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# Stereoscopic 3-D in 2008

By Neil B. Feldman, In-Three, Inc.

## Introduction

It is often said that "good things come in 3s." Stereoscopic 3-D film/video aficionados might modify that to say "good things come in 3-D." (3-D being to stereographic 3-D displays that create the illusion of depth.)

There are three major constituencies to consider in this emerging industry—content creators (producers, directors, and post-producers), content packagers (studios and distributors), and the content displayers (theater exhibitors and home consumers). All anticipate great things from the swift deployment of digital stereographic 3-D infrastructures.

## Content Creators

The top content creators—luminaries such as Peter Jackson, James Cameron, George Lucas, Robert Zemeckis, Robert Rodriguez, and digitally phobic Steven Spielberg—were first to express a deep interest and commitment to producing high-quality stereographic 3-D content. Peter Jackson suggested showing members of the other two constituencies how they could reap financial and creative rewards by displaying digital stereographic 3-D content. That was the genesis of a historic demonstration sponsored by Texas Instruments (TI) and hosted by George Lucas, James Cameron, and Peter Jackson (via videotape) at ShoWest in March of 2005.

That ShoWest demo spurred attention because, for the first time, a single (TI DLP-chip based) projector lit up a 50-ft screen with impressive stereoscopic 3-D images. This event inspired Walt Disney Studios to repurpose a 2-D animated motion picture that was already in production (*Chicken Little*) for stereographic 3-D display. A new era in digital stereoscopic capture, editing, and display got under way after that event.

There are basically three different ways to create high-quality stereoscopic 3-D content.

The oldest technique is using dual imagers/cameras that are spaced apart by 65mm—the distance between an average adult's eyes—although this interocular distance may be varied for optimal effects.

The introduction of small, lightweight, low-cost, digital cinema cameras featuring high-resolution imaging (4K, 2K, and HD) has revolutionized production in the field. One of the most interesting products is the HD-RH1 2K camera by Iconix Video, which is "no larger than an egg." 3ality Digital employed it in a unique dual-camera side-by-side mount, resulting in the TS3 3-D system.

Dual Red cameras have been utilized by Paradise FX in a low-budget film to be released later this year—*Dark Country* from Stage 6 Films. In addition, these filmmakers also incorporated a Silicon Imaging SI-2K MINI stereo rig for steadycam style shots. The tiny imager has a 2K-optical block that is advertised to be "the size of a cigarette pack." The stereo rig was small enough to be mounted inside an MK-V AR camera stabilization system.

Silicon Imaging SI-2K MINI stereo cameras were also used in the production of Bjork's recent music video, "Wanderlust." A beam-splitter mount with wide-angle lenses was employed on this interesting artistic venture.

The most important rule for the success of stereoscopic 3-D is “to do no harm” to the audience. That means to eliminate and minimize any aspects of stereoscopy that might induce eye fatigue or headaches. Many people mistakenly assume that wearing 3-D glasses causes the problem, however, the real culprit is simply “bad 3-D.” One of the most common sources of eye fatigue comes from small vertical discrepancies between the left and right images. These discrepancies can be easily introduced because of misalignment between the dual camera sensor/optic paths, especially when using dual zoom lenses. 3ality Digital and other companies made significant strides in eliminating this problem by incorporating look-up table (LUT) compensation for selected lens/camera combinations. This system moves the camera’s optical center as it is zoomed in and out. 3ality also states that it used “artificial intelligence” to automatically align and adapt to mechanical and lens imperfections and to remove built-in telecentricity errors. Its TS1 system is based on dual Sony HDVS HD-SDI cameras with Zeiss DigiZoom lenses mounted at right angles to one another. Each camera looks through common beam-splitting optics.

3ality Digital was responsible for shooting “U23-D”—a digital stereographic 3-D production that employed nine Pace Technologies Fusion 3-D systems, each equipped with dual Sony HDC-F950 cameras. Live-action stereo 3-D was captured during successive U2 concerts held in Buenos Aires in March 2006.

During NAB 2008 3ality Digital presented an ambitious live demo that hinted at the ease with which live-action stereoscopic 3-D production could be accomplished in the studio. The NAB audience was able to interact directly with comic host Howie Mandel, who was performing hundreds of miles away in a studio in Burbank, CA. The demo also showed the ability to broadcast a live stereo 3-D feed using an existing video/data infrastructure.

On very short notice and with little time for extensive post-production, Pace Technologies produced a different stereoscopic 3-D concert movie, *Hannah Montana/Miley Cyrus: Best of Both Worlds Concert Tour* for Disney. This movie opened on only 683 RealD equipped digital stereo 3-D screens, but it managed to book over \$31 million. At an average of \$45,000 per screen this set a new Hollywood record. Disney recently announced that it would use Pace to shoot the “Jonas Brothers Concert Tour” in stereoscopic 3-D starting in July.

The Pace Fusion 3-D systems rely on pairing two Sony HDC-950 cameras together, with their imagers spaced approximately 70mm apart. These camera rigs were also used to capture an NBA basketball game in stereoscopic 3-D. Select Dallas Mavericks fans were to see the results at a local Landmark Theater, which employed dual Sony 4K LCoS-chip based projectors to light up the 3-D screen.

Several experiments in live-action stereoscopic 3-D sports capture were also done in Europe. A trial of the IIHF Hockey World Championship finals from Canada in stereoscopic HD was successfully conducted (although it was not broadcast). HBS, a Swiss company, worked in conjunction with the 3-DFirm, a British consortium of three other companies (Can Communicate, Inition, and Axis Films). The trial employed three static pairs of Thomson LDK6000 cameras placed around the hockey rink. There was also a pair of Iconix HD-RH1’s stationed at one of the goals, for intimate closeups.

The 3-DFirm also produced a satellite-delivered multicamera stereoscopic broadcast of the Scotland vs. England Six Nations Rugby International match held in March 2008. Here pairs of Sony HDC-950 cameras with wide-angle HD zoom lenses were used.

Orange, the French telecom, announced plans to broadcast a live stereoscopic 3-D trial of tennis matches held on the Suzanne Lenglen court in May 2008. It planned on using cam-

era rigs from Japan Broadcasting Corp. (NHK) Media Technology and Iconix.

*Journey to the Center of the Earth 3-D* was released by Walden Pictures in July; it had been advertised as the first live-action film shot entirely in stereoscopic 3-D. However, another live-action film, from Norman Twain Productions, called *Scar 3-D* was released earlier (but limited) in Eastern Europe at the start of the year. This movie utilized side-by-side Sony HDC-950 cameras to capture the (quite gory) stereoscopic live-action.

*Journey to the Center of the Earth 3-D* utilized modified dual Sony HDC-950 cameras from Pace. The lenses and optical blocks of these cameras were connected via fiber optics to electronics housed separately in remote racks.

Virtually every manufacturer of high-resolution digital capture systems has a new stereoscopic imaging system. These include Sony’s F35 and PMW-EX3 cameras, Red’s new 5K Epic; 4K Red Ray, and 3K Scarlett. Other innovative rigs and mounts were also introduced. P+S Technik GmbH and 21st Century 3-D showed new beam-splitter based mounts designed for dual camera systems.

A second technique for the creation of high-quality stereo 3-D images relies on CGI computing. This approach relies on sophisticated software algorithms to render a virtual second camera or multiple virtual cameras inside computer space.

The most recent example of an animated feature film being released in stereographic 3-D is *Fly Me to the Moon* from nWave Pictures.

After the release of its first stereographic 3-D animated feature, *Chicken Little* in November 2005, Disney followed with *Meet the Robinsons* in March 2007. Hollywood took great interest when the stereoscopic 3-D version of this animated movie generated nearly three times more revenue per screen than those displaying it in 2-D.

In November Disney will release a new stereoscopic 3-D animated fea-

ture called *Bolt*. Significantly, Disney/Pixar, following a similar declaration made by DreamWorks Animation earlier this year, announced that all of its animated films, starting with *Bolt*, will be released in stereoscopic 3-D.

Focus Features will follow Disney with its release of the stereoscopic 3-D animated feature *Coraline* in December 2008.

DreamWorks Animation will offer their first stereoscopic 3-D release of an animated feature with *Monsters vs. Aliens* in March 2009. All of its animated releases to follow will be released in stereo 3-D.

A clever subset of the CGI computer-based approach to creating stereoscopic 3-D is by using motion or performance capture. Actors are outfitted with hundreds of sensors in this technique. These sensors send motion and location data directly into a computer. The computer data is used to generate and/or animate CGI characters in both computer 3-D and stereographic 3-D space.

Robert Zemeckis successfully used this technique in the creation of Warner Brothers' *The Polar Express*. Sony Pictures ImageWorks handled the performance capture and subsequent stereoscopic 3-D rendering on this animated tale. Hollywood again took notice when the stereoscopic 3-D version of the film, released in limited IMAX 3-D film-based theaters, showed impressive box office numbers as the flat 2-D versions flirted with disaster.

Two years later, Zemeckis used Sony Pictures ImageWorks for the performance capture and stereoscopic 3-D rendering on the animated film *Monster House*. Again, the 3-D version repeated significant financial success.

However, in this year's release of *Beowulf*, performance capture technology truly raised the bar in the creation of "humanly realistic" CGI-generated characters. This animated feature was another collaboration between Robert Zemeckis and Sony Pictures ImageWorks. The box office results were also

tantalizing. The stereo 3-D version of *Beowulf* easily grossed twice as much per screen as the 2-D release, although the overall numbers for the movie were somewhat disappointing.

Many other top filmmakers are planning to use performance-capture computer graphics imaging (CGI) techniques for their upcoming stereoscopic 3-D releases such as *Tin-Tin* from Steven Spielberg and Peter Jackson; on portions of James Cameron's *Avatar* and Tim Burton's *Alice in Wonderland*; and, not surprising, Robert Zemeckis next stereoscopic 3-D release—a remake of *A Christmas Carol*.

The final and, perhaps, most interesting method of creating high-quality stereographic 3-D images is by synthesizing them from 2-D film or video sources. Conversion of 2-D content into stereoscopic 3-D can be accomplished in a number of ways.

Industrial Light & Magic (in collaboration with In-Three) used some of its own proprietary software to convert Tim Burton's 1993 animated classic, *Nightmare Before Christmas* for stereoscopic display. It was first released in October 2006 to about 183 RealD-equipped digital 3-D theaters and has been re-released to an increasing population of digital 3-D theaters every Halloween since then.

With today's increasing computing power and sophisticated off-the-shelf software programs such as Autodesk Maya and Adobe After Effects, it is possible to accomplish 2-D to 3-D conversions at a high premium in time and expense. IMAX used such an approach to convert portions of Warner Brothers' *Superman Returns* in June 2006. This approach was also used in the last 20 minutes of Warner Brothers' *Harry Potter and the Order of the Phoenix* in July 2007. Both of these movies were exclusively released in IMAX 3-D theaters employing dual print (nondigital) film projectors.

SFD VFX and Creative Post employed off-the-shelf software to convert an IMAX documentary movie, *Lions 3-D: Roar of the Kalahari*, for stereo theat-

rical release in 2007. This year, the same shop converted an IMAX documentary, *Mummies 3-D: Secrets of the Pharaohs*, for stereoscopic display.

In-Three has been pioneering another stereo synthesis technique called Dimensionalization. The patented process is not simply a conversion of 2-D content into stereoscopic 3-D, but (to employ an imperfect analogy), it is akin to re-rendering each object within a given scene with its own virtual dual-camera rig. This allows the use of complete depth-grading—adjusting of the explicit depth of each object by shaping and moving individual or groups of objects toward or away from the viewer. This approach makes the creation of stereoscopic 3-D a complete post-production process.

The first feature movies employing this 2-D to 3-D synthesis technique will be released during 2009.

### Content Packagers—3-D Editorial and Mastering Tools

The rapidity at which both Hollywood and the real world have rediscovered stereoscopic 3-D seemed to have caught some of the major post-production equipment manufacturers off-guard this past year.

Assimilate was an exception. Its scratch editing system was utilized by 3ality Digital in the post-production of the U23-D concert footage.

Quantel was another exception. Last year, it revamped its Pablo 4K nonlinear editing system (which already could handle dual 2K streams of data for realtime display) to perform stereoscopic 3-D editing. This year it showed an optional "true realtime end-to-end 3-D post process" toolset on its new Pablo 4K, iQ4, and Max 4K systems. It also introduced Sid for limited and lower cost applications. The Quantel workflow includes previsualization, standard editing, color correction, visual effects tools, and support for creating trailers and digital masters.

The Foundry incorporated stereoscopic 3-D workflows as part of its new Nuke 5. It featured added support for Open-

EXR files with 3-D preview and rendered 3-D anaglyph display.

Iconix introduced new stereoscopic 3-D post-production tools in conjunction with Digital Ordnance's popular Flame Thrower playback system.

Silicon Imaging collaborated with its partners CineForm, P+S Technik, and IRIDAS to provide an "integrated suite of 3-D visualization features in an intuitive cinema-oriented camera control and recording toolset" designed around its clever SI-2K mini camera.

Meanwhile, Avid, Autodesk, and Apple have yet to introduce formal products specifically geared for stereoscopic 3-D editing and post-production. Avid has hinted that its new stereoscopic 3-D editing system will include a scheme to edit in 2-D while carrying all the information for left and right eye views to a 3-D display. Autodesk unveils its new stereoscopic 3-D editing system and toolsets at Siggraph in August 2008.

### Content Displayers— D-Cinema

Just eight months after ShoWest in March 2005, Disney's *Chicken Little* premiered in 84 RealD 3-D cinemas. This rapid deployment was truly an amazing feat.

Today, there are well over 1,600 RealD systems in operation. The company has just announced commitments to add another 3,000 screens with 1,500 each going to the Regal and Cinemark theater chains—as soon as the DCIP VPF deal is finalized with the major studios. Meanwhile, with competition from KDC/MasterImage, Dolby Laboratories, and XpanD/NuVision, the total number of digital 3-D theaters is destined to jump even higher. IMAX also announced a digital 3-D projection system of its own that will be deployed in over 200 theaters; however, there are scant technical details available about this new system.

Using a single projector to display stereoscopic 3-D eliminates many of the sources of "bad 3-D" from the past such as mismatched left and right eye images with varying light intensity, col-

orimetry, and/or frame synchronization between dual projectors.

Sony finally announced the introduction (available in late December 2008) of its first single 4K LCoS-based projector capable of displaying stereoscopic 3-D. This will make it a credible competitor to 2K DLP-based systems from Christie, Barco, and NEC in DCI-compliant stereoscopic 3-D D-Cinemas.

Once a DCI-compliant projector and server are put in place, the theater owner decides what technology to deploy for stereoscopic 3-D display. RealD appears to be the preferred choice for domestic exhibitors (having over 97% of all U.S. orders to date). Its lightweight, circularly polarized glasses always "work" and are so inexpensive, they can be given away for free (and/or easily recycled). No extra management of these glasses is needed. Its Z-axis polarizer puts the left and right eye image shuttering mechanism in front of the projector lens. This, in turn, requires the exhibitor to install a non-depolarizing ("silver" or aluminized) screen in the auditorium. Some theater owners object to using screens that employ gain for 2-D projection, because there can be hot spots and/or uneven lighting or color shifts from edge to edge. Regardless, RealD has made great advances in minimizing all of these annoying artifacts.

Using a non-depolarizing screen can also make it difficult to shift stereoscopic 3-D content from one auditorium to another. However, if all the screens in a given multiplex are converted for stereoscopic display this issue becomes moot.

RealD now supplies a device called the "ghost-buster" directly in the projection booth. This eliminates the need to distribute or separate a ghost-busted version of a movie. This device is used to reduce or eliminate cross-talk between the left and right eye images.

RealD's major technology jump this year was the introduction of its XL Z-Filter, a proprietary "light-doubling" system, which basically captures much of the lost light in the Z-axis po-

larizer and redirects it back onto the screen. This device allows lighting of much larger screens—even beyond 70 ft wide when using a suitable single projector.

KDC/MasterImage, a company based in Korea, offers a somewhat similar—albeit mechanically based—shuttering mechanism that also slips in front of the projector lens. It too requires the installation of a non-depolarizing screen and offers low-cost circularly polarized passive glasses for the audience.

XpanD/NuVision puts an active LCD-shuttering mechanism inside each pair of glasses. No replacement of the matte screen is required, making it easy to shift between auditoriums. An infra-red pulse synchronizes the left and right eye shuttering sequence with the projector. The LCD's extinction ratio is good, so no extra "ghost-busting" is required, although this ratio may decrease in off-axis viewing. The battery and electronics to drive the LCDs makes them a bit heavier and bulkier than passive devices. Plus, there is always the possibility of random electrical failure or misuse. These glasses are far too expensive to be given away and there is significant cost to replace if stolen or damaged. In short, the glasses must be properly managed and cleaned/sterilized for re-use.

Dolby Laboratories licensed Spectral Division technology from Infitec of Germany to offer a unique solution for stereoscopic 3-D display. They place a spinning color filter wheel directly inside the D-Cinema projector. This color filter slices the visible spectrum into six precise frequency bands (three per eye). Each eye then receives a filtered and highly selective color spectrum. The audience wears passive glasses that are precisely tuned to these selective bands. This approach is passive, therefore these glasses always work. In addition, there is no need for a special non-depolarizing screen in the theater. However, the glasses are also expensive (costing even more than active LCD units) and have to be properly managed, cleaned/sterilized, and accounted for as well.

In all of these various display schemes, only 12% to 15% of the available light ever makes it to the viewer's eyes. The recommended standard reference white level for 2-D D-Cinema display is 48 nits (48 candelas per square meter). Yet all of the present stereoscopic 3-D display systems struggle to get 25 nits to the eyes. This is a tremendous constraint confronting the industry. To the theater owner it means that the largest lamp possible must be installed and properly maintained in the projector. To the content creator it means that the audience is not able to experience the same colorimetry, contrast, and brightness levels available in the 2-D display of the same work. A solution based on laser light sources delivering high light levels via fiber optics onto the imaging chips may solve the dilemma someday in the future. Until then, the low light level for stereoscopic D-Cinema presentations remains a very serious limitation.

One other major technology issue concerns how to handle captioning in stereoscopic 3-D displays. There is no simple solution to this issue. Captions threaten to "break" the stereoscopic 3-D depth illusion because of their placement within the viewing field. This can trigger conflicting messages to the brain regarding the depth placement of objects within the scene. In the worst case scenario, it can cause eye fatigue and be a constant annoyance. Preliminary tests by Wendy Aylsworth of Warner Brothers (using clips from *The Polar Express*) suggest that this will be a topic of concern for many years to come.

### Content Displayers—Home Theater and Interactive (Games)

This year saw some very significant advances in stereoscopic 3-D HD resolution displays designed for the home consumer. Some of these units were first introduced in 2007 but now they have become readily available for purchase at low cost. For example, a 61-in. Samsung display can be found on the internet for under \$1,300.

Both Samsung and Mitsubishi introduced their own families of "3-D Ready" DLP-based HDTVs. These

units employ a Texas Instruments single chip DLP-engine capable of running at a 120 Hz frame rate. They are rear-projection (RP) units with folded optics and come in sizes ranging from 42 in. to 73 in. They all require the addition of active LCD shutter glasses, a stereo 3-D video processor, and a suitable device to provide playback of (mostly non-existent) 3-D content.

Mitsubishi created some excitement this year with the introduction of its LaserVue RP HDTV line. These units are DLP-based but laser-light sourced and available in 65-in. and 73-in. models. Laser-based HDTV displays promise a much wider color gamut and higher brightness while maintaining low wattage. This is a long-anticipated and notable technology leap.

The very first front projection (FP) HD resolution (1920 x 1080p) 120-Hz 3-D Ready device called the F10 AS3-D, was introduced by ProjectionDesign of Norway during InfoComm. It too is based on a single TI DLP-engine.

At the beginning of 2008 Samsung introduced its Series 4 450 line of 3-D Ready Plasma HDTVs (720p) available in 42-in. and 50-in. models. Its Series 5 line (1080p) became available a few months later in 50-in. and 58-in. sizes.

Finally, in 2008, the first LCD-based HD resolution 3-D-capable displays from Hyundai of Japan and SpectronIQ were introduced. The SpectronIQ unit is a 46-in. flat screen LCD featuring Kerner Optical Research technology. These devices employ circularly polarized passive glasses for stereoscopic 3-D viewing.

It is expected that by the end of 2008 there will be more than 2 million 3-D Ready HDTVs in U.S. homes. Many of these early-adopters will be clamoring for high-quality 3-D content and will not settle for just interactive 3-D games; they will want to see everything in stereoscopic 3-D—from live-action sports to feature films—from television series to reality shows.

Without the adoption of a universal Blu-ray stereoscopic 3-D format in HD, all of these home consumer devices are presently "all dressed up with no place to go." Hence, they are simply called, 3-D Ready. And yet they continue to be purchased.

Are we about to witness another format war? At least three different companies (so far) have announced proprietary 3-D video formats intended for distribution to the home. TDVision Systems heavily promoted its TDVCodec during NAB, claiming it to be "the world's first 2-D and MPEG compatible stereoscopic format that maintains 2-D and MPEG compatibility with legacy systems."

Sensio from Montreal showed its own compression algorithms designed to reduce resolution loss associated with approaches that relied on Anamorphic processing techniques.

DDD was yet another contender for placing its own proprietary processor inside 3-D display devices. It can decode a variety of legacy formats and has its own unique 2-D+ depth map format.

Other companies are still secretly working on their own proposed solutions. All of this activity in the consumer arena inspired the formation of the 3-D@Home Consortium—an industry initiative (started by Insight Media) that formally got under way during NAB. Founding members (at the board level) include Samsung, Philips, Sony, Intel and many other key industry players. Hopefully, a cooperative spirit will prevail and a universal stereoscopic 3-D distribution format for Blu-ray and other devices will emerge in the months to come.

### Content Displayers—Glasses-Free (Autostereoscopic) Displays

Although these technologies offer great promise in the future, currently, the quality of these devices is not very credible for high-end applications, with the exception, perhaps, of 3-D signage and similar specialized venues.

Many of these displays rely on displaying multiple views (typically 7 to 9 of them) on an LCD flat-screen married to a transparent plastic sheet of lenticular (cylindrically shaped) lenses. The lenticular array guides the corresponding left and right images into multiple viewing zones in front of the display. Portraying multiple views simultaneously means that the resolution is compromised. Also, many (such as those employing the Philips WOWvx file format) expect to be fed 2-D+ depth map data input. From this file data the display internally generates an autostereoscopic 3-D image. However,

this kind of approach can result in the occluded areas within the scene, generating objectionable artifacts because of missing scene information.

This year, Philips showed new displays, based on this technology in its WOW family of autostereoscopic monitors; it introduced a 52-in., a 22-in., and a small 8-in. unit.

VisuMotion of Jena (VMJ) and Sharp are apparently collaborating to create "the largest commercial 3-D autostereoscopic display in the world," which measures 65 in. with a base resolution of 1920 x 1080. It uses a parallel-pix-

el barrier rather than a lenticular lens to guide the left and right images to the appropriate viewing zones in front of the display.

A new Alioscopy autostereoscopic display was demonstrated at the Dimension 3 Expo in France. It too was impressive. Toshiba, NEC, Samsung, LG, RealD, and many others have various-size products in this emerging field. Apple has also filed a patent on its proprietary approach. Is an autostereoscopic 3-D iPod in the future? Next year will certainly prove to be very interesting. Keep both eyes open!

## The Digital Evolution of Stereoscopic (3-D)

By Howard Lukk, Walt Disney Studios

**T**he field of stereoscopic (i.e., 3-D) content creation and display has taken a dramatic leap forward in the past three years. With the introduction of digital cinema to the stereographer's toolkit, the palate has increased and the consumer seems delighted with the new renaissance of stereoscopic cinema. This resurgence has taken place on two sides of the workflow: on the camera capture and creation side, and on the display side. One could say that the introduction of digital cinema projectors as a stable platform for theatrical stereoscopic display has amplified the amount of capture and creation to take advantage of this surge.

### Theatrical Projection

In November of 2005, The Walt Disney Studios released the first commercial stereoscopic digital cinema feature, *Chicken Little*, using two standard MPEG-2 digital cinema servers synchronized together, supplied by Dolby. This provided the left and right eye signals via a 4:2:2; Y', C'R, C'B dual-link HD-SDI interface, supplied at 24 frames/sec to the digital cinema projectors supplied by Barco and Christie. The projectors then fed a framing pulse to a RealD switching polarizer panel called a Z-screen, set in front of the lens of the projector, along with a silver screen, to keep the polarized light coherent to the passive circular polarized glasses. Early tests indicated that content creators preferred a refresh rate of 144 Hz, also called "Triple Flash," which provides a sequence of L,R,L,R,L,R before moving to the next frame in the 24-frame sequence. The only issue with this was that the electronics within the projector head at that time would not support this bandwidth at the digital cinema pixel matrixes of 1920 x 1038 (1.85:1) out to the DLP chip; it could handle only 1628 x 858 (1.85) or 1920 x 803 (2.39). (Note: this was an output limitation at 144 Hz not an input limitation.) There were also international installations, which used QuVIS servers, which were already de-



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