3D-TV production standards
— first report of the ITU-R Rapporteurs

Andy Quested
BBC HD and 3D

Barry Zegel
CBS Television City

This article is based on the first report written by the ITU-R co-Rapporteurs on 3D-TV production formats: Andy Quested (BBC) and Barry Zegel (CBS).

Published in early May 2011 as ITU-R Document 6C/468-E, the report assembles information on the image systems and techniques currently being utilized for 3D-TV programme production, along with their pros and cons. The report also discusses their effect on a number of other elements that are likely to be linked to the choice of programme production solutions that would play a role in the success of any eventual deployment of permanent international 3D-TV broadcasting services.

1. Introduction

Working Party 6C of the ITU-R recently completed a new report **"Features of three-dimensional television video systems for broadcasting"** (Report ITU-R BT.2160-1, 10/2010). This includes some descriptions of the end-to-end broadcasting chain including methods of image capture and subsequent programme production. In order to further facilitate the study of methods for programme production and international exchange, the Working Party has also appointed two Rapporteurs with the following mandate (Annex 22 to Document 6C/287):

> **"**Considering that several broadcasting organizations are known to have recently been conducting experiments in stereoscopic 3D-TV programme production using equipment conforming to Recommendation ITU-R BT.709:
>
> - consult with broadcasting organizations to establish what broadcasting systems currently exist or are being developed for the purposes of 3D-TV programme production, post-production, television recording, archiving and distribution;
> - assess whether there are barriers to the future exchange of stereoscopic 3D-TV programmes.
>
> The work of the Rapporteurs should be conducted in a timely way; progress should be reflected in a report to the next meeting of Working Party 6C. The Rapporteurs should work in accordance with § 2.13 of Resolution ITU-R 1-4.**"**

The two Rapporteurs have jointly prepared the present preliminary report, having begun to assemble available information on the image systems and techniques currently being utilized for 3D-TV programme production, their pros and cons, and their effect on a number of other elements that are

likely to be linked to the choice of the programme production solutions that would play a role in the success of any eventual deployment of permanent international 3D-TV broadcasting services.

2. Field survey by the 3D Rapporteurs

In early March, 2011, as preparation for this report, the 3D Rapporteurs and authors of this report – ***Andy Quested*** (Head of Technology, BBC HD and 3D, and Chair of the EBU S3D Committee) and ***Barry Zegel*** (Vice President & General Manager, CBS Television City) – met with some top 3D production experts in Los Angeles, including:

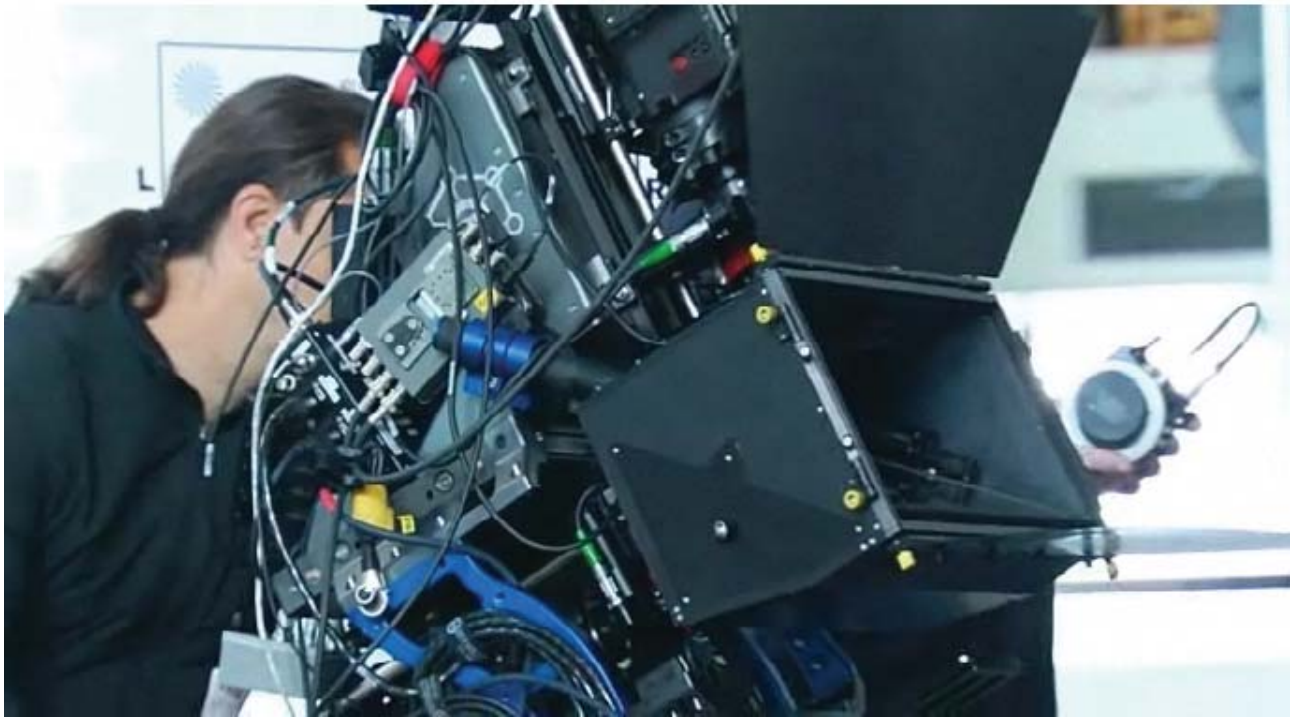
- 3ality Digital Founder and CEO, Steve Schklair, and COO/CTO, Howard Postley.
- Lenny Lipton, 3D inventor, expert and film producer.
- Sony 3D Technology Center Chief Officer, Chris Cookson, and Sony Pictures Senior V.P. Technical Services, Spencer Stephens.
- George Taweel, founder of St. George Entertainment and George Taweel Productions.

In addition, in his role as Vice President and General Manager of CBS Television City, Mr Zegel has had the opportunity to interact with many of the leading television programme production companies in Hollywood for discussions regarding producing their shows in 3D. Shows currently produced in HD at CBS Television City include “American Idol”, “Dancing with the Stars”, “America’s Got Talent”, and “The Bold and the Beautiful”. (Note that some of these are for non-CBS broadcast networks).

3. Description of some experimental 3D-TV productions for broadcast use

3.1. Cameras used, recorders used, and how they are adapted to accommodate the left- and right-eye images

There is a wide variation in methodology, opinion, equipment and quality surrounding stereoscopic 3D (S3D) acquisition. Camera types and rigging vary from semi-professional and professional single cameras with two lenses and processing of left and right images, to two single cameras mounted either side-by-side or on beam-splitter (mirror) rigs.



Although the concept of S3D is very simple – a scene is acquired by two cameras fixed close together to provide video streams for the Left and the Right eye – there is much discussion about what constitutes best industry practice.

The type, positioning and set-up of the cameras are usually controlled by a ***Stereographer***, a new job role to the programme team. The Stereographers have influenced and in many cases, designed the camera rigs used to mount and control two cameras.

There are many rig and camera frame manufacturers in the S3D market, including companies such as 3ality Digital, Technica 3D, P+S Technik, 3D Film Factory and Swiss Rig. To work well they are built to extremely tight tolerances and are therefore expensive. Computer control allows and maintains line-up of the attached cameras but these rigs must be seen as a "means to an end". For long-term daily use in all environments, an S3D camera set-up must come closer to matching the bulk, weight, features and flexibility of the current 2D camera rigs.

3.2. Image transport in production

There are no agreed standards for transporting synchronous HD images, however HD SDI is still at the heart of the process.

- The 5th April 2011 issue of TVB Europe magazine provides a summary description of a method to multiplex a stereo signal pair on an optical fibre:

  "Each signal pair will be fed to HDFA-200 optical fibre transmission adapters. First trialled during last October's Ryder Cup, these boxes combine 1.5 GB signals into a single 3G-capable SMPTE fibre-optic feed. The device also incorporates a viewfinder output with video, intercom and control signals for inter-axial and convergence as well as power, enabling a single cable to realise full system operation for two-camera head systems."

  "On leaving the HDFA each single fibre will be fed to an OB truck where the signal will be broken back out to left and right channels through a CCU and directly into a Sony MPE-200 processor."

  "By enabling a pair of 3D cameras to work down a single fibre it significantly reduced the amount of fibre required, as well as speeding up the rigging process," explained Mark Grinyer, Sony's 3D Sports Solutions Business Head. Acquisition will be at 50i to accommodate mixing with converted shots from 2D camera angles."

- The SMPTE describes the mapping for two independent 1.5Gbit/s streams in a 3Gbit/s stream – Level B DS (Dual Stream).

- The relevant EBU Technical Publication notes on the uses of 3G-SDI:

  "Level B-DS … is the dual-stream mapping of two independent 1080i/25 (or 1080p/25) video streams into a single serial digital interface operating at a nominal rate of 3Gbit/s."

  "Level B-DS provides a mapping structure for the carriage of two bit synchronized 1.5G-SDI compliant interfaces over the nominal 3Gbit/s SDI. Any two formats supported by 1.5G-SDI interface may be carried on the 3Gbit/s SDI, so long as they have the same vertical line structure and frame rate."

  "These include the HD rasters of 1920x1080, 1280x720 and the 2K Cinematography raster of 2048x1080 that can be transported through Single-link 1.5G-SDI ..."

- The EBU also point out that:

  "*…In the absence of other standards, Level B-DS is being used by some organizations to carry the left and right eye signals of stereoscopic 3D-TV.*"

There are as yet no agreed standards for carrying the Left/Right Eye metadata from camera though the live programme environment or through post-production processing. This is a possible point of failure in the system as there is no provision within the current consumer S3D displays to identify and reverse the images should they cross during transit on the chain from camera to the home.

3.3. Some current presentation devices and related viewer constraints

As a longer-term aspiration for home 3D-TV viewing, auto-stereoscopic displays (no glasses required for 3D viewing) are developing technologies at the moment, and fall into various varieties. Some, as with the first two described below, allow the viewer to see different "parallax" as the head is moved.

- **Head-tracking displays which provide an image to each eye appropriate to the viewer's head position**

  Head tracking displays for a single user are already feasible, and research on tracking and providing images for multiple viewers is advancing. The Fraunhofer Heinrich Hertz Institute (HHI) is heavily involved in leading collaborative work in this area.

- **Multi-view displays, which allow users to move their head within a certain zone and their eyes to see different views depending on where they are within that zone**

  Until displays with vastly greater pixel counts than at present are available, multi-view systems suffer from relatively low resolution in each view. Philips has developed a 9-view display in this area, and has shown a 46-view prototype based on a 4k horizontal-resolution panel. However Philips has recently announced that it is ending commercial activity in this area, but is continuing with collaborative research projects in this field.

Simpler stereoscopic displays – that are closer to practical production technology (without multi-view capability) – present two views, one for each eye. There is a variety of different techniques. Except for the first auto-stereoscopic approach listed below, these requires special glasses for 3D viewing:

- An auto-stereoscopic approach applies lenticular barrier or micro-lens based techniques, essentially the same technology as multi-view displays, but with only two views, where the viewer is required to keep his/her head relatively still, but does not need to wear glasses.
- Glasses-mounted micro-displays, with individual displays dedicated to each eye.
- Polarization separation – either diagonally or circularly polarized for each view, with appropriate polarization in the glasses. LG has introduced spatially-patterned polarized displays in 3D-TV products with passive polarized glasses (LG also provides these display panels to Philips and Vizio as well for their polarized 3D-TV products). Zalman (in the games area) and Hyundai/ Arisawa (for TV) are also readily-available polarizing displays. These are usually based on LCD technology.
- Time-sequential 3D displays with synchronized shuttered glasses, such as those from Sony, Panasonic, Samsung, Mitsubishi, Sharp and LG. Early displays of this type were rear-projection DLPs, but now LCD displays are dominant in the domestic environment, with a substantial number (a few million) such displays having been sold in the USA alone.

The last two types of stereoscopic display listed above, both requiring glasses, are the most common types in the market at present. In both cases the quality of the 3D effect depends largely on the level of perceived crosstalk between views (i.e. visibility of the right-view to the left eye and vice-versa), and is dependent on the display and the glasses, in combination. If the display knows the characteristics of the glasses, then some cross-talk may be able to be pre-corrected in the signal.

- Time sequential polarization – this involves shifting the direction of polarization for the entire display on sequential frames (or fields). This combines the benefits of polarization (inexpensive and easy to manufacture glasses) with time sequential quality, because it presents full screen resolution and avoids loss of brightness, which are disadvantages of spatially-patterned polarization approaches. *See:* **http://bit.ly/iZXd3R**.

3.4. Evidence of consumer resistance to the use of 3D-TV viewing glasses

Interestingly, recent consumer research reveals that there may be substantial consumer resistance to using 3D viewing glasses with a 3D-TV display. Market research firm The Nielsen Company and CTAM (the U.S. Cable & Telecommunications Association for Marketing) released a report on

9 September 2010 entitled, "**Focusing on the 3D-TV Experience**". The qualitative phase of this research was conducted at the "CBS Television City" media research laboratory in Las Vegas, Nevada.

While substantial interest was shown in 3D-TV, especially for movies, sports and special events, there were concerns about 3D glasses.

Nielsen's Frank Stagliano, EVP & GM of TV Primary Research stated, "*…*(the) *purchase interest for a 3D-TV set among those planning to buy a new TV in the next 12 months decreased after seeing a demonstration of the technology, experiencing the glasses, and learning more about product costs.*"

In the study, some of the most commonly cited reasons for lack of interest in purchasing include the cost of the set (68%), having to wear the 3D glasses (57%), and not enough 3D programming (44%).

Overall, 89% of study participants felt the 3D glasses would constrain their multitasking activities as compared to 2D viewing habits in the household. More than half the participants mentioned that the glasses are a "hassle" and that was the reason cited by 57% of those "not likely" to purchase a 3D-TV set. Consumers were also concerned with discomfort from wearing the glasses (45%).

Note: An updated paper on S3D displays is being prepared by BBC R&D, the EBU and the UK DTG (Digital Television Group). The EBU S3D group and the UK DTG are also coordinating S3D production guidelines for the UK and wider European broadcasters.

4. Description of the creative constraints attendant to a 3D-TV programme production

A new production "grammar and syntax" has evolved around S3D in the same way that a new grammar and syntax developed around HDTV.

The differences in grammar and syntax between 3D-TV and HDTV are not negligible, since 3D-TV provides a greater viewer immersion, but does so by demanding near-continuous "exercise" of viewers' eye convergence muscles and brain image processing to fuse the left and right images of varying parallax (visual depth). Most believe that for avoidance of eye fatigue and related stresses (possible headache, eye strain, nausea, etc.), 3D programme creation will necessitate a careful avoidance of camera cuts that instantaneously force viewers to adapt to scenes with widely differing three-dimensional depths. Many report also that the pace in editing, panning, zooming, and changes in parallax apart will have a substantial impact on story-telling in the 3D realm. There are other complications, such as with captioning and subtitles, involving complex judgments regarding where to place captions in the Z-axis (in the screen plane, in front or behind, or perhaps correlated with characters appearing at different depths in the scene).

Other requirements may include the need to consider at the scripting, production planning and shooting stages, the intended viewing screen size (or subtended viewing angle) and perhaps the age of the intended audience (children and adults having differing inter-ocular distances that create differing perceptions of depth when viewing the same 3D material). Without special care in production, the latter may allow production of excessively large parallax conditions that may prevent image fusion by young and close-to-the-screen viewers, with resulting perceptions of double images. New rules for an appropriate rate of scene cuts, close-ups, wide shots, reverse shots etc. may even point to a possible requirement to have separate S3D and 2D versions of the programme if each is to be optimized, rather than compromised. Currently this "dual-shoot" problem appears to be one of the looming barriers to affordable and sustainable S3D production.

It should be noted that properly-produced 3D is more of a POV (Point of View) experience. Camera positions and shot composition to achieve an acceptable 3D effect are considerably different from those required for 2D.

In contrast, the Avatar (3D) film director ,James Cameron, was reported to have suggested the problems cited above may not be as onerous as some believe. In a report in Daily Variety, 12 April 2011,

it was reported that Cameron and 3D cinematographer, Vince Pace, have formed a new venture, Cameron-Pace, which will provide technical and creative products and solutions for 3D productions worldwide. The article states:

> ***"Cameron and Pace painted a very specific vision for the future of 3D broadcasting – a vision that differs from many earlier predictions. They see distinctions between 3D and 2D fast disappearing, with directors and technicians simply putting 3D cameras where they put 2D cameras, shooting more or less the way they do now and grabbing one eye from the 3D cameras for 2D telecasts. That would eliminate the need for a separate 3D production and telecast, "Otherwise the business model just doesn't make sense," Cameron said.***
>
> ***…"Cameron and Pace see the world shifting from having fewer than 100 3D rigs, to having thousands of such rigs, mostly for broadcasting." [emphasis added]***
>
> ***…"If you want to shoot everything with a long lens, we have the technology to make that good 3D," he said. "But if you want to embrace 3D and do something in and of the fabric of 3D, you will do it differently. But that's an opportunity, it's not a penalty."***
>
> **http://www.variety.com/article/VR1118035268**

If this Daily Variety article has reported Cameron's views accurately, they are intriguing, even if somewhat self-contradictory. Cameron first suggests that, for broadcasters at least, 3D cameras can be almost dropped in where a 2D camera might ordinarily be used. Then he acknowledges that this is ***essential*** to making the business model work, which raises the critical point that such a single-shoot approach should be proven workable. Later he suggests that a production "*in and of the fabric of 3D*" will be done "*differently*", raising questions as to whether he believes the drop-in 3D camera scenario involves 3D performance compromises that he did not elucidate. Certainly, the James Cameron / Vince Pace experience base is considerable, and their views are certain to be quite valuable, even if needing some clarification.

These apparent contradictions may reflect uncertainty that should remind ITU-R that they are still in the very early stages of the 3D-TV era. In the article, Cameron also stated, "*What are we [the industry], five years into this thing? We're the equivalent of the auto industry in 1903.*"

A good review of 3D programme quality issues is available in an April, 2011 paper entitled, "**Quality Assurance for 3D Television**" by Stefan Winkler and Jeremy Bennington of Cheetah Technologies, San Jose, CA. It is contained in the 2011 NAB Broadcast Engineering Proceedings, and may be available upon request to the authors via **www.cheetahtech.com**; it may also be available by contacting NAB at **www.nab.org**.

Another paper of interest presented at the 2011 NAB Conference is "**3D Intensity Adjustment of a Stereo Content to Improve Quality of Experience**" by six authors from Technicolor, France. It observes that control of 3D parallax/depth parameters can be difficult to achieve for live events. Also, efforts to keep parallax values in a comfortable range and a safe range for viewers can be disrupted when highlights are extracted from what may otherwise have been a carefully constructed 3D programme (consider sports game summaries and movie promotional trailers) and even by uncorrelated 3D advertisements inserted in programmes. The authors also propose a system for "intensity" control of parallax disparity discontinuities to increase 3D effect success, along with viewer comfort and satisfaction.

5. The performance required of 3D-TV production tools and consumer displays

Audiences that have come to appreciate HDTV resolution will expect S3D-TV programming to provide at least the same perception of picture quality.

The limitations of the current distribution and transmission technologies should not be taken into account when deciding the quality requirements for acquisition, post-production, *programme exchange* and, especially, archives.

There is some evidence that human 3D perception will allow the Left and Right images to be of lower resolution than would be required for an individual 2D programme (similar in concept to the use of 4:2:2 video sampling due to the lower human colour resolution perception). There is no evidence, however, to suggest this is true for long-term S3D viewing on larger and higher resolution displays. It must also be remembered that domestic viewing distances are not changing as screen sizes increase. A BBC R&D paper (WHP090 2004) suggests the average viewing distance is 2.7m!

Although in the early days it may be acceptable to use lower resolution L/R images, it is not safe to assume this will hold true in the long term. This means that archives must receive programme material that will allow later exploitation at higher resolution.

There is clear evidence to support this position in the transition from SD to HDTV.

Much has been made of the archives of certain international distribution companies who have benefited from the foresight of using 35mm film for television acquisition. Many hundreds of hours of archive made for SDTV with 4:3 aspect ratio have been successfully re-mastered to HDTV with 16:9 aspect ratio.

S3D-TV production at this nascent stage should be similarly treated:

- programmes should be acquired at the highest affordable resolution for both left and right eyes;
- programmes should be post-produced and processed at the highest viable resolution and quality;
- programmes should be archived in such a way that the original left and right images can be extracted and re-packaged to meet the requirements of future S3D distribution technologies.

The above suggestions are supported by the strong current trends to:

1) increase the resolution of camera sensors (over and above 1920 x 1080 native);
2) increase the storage and processing power of recording devices to allow less or even no compression during acquisition;
3) increase the processing capabilities of post-production processing tools;
4) Continue to use the current interchange format (Rec. ITU-R BT.709) until carriage or exchange of programmes in excess of 2k resolution may be required as standard.

6. 3D-TV service introduction in markets where HDTV has not yet reached saturation

There are questions of commercial viability that need to be addressed. Will television audiences be willing to purchase 3D-TV displays? What level of 3D content availability is needed to trigger mass adoption? Will broadcasters reap some benefits, or will they simply be forced to re-equip for the new 3D service expectation without recoupment? Will there be enough spectrum for the new 3D-TV service or will free-to-air broadcasters need to time-share 3D-TV with HDTV programming?

An example of the lack of HD saturation is available from Harris Interactive, the New York-based polling and market research firm, which published a study entitled "**The Future of Entertainment 2010**" in which they queried 2,013 online consumers in Great Britain aged 16+ in November, 2010. They found that only 48% owned an HD set. Of these, only 45% had watched HD content on their HD set. *See:* **http://bit.ly/mdHKko** *(Slide 15 in this PDF file)*.

BBC Technical Note 2028 September 2008 states that:

> ***"This rush to 3-D TV is likely to result in a number of incompatible formats and displays leading to at least one format war much like the recent Blu-ray/HD-DVD war. Indeed, as different display technologies will need different input signals (e.g. stereoscopy vs. 2-D plus depth-map) the market could potentially contain several fundamentally incompatible systems."***

Note that major display manufacturers are driving the sales of S3D displays by simply adding it as a feature to all displays over a certain value or size (or both). It appears that the 120 Hz (and higher) display capability that is the key component of a 3D-capable LCD TV receiver comes at a relatively small increment in manufacturing cost, which would account for the near ubiquitous appearance of "3D-ready" as a marketing feature. This will distort the meaning to be taken from reported 3D "take-up" figures in certain territories, especially where the analogue-to-digital switchover is currently underway, i.e. consumers using the switchover to buy new displays may get S3D by default, not because they have shown an actual interest in 3D-TV viewing.

Many displays only include one or two pairs of glasses, however, and a better measure of the real uptake of S3D ***services*** may well be the figures for the sale of additional or replacement glasses.

The consumer display market appears to be making two moves toward a standard for active glasses:

> ***Panasonic and XPAND 3D announced that they have formulated M-3DI, a new standard for 3D active-shutter eyewear products that will bring about compatibility among 3D TVs, computers, home projectors and cinema projection. Other leading 3D technology providers for televisions, projectors and cinemas have agreed to participate in supporting the new standard, including Changhong Electric Co., Ltd., FUNAI Electric Co., Ltd., Hisense Electric Co., Ltd., Hitachi Consumer Electronics Co., Ltd., Mitsubishi Electric Corporation, Seiko Epson Corporation, SIM2 Multi-media S.p.A. and ViewSonic Corporation.***

In addition, the US-based Consumer Electronics Association (CEA) announced on 8 March 2011 that its 3D Technologies Working Group was initiating a process to standardize an IR-based 3D display eyewear synchronization interface. The CEA has sought submissions of proposals for this standard via a Request for Proposal with a deadline of 31 March 2011.

(*See:* **http://www.ce.org/Press/CurrentNews/press_release_detail.asp?id=12067**)

The consumer market and manufacturers can be expected to lead and promote this market irrespective of the traditional broadcasters' ability to supply it with content. They may, if necessary, bypass broadcasters with other means of S3D distribution and content production.

According to the UK Royal Television Society Magazine, February 2011:

> ***"…Too many hardware and entertainment companies have committed to the new format to let mere public indifference to thwart their ambitions…"***

7. Limited US availability of 3D-TV services

In the United States, the consumer electronics industry's promotion of 3D-TV is in sharp contrast to the very limited availability of 3D-TV programming. Direct-to-Home satellite broadcaster DirecTV carries three 3D programme channels, some of which are carried on certain cable systems and one telecom carrier's multichannel distribution systems:

- ESPN 3D, launched on June 11, 2010, carried on DirecTV channel 106. This channel delivers sporting events. From launch, sporting events were carried when they occurred, on a less than full-time schedule, until ESPN 3D converted to a 24-hour schedule, 7 days a week, in February 2011. A part of the schedule now consists of previous 3D sporting events replayed when no new live events are being covered. This channel also is distributed in certain geographic areas

by a number of cable operators such as Comcast, Cox Communications, Cablevision and others. It is also carried by the US Verizon FiOS TV telco fibre-to-the-home system.

- n3D, "powered by Panasonic", launched on July 1, 2010, carried on DirecTV channel 103. This channel delivers sports, music, nature, arts and other programming.
- 3net, a joint venture of Discovery Communications, Sony and IMAX, launched on February 13, 2011, carried on DirecTV channel 107. This is a 24/7 3D channel with a variety of nature documentaries and some original 3D series.
- DirecTV also makes 3D-TV programmes, mainly feature films, available as scheduled pay-per-view events (on two channels), and on a video-on-demand basis for consumers with the appropriate DirecTV DVR (digital video recorder).

More details can be found at:

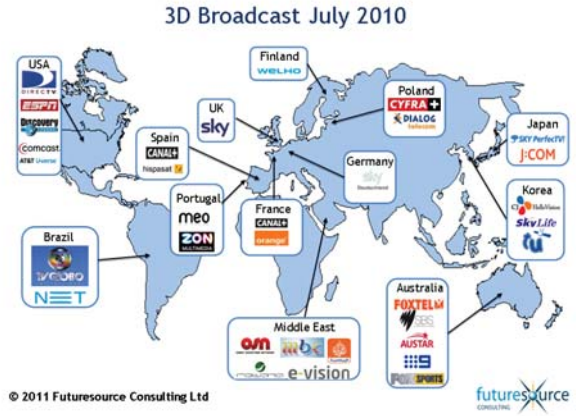
http://espn.go.com/3d/
http://www.directv.com/DTVAPP/content/hd/3d?footernavtype=-1
http://www.3net.com/

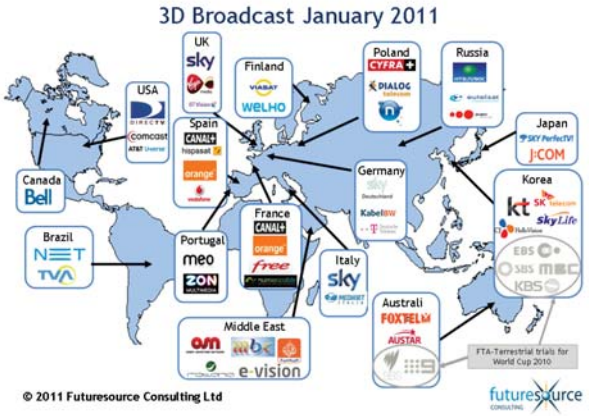
Beyond real-time 3D-TV networks, the remaining source of 3D-TV programming in the U.S. is via Blu-ray optical disks. The full catalogue of 3D feature film titles on Blu-ray is relatively small, and for many feature film titles, availability has been impaired by proprietary tie-ups between 3D-TV manufacturers and certain movie titles, which promote joint marketing of 3D-TV receivers and some top 3D cinema titles.

8. Limited European availability of 3D-TV services

The position in Europe is very similar to that of the United States. Again the consumer electronics industry's promotion of 3D-TV is in sharp contrast to the very limited availability of 3D-TV programming.

In the UK, BSkyB offer a single S3D mixed-genre channel via satellite (in contrast to 57 HDTV channels and over 500 SDTV channels).





The number of S3D channels in Europe is growing – however this is more likely a result of territorial rights and language issues than a rapid growth in locally generated or "bought in" S3D programming.

9. Alternative distribution platforms

The power and influence of IP delivery of S3D services must not be overlooked. The BBC's iPlayer product is now available on IP-enabled set-top boxes, televisions, Blu-ray players and gaming machines. These devices are commonly linked to the home's large screen displays which, over

time, will be S3D enabled. Choosing, in real time, to watch a programme in S3D via an HDTV's IP connection by simply pressing an "alternate content" button will make it far simpler for consumers to make a choice. It also allows broadcasters to invest in on-demand S3D programming via IP networks, instead of in dedicated channels, thus saving investment in scarce and expensive spectrum.

Here is a relevant quote from ipTVnews 14:04:2011: **Fujitsu throws hat into ring for UK fibre funds**:

> ***"Fujitsu has upped the ante for UK fibre proposals by forming a collaboration with Virgin Media, TalkTalk and Cisco to build a new super-fast fibre network capable of delivering Internet speeds of 1 Gbit/s and upwards to 5m homes in rural Britain."***

10. Basics of vision and health issues

The risk of eye fatigue, strain, headache, dizziness, and nausea is related in part to the fact that 3D-TV images are currently formed on a display screen which is at a fixed distance from the viewer, while depicting objects that appear through a range of depths in front of and behind the screen. These symptoms are due to a conflict between "accommodation" (eye focus) and "convergence" (horizontal rotation of the eyes). In real life, focus distance and eye convergence track one another according to vision skills acquired during the first few years of life. Plano-stereoscopic 3D-TV violates this normal mode of human seeing, because it forces lens focus to remain fixed while convergence varies. This may someday be solved if 3D images can be presented to viewers by forming them in free space rather than on a flat surface.

We perceive the three-dimensionality of the world through a number of visual mechanisms, and the visual system will weight the evidence from each of these mechanisms and present the depth information based on whichever mechanisms seem to be giving useful information. Only the mechanisms of stereopsis (human perception of depth) and vergence (convergence and divergence) involve the use of both eyes.

Where conflict arises between different depth cues, the brain will fall back on the most reliable cues, particularly occlusion (objects hidden by objects in "front" of them) and motion parallax (relative apparent speeds of moving objects yielding clues to their depth in the scene), which are just as reliable through one eye. These mechanisms can easily override stereopsis and vergence, but the conflict will increase the cognitive load and may lead to discomfort and even nausea. The human visual system does not see the world directly but builds up a hypothesis based on the available information and it is this hypothesis which is seen by the viewer. As a consequence our visual system can sometimes mislead us by correcting errors in a visual image, and in this way make it difficult to see problems in a poorly constructed stereoscopic image.

The pair of images needs to be rectilinear projections on a flat screen and the image planes of the cameras need to be parallel for good stereoscopic reproduction. Alternatively, if the cameras are converged, then the pairs of images will suffer opposing trapezoid distortion and image manipulation is applied to remove the image distortion. Shooting converged is unavoidable in the case of telephoto shots where a long lens is combined with a large inter-axial spacing to give an adequate stereoscopic effect (albeit at the cost of miniaturization – see below).

Alignment of the two images is crucial for comfortable viewing. Whilst some static horizontal misalignment may be tolerable, vertical or rotational misalignment of the two images or alignment instability will cause immediate eye-strain and result in headaches and nausea if viewed for any length of time. Such misalignments are difficult to diagnose when viewing in stereo as the brain tries to compensate for the problems, so any stereoscopic image should be viewed without glasses when setting up a projection system or aligning the two images in post-production.

Whilst divergence is directly related to screen size, the divergence angle for a displayed 3D programme can be reduced by increasing the viewing distance, but not eliminated, of course. (This is

one good reason for sitting near the back of the cinema in a live action 3D presentation. Sitting at the back of cinema also enhances the depth effect whilst minimizing the focus/vergence conflict.)

A fascinating bit of evidence, demonstarting at least one 3D-TV manufacturers' concerns about the possible vision and health effects of 3D-TV viewing, is given here at the US customer support web site of Samsung: **http://bit.ly/mSTXoc** *(a shortened URL)*

11. International programme exchange for 3D-TV programmes

For this report, the Rapporteurs have not yet been able to conduct a survey of existing worldwide industry concerns regarding international exchange of 3D programmes. There seems no reason to expect any particular difficulties in this regard, as long as the image format for Left and Right eyes complies with Recommendation ITU-R BT.709 and any necessary 3D-specific metadata is incorporated with the programme tapes or files. Treatment of this topic may be dealt with in a future update of this report, to also include a report on 3D programme file formats that may be under development by organizations such as the SMPTE, EBU, ETSI, ARIB and others.

12. Conclusions

Taking into account the importance attached to international programme exchange standards within the ITU-R, the Rapporteurs intend, in future Reports, to consider the potential of the various 3D-TV

Andy Quested was a much sought-after editor with BBC Resources for many years, working on programmes as diverse as *The Human Body* and *Keeping Up Appearances* but, in 2000, he gave up the life of a hermit editor and moved into the sunshine and bright lights of BBC Future Media and Technology.

As Head of Technology for BBC HD and 3D, Mr Quested has been involved with all aspects of the BBC's high-definition services where his key role is responsibility for the BBC's high-definition technical standards and programme quality control. This responsibility extends to all the BBC's platforms capable of delivering HD and, working with BBC Worldwide, the standards for international programme exchange.

Part of Andy Quested's role is to promote the BBC's high definition and 3D position with the international standards bodies and other broadcasters in order to maintain the quality and scope of the BBC's programmes. This has involved challenging organizations and manufacturers to produce products and broadcast equipment that not only meets high technical standards but is affordable to commercial and public service broadcasters alike.

Barry Zegel has been with CBS for over 30 years. He spent 15 years working at the CBS Broadcast Center in New York where he managed various departments in Engineering, Operations and Technology Development.

In 1992, Mr Zegel managed the International Broadcast Center operation in France for CBS's coverage of the 1992 Winter Olympic Games. He was then promoted to Director of Olympic Operations for the 1994 Winter Olympic Games in Lillehammer, Norway were he was in charge of the entire Olympic operation. He and his team are credited with various innovations to improve Olympic sports coverage including rail-cam, helmet-cam, and speed activated "coming and going-cam for the downhill". He has received two Emmy awards for his work in Olympic Sports coverage.

Barry Zegel is currently Vice President and General Manager, CBS Television City in Hollywood. This includes overall responsibility for Television City and technical responsibility for CBS Studio Center.

production systems presently in use, as well as those systems and techniques being innovated now and expected in the coming years.

The early and to some extent "experimental" 3D-TV programmes produced until now have mainly used a number of early innovations in 3D camera rigs and controls that adapt and involve the support of many pieces of production and post-production equipment originally designed for 2DTV production. As would be expected, this has often resulted in tools and solutions that, while representing progress and producing interesting and usable results in the near-term, are acknowledged to be less than optimal, and known to fall short of the performance desired of true long-term solutions for high quality 3D programme production and international exchange. One need only observe the pace of introduction of new products by equipment vendors and developments by international standards organizations to realize that ITU-R Working Party 6C must take care not to assume that current, early practices should be recommended by ITU-R as if they represent fully evolved systems.

Further, it can be observed that a very large segment of the world's television viewers are just now becoming introduced to and satisfied by the quality level of 2D HDTV broadcasting services, and yet, in some countries, these same consumers are already being asked to comprehend, assimilate and demonstrate commercial demand for 3D-TV services and "3D-capable" consumer displays. Further, there is currently quite often a lack of clarity that 3D services and 3D Blu-ray disks are quite few in number, even though 3D consumer TV receivers are offered for sale. The natural tension caused by this rapid but incomplete 3D-TV follow-on to HDTV service introduction presents good cause for circumspection by WP 6C and ITU-R as it considers 3D-TV recommendations.

Given the current interest in an emergence of viable techniques and technology that are expected to make possible 3D television production, distribution and international programme exchange, the Rapporteurs, as their first advice to their parent Groups, recommend that Working Party 6C and Study Group 6:

- Should concentrate its efforts and resources on ensuring compliance with the existing HD interchange standard (Recommendation ITU-R BT.709) in order that twin 1920 x 1080 50/60p images can be carried;
- Should look further forward than the current iterations of S3D and investigate a final, full-quality 3D-TV standard, based on the use of 3D-TV consumer displays that do not require glasses;
- Should not focus on "intermediate" standards for the sake of interim compatibility with current consumer equipment;
- Should encourage research on how the ultimate 3D-TV experience (without glasses) can become a reality that will engage the public, and on the performance required of 3D-TV consumer displays that are capable of providing that experience;
- Should note the preliminary results of experimentation with higher frame-rate production for 3D cinema [1] and SD and HD television [2] in general, and if deemed relevant, investigate possible recommendations for delivery and international exchange of high frame-rate HD and 3D-TV. ***Display rates*** will vary as implemented by 3D-TV consumer manufacturers' technology and design, they will provide marketplace choice, and need not be standardized;
- Should continue to interact with representatives of the World Health Organization (WHO) to secure clear and concise information to broadcasters to dispel the myths and rumours associated with consumer S3D, and to provide correct guidelines as to the vision comfort and health associated with consumer viewing of 3D-TV services;
- Should research and recommend techniques for assessing the quality of S3D images in production, post-production and transmission and display – so that a common, high-quality standard can be achieved and maintained.

1. See: **http://www.hollywoodreporter.com/news/james-cameron-fully-intends-make-172916**.
2. See: **http://downloads.bbc.co.uk/rd/pubs/whp/whp-pdf-files/WHP169.pdf**.

3D technology is a rapidly evolving field and investigations should continue in this area. If required, the Rapporteurs are prepared to provide an update on this topic as developments warrant.

For the convenience of readers, the attachment to the present report lists and explains some 3D-TV terms used in this report and in the 3D-TV literature.

Appendix: Glossary of some 3D terms

Accommodation	Focusing of an observed point
Angulation / Convergence	Resulting angle spanned between the optical axes of the two cameras
Autostereoscopic	Display that allows three-dimensional viewing by direct observation, without glasses
Binocular	With both eyes
Convergence	To pivot both optical axes to an observed object
Depth cues	Information about the depth of a scene; there are monocular depth cues like perspective, and binocular depth cues like stereopsis
Deviation	Parallactic displacement of corresponding points on two 3D-exposures (left and right images)
Disparity	Distance of two corresponding points on the retina
Far point	The farthest point from the nodal point of the camera
Fovea Centralis	Area of the sharpest vision on the retina
Horopter	Set of points for which the light falls on corresponding areas in the two retinas
Interaxial (distance) / Stereo base	Distance of the centre-points of the two camera lenses
Interocular distance	Distance of the centre-points of the eyes
Monocular	With one eye
Motion parallax	Change of angular position of two stationary points relative to each other as seen by an observer, caused by the motion of an observer
Near point	The nearest point from the nodal point of the camera
Nodal point	Point about which a lens is rotated where close and distant subjects focused on the film plane maintain their relative positions to one another
Panum's fusional area	Region of binocular single vision
Parallax	Change of angular position of two stationary points relative to each other as seen by an observer. If there is no parallax between two objects then they occupy the same position.
Pseudoscopy	Inversion of the spatial impression
Plane of screen	Image plane mapped directly on the surface of the screen
Screen parallax	Distance of two corresponding points on the screen surface
Stereopsis	Ability to make fine depth discriminations from parallax provided by the two eye's different positions on the head

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Editeur Responsable: Lieven Vermaele

Editor: Mike Meyer

E-mail: tech@ebu.ch

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