High Definition for Europe — a progressive approach

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This article gives the background to recent discussions in the EBU about High-Definition Television (HDTV). The work described here was largely undertaken by EBU Project Group B/TQE (Television Quality Evolution) whose current membership is given in Appendix 1.

The balance of evidence suggests that the public interest will best be served by using a progressively-scanned delivery channel. Evidence about which progressive format would be optimum for the EBU environment has also been gathered, and is discussed in the article.

For over twelve years, the expensive and unsuccessful "HD MAC" venture left a legacy of doubt that HD broadcasting could be viable in Europe. Though it will not arrive overnight and there are many barriers still to be overcome, HD is now acknowledged to be a serious proposition for digital broadcasting in Europe for the relatively near future. There are a number of reasons, which include the following:

- Large flat LCD screens with HD resolution are becoming readily available at prices which the European public seems prepared to pay, providing the means to view HD.
- HD DVDs, together with equipment to play and record them, will be available in the next two years, stimulating the public appetite for HD.
- PC displays with HD quality potential are becoming widely used, which will acclimatise the public to HD.

Without minimizing the economic and practical problems, it is time for broadcasters in Europe to review the options for HD broadcasting. The EBU has been doing that, on their behalf, over the last nine months. A first conclusion has been drawn by the EBU Technical Committee, and work on a refinement of the recommendation is in progress.

Though some of the work on HD-MAC found useful spin-offs in other areas, there is a determination in Europe to make decisions this time around which are very, very solidly based. We need to learn from the lessons of the past. We need to choose HD technology with a future. This time, for digital HD, Europe needs to "*do it once, and do it right*".

European broadcasters need to analyse three core technical issues when they plan a route to HD. These are:

- the platform to use for delivering the HD package – satellite, cable and/or terrestrial;
- the scanning format to use for the delivery channel, and;
- the compression system to be used for delivering the HD.

All three are complex issues. Though all three are being studied, in this article we focus on the choice of scanning format for the delivery channel. This has been the larger part of the EBU's work to date.

The EBU recommendation for progressive scanning for HD delivery

In April 2004, the EBU Technical Committee recommended the use of progressive scanning, rather than interlace scanning, for the delivery of HD services by EBU Members. Their statement was as follows:

- **EMISSION** standards for HDTV in Europe should be based on progressive scanning, such as 720p/50 or 1080p/50.
- The EBU Production Management Committee (PMC) will consider the options for **PRODUCTION** standards for HDTV.
- The EBU Technical Committee notes that the standards for production and emission do not need to be identical.

Outside the EBU, this decision has been both applauded by some and criticised by others. The factors which led to the decision to recommend progressive scanning are outlined below. The concept of specifying the HD progressive *delivery* format separately from an HD *production* format, and thus of "decoupling" production from delivery is, we believe, an important and innovative one. It is an insurance policy which will lead to the maximum viewed quality, whichever production format is used.

EBU Project Group B/TQE is currently evaluating whether one or both of the two relevant specified SMPTE progressive HD formats for the 50 Hz world, 720p/50 and 1080p/50, should be recommended, and its current conclusions are given in the second part of this article. First, however, we outline below the case for progressive scanning itself as a background to the Technical Committee's recommendation.

The environment we have to consider is a world where HD-capable flat-panel displays (and others) in the home will use progressive scanning. These will supersede interlace-scanned CRT displays in the next five to ten years.

The display manufacturers tell us that the "core" flat panel – the "design target" for broadcasting – should be the "WideXGA" flat panel, which is a 768-line progressively-scanned display. This is a key assumption, and it should be clearly stated that we have to rely here on information received from outside sources. It is not the "wish" of the EBU that the 768p is the main display; this is simply the tool that nearly all manufactures tell us is, essentially, going to be the main game in town.

The environment we have to consider is also one where advanced content-adaptive digital compression technology is available and affordable in consumer equipment.

Interlace scanning is an ingenious and simple analogue compression system, devised seventy years ago. It is superfluous to say that we have more knowledge and processing power available today. Would it be a surprise to find interlace is no longer the best way to compress video, if you have a blank sheet of paper? Probably not, but we must look impartially at whether it is still the optimum. If it is, we should use it. If it is not, we need the fortitude to move on.

Externalities to consider

Since about 1990, all PC displays have used progressive scanning. The PC delivers progressive scanning, and the working basis of the IT world is progressive scanning. This applies throughout the world without regional or national variation. The PC environment has grown up in relatively recent times, compared to broadcasting, and PC systems could benefit from contemporary knowledge. On the other hand, we cannot take progressive scanning to be the best option for digital HD broadcasting without a fair and reasoned comparative analysis.

Today in the DVD world, progressive scanning outputs for DVD players are becoming a major selling point, and progressive scanning is being presented to the public as a major improvement in quality by the receiver industry.

Manufacturers who have major investments in interlaced scanning equipment development can be expected to, and do, support interlaced scanning.

Although interesting as evidence, we cannot finally take a decision based on how many organizations use interlace scanning or progressive scanning for HD delivery today and, if one or other were to be the majority, we cannot see this as the case for using it. The only way to approach this is to look objectively at the evidence in favour of interlace scanning and progressive scanning.

As public service broadcasters, the public are our stakeholders. We have to, and do, listen carefully to the manufacturers, but we have to seek the long-term public interest – even if it is different.

One of the fundamental questions considered by the EBU Project Group was whether Europe should change to a 60 Hz system for the sake of commonality with the 60 Hz world.

It certainly would be attractive to have a common worldwide standard and there would be benefits in using 60 Hz in terms of *motion portrayal*; and, for some types of display, *large area flicker* would be reduced. Weighed against this is the higher bitrate that an equivalent 60 Hz system would need.

On balance, it is difficult to make the case in a Europe where there is serious frequency congestion for what may be unnecessarily high bitrates. It is also true that those countries that have already started HD have a plurality of standards, so even adoption of a 60 Hz picture rate would not bring a common worldwide standard. If might have been feasible if there were universal adoption of a single progressive 60 Hz system, but we have been told by the 60 Hz world that this is impossible to expect.

The conclusions of the technical analysis

EBU Project Group B/TQE looked objectively at the technical case for retaining interlaced scanning or using progressive scanning. Although it may be surprising, the group has not been able to find technical arguments to support the continued use of interlaced scanning in the circumstances being considered. These are the delivery of new HD services to progressively scanned receivers, in an environment where advanced bitrate reduction is available. The technical arguments that we have found come down in favour of progressive scanning.

This is not to say that decisions taken years ago in other parts of the world to use interlace scanning for HD, principally in a CRT analogue world, were wrong. They were right for their time, and they may be right today for other circumstances. Furthermore, if a decision has already been made, and there is an interlace legacy, then the question "*Which is the best system for new services?*" is the wrong one. The question here is whether what you already have can be made to work. Interlace scanning can work well with advanced compression and progressive displays – it is just less efficient in transmission, needs complex standards-conversion in the flat-panel display, and has less motion-portrayal quality potential.

It may or may not be most cost-effective to use progressive scanning for programme production, or a mix of interlace and progressive. It may be that interlace production equipment will be cheaper for

Abbreviations

1080p/50	1080 lines, progressive scan, 50 Hz
720p/50	720 lines, progressive scan, 50 Hz
BMC	(EBU) Broadcast-technology Management Committee
CCD	Charge-Coupled Device
CMOS	Complementary Metal-Oxide Semiconductor
CRT	Cathode Ray Tube
DCT	Discrete Cosine Transform
HD	High-Definition
HD-MAC	High-Definition – Multiplexed Analogue Component
LCD	Liquid Crystal Display
MC	Multi-Channel
PMC	(EBU) Production-technology Management Committee
SD	Standard-Definition
SMPTE	Society of Motion Picture and Television Engineers (USA)

today. But by specifying a progressive delivery channel, we keep all the production options open, and make ourselves as future-proof as technology allows.

Arguments for progressive scanning

Coding gain

When we canvassed academic opinion – from those who have no financial or personal stake in interlace or progressive scanning – it was always the same story. In simple terms, anything an interlaced analogue bandwidth-compression system can do in series with a digital compression system, a content-adaptive digital compression system alone can do better, working on the "original" progressive signal.

Thus, one of the advantages of progressive scanning is that we can compress video in a content-adaptive way, rather than partly in a simple systematic way. A system such as interlace never cares what is best for the particular content being seen, or the bitrate available in the channel. In the twenty-first century, if you start with a blank piece of paper, there are – it has been argued to us – better ways to reduce bandwidth than to use interlaced scanning.

Taken overall, the application of digital adaptive compression must be more "quality efficient" than using interlaced scanning. There must be a "coding gain" associated with progressive scanning and adaptive compression, when compared to using interlace scanning and then adaptive compression.

Quantifying precisely how much this is, or will be, is difficult because it depends on the scene content. It cannot be done in terms of a set of a small number of subjective evaluation results; it has to be seen as the long-term result for the channel efficiency. In practice it seems that most of the coding gain of progressive scanning in a MC hybrid DCT environment comes from the improvement in the effectiveness of the motion compensation stages of compression.

Tests with the H.264 and Windows Media 9 compression systems have established that they compress progressive images "better" than they compress interlace images. The bitrate required to deliver a "good" quality 720p/50 image has been found to be less than that required to deliver 1080i (interlace) for material which is "critical but not unduly so".

Avoidance of display up-conversion

New LCD, plasma and non-CRT-based projection technologies are different from the CRT technology they replace [5]. It is relatively easy to convert a progressive delivered image to an interlaced form, but it's much more difficult to convert an interlaced image to progressive form to suit it to the new displays**.**

If you have a choice about whether to broadcast a signal which does, or does not, need de-interlacing in the receiver, all the arguments we have found support broadcasting a signal that does not need de-interlacing.

1) Firstly because creating whole pictures for a progressive display from an interlace signal is no simple task.

   Essentially you need different conversion algorithms in the receiver for when the picture is static and for when it is moving. It is complex because you are trying to compensate for information which is not there. Once the upper segment of the vertical/temporal spectrum is taken away by the interlacing, it cannot be recuperated.

   Certainly there has been much research and development of consumer interlace-to-progressive conversion by the large receiver manufacturers. But, even so, we are told (openly or in private) that progress – especially for HD resolution – is not matching its original promise.

We see on sale only equipment with simple “motion adaptive” designs, without motion compensation. While good for still images and for film mode, these methods are less good for television moving images. In television, our core business is moving images.

2) Secondly, if you must have a de-interlacer, it is better to do something once with expensive and complex equipment at the studio output, than to do it a thousand times less well using low-cost equipment in each and every receiver across the land.

EBU Group B/TQE assessed de-interlacers that are common in the domestic display environment and found they generally contributed impairment and limited the final quality of an HD-delivered image. However, professional conversion equipment of very good performance has been developed and good de-interlacers are available from a range of manufacturers for studio use.

From all this, we concluded that conversion from interlace to progressive should not be carried out at the receiver if we can avoid it.

Improvements in motion portrayal

Though the B/TQE group has not investigated the best forms for HD production [1], those broadcasters in the United States who are using 720p/60 progressive scanning have told us that the greatest reason for their using it is because of motion portrayal for sports content. When there is much movement, progressive scanning looks better, and indeed slow motion replay looks better.

History has taught us that sport was the major reason for people to buy colour television receivers in the sixties and seventies. For HD, sport will be a “killer” incentive to move to HD. There is every reason to take particular care of sports content for public service broadcasting where it is critical content.

Whether or not progressive scanning is used for production, the choice of progressive scanning for the delivery channel is an advantage. If we choose an interlace delivery channel, we are locked out of fully seeing the advantages of progressive production – they cannot be carried forward to the public. Having a progressive delivery channel allows us the option of using progressive production or not, as circumstances dictate, and this seems the responsible approach.

The future broadcast chain will begin and end with progressive scanning

Current picture sources are fundamentally “progressive”. The CCD/CMOS at the heart of each camera converts the optical image into electrical form with charges from all the rows of CCD elements transferred into a storage device at the same instant. “Interlaced” or “progressive” images are formed when the signal is “read” out of the chip: indeed, the interlaced signal is formed by discarding information.

We can also note that much electronic graphic programme material is generated in progressive form to avoid the twitter or flicker of fine detail.

Objectively, we will have a broadcast chain which begins and ends with progressive scanning and, given that you have the choice, one can see the use of interlace as an un-necessary limitation on quality built into the chain.

1. A new EBU Project Group, P/HDTP, has been established to do so.

The work of B/TQE in establishing the optimum progressive format

The above experiences led the Technical Committee to recommend that Europe's best interests are served by a progressive delivery channel, of which two are specified by the SMPTE – 720p/50 and 1080p/50.

To reach conclusions on whether one or the other, or both, should be recommended, the B/TQE group went back to first principles to establish what HD brings to the viewer.

Deciding on a proposition for an HD format is not purely a matter of simply citing who uses which system, or drawing three dimensional diagrams of the responses of different scanning formats. There are too many variables to take into account and, unless actually related to real equipment, these diagrams are misleading.

An appraisal needs to be done based on the results of controlled tests with real equipment and real people.

Figure 1
Comparing standard-definition and HD images

How much do we gain with HD?

Overall, of course, the SD image falls short of the equivalent HD-delivered image. For a general idea of the difference, *Fig. 1* shows a comparison between SD delivered with current MPEG-2, and HD delivered using a more advanced coding method. The shots are sections of a complex moving sequence. This is not a scientific test, but it is simply to show the general impact of the order of difference.

Fig. 2 shows how SD and HD have been compared by a large population sample in tests in Sweden. In this case, very good quality standard-definition DVDs were compared with HD Digital VHS on adjacent screens. The results showed that the SD picture quality was generally “fair” whilst the HD picture quality was judged as “excellent”. If they are seen together, there is about two quality grades difference between HD and SD.

This suggests that the critical factor for the viewer's perception of quality is the “context”. If the viewer can experience both HD pictures and SD pictures, he or she will evaluate the SD pictures as two grades worse than the HD pictures. When HD DVDs and HD-capable displays become popular, the viewer will experience this “context”, and this will lead to pressure on broadcasters to provide matching HD quality.

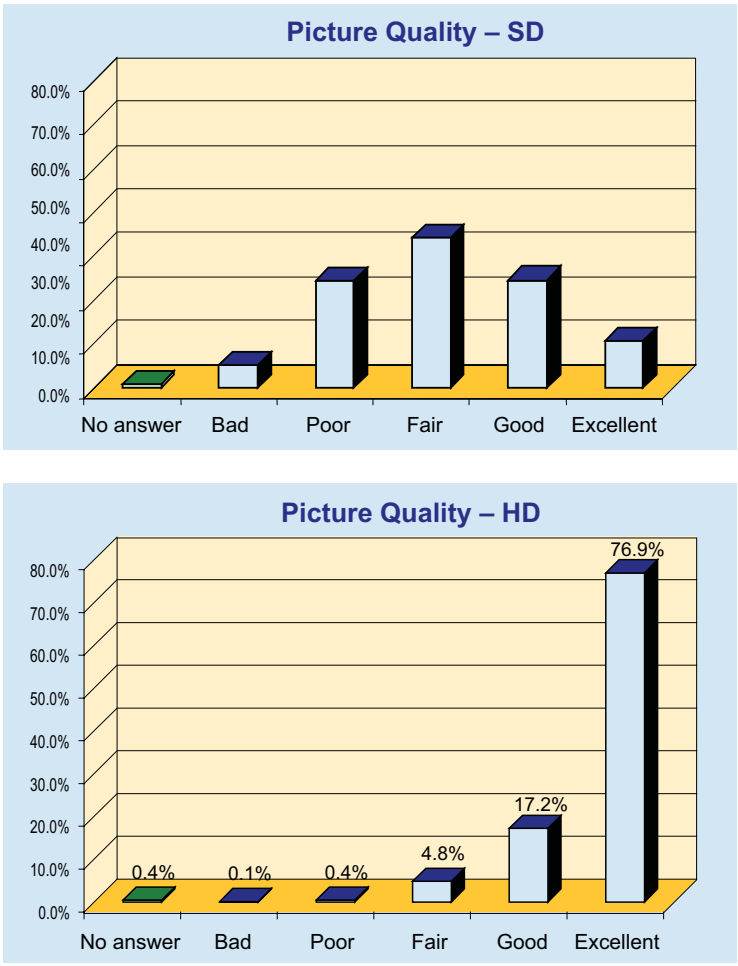

Figure 2
Comparison of SD and HD assessments

The screen sizes that are likely to be purchased in future

The display manufacturers and broadcasters have conducted extensive surveys to establish the size of flat-screen displays that consumers are likely to purchase.

As a representative example, *Fig. 3* shows results from one survey that was conducted in Stockholm. Visitors to an exhibition were asked to consider the large flat screen as "furniture" and decide what sizes would be desirable in their homes.

The results were very similar to those of other sources, and confirmed that the vast majority of large flat screens for European homes will be in the range 30 to 40 inches. This is the display size we will need to serve and, arguably, to "saturate" with detail.

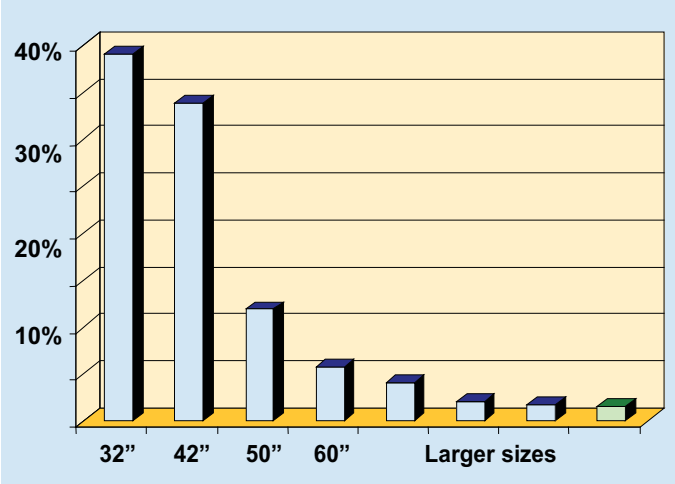

Figure 3
Percentage of audiece who would purchase different sizes of flat-screen TVs

The viewing distances for a 30 - 40 inch screen

In a series of tests conducted by the BBC, some 170 people measured the viewing distance they would choose if they were to introduce a large flat screen into their home. The results showed that the median viewing distance would be about 2.7m [7]. This figure is remarkably similar to that measured 15 years ago.

How much detail is needed to saturate the representative screen size for the representative viewing distance?

In a further series of tests, a range of still pictures were displayed on a monitor and observers were asked to adjust the level of detail (using pre-filtered versions of the pictures) until they could perceive no improvement in detail. The monitor actually displayed small portions of the pictures with two versions alongside each over; one filtered and the other unfiltered.

The results are shown in *Fig. 4*, expressed as the number of observers requiring a particular TV standard to provide adequate resolution at different screen sizes.

Fig. 4 suggests that 720p/50 delivery would largely saturate the eye with detail in the case of flat screens up to 50 inches at the representative viewing distance. This is the main basis for the current conclusion of the B/TQE group. 1080p/50 would provide more detail than needed to saturate the eye with the kind of screen sizes and viewing distances that will probably exist in European homes.

The balance between requirements for detail and spectrum efficiency

B/TQE believes that a judgment on the optimum delivery format needs to take into account both the requirement to saturate the eye with detail in representative circumstances, and the need to provide the lowest possible delivery bitrates for spectrum efficiency.

The European terrestrial airwaves, in particular, are highly congested and all broadcasters arguably need to be as spectrum-efficient as possible. There is no doubt that whatever the compression system used, the delivery bitrate for a 1080p/50 signal would be higher than for a 720p/50 signal. If a 720p/50 delivery signal is adequate, it is argued, it would be responsible to use it, rather than use a higher scanning format that provides detail which will not be noticed. This is not to say, however,

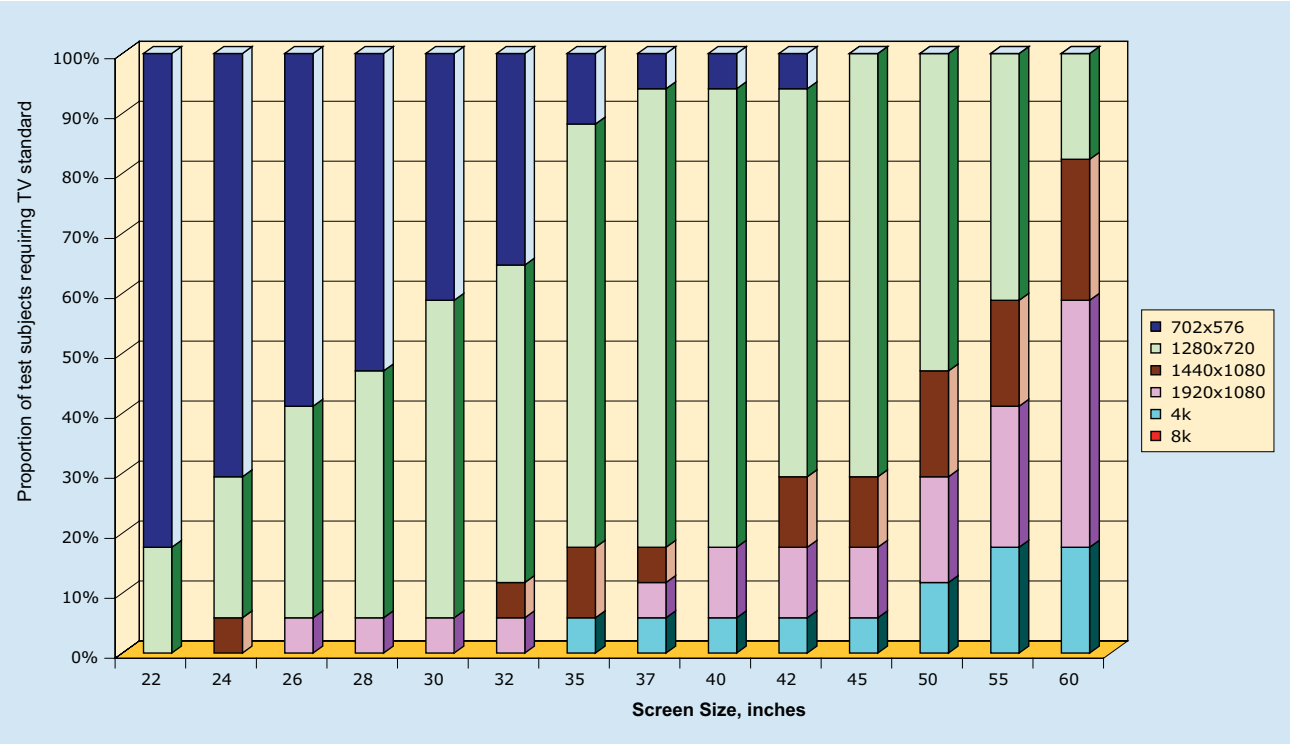

Figure 4
TV standard required to provide adequate horizontal resolution for 2.7m viewing distance

that 1080p/50 should not be used for programme production, where headroom could be an advantage – but this is the subject of another study.

This choice of the 720p/50 format, rather than 1080p/50, with an advanced compression system would decrease the risk of compression artefacts for practical bitrates. If we choose the lower of the two scanning formats, for a given delivery bitrate, we have a higher chance of providing artefact-free delivery.

What if the core display was a 1080p display?

A question to consider is: *What if events took a different turn to the one that the majority of receiver manufacturers believe?* One manufacture and several Japanese broadcasters tell us that rather than the WideXGA display becoming the core model, it will be one with higher resolution – a 1080p display. Should we take account of this scenario? If the world watched video content on 1080p displays, and 1080p DVDs were widely used, would 720p broadcasts look inadequate?

The research seems to suggest that if they are at the 2.7 m representative viewing distance, they would not notice the difference between 720p and 1080p content on the 1080p display, because the eye would already be saturated with detail by the 720p content. But if they watched at closer range, they *would* notice the difference.

It is difficult to base a decision about a broadcast format to be introduced in the next few years on a hypothesis about displays and future DVD formats. The B/TQE group believes that, on balance, it is better to begin broadcasting with the “adequate” and lowest bitrate system.

On the other hand, if manufacturers made receivers and set-top units which were able to decode any format up to and including 1080p this would allow 1080p to be used if the 1080p world emerges. The EBU is not at all against this, and indeed its Members have argued for such a scenario in several discussions.

However, in an open market in which public service broadcasters operate, the broadcaster cannot dictate to receiver manufactures what their receivers should do. But it does seem clear that if: (i) the

manufacturers decided to make receivers capable of handling progressive formats up to and including 1080p; (ii) the majority of displays were 1080p and (iii) there were 1080p DVDs in the public hands, then this is what the broadcasters would have to deliver.

Another issue which remains to be explored concerns the extent to which a given progressive input signal can be fully explored in practice by a given flat-panel display. If the three colour primary points are not spatially coincident (as they are not in practice), it may be that to fully exploit a given signal resolution, a higher resolution panel is needed to avoid spatial aliasing effects. In other words, it may be that a 1080p panel is needed in order to fully use the 720p delivery format. This remains to be seen. In the near term, however, the evidence before B/TQE at this time suggests that the best delivery format would be 720p.

How much will the viewer gain with 720p/50 compared with 625i/50?

Comparing the picture quality of any two systems is complex because there are different elements which affect the picture quality. The main ones are probably: (i) the level of artefacts in the picture, (ii) the resolution in the picture and (iii) the line visibility.

Of these, only the line visibility – the least important – would be relatively independent of the picture content. Here, traditionally, to equate the line visibility of an interlace picture to that of a progressive picture, we need to multiply the number of active lines in the interlace picture (576 in the case of the 625i/50 format) by about 0.6. Thus, a progressively-scanned image that offers the same line visibility as 625i/50 has 0.6 x 576 = 345 vertical lines.

Comparing the level of artefacts, and their degree of annoyance, between 625i and 720p is more difficult. The noise structure for interlace and progressive is different, so the same signal-to-noise ratio does not have the same visual effect. An interlace picture has more “structured” noise and this means that a given noise level is more annoying than the same level of noise in a progressive picture.

Comparing the resolution potential of the two systems is again difficult because the vertical resolution of the interlaced picture is limited; firstly, by alias effects (interline twitter) and then by the triangular vertical temporal response. You cannot easily define a single “pixel count” for an interlace picture, because the count varies with content. You cannot ask for “twice the resolution” of an interlace picture because: (i) the resolution is a variable, and (ii) the vertical resolution is not related to the number of active lines alone, but also to aliasing effects.

As an approximation, we could take the case of static resolution, and then note that this represents the minimum gain in resolution of the 720p format over 625i (in reality, 576i, as explained above). For the static case, we could use the so-called *interlace factor* to compensate for the aliasing, which is said to be about 0.7 for a 50 Hz system. Thus, for the 625i (interlace) format, the useable static resolution is 0.7 x 576 = 403 lines. Hence, the static resolution of 720p, when compared with 625i, is 720/403. This is the minimum improvement, and the figure would increase with movement which has a vertical element.

Making an overall appraisal is quite difficult then, and the best measure is probably the results of subjective evaluations. Here we found, as mentioned earlier, that there are about two quality grades of difference between HD and SD, when seen together.

Some future work

The next stages of the B/TQE work will be to assess the quality of service that can be achieved, and to obtain some measure of the number of premium services that could be delivered via a channel for terrestrial, satellite and cable systems. The character of new compression systems will also need a new study of the optimum multiplexing arrangements.

One potentially interesting new feature that may influence future services to large-screen displays is the use of non-real-time delivery. The receiving equipment for new services will be different in any

event from that currently used for standard definition. This may widen the options for new features, such as non-real-time delivery. Including this within the service proposition and specifying that new HD receivers should be able to include this option would maximize the data that could be allocated to the delivery of each programme.

Future work must also address the current shortage of 720p/50 equipment. This has hampered demonstrations and needs to be solved if 720p/50 is to be used before EBU Members can commit to the commencement of a service.

We extol our European and non-European colleagues in industry to encourage and develop HD equipment for Europe – based on progressive delivery.

Conclusions

The EBU Technical Committee recommends progressive scanning for HD delivery, for a number of reasons. The principal reason is that it removes the need for interlace-to-progressive display conversion at the receiver, and it makes the delivery system more future-proof.

The work reported here has led members of EBU Project Group B/TQE to believe that a single standard, 720p/50, could be selected for Europe for delivering HD quality images to new large flat-screen displays. It will provide the lowest delivery bitrate for HD that satisfies the demands of the HD viewer, given the assumption that he/she has a WideXGA display. This matter will be discussed within the Technical Committee over the coming months.

The B/TQE Group is currently encouraging other broadcasters and members of the broadcast and consumer industry to consider this and, based on its overall appraisal, will be making a proposal to its parent bodies in autumn 2004.

You may agree with the above appraisal, or you may not. In any event, the most important thing is to care about these issues, and to help shape a successful HD future for Europe.

We should be under no illusion that we can simply throw a switch and start HD broadcasting. The financial basis needs to be established. The receiver industry needs to be mobilised. There is still some way to go. But at least we have started.

Update, 11 October 2004

Readers may like to note that the EBU Technical Committee issued a Recommendation in October 2004 – document R112-2004 – which builds on the conclusions reported in this article.

It can be found **here** (listed under “HDTV”).

References

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[2] EBU Technical Statement D84-1999: **Use of 50Mbps MPEG compression in television programme production**.

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[4] EBU Report BPN 037: **Final report on statistical multiplexing**.

[5] R.A. Salmon: **The Changing world of TV displays – CRTs challenged by flat-panel displays**
BBC White Paper WHP 089, 2004. Also available as a **Technical Review article**.

[6] G.A. Thomas: **A comparison of motion compensated interlace-to-progressive conversion methods**
BBC R&D Report 1996/9

[7] N.E. Tanton: **Results of a survey on television viewing distance**
BBC R&D White Paper WHP 090.

Appendix 1: Membership of B/TQE

EBU Project Group B/TQE – current membership (2 September 2004)

Mike Croll (Chairman)	BBC	UK
Richard Salmon	BBC	UK
Simon Gauntlett	BBC	UK
Thomas Davies	BBC	UK
Jorn Tuxen	DR	Denmark
Xavier Drumare	FranceTV	France
Chris Hearn	Granada/ITV	UK
Hubert Graf	IRT	Germany
Wolfgang Graf	IRT	Germany
Per Böhler	NRK	Norway
Mario Stroppiana	RAI	Italy
Colin Kennedy	RTE	Ireland
Stanko Perpar	RTVSLO	Slovenia
Colin Wright	Seven Network	Australia
Lars Haglund	SVT	Sweden
Nathalie Montard	TDF	France
Olivier Louis Dusautoir	TF1	France
Vesa Vaarala	YLE	Finland
Eckhard Matzel	ZDF	Germany
Hans Hoffmann	EBU	Switzerland
David Wood (Secretary)	EBU	Switzerland
Yukihiro Nishida [a]	NHK	Japan
Giles Godart-Brown [b]	BSkyB	UK

a. Invited by the Chairman.

b. Invited as an observer by the Chairman.