Image formats for HDTV

John Ive
Sony Europe – PSE

For several years, European broadcasters have been making programmes in high definition – often based upon co-production deals with the USA and Japan – using the 1920 x 1080 Common Image Format. However, European consumers are currently restricted to down-converted standard-definition versions of the original full-resolution HD content. This situation will soon change as more broadcasters offer HD services – in addition to the pioneering and ground-breaking start made by Euro1080.

This article offers an overview of HD scanning formats and advises European broadcasters not to go against the tide by introducing new production formats for HDTV.

Broadcasting and television are now entering the era of High Definition (HD) – a transition as profound as the first introduction of television and the subsequent transition from black-and-white to colour television.

Unfortunately Europe lags behind other parts of the world, denying consumers the chance to view HD programmes in anything other than standard definition. HD has been with us since the early 1990s but those early European attempts unfortunately proved to be unsuccessful. So what has changed? The renewed interest can be attributed to several factors, the main ones being:

- the availability of high-resolution, large, flat-panel displays for consumer use;
- a track record of success in other parts of the world;
- desk-top high-definition production and editing;
- significantly reduced costs.

Baird's 1928 30-line disc recording "Miss Pounsford"

Before delving in to the details of scanning formats for high definition, it may be of interest to briefly review the origins of television and their respective picture formats. One of the early pioneers of television was John Logie Baird who introduced television in to the UK with a 30-line vertical mechanical scanning format *(see Fig. 1)*. Despite refinements, it was of course inevitable that electronic scanning should become the mainstream. In the early 30s, the UK moved to 405 lines with a theoretical video bandwidth of 3 MHz. Germany, also an early pioneer of television,

broadcast the 1936 Olympic Games using 180 lines, later moving to 441 lines. France started with 441 lines and subsequently moved to 819 lines.

It is interesting to note, in the context of high definition, that these early 405/441 services were officially named "High Definition". Additionally the 4:3 aspect ratio was the so-called "Academy" film format from that time. Apart from the obvious decision to follow the film aspect ratio, it was also a practical necessity, resulting from the early CRT circular screen construction, with 4:3 (1.33:1) being the widest screen format that could realistically be supported without wasting excessive screen area.

In the 50s, the film industry started the migration to wider screen formats of 16:9 and beyond. It has taken television approximately 50 years to catch up with this innovation!

As technology improved and colour television was introduced, Europe migrated to **625 lines, 50 fields/sec, interlaced** scanning and several other parts of the world – including of course North America – settled on **525 lines, 59.94 fields/sec, interlaced** but in both cases still retaining the 4:3 Academy format.

And so to high definition

High definition, as we know it today, has always been a widescreen 16:9 (1.78:1) format, not quite going to the extremes of the film industry with ratios of 1.85:1 up to 2.35:1, but a reasonable compromise between the needs of television and movies. In fact DVD has been one of the motivations for the television transition to widescreen. Several European countries have also used the introduction of digital standard-definition services to instigate this change.

As previously stated, the commercial introduction of high-definition services has been established in several other regions of the world and they are at last showing positive signs of commercial success and consumer acceptance.

Perhaps one of the first questions to be asked is: *"How should high definition be defined?"*. In fact the term has already been abused by marketing actions through the labelling of some consumer products as "High Definition Ready" or "DTV Ready" or "High Resolution" without a clear definition of the meaning. Consumers have been disappointed when they realize that they may need to buy additional equipment to receive HD on their "HD Ready" display, or that DTV means "Digital Television" not HD and that "High Resolution" products may not be high-definition capable at all! It is of course possible to receive high definition and down convert to standard definition for display, something that must be done for low-end plasma displays capable of just 480 lines native resolution, but the end result is certainly not high definition!

Figure 2
Worldwide HD broadcasting

	**USA**	**1080/60i, 720/60P** 1,060 DTV/HDTV stations on-air (as of Oct 2003), 99.17% coverage – HD available through terrestrial, satellite and cable.
	**Japan**	**1080/60i** BS-4b satellite HDTV started in Dec 2000 (7 channels). Terrestrial DTV started in Dec 2003.
	**China**	**1080/50i** was announced in Aug 2000 3 major cities started on-air tests in July 2001. Official DTV starts from 2005 (66 cities).
	**Korea**	**1080/60i** Terrestrial HDTV tests started in Sept 2000. Simulcasts started in Dec 2001. Digitalization to be completed by 2005.
	**Australia**	**1080/50i (or 576p)** DTV/HDTV started in Jan 2001. DTV official kick-off at SMPTE 2003.

Looking at the current worldwide situation *(Fig. 2)* and the USA in particular *(Fig.3)*, high definition can be characterized from a consumer perspective in terms of spatial resolution as follows:

- image format – 1920 x 1080 with a minimum of 1280 x 720;
- flat-panel display format – 1920 x 1080 with a minimum of 1440 x 768.

(The origins of these parameters and their further justification becomes clear later in this article.)

Figs 2 and *3* provide an overview of the picture format decisions already in place and planned. As can be seen from these illustrations, the major land masses of Asia, North America and Australia have chosen to produce programmes and broadcasts using 1080i. In the USA, where 1080i is the dominant format, ABC and ESPN also transmit 720/60p, trading off the lower static resolution for improved motion portrayal.

Figure 3
US HDTV broadcasters

abc	720p	upn	1080i	Discovery HD	1080i	HDNet Movies	1080i	STARZ!	1080i
	1080i	WB	1080i	encore	1080i	themoviechannel	1080i		1080i
FOX	Autumn 2004	A&E	1080i	ESPN HD	720p	MSG	1080i		
NBC	1080i	Bravo	1080i	HBO HDTV	1080i	TV	1080i		
	1080i	Comcast SportsNet	1080i	HDNet	1080i	SHOWTIME HDTV	1080i		

The worldwide situation is of course of significance to Europe because, as a “late-comer”, it is highly preferable that one or more of these formats should be selected, rather than inventing yet another variant. Inventing a new picture format at this late stage would not be welcomed by manufacturers or end users. The benefits of maximizing commonality can be summarized as follows:

- to maximize interoperability and to minimize quality loss associated with format conversion;
- to take advantage of current product manufacturing, creating a greater mass market and thus reducing the costs;
- to encourage international HD programme exchanges and co-productions.

In production, three image formats currently predominate:

- 1920 x 1080 x 60/50i
- 1920 x 1080 x 24/25/30p
- 1280 x 720 x 60p

Note: for simplicity, 60 in this article represents both 59.94 Hz and 60 Hz.

The introduction of the 1920 x 1080 picture format represented an industry breakthrough when it was recognized and accepted by the ITU as the worldwide “Common Image Format”. For the first time in television history, an image format exists that is accepted by all parts of the world for both television and film use. Although technically more demanding, it is inevitable – as time progresses – that 1920 x 1080 x 50p will be added to the production format line-up – it combines the benefit of high resolution with superior movement portrayal. This is particularly important in production where the quality requirements are at their highest. Interestingly, living in a multi-format transmission environment, all the other formats can elegantly be derived from this one source.

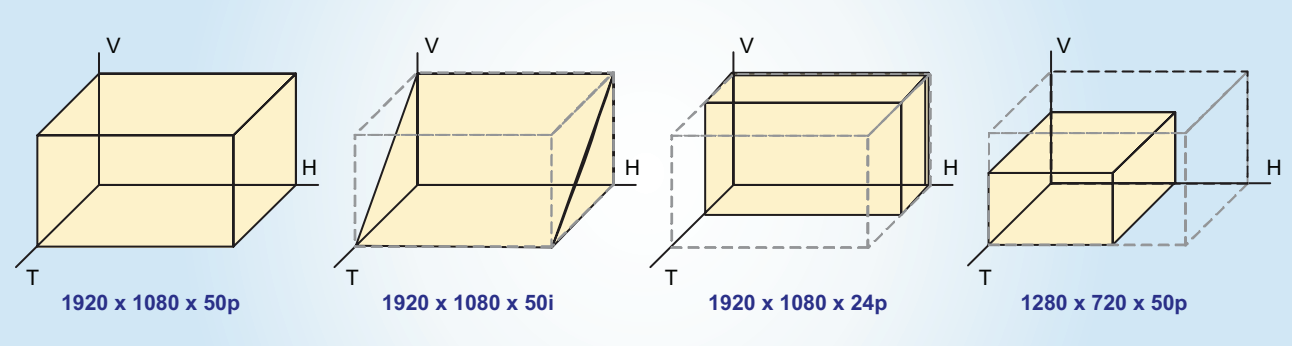

Figure 4
Four image formats – spectral limits relative to 1920 x 1080 x 50p

When the three-dimensional spectrum limits of 1920 x 1080 x 50P are observed *(Fig. 4),* it can be seen that all the other formats are a subset. The picture quality of down-sampled 1080/50p exceeds that achieved using native acquisition for each individual format – in much the same way that 35 mm film material, when converted to standard definition, looks outstanding with many of the annoying alias components removed by the down-sampling and filtering process.

It should be said, however, that the film industry intends to go further and additionally introduce an even higher resolution "4k" picture format for movie production. But, none-the-less, 1920 x 1080 is the closest to a universal scanning format that exists – in a similar way that made 35 and 16 mm film so popular. It would have been even better if commonality could have extended to the frame and field rates but, for the moment, the 50/60 Hz divide still remains.

1920 x 1080 x 60/50i

The Japanese should be credited with pioneering high definition when they started with the analogue "Muse" system, with broadcasts starting in the early 1990s. The vertical resolution at that time was chosen to be 1035 interlaced. Unfortunately, the worldwide television community could not agree on 1035 but eventually chose 1080 interlace to establish the "Common Image Format". Since that time, Japan has transitioned its services to 1080 which has contributed to a healthy trade in high-definition programme exchanges and co-productions between the USA, Europe and Japan.

One might ask: *"Why these particular parameters?"*.

Apart from the usual anomalies of a politically driven decision that is acceptable to all parties, some specific and useful simple sample ratios are recognizable. For example, if the standard-definition 4:3 horizontal pixel count of 720 is reworked for 16:9 and, at the same time, the resolution is doubled, the following relationships can be observed:

- 720 x 3/4 x 16/9 x 2 = 1920 pixels/line;
- 1920 x 9/16 = 1080 lines (based on square pixels).

Originally, interlace was perceived as a method corresponding to the scanning limitations of CRT tubes but more relevant today are the interlace benefits of high spatial resolution at reduced data rates when compared to the equivalent progressive scan. The price paid for this is a slight softening and increase of alias components for high-resolution moving images to which, fortunately, the human eye is psycho-visually not sensitive. Interlace scanning has facilitated cost-effective acquisition and production equipment, forming the majority of currently installed high-definition production hardware.

Abbreviations

AVC	(MPEG-4) Advanced Video Coding	**HD**	High-Definition
CMOS	Complementary Metal-Oxide Semiconductor	**HDTV**	High-Definition Television
DTV	Digital Television	**ITU**	International Telecommunication Union

The higher field rate of 50/60 Hz makes 1080i the preferred choice for sports content, rather than 1080 x 24/25/30P which is discussed next.

1920 x 1080 x 24/25/30p

One of the most remarkable changes "behind the scenes" of high definition is the way in which drama and television series production has evolved in the United States. The USA is a well-known exporter of movies but, in addition, many of the so-called "Soap" series are produced there and exported worldwide.

In line with the Hollywood tradition, the majority of the high-value Soaps were shot using 35 mm and subsequently converted to the target television standard(s). For a series that needs to produce a large volume of programme material in a short period of time, the use of 35 mm film is time consuming, expensive and inconvenient. It should therefore come as no surprise that many of these programmes are now shot in high definition at the film-friendly frame rate of 1920 x 1080 x 24p (or 25/30p). Cheaper recording media and instant playback are very tangible benefits.

Fig. 5 shows examples of programmes shot and broadcast in HD by the major US networks. Material produced in this way can be conveniently converted for worldwide distribution and can also be converted to other formats for transmission.

Therefore 1920 x 1080 x 24p represents a universal solution, retaining a certain commonality with film production but also offering convenient transfers to all worldwide high-definition and standard-definition formats. This format is not however popular for sports where the slow frame rate "film look" is not well appreciated and for which 50/60i or 50/60p offer better movement portrayal.

Figure 5
HD productions

Net-work	Show	Format
abc	8 Simple Rules	1080/24P
	I'm With Her	1080/24P
	According to Jim	1080/24P
	Less Than Perfect	1080/24P
	My Wife & Kids	1080/24P
	It's All Relative	1080/24P
	George Lopez	1080/24P
	Hope & Faith	1080/24P
	Life with Bonnie	1080/24P
CBS	Yes Dear	1080/24P
	Still Standing	1080/24P
	Becker	1080/24P
	Joan of Arcadia	1080/24P
	Hack	60i/35
FOX	One Minute w/ Stan Hooper	1080/24P
	Wanda at Large	1080/24P
	Luis	1080/24P
	Oliver Beene	1080/24P
	Bernie Mac Show	1080/24P
NBC	Whoopi	1080/24P
	Happy Family	1080/24P
	American Dreams	1080/24P
upn	The Parkers	1080/24P
	Girlfriends	1080/24P
	Half & Half	1080/24P
	One on One	1080/24P
	All of Us	1080/24P
	Rock Me Baby	1080/24P
	Enterprise	1080/24P
WB	Angel	1080/24P
	What I Like About You	1080/24P
	Reba	1080/24P
	Like Family	1080/24P
	Grounded for Life	1080/24P
	All About the Andersons	1080/24P

1280 x 720 x 60p

In the USA, ABC and ESPN transmit in 720/60P, even though some of their productions are also 1080-based. 720/60p is recognized also by the ITU – but not 720/50p. It can be argued that at a time when display sizes are predominantly 480 and 768 lines, the benefit of a higher transmission resolution is reduced. As previously described however, down-sampling from a higher resolution does produce superior pictures. With the current status of display technology, for stations such as ESPN whose output is primarily sports, the choice of 720P in the short term is understandable.

However there are some new considerations on the horizon. All the major flat-panel screen manufacturers have announced that the next generation of

television displays will follow the 1920 x 1080 common image format. This is the first time that screen sizes are to be video-centric rather than computer-centric. It represents the recognition by manufacturers that 1920 x 1080 will be the "sweet-spot" and the mass market of the future. With HD format decisions preferably remaining valid for the next 30 years or more, it becomes clear that significantly larger screens and higher resolution will become common-place.

720p can be up-converted to the 1920 x 1080 but broadcasters should think very carefully whether it is wise to undertake production in 720 – considering the rapid improvements in flat-panel displays, the need to future-proof their archives, the requirement to display some programme material on theatre screens, in addition to maximizing the potential for international programme exchange.

Broadcast delivery options for Europe

From January 2004, high-definition broadcasting was launched in Europe with the introduction of Euro1080. As the name implies, the transmission format is 1920 x 1080i using MPEG-2 compression. The transmission is handled by an Astra satellite and covers the major part of Europe.

The parameters chosen for satellite transmission, and indeed for other transmissions around the world, expose an acute problem facing European terrestrial broadcasters; **lack of bandwidth**. Most services have access to 15 Mbit/s or more for transmission but, because of the European digital multiplex structure, terrestrial broadcasters are trying to develop HD services that fit within an 8 - 10 Mbit/s data rate. Therefore every possible method of reducing the data rate is under study including new compression schemes such as AVC / H.264 and lower resolutions. As these services are dependent on new technologies and the available spectrum, it is unlikely that HD terrestrial transmissions will take off before 2008.

In contrast, satellite HD services have been announced by private broadcasters in the UK, France and Germany with a 2005/6 time-frame ahead of the 2006 football World Cup [1]. The better availability of satellite capacity will allow these private broadcasters more freedom to select the transmission format and use 1080i with MPEG-2 or AVC / H.264.

High-definition formats for non-broadcast applications

The future of high definition looks bright, not only because of broadcast television applications. There are many other consumer and entertainment options that will help to expand the market and make HD more commercially attractive. A selection of these applications include:

- movie production;
- Digital Cinema – movie distribution and exhibition;
- high-definition DVDs for packaged media and recording;
- Internet streaming and distribution;
- high-resolution video games consoles;
- consumer home-movie making;
- medical applications;
- military and surveillance.

Some of the applications represented above will influence the evolution of broadcast television, so are worth mentioning in more detail.

1. These broadcasters do not necessarily have the broadcast rights to this and other major sports events *(Ed.)*.

Movie production

Movie production has a history and tradition going back long before the beginning of television. Making a movie is considered to be an art form in addition to a craft skill. The movie industry has been supported by 35 mm film, the parameters of which have been steadily improved over the years. This, of course, is a tough act to follow for high definition TV.

When looking at movie production formats, 35 mm film cameras are generally judged to be equivalent in resolution to so-called "4k" images (4096 x 2160 or similar). Currently there are no commercial HD cameras available to support this resolution but, with pressure from the movie industry and improvements in image capture devices (in particular CMOS), it is only a matter of time.

Some would argue that 4k is the maximum theoretical resolution of 35 mm film but this quality level is rarely achieved in the final cinema presentation and, as a result, the cost-saving benefits of shooting in 1920 x 1080 x 24p frequently become a deciding factor. Over the past few years, several "blockbuster" movies have been shot entirely, or in part, using HD – the best known being the Star Wars series.

Whether shooting on film or in HD, image processing and post production are increasingly done electronically using what is called "Digital Intermediate" for which 4k transfers are now possible. The blockbuster "Spiderman 2" movie released in June 2004 was captured at 4k as a part of the digital intermediate process.

Digital cinema

The installation of digital projectors in movie theatres continues to grow and distribution networks are gradually being established. In Europe, Euro1080 has established a network of cinemas for its "Events" channel, showing for example live sporting events and concerts. Euro1080, as the name implies, uses 1920 x 1080 compressed with MPEG-2 and transmitted via Astra.

Theatre projectors have until recently been restricted to 1280 x 1024 but are now becoming available with a full resolution of 1920 x 1080 and even 4k projectors have been demonstrated as prototypes.

Consumer applications of HD

Europe faces a situation where consumers will soon become familiar with high definition through a range of products ... before they can even receive HD broadcasts.

For example, in Japan and recently in the United States, consumer HD recorders are now available. The most visible is probably the Blu-Ray format, based on optical disc technology similar in size to DVDs and CDs. The initial application was the recording of Japanese 1920 x 1080i HD broadcasts, compressed using MPEG-2. It will not be long before these devices have access to packaged media such as movies, exposing consumers to a quality that is far superior to broadcast transmissions.

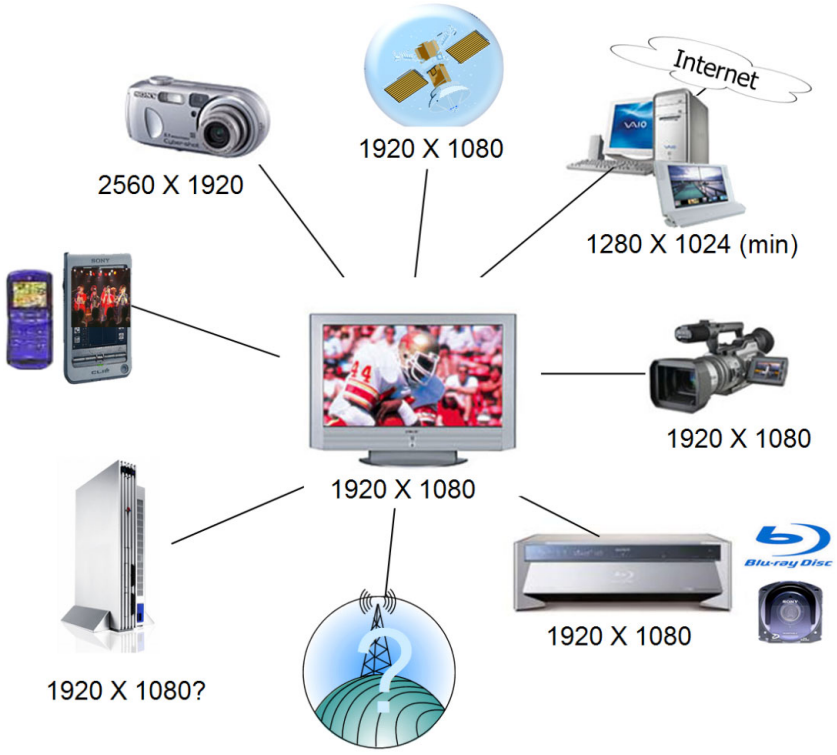

Figure 6
Consumer HD products

In addition to home recording and playback, the format specifications for HDTV targeted primarily at consumer camcorders have been recently updated to include 1080i as well as 720p image formats recording MPEG on to DV cassettes. To complement this development, software-editing companies now include HD in their list of supported formats. Consumer and professional HD products are therefore emerging – placing production tools in the hands of consumers and capable of producing images beyond those originated by broadcasters.

With the introduction of high-definition flat-panel displays in the home, further applications can be envisaged; for example, the display of still camera pictures (e.g. a 5 megapixel 2560 x 1920 image), viewing of websites (1280 x 1024 minimum resolution), playing of high-resolution video games (1920 x 1080) and downloading HD video programming from the Internet (at all resolutions).

Conclusions

For several years, European broadcasters have been making programmes in high definition, often based on co-production deals with the USA and Japan using the 1920 x 1080 Common Image Format. As has been demonstrated in this article, there is a rapidly growing library of programmes in countries that have pushed ahead with HD transmission, in particular the USA. Unfortunately European consumers are currently restricted to down-converted standard-definition versions and are denied access to the original full-resolution HD content.

This situation will soon change as more broadcasters offer HD services in addition to the pioneering and ground-breaking start made by Euro1080. It seems that satellites – having both the necessary channels and the available bandwidth for full 1920 x 1080 transmissions – are most suited to high-definition broadcasting in the short term.

There seems to be little justification for adopting production formats other than those already in extensive use around the world today – predominantly 1080i with two exceptions, ABC and ESPN-HD. Adopting different standards would just position Europe as a minority player and make international programme exchange unnecessarily more complex.

However the story does not stop at 1080i. The movie industry is pushing for higher resolutions both in acquisition and presentation. It seems entirely feasible that, in the near future, cameras will be capable of acquiring images at 1920 x 1080 x 50/60p and 4096 x 2160 x 24p resolutions. In addition, cinema projectors will rise to the challenge of projecting 4k images.

The technology is available now and consumer awareness of high definition is increasing. It really does look as if the false start of the early 1990s can be put behind us. Broadcasters should ready themselves to “ride the HD wave” before the end of this decade!

After obtaining an honours degree in electronics, **John Ive** joined the BBC in London where he gained valuable operational experience. In 1974 he started a four-year period at the Independent Broadcasting Authority (IBA), working on digital video research. He then joined Sony Broadcast & Professional Europe in 1978 as General Manager, Advanced Developments, leading an extensive team of research engineers. In 1985 he was promoted to Director, Product Management, responsible for the planning and introduction of new broadcast and professional products. In 1990 he was made head of the company's Broadcast & Professional Audio Business Division. He assumed his current position of Director, Strategic Planning, Sony Europe, in 1998.

Throughout his career at Sony, Mr Ive has contributed to the digitalization of the television industry. In recent years he has had similar involvement in the move towards IT-based production and HDTV. He is a Fellow of the Society of Motion Picture and Television Engineers (SMPTE), a Fellow and Silver Medal holder of the Royal Television Society (RTS), a member of the FKTG in Germany, a member of the IEE, member of the Audio Engineering Society (AES) and a Chartered Engineer. He is also a Director of the Professional MPEG Forum, an open industry organization working towards interoperability in networked environments.

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