WHITE BOOK
Beyond HD

Working Group “Devices and Connectivity”
of the German TV Platform
CONTENTS

1. The Status Quo of HDTV and 3DTV in Germany
   1.1 HDTV
   1.2 3DTV
   1.3 HDTV and 3DTV Programming
   1.4 Consumer Hardware
       1.4.1 Video
       1.4.2 Audio Surround Systems

2. Technological Developments
   2.1 HDTV in 1080p
   2.2 3DTV
       2.2.1 Frame-Compatible Broadcast (Phase 1)
       2.2.2 Service-Compatible Broadcast (Phase 2)
       2.2.3 Frame-Compatible Broadcast HEVC (Phase 3)
       2.2.4 Autostereoscopic Displays
   2.3 Audio
   2.4 Ultra HD
       2.4.1 Implications for HDTV and 3DTV

3. Ultra HD – from Production to Reception
   3.1 Content for Ultra HD
       3.1.1 Scanning Existing Content for Ultra HD
       3.1.2 Motion Picture Production for Ultra HD
       3.1.3 Live-Broadcast Production for Ultra HD
   3.2 Post-Production for Ultra HD
   3.3 Broadcast of Ultra HD
       3.3.1 H.264/AVC
       3.3.2 H.265/HEVC
   3.4 Receivers for Ultra HD
   3.5 Displays for Ultra HD
   3.6 Introduction of Ultra HD in Germany

4. Glossary

5. Appendices

Imprint Publisher, Editorial Staff, Authors, Disclaimer, Contact, About Us
It is hard to ignore how high-definition television (HDTV) has been taking Germany by storm since 2005: Following in the footsteps of ProSiebenSat.1 and Premiere (now Sky Deutschland), more HD options were offered by commercial broadcasters via the HD+ platform, starting in late 2009, and finally, ARD and ZDF began to augment their public-service bouquet with high-definition channels in early 2010. Today, HDTV is considered “state of the art,” and the average German household is equipped to receive 75 HD programs and more, depending on the type of reception. At the same time, the number of HDTV devices has, of course, increased steadily: 58 million high definition television sets have been sold by the end of 2013 (GfK retail & technology GmbH). HDTV is available via satellite, cable, and IPTV; only digital terrestrial broadcast (DVB-T) does not (yet) offer high-definition programming.

From the outset, the German TV Platform – established in 1991 as “National HDTV Platform Germany” – has been concerned with this development. Numerous working groups have supported the evolution and introduction of HDTV in Germany by informing and enlightening consumers, publishing a wide variety of documents for the industry, hosting events, producing Web specials, and introducing an interactive tool for consumers. It has been a long journey for the German TV Platform, but certainly worthwhile: HDTV has become a mainstream feature in Germany’s TV households.

In the meantime, new developments have built on this foundation, such as, for example, so-called “three-dimensional” (stereoscopic) television (3DTV), which was introduced in late 2010, but has yet to match the success of “3D” in movie theaters. One of the main reasons for consumers’ reluctance to embrace this technology may be the necessity to wear special 3D glasses in the home environment. While virtually every modern HD display supports 3D and the market penetration of 3D-capable consumer devices is steadily rising, less than one pair of 3D glasses is sold with every TV set. For this reason, the industry is not only working intensely on “no-glasses” 3DTV screens – so-called autostereoscopic displays – but also on merging 2D and 3D programming. A decrease of 3D programming on a global scale can hardly be denied, even though in Germany, the quantity has remained relatively stable – though small – since the launch of Sky 3D in October 2010. There is reason to hope, however, that the next big step after HDTV – Ultra HD – will also boost the acceptance of 3DTV.
Since 2012, all major manufacturers have either announced the release of Ultra HD displays or even presented early models. At two of the leading trade fairs, CES and NAB, which were held in Las Vegas in early 2013, Ultra HD was the dominant topic, and with IFA 2013 in Berlin, it has now reached German consumers as well. However, Ultra HD with a pixel resolution of 3,840 x 2,160 – four times the resolution of Full HD – is only a first stage, as Japanese broadcaster NHK has been working for several years now on a system with 7,680 pixels x 4,320 pixels, or sixteen times the resolution of Full HD, known in Japan as "Super Hi-Vision." By now, both formats have been approved by the International Telecommunication Union (ITU) as UHD-1 (3,840 x 2,160) and UHD-2 (7,680 x 4,320), respectively.

The German TV Platform started dealing with the subject of Ultra HD as early as 2012 in a project group (PG), “Further Development of HD and 3D” (PG HD3D), headed by Stephan Heimbecher (Sky Deutschland).

This PG reports directly to the “Devices and Connectivity” working group (WG), led by Dr. Helmut Stein (ISDM). Although the PG currently focuses primarily on Ultra HD, it also deals with other aspects of the future development of HDTV and especially 3DTV. To realize the scope and variety of this subject matter, it suffices to take a look at this White Book, which attempts to give a realistic assessment of the current state of HDTV and 3DTV and, at the same time, point out prospects, such as Ultra HD. For future program dissemination, the new H.265/HEVC compression format is likely to play a key role. Furthermore, the White Book tries to look at all aspects that may be relevant to the eventual introduction of Ultra HD in Germany.

Dr. Helmut Stein (ISDM),
Head of the Working Group and Member of the Board of the German TV Platform

Stephan Heimbecher (Sky Deutschland),
Project Manager HD3D for the German TV Platform
Preface

What is ‘Beyond HD’?

Our sense of involvement in a television program increases with the realness of the images. We judge an image to be good quality or not depending on what we normally see – once we have seen higher quality our expectations rise. Human beings educate themselves to quality.

So we must continue to develop the tools to create ever more real images. Television program makers will then have greater creative choices. Viewers will gain more from the television experience.

This volume explains the implementation of television systems ‘beyond HD’ with a range of quality factor and efficiency improvements, including binocular disparity.

Television quality has evolved over the past decades. Important milestones were set down by German scientists and engineers with PAL and PAL plus. HDTV has made its mark. But there is to be no rest. The further rise of image quality is inevitable.

We are fortunate to have a worldwide alliance of organizations in the DVB Project. We join together on digital broadcast formats, sharing ideas and knowledge. It is the most successful forum of its kind in the world. The Deutsche TV-Plattform is an outstanding national platform, and the DVB Project is fortunate to work with you and your members. It is an honor to offer a foreword to this very important step in broadcasting. This book will go well beyond Germany. It is full of exciting technical developments, and represents the future of television technology. After reading it you will wonder if television can ever evolve even further. For the answer to that, remember the wise phrase of Werner von Braun “I’ve learned to use the word ‘impossible’ with the greatest caution”.

Dr David Wood
Chair DVB CM-3DTV & CM-UHDTV
1. The Status Quo of HDTV and 3DTV in Germany

Following the replacement of analog television by standard-definition digital television (SDTV), the next step into TV’s future has been underway since 2005: High-definition television (HDTV) offers crisp, sharp images on large flat display panels, plus surround audio. It has since slowly found its way into German homes and has now become standard — both in terms of programming and market penetration — for most television distribution systems: satellite, cable, and DSL (IPTV).

3D TV was introduced in Germany in 2010, and suitable television sets are fed sportscasts as well as feature films, concerts, and documentaries on dedicated channels. 3D TV is currently being offered via satellite as DVB-S2, via DSL as IPTV, and in some locations also via cable.

The entire development has been actively supported from the outset by the German TV Platform, where special working groups aim to facilitate the exchange of information between all players in the industry and to provide information to consumers. To this end, experts of the German TV Platform have published a brochure entitled “Wissenswertes über HDTV” (“What You Should Know about HDTV”), designed an interactive tool called “Wege zu HDTV” (“How to Get HDTV”), and, in co-operation with partners, developed shopping guides for HDTV, 3D devices, and home theaters. Anyone who is interested will find all this information concentrated in one place, either in the HDTV Web special or under “Publications” → “HDTV, 3D & UHD” on the German TV Platform’s Website (www.tv-plattform.de).
Milestones

Development digital TV-standards, German market and German TV Platform

2003/4 2005 2006 2007 2008

- Creation of Working Group (WG) HDTV & Picture Quality Improvement
- Launch Premiere HD
- Launch Anixe HD
- Launch Discovery HD
- Launch arte HD
- ARD/ZDF Roadmap for HDTV introduction
- Introduction of DVB-S2
- Introduction of DVB IPTV
- Introduction of DVB-T2
- Launch IPTV offer by Deutsche Telekom
- First HDTV Showcase ARD (EinsFestival)
1.1 HDTV

In its initial phase, the development of the HDTV market in Germany suffered from the “chicken-and-egg dilemma”: While device manufacturers were offering an increasing number of HD-capable sets, program providers were hesitant to come up with suitable channels and programming. By the end of 2013, 58 million HDTV displays were sold, many of those with an integrated HD-tuner. In addition, a large amount of HDTV set-top boxes and Blu-ray players penetrated the market (for details, cf. chapter 1.4). As far as distribution systems are concerned, satellite has become the trailblazer: Astra and Eutelsat in particular are offering an increasing number of HD channels and programs. But the amount of HDTV programming offered via cable and IPTV is also steadily on the rise.

The overall variety of HDTV programming is growing in a very dynamic fashion: While there were but four HDTV channels in Germany up until May 2009, there are now about 120 (cf. chapter 1.3). The most comprehensive packages are Entertain by Deutsche Telekom (IPTV) and the Sky (formerly Premiere) pay-TV platform. The range of special-interest channels covers everything from sports to recent movies to documentaries on nature, history, science, and technology. Among unscrambled channels, the pioneer broadcaster was Anixe HD.

Following ARD’s “showcase” broadcasts on one of their digital channels, public broadcasters ARD and ZDF started regular operation of their respective nationwide HD channels with the Winter Olympics in February 2010. Just a few months earlier, arte HD had been launched. Step by step, nearly all of ARD’s channels (regional channels, ARD’s three digital channels, and specialized channels such as 3sat, KiKA, and Phoenix) have been converted to HDTV, which saw a boost when analog broadcasting via satellite was discontinued on 30 April 2012.

Among commercial broadcasters, the ProSieben and Sat.1 channels already started HD broadcasting between October 2005 and February 2008, and since January 2010, these two channels plus additional channels from the same broadcast group can be received in high definition via the HD+ satellite broadcast platform. Since the launch of HD+ in November 2009, the RTL Deutschland media group also uses this platform provided by the Astra satellite operator to broadcast its RTL and Vox channels in HD, and further channels have been added in the meantime.

Two HDTV formats are currently used in Germany: 720p and 1080i. On the production side, an increasing number of providers is trying to produce programs in HD from end to end across the entire production chain and to cut the share of upscaled SD material in favor of native HD programs. At the same time, the share of 5.1 surround audio programs (cf. chapter 1.4.2) among HD productions is also growing, and in the meantime, high definition has even reached smartphones and tablet computers.
1.2 3DTV

So-called “three-dimensional” television (3DTV) is a logical next step in the development of HDTV on all levels of usage: in live broadcasting, for video on demand (VOD), from storage media such as the Blu-ray Disc, for game-console software (e.g. Xbox, PlayStation), for Smart-TV portals and for user-generated content via 3D-capable camcorders.

As early as 2009 and 2010, satellite operators Eutelsat and Astra, respectively, started to run demo channels for 3D broadcasts. Sky Deutschland began regular 3D broadcasting in the fall of 2010 with the launch of a dedicated 3D channel.

For 3D broadcasts, the system of choice is usually the “side-by-side” (SbS) format (cf. chapter 2.2), in which both stereoscopic component images for the left (L) and right (R) eye are arranged side by side in a compressed form. This method allows the dimensions of the broadcast channel in satellite and cable transmission to remain unchanged, although it leads to a loss in quality, since the horizontal resolution is compromised.

3D (stereoscopic) viewing requires the viewer to wear either (active) shutter glasses or (passive) polarized glasses. On smartphones and other portable devices with a relatively small display size, glasses-free (or “no-glasses”) viewing is also possible. The use of shutter glasses requires a synchronization between display and glasses, which is usually achieved via infrared (IR) transmission.

For 3D content, a distinction has to be made between original broadcasts, content stored on Blu-ray Disc (BD), and user-generated content. The amount of 3DTV programs offered via satellite, cable, and DSL (IPTV) on dedicated channels is currently quite limited. Users can only choose between a small number of available 3DTV channels. The range of 3DTV content available on demand in media libraries is similarly limited.

However, the situation is much better for Blu-ray Discs. A large number of 3D motion pictures is available, and their number is rising. Due to the large storage capacity of the Blu-ray Disc, the HD quality of the content is preserved in full, since no compression is required for recording or playback.

Apart from features produced in 3D, there are also converted 3D versions of original 2D content. The depth information required for this process is generated in a computer-assisted image analysis, and the quality of the result thus depends largely on the quality of the software employed and of the studio performing the conversion. Even though the resulting product is not genuine 3DTV, high-quality conversions are hard to tell from native 3D content.

User-generated 3D content is often uploaded on YouTube. There is no reliable information on the quantity of this type of content, but it is certainly growing. User-acceptance of 3DTV is still quite low. This situation may be remedied by more “genuine” 3D content, better video quality, and more targeted marketing efforts.
1.3 HDTV and 3DTV Programming

Especially with regard to HDTV programming, the rapid development is quite obvious: While only 48 channels were available in early 2012, the number of channels broadcast via satellite, cable, and IPTV has grown to 120 by early 2014, only two years later. Although no HDTV is currently offered via DVB-T, a distribution of HDTV programming is planned to go along with the introduction of DVB-T2 in Germany, planned for 2017.

Starting in early 2010, Germany’s public broadcasters gradually switched the majority of their channels to HDTV, and all of them are being broadcast free and unscrambled. The simulcast of SDTV and HDTV by ARD and ZDF will be terminated in 2019, at the latest, since the public broadcasters’ budgeting committee (Kommission zur Ermittlung des Finanzbedarfs der Rundfunkanstalten, KEF) has announced that they will not provide any SDTV funding beyond that point. In a long-term outlook, it is thus expected that the transition from SDTV to HDTV in Germany will be completed by 2020.

Commercial broadcasters, on the other hand, are clearly banking on scrambling their HDTV channels and levying so-called “service charges” for their distribution and descrambling. This system was pioneered by Astra’s satellite-based HD+ platform, but in the meantime, commercial HDTV channels are also being offered in subscription packages by cable operators. Overall, HDTV can be considered a mass-market and mainstream phenomenon in Germany by now.

To reach this status, 3DTV in Germany, on the other hand, still has quite a distance to go. There is a wide divergence between the large number of 3D-capable user devices (many HDTV displays feature built-in 3D capability) and the small amount of 3DTV programming available. Sky has been operating a 3DTV “event channel” since 2010 and has been broadcasting Bundesliga soccer live in 3D since the 2010/2011 season (currently one top game per month). Deutsche Telekom’s IPTV-based Entertain platform is offering one 3D channel with various documentaries and events as well as over 200 3D titles for video on demand (VOD). In May 2010, the opening game of the Ice Hockey World Championships was the first live 3D telecast via IPTV. Some 3D apps can be found in the Smart TV portals of various hardware manufacturers, enabling users to access games or video and music clips and trailers in 3D.

On a worldwide scale, the 2012 Summer Olympics in London kicked off an unprecedented array of multimedia programming. In addition to HbbTV and Red Button, apps and second screen, Web TV and social TV, HDTV and 3DTV played a major role among the technological highlights. All Olympic events were offered simultaneously in standard-definition digital TV (SDTV) and high-definition TV (HDTV) by the Olympic Broadcasting Services (OBS). In cooperation with host broadcaster BBC, 24 SDTV channels and 24 HDTV channels were broadcast via the transponders of the Astra and Eutelsat satellites. On top of this, nearly 300 hours of 3DTV were broadcast, produced in conjunction with Panasonic, official partner of the 2012 Olympic Summer Games. 3DTV broadcasts of a dozen different sports were aired by various broadcasters, including Eurosport, 3D, BBC HD, BSkyB, and NBC. In Germany, Olympic 3DTV was, unfortunately, only available to a limited audience through special Panasonic outlets.

The Olympic Summer Games of 2012 also saw the very first test broadcasts in Super Hi-Vision (UHD-2). Images with sixteen times the resolution of HDTV were screened for the public in three London locations (Hyde Park, Victoria Park, and Trafalgar Square). 3DTV and Ultra HD telecasts are also scheduled for the 2014 Olympic Winter Games in Sochi and for the 2014 FIFA World Cup (men’s soccer) in Brazil.
1.4 Consumer Hardware

1.4.1 Video

Three words can summarize the trend in TV displays over the past decade: flatter, larger, sharper. In addition to growing in screen diagonal, the displays of sets found in people’s homes have shown vast improvements in picture sharpness. The growing tendency to interconnect various multimedia devices – such as Smart TVs, tablet computers, and smartphones – is also bound to gain traction over the next few years.

Flat-Panel TVs

The first flat screens entered the German market in 1997. They were plasma display panels (PDPs) with standard resolution. Only about 1,000 were sold in the first year, but over the next few years, their market share grew exponentially, and in 2004, more than 400,000 LCD TVs and approximately 100,000 plasma TV were sold.

2005 can be considered the breakthrough year of flat-panel TV sets. With 1.2 million LCD sets and about 300,000 plasma sets sold in Germany, mass-market status had been attained by then.

In the years between 2006 and 2010, flat-screen TVs gradually replaced cathode-ray-tube (CRT) TV sets. As early as 2006, more flat-panel sets than CRT sets were sold. In 2009, the sale of CRT TVs had dropped to a mere 150,000, and the following year, sales dipped again sharply to a mere 34,000 sets. Since 2011, CRT-TV sales are no longer recorded by the Consumer Electronics Market IndeX (CEMIX), a joint project of gfu (Gesellschaft für Unterhaltungs- und Kommunikationselektronik), BVT (Bundesverband Technik des Einzelhandels), and GfK R&T (Gesellschaft für Konsumforschung Retail and Technology). As already in 2012, LCD TVs were the best-selling product category in 2013 with 7.6 million of 7.8 million TV sets according to the CEMIX (Germany).

Even at the time of the breakthrough, the share of PDP-based TVs was significantly smaller than that of LCD-based TVs, but over time, they have carved out and secured a niche existence with a market share of about ten percent of LCD-TV sales.

As a new technology, OLED displays may soon take hold. OLEDs (Organic LEDs) are light-emitting diodes (LEDs) which contain organic semiconductors. These novel displays light up each pixel with an LED, without use of a backlight, and are thus able to generate images of outstanding brilliance, high contrast, and sharply contoured motion. At IFA 2013 in Berlin, all major manufacturers presented OLED panels with screen diagonals in excess of 140 centimeters (55”) – some as prototypes, others in TV sets already for sale.

The latest product innovation is a slightly concave OLED display that creates a more immersive illusion of spatial depth. Technologically, the curvature is possible because OLED displays consist of flexible materials. It is therefore conceivable that such displays may even be rolled up or folded for mobile applications.

And while displays became flatter, their aspect ratio also changed. The traditional 4:3 aspect ratio was replaced by the 16:9 widescreen format in broadcast television between 2005 and 2008, virtually in sync with the switch from CRT TVs to flat-screen TVs, which were produced in the widescreen format from the outset. Nowadays, there is even a growing number of 21:9 displays on the market, which further mimic a cinematic experience for viewers.
HDTV
With the introduction of HDTV, the image quality of television screens made a quantum leap forward. In early 2005, the European Information, Communications and Consumer Electronics Technology Industry Association (EICTA) created the “HD ready” label to tag TV sets capable of processing HDTV signals. In Germany, the sales of “HD ready” sets jumped from 2.1 million in 2006 and 5.9 million in 2008 to more than 7.7 million in 2009. From 2010 on, nearly every TV set sold was “HD ready.”

Initially, sales of the devices required for the reception and display of HDTV were sluggish. By the end of 2008, only slightly more than a million HDTV receivers had been sold in Germany, compared to nearly twelve million HD-capable TV sets. In 2009, the first flat-panel TVs with integrated HDTV tuners were marketed (3.7 million), and in 2010, their sales skyrocketed to more than eight million. At the same time, the sales of HDTV satellite receivers (2.3 million) grew, and HDTV cable and IPTV receivers were introduced (half a million each). Since 2011, a vast majority of flat-screen TVs features built-in HDTV tuners.

By now, HDTV has become a standard feature: almost all flat-panel TVs sold in 2013 were high resolution displays and over 90 percent were equipped with an integrated HDTV-receiver. Altogether, 58 million HDTV displays were sold in Germany by the end of 2013, 33.7 million of which were equipped with an integrated HD-receiver. In addition, 15.4 million HDTV-receiver were sold by end of 2013. Therefore, between 2004 and 2013 more than 49 million HDTV-receiving devices were delivered to the German households.

Display Sizes
As another trend, the average display size has changed significantly over the past few years. While the majority of consumers bought TV sets with a screen diagonal of 80 to 90 centimeters (31”-36”) up until 2010, the best-selling displays from 2010 on featured a diagonal of more than 90 centimeters, and the trend towards larger screens continues: More than half of the 9.6 million TV sets sold in 2012 had display sizes larger than 94 centimeters (37”). The fastest-growing segment was that of sizes 106 centimeters (42”) and up, with a market share of nearly twenty percent. According to a ZVEI forecast, this segment is bound to continue its dynamic growth in 2014. At CES 2014, LCDs with a diagonal of up 305 centimeters (120”) were presented, and display sizes are thus entering a whole new dimension.

iDTV
Integrating digital technology into TV sets marks another step in the development. The consumer electronics industry started around 2004 to furnish their flat-panel TVs with digital tuners, which also became HD-capable from 2008 on. Initially, only DVB-T receivers were built into the sets, but later, DVB-C and DVB-S/S2 tuners were added for receiving and decoding digital cable and satellite broadcasts.

In 2012, according to GfK, 99 percent of all flat-panel TVs were equipped with a DVB-T tuner, 93 percent with an additional DVB-C tuner, and 56 percent with an additional DVB-S tuner, and the share of TV sets with triple tuners is growing steadily. With these integrated devices, there is no need for viewers to purchase stand-alone receiver units for watching digital television. Thanks to the CI Plus interface, it is also possible to watch scrambled TV programs via integrated digital receivers by simply inserting a chip card supplied by the platform provider.
Smart TV

Another step in making TVs “smarter” is embodied by the latest generation of devices offered by the consumer electronics industry: “Smart TVs” merge broadcast and Internet services and enable consumers to install apps on their TVs, allowing them to consume media on a large display whenever they want. According to CEMIX, the fusion of television and Internet is a strong trend on the TV market. Already 59 percent (4.7 million) of the TVs sold in Germany during 2013 were capable of displaying Web-based content (2012: 4.8 million, 2011: 3.4 million).

3DTV

In the fall of 2010, the range of available television types was expanded further by the introduction of 3D sets, and with 200,000 units sold that same year, the technology immediately took off like a rocket. In 2011, as many as 1.7 million 3D-capable TV sets were sold, and in 2012, the number had nearly doubled to 3.2 million, including the first models that allowed watching 3D images without the need for special glasses. By the end of 2013, almost 3 million 3D-TVs were sold in Germany, meaning around 7.9 million 3D-capable television sets penetrated the German households. Moreover, 3 million 3D Blu-ray player and one million 3D home cinema systems were sold.

Smartphones and Tablet Computers

Simultaneously, smartphones tend to feature ever larger displays and Full HD resolution (1,920 pixels x 1,080 pixels). With Full HD displays and 13-centimeter (5”) diagonals, the size of smartphone displays is approaching that of small tablet computers. The cameras integrated into these smartphones and tablet computers are capable of capturing images and video sequences in high definition as well, and early cell phones have shown up that are capable of capturing and displaying 3D images and video, viewable without special glasses.

1.4.2 Audio Surround Systems

Just as SDTV, HDTV also offers 5.1 surround sound, in addition to stereophonic sound, for audio playback.

The 5.1 surround process makes use of five discrete audio channels: a left and right stereo signal, a center signal, and two surround signals in the rear of the room. These are complemented by a low-frequency effect (LFE) signal for frequencies up to approximately 200 Hz (subwoofer), resulting in the “5.1” channel configuration for surround sound.

Ideally, audio would be played back in exactly the same channel configuration in which it was recorded. In reality, however, there are both more elaborate home-theater setups with more speakers (including subwoofers) – up to a configuration of 13.2 – and smaller systems without rear speakers – as 2.1 and 3.1 configurations, with so-called sound bars – on the market.

The audio processing within the receiver or home-theater system should adapt the broadcast signal to the actual conditions in the playback environment. Should the channel configuration of the program differ from the situation
in which it is played, the signal must either be downmixed or upmixed. For a downmix, the number of channels received is reduced by remixing the signal to match a smaller number of available speakers. For an upmix, on the other hand, the number of channels received is expanded by processing the signal accordingly to match a larger number of speakers.

Various audio encoding formats are employed in broadcasting. In addition to the Dolby Digital format currently used in Germany, MPEG-4 HE-AAC and Dolby Digital Plus are used in other countries. However, the OTT services Maxdome (ProSiebenSat.1) and Videoload (Deutsche Telekom) as well as the IPTV platform Entertain (Deutsche Telekom) also use Dolby Digital Plus in Germany. For smartphones and tablet computers with video capability, special apps are available for reproducing surround sound.

5.1 audio surround system

1 Seating Position
2 Left and Right Speakers
3 Center Speaker
4 Left and Right Speaker Angle
5 Subwoofer (the "1")
6 Left and Right Surround Speakers
2. Technological Developments

So far, German broadcasters supply HDTV signals in the 720p50 and 1080i25 scanning formats, and the receivers in use today do not support progressive Full HD signals beyond 30 fps (frames per second). New compression technologies, such as HEVC (H.265, cf. chapter 3.3.2), however, will facilitate a progression towards Full HD in 1080p50, especially since the new codec no longer supports interlacing, an obsolete process once necessitated by the limitations of analog television technology.

To be able to also offer 3D TV within the conventional infrastructure at hand, a so-called “frame-compatible” broadcast method was agreed upon. As described in chapter 1.2, most of the time, a “side-by-side” (SbS) mode with 1,080 lines is used. In this respect, the new codec technologies are also helpful in eventually transitioning to a Full HD resolution of both component images (cf. chapter 3.3).

2.1 HDTV in 1080p

With the introduction of HDTV (1080i25 and 720p50), many areas on the production side (studios, control rooms, infrastructure, and other equipment) were updated and modernized. Much of the equipment is already 1080p50-capable or merely requires a software upgrade to become so. Issues might arise in infrastructure, as the SDI cabling also has to meet higher standards for 1080p50, but most broadcasters have already adapted (3G SDI).

1080p50-compatible codecs are already available in the production chain, and newer H.264 production codecs allow a high-quality production chain even at a data rate of 50 Mbit/s. For broadcast, 1080p50 was standardized as early as 2009. However, no implementations or decoders built into consumer devices are currently known, even though various decoder chipsets have been available for quite a while. Flat-panel displays labeled “HD ready 1080p” are capable of displaying 1080p50, and a large share of the displays in consumer homes already meets these requirements.

For theatrical motion pictures produced with a 24-fps frame rate, receiver support of 1080p24 and 1080p25 is sufficient and frequently used for video on demand (VOD) via IPTV or over-the-top (OTT) content via Web portals. However, for sportscasts with a large amount of fast motion and for live telecasts in general, the situation is quite different. In order to replace 1080i25, the decoder has to support 1080p50, creating a need for greater bandwidth or more efficient codecs.

2.2 3DTV

2.2.1 Frame-Compatible Broadcast (Phase 1)

Since 3DTV was introduced in October 2010, 3D signals have been transmitted in the so-called “conventional HD frame-compatible” (CFC) format, broadcasting the video signal for the left and right eye side by side – i.e. horizontally “squeezed” – via a single conventional HD channel. The receiver relays this incoming signal, as is, to the 3D display, which then generates the stereoscopic (“3D”) representation of the image, depending on the
system used: active (with shutter glasses), passive (with polarized glasses), or even autostereoscopic (without glasses). The broadcast format is thus independent of the consumer device used and also does not require any additional receiver logic. It was the broadcasters’ explicit wish for “Phase 1” of 3DTV broadcasting to be able to continue using the existing HD infrastructure both in broadcast management and playout, and for consumers to be able to continue using their existing HD receivers, in order to facilitate a quick adoption of the new technology.

In spite of the (arithmetical) quality loss due to the horizontal reduction (“squeeze”) of the L and R video signals and the technically required vertical reduction when using polarized displays (with passive glasses), users subjectively perceive the resulting image as a three-dimensional high-definition image. The fact that the right and left image transmitted in one particular HD frame are nearly identical – apart from the slight horizontal offset – apparently compensates the theoretical quality deficit. In terms of the bandwidth required, a 3D channel using frame-compatible transmission is, to all intents and purposes, identical to a conventional HD channel. Even before its official launch in October 2010, Sky 3D had performed on-air test runs to confirm this, and BSkyB had reached the same conclusions based on their own tests.

One of the drawbacks of CFC is that the programs broadcast in this fashion can only be viewed in 3D, i.e. on a 3D display. Viewers without a 3D display to decode the signal would only see the squeezed L and R images side by side on their 2D screen. As this situation is hardly user-friendly, the idea came up early on to develop a service-compatible format (Phase 2), in which a 3D signal carrying the stereoscopic information is simply piggy-backed on the conventional signal of a 2D channel. Various processes exist to achieve this result, and on average, they require only a 30 percent overhead for the added 3D data. Viewers without 3D displays can view these channels in 2D, but to fully enjoy the program in 3D, a special 3D receiver is required in addition to the 3D display (for details, cf. Appendix 1).

Frame-compatible Format for broadcast of 3D content

![Frame-compatible Format for broadcast of 3D content](image)
2.2.2 Service-Compatible Broadcast (Phase 2)

The service-compatible method for broadcasting 3D content was discussed in DVB as a so-called “Phase 2a” and, after identifying the corresponding commercial requirements, technical specifications were successfully defined. However, when the initial 3D euphoria had begun to slow down, the interest in converting existing 3D channels to the service-compatible format – or even offering entirely new service-compatible channels – also faded away. Moreover, the content of native 3D productions is often not 2D-compatible, as it appears “flat” – in both senses of the word – in the absence of “depth” information. While this issue poses less of a problem in the case of drama or documentaries, it becomes very apparent in 3D soccer sportscasts, where 3D cameras are placed in positions completely different from 2D broadcasts, and the sequences between cuts are much longer to give viewers sufficient time to adjust to the spatial arrangement and “absorb” the depth of the scene. If viewers watch a 3D-optimized production of this kind in 2D (i.e. the left-eye signal only), they might easily feel bored, since the style does not correspond to what they are used to from modern-day conventional 2D sportscasts. For all these reasons, it is highly unlikely that there will be any service-compatible 3D channels in the near future (for details, cf. Appendix 1).

Service-compatible broadcast has officially been designated as “Phase 2a” within DVB. Apart from this option, there is a “Phase 2b,” referring to a frame-compatible broadcast enhanced by a top-up signal. These additional data are intended to compensate the loss in image quality caused by the fact that the horizontal resolution of the L and R image is cut in half in Phase 1. Contrary to Phase 1 broadcasts, however, Phase 2b requires new receivers, which may be one of the reasons this new type of 3D broadcast has failed to gain acceptance so far.

2.2.3 Frame-Compatible Broadcast HEVC (Phase 3)

In late 2013, DVB specified the commercial requirements for Phase 3 of DVB 3DTV. The main objective was to make the broadcast of frame-compatible 3D channels even more efficient by using HEVC. At the same time, the broadcast signal should be rendered in such a way that viewers can watch the 3D channel service-compatible in 2D, if they have an appropriate receiver. The technical specifications for this standard are expected to be finalized by the end of 2014.

2.2.4 Autostereoscopic Displays

A three-dimensional representation of reality in motion pictures and videos is supposed to give viewers a more lifelike visual impression and let them enjoy a visual experience that is as close as possible to the actual three-dimensional perception of the world. The stereoscopic display of images achieved by feeding separate signals to the left and right eye has been employed for more than a century in still photography and, on a more or less experimental level, in cinematography as well. But only with the advent of HDTV-based 3D-capable television sets a few years ago has it become possible for audiences to enjoy full-color high-resolution three-dimensional video in the comfort of their own homes.

However, nearly all 3DTV sets currently available require viewers to wear special glasses, in order to enjoy the three-dimensional effect. In movie theaters, 3D viewing with glasses has taken hold, because theatergoers accept the need within the scenario of a darkened theater with a fixed position of each viewer relative to the
screen. In this particular environment, viewers are fully focused on the feature presentation without any distractions. But while glasses may seem acceptable to theater audiences, most home viewers regard them as a nuisance. Although Sky has been broadcasting select programs in Germany in 3D since 2010, the utilization rate of the technology is hardly exhausted. A commercial success of 3DTV has yet to materialize, due to a lack of consumer acceptance on the one hand and to a significant increase in production effort and expense on the other. A new technology promises to solve this "chicken-and-egg dilemma" by enabling audiences to perceive a three-dimensional image without any viewing aids: autostereoscopy.

Autostereoscopic displays are not only likely to generate a higher rate of acceptance with home users but are also suitable for use in environments where wearing additional glasses is impractical, e.g. public spaces with video walls, information displays, or other types of electronic digital signage. In order to boost acceptance, the 3D displays set up in sports bars or theater lobbies should also not require viewers to wear 3D glasses.

Unfortunately, the picture quality of today’s autostereoscopic 3D displays cannot yet measure up to the quality achievable by displays that require glasses. A lower resolution, limited viewing angles and distances, and a less pronounced illusion of depth are the current tradeoffs. For this reason, autostereoscopic 3D displays have only found acceptance in professional niche markets. But there are early attempts to develop them for home use. An increase of the display’s pixel resolution to 3,840 x 2,160 or even 7,680 x 4,320 – as demonstrated at CES 2014 – would compensate for the current drawback of a decreased resolution.

Technologies for 3D Displays
The autostereoscopic 3D displays currently available mainly employ one of two different technologies to display the two distinct images intended for the viewer’s left and right eye: one technology is the “parallax barrier,” the other the “lenticular array.” Both make use of the fact that a viewer’s two eyes look at the display from slightly different angles, and that for these two separate viewing angles, distinct images may be offered – one for each eye. The left eye will thus only see information intended for the left eye, the right eye only information intended for the right eye (for details, cf. Appendix 2). Compared to the alternative 3D solutions which require glasses, both concepts have pros and cons:

Pros of autostereoscopic 3D displays, compared to glasses:
• no glasses required
• usable in public spaces

Cons of autostereoscopic 3D displays, compared to glasses:
• sufficient resolution only achievable with higher-resolution displays (e.g. Ultra HD displays with resolutions of up to 7,680 pixels x 4,320 pixels)
• comparatively high manufacturing costs
• reduced depth impression
• perceived 3D effect depends on viewing angle and distance
Pros of glasses, compared to autostereoscopic 3D displays:
• comparatively cheap display solution
• wide range of manufacturers
• HD resolution achievable

Cons of glasses, compared to autostereoscopic 3D displays:
• additional glasses required
• unsuitable for public spaces, e.g. sign boards, information displays

Manufacturers of 3D Displays
Most manufacturers of autostereoscopic 3D displays today produce displays for professional use. Consumer displays are produced, for example, by Toshiba, Sharp and Philips, but retail prices of several thousand euro apiece limit production to small, insignificant quantities. Broad home-user acceptance can only be achieved by substantial price cuts and simultaneous improvements in resolution. The widespread future availability of higher-resolution panels (e.g. Ultra HD) will improve the picture quality of autostereoscopic 3D displays (for a table listing the manufacturers of autostereoscopic 3D displays worldwide, cf. Appendix 2).

Frame-compatible Full Resolution format for the transmission of 3D content (e.g. as used by “Dolby® 3D glasses-free 3D”)
Private Home Use
In addition to a few manufacturers of autostereoscopic 3D displays for home use (see above), Dolby Laboratories, in co-operation with Philips, has developed a system which covers all technical aspects of the entire video-signal processing chain for autostereoscopic 3D home systems.

This technology is called “Dolby® 3D glasses-free 3D,” and it takes into consideration both the production of 3D content and its display on 3D panels. It offers viewers autostereoscopic 3D and is supposed to produce clear, vibrant 3D images. Consumer devices could be 3D-capable TVs, laptop or tablet computers, and smartphones. Signal processing includes an automatic video signal optimization for each of the device types used. Viewers should be able to move freely in front of the display panel without being restrained by glasses or a fixed viewing position. Dolby® 3D has been demonstrated at various trade shows since 2012 and shows a promising quality, but so far no appliances employing this technology have become commercially available.

Some manufacturers offer lenticular screens to be mounted on the displays of laptop or personal computers. These screens are usually intended for single viewers and severely limit the user’s freedom of motion, but the 3D effect they achieve is usually quite satisfactory. These lenticular screens, however, have to match the display’s pixels with extreme precision, which makes it difficult to retrofit existing 2D displays.

Professionals Use
Currently, autostereoscopic 3D displays are rarely being used for professional purposes. On the one hand, digital signage in public spaces would present a useful application for glasses-free 3D, but on the other hand, the narrow viewing angles (“sweet spots”) of the technology at its current stage of evolution would result in a loss of image quality whenever the viewer changes position in front of the display. Moreover, public spaces would require large display diagonals and very bright displays, but current autostereoscopic 3D displays rarely come in display sizes larger than 130 centimeters (52”).

In the United States and Asia, acceptance of current autostereoscopic 3D technology is higher than in Europe. In these places, so-called “menu boards” – electronic menus in front of restaurants – are successfully being used for a stereoscopic display of words, graphics, and video that catch the attention of prospective patrons. In Europe, autostereoscopic 3D displays have been employed in the lobbies of movie theaters to advertise 3D movies and commercial products. Sport bars also constitute a conceivable venue for glasses-free 3D displays, but the limited viewing angle and the low resolution are still being regarded as major drawbacks in these locations.

Outlook
Looking at the drawbacks of present-day autostereoscopic 3D displays, it is obvious that technical improvements will be necessary. The sweet spots place severe restrictions on the viewer’s choice of position, and therefore a widening of acceptable viewing angles is called for. This would result in a further reduction of the maximum resolution that can be achieved, but this handicap may eventually be compensated by displays with a larger number of pixels. The development of Ultra HD displays might thus lead to an improvement in the quality of autostereoscopic 3D displays as well. Prototypes of autostereoscopic display panels with pixel resolutions of 3,840 x 2,160 and 7,680 x 4,320 have already been presented (cf. chapter 3.3).
The Fraunhofer Heinrich Hertz Institute (HHI) in Berlin is studying an attempt to eliminate the restrictive sweet spots: So-called “eye trackers” capture the viewer’s face and eye position and electronically track the parallax-barrier or lenticular-array system in front of the actual display accordingly to compensate for head movements. This system, however, can only render a satisfactory solution for a single viewer and is thus of limited practical use.

As a potential alternative, holographic displays offer actual three-dimensionality (as opposed to stereoscopy, which creates an illusion of three-dimensionality in two dimensions) by projecting objects that seem to “hover” in space. Such display types are currently only at a prototype stage. They are available for a few very special applications – such as “virtual product display cases” for small objects -, but larger displays for an actual three-dimensional representation of video signals are not to be expected to enter the market for commercial use anytime in the near future.

### 2.3 Audio

For the next generation of digital broadcasting, there is an opportunity to redefine how audio is sent and experienced. Getting away from a channel-based approach in favor of a more flexible design, using e.g. audio objects, will accomplish two things:

- have a single audio production for all rendering configurations:
  The content creator will be allowed to focus on the experience rather than being concerned with specific renderings.

- enable the audio to be adapted to the room, rather than the room to the audio:
  This is accomplished by having one production that can be rendered in stereo, 5.1, with a sound bar or multiple sound bars, speakers in the wall or ceiling or behind a potted plant, into surround headphones, etc., through versatile rendering algorithms at the consumer end. By isolating the rendering function(s) to the playback device, the consumer can have an experience that much more closely resembles what the content creator intended.

Work has begun on defining end-to-end work flows and processes to create and present object-based audio. A standardization of metadata, respective formats, and delivery packaging are the final steps necessary to enable a new paradigm in audio delivery to the consumer.
2.4 Ultra HD

The term “Ultra HD” designates a digital video format developed by NHK Science & Technology Research Laboratories, the R&D branch of Japan’s public broadcaster, NHK, and proposed as a future broadcast format with the following pixel resolutions, subsequently standardized by ITU and SMPTE:

• 3,840 pixels x 2,160 pixels (the so-called “4k” format with 4 times the resolution of HD)
• 7,680 pixels x 4,320 pixels (the so-called “8k” format with 16 times the resolution of HD)

The “4k” and “8k” designations are derived from the horizontal number of approximately 4 and 8 kilopixels, respectively, in these formats. NHK also applies the alternative term “Super Hi-Vision” to the 8k format.

The ITU ad SMPTE standardization committees have adopted both resolution standards and specified them, together with additional parameters, under the term “Ultra High Definition Television” (UHDTV), whereas ITU applies UHDTV to both pixel resolutions and SMPTE differentiates between UHDTV 1 (3,840x2,160) and UHDTV 2 (7,680x4,320). A UHDTV-1 picture thus has four times the number of pixels (approx. 8.3 megapixels) of a Full HD picture with a resolution of 1,920 x 1,080 pixels (approx. 2.1 megapixels), and a UHDTV-2 picture has sixteen times the number of pixels (approx. 33.2 megapixels) of Full HD.

In analogy to short forms like 720p, 1080i, or 1080p, the two UHDTV formats are commonly identified as 2160p and 4320p, respectively. The numerical value equals the vertical resolution of the image (the number of lines), and “p” stands for “progressive scanning,” which is mandated by the technical specifications of these formats. In contrast to some of the HD formats, interlacing (represented by the letter “i”) is no longer permitted for UHDTV.

Another significant difference to HD is that the UHDTV formats not only comprise advances in resolution but also in frame rate, bit depth, and color gamut. For example, high frame rates of up to 100/120 Hz and color depths of up to 12 bit have been included in the standard.

On 18 October 2012, the Consumer Electronics Association (CEA) declared itself in favor of the term “Ultra High Definition (Ultra HD).” In addition, basic requirements for Ultra HD-capable displays and projectors were specified. They have to have a minimum of 8 million active pixels at a 16:9 aspect ratio and be able to display no less than 3,840 horizontal and 2,160 vertical pixels. Moreover, they have to have at least one digital input that supports the transmission of UHDTV-1 content at a full resolution of 3,840 pixels x 2,160 pixels.

The appliance manufacturers associated in the DIGITALEUROPE organization have worked out a family of Ultra HD labels which is supposed to be publicized before the end of 2014, in order to provide trade and consumers with certain guidelines.

ITU Standardization

The International Telecommunication Union (ITU) is a specialized agency of the United Nations, headquartered in Geneva, Switzerland. It is concerned with the technical aspects of telecommunication and establishes standards, which are published as Recommendations (Rec). ITU-R’s (ITU-Radiocommunication Sector) Working Party 6C (Study Group 6) has been working on the standardization of Ultra HD. As of February 2014, they have published the following Recommendations for Ultra HD (for additional details, cf. Appendix 3):
SMPTE Standardization

The Society of Motion Picture and Television Engineers (SMPTE) is an international association of professional film and video technicians, headquartered in White Plains, NY, U.S.A. It provides a forum for discussion and documentation by allowing members from more than 80 countries to contribute to the standardization of new technologies. SMPTE co-operates with other standardization organizations, such as ISO, IEC, and ITU. Within SMPTE, “Technology Committees” are in charge of developing SMPTE Engineering Documents, which contain standards in the form of “Recommended Practices” and “Engineering Guidelines.” On the standardization of Ultra HD, the Tech Committees have published the following documents so far:

ST 2036-0:2012 ("SMPTE Roadmap – Ultra High Definition Television")
ST 2036-1:2013 ("Ultra High Definition Television – Image Parameter Values for Program Production")
ST 2036-2:2008 ("Ultra High Definition Television 1 – Audio Characteristics and Audio Channel Mapping for Program Production")
ST 2036-3:2012 ("Ultra High Definition Television – Mapping into Single-link or Multi-link 10 Gbit/s Serial Signal/Data Interface")

Expanded, future-proof interfaces for the studio and production infrastructure are currently in development.

In addition to the Ultra HD-related documents mentioned below, document ST 2036-0:2012 lists relevant standards previously published by ITU and SMPTE. The following chart illustrates their relationship:

![Development of the SMPTE 2036 family chart]

Document SMPTE ST 2036-1:2009, which was developed by Technology Committee 10E, defined “a family of progressive image sample structures for the representation of stationary or moving two-dimensional images sampled temporally at a constant frame rate and having an image format (sample structure) of 3,840 x 2,160 or 7,680 x 4,320 which has a hierarchical relationship with 1,920 x 1,080 and an aspect ratio of 16:9, called ultra high definition television (UHDTV)."
ITU (like SMPTE) subsequently specified the former as UHDTV 1 and the latter as UHDTV 2.

In addition, the following parameters were defined for both versions:

- sampling lattice: orthogonal
- pixel aspect ratio: 1:1 (square pixels)
- picture aspect ratio: 16:9
- frame rate [Hz]: 24, 24/1,001, 25, 30, 30/1,001, 50, 60, 60/1,001, 120 (100 Hz and 120/1,001 proposed)
- chroma subsampling: 4:4:4, 4:2:2, 4:2:0
- bit depth [bit/pixel]: 10, 12

**New Parameters for Colorimetry, Dynamic Range, and Frame Rate**

In addition to the parameters mentioned above, an improved colorimetry, a higher dynamic range (HDR), and a higher frame rate (HFR) play an important role in the ITU and SMPTE specifications for Ultra HD. While in the course of Ultra HD standardization, HDR and HFR are still being discussed by experts, a new standard for an extended (relative to HDTV) color gamut has already been defined. Rec. ITU-R BT.2020 replacing Rec. ITU-R BT.709 would result in a substantial gain in quality (illustration in Appendix 3), since HDTV is only capable of representing a small fraction of the colors present in nature, whereas Ultra HD has the potential to represent a much wider variety of hues. This, however, requires bit depths of 11 to 12 bit per color component. Moreover, the transition from the HDTV gamut to the Ultra HD gamut will entail a transition from non-linear pre-corrected signals to linear components. For details on Ultra HD parameters, standardization, and color representation, cf. Appendix 3.

2.4.1 Implications for HDTV and 3DTV

In the long term, Ultra HD displays with 3,840 pixels x 2,160 pixels and thus four times the resolution of today’s Full HD panels will only be able to show off their superior characteristics with appropriate native Ultra HD content. But even in the introductory phase, which started with IFA 2013, these new devices will provide viewers with added benefits, as the upscaling of HD broadcasts or Blu-ray-Disc content on an Ultra HD display already results in a visible improvement in image quality. It has to be noted, however, that the results of the scaling process differ from one manufacturer to another. Due to the limited number of display-panel manufacturers worldwide, many Ultra HD devices sold by different manufacturers are built around the same display panel, but the ancillary technology – including the scaler – differs between manufacturers.

The European Broadcasting Union (EBU) conducted a “blind” test on upscaled video in late January 2013, in which subjects were presented with various video sequences on an Ultra HD display. They were shown short clips back-to-back and twice in each of four formats – 720p50, 1080i25, 1080p50, and 2160p50 (Ultra HD) – and asked to compare picture quality. For each session, two subjects were seated at a distance of 1.5 times the height of the display panel, which is the optimum viewing distance for Ultra HD displays, while two other subjects were seated 2.7 meters from the screen, which represents the average viewing distance in U.K. households.
The statistical evaluation of the test showed that from both viewing positions, subjects gave better grades to native Ultra HD material than to upscaled HD sequences, yet the difference in subjectively perceived image quality was only marginal. (It has to be mentioned that the HD sequences presented had been generated by downscaling the Ultra HD clips and that the content was fed into the displays in uncompressed form.)

The test thus illustrated the potential of upscaling HD content to Ultra HD on the one hand, but also showed that, on the other hand, the higher resolution of Ultra HD panels alone does not constitute a decisive benefit, even when native Ultra HD content is displayed. Other tests conducted by the EBU, e.g. on higher frame rates, yielded far more significant perceived differences and hardened the EBU’s position that a television system of the future, based on the UHD standard, should also comprise HFR, an improved dynamic range, and an extended color gamut.

However, with regard to 3DTV – written off and over again –, the higher resolution may indeed play a key role, because it eliminates the deficiencies of the frame-compatible format (cf. chapter 2.2.1), in which the picture that the viewer sees has only half the resolution of a Full HD image, due to the side-by-side broadcast of the left- and right-eye video signal with half the horizontal resolution for each. On top of this, if the viewer watches the image through polarized glasses, he or she also loses one half of the vertical resolution, due to the alternation of lines representing the left- and right-eye images. As a result, viewers end up with a 3D image that has merely one quarter the resolution of Full HD. Since Ultra HD panels achieve four times the resolution of Full HD, viewers in the above-mentioned case receive 4x 1/4 of Full HD, which means that they can finally watch 3D content, broadcast in either side-by-side (SbS) or top-and-bottom (TaB) mode, in Full HD.

Especially with regard to no-glasses 3D technology using autostereoscopic displays (cf. chapter 2.2.4), the enhanced resolution will result in a visible improvement in quality, since more pixels mean more sweet spots and thus an improved viewing experience. It has been noted, though, that native Ultra HD content – especially when displayed on large panels – will by itself create a subjective depth perception for the viewer, even without any form of stereoscopy. This may be due to the enhanced sharpness of the images, which brings them “closer to life.” It seems that in these cases, the human brain adds depth information from experience and from other clues contained in the image (e.g. occultation of objects).
3. Ultra HD – from Production to Reception

With regard to the introduction of Ultra HD services on the German market, a multitude of aspects come into play, which already had to be taken into account during the transition from SD to HD. In the end, the entire chain, from the acquisition of content to the reception and display on the consumer side, will be affected by the switch to Ultra HD and is therefore described in detail in the following chapter. In technical terms, the launch of 3D TV in 2010 was comparatively easy to accomplish, since intentionally a solution had been chosen that was, for the most part, based upon the existing technical HD infrastructure, namely the frame-compatible format (cf. chapter 2.2.1).

3.1 Content for Ultra HD

The ground rule for Ultra HD, as for HDTV, is: better production quality means better playback quality. This would boost user acceptance – but so far, very few "genuine" Ultra HD productions are available.

The British Broadcasting Corporation (BBC), in co-operation with the Japan Broadcasting Corporation (Nippon Hōsō Kyōkai, NHK), recorded select events of the 2012 Summer Olympics (25 July through 12 August 2012 in London) in Super Hi-Vision format with a resolution of 7,680 pixels x 4,320 pixels, which were transmitted to large screens in three public-screening locations.

There is also a growing number of motion-picture productions in Ultra HD resolution. The movie TimeScapes was produced with a resolution of 4,096 pixels x 2,304 pixels. It contains footage of landscapes, people, and wilderness in the Southern United States. Another example is the animated short, Sintel, with a resolution of 4,096 pixels x 1,744 pixels.

Moreover, the YouTube video-sharing Website permits uploading of video content with a maximum resolution of 4,096 pixels x 3,072 pixels. By searching for "4k video" or "Ultra HD video," users may find recordings with these resolutions. For appropriate playback in full resolution, "original resolution" has to be selected in the playback quality menu.

3.1.1 Scanning Existing Content for Ultra HD

Film material in the 35-mm format or larger is perfectly suited for creating high-quality Ultra HD content. Most experts agree that the spatial (angular) resolution equivalent of 35-mm film is 4 kilopixels per line (4k) and thus equal to the spatial resolution of UHD-1.

Film scanners produced by the leading manufacturers are able to digitize film material in UHD-1 resolution, and there are even scanners available with a spatial resolution up to UHD-2. Until recently, the main application for film scanners was the creation of high-definition video sequences ("digital intermediates") for digital post-production, or the creation of high-quality material for digital archiving.

With the generation of Ultra HD content from analog film material, a new area of application for film scanning is about to emerge: High-quality scanning can convert existing 35- and 70-mm material into Ultra HD material.
that can pass straight into Ultra HD distribution, after only a few extra steps of processing (e.g. panning and
scanning, or cropping). Due to the scanners’ technical characteristics, an option exists to generate content with
a color resolution of ≥ 12 bit per color component, which is even suitable for HDR (high dynamic range) applica-
tions. Nevertheless, it cannot be expected that all library titles will instantly be available in an “HDR re-mastered”
format, since these conversions may not always concur with the filmmakers’ artistic intent.

In any case, Ultra HD will thus be able – for the first time ever – to carry the full resolution of an analog film into
viewers’ homes, and so numerous scanned and up-converted Ultra HD motion pictures may become available,
especially in the early days of the Ultra HD age.

3.1.2 Motion Picture Production for Ultra HD

The requirements for feature-length motion-picture production in UHD-1 are comparable to those for the
4k digital theatrical format. 4k material for digital cinema is currently produced at frame rates of 24 fps (standard),
25 fps (optional), or 30 fps (maximum). Television productions not intended for theatrical release might additio-
nally use refresh rates of 50 Hz, 100 Hz, or 120 Hz in case of progressive video broadcasts.

The workflow for 4k motion-picture production has been established and is state of the art. 4k post-production
for theatrical motion pictures usually works with uncompressed video material end-to-end, based on the camera’s
raw data. Due to the lower distribution bit rate in TV broadcasting (e.g. 20 Mbit/s with H.265/HEVC in a TV
broadcast, compared to 250 Mbit/s with JPEG2000 for digital cinema), this would not be necessary in a pure
UHD-1 TV production environment. In UHD-1 feature production, employing a moderate intraframe compression
is thus an option for reducing memory capacity and cutting costs. The spatial resolution of 4k motion-picture
 cameras is usually 4,096 pixels x 2,160 pixels, which may be reduced to the UHD-1 format by cropping, which
requires cinematographers to take into account a corresponding safe area of the frame (for details, cf. Appen-
dix 4).

All in all, Ultra HD production will inevitably mean another considerable boost in production costs, compared to
HD – not only because of the increased data volume (caused by the – at minimum – quadruple resolution) and
consequent demands on data storage, transmission, and processing. In the case of a “Hollywood blockbuster”-
type 4k production, special effects alone might inflate the budget. (Due to their immense price tag, SFX today
are still frequently computed in 2k – even for a 4k production – and subsequently converted up to 4k.)

Today’s 4k-movie workflow includes many of the image parameters that have now been specified for Ultra HD
as well, but due to the technical limitations of consumer electronics, producers frequently had to down-convert
4k content to conventional HDTV, in order to ensure compatibility with the first generation of consumer Ultra HD
devices HD. While a pixel resolution of 3,840 x 2,160 had been achieved, 4k content was often corrected to the
HDTV color gamut with a maximum of 30 frames per second and a color depth of 8 bit with a chroma subsam-
ping rate of 4:2:0. Only rapid progress in data compression (e.g. the HEVC Main 422@10 profile) and the cor-
responding encoder/decoder-chip capabilities, plus improved interfaces – such as HDMI 2.0 or DisplayPort –
will from now on permit a high-quality implementation of the UHD-1 specifications, which – with the introduction
of UHD-1 Phase 2, at the latest – will contain additional parameters, such as HFR (100/120 Hz frame rates),
10- or 12-bit bit depth in a 4:2:2 or 4:4:4 color sampling format, and an extended color gamut. For this reason,
the majors are already envisaging a high dynamic range (HDR) and an extended color space (BT.2020 or XYZ)
not only for the theatrical-release version but also for the production of the home-video version of a 4k motion picture. There is a general consensus that only improvements of this type ("better pixels"), which are independent of viewing distance, will, in the medium and long term, generate a commercially exploitable benefit in both theatrical and home presentation of movies that would make the investment into 4k post-production equipment pay off for the studios in the long run. Otherwise, the production of 4k content for theatrical use only would make little sense, since the increased resolution could only be noticed in the front rows, and only a comparatively small number of theaters is, so far, equipped to project movies in 4k, anyway.

The majors’ activities in this respect are driven by their jointly operated R&D institution, MovieLabs. They have also considered generating metadata along with content and thus transmit information to the display panel which would ensure that artistic intent is preserved by displaying the content in exactly the form the director had intended and specified. For further details, please refer to http://movielabs.com/ngvideo/.

In any case, times when home video versions differed significantly in various image characteristics from the theatrical version will soon be a thing of the past. Thanks to the introduction of Ultra HD, viewers at home will soon enjoy a motion-picture quality that has so far been reserved for moviegoers in theaters. For the studios, this merger of theatrical and video production means that a uniform workflow will cut costs and create new business models for the future.

3.1.3 Live-Broadcast Production for Ultra HD

At the beginning of any production chain is, obviously, the production of content, and this will be no different for Ultra HD. As far as live production in Ultra HD is concerned, a number of challenges have come up, mainly due to the fact that the higher resolution of this format, the progressive scanning throughout, and the increased bit depth of at least 10 bit create a significantly higher data volume than HD productions. Whereas a 1080i25 signal (4:2:2) with 8 bit and a total of about 0.83 Gbit/s can easily be transmitted via one HD SDI fiber-optic cable from a stadium into a broadcast operations center (BOC), 2160p50 (4:2:2) with 10 bit will create a bit rate of 8.3 Gbit/s and thus ten times the previous data volume to be processed. This quantity can only be transmitted to the BOC by bundling several lines, which, of course, translates into increased cost and effort. Moreover, the professional interfaces have not yet been fully standardized. At the same time, studies are underway to find out how contributed data could be compressed (mezzanine-level compression), in order to contain the resulting cost explosion.

Even at an earlier stage in the chain, similar issues arise for the signal transmission from the Ultra HD cameras to the OB van, many of which are not yet Ultra HD-compatible and can thus process such signals only with appropriate workarounds, e.g. by bundling four HD channels into one Ultra HD channel in the vision mixer, which, of course, reduces the total capacity of the mixer to one quarter.

And the increased data volume not only causes concerns in distribution but also because storage – both short-term (e.g. for slow motion and instant replay) and long-term (e.g. archiving) – will require larger capacities and thus increase costs.
So far, Sky is the only broadcaster in Germany who has commissioned several Ultra HD test productions, in order to acquire a certain level of experience in this field. Starting in December 2012 and in co-operation with Ingolstadt-based Kropac Media GmbH, various soccer games were test-recorded with one or multiple Ultra HD cameras, and trailers were produced in post-production test runs. It has to be noted here, that the main focus of these early tests was on the acquisition of content. A full-fledged live-broadcast production with a live camera system and subsequent live contribution and distribution was not feasible, since neither an adequate infrastructure nor Ultra HD technology across the entire production chain were available at the time. In the first half of 2014, however, all remaining gaps in the Ultra HD live production chain are expected to be closed, as soon as appropriate HEVC live encoders have been installed.

The test footage produced as well as the trailers are available to Sky for in-house testing, and they have been shown to Sky staff on various occasions for demonstration purposes. The first Ultra HD production of a Bundesliga match between Borussia Dortmund and FC Bayern on 1 December 2012 was followed by numerous additional tests, which included further steps towards live-broadcast production. During a production of the soccer Champions-League semifinal game between FC Barcelona and FC Bayern Munich on 23 April 2013, signals from Ultra HD cameras were, for the first time, carried to the OB in real time and used there, e.g. for slo-mo replay. At the same time, potential benefits for HD productions were studied, e.g. the option to zoom into certain portions of the Ultra HD frame while preserving HD quality. This way, a single Ultra HD camera might “virtually” and flexibly replace several HD cameras.

In an exhibition game on 24 July 2013, FC Bayern Munich and FC Barcelona met again, and Sky was back to record the match in Ultra HD. Individual results of this production were presented at the joint Ultra HD booth at IFA 2013’s TecWatch. Another test production on the occasion of a Champions League match between FC Chelsea and FC Schalke 04 on 22 October 2013 marked the first time a 4k camera signal was inserted into the live signal of an HD production in the form of a so-called “super-zoom,” where the 4k signal provided the source for a virtual zoom in HD resolution. For further information, please refer to Appendix 5.

3.2 Post-Production for Ultra HD

Not only in live production but also in post-production, the increased data volume for Ultra HD content becomes apparent. Key issues that need to be resolved include professional interfaces as well as filing and storage. Moreover, editing facilities and graphics applications have to be converted to Ultra HD capability first of all.

For Sky’s first Ultra HD test run on 1 December 2012, a trailer was edited in post-production for use at in-house presentations. The post-production team, consisting of a video editor and a technical assistant, first transferred all the footage via a Mac Pro computer to a local RAID and subsequently created so-called “HD rushes” from the raw material.
Since the Ultra HD acquisition had created very large files, this procedure permitted simpler and faster processing of the material. Editing could be performed at the HD level. The HD rushes were encoded with the Apple ProRes Codec and the following parameters:

- resolution: 1,920 pixels x 1,080 pixels (progressive)
- chroma subsampling: 4:2:2
- bit depth [bit/pixel]: 8
- frame rate [Hz]: 50

The HD rushes were subsequently imported into the appropriate editing application, and a trailer was edited. The post-production team then exported an edit decision list (EDL) in the form of an XML file, which was applied to the Ultra HD raw material. In addition, appropriate audio tracks were added, consisting of recordings of the commentary and ambient sound provided by the sound editor of the HD production in the OB vehicle.

The next step was color grading, meaning that the trailer was “color-corrected” according to the color gamut defined in Rec. ITU-R BT.709, and finally, the Sky Ultra HD and DFL logos were inserted into the trailer.

This post-production chain – which was quite time-consuming and thus atypical for a (live) sportscast – vividly demonstrated that Ultra HD still had a long way to go in late 2012 before reaching live telecast potential. In the meantime, progress has been made, but the majors’ additional requirements in terms of HDR (high dynamic range) and extended color space are now offering new challenges to post-production which have to be dealt with.
3.3 Broadcast of Ultra HD

The quadruple resolution of Ultra HD in comparison to Full HD means, of course, that the data volume which has to be transmitted also quadruples in the acquisition of content. In the production and post-production stages, where data is usually handled in uncompressed form, this enormous explosion of bandwidth already creates major challenges, but when broadcasting this content to the consumers, at the latest, economical aspects also play a decisive role. In digital television, compression algorithms have been employed from the beginning, significantly reducing the bit rate of the broadcast signal, ideally with no or only insignificant visible loss in picture quality. Following MPEG-2, used in the early days of digital TV broadcasting, H.264/AVC has become the most common compression format since the introduction of HDTV. It seems that now, with the launch of Ultra HD, H.265/HEVC will become the new standard, boosting efficiency by about 50 percent over its predecessor. To put it simply: the bandwidth required for the broadcast of UltraHD content will "only" double, while the original data volume has quadrupled.

Even though the implementation of the comparatively recent HEVC standard is still in its infancy – both in terms of encoders and the decoders -, it is safe to say that there are no technical impediments that would preclude the introduction of HEVC for the broadcast of Ultra HD services. In theory, nothing is stopping the distribution of such programs via satellite and/or cable. However, actual implementation is blocked by the current unavailability of HEVC real-time encoders, and HEVC decoder chipsets to be built into appropriate receivers are still at an early stage of development, too.

Internet protocol (IP) is also a distribution system suitable for the broadcast of Ultra HD content, and more than a few experts believe that the fastest way to make UHDTV programs available to consumers might be via IPTV. As long as HEVC real-time encoding is unavailable and live programming is thus unfeasible, a first step towards Ultra HD might be the introduction of on-demand services (e.g. media libraries) that distribute pre-encoded Ultra HD content.

3.3.1 H.264/AVC

H.264/MPEG-4 AVC was adopted in 2003 by ITU (Study Group 16, Video Coding Experts Group) and MPEG. At the time, the objective was to develop a compression process which was – in contrast to previous standards – suitable for both mobile applications and HDTV by cutting the required bit rate by at least half. Typically, H.264 achieves an encoding efficiency two times higher than MPEG-2 and is particularly suited for HDTV. However, H.264/AVC also has a higher complexity than MPEG-2.

Although H.264/AVC was employed in early experimental Ultra HD broadcasts, it is highly unlikely that this format will play any role in the commercial distribution of Ultra HD programming. For satellite distribution, H.264/AVC would amount, more or less, to a regression to the analog age, since – due to the increased data volume – AVC-encoded Ultra HD content would require bandwidths occupying an entire transponder, which typically carries four AVC-encoded HD channels today. It is conceivable, however, that AVC will remain in use for a couple of years as a professional codec for Ultra HD contribution.
3.3.2 H.265/HEVC

In early 2008, the Video Coding Experts Group (VCEG) of ITU-T and the Moving Pictures Expert Group (MPEG) of ISO/IEC formed the Joint Collaborative Team on Video Coding (JCT-VC), in order to jointly develop the standard now known as High-Efficiency Video Coding (HEVC), or H.265. Like its predecessors (e.g. MPEG-2 and H.264/AVC), this standard is based on a hybrid encoding approach. The structure consists of a Video Coding Layer (VCL) containing the compressed video information on the one hand and a Network Abstraction Layer (NAL), which maps the VCL data onto various communication protocols, on the other.

The NAL high-level syntax of H.264/AVC with parameter sets, NAL unit syntax structures, slices, and SEI and VUI metadata was more or less preserved and adopted from the previous standard, except for the following modifications and expansions:

- Tiles and wavefronts are introduced as high-level tools for parallelization.
- Dependent slice segments are added that have only a minimal slice header and are thus well suited for short-lag encoding.
- The reference picture memory is explicitly signaled by means of reference picture sets (RPS) instead of memory management operations.

At the VCL encoding core, the main innovations with respect to H.264/AVC are:

- adaptive quadtree-based block structures for prediction and transformation;
- inter-picture prediction block merging for the efficient encoding of motion parameters;
- additional sample-adaptive offset (SAO);
- context-adaptive binary arithmetic coding (CABAC) as the only method for entropy encoding.

In HEVC, an image is broken down into coding-tree units (CTU), each of which contains one coding-tree block (CTB) with luma pixels, several coding-tree blocks for chroma pixels, and a syntax for their encoding. The CTUs in HEVC are more flexible than the macroblocks in H.264, since the CTB luma pixel size per sequence can be adjusted to 16x16, 32x32, or 64x64.

In order to cover a variety of applications, two configurations were chosen: an entertainment configuration for motion pictures and broadcast, and an interactive configuration for video communication with minimum lag.

In HEVC, profiles, tiers, and levels have been defined. While profiles (sets of compression tools) and levels (e.g. maximum sample rate) are already familiar from H.264/AVC and MPEG-2, tiers have been introduced in HEVC for each level, which further limit coded-picture-buffer (CPB) size and maximum bit rate. The first version of the HEVC standard specifies three profiles: Main, Main 10, and Main Still Picture.

In general, all tools are supported in the HEVC Main profile, with the following constraints:

- 4:2:0 chroma subsampling rate only;
- 8-bit video only;
- tiles and wavefronts may not be used simultaneously;
- each tile must have a width of at least 256 and a height of at least 64 luma pixels.
The Main 10 profile additionally supports 9- and 10-bit video. The rate restrictions do not apply to the Main Still Picture profile, since it is intended for encoding still frames and not video sequences. For each profile, 13 levels have been defined, each with a main tier and a high tier, whereby the scope of the main tier is sufficient for most applications and the high tier is intended for more demanding applications. Professional extensions towards a 4:2:2 and 4:4:4 chroma subsampling as well as higher bit depths have been envisioned for the first half of 2014. Moreover, work is underway to develop an extension of the standard for the encoding of 3D video and for scalable video encoding.

3.4 Receivers for Ultra HD

Initially, the introduction of UHDTV will most likely be accomplished by the use of suitable set-top boxes (STB), mainly for two reasons:

1. As for the introduction of HDTV, the launch of UHDTV will be spearheaded by the pay-TV providers, who are using STBs on a grand scale, which contain their user interface and the CAS (Conditional Access System). They are therefore able to support new systems during their launch phase in a comparatively flexible manner.

2. Since TV sets with large screen diagonals are still a major investment these days, they have a lifespan of about ten years. The implementation of a new television standard will thus only take place once the system has been fully developed and established on the market.

Although initial broadcasts have been aired and innovative pay-TV operators are expected to launch their first (test) services soon, many of the parameters of the upcoming UHDTV have yet to be discussed and standardized. Moreover, chip concepts for the required algorithms have to be optimized, based on the eventual standards, in order to develop and produce marketable appliances.

ITU-R has published their first standards for UHDTV production (cf. chapter 2.4), but discussion of suitable broadcast parameters has only just begun. It is now up to the relevant working groups to define those parameters in accordance with commercial requirements.

One of the first results is the specification that video signal coding will employ the new H.265 standard (HEVC, cf. chapter 3.3.2), in order to achieve the crucial reduction in data volume. For DVB, however, the exact parameters have yet to be specified, and this process is currently underway in the relevant DVB working group.

There is widespread consensus that UHDTV has to deliver a significant improvement in picture quality, compared to today’s HDTV, in order to find wide market acceptance. An enhancement of spatial resolution, along with even larger display panels, is not the only parameter. Higher frame rates (HFR), an extended color gamut, and a higher dynamic range (HDR) are other items to be discussed. But an introduction of all these improvements at the receiving end only makes sense if they are implemented across the entire chain, from production via transmission to the receiver and the display. It will probably take a while until a general consensus in standardization is found.
The High-Definition Multimedia Interface (HDMI) is used for the transmission of video and audio content between receiving devices (e.g. set-top box), playback devices (e.g. Blu-ray-Disc player), and displays. Since the new features of HDMI 2.0 were introduced at IFA 2013 in Berlin, a pixel resolution of 4,096 x 2,160 can now be transmitted at a frame rate of 50 and/or 60 Hz. This is an essential prerequisite for the introduction of UHDTV, but in order to realize the wishful thinking of some broadcasters who would also like to broadcast the improved video at higher frame rates (e.g. 100 or 120 Hz), the standard would have to be amended again. It is therefore important for all those who are interested in a better picture to contribute their ideas at the HDMI Forum.

Another consideration is the copy-protection process at the HDMI interface. Up until now, the HDCP system, version 1.4, is used worldwide, even though it is no longer considered secure, since it has been cracked. The Hollywood majors therefore demand the successor version, HDCP 2.2, for content of an even higher quality, in order to ensure adequate protection. Discussions are currently underway on when and how this might be realized. It is obvious that the transition to a new broadcast system would offer an excellent opportunity to introduce this new standard.

At the major trade shows in the fall of 2013 (IFA, IBC), prototypes of UHDTV set-top boxes were presented. The technical parameters of these STBs, however, rely on available chip concepts, which, by necessity, fail to conform to the (pending) final specifications of the standard. Initial prototypes of chips which support 50/60 Hz frame rates and 10-bit bit depths are close to production-line status.

This situation in Germany is reminiscent of the HDTV launch, when no STBs in conformity with the final standard were available at IFA 2005, since the chip concepts had not been finalized at the time.

3.5 Displays for Ultra HD

High-definition television (HDTV) with a pixel resolution of 1,920 x 1,080 may be considered standard for home use by now (cf. chapter 1.1). While, over the last few years, manufacturers had focused primarily on offering consumers TV sets with ever-increasing display sizes, they have also been working intensely for some time now on an HDTV successor format with a significantly enhanced resolution, i.e. a larger number of visible pixels. As early as IFA 2012, nearly all the booths of the major consumer-elecronics manufacturers featured new high-definition displays designated as “Ultra HD.” Since early 2013, manufacturers seem to be playing a game of one-upmanship in announcing jumbo display panels with UHD resolution, promising consumers a sharper, clearer, more detailed picture for a more enjoyable viewing experience.

In January 2013, Ultra HD was the dominant topic in the TV-set segment at the Consumer Electronics Show (CES) in Las Vegas, Nevada. All major TV manufacturers presented sets with various screen diagonals between 130 and 280 centimeters (55", 56", 60", 65", 84", 85", and 110”), including some with OLED display panels. Even early 8k prototypes were presented. One year later, at CES 2014, curved and bendable (flexible) Ultra HD displays shifted into focus, and screen diagonals reached the 305-centimeter mark (120”). At the same time, nearly all manufacturers of large sets had added image enhancements – under the label “X-tended Dynamic Range Pro,” for example – intended to improve display contrast for the time being, as long as there is no HDR standard that would embed such improvements into the content.
In the summer of 2013, the sale of Ultra HD displays gradually kicked into gear in Germany, but these devices were far too expensive for most consumers. Many manufacturers have already announced new Ultra HD models for the first half of 2014, which already show a marked drop in retail prices. However, it will take a few more years until sufficiently large production quantities will allow a more significant decline in price levels. Screen diagonals vary between home-theater dream sizes of 216 to 305 centimeters (85”-120”) and a range of 140 to 165 centimeters (55”-65”), which seems more suitable for most living rooms. In addition, most newer sets nowadays have at least one Ultra HD-capable HDMI input, which also supports 50/60 Hz frame rates. An overview of currently available Ultra HD consumer displays can be found in Appendix 6.

The most apparent innovation of the Ultra HD standard is the significantly enhanced image resolution. Dependent on the native resolution and pixel density of the display, the enormous amount of picture information results in significant improvements in sharpness and the representation of details, especially in static scenes. In addition to the enhanced picture resolution, the Ultra HD standard boasts an increased bit depth (quantization) of up to 12 bit for better contrast, an expansion of the representable color space (gamut), and an extremely high frame rate of up to 120 Hz (cf. chapter 2.4).

Apart from the improvements mentioned above (brilliant video images in an extremely high resolution), the Ultra HD video format provides other decisive benefits vis-à-vis HDTV. Due to the high pixel density of the displays, the recommended viewing distance can be cut in half for UHD-1, compared to the HDTV standard (and reduced to merely a quarter for UHD-2). The correspondent widening of the viewing angle results in a more immersive and thus more emotionally involved viewing experience.

Since only a very small amount of Ultra HD content is available so far, the focus is currently on the display panels’ capability to upscale HD material from broadcast sources, Blu-ray Discs, or the Internet, in order to display this content on a large panel in full size.

In addition, Ultra HD panels allow the simultaneous display of large data quantities. In commercial applications, this should be of interest, for example, for air-traffic controllers or atmospheric researchers, because displaying the same number of pixels would otherwise require four (or sixteen) HDTV monitors (and include irritating display frames). In home use, Ultra HD displays will permit the viewing of consumer-generated digital photographs in an unparalleled quality, since – instead of the 2 megapixels of the HDTV standard – 8 (UHD-1) and 33 (UHD-2) megapixels will now be available for their on-screen presentation.

The future development of Ultra HD displays for consumers is advanced by manufacturers and service providers alike on various levels. First of all, adequate production capacities will have to be provided. The manufacturers of TV sets will attempt to offer Ultra HD sets at salable prices. This will be a key factor in finding the critical mass of consumers that will make the various business models profitable.
3.6 Introduction of Ultra HD in Germany

To put it briefly, actual Ultra HD options will not become available as rapidly as the early availability of suitable display panels suggests – even disregarding their less than attractive price range at the moment. In this respect, there are parallels to the launch of HDTV, when CE manufacturers flooded the market with high-definition displays long before content providers were able to supply channels and content in HDTV resolution. And while some broadcasters are still struggling to switch to HDTV, the growing market presence of Ultra HD displays starts to create pressure to further upgrade production and distribution channels.

But this is exactly where the problems and weaknesses lie that hamper, or at best delay, a similarly speedy launch of Ultra HD programming. Looking at the signal flow from (live) production via post-production and distribution all the way to the consumer, it is obvious that there is no stable end-to-end chain yet, as of early 2014. On the one hand, fully developed production techniques are lacking, e.g. in the area of live sportscasts, and on the other hand, some of the interfaces are not yet capable of handling the vastly increased data volume caused by the higher resolution. In some areas, these issues can be solved by workarounds for the time being, but in the medium and long term, these temporary solutions will have to be replaced by new standards. And the last link in the chain – the broadcast from the content provider to the consumer – still needs time. A foundation has been laid with the HEVC standard, which allows the encoding and transmission of Ultra HD’s significantly higher data volume in an efficient and economically sensible way, but the actual implementation of this new standard with regard to the higher frame rates of up to 50/60 Hz is still in progress, both on the decoder side (i.e. in the receiver) and, even more so, on the encoder side. Only during the first half of 2014 will it probably be feasible for a live production in 2160p50 with 10 bit to be HEVC-encoded in real time, transmitted, and decoded by a (prototype) receiver.

An April 2013 IHS study on Ultra HD, commissioned by SES, came to the conclusion that a full-fledged technical ecosystem will not exist before 2017, which would then allow a commercial mass-marketing of UHD from 2023 on. The study also draws parallels to the HDTV launch and – in addition to the production and distribution issues mentioned above – takes a look at the market penetration of Ultra HD displays. IHS defines a hardware penetration threshold of 3 percent, which they predict will be reached in 2017, for content providers to make Ultra HD programming profitable. As in the case of HDTV, it is likely that pay-TV providers will take the first step. Until then, major sports events – such as the FIFA men’s soccer World Cup in Brazil in the summer of 2014, the 2016 Summer Olympics in Rio de Janeiro, and the 2016 UEFA European men’s soccer Championship in France – will drive development and offer opportunities for test broadcasts and Ultra HD demo channels. At each step of the way, the market has to find a balance between consumers’ wishes and expectations for Ultra HD and technical feasibility at that particular point in time.

Numerous national and international institutions are already dealing with the technical implementation of Ultra HD in all its aspects. The “Further Development of HD and 3D” project group (PG HD3D) of the German TV Platform is keeping a close eye on most of these activities and is in close contact with many other international working groups, in order to ensure a launch of Ultra HD in Germany that is in sync with corresponding developments in the rest of Europe.

The activities of DVB play a key role in this respect. In a joint fact-finding meeting in late May 2013, representatives of DVB and the EBU agreed that a two-tiered introduction would be the most sensible solution for UHD-1. After a long and heated discussion throughout the summer months, this approach was adopted by DVB in
November 2013, albeit with some crucial backpedaling on the planned parameters. In Phase 1, also known as “Conventional Profile,” viewers would be introduced to the ultra-high-resolution world of Ultra HD with a bit depth of 8 and 10 bit (with 4:2:0 remaining as the only mandatory sampling rate) on the basis of the conventional color gamut (Rec. 709) and the 5.1 audio surround system in use today, whereas the original proposal had called for exclusive 10-bit support and thus an implementation of the HEVC Main 10 profile. Moreover, having abandoned 1080p100/120 in the course of the discussions, Phase 1 will now only support the 2160p50/60 format.

It is expected that a soft launch of UHDTV can be accomplished as early as 2014/2015. For a second stage, the consortium suggests a profile which, apart from higher frame rates (HFR) of 2160p100/120, also uses the extended color gamut recommended in ITU-R Rec. 2020, a high dynamic range (HDR), and a yet to be specified (probably object-based) audio surround system. The transition to Phase 2 is estimated to be feasible in 2017 or 2018, which more or less matches the IHS forecast mentioned above. Only on the basis of this second profile would a live broadcast – e.g. of sports events – be sensible and realistic, since only these higher frame rates would be able to prevent disturbing motion artifacts in Ultra HD.

The key features of the phase model are illustrated in the following diagram.

In addition to the two-tiered introduction of UHD-1 (3,840 x 2,160), it also shows UHD-2 (7,680 x 4,320) as Phase 3. It is important to note that this is not yet a DVB standard but merely a proposal, which is still under discussion. As a first step, however, DVB will take care of formulating the commercial requirements for Phase 2.
All the considerations so far have focused on the introduction of UHDTV programming, i.e. the linear distribution of Ultra HD content via satellite, cable, or Internet protocol (IPTV), over the air (OTA) and over the top (OTT) for reception via receiver or personal computer. If current retail prices keep dropping, the Ultra HD display panels now pushing into the market, however, could be of interest to consumers at a much earlier point in time, since most of the devices offer excellent upscaling algorithms, and the display panels with a pixel resolution of 3,840 x 2,160 may also be used to watch consumer-generated content, such as photos, which could be transmitted to the screen from flash drives, memory cards, or via HDMI. IP-based video on demand (VOD) with Ultra HD content is also feasible and even available today.

The YouTube video-sharing platform, for example, already offers a wide variety of Ultra HD content, which may be watched on an Ultra HD display via an HDMI connection to a computer with a 4k graphics board. Smart TVs in Ultra HD resolution even permit viewing this content without an external computer. Content providers, such as Amazon, M-Go, and Netflix, have announced at CES 2014 that they will start providing the first Ultra HD over-the-top (OTT) content during 2014, even though their range of offers might remain quite limited in size for a while. With the Sony 4k Ultra HD Media Player (sold only in the United States so far), Sony is already offering a technically similar product for sale, containing Hollywood movies in high resolution, which can be updated via download. At CES 2014, Samsung offered a similar service with content from Twentieth Century Fox and Paramount Pictures, but most of the titles will be upcaled library titles rather than new features produced in 4k.

For media aficionados with an interest in the latest technology, Ultra HD – even in early 2014 – offers an option to enter a new universe of brilliant pictures on larger display panels, with a higher resolution and an enhanced image quality. This was also the key message delivered at the German TV Platform's Ultra HD booth in the TecWatch section of IFA 2013, which also demonstrated – in co-operation with partners Astra, Fraunhofer HHI, Harmonic, Sky Deutschland, and Sony – the satellite transmission of an HEVC-based Ultra HD demo channel, new television concepts for Ultra HD, and how 3D TV could profit from higher resolutions. But only the eventual arrival of elements such as extended color space, higher dynamic range, higher frame rates, and an improved overall picture perception, along with an expanded audio surround system, will allow Ultra HD to demonstrate all its benefits by offering enhanced realism and a more immersive viewing experience. This is not expected to happen before 2017, even though early UHDTV (test) broadcasts might begin as early as 2014/2015.
### 4. Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>100-Hz technology</strong></td>
<td>display method for reducing image flicker on television screens by buffering the fifty frames per second (50 Hertz or Hz) supplied by the broadcast source and duplicating them for output (100 Hz); some TV sets on the market are able to multiply the incoming signal further, resulting in 200-, 400-, 600-, or 800-Hertz output</td>
</tr>
<tr>
<td><strong>3D television</strong></td>
<td>cf. three-dimensional television</td>
</tr>
<tr>
<td><strong>3D Full HD</strong></td>
<td>3D (stereoscopic) playback method with both component images for the left and right eye having a Full HD pixel resolution of 1,920 pixels x 1,080 pixels</td>
</tr>
<tr>
<td><strong>3DTV</strong></td>
<td>cf. three-dimensional television</td>
</tr>
<tr>
<td><strong>4k</strong></td>
<td>cf. UHD-1</td>
</tr>
<tr>
<td><strong>8k</strong></td>
<td>cf. UHD-2</td>
</tr>
<tr>
<td><strong>Aspect ratio</strong></td>
<td>width-to-height ratio of an image</td>
</tr>
<tr>
<td><strong>Autostereoscopic display</strong></td>
<td>display on which “3D” images may be viewed without the aid of special glasses, using either lenticular arrays or parallax barriers</td>
</tr>
<tr>
<td><strong>AVC</strong></td>
<td>Advanced Video Coding: video encoding system which is particularly suited for HD signals</td>
</tr>
<tr>
<td><strong>BD</strong></td>
<td>cf. Blu-ray Disc</td>
</tr>
<tr>
<td><strong>Blu-ray Disc</strong></td>
<td>BD: optical storage device for digital media, based on the DVD, used primarily for storing content in high-definition (HD) quality</td>
</tr>
<tr>
<td><strong>Chrominance</strong></td>
<td>color information of a television image’s pixels</td>
</tr>
<tr>
<td><strong>Color gamut / space</strong></td>
<td>the entirety of all colors that may theoretically be generated from the three primary colors, red (R), green (G), and blue (B), whereby each primary color has a hue and a saturation value</td>
</tr>
<tr>
<td><strong>Component image</strong></td>
<td>result of separating a frame into two components, one intended for viewing by the right eye (R) and the other by the left eye (L)</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Decoder</td>
<td>technical device which converts encoded transmission signals back into their original form</td>
</tr>
<tr>
<td>De-interlacing</td>
<td>processing stage in digital broadcasting at which the fields received in interlaced video transmission are converted back into full frames, which may result in video artifacts</td>
</tr>
<tr>
<td>Depth of field</td>
<td>in 3D imaging, designates the depth range at which viewers perceive the image as sharp (“in focus”)</td>
</tr>
<tr>
<td>Descrambling</td>
<td>cf. scrambling</td>
</tr>
<tr>
<td>Field</td>
<td>result of separating a frame into two components, one of which carries the content of the even- and the other of the odd-numbered lines</td>
</tr>
<tr>
<td>fps</td>
<td>frames per second: number of frames of a television pictures transmitted in each second</td>
</tr>
<tr>
<td>Frame</td>
<td>cf. interlaced video</td>
</tr>
<tr>
<td>HD</td>
<td>High Definition: video signals with a pixel resolution of 1,280 x 720 to 1,920 x 1,080 at a 16:9 aspect ratio</td>
</tr>
<tr>
<td>HDCP</td>
<td>High-bandwidth Digital Content Protection: process to protect high-definition digital content – such as HD video and HDTV broadcasts – and prevent illegal copying</td>
</tr>
<tr>
<td>HDMI</td>
<td>High-Definition Multimedia Interface: compact interface for high-definition multimedia signals, connecting digital consumer devices and carrying control data in addition to audio and video signals</td>
</tr>
<tr>
<td>HD ready</td>
<td>label developed by DIGITALEUROPE (formerly known as EICTA), the organization of European consumer-electronics manufacturers, for high-definition digital playback devices, such as flat display panels and video projectors; devices carrying the “HD ready” label are guaranteed to fulfill certain technical specifications (in terms of e.g. resolution, aspect ratio, etc.)</td>
</tr>
<tr>
<td>HD ready 1080p</td>
<td>label for consumer devices with a 16:9 aspect ratio and a 1,920 x 1,080 pixel resolution</td>
</tr>
</tbody>
</table>
**HDTV**

High-Definition Television: digital television with a high pixel resolution, usually no less than 1,280 x 720, but preferably 1,920 x 1,080 (Full HD); standard-definition television (SDTV) has a resolution of only 720 pixels x 576 pixels. HDTV requires all devices on the receiving side to be HDTV-compliant and connected via HDMI cables.

**HEVC**

High-Efficiency Video Coding (H.265): highly efficient video compression format, which requires only about 50 percent of the data rate, compared to the previously used standard, MPEG-4 AVC / H.264.

**H.264 ITU**

(International Telecommunication Union) designation for the AVC video compression format.

**H.265 ITU**

(International Telecommunication Union) designation for the HEVC video compression format.

**iDTV**

Integrated Digital Television: digital flat-panel TV set with integrated tuners for DVB-S/S2, DVB-C, and/or DVB-T/T2.

**Interlaced video**

Flicker-reduction method used in capturing and broadcasting television images, where each frame is separated into two fields, which are recomposed by the receiver into a full frame.

**Interlacing**

Capturing and broadcasting separate fields for interlaced video; in digital television, these broadcast formats are designated by the letter “i”.

**Interleaving**

Method to safeguard digital video signals against transmission errors: The bit sequence is intentionally altered on the source side. With this interleaving, a transmission error that affects several adjacent bits (burst error) will only have limited consequences for the original sequence, because only single bits will be affected, and these errors can usually be compensated easily by suitable error correction procedures, once the original sequence has been restored on the receiving end through de-interleaving. This process requires buffering, which causes a display lag.

**Luminance**

Brightness information of a television image’s pixels.

**MPEG**

Moving Picture Experts Group: international working group of experts, which defines standards for video and audio coding; these standards are designated globally as MPEG-x. MPEG-2 is used worldwide today in nearly all digital television systems, while the more advanced MPEG-4 standard offers an even higher data compression and is used mainly in HDTV.
OLED

Organic Light-Emitting Diode: variation of the light-emitting diode (LED) used in particular for television and computer screens and the displays of mobile telecommunication devices; compared to standard liquid-crystal displays (LCD), OLED screens have a much higher contrast, consume significantly less energy, and have a shorter response time.

Parallax
difference in the apparent position of an object when viewed with the right and left eye; in moving images, it can change the apparent two-dimensional distance between objects in the foreground and objects in the background.

Pixel
short for picture element: smallest brightness- and color-controllable element in digital images; on flat screens and in video projectors, a pixel usually consists of the primary colors, red (R), green (G), and blue (B). The actual pixel size depends on the size of the screen; the quality of the image perceived by the viewer increases with the number of pixels per frame, but also depends on viewing distance.

Pixel resolution
specification of the number of horizontal and vertical pixels in a full frame, given as [number of pixels per line] x [number of lines] per frame; in addition, the frame (refresh) rate in Hz (Hertz) or fps (frames per second) is often indicated.

Plasma display panel
(PDP): a type of flat-panel display on which light of various colors is produced by phosphors triggered by a plasma, which is created by gas discharges; this technology is mostly used for displays with a screen diagonal of more than 94 centimeters (37”).

Polarized glasses
or polarization glasses: glasses used for viewing 3D images created from two superimposed component images projected through different polarizing filters; the polarization of the lenses in the glasses ensures that each eye will only see the component image intended for this eye.

Progressive
capturing and broadcasting full frames sequentially (progressively); in digital television, these broadcast formats are designated by the letter "p".

Scrambling
signal-protection method used for digital television broadcasts, achieved by rearranging the data stream’s bit sequence according to a given algorithm; in order to view the broadcast properly, scrambling has to be reversed by descrambling signal on the receiving end.

SDTV
Standard-Definition Television: digital television in traditional pixel resolution, in Europe usually 720 pixels x 576 pixels (576i) for a 4:3 aspect ratio at 25 frames or 50 fields per second; SDTV is similar in quality to analog television.
Shutter glasses
glasses used for viewing “3D” video, in which the two component images are displayed in quick alternation; these “active” glasses are electronically synchronized with the display to ensure that each eye can only see the intended component image, while the other eye is blocked.

Stereoscopic image
a pair of images, consisting of two component images intended to be viewed by either the right or left eye only, in order to create an illusion of depth (three-dimensionality); these images may be juxtaposed, superimposed or alternated, depending on the viewing system.

Stereoscopy
technique for creating an illusion of depth by capturing and displaying two separate two-dimensional (stereoscopic) images representing the distinct viewing angles of the two eyes.

Sweet spot
designation for an area in front of an autostereoscopic display where a viewer has the best possible view of the stereoscopic image.

Three-dimensional television or 3D television (3DTV)
television broadcast methods that transmit stereoscopic images to create an illusion of depth, in addition to height and width.

UHD
cf. Ultra HD

UHD-1
ITU (International Telecommunication Union) designation for ultra-high-definition signals with a pixel resolution of 3,840 x 2,160, otherwise known as “4k”

UHD-2
ITU (International Telecommunication Union) designation for ultra-high-definition signals with a pixel resolution of 7,680 x 4,320, otherwise known as “8k”

UHDTV
cf. Ultra HD

Ultra HD
Ultra High Definition (UHD), also known as UHDTV: video signals with a pixel resolution several times higher than HDTV, initially 3,840 x 2,160, later 7,680 x 4,320, which is four and 16 times the resolution of HDTV (1,920 x 1,080), respectively; additional improvements in technical parameters – such as a higher frame rate, a higher bit depth for brightness and color, as well as an extended color gamut – provide a more lifelike viewing experience.

Widescreen format
16:9 aspect ratio (width : height) used in television, replacing the previous “full frame” format of 4:3 (= 12:9); some displays are being sold with an aspect ratio of 21:9, approximating the widescreen cinema format of 2.40:1.
5. Appendices

Appendix 1: Addenda Chapter 2.2

3DTV

Key criteria for each television picture are aspect ratio and resolution. The aspect ratio describes the ratio of an image’s width to its height, which is 16:9 in digital television, also known as “widescreen.” Standard television images thus have two dimensions, which does not correspond to natural vision, which also includes depth perception. In order to simulate this natural perception in digital television, it is not possible, however, to simply transmit depth as an additional dimensional information. Human depth perception is based on the discrepancy in visual information projected onto the respective retina of the two eyes, which are usually located about 65 mm apart. This difference can easily be verified by covering or closing first one eye and then the other. Even though the image that is displayed on each retina is two-dimensional, the human brain is able to process the two separate images and convey an impression of depth, i.e. of the three-dimensionality of space.

In physical terms, three-dimensional vision is a form of stereoscopy, i.e. the viewing of two horizontally offset “left” and “right” component images. This may be compared to stereophony in audio, where separate information about a sound is recorded and transmitted for the right and left side. This information is played back separately over two speakers placed at a certain distance to each other. Each of the two ears will receive different sound information and allow the brain to reconstruct a spatial sound experience.

When television pictures are supposed to appear three-dimensional to the viewer, the two eyes have to be fed separate, offset two-dimensional images. There are different concepts for displaying and viewing such left and right component images, all resulting in what is known as “three-dimensional television,” or 3DTV for short.
In the anaglyph method, the two stereoscopic component images are tinted in different colors (e.g. red and green) and superimposed. Viewing requires 3D glasses with colored filters, usually a red filter for the right and a green filter for the left eye. The red filter will suppress the red-tinted image for the red eye, which then sees only the remaining green-tinted image — as “black and white” — and vice versa. As a result, both eyes perceive different images, which the brain composes into one apparently three-dimensional image. The anaglyph method is relatively easily to accomplish and has been used on static images and early “3D” movies for many years with satisfying results. For colored moving pictures, like those on television, it is only of limited use and therefore not taken into consideration for modern-day 3DTV.

The display of stereoscopic images can also be accomplished by using polarized light. Typically, the light waves emitted by one component image would travel in a horizontal direction and those for the other in a vertical direction, thus forming an orthogonal system. Again, the two components — in this case with different polarization — are superimposed when displayed. To view the image properly, viewers have to wear 3D glasses with polarized lenses — one horizontal and one vertical —, allowing each eye to view only the component image intended for this particular eye and the brain to build a stereoscopic image perceived as three-dimensional.

One of the problems with this method is achieving even polarization over the entire image area and avoiding distortions when viewing the picture from different angles. To avoid these issues, the concept of so-called “shutter glasses” was developed for 3DTV, in which the two component images are broadcast in temporal alternation:

\[
\begin{array}{cccccccc}
1lA & 1rA & 2lA & 2rA & 3lA & 3rA & \ldots \ldots & (n-1)lA & (n-1)rA & n lA & n rA \\
\end{array}
\]

\[
lA = \text{left eye} / rA = \text{right eye} / 1 \ldots n = \text{frame numbers}
\]

The shutter glasses ensure that each eye can see only the corresponding component by alternately blocking one eye or the other with a "shutter" in sync with the frame rate. The receiver or playback device is synched with the shutter glasses either via cable, radio, or infrared connection.

In contrast to anaglyph or polarized glasses, which are passive, the shutter glasses represent an active system. The shutter effect is usually accomplished by a liquid crystals, similar in function to those in the liquid-crystal display (LCD) of many flat-screen TVs.

For the broadcast of current 3DTV via satellite, cable, and DSL (IPTV), existing HDTV receivers can be used without any modifications, but special displays are required for viewing. Since 3DTV has to carry two stereoscopic component images, which have to fit into a single HDTV broadcast frame, either the horizontal or vertical resolution of each component has to be cut in half. This will result in a satisfactory 3D illusion, but at the price of a reduced picture quality. This situation is different for HD content on Blue-ray Disc (BD), the DVD successor, which is able to retain the Full HD resolution for each of the two component images.

3DTV can be displayed on suitable, 3D-capable flat screens, either in liquid-crystal (LCD) or plasma (PDP) technology, but also projected by means of a suitable video projector. While 50 full frames are transmitted for standard 2D television, the component frames play a key role in 3DTV. The display unit thus has to be capable of displaying a minimum of 100 component frames per second in full resolution, in order to ensure judderfree playback.
The optimum solution would be a refresh rate of 120 Hz, i.e. 120 (component) frames per second, equaling 60 dual frames per second. This technology is marketed by device manufacturers as “Full HD 3D,” as it fully preserves the resolution of “Full HD 1080p.” Although this system is currently unsuitable for 3DTV broadcasting, it works well with BDs as signal sources, since they have sufficient storage capacity.

“3D” on BD works like this:
- acquisition of stereoscopic component images;
- parallel recording of these component images on BD;
- sequential output of component images to the display unit (flat panel or video projector), alternating between right- and left-eye component.

This will result in the best possible 3D quality currently achievable. In principle, this system would also work in broadcast television, but it would require new receivers.

The display of stereoscopic television images requires a 3DTV-capable flat panel TV or video projector (with a suitable projection screen), which can display at least 100 (component) frames per second. Higher frame rates claimed by some devices include computer-generated interpolated frames which are not present in the source material.

It has to be noted that for viewing 3D images with glasses of any kind, each viewer has to wear a pair. Moreover, the shutter glasses currently available are usually only compatible with a specific display panel or projector, as there is no universal standard (yet).

Another development that should be mentioned is that of autostereoscopic displays, which do not require special glasses for viewing the 3D effect, since the filters required for stereoscopic viewing of the component images are integrated into the display surface.

Currently, however, these displays still restrict viewers to specific positions in front of the display, which limits the number of viewers and their movement. Autostereoscopic displays, however, are likely to boost user acceptance of “three-dimensional” (stereoscopic) television.

**Appendix 2: Addenda Chapter 2.2.3**

**Autostereoscopic Displays**

In a parallax-barrier display, a mechanical or electronic LCD vertical strip pattern is placed at a short distance in front of the display panel, partially blocking certain pixels for each eye and allowing each eye to see only the pixels intended for this particular eye, thus feeding separate images to each eye and creating a stereoscopic effect.
In a lenticular-array display, a system of vertical lenses is mounted in front of the display panel, which deflect the light of certain pixels at one particular angle and the light of other pixels at a different angle. Each eye can thus see only those parts of the display that contain the image information intended for this particular eye, which permits feeding separate images to each eye and creating a stereoscopic effect.

The following table (as of January 2014) lists the major manufacturers of autostereoscopic displays worldwide.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Country</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACX</td>
<td>USA</td>
<td>autostereoscopic displays for consumers (manufacturer)</td>
</tr>
<tr>
<td>Alloscopy</td>
<td>France</td>
<td>autostereoscopic 3D technology (displays, services, software)</td>
</tr>
<tr>
<td>DataDisplayGroup</td>
<td>Germany</td>
<td>AS3D displays (manufacturer/distributor)</td>
</tr>
<tr>
<td>Dimenco Displays</td>
<td>Netherlands</td>
<td>end-to-end 3D autostereoscopic solutions, including displays, components, software, content conversion, and consultancy</td>
</tr>
<tr>
<td>emotion3D</td>
<td>Austria</td>
<td>displays, 3D-MV software, and services for professionals and consumers</td>
</tr>
<tr>
<td>exceptional 3D</td>
<td>USA</td>
<td>premium 3D digital signage, no-glasses 3D solutions and autostereoscopic 3D creative services</td>
</tr>
<tr>
<td>iPont</td>
<td>Hungary</td>
<td>3D digital signage and entertainment</td>
</tr>
<tr>
<td>Magnetic 3D</td>
<td>USA</td>
<td>autostereoscopic 3D technology (global leader in autostereoscopic 3D displays and 3D digital signage solutions)</td>
</tr>
<tr>
<td>Philips</td>
<td>Netherlands</td>
<td>displays (manufacturer)</td>
</tr>
<tr>
<td>SeeCubic</td>
<td>Netherlands</td>
<td>R&amp;D on autostereoscopic systems and software</td>
</tr>
<tr>
<td>SeeFront GmbH</td>
<td>Germany</td>
<td>autostereoscopic display solutions, unique technology</td>
</tr>
<tr>
<td>Sharp</td>
<td>Japan</td>
<td>displays (manufacturer)</td>
</tr>
<tr>
<td>Simtech 3D</td>
<td>Australia</td>
<td>autostereoscopic 3D visualization technology</td>
</tr>
<tr>
<td>Sony</td>
<td>Japan</td>
<td>46”, 24” autostereoscopic 3D displays (46” 4k-based)</td>
</tr>
<tr>
<td>3ality</td>
<td>Israel / USA</td>
<td>autostereoscopic 3D display technology</td>
</tr>
<tr>
<td>3D Fusion Corp.</td>
<td>USA</td>
<td>3D displays and systems (manufacturer)</td>
</tr>
<tr>
<td>3D International</td>
<td>Malaysia / Germany</td>
<td>glasses-free 3D hardware, software, and content-provisioning solutions</td>
</tr>
<tr>
<td>3DVIZION</td>
<td>Philippines</td>
<td>3D display systems (manufacturer)</td>
</tr>
<tr>
<td>3M</td>
<td>USA</td>
<td>3D foils for autostereoscopic displays (manufacturer)</td>
</tr>
<tr>
<td>Toshiba</td>
<td>Japan</td>
<td>autostereoscopic 3D displays for consumers</td>
</tr>
<tr>
<td>TRIDEILITY AG</td>
<td>Germany</td>
<td>displays (manufacturer)</td>
</tr>
<tr>
<td>Zero Creative</td>
<td>Netherlands</td>
<td>3D visualization</td>
</tr>
</tbody>
</table>
Appendix 3: Addenda Chapter 2.4

Ultra HD

**Recommendation ITU-R BT.1201-1** defines resolutions beyond the HD resolution of 1,920 pixels x 1,080 pixels as a future video standard for a variety of applications – including computer graphics, industry, health care, education, and television – and designates them as extremely high resolution imagery (EHRI). It does not yet explicitly list specific pixel resolutions, but it does specify that the pixels should be square – i.e. have an aspect ratio of 1:1 – both in image capture and display. Moreover, the spatial resolution should be a multiple of the horizontal resolution of 1,920 pixels and the vertical resolution of 1,080 pixels (based on Rec. ITU-R BT.709).

**Rec. ITU-R BT.1769** specifies two successor formats to the HD standard (with a resolution of 1,920 pixels x 1,080 pixels), classified as LSDI (large screen digital imagery) systems and defined as follows:

“LSDI is a family of digital imagery systems applicable to programmes such as dramas, plays, sporting events, concerts, cultural events, etc., from capture to large screen presentation in high-resolution quality in appropriately equipped theatres, halls, and other venues.”

Working Party 6C defines the following LSDI systems:

- 3,840 x 2,160 LSDI system
- 7,680 x 4,320 LSDI system

The pixels are square (1:1 aspect ratio), and the given options for color subsampling rates are 4:2:0, 4:2:2, and 4:4:4. Frame rates may be 24, 24/1,001, 25, 30, 30/1,001, 50, 60, and 60/1,001 Hz. Progressive scanning of the entire frame and bit depths of either 10 or 12 bit/pixel are mandatory. As for colorimetry, the document refers to Rec. ITU-R BT.1361 (“Worldwide unified colorimetry and related characteristics of future television and imaging systems”).

For viewing images with a resolution of 3,840 pixels x 2,160 pixels, a viewing distance of 1.5 times the height of the display panel and a viewing angle of up to 58° is given. For a resolution of 7,680 pixels x 4,320 pixels, the viewing distance should be three quarters of the height of the display, and the viewing angle could be up to 96°.

**Rec. ITU-R BT.2020** applies the term “Ultra-High Definition Television” for the first time to the two LSDI systems with 3,840 pixels x 2,160 pixels and 7,680 pixels x 4,320 pixels, repeating the previously defined parameters and adding 120 Hz as an additional frame-rate option. Moreover, the parameters for colorimetry are defined in this document for the first time.

“Ultra-high definition television (UHDTV) will provide viewers with an enhanced visual experience primarily by having a wide field of view both horizontally and vertically with appropriate screen sizes relevant to usage at home and in public places. UHDTV applications require system parameters that go beyond the levels of HDTV. This Recommendation specifies UHDTV image system parameters for production and international programme exchange.”
Document SMPTE 2036-2-2008 (by Technology Committee A29) describes the characteristics of the audio to be used in UHDTV production and distribution.

AES3-2003 is specified as digital audio standard, and a 22.2 (multi-channel) audio system with three vertical speaker layers (top, middle, and bottom) is defined, comprising 22 full-bandwidth channels and two LFE channels. In addition, the following parameters are specified for audio:

- sampling rate [kHz]: 48, 96 (corresponding to video)
- bit depth [bits/sampling value]: 16, 20, 24
- number of channels: 24 (full bandwidth)

Part 3 of the SMPTE ST 2036 family (SMPTE ST 2036-3:2012, by Technology Committee 32NF) defines the mapping of the UHDTV 1/2 video payload onto single-link, dual-link, quad-link, or octa-link 10G-SDI Mode-D signals (defined in SMPTE ST 435-2). Moreover, the mapping of ancillary data, audio data, payload ID and other additional data (specified in SMPTE ST 291) is described. For multiplexing in a single-mode fiber, WDM (Wavelength Division Multiplexing) or DWDM (Dense Wavelength Division Multiplexing) are available options.

At the beginning of the document, the terms UHDTV 1 and UHDTV 2 are once more defined, referring to pixel resolutions of 3,840 x 2,160 and 7,680 x 4,320, respectively. In addition, the “Basic Stream” is described as a parallel 10-bit stream, which has the same structure as the source data stream (defined in SMPTE ST 292-1). It contains the image structure information defined in the source format data and is carried via a 1.5 Gbit/s SDI signal. The images of UHDTV 1/2 are mapped into four or sixteen sub-images, respectively, by means of two-sample interleave division. Each of the sub-images has a resolution of 1,920 pixels x 1,080 pixels. The sub-images are then packaged into the 1.5-Gbit/s Basic Streams, in order for transmission via a single-link, dual-link, quad-link, or octa-link 10G-SDI Mode-D signal (cf. illustration on page 52).
The following remarks refer only to the mapping of UHDTV 1 into a 10G-SDI Mode-D signal. UHDTV 1 images with a frame rate of 24, 24/1,001, 25, 30, or 30/1,001 Hz are split into four sub-images, which are then available to four single- or dual-link Basic Streams, in order to be transmitted eventually via a single-link 10G-SDI Mode-D signal. The four sub-images in UHDTV 1 with a frame rate of 50, 60, or 60/1,001 Hz, on the other hand, are mapped into dual- or quad-link Basic Streams for transmission via a dual-link 10G-SDI Mode-D signal.

Ancillary (ANC) data is supposed to be filed only in Basic Stream Channel 1, both in single- and dual-link 10G-SDI-signal broadcasts. Audio data should be filed in the horizontal blanking interval of Basic Stream Channel 1. The maximum number of channels in a dual-link 10G-SDI Mode-D signal is 32 at a sampling rate of 48 kHz, or 16 at a sampling rate of 96 kHz. The payload ID should be filed in the blanking intervals of each Basic Stream.

**Color Perception and Representation**

The limited representation of colors in television systems can only be understood in terms of the basic characteristics of human vision. The human eye has three different kinds of photoreceptor cells (“cones”) for trichromatic (three-color) vision, each with a different spectral sensitivity (long, medium, and short wavelengths). In simple terms, the human eye has cones that are primarily sensitive to red (L), green (M), and blue (S) light. The combination of stimuli relayed to the brain by the three types of cone cells is processed by the brain, resulting in a perception of color. The spectral responsiveness of the three cone types shows a distinct overlap, which is important for the subtle differentiation of hues.

In the human perception of color, the principle of metam erism applies: Two colors are called metamers, if an observer perceives them as identical, even though their spectral power distributions might be significantly different.

In color theory, color spaces are used to map actual color spectra — e.g. the colors of the individual pixels in a television production — onto three so-called color values. This process thus emulates the characteristics of the human eye, which also “reports” any color to the brain via neural pathways in the form of only three "color values."

In mathematical terms, the color matching functions are multiplied by the spectrum of the color to be mapped, and the product is integrated over. Well-known color matching functions are the XYZ color analysis and various RGB analysis functions. In this manner, each color can be represented unambiguously by just three numbers, the color values.

The entire gamut of colors visible to the human eye is represented in a chromaticity diagram colloquially known as a "horseshoe curve." It is based on a color analysis in the CIE-XYZ color space (CIE = Commission internationale de l’éclairage / International Commission on Illumination). The area plotted in this graph is two-dimensional, since the dimension of luminance (brightness) is suppressed in the diagram. The two-dimensional representation thus only contains hue and saturation information, which are sufficient to describe color perception. At the center of the horseshoe is white (zero saturation), while the fully saturated monochromatic spectral colors are located along the outer edges. The straight line between the red and blue end of the curve is called the "line of purples."
Color Representation in HDTV

The color representation on monitor displays is also based on metamericism. In order to create a specific color perception for the viewer, it is not necessary to reproduce the existing color spectrum (e.g. on set) exactly – it is sufficient to just create a metamer. According to the principle of additive color mixing, colors on a television display are created by superimposing the three primary colors, red (R), green (G), and blue (B). Because of metameric matching, viewers cannot distinguish between the original color (on set) and the metamer composed of the three primaries, as long as the coordinates of the two colors (in the horseshoe curve above) are identical.

One important limitation in RGB color reproduction is that only colors within the “color triangle” created by the three primary colors can be reproduced. In HDTV, the primaries only cover the plotted area of Rec. ITU-R BT.709 – colors outside this triangle cannot be reproduced. This means that in HDTV, a wide range of natural colors also can be displayed only in approximation, but not correctly. Frequently quoted examples are sweet peppers and certain flowers, which reflect particularly saturated hues.

Approaches to extend the color gamut of HDTV included the so-called xvYCC color space and displays with four color stimulus values (which cannot be elaborated on here, due to lack of space). The term "xvYCC" stands for "extended-gamut video YCbCr" (also marketed as "x.v.Color") and describes manufacturer-specific but compatible extensions of the existing HDTV color gamut.
**Color Representation in Ultra HDTV**

On Ultra HD, peppers finally get a chance to show their true colors. ITU-R BT.2020, which covers UHDTV production and program exchange, recommends the coding of colors in the extended (relative to HDTV) color gamut, which is represented in the diagram by the Rec. ITU-R BT.2020 triangle. It covers a much wider range of visible colors than the Rec. 709 color triangle. Ultra HD thus has the potential to display a much greater variety of colors.

For a potential extension of the color gamut in Ultra HD distribution, it is important to know that an encoding in the Rec. 2020 color gamut requires a bit depth of at least 11 to 12 bit per color component. It also has to be taken into account that the tristimulus values according to Rec. 2020 are monochromatic. It appears that a reproduction of the Rec. 2020 color gamut is feasible with both laser displays and AMOLED- or LCD-based flat panels.

An advantage of the Rec. 2020 color gamut is that the coded colors can be represented on a display with Rec. 2020 stimulus values without any conversions. Apart from the choice of stimulus values, the color coding in luma and chroma signals as well as the non-linear pre-correction ("gamma") are relevant. In SDTV and HDTV, the non-linear pre-corrected signals – R', G', B' – are matrixed into one luma and two chroma signals. The subsequent chroma subsampling (4:2:0 or 4:2:2) creates a (small) luminance error on the display, caused by the violation of the principle of constant luminance.

For Ultra HD, Rec. 2020 permits the alternative generation of a luminance signal based on the linear primaries – R, G, B –, which results in a precise separation of brightness and color information, as subsampling or other processing of the chroma signals will not affect the picture’s luminance anymore. For the transmission of this novel luma signal as well as for the generation of the chroma signal, a non-linear pre-correction is performed, as before. This non-linear pre-correction, which was originally necessitated by the characteristics of the earlier CRT monitors, adjusts the luma signals to the human perception of brightness and results in a more efficient encoding. An SMPTE Working Group is currently developing a further optimization of non-linear pre-correction with regard to human perception characteristics.

An Enhanced Dynamic Reproduction (EDR) system for increasing the dynamic range and the color gamut has been shown at CES 2014 under the name Dolby Vision. The system is suitable for HDTV as well as Ultra HD.
The codec utilizes a dual-layer approach where today’s HD format is provided as the base layer, decodable by existing devices. The basis layer is joined by a second layer, to be decoded by new devices, which adds the additional information and metadata to recreate the full signal. EDR works independent of the resolution and frame rate and can be used with AVC and BT.709 as well as HEVC and BT.2020 color space – as planned for the introduction of Ultra HD.

Appendix 4: Addenda Chapter 3.1.2
Motion Picture Production for Ultra HD

The cameras currently used in 4k production for digital cinema and potentially suitable for future UHD 1 television productions are listed in the following table of 4k motion-picture cameras.

All the available 4k cameras listed share these features:

- Use of large-format Bayer-pattern CMOS sensor: full 4k resolution is only achieved for the green component, while the resolution of red and blue is reduced by half in both spatial dimensions. The output signal is interpolated up to 4k resolution in a “debayering” process.

- The large-format sensor typically results in a small depth of field, requiring extremely precise focusing during production, even though the monitors used during capture usually have comparatively small screens.

- Nearly all cameras (except for the Sony F55 and the JVC GY-HMQ10) lack uncompressed UHD-1 outputs. All cameras either record in a compressed format (e.g. ProRes) or in a proprietary RAW format. Only for Sony F55, a 4x3G-SDI-real-time interface has recently become available.

N.B.: The following table (as of April 2013) is not claimed to be exhaustive:

<table>
<thead>
<tr>
<th>Manuf.</th>
<th>Model</th>
<th>Introduced</th>
<th>Sensor</th>
<th>Max. pixel resolution</th>
<th>Max. fps [Hz] @ 4k</th>
<th>Compression</th>
<th>Acquisition medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canon</td>
<td>EOS C500 / C500 PL</td>
<td>Oct 2012</td>
<td>Super 35 mm [CMOS/8.85 Mpix.]</td>
<td>4,096x2,160</td>
<td>60</td>
<td>up to CBR 422P/422P/422H, HD (50 Mbit/s)</td>
<td>Dual CF Cards 4k RAW (only with external recorder)</td>
</tr>
<tr>
<td>For-A</td>
<td>FT-One</td>
<td>Sept 2012</td>
<td>Super 35 mm [CMOS/8.8 Mpix.]</td>
<td>4,096x2,160</td>
<td>900 (super-slo-mo)</td>
<td>-</td>
<td>SSD cartridges</td>
</tr>
<tr>
<td>JVC</td>
<td>GY-HMQ10</td>
<td>April 2012</td>
<td>1/2.3” [CMOS/8.3 Mpix.]</td>
<td>3,840x2,160</td>
<td>60</td>
<td>VBR 1/2.6/4/MPEG-4 four-stream recording (144 Mbit/s per stream/card)</td>
<td>SDHC/SDXC card</td>
</tr>
<tr>
<td>Red</td>
<td>Scarlet</td>
<td>Nov 2011</td>
<td>Super 35 mm [CMOS/13.8 Mpix.]</td>
<td>5,120x2,700</td>
<td>30</td>
<td>Redcode RAW (compression ratio between 18:1 and 3:1)</td>
<td>Redmag 1.8” SSD</td>
</tr>
<tr>
<td>Red</td>
<td>Epic</td>
<td>Sept 2011</td>
<td>Super 35 mm [CMOS/13.8 Mpix.]</td>
<td>5,120x2,700</td>
<td>150</td>
<td>Redcode RAW (compression ratio between 18:1 and 3:1)</td>
<td>Redmag 1.8” SSD</td>
</tr>
</tbody>
</table>
Appendix 5: Addenda Chapter 3.1.3
Live Production for Ultra HD

The following is a step-by-step description of Sky Germany’s very first Ultra HD test production on 1 December 2012. Further details on other test productions, some of which were mentioned in chapter 3.1.3, would exceed the scope of this document.

The first test production took place at the Allianz Arena stadium in Munich, Germany, during a Bundesliga (Federal League) soccer game between Borussia Dortmund and FC Bayern Munich on 1 December 2012. For this purpose, Sky and Kropac Media GmbH assembled the following team to carry out content acquisition and post-production:

- director/camera operator (Kropac Media GmbH)
- focus puller (Kropac Media GmbH)
- 2nd Assistant Camera/boom operator (Kropac Media GmbH)
- professional camera operator specializing in soccer (Sky)
- assistant for changing memory cards and backing up recordings (Kropac Media GmbH)
- post-production team of two (Sky/Kropac Media GmbH)

A Sony F65 Cinealta 4k camera was used for the test recordings, which features a resolution of 4,096 (4k) pixels x 2,160 pixels and records material in the Sony F65 RAW Lite format. The frame rate used was 50 frames per second (additionally 25 fps for test purposes). In addition, some sequences were recorded at 100 fps for use in slow motion replay. The material was saved to ten SRMemory Cards (@ 512 GB each), which were exchanged at regular intervals by the assistant during the game. In addition, memory-card content was extracted via an SR-D1 card reader, and subsequently backed up via an Apple MacBook Pro on an external Thunderbolt RAID (8 TB).
Apart from a variety of lenses, an Easy Focus focusing system was employed for measuring distances between the camera lens and the object and adjusting focus automatically. In some cases, however, the focus puller adjusted the focus manually.

During the soccer game, relatively small relative apertures (f-stops) were used (1.3 to 4), since light was low as a result of the late-afternoon kick-off time (17:30 hrs.). A 1.3 f-stop was used only for 100-fps sequences.

The following locations were used:
- Sky main building (ext. entrance)
- Allianz Arena (ext.)
- Allianz Arena (int./three different positions)

Inside the stadium, game sequences were first recorded from the sidelines, focusing on Sky presenter Sebastian Hellmann, who introduced the trailer. In addition, fan sections and individual players were recorded while preparing for the match. For these sequences, Arri Master Prime lenses and a Fujinon Premier 75-400 mm lens were used.

During the game, the cameras took three different positions, one after another.

Position #1 was also the primary camera position.
It was used to record the teams entering the arena, the kick-off, and the first ten minutes of the game. An Arri Ultra Prime 8 mm lens was used to capture a long shot of the entire playing field and adjacent sections of the stands.

After this, the camera moved into position #2, from which it recorded play action from approximate 15 minutes into the game to the end of the first half. In this position, a professional camera operator operated the camera most of the time, panning very quickly, as in today’s soccer productions in HD. For some sequences, the Fujinon Premier 75-400 mm lens was used. The HD cameras’ position on the same level facilitated a comparison of picture quality between HD and UHD later on.

The second half of the game was then recorded from camera position #3. The camera operator provided the fast pans necessary to follow play action. The Fujinon Premier 75-400 mm lens allowed him to capture action that was close to the camera as well as scenes in the distance (e.g. in front of the opponent’s goal).

Appendix 6: Addenda Chapter 3.5
Displays for Ultra HD

The table lists television sets already available for consumers. Professional displays used in studios and projectors used in digital theaters are not listed.

N.B.: The following table (as of January 2014) is not claimed to be exhaustive:
## Table: Ultra HD TV Sets (Consumer).

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Available from</th>
<th>Screen size [inch]</th>
<th>Native resolution</th>
<th>Interface (for representation of Ultra HD content)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grundig</td>
<td>Fine Arts 65 FLX 9490 SL</td>
<td>Apr 2014</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 1.4 (1x 4k interface)</td>
</tr>
<tr>
<td></td>
<td>Fine Arts 55 FLX 9490 SL</td>
<td>June / July 2014</td>
<td>55</td>
<td>3,840x2,160</td>
<td>HDMI 1.4 (1x 4k interface)</td>
</tr>
<tr>
<td>LG</td>
<td>84LM960V</td>
<td>Dec 2012</td>
<td>84</td>
<td>3,840x2,160</td>
<td>HDMI 1.4</td>
</tr>
<tr>
<td></td>
<td>65LA9709</td>
<td>Aug 2013</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 1.4</td>
</tr>
<tr>
<td></td>
<td>55LA9709</td>
<td>Aug 2013</td>
<td>55</td>
<td>3,840x2,160</td>
<td>HDMI 1.4</td>
</tr>
<tr>
<td></td>
<td>65LA965B</td>
<td>Aug 2013</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 1.4</td>
</tr>
<tr>
<td></td>
<td>55LA965B</td>
<td>Aug 2013</td>
<td>55</td>
<td>3,840x2,160</td>
<td>HDMI 1.4</td>
</tr>
<tr>
<td></td>
<td>49UB850V</td>
<td>approx. June 2014</td>
<td>49</td>
<td>3,840x2,160</td>
<td>HDMI 2.0 / USB</td>
</tr>
<tr>
<td></td>
<td>55UB850V</td>
<td>approx. June 2014</td>
<td>55</td>
<td>3,840x2,160</td>
<td>HDMI 2.0 / USB</td>
</tr>
<tr>
<td></td>
<td>55UB950V</td>
<td>approx. Aug 2014</td>
<td>55</td>
<td>3,840x2,160</td>
<td>HDMI 2.0 / USB</td>
</tr>
<tr>
<td></td>
<td>65UB950V</td>
<td>approx. Aug 2014</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 2.0 / USB</td>
</tr>
<tr>
<td></td>
<td>84UB980V</td>
<td>approx. Sep 2014</td>
<td>85</td>
<td>3,840x2,160</td>
<td>HDMI 2.0 / USB</td>
</tr>
<tr>
<td>Metz</td>
<td>Primus 55 UHD</td>
<td>Sep 2014</td>
<td>55</td>
<td>3,840x2,160</td>
<td>HDMI 2.0 / USB (photos)</td>
</tr>
<tr>
<td></td>
<td>Primus 65 UHD</td>
<td>Sep 2014</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 2.0 / USB (photos)</td>
</tr>
<tr>
<td>Philips</td>
<td>65PFL7018</td>
<td>Sep 2013</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 1.4 with UHD</td>
</tr>
<tr>
<td></td>
<td>84PFL7018</td>
<td>Sep 2013</td>
<td>84</td>
<td>3,840x2,160</td>
<td>HDMI 1.4 with UHD</td>
</tr>
<tr>
<td></td>
<td>40PUK6809/12</td>
<td>H1 2014</td>
<td>40</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>42PUK7809/12</td>
<td>H1 2014</td>
<td>42</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>49PUK7809/12</td>
<td>H1 2014</td>
<td>49</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50PUK6809/12</td>
<td>H1 2014</td>
<td>50</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55PUK7809/12</td>
<td>H1 2014</td>
<td>55</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55PUS8809/12</td>
<td>H1 2014</td>
<td>55</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55PUS9109/12</td>
<td>H2 2014</td>
<td>55</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>58PUK6809/12</td>
<td>H1 2014</td>
<td>58</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>65PUS9109/12</td>
<td>H2 2014</td>
<td>65</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>65PUS9809/12</td>
<td>H2 2014</td>
<td>65</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td></td>
<td>75PUS9809/12</td>
<td>H2 2014</td>
<td>75</td>
<td>3,840x2,160</td>
<td></td>
</tr>
<tr>
<td>Samsung</td>
<td>55F9090</td>
<td>Aug 2013</td>
<td>55</td>
<td>3,840x2,160</td>
<td>HDMI 1.4 / USB</td>
</tr>
<tr>
<td></td>
<td>65F9090</td>
<td>Aug 2013</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 1.4 / USB</td>
</tr>
<tr>
<td></td>
<td>85S9</td>
<td>June 2013</td>
<td>85</td>
<td>3,840x2,160</td>
<td>HDMI 1.4 / USB</td>
</tr>
<tr>
<td>Sony</td>
<td>KD-84X9005</td>
<td>Dec 2012</td>
<td>84</td>
<td>3,840x2,160</td>
<td>HDMI 1.4  [6op 4:2:0]</td>
</tr>
<tr>
<td></td>
<td>KD-65X9005</td>
<td>June 2013</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 1.4  [6op 4:2:0]</td>
</tr>
<tr>
<td></td>
<td>KD-55X9005</td>
<td>June 2013</td>
<td>55</td>
<td>3,840x2,160</td>
<td>HDMI 1.4  [6op 4:2:0]</td>
</tr>
<tr>
<td>Toshiba</td>
<td>55ZL2G</td>
<td>Aug 2012</td>
<td>55</td>
<td>3,840x2,160</td>
<td>Input of Ultra HD content via special connector only</td>
</tr>
<tr>
<td></td>
<td>58M9165DG</td>
<td>Sep 2013</td>
<td>58</td>
<td>3,840x2,160</td>
<td>HDMI 1.4</td>
</tr>
<tr>
<td></td>
<td>65M9165DG</td>
<td>Sep 2013</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 1.4</td>
</tr>
<tr>
<td></td>
<td>84M9163DG</td>
<td>Sep 2013</td>
<td>84</td>
<td>3,840x2,160</td>
<td>HDMI 1.4</td>
</tr>
<tr>
<td>Vestel</td>
<td>50”</td>
<td>May 2014</td>
<td>50</td>
<td>3,840x2,160</td>
<td>HDMI 2.0  HDCP 2.2</td>
</tr>
<tr>
<td></td>
<td>65”</td>
<td>May 2014</td>
<td>65</td>
<td>3,840x2,160</td>
<td>HDMI 2.0  HDCP 2.2</td>
</tr>
<tr>
<td></td>
<td>84”</td>
<td>June 2014</td>
<td>84</td>
<td>3,840x2,160</td>
<td>HDMI 2.0  HDCP 2.2</td>
</tr>
</tbody>
</table>
Content:
Project Group HD3D of the Working Group Devices and Connectivity of the German TV-Platform

The original German version of this White Book was produced in August 2013 (published in September 2013) and updated for this English-language edition (February 2014).

Translation: Dr. Thomas J. Kinne, Nauheim

Special Thanks

to the GfK Retail and Technology GmbH
for the provision of market data

Authors:
Ulrich Freyer (Agentur für Medientechnik),
Stephan Heimbecher (Sky Deutschland),
Holger Wenk (press liaison, German TV Platform/konzeptW),
Dr. Dietrich Westerkamp (Technicolor),
Sebastian Artymiak (VPRT),
Jürgen Burghardt (FKTG),
Carine Chardon (German TV Platform/ZVEI),
Alexa Christ (ZVEI),
Dagmar Driesnack (IRT),
Marcel Gonska (WLC),
Frank Hofmeyer (Technical University Ilmenau),
Eckard Matzel (ZDF),
Arnd Paulsen (Dolby),
Prof. Dr. Wolfgang Ruppel (Hochschule RheinMain),
Prof. Dr. Hans-Peter Schade (Technical University Ilmenau)
Dr. Ralf Schäfer (Fraunhofer Heinrich Hertz Institute),
Konstantin Schinas (Deutsche Telekom),
Nico Schultz (Hochschule RheinMain),
Dr. Helmut Stein (ISDM).

Disclaimer:
The information in this report was thoroughly researched with an unbiased approach, consolidated by our Working Group, and was, to the best of our knowledge, true and accurate at the time of publication. Any information herein reflects the status quo at the editorial deadline for each chapter. While every effort was made, the members of the Working Group and the German TV Platform cannot guarantee that the compiled information is current, correct, and complete, and therefore cannot accept any liability for material or immaterial loss or damage arising as a result of inaccuracies or omissions or the reliance on or application of false or incomplete information.

About Us – German TV Platform

The German TV Platform is an association of commercial and public-service broadcasters, device manufacturers, network operators, service and technology providers, research institutes and universities, state and federal authorities, and other companies, associations, and institutions concerned with digital media.

For more than two decades, it has been the goal of this non-profit organization to establish digital technologies in television broadcasting, based on open standards. In our Working and Project Groups, representatives from nearly every field in the consumer-electronics and media industry are committed to set the course on key issues of digital broadcasting.