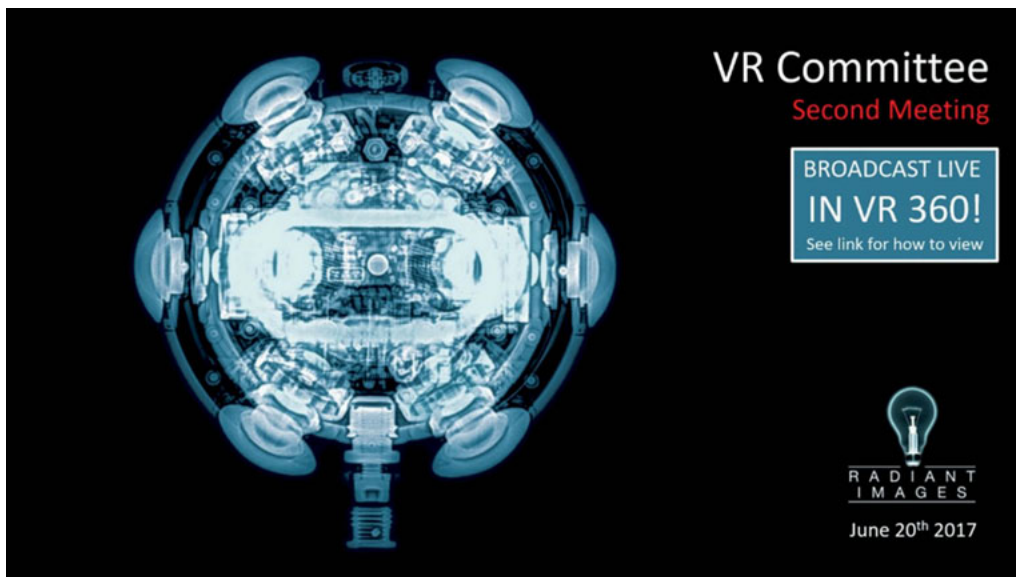
FIGURE 10. Virtual Reality Committee 2nd Meeting.

PROOF Inc. (a visualization company) is currently working on a VR storyboard for the project which will be used as a template for the placement of characters, cameras and lights, and will serve as an initial previs guide for all departments. Set design will follow, and the participation of the cinematographer at this stage will be critical in order to address a lighting plan which will not create a financially prohibitive situation for "painting out" lighting units on a large scale.

Ultimately, the short subject may be repurposed in traditional 2D and 3D formats to examine the viability of distributing VR-created narrative content on multiple platforms.

Virtual Reality Committee 2nd Meeting

The second meeting of the VR Committee was held at Radiant Images on 20 June 2017 (**Fig. 10**). The event was live–streamed in 360. Michael Mansouri and his team hosted the meeting at their facility and had a full array of 360 camera rigs on display. Radiant can source 360 camera gear for just about any need; they represent the majority of camera technology and also provide their own custom configurations. The Radiant team gave an extensive presentation on types of VR displays and 360 camera rigs. The second half of the meeting was a case study on a VR piece entitled "My Brother's Keeper," which covered practical production issues and challenges of content design and composition when dealing with the 360 format.

Virtual Reality Committee 3rd Meeting

The third VR Committee meeting was held at the Technicolor Experience Center on 11 December 2017 (**Fig. 11**). Marcie Jastrow and her team hosted the meeting in their virtual production volume and had a variety

FIGURE 11. Virtual Reality Committee 3rd Meeting.

of technologies on display including motion-chair VR demos and full-body photogrammetry. Jastrow gave an overview of Technicolor's vision with the center and their extensive collaboration with industry partners. Then the Technicolor team gave a presentation on their 2017 360 camera shootout which covered a range of challenging shooting conditions and pros/cons of the major 360 camera options. They are rumored to be working on an updated shootout. The second half of the meeting covered non-360 content capture technologies, mostly referring to plenoptic, photogrammetry, and volumetric capture. An overview of the state-of-the-industry on volumetric was given by Mike Sanders, which included material from Lytro, 8i, Uncorporeal and a few others. Xrez presented their workflow and experience with environment photogrammetry. Lastly, Microsoft presented their holocapture technology which is a 4D volumetric capture and streaming pipeline leveraging RGB and IR machine vision arrays in a controlled stage.

Participation is encouraged. Those interested in the VR Committee may contact:

David Morin, Chair, davidmorin@davidmorin.com.
Michael Goi, Vice Chair, mgoi@aol.com.
Mike Sanders, Vice-Chair, Mike.
Sanders@activision.com.

SSIMWave HDR Evaluation Working Group

Coordinator: W. Thomas Wall

As the ability of professional cameras to capture motion picture images has improved to never-before-seen levels of color accuracy and dynamic range, the ability of consumer display devices to accurately represent that HDR imagery across almost the entire range of human color perception has also continued to improve – in form factors from phones and tablets and laptops to desktop computer monitors, all the way to 80 in. and larger television displays. (See the ASC MITC UHD Committee report.) For the first time in the history of photographic reproduction, displays are becoming able to accurately reproduce essentially the full visually perceptible range of imagery that such cameras can capture. The resulting palette of options available to creatives can be stunning.

However, the actual quality of the motion imagery being displayed – in terms of reproducing exactly what its creators intended – is completely dependent upon the quality of the data being delivered to those devices.

The visually perceptible quality of those images – the ability to faithfully reproduce their originally intended look – is diminished to varying degrees all along the delivery chain from that of the original carefully crafted images as viewed in a color grading theater. Degradation can start even with the formats used in the mezzanine files used to transport HDR, WCG imagery from the color grading suite to video distributors – often converted from RGB to integer Y'CC format – color sub-sampled, limited in bit depth and restricted to SMPTE-legal code values – and further lossily compressed at even this very first step in distribution. These already-modified images may then undergo further color space transformations, frame rate alterations, and resolution changes, without the benefit of any input from their creators. Further processing and compression required for storage and distribution over various delivery mechanisms add additional artifacts that affect the visual appearance that any consumer sees or can see.

The result is sometimes drastically different from what was originally intended.

It is the objective of this study to evaluate that quality difference between what is seen and approved in a color grading theater by DPs and colorists versus what is actually delivered to consumer display devices, as judged by the creators of that imagery; and to evaluate whether the Structural SIMilarity Plus visual quality metric as implemented in the SSIMWave Inc. software accurately represents that professional judgment.

The Working Group will, with industry partners:

a) establish a controlled testbed environment where cinematographers and colorists can evaluate the quality of HDR, WCG, ultrahigh-resolution digital motion picture imagery as delivered to high-end consumer displays compared to that same imagery as seen and approved in a color grading suite;

b) establish and execute a process to evaluate the efficacy of the Structural SIMilarity (SSIM) perceptual quality metric – as implemented in the latest SSIMWave Inc. SSIMPLUS quality metric software – to quantify the delivered quality of HDR, WCG imagery, as judged by the content creators;[i]

c) evaluate the usefulness of SSIM perceptual quality monitoring software in the creative process;

d) suggest improvements where necessary, to improve such quality metrics and the delivered image quality, in order to better preserve the original creative intent.

Researchers under the direction of Professor Zhou Wang at the University of Waterloo Image and Vision Computing Laboratory, and at SSIMWave Inc. under the guidance of Chief Executive Officer and co-founder Dr. Abdul Rehman, have developed an "alpha" version of the testbed software, for review by the Working Group. That software allows a test subject to view and

[i.] For information on the SSIM Plus quality-of-experience metric, see: Rehman, A., Zeng, K., Wang, Z., "Display Device-Adapted Video Quality-of-Experience Assessment", Human Vision and Electronic Imaging XX, Proc. SPIE vol. 9394 (2015); also available at https://ece.uwaterloo.ca/~z70wang/publications/HVEI15.pdf.

Labels on figure:
navigating the video | division line | the threshold of the displayed quality map | Quality map | Displayed frame | Name of video file | Scoring sliders | Comment box

Test: as delivered video | Reference: as graded video

Controls for navigating the video | Slider to control division line | Slider to adjust the the threshold of the displayed quality map | Controls to navigate through the different videos
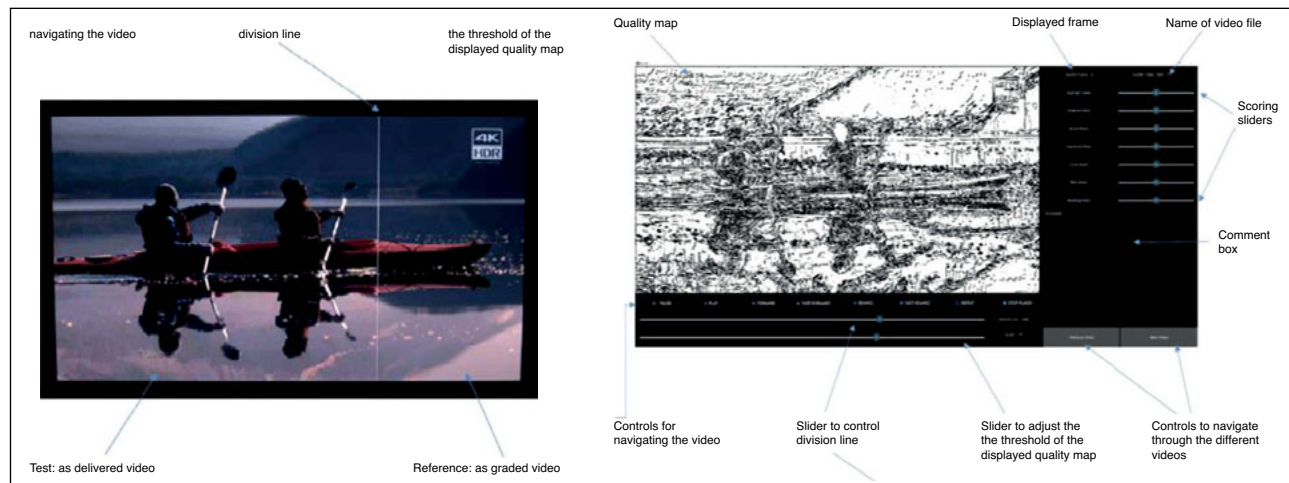
FIGURE 12 HDR Evaluation Testbed - Software User Interface.

to compare original, as-graded images with those same images as-delivered to consumer devices, displayed on an HDR full-4K reference monitor (in this case, a 1200-nit peak luminance Canon DP-V2420 – see **Fig. 12**). A user interface on a separate monitor allows a participant to control playback of each test clip and to enter results of their evaluations.

To perform that evaluation, the computer system for our testbed must reliably display two full 4K streams of input HDR test image data, in perfect synchronization, for comparison by test subjects. Pierre Couture of Lenovo and Mark Noland of Liqid, Inc., have joined the Working Group to lend their considerable expertise and experience to determining a suitable computer system configuration that will provide:

■ Simultaneous, in-sync playback of two streams of 4096 x 2160 ST 2084 PQ-encoded 12-bits/color RGB data at up to 30 fps, uncompressed, displayed on the reference HDR monitor; [ii]
■ User interface that allows a test subject to manually "swipe" between the two streams displayed on the reference monitor without stuttering or dropped frames;
■ Simultaneous synchronized display on a 4K computer monitor of the corresponding "quality difference map" of visually perceptible differences between the original "as-graded" vs. the "as-delivered" versions, as determined by the SSIMWave-software; and,
■ GUI for test subject DPs and colorists to enter their responses to perceived differences between the two HDR streams, and how well the SSIMPLUS metric software matches their perceptions.

NVidia has provided a Quadro graphics card for use in that system (thanks to Thomas True at NVidia),

and Blackmagic Design has agreed to provide interface cards that can maintain the required data rate to the reference monitor.

In terms of high-quality HDR test material, the files that we had assembled for this study were transferred to EFILM for viewing in a grading theater at their Hollywood facility. Those files included:

■ Camera RAW clips from the ASC's Image Control Assessment Series (ICAS) tests. Lead cinematographers Bob Primes, ASC (Cafe interior), Nancy Shreiber, ASC (Night exterior).
■ The graded ACES master of Curtis Clark, ASC's short *Meridian*, shot for Netflix and graded by Curtis and colorist John Daro at FotoKem, in ACES ST 2065-5 AP0 OpenEXR format, at 60 fps, for 0 nits minimum to 1000 nits peak luminance display.
■ In addition, Bill Bennett, ASC supplied ARRIRAW clips from tests he had shot with the ARRI Alexa 65 camera.

There, in coordination with members of the ASC MITC Next Generation Cinema Display ("NGCD") Committee, the UHDTV Committee, and the Academy's ACES Next project working group, Joachim Zell ("JZ") hosted two sessions where specific clips were chosen for inclusion in our various HDR tests:

■ a clip of one scene from ICAS shot on a Sony F65,
■ two clips of another scene from ICAS shot on an ARRI Alexa,
■ two clips from Bill Bennett's Alexa 65 desert scenes, and
■ *Meridian* (with specific scenes to be selected later).

Ungraded material was to be graded using an ACES 1.1 workflow specifically for our mutual use in testing various HDR display technologies.

In addition, Tony Davis and RealD Inc. have generously allowed our use of their *Flamenco* short, illustrating how the effects of strobing and judder can be

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[ii.] *30 frames per second is currently the maximum standard frame rate that 12 bits/color 4096x2160 frames can be displayed on available HDR reference monitors using a quad 3G SDI interface, and at which interface cards can drive those monitors. Ongoing developments may soon remove that restriction.*

mitigated or removed by their TrueMotion software, and shot by Bill Bennett, ASC. (The effects of strobing on HDR material shot and displayed at 24 or 30 fps is a major issue for cinematographers wanting to maintain a cinematic look.)

In mid-April, these files were transferred to Roundabout Entertainment, where Jerome Dewhurst, senior color scientist, and Bryan McMahan, head colorist, produced 0 nits minimum – 1000 nits peak, DCI P3 "reference" HDR grades of the ASC's test material with DPs Dave Stump, ASC and Bill Bennett, ASC – using ACES 1.1 and producing graded ACES as well as PQ-encoded deliverables. A 0 – 300 nits grade was also done for use by the NGCD in testing of emissive LED HDR cinema displays. Curtis Clark, ASC's *Meridian* was also re-graded with Curtis for 300 nits peak for use by the NGCD. [iii]

At the time of writing, the original *Flamenco* – originally graded for theatrical display – is being re-graded at Roundabout Entertainment West for HDR at 0 nits minimum to 1000 nits peak and at 0 – 300 nits for HDR cinema, again with the cooperation of Bill Bennett, Jerome Dewhurst, and Bryan McMahan.

With the availability of suitable HDR test material, and as the testbed computer system to run it is assembled, the Working Group is beginning our review of the University of Waterloo/SSIMWave Inc. test software, to finalize the actual process that will be used by evaluation participants. At the same time, further involvement of major distributors of HDR content is being solicited, to ensure that these evaluations by content creators reflect real-world issues in the delivery of such material to consumers.

[iii].*The SMPTE ST 2084 specification for PQ-encoding specifies Rec. 2020 color space, allowing colors outside of the DCI-P3 color gamut. Similarly, the Digital Cinema Initiative specification calls for DCI-P3 as the minimum acceptable color space. Both specifications therefore allow respective color codes for colors that lie outside of P3. However, while the P3 "red" color primary lies slightly outside of the Rec. 2020 color space, in practice P3 has become a default minimum standard for displays of various types and technologies to accurately display cinematic material: available HDR reference monitors as well as consumer displays and HDR cinema displays either cannot exceed P3 or do so only slightly (and to varying degrees). This study excludes evaluation of material shot only for live broadcast television, and the NGCD testing is specifically for cinema displays; therefore, this initial test material was graded to be limited to P3 color, not Rec. 2020, and targeted for D65 white point.*

About the Authors

Curtis Clark, ASC, studied theater at the Art Institute of Chicago's Goodman School of Drama and cinematography at the London Film School. After graduation, he began his career by shooting and directing documentary films in Britain before transitioning to shooting feature films and TV commercials in Britain and the US. Following on the success of his short film, *The Arrival*, Clark completed his highly praised short film *Eldorado*. His most recent short film, *Meridian* (Netflix), is a creatively accomplished work that has already gained the status of an essential demonstration for High Dynamic Range imaging. Clark is chairman of the ASC Motion Imaging Technology Council (MITC) and is a current member of the ASC Board of Governors. Since its inception in 2003, the Council under Clark's leadership has achieved a series of notable successes including its collaborative work with Digital Cinema Initiatives, LLC (DCI) to produce standardized evaluation material for assessing the performance of digital projectors and other elements of DCI standards-based digital cinema systems, as well as the 2009 Camera Assessment Series and 2012 Image Control Assessment Series. Clark is also a member of the Academy of Motion Picture Arts and Sciences. The ASC Motion Imaging Technology Council, at Clark's instigation, embarked on the development of a groundbreaking project to create cross-platform data exchange for primary RGB digital color correction known as the ASC CDL. The ASC CDL was recognized by the Academy of Television Arts and Sciences with a prestigious 2012 Primetime Emmy Engineering Award. Clark also received an AMPAS Technical Achievement Award recognizing his work developing the ASC CDL. Clark was recipient of the prestigious ASC Presidents Award.

David Reisner is a consultant at www.d-cinema.us and snythesis.com. He received a 2014 Academy Technical Achievement Award, a 2014 Hollywood Post Alliance Judges Award for Creativity and Innovation, and was recognized in a 2012 Primetime Emmy Engineering Award as co-designer of the ASC CDL, now used nearly universally in the workflow of motion pictures, scripted TV, and visual effects turn over. He was lead designer of the ASC-DCI StEM Standard Evaluation Material used to determine the quality required for the deployment of digital cinema, and Vice-Chair'ed the SMPTE Working Groups responsible for digital cinema imaging – showing on 97% of cinema screens worldwide - and security standards – protecting $35B of IP each year. Reisner also had leading roles in activities including design and production of the ASC-PGA CAS Camera Assessment Series and elements of the Academy Color Encoding System. He made one of the first proposals for the Virtual Print Fee model used to fund the digital cinema roll-out. Reisner's "firsts" include programmable portable computers, the handheld video jukebox, and VLIW computer architecture – one of the enablers of modern multi-processor computing. He made early contribution to the introduction of neural networks – the basis of modern Artificial Intelligence and Machine Learning – and originated Pervasive Computing – a parent of IoT (Internet of Things). He has shot celebrity and fashion for books and magazines including Vogue Italia, produced concerts internationally, and trained killer whales. Reisner is well-published in books, technical articles,

and has spoken widely, including on manned space exploration at the 2014 International Space Development Conference. He is a member of SMPTE; the founding Secretary of the ASC Technology Committee and an ASC Associate; a Member of the Visual Effects Society; and Chairs committees for the Academy Scientific and Technical Awards.

David Stump, ASC, is a working director of photography (DP), visual effects DP, visual effects supervisor, and stereographer, earning an Emmy Award, an Academy Award for Scientific and Technical Achievement, and an International Cinematographers Guild Award. He is currently the chairman of the Camera Subcommittee of the ASC Technology Committee and a member of the AMPAS Science and Technology Council, where he chairs the Next Generation Cinema Technology Work Group and participates in the AMPAS ACES project. Under his guidance, the combined efforts of the PGA and the ASC produced both the ASC-PGA Camera Assessment Series and the ASC-PGA ICAS, which are side-by-side comparisons of virtually all of the high-end digital cinema cameras against film. He has lectured and taught classes in cinematography and visual effects and has spoken at many conferences and trade shows, including the National Association of Broadcasters and the International Broadcast Convention.
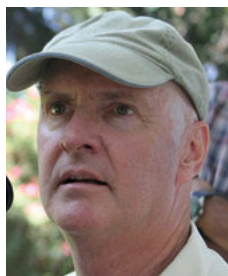
Bill Bennett, ASC has been a cinematographer for over 35 years, primarily shooting television commercials for hundreds of major clients, including Ford, Lexus, Coca Cola, Apple Computer, American Airlines, McDonalds, and Budweiser. Bennett had the great honor of being the first cinematographer, with a career consisting of primarily shooting television commercials, to be invited to join the American Society of Cinematographers. In 2016, the ASC presented Bennett with the President's Award at the 30th annual ASC Awards Show. He is currently serving as Vice President at the ASC. Bennett often advises ARRI, ZEISS and others on equipment design.

Jay Holben is an independent producer/director in Los Angeles. A former cinematographer, he is a contributing editor to *American Cinematographer* magazine, the author of two commercially-published books on cinematography, a faculty instructor for the Global Cinematography Institute and an Associate Member of the ASC.

Michael Karagosian is President of MKPE Consulting LLC, a consultancy in business development for entertainment technology. He is known for his work during the transition to digital cinema, where his accomplishments include the negotiation of virtual print fee (VPF) subsidies with the major Hollywood studios and representation of the technology interests of the National Association of Theatre Owners (NATO) for 11 years. He was co-founder of CinemaAcoustics, a division of Peavey Electronics, and a member of the Board of Directors for pioneering 3D conversion company In-Three. A graduate of UC Berkeley, Karagosian is co-chair of the ASC Motion Imaging Technology Council Committee on Next Generation Cinema Display, a SMPTE Life Fellow, and a Life Member of the Audio Engineering Society.

Eric Rodli has been involved in the management and development of entertainment technology since the late 1980s when he became President of Iwerks Entertainment; a pioneer in large-format film, motion simulation theaters and other immersive technologies. He subsequently has had senior roles in a variety of entertainment and media organizations, including being a partner in the entertainment consulting practice of PwC as well as President of Kodak's Motion Picture Division. He is currently the Executive Director of the ASC. He is also an Associate Member of the ASC. Rodli received a BA in Economics from the University of California, San Diego (UCSD) and MBA from the University of Chicago.

Joachim Zell is Vice President of Technology at EFILM/Deluxe, where he designs and monitors production workflows from onset production to movie release. Previously, he was Vice President of Advanced Technology at Technicolor Thomson in Burbank and before that Marketing Manager Americas at Grass Valley Thomson. During his time in London, Zell worked as Product Manager Digital Film Systems for Pandora International. He is a SMPTE Hollywood Section Manager, was part of the ASC Technology Committee work that created the ASC CDL, and holds the position of ACES Project Vice Chair at the Academy of Motion Picture Arts and Sciences. Zell holds a Master's degree in Film and Television Engineering and was co-writer on four image processing patents.

Don Eklund serves as Chief Technology Officer at Sony Pictures Entertainment. He has helped launch multiple consumer entertainment formats since starting his career at Sony. He co-developed and staffed the operation that launched DVD at Sony Pictures and went on to oversee the development of software tools and hardware systems which supported compression, authoring, and quality control for Blu-ray. Eklund participates in a number industry standards organizations and consortiums which focus on next-generation entertainment.

Bill Mandel is Vice President Industry Relations at Samsung Research America, representing Samsung in various industry groups on topics of HDR10+, Cinema LED technologies, and picture quality. His interests lie in imagery, image processing and video technologies. He has more than 20 years of experience working on new media technologies for Universal Pictures in areas of formats, interactivity, and digital distribution.

Gary Demos has been a pioneer in the development of computer-generated images for use in motion pictures, digital image processing, and image compression. He was a founder of Digital Productions (1982-1986), and was awarded an Academy of Motion Picture Arts and Sciences (AMPAS) Scientific and Engineering Award in 1984 along with John Whitney Jr. "For the Practical Simulation of Motion Picture Photograph by Means of Computer-Generated Images." Demos also founded Whitney-Demos Productions (1986-1988), DemoGraFX (1988-2003), and Image Essence LLC (2005 to present). Demos is the recipient of the AMPAS 2005 Gordon E. Sawyer Oscar for lifetime technical achievement. He is actively involved in the ASC Motion Imaging Technology Council and has worked on the AMPAS ACES project. Demos has presented numerous papers at SMPTE, given a SMPTE webinar, is a SMPTE Fellow, and received the 2012 SMPTE Digital Processing Medal. Demos is the inventor of approximately 100 patents.

Jim Fancher developed next-generation technology in digital asset management for Deluxe Digital Media in Burbank, CA. Previously, he was Chief Science Officer at the Thomson Corporate Research facility in Burbank, where he worked on cluster computing architectures for image processing, 3D color correction systems, and digital asset management technology. As Chief Technology Officer for Technicolor Creative Services, the post-production arm of Technicolor, he was involved in the development of color management systems, image processing, and media asset management. Fancher was a part of managing Technicolor's world class Digital Intermediate facility (formerly known as Technique) as well as the deployment of DI processes to Montreal and New York. Prior to his engagement at Technicolor, he was Chief Science Officer for Pacific Ocean Post, where he started POP Sound, POP Film, which won two Academy Awards for visual effects, and the POP - Cinram DVD center. Fancher holds a Bachelor's degree in Chemistry from Princeton University, numerous patents, and has been a member of SMPTE since 1974.

Joe Kane specializes in the sciences of electronic imaging, accurately reproducing video signals on electronic display devices. These efforts have been the focus of his company, Joe Kane Productions, (JKP) since its founding in 1982. He has produced multiple ground-breaking programs on the subject, creating references for both the program production and consumer worlds. His company's current efforts are focused on defining the ultimate UHD system, one that would include and benefit the majority of consumers interested in viewing program content. His goal is to better define the canvas on which artists create content and to expand the capability of the canvas to bring better picture quality to the viewer.

Greg Ciaccio, VP Post at Sim International, is passionate about finding new technology and workflow solutions for the motion picture, television and emerging XR industries. Previously, Ciaccio served in technical management roles for the respective Creative Services divisions for Ascent, Deluxe and Technicolor. Key developments include the first DP Lights deployments for Technicolor and full near-set dailies solutions for Deluxe Television. Ciaccio is a SMPTE Hollywood Section Manager and member of the ASC MITC, HPA and DCS. He holds a BA degree in Radio-Television-Film from California State University, Northridge, and is currently an adjunct professor teaching Post-Production Management.

Tim Kang is a Los Angeles-based cinematographer, working in the film and television industry, primarily as a director of photography on narrative, commercial, music video and documentary projects. In addition to multiple features, pilots, and shorts, his list of commercial

clients includes Cover Girl, Delta, LA Kings, Disney Interactive, DreamworksTV, NBC Universal, and YouTube. He has taught cinematography classes and seminars at AFI, Chapman University, and Woodbury University. For formal training, he received a Master of Fine Arts (MFA) in cinematography at the renowned American Film Institute Conservatory and proudly received mentorship from Stephen Lighthill, ASC; Robert Primes, ASC; David Stump, ASC; Greg McMurry, ASC; and Ron Garcia, ASC. He previously studied Biomedical Engineering at Johns Hopkins University, worked in the scientific imaging world for seven years at Mount Sinai School of Medicine, and developed his photographic skills in the streets, subways, and byways of New York City.

Joshua Pines is Vice President of Imaging Research and Development, Technicolor Digital Intermediates, which provides the motion picture industry with digital color correction processes for theatrically released films. Pines is in charge of imaging and color science projects. He joined Technicolor after more than 10 years at Industrial Light & Magic (ILM), where he supervised the company's film scanning/recording department from its inception, and worked extensively with both traditional and digital cinema technologies. He earned a degree in Electrical Engineering from Cooper Union in New York City, where he started his career teaching film courses. He began working in visual effects at MAGI in 1982 at the tail end of their work on *Tron*, went on to lead the computer graphics division at R/Greenberg Associates in New York City, and then supervised film effects and film recording at Degraf/Wahrman in Los Angeles before working for ILM. He has received a Technical Achievement Award from the Academy of Motion Picture Arts and Sciences, and has credits on several zillion feature films.

Pete Ludé is co-chair of the Plenoptic and Computational Imaging Committee. He is past-president of SMPTE, and a SMPTE Fellow. Ludé has been involved in advancing motion imaging technology for several decades, and currently serves as Chief Technology Officer of Mission Rock Digital, an engineering consultancy based in San Francisco.

David Morin is chairman of the Joint Technology Committee on Virtual Production. He is also chairman of the ASC-ICG-VES-PGA Joint Committee on Virtual Reality that was started to study VR from the cinematographer's point of view, and a past co-chair of the ASC-ADG-VES Joint Technology Subcommittee on Previsualization, a committee that helped define the role of previsualization in the film industry. Morin also organized the Academy Summits on Open Source Software on behalf of the Science and Technology Council of the Academy of Motion Picture Arts and Sciences. Morin earned a BScA in computer science from Laval University (Quebec City, Canada) and has participated in the development of motion capture and 3D software since *Jurassic Park* at companies such as Softimage, Microsoft, Avid Technology and Autodesk. He is President of David Morin, LLC, a diversified consultancy specializing in immersive production.

Michael Goi, ASC, was born and raised in Chicago, IL, where he established himself in the fields of documentaries and commercials. As a cinematographer he has compiled over 70 narrative credits, four Emmy nominations and four ASC Award Nominations. As a director, he has helmed numerous episodes of "American Horror Story" and individual episodes of "Pretty Little Liars", "Famous In Love", "Sleepy Hollow," "Shadowhunters," "Nashville," "Falling Water," and others. Goi is a three-time past President of the American Society of Cinematographers, served on the Board of Governors of the ASC, and is the editor of the 10th Edition of the ASC Manual. He is the co-chair of the Directors Guild of America's Asian American Committee. Goi is a member of the Academy of Television Arts and Sciences, the Academy of Motion Picture Arts and Sciences, and the National Executive Board of the International Cinematographers Guild. He mentors students for various industry programs. An unrepentant movie buff, he has more than 18,000 films in his collection.

Mike Sanders is the Senior Visual Director for Activision's Central Studios overseeing innovation in art, animation, and production across Activision's game franchises, most notably "Call of Duty." Sanders is focused on bringing film visual effects quality to game develop-

ment and emerging AR/VR markets. He was previously Director of Virtual Production for Industrial Light & Magic, collaborating with Disney divisions such as Lucasfilm, Pixar, Marvel, and Imagineering and built much of the foundational creative technology of the ILMxLAB. He has been awarded numerous patents for digital production and virtual cinematography. In 2009, Sanders was recognized by the Producer's Guild of America as a member of their inaugural Digital 25 list of the most notable contributors to digital storytelling. Sanders has more than 20 years of experience in creating cutting-edge imagery for more than 85 major motion pictures and AAA game titles. He has worked with top directors in major studios on memorable projects, including the *Titanic*, *Star Wars*, *Avatar*, and *Pirates of the Caribbean*.

W. Thomas Wall is a retired computer systems designer and professional photographer. He is CTO of LightView.

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