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# Applications of novel video compression technology in television

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## Abstract

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# APPLICATIONS OF NOVEL VIDEO COMPRESSION TECHNOLOGY IN TELEVISION

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## ABSTRACT

Digital technology is now widespread throughout television production, and opportunities for the application of novel video compression technologies are increasing throughout television production, distribution and delivery. The requirements for these applications are diverse, and such technologies will need to be flexible and easily integrated. The paper discusses five technology areas that the BBC is researching, where there is potential for new video compression technologies to provide significant benefits. These areas are: digital radio cameras, IT production systems, D-cinema, low-bit-rate networking applications and digital delivery to the home. In each case the requirements for compression are discussed. In the case of digital delivery, results of tests conducted in collaboration with the EBU's Display Group are presented.

## INTRODUCTION

Over recent years, advances in video compression technology have continued apace, with ever-improving compression ratios and an ever-increasing variety of compression tools and methods. In particular, the emerging MPEG/ITU-T JVT standard is demonstrating extremely impressive performance (1). In the meantime, broadcasters now employ digital systems for delivery, production, contribution, distribution and new Internet services. Contribution, production and post-production applications are for the most part private to the broadcaster and so can employ novel compression systems, unconstrained by standardisation considerations. Even in digital delivery, there is pressure on broadcasters to improve performance in order to broadcast additional channels, or new services such as HDTV, as well as to take advantage of the coming generation of home-storage devices.

Video compression applications in broadcasting largely comprise compressed storage formats for capture and playout, based on I-frame CBR encoding, and long-GOP MPEG-2 encoding for distribution and transmission. However, these technologies have limited performance and flexibility in new application areas, which require properties such as scalability, constant quality compression, or lightweight software decoding. There are now significant opportunities to apply new, more powerful and flexible compression technologies.

This paper describes five technology areas that the BBC is researching, where there is potential for new video compression solutions to provide significant benefits. These areas are digital delivery to the home, digital radio cameras, IT production systems, Digital Cinema and low bit-rate video streaming.

## COMPRESSION APPLICATIONS IN BROADCASTING

### Digital television delivery

The domestic television market has changed rapidly in recent years and will continue to do so. Digital Television (DTV) delivery via various media will continue to grow, and the difficulties experienced by Digital Terrestrial Television (DTT) operators represent an opportunity for new technology as well as new business approaches to be brought to bear. At the same time, the domestic viewing environment is changing rapidly as new storage devices based on PC technology and digital media, and new flat panel displays, are increasingly penetrating the market.

The possession by viewers of significant storage capacity opens the possibility of delayed and even non-real-time delivery. In this context, the compression methodology can also change to become closer to a video streaming model: for example, traditional video GOP structures become irrelevant, since the viewer will have already selected what he wishes to watch and providing frequent I-frames to facilitate channel switching becomes unnecessary. This in itself results in greater compression efficiency. Nevertheless, it is worth remembering that for many types of content, such as news, sport or live events, delayed delivery is not an option: the set-top box of the future will therefore operate a mixed economy.

Recently, new flat panel technologies, such as Plasma Display Panels (PDPs) and LCDs have also begun to appear in the retail market. These displays offer the purchaser the ability to greatly increase his display screen area without impinging significantly on his living space, and in addition, the display technologies themselves offer the potential for much greater picture resolution and sharpness. Flat panel displays therefore provide an opportunity to broadcasters to deliver much higher picture quality to the viewer, who will watch television at much closer range relative to the picture dimensions. Correspondingly, this presents a problem in that picture artefacts, particularly from compressed digital delivery, are magnified. As a result, the requirements for video compression systems used for digital delivery are likely to change as these displays obtain greater market penetration.

*EBU flat panel display tests*

The EBU's Displays Group instigated research into this issue in order to understand the relationship between MPEG bit-rates and quality and the consequent requirements imposed on digital delivery. As part of this activity, the BBC performed formal subjective tests (2,3) earlier this year to establish the relationship between bit rate and perceived quality for both High Definition (HD) and Standard Definition (SD) MPEG-2 delivery to large PDPs. The HD standard used was 720/50p, rather than the more widely used 1080i standards, in order to explore the benefits of delivery via progressive video formats. Complementary tests performed by SVT and IRT (3,4) compared 720p and 1080i. Of particular interest was the comparison between SD and HD delivery at comparable bit-rates.

The test methodology is summarised in Figures 1 and 2 below. Tests were performed on two PDP panels: the first was a 480 line model with a digital SDI interface and no HD interface, viewed at 4x picture height; the second was a 768-line model with HD-SDI interface viewed at 3x picture height; both PDPs employed BBC-designed standards conversion and display algorithms. The SD material in both tests was derived via downconversion from HD sources, allowing direct comparison of HD and SD delivery.

The 480-line test compared two groups of MPEG-2 coded material with an uncompressed SD reference. The first was HD material, coded, decoded and then downconverted for display on the panel. The second group was the same material, downconverted to SD prior to coding/decoding, and display on the panel. The test therefore not only allowed the quality of SD MPEG-2 DTV to be measured on the PDP, but also tested whether there was a penalty to delivering SDTV to a display via an HDTV video source, which is one way in which an HDTV service could be introduced without simulcasting.

The 768-line PDP test likewise compared two groups of MPEG-2 coded material, this time with an uncompressed HD reference. The first group consisted of material coded at HD and displayed via the HD-SDI interface; the second group consisted of material downconverted to SD, coded and decoded, before being upconverted for display. This test effectively compared the subjective impact of the greater coding artefacts supposedly present in the HD material with the lower resolution present in the SD coded material. As a result of this test it was hoped to determine at what MPEG-2 bit-rate it becomes more worthwhile to transmit HD rather than SD.

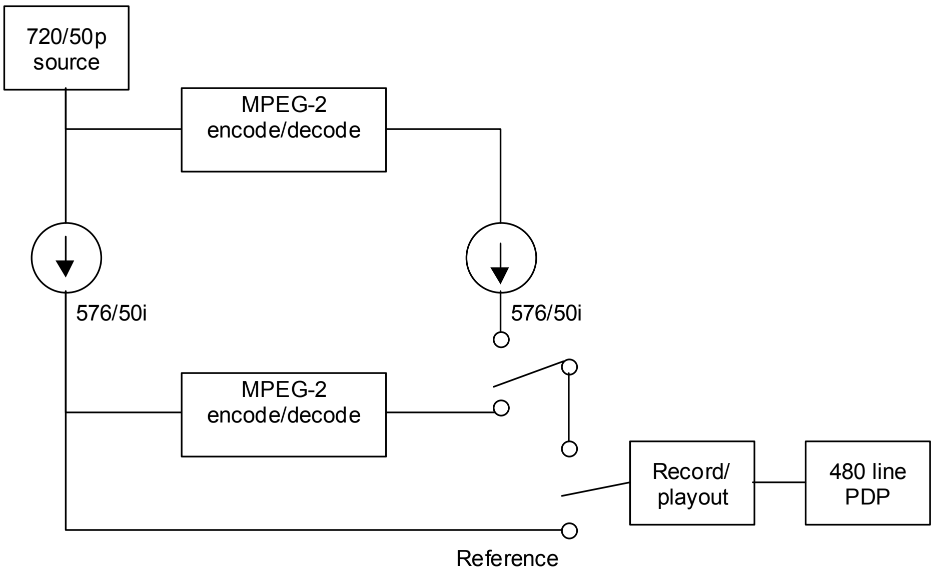


Figure 1. 480-line PDP test.

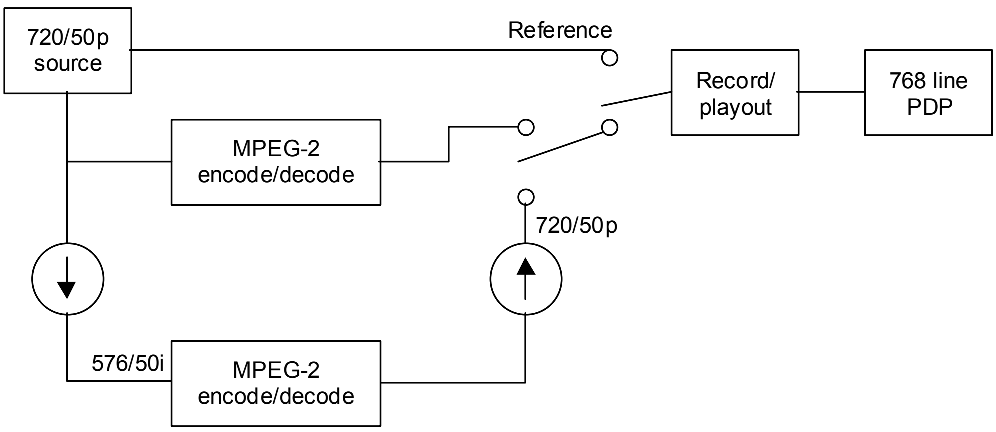


Figure 2. 768-line PDP test

*Test results*

The test results for the 480-line PDP are summarised in Figure 3, below, in which the vertical scale corresponds to ITU-T quality grades. The results showed that 8-10 Mbit/s was required to ensure that SD pictures on a 480-line PDP were within half a grade of uncompressed SD pictures. This is consistent with previous work by RAI (5), performed on similar PDPs, which showed that 7-8 Mbit/s was needed to ensure a quality degradation of less than one grade. For all common bit-rates, 720p HD and 576i SD delivery were, surprisingly, roughly comparable in picture quality, showing the efficiency of progressive-scan delivery.

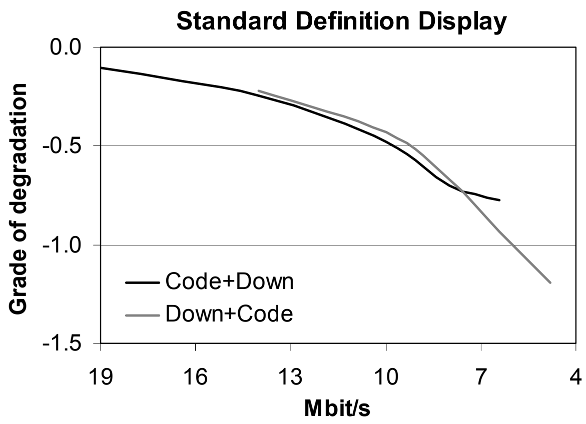


Figure 3: subjective quality of video coded at HD and SD relative to uncompressed SD video displayed on a 480-line PDP.

The results for the 768-line panel are summarised in Figure 4 below. In this test, the material split naturally into two sets. In the first set, characterised by simple motion and high levels of detail, there was a marked preference for HD delivery even for bit-rates as low as 6.4Mbit/s. For the second set, which were water sequences with little texture but with specular reflections and highly complex motion, a cross-over point was detected at between 10 and 14Mbit/s. Overall, the results showed that up to 19Mbit/s was required to ensure that all the HD pictures were within a grade of uncompressed HD.

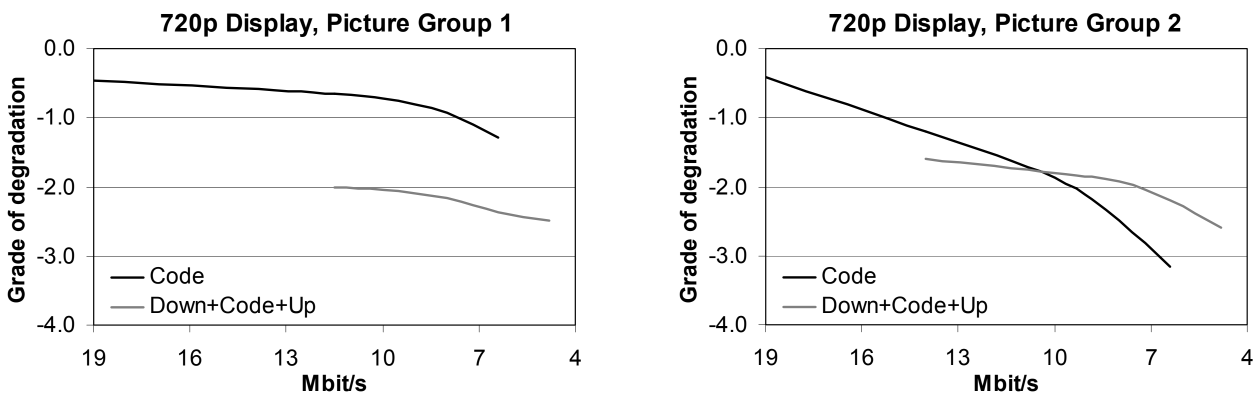


Figure 4: subjective quality of video coded at HD and SD relative to uncompressed HD video displayed on a 768-line PDP.

*Implications for DTV delivery*

These results have significant implications for setting requirements for digital television delivery over the coming years, whether by MPEG-2 or novel compression technologies. The results show that typical DTV MPEG-2 bit-rates of 3-6Mbit/s will not be adequate for display on large PDPs. The concern is that quality will suffer by comparison with DVD, where much higher bit-rates are available, and even analogue broadcasts. Currently flat panels remain rare and expensive: as costs fall and market penetration increases, broadcasters must decide whether they can or should attempt to provide adequate quality for this market segment. If broadcasters do choose to address this issue, then they have the option either of increasing bit-rates or delivering DTV using more efficient video compression than MPEG-2: however, bit-rates are highly constrained in the current DTV market.

The impressive performance of 720p over the sequences under test demonstrated the advantages of delivering in a progressive format, particularly when matched to a progressive-scan display. In addition, progressive formats facilitate standards conversion, thus making them ideal for delivery to a heterogeneous display environment of flat panels and interlaced CRTs via a standards-converting set-top box.

For DTT in particular, the use of alternative compression technology would open the way for one or more of a number of attractive options: more robust delivery, improved quality, increased coverage, and/or increased numbers of channels supported. Nevertheless, any changes to DTV compression technology or to video formats must take account of the considerable installed base of MPEG-2 based SD interlaced receivers, offering some form of compatibility or migration path to new systems. Furthermore, whilst the delivery mechanism between service provider and set-top box might appear to be private to the service provider, open standards are essential to ensure that costs for consumers remain low and that broadcasters can control quality throughout the full broadcast chain. For this reason, the most promising new technology for DTV delivery is the ITU/MPEG JVT system.

All of these options must now be carefully considered in order to ensure that the success of DTV continues and becomes available to the widest constituency of viewers throughout Europe.

**Digital Radio Cameras**

Radio cameras have been used in outside broadcast (OB) applications for some time, but the advent of digital radio cameras, developed by the BBC amongst other organisations (6,7,8), provides a step forward in quality and flexibility to the point where future studios can be envisaged operating solely with radio cameras. Digital radio cameras depend upon compression because of the RF bandwidth necessary for uncompressed video; but compression requirements will depend on the role of the radio camera. These requirements can be expressed in terms of three properties: quality, delay and robustness. Each of these properties affects bit-rates. Clearly improved quality requires higher bit-rates, but delay and robustness requirements impose severe constraints on what quality can be achieved within a finite spectrum allocation. Greater robustness in operation, in particular, whilst assisted by improved transmission and reception hardware, ultimately requires the use of lower transmit data rates or increased error protection, both of which reduce the capacity available for video. Reducing the end-to-end delay imposed by video encoding and decoding not only reduces the redundancy in the video sequence that can be exploited (for example, eliminating B-frames) but also constrains bit allocation severely, since the lower the delay the smaller the picture area over which the mean bit-rate must be met.

Radio camera roles can likewise be roughly divided into four categories: news cameras, used for gathering live and recorded footage; studio cameras; sport; and other OBs. Moderate or even low quality video can be tolerated from news cameras, which can usually work with long delays unless part of a live contribution link. Robustness of the system is paramount, as the RF environment cannot be controlled: this limits available bit-rate as the data stream must be made more resilient through robust modulation and FEC. By contrast, studio radio cameras will operate in a more benign RF environment allowing the high data rates necessary for studio quality. However, they may be integrated with cabled cameras, in which case low delay (2 frames or much less) is essential so that live editing can be done without anomaly. Sport requires low-delay cameras for the same reason, but also robustness as often only a limited receiving system can be cabled in; quality is less significant. Most demanding of all are high-quality Outside Broadcasts, such as concerts, where mixed cabled and cable-free coverage will limit delay, high quality is required but the RF environment may be difficult. These requirements are summarised in Table 1.

| | Requirements | | |
|---|---|---|---|
| Application | Delay | Robustness | Quality |
| News | High (low for contribution) | High | Moderate/low |
| Studio | Low | Moderate | High |
| Sport | Low | High | Moderate |
| Other OBs | Low | Moderate/High | High |

Table 1 – requirements for digital radio cameras

To date, the BBC has pursued a joint strategy to meet these various requirements, using the DVB-T COFDM modulation scheme in conjunction with either a long-GOP variable bit-rate MPEG compression system occupying a single DVB-T channel, or a dual-channel low-delay DVCPRO25 system, as well as pursuing other coding techniques. In all applications, the best compression that meets the delay and quality requirements should be used with the aim of minimising expensive bandwidth. Equally, there is a need to keep power consumption of hardware low to improve battery life and increase transmitted power. Radio cameras therefore require flexible solutions in which bit-rate, delay and quality can be traded off within constraints imposed by available bandwidth, power, and RF technology.

**Desktop production**

As costs fall and processing power increases, it is becoming increasingly attractive to use off-the-shelf IT equipment within broadcasting systems to perform functions hitherto done by specialist equipment. This trend applies to all aspects of the production process, including editing, post-production and archive retrieval and BBC R&D is developing systems to show the benefits of using IT equipment in broadcast systems (9). Compression is an essential part of PC-based production, and improvements in flexibility and compression, and reduction in complexity can reduce hardware, computing and networking costs significantly.

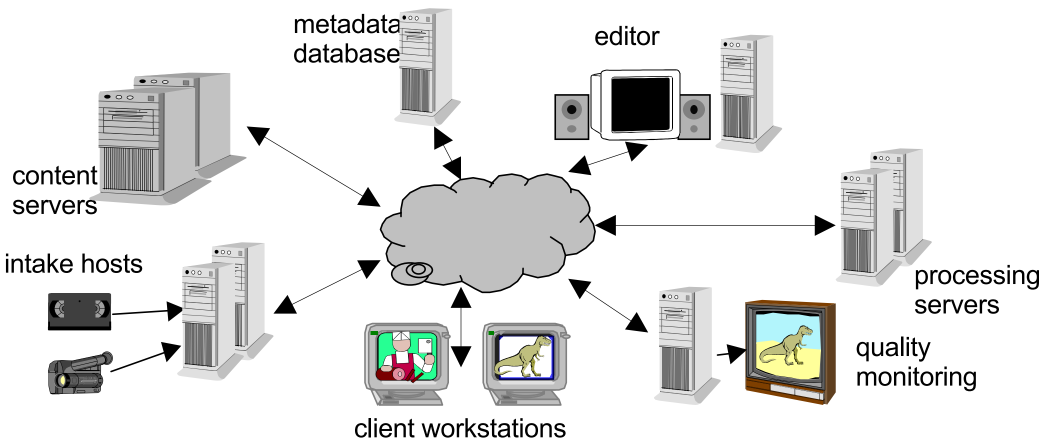


Figure 5 – local area production network

Typically, desktop production systems will be based on a client-server structure in which video is stored at a server and viewed and edited at low-cost clients (Figure 5). In such a system, it is natural to define two ways of viewing material to reduce costs: a browse-quality low bit-rate video stream suitable for editing and reviewing material and a full-quality stream on which the final assemble and edit can be performed on the basis of the editing metadata generated.

In this architecture, the browse-quality video processing will occupy network bandwidth and computer processing resources, whilst the high-quality video will dominate storage resources. In both cases improved compression technology, in terms of bit-rate and complexity, will produce significant savings.

BBC R&D has pursued an approach based on low-resolution MPEG-2 I-frame encoding for the browse-quality video, and long-GOP MPEG-2 encoding for the full-quality video, not least because MPEG-2 is standardised and well-understood. Nevertheless, other (potentially more powerful) codec strategies can certainly be envisaged, but any approach should satisfy the following requirements:

- frame lock between browse-quality and full-quality video;
- scrubbable browse-quality video for speedy reviewing;
- fast encoding and decoding, in software, for the browse-quality video;
- scalable browse-quality encoding across a wide range of bit-rates and qualities;
- near-lossless coding at high compression ratios for full-quality video.

Frame lock between the two video streams is essential if editing is to be performed to frame accuracy. The browse-quality video needs to be reviewed quickly and easily, so any system will have to allow for sufficiently fast decoding so that the video can be scrubbed forward and backward at high speed, as well as permitting random frame access. One of the most imprecise factors is what browse quality actually represents. In most cases a fixed quality will be sufficient, but in some cases (e.g. Natural History) it might be necessary to vary quality for some shots, for example to determine whether they are in focus. Likewise, in applications such as archive retrieval a fixed, low quality might be useful for initial reviewing but enhanced quality is needed for sections of interest. These requirements imply that the basic compression algorithm must operate well over a wide range of bit-rates, and that scalability within the bitstream itself, perhaps directed by the client application, is also desirable.

### D-cinema

D-cinema encompasses the generation, distribution and display of motion pictures using digital technology. Although not ostensibly a broadcasting application, D-cinema allows a whole range of new uses of cinema venues, many of which are of interest to broadcasters. The European Digital Cinema Forum (EDCF), as one of the interested bodies, has identified a quality hierarchy of four types of D-cinema application:

- 1st run/IMAX presentation;
- General Cinema release;
- Small theatre;
- Pubs, clubs, community/village screenings.

Although broadcasters may wish to showcase content via digital cinema release, the application of inexpensive digital distribution and projection technology across a range of venues will allow broadcasters to provide and enhance communal coverage of live events, such as the football World Cup, national occasions or even New Year revels, via alternative distribution networks to standard broadcast networks.

A key element of reducing costs for broadcasters is the provision of a common distribution infrastructure, at least for large classes of venue. This means providing, sometimes simultaneously, content in a variety of formats, covering such features as spatial and temporal resolution, bit depth, chroma resolution and colour space. For the majority of D-cinema applications, video compression ratios will be a relatively minor consideration as distribution will be via DVD or non-real-time download. However, for live broadcasting applications, compression performance will be a key cost driver. The ideal distribution video compression system would be both highly efficient and incorporate scalability in spatial, temporal, and chroma resolution terms. It would also allow for lightweight, cheap decoding to reduce costs for smaller venues. It must also cascade well with other compression algorithms used for distribution within standard broadcast networks.

**Networking applications**

As networking technology develops, broadcasters are increasingly involved in transmitting video over data networks of various sorts. Whereas fixed-rate point-to-point compressed video links have been used for broadcast distribution for some time, compressed video streaming is now increasingly being used for contribution links and Internet delivery. Video streaming technology will also be used to facilitate remote working, for example allowing a costume or set designer to view a production on location remotely. These applications are characterised by low, perhaps variable, bit-rates and costs dominated by bandwidth occupancy, whether paid for by the broadcaster or by customers. As a result, broadcasters are looking to compression technology to reduce costs whilst improving or maintaining quality.

The current generation of satellite video codecs have greatly enhanced news coverage, allowing live video to be contributed from the most remote locations, such as Afghanistan. The most significant requirements in this area are scalability and flexibility: for example, unified systems which can be used to contribute pre-recorded video at relatively high quality non-real time over satellite or ISDN links as well as live video at low bit-rate with a fixed maximum delay. Codecs which provide the flexibility to provide good performance over a wide range of material, as well as supporting more specialist modes such as face-to-camera shots with high efficiency, will allow broadcasters to widen the application of the technology.

New video streaming services employ non-conventional broadcast media – the Internet, xDSL or 2.5/3G mobile networks. These applications are, unlike those so far discussed, not private to the broadcaster. However, the flexibility of PC platforms creates opportunities for compression technology to be continuously updated and downloaded to the customer. Codecs that are modular and extensible are therefore highly desirable, particularly if they allow acceptable video streams to still be decoded by out-of-date decoders. The decoding application should also be compact, as there is a large base of customers with lower-powered machines that broadcasters would like to reach.

In streaming media the incremental cost per viewer is the most significant driver, and video compression is central to reducing these costs. Customers also need acceptable results over a wide range of bit-rates, especially very low and variable bit-rates. In this context, embedded and scalable coding has a particular advantage to broadcasters in eliminating the cost of maintaining multiple versions of a video clip, and an advantage to customers in mitigating network congestion and optimising narrowband connections.

## CONCLUSION

The move to all-digital networks and production within television is generating an increasing number of opportunities for novel compression technologies, and at the same time, compression technology is advancing rapidly. In areas as diverse as DTV, desktop production, radio cameras, D-cinema and video streaming, new compression technologies will allow for significant savings to be made in infrastructure costs, as well as creating new and exciting ways of working and delivering new services to customers. In all such applications, compression solutions have not only to provide good performance but must also satisfy many other challenging and perhaps conflicting requirements in order to integrate successfully into television systems.

Recent BBC tests for the EBU have also shown that large flat panels significantly increase the visibility of video impairments and of compression artefacts in particular. Whilst DTV bit-rates remain heavily constrained, especially for DTT, adopting new compression technologies may yet prove attractive in the longer term. This has many potential benefits in increasing DTT ruggedness, quality and the number of available channels. The tests also demonstrated the advantages of delivering progressive-scan video, improving compression performance and allowing both HD and SD services to be supported via simple standards conversion. However, there would be significant difficulties and costs in pursuing these policies resulting from the large installed base of MPEG-2 technology.

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