

HDTV

— EBU format comparisons at IBC-2006

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This article provides some background information on the HDTV format comparisons conducted by EBU Technical Department at the International Broadcasting Convention (IBC) in Amsterdam during September 2006. The objective of the demonstration was to provide neutral and educative information for the HDTV format debate.

The demonstration not only showed the two current HDTV formats, 720p/50 and 1080i/25, but also introduced the next-generation HDTV format – 1080p/50. All three formats were presented with identical content and simultaneously on three Full-HD displays, in uncompressed and compressed form. Thus, viewers of the demonstration were able to judge the HDTV image quality for themselves.

The overall goal of the IBC demonstration was to give viewers an opportunity to evaluate the HDTV image quality depending on whether *interlaced* or *progressive* scanning was used. Further objectives were:

- Direct simultaneous comparison of **720p/50**, **1080i/25** and the next-generation **1080p/50** formats;
- Display of uncompressed and compressed sequences by applying **MPEG-4 AVC** compression;
- Visualisation of the image quality by using large 50-inch-diagonal consumer flat-panel displays with full HD (**1920 x 1080 pixel**) resolution.

720p/50	An HDTV format with 720 horizontal lines and each line with 1280 pixels, progressively scanned at 50 frames per second, as specified in SMPTE 296M-2001 and EBU Tech3299
1080i/25	An HDTV format with 1080 horizontal lines and each line with 1920 pixels, interlaced scanned at 25 frames per second or 50 fields per second as specified in SMPTE 274 and ITU-R BT.709-5
1080p/50	An HDTV format with 1080 horizontal lines and each line with 1920 pixels, progressively scanned at 50 frames per second as specified in SMPTE 274 and ITU-R BT.709-5

Abbreviations

AVC	(MPEG-4) Advanced Video Coding	MPEG	Moving Picture Experts Group http://www.chiariglione.org/mpeg/
CCD	Charge-Coupled Device	PLUGE	Picture Line-Up Generation Equipment
CRT	Cathode Ray Tube	SDI	Serial Digital Interface
DVI	Digital Visual Interface	SMPTE	Society of Motion Picture and Television Engineers (USA) http://www.smpete.org/
HD-SDI	High-Definition SDI	VQEG	Video Quality Experts Group http://www.its.bldrdoc.gov/vqeg/
ITU	International Telecommunication Union		
ITU-R	ITU - Radiocommunication Sector http://www.itu.int/publications/		

Demonstration, equipment and set up ¹

Simultaneous presentation of 1080p/50, 1080i/25 and 720p/50

In order to meet the objectives of showing all three formats in synchronized form, it was necessary to find technologies that could provide the three signal sources, 1080p/50, 1080i/25 and 720p/50, synchronized via timecode and in uncompressed form on DVI. The availability of a DVI interface on the playout device was particularly important since the chosen displays could handle the 1080p/50 format only on DVI. As playout servers, we chose three DVS Clipster Workstations that were synchronized via RS-422 timecode and which provided HDTV signals individually on their DVI interface.

Display and viewing environment

The bottleneck for the demonstration was the choice of a suitable display. Due to the fact that, today, no grade 1 flat-panel displays in the required size of 50-inch diagonal are available, we had to search for a consumer display that fulfilled our major requirements:

- full-HD resolution, 1920 x 1080 pixels;
- approximately 50-inch diagonal size, representing consumer high-end quality demands;
- interfaces that could accept 720p/50, 1080i/25 and, in particular, 1080p/50;
- little motion blur;
- good spatial scaler and de-interlacer performance;
- chromaticity and white point close to CRT parameters;
- availability for our IBC demonstration.

We chose three Pioneer plasma displays, type EX5000. For the demonstrations, the displays were aligned with a PLUGE signal and were set to 100 cd/m² peak luminance measured on a white surface of about 1800 cm² of the screen. All artificial noise-reduction or image-enhancement functionalities (except the de-interlacer) were switched off to provide as-balanced-as-possible processing for the three HDTV formats.

A further critical point was the viewing environment, namely the setup for the displays. We wanted to accommodate at least eight viewers – four persons seated at a 3 x picture height (3h) viewing distance and four persons at a 4h viewing distance. A horizontal configuration of three displays, side by side, would have had the disadvantage that none of the viewers could get an optimum view to all three displays in terms of distance, viewing angle and so forth. For that reason we decided to go for a vertical setup of the displays, where each of the three displays was slightly angled to provide

1. See IBC publicity handout – available [here](#) in PDF format (4.7 MB).

an optimum viewing distance and position. The construction and the centre seat with its ideal 3h distance point for all screens is shown in *Fig. 1*.

Source content

We wanted to show the same content in all three HDTV formats. In order to achieve this, we either had to use three simulation shots with three different cameras at the same time or one camera providing at least a 1080p/50 signal that we later could down-convert to 720p/50 and 1080i/25.

For practical reasons, we chose the latter approach. The first three sequences of our demonstration were part of the “Multi-format Test Set²” sequences provided by Swedish Television (SVT). The second three

sequences³ were created by the Technical Department of the EBU in conjunction with EBU Members during the first half of 2006 – soccer preparation games for the World Cup in Basel (Switzerland), festivals in Zurich (Switzerland) and the Eurovision Song Contest in Athens (Greece).



Figure 1
Three display rack with constant distance for central viewing position at 3h distance

SVT sequences

These were shot on 65 mm film at 50 fps, digitized to 2160p/50 and further down-sampled to 1080p/50, 720p/50 and 1080i/25.

EBU sequences

These were shot with the help of SRG-TPC Switzerland and TVN Germany using a CCD Camera (type HDC1500) with dual-link output for 1080p/50. 1080p/50 material was used as the source for creating the down-sampled 720p/50 and 1080i/25 content. The 720p/50 down-sampling was performed in software via low-pass and sync-window filtering in the DVS server. The 1080i/25 content was generated via box-filtering (line/pixel averaging) over two consecutive frames. Both methods were very close to practical applications in today's cameras.

Coding in MPEG-4 AVC

The uncompressed sequences were coded in MPEG-4 AVC with a software codec. This eliminated the observed variability in performance of manufacturer's current AVC hardware encoders and, furthermore, there is no 1080p/50 hardware coder available. We chose the Heinrich Hertz Institute (HHI) in Berlin as an internationally-recognized partner for the coding of the sequences. The

2. Free download – ftp server managed by Video Quality Experts group (VQEG), <http://www.its.bldrdoc.gov/vqeg/>
3. Available to EBU Members via <http://www.ebu.ch/en/technical>

encoder used was very close to the JVT9.0 reference encoder. All sequences were coded at bitrates of 20, 18, 16, 13, 10, 8 and 6 Mbit/s.

Presentation

The bottom screen was set up to show the 1080p/50 signal, the middle screen the 720p/50 signal and the top screen the 1080i/25 format. The reason for putting 720p/50 into the middle was to permit viewers a direct comparison between the formats under discussion today (1080i/25 and 720p/50) and a comparison to the next-generation HDTV format.

The viewers were “educated” on the impact of the displays and how the displays processed the incoming signals. In the case of 1080i/25, the display performed a de-interlacing. For 720p/50, a spatial up-scaling was used and in the



Figure 2
EBU Technical Director, Philip Laven, conducting an HDTV format comparison at IBC-2006

case of 1080p/50, an approximate one-to-one pixel mapping was used. Viewers were also informed about the approximate 3% over-scan of the displays.

In the demonstration, we first showed six sequences in uncompressed form (1080p/50, 720p/50 and 1080i/25). This was followed by a set of training sequences with high compression (6 Mbit/s). A detailed explanation was given to the viewers about the critical areas in the image and where to look for compression (coding) artefacts. After this training sequence, the same sequences were presented in compressed form at 18, 16, 13, 10, 8 and (again) 6 Mbit/s.

Summary of results, conclusions and future work

The demonstration was not intended to be a formal scientific subjective evaluation of the HDTV formats, but rather a first-hand look at the qualitative differences in the formats, in as fair and controlled an environment as we could arrange.

In the presentation of uncompressed sequences, the delegates reported difficulties in seeing difference between the three formats – even at a viewing distance of 3h. But when the compressed images were shown, the viewers did notice differences in the visibility of compression artefacts. Depending on the viewing distance and scene content, the artefacts became visible to a greater or lesser extent and, with few exceptions, the following were reported:

- The 720p/50 format showed better image quality than the 1080i/25 format for all sequences and for all bitrates;
- With decreasing bitrate in the compressed domain, the difference between the 720p/50 and 1080i/25 format became more marked;
- The 1080p/50 format was rated equal or better than 720p/50 for the higher bitrates – the extent depending on the test sequence. However, 720p/50 was rated better than 1080p/50 at the lower bitrates.

Conclusions and future work

For production

Our work suggests that the 1080p/50 format is of high value for content capturing, whatever the emission format. The 720p/50 format derived from a 1080p/50 (or higher spatial source) format was of very high quality. Many professional HDTV cameras in use today have sensors that capture progressively in 1920 x 1080 pixels (or even higher spatial resolutions) but, for studio interface reasons ^{4,5}, provide only a down-sampled 720p/50 or 1080i/25 signal on their HD-SDI outputs.

We can clearly recommend the use of 720p/50 as a television production format today. The fact that the 1080p/50 format (or higher resolutions) is used inside many of today's cameras raises the question of whether this would be a suitable HDTV production format in the future.

We believe that 1080p/50 in fact would be an ideal high-quality production format for the future – as soon as the following three fundamental issues are solved:

- 1080p/50 studio infrastructure;
- highly-efficient studio compression systems become available that can handle 1080p/50 whilst maintaining high quality (i.e. 7th generation transparency criteria) and without overloading the network and storage systems;
- availability at reasonable prices and with industry-wide support.

For emission

The demonstration suggests that a progressive format for emission provides the best image quality / bitrate compromise with MPEG-4 AVC compression. EBU Members have already been advised in EBU Recommendation R-112 that the 720p/50 emission format is currently the best option. The demonstration has underlined this statement. Once interlacing is applied to an image format, vertical-temporal information is lost that can never be recreated. The interlaced “footprint” causes an unnecessary burden in the digital broadcast chain, particularly since modern content-adaptive compression systems such as MPEG-4 AVC perform better with progressive signal sources than with interlaced signals. Furthermore, de-interlacing chips are not needed in flat-panel matrix displays ⁶ thus avoiding a further point of image-quality impairment and video-audio delay.

1080i/25 already suffers a first spatio-temporal “compression” in the baseband domain when interlacing is applied and this affects the whole digital chain (particular the encoders). Although different interlacing techniques are possible, roughly half the vertical-temporal information compared to 1080p/50 is removed. Consequently, an encoder has less information available to make intelligent decisions for compression and it is necessary to make more approximations which become visible as artefacts. 1080p/50 provides more information in the spatio-temporal domain and encoders can conduct the compression more efficiently. However, at the lower bitrates (i.e. <10...13 Mbit/s) the 1080p/50 encoder becomes more overloaded with information, depending on the content, and this information overload appears to become the dominant factor affecting quality. The impairments with high compression are not as bad as those for 1080i/25 but more visible than 720p/50. 1080p/50 has the potential to be a future HDTV format for emission, particularly if higher resolution displays are available, but further studies are required.

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4. Current HD-SDI is limited to 1.485 Gbit/s. New HD-SDI chipsets support up to 3 Gbit/s and consequently 1080p/50.
 5. Some cameras provide a dual-link HD-SDI output for 1080p/50 but this output is unsuitable for studio-wide use.
 6. Legacy format support would still require de-interlacers, but broadcasters using progressive-scan would provide better perceived images to the consumer.

The EBU is working via its HDTV project groups on a number of issues that have been outlined in this article. These include subjective evaluations of HDTV, the evaluation of HDTV codecs, HDTV production technologies and a route map to a fully-progressive chain including 1080p/50, standardization matters and the definitions for new flat-panel professional monitors.

Feedback on this report is welcome and should be sent to hdtv@ebu.ch.

Appendix A: HDTV Formats and Interlaced Scanning

In the 1930s, it was recognized that a frame rate of about 24 Hz (film) is not enough for good motion portrayal or for flicker-free display. However, at that time, it was difficult to handle frame rates substantially higher than 24 Hz in production, broadcasting and receivers. Consequently, a trick (interlacing) was applied to split up a frame into two fields with a field rate of twice the frame rate.

The suitability of CRTs for interlaced television representation, and the fact the human eye and the display acts here as an integrator between the fields, has provided a satisfying image quality for television throughout the world for the last 70 years. Today, we have a new display environment and we see a clear trend towards non-CRT progressive matrix displays, requiring incoming interlaced video signals to be de-interlaced.

To better understand the issues about interlaced-versus-progressive scan, we consider in the following sections the idealised spectrum of the three HDTV formats: 1080p/50, 1080i/25 and 720p/50. In the following diagrams we apply on the three axes: cycles per vertical resolution (picture height), cycles per horizontal resolution (picture width) and a temporal resolution (cycles per second). We assume for the following consideration the impact of a *vertical* Kell factor and an interlace factor applied to the vertical resolution, although it can be assumed that the low-pass characteristic of the HDTV system will also cause a reduction in realisable horizontal resolution. Therefore we denote the Kell factor as K_v (v for vertical) and the interlaced factor with a capital “I”.

The Kell factor K_v is defined as the ratio of the number of perceived lines to the number of total active video lines and usually has a value of 0.7 [1]. This factor was based on CRT measurements, and ideally would be measured in a non-CRT environment. The interlaced factor is field-rate dependent and is given in the literature [2] between 0.6 and 0.7. We use here a factor of $I = 0.7$ for 50 Hz field rates.

As we can see from *Fig. A1*, the 1920 x 1080p format has a larger horizontal and vertical resolution than the 1280 x 720p format. When a Kell factor of $K_v = 0.7$ is applied, both formats suffer from a reduction of vertical resolution.

In *Fig. A2* we show the 1920 x 1080i format and the impact of interlace which results in a gradual reduction of vertical resolution with movement, caused by subdividing a single frame into two fields (interlaced). *Fig. A2 (right)* shows the 1080i/25 format with a Kell factor of $K_v = 0.7$ and in addition the interlace factor $I = 0.7$ caused by incomplete cancellation of the fields (interline twitter). Both factors further reduce the available vertical resolution of the format.

In *Fig. A3* we show the idealised spectrum of the 1920 x 1080i format with Kell and interlaced factor compared to the 1280 x 720p signal with Kell factor.

The impact of horizontal sub-sampling, which is used by popular production recording systems (i.e. HDCAM, DVCPROHD), results in a further significant reduction of the spectrum volume. In the case

of concatenation of different systems in the digital chain, the final spectrum will be constrained by the sum of all the different spectrums.

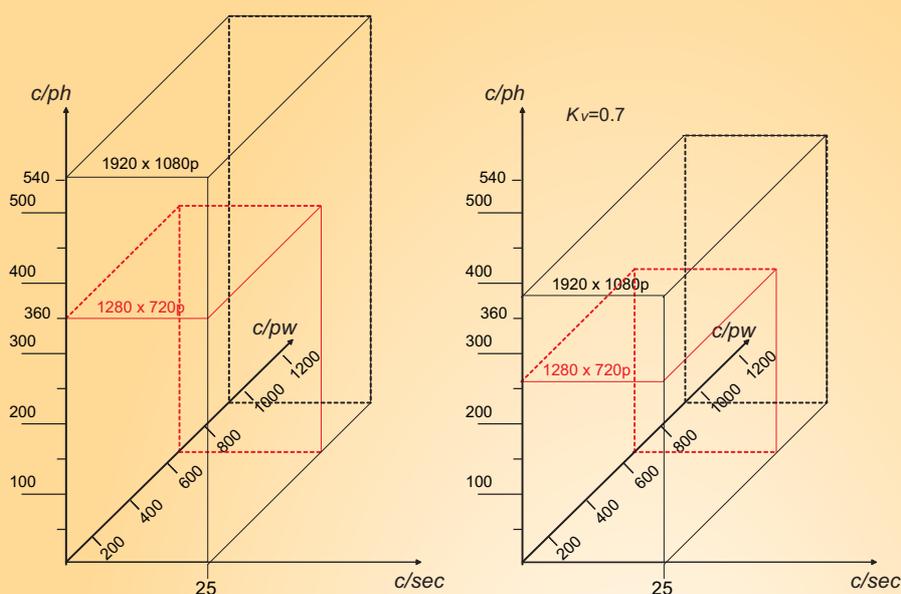


Figure A1
Ideal spectrum of 1080p and 720p HDTV base-band format in cycles per picture height, picture width and temporal value of 25Hz for the Nyquist temporal resolution of a 50Hz system. (Left) the progressive format without Kell factor and (right) with Kell factor leading to a reduced vertical resolution

Figure A2
Ideal spectrum of 1080i HDTV base-band format in cycles per picture height, picture width and temporal value of 25Hz for the Nyquist temporal resolution of a 50Hz system. (Left) the 1080i signal spectrum without Kell and interlaced factor and (right) with Kell and interlaced factor

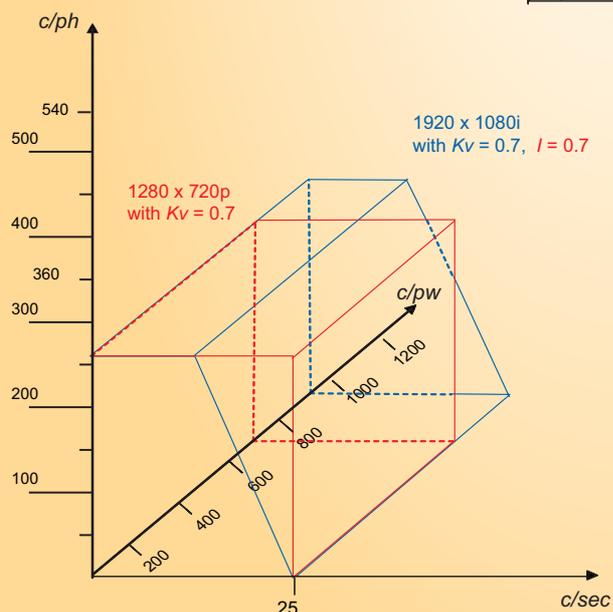
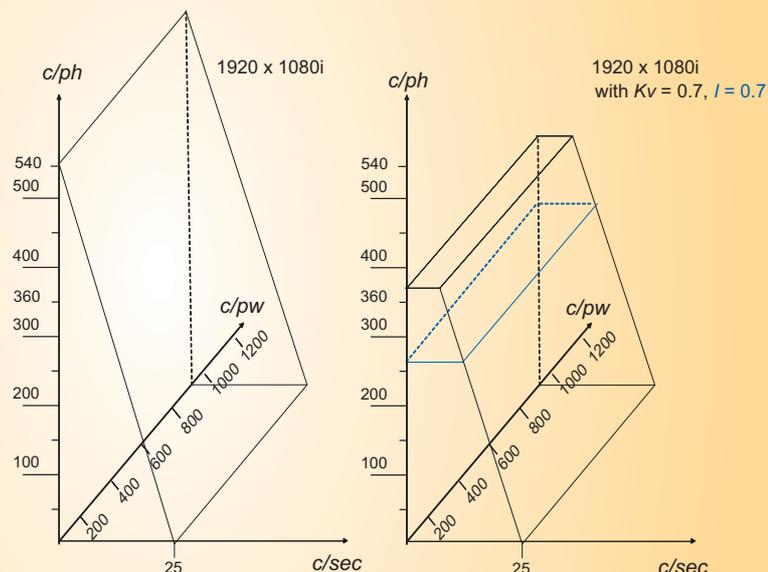


Figure A3
1080i format compared to the 720p format with Kell and interlaced factor



Hans Hoffmann was born in Munich, Germany in 1964 and received an Engineering Diploma from the University of Applied Sciences, Munich. He joined the Institut für Rundfunktechnik (IRT) in 1993, later moving to the television production section where he became involved in activities of the EBU and SMPTE. He chaired the EBU project groups P/BRRTV and P/PITV which were both involved in activities for studio interfaces and file formats. He also chaired a subgroup of the joint EBU-SMPTE Task Force and later the SMPTE technology committee on Networks and File Management. He went on to become the SMPTE Engineering Director Television until the end of 2005.

In 2000, Mr Hoffmann joined the EBU Technical Department in Geneva as a Senior Engineer. Here he became particularly involved in the EBU projects on IT-based production, file formats, metadata etc. Over the last three years, he has been very involved in EBU activities on HDTV and has set up the HDTV testing laboratory at the EBU headquarters in Geneva. He has published a number of technical papers and is a Fellow of the SMPTE and a Member of the SID, IEEE and FKT.

From the considerations given in this *Appendix* we can conclude the following:

- The spectral distribution of a 720p/50 and an 1080i/25 signal is basically similar in spatio-temporal volume;
- The 720p/50 signal should provide better movement portrayal and the 1080i/25 system should provide more detail via the higher horizontal resolution;
- Kell and interlaced factor both “reduce” the available resolution while the interlaced factor reduces the vertical resolution of the 1080i/25 signal. Considering all factors, a 720p/50 signal seems to have more advantages than a 1080i/25 signal;
- A concatenation of different HDTV formats and operating with horizontal sub-sampling should be avoided.

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Further reading

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