MPEG-2 4:2:2 Profile

– its use for contribution/collection and primary distribution

A. Caruso
CBC

L. Cheveau
EBU Technical Department

B. Flowers
ex. EBU Technical Department

This article [1] investigates the use of MPEG-2 4:2:2 technology for both contribution/collection and primary distribution networks – as a means of reducing the level of complexity created by the imminent migration into the digital world.

Extensive testing, organized by the CBC with the assistance of the EBU and NDS, has shown very clearly that the performance of the 4:2:2 Profile – at bit-rates between 15 and 4 Mbit/s – remains superior to the 4:2:0 Profile (MP@ML).

The results of this investigation had an immediate impact on two major broadcasting organizations; the EBU has decided to implement digital video compression technology based only on the MPEG-2 4:2:2 Profile for contribution at both 8 and 20 Mbit/s. The CBC has also decided to utilize the MPEG-2 4:2:2 Profile in its television networks at 8 - 10 Mbit/s for primary distribution and 18 - 20 Mbit/s for contribution/collection.

1. Introduction

The MPEG-2 group of standards concentrates on relaying compressed video signals from the studio to the viewer, but pays less attention to the transmission of those signals between studios within complex broadcasting networks. MPEG compression brings additional options in terms of different bit-rates, levels and profiles, and different kinds of bitstreams such as elementary streams, programme streams and transport streams. Additionally, transcoding between different bit-rates, levels and profiles – as well as transmultiplexing from one transport stream into another – become issues that have to be considered.

When a signal is described as "MPEG-2 compatible", it too often means a great deal less than its purveyors might have us think. MPEG-2 is neither a performance specification, nor an indication of quality. It is more a set of syntactical guidelines – much like those used to make music

1. Based on the presentation made by the Authors at IBC-98 in Amsterdam during September.

Original language: English
Manuscript received: 23/6/98.

convey information both properly and understandably. In the case of music, there is ample room within its syntax to allow the creation of Wagner's cycles of operas, or the waltzes of Strauss.

Studies have been made in Europe by the EBU [1] and in Canada by the CBC [2] to investigate the use of the MPEG-2 4:2:2 Profile in their respective networks. In Europe, the digitalization of the *Eurovision* network [3]) has been envisaged since 1990, but only recently have the economics of the process become positive.

The decision to use the new MPEG-2 4:2:2 Profile for *Eurovision* was taken in 1997. In arriving at this decision, the potential advantages of this solution included:

- The world-wide adoption of MPEG-2 technology by the broadcasting community for the distribution of television programmes.
- The flexibility of the MPEG-2 system allows the bit-rate to be optimized according to the application; around 8 Mbit/s for news applications, around 20 Mbit/s for higher quality contribution by satellite, and up to 50 Mbit/s in the studio. This allows the same equipment to be reconfigured easily by changing the compression rates.
- The possibility of operating at non-hierarchical levels, (i.e. 34 & 45 Mbit/s) in order to optimize the transponder utilization. As an example, one 72 MHz transponder can be loaded with either four TV channels at 20 Mbit/s each, or only three TV channels at 34 Mbit/s each.
- The substantial cost reductions, mainly at the IRD level, that can be achieved through the large volume production of MPEG-related technologies such as DVD and DVB.

Tests on the subjective quality and the objective performance of the 4:2:2 Profile were performed in 1997 by the EBU.

In Canada, the CBC operates a complex television network which carries signals from coast to coast, utilizing terrestrial networks and domestic satellites. It can be considered generally as two separate networks – the *contribution/collection* network and the *primary distribution* network.

The *contribution/collection* network is basically utilized to route TV signals from the source point to the studio, and between production centres which possess multiple post-production and editing facilities. The *primary distribution* network basically transmits the signal from the production facilities to the television transmitters, with no editing permitted except for local commercial insertion.

The original migration plan to upgrade the CBC network from analogue to digital video compression (DVC) proposed the adoption of MPEG-2 MP@ML (i.e. 4:2:0 Profile) technology for the primary distribution network and MPEG-2 4:2:2 P@ML technology for the contribution/collection network. This approach created a new complexity – the migration from a uniform analogue contribution/collection and primary distribution system towards a hybrid one with two different compression profiles.

The introduction of the 4:2:2 Profile for digital video coding within studios, and in contribution/collection, could reduce the number of transformations required in a complex broadcasting network – if the standard were to extend its application into the area of primary distribution.

2. 4:2:2 Profile and data-rate

Originally, the MPEG-2 4:2:0 Profile was developed for distribution applications. The importance of this profile is that the chrominance resolution is reduced before the encoding process, thus reducing (by a theoretical factor of 25%) the number of pixels to be compressed.

The new 4:2:2 Profile has been introduced specifically for studio and contribution applications at high bit-rates, because it can better maintain the quality of the video signal during multiple cascaded stages of post-production processing. The data required to encode the additional chrominance in the 4:2:2 Profile varies quite significantly with the programme content. On average, the data-rate to encode video signals rises by a few percent when coding is switched from the 4:2:0 to the 4:2:2 Profile.

4:2:2 Profile codecs are able to encode video signals with the same picture quality as “Main Profile” codecs, while utilizing almost the same data-rate. This is achieved by adjusting mode decisions and quantization in such a way that the additional chrominance information is transmitted by allocating bits to those areas of the picture which are subjectively most important.

A GoP length of 12 frames was used throughout the EBU / CBC tests for both the 4:2:2 and 4:2:0 Profiles. Such a GoP length represents a useful compromise between coding efficiency and receiver start-up time.

Long GoPs are important, even above 15 Mbit / s, for achieving the highest possible picture quality. At lower data-rates (below 15 Mbit / s), long GoPs are even more important.

It has been established in the broadcasting industry that long GoPs are preferable for optimum picture quality. When post-production processing is performed in the composite domain, this will remain almost the best configuration for a 4:2:2 encoder in order to maintain the best picture quality. However, when post-production processing is performed entirely in the digital domain, shorter GoPs may be desirable.

The penalty for using shorter GoPs is a loss of picture quality but this may be compensated for by increasing the encoding data-rate. The amount of data-rate increase needed to compensate for a shorter GoP, at constant picture quality, is a function of the programme content.

3. Aims of the investigation

The overall aim of this investigation was to determine the *bit-rate crossover point* between the MP@ML and the 4:2:2 P@ML, at bit-rates between 4 Mbit / s and 15 Mbit / s. The crossover point may be defined as the bit-rate threshold where the video quality of the 4:2:2 P@ML becomes worst than the MP@ML.

The objective (laboratory) tests were conducted primarily to assess the performance of the MPEG-2 4:2:2 P@ML encoding method at bit-rates below 15 Mbit / s – after both one and two cycles of compression / decompression – while using the MP@ML as a reference.

3.1. Objective tests

The objective tests were performed at the NDS [4] laboratory in Southampton (UK) in early November 1997. NDS provided the necessary hardware and engineering assistance to set up two parallel MPEG-2 systems. The tests were performed with the participation of experienced engineering personnel from the CBC, the EBU and NDS.

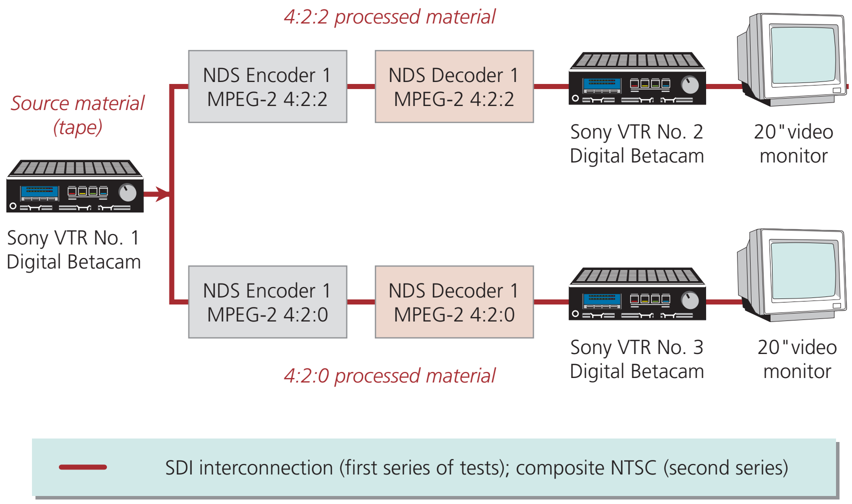


Figure 1
The system set-up used for stage 1 of the tests.

A first series of tests was performed on a system (see *Fig. 1*) consisting of one 4:2:2 P@ML encoder and one decoder to simulate one cycle of compression / decompression. The reference system consisted of one 4:2:0 encoder and one 4:2:0 decoder to simulate the same compression cycle. The electrical interface between the VTRs, encoder and decoder was kept in the digital domain via the SMPTE 259M interface protocol using a Serial Digital Interface (SDI).

A second series of tests was performed on the same system but with the electrical interface between the VTRs, encoder and decoder carrying composite NTSC.

A third series of tests was performed on a system (see *Fig. 2*) composed of two 4:2:2 P@ML encoders and two decoders simulating two cycles of compression / decompression. The reference system here comprised two 4:2:0 encoders and two 4:2:0 decoders to simulate the same compression cycles. The electrical interface between the VTRs, encoder and decoder was kept in the digital domain via the 259M interface protocol.

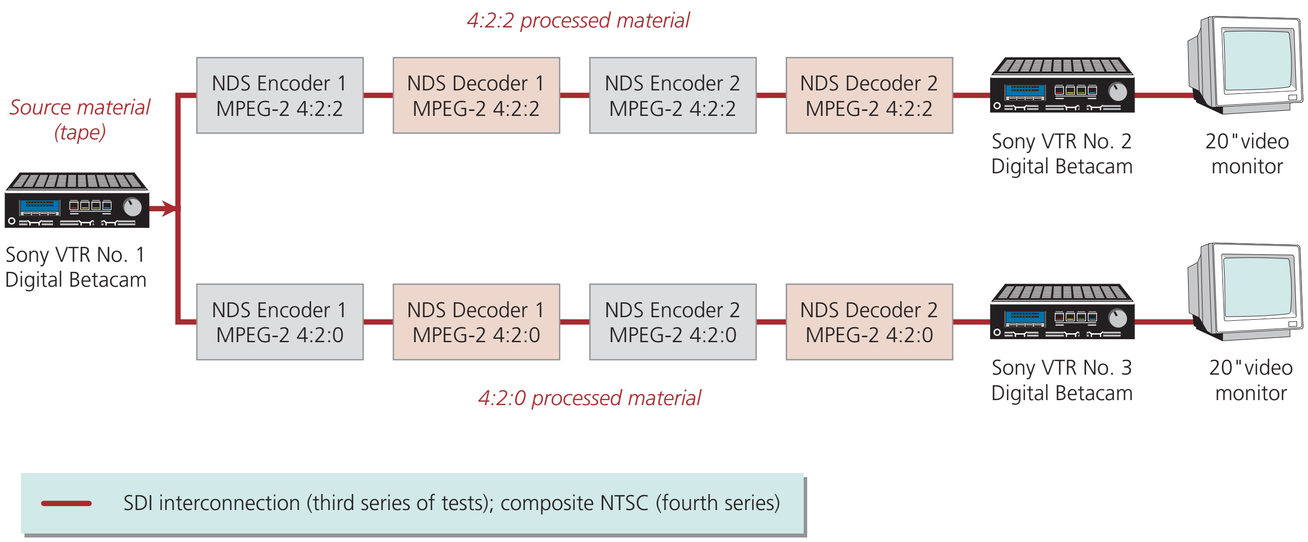


Figure 2
The system set-up used for stage 2 of the tests.

A fourth series of tests was performed on the same system but with the electrical interface between the VTRs, encoder and decoder carrying composite NTSC.

The purpose of the NTSC tests was to simulate post-production processing and TV transmitter interfaces currently performed in the composite domain. The purpose of the SDI tests was to simulate future editing processes and DTV transmitter interfaces which will be performed in the digital domain.

3.1.1. Test plan and execution

The laboratory tests were performed in two stages. In the first stage, shown in *Fig. 1*, a digital VTR machine was played back simultaneously into both the 4:2:2 and 4:2:0 chains. Two additional digital VTR machines were interfaced to the decoders and used to simultaneously record the compressed / decompressed video material through the two different profiles.

This test configuration simulated one cycle of compression / decompression with both composite NTSC and SDI being used for the interfacing. The bit-rate of both encoding engines was simultaneously varied from 15 Mbit / s down to 4 Mbit / s in six steps: 15, 12, 10, 8, 6 and 4 Mbit / s.

The GoP length of 12 frames (N = 12) remained constant for both the 4:2:2 and 4:2:0 compression systems in order to reduce the number of variables. In addition, the full resolution of 704 x 480 pixels-per-frame was utilized in both the 4:2:2 and 4:2:0 compression systems.

The second stage, shown in *Fig. 2*, used additional encoders and decoders to simulate two cycles of compression / decompression with both composite NTSC and SDI being used for interfacing. The bit-rate of both encoding engines was simultaneously varied from 15 Mbit / s down to 4 Mbit / s in six steps, as for the first stage of the tests.

Again, the GoP length of 12 frames remained constant for both the 4:2:2 and 4:2:0 compression systems, and full vertical and horizontal resolution was used.

The source material used for all tests – amounting to a total duration of 10 minutes – consisted of 25 excerpts of a large variety of scenes, including sport, film, computer-generated scenes and ITU test material.

Two tapes (one for the 4:2:2 P@ML and one for the MP@ML) were recorded for each of the four configurations described above, resulting in a total of eight video tapes (Digital Betacam format) being produced during the entire series of tests.

The embedded timecode was used to synchronize each pair of tapes during the subsequent comparative subjective assessment sessions.

3.2. *Subjective analysis of the tests*

The subjective assessment of the tests was performed at a later date in Canada, utilizing the double-stimulus comparison method described in ITU-R Recommendation BT. 500 [5].

The assessment sessions used two well-matched 20- inch monitors (as shown in *Figs. 1* and *2*) and the test sequences were shown simultaneously. A special rating form was used to collect the raw data which resulted from the assessment sessions.

This form is divided into two parts. “Part 1” contains a short group of sequences and “Part 2” has a large group of sequences with a different mix of scenes. The purpose of this split is to reduce the subjective assessment time.

If the data gathered for “Part 1” indicates a tendency towards one end of the comparative scale, then “Part 2” can be aborted. However, if the results of “Part 1” are not very well defined in terms of the direction tendency, then “Part 2” must be completed in order to better define the comparative results.

A large group of people was involved in the subjective assessment of the four system configurations and the six different bit-rates tested for each configuration. For every bit-rate and configuration tested, each individual participating in this subjective exercise filled out the special rating form.

The results for each configuration and bit-rate tested were averaged over the number of participating persons in the viewing session and is summarized in 24 tables, one for each configuration and bit-rate tested. A typical example of one of these tables is shown in *Table 1*.

CONFIGURATION: **M-4**	VIDEO BIT-RATE: **8 Mbit/s**						
Video Sequences	**Comparative Scale**						
	–3	**–2**	**–1**	**0**	**1**	**2**	**3**
Part 1	**Average Values**						
Colour Bars					X		
Carrousel					X		
Football Game				X			
Girl					X		
World Cup Skiing				X			
Canadian Grand Prix					X		
Part 2	**Average Values**						
Colour Bars					X		
Air Farce					X		
Soldier Scene				X			
Ice Skating					X		
Panel Discussions				X			
Japanese Army				X			
Baseball				X			
Tennis				X			
Le Dragon				X			
Film					X		
Flags					X		
Montreal Sunset				X			
Duck Scene				X			
Bear Cartoon				X			
Flower Bed					X		
Dancing Girls					X		
Bird Cage					X		
Bicycle Riding				X			
Calendar				X			
	Much Worse	Worse	Slightly Worse	**The Same**	Slightly Better	Better	Much Better

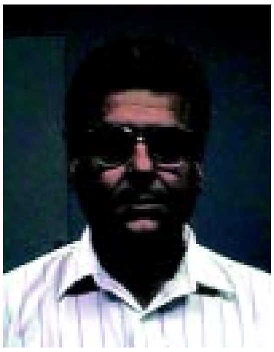
Table 1
A sample table of results from the comparative listening tests.

4. Conclusions

Examining the data collected from the tests described here allowed us to draw the most important conclusions of the investigation.

➪ It could be observed that after one cycle of compression / decompression, with either SDI or composite NTSC used for interfacing the equipment, the video that was encoded using the 4:2:2 P@ML remained on the whole "The Same" as the video encoded using the (4:2:0) MP@ML. A few sequences encoded using the 4:2:2 P@ML were deemed to be on average "Slightly Better" than the reference MP@ML. This was true for all the bit-rates tested.

➪ After two cycles of compression / decompression, with the SDI interface, the video encoded using the 4:2:2 P@ML remained on the whole "The Same" as the video encoded using the (4:2:0) MP@ML. A few video sequences encoded at the 4:2:2 P@ML were deemed to be "Slightly Better" (on average) than the reference MP@ML. This was also true for all the bit-rates tested.



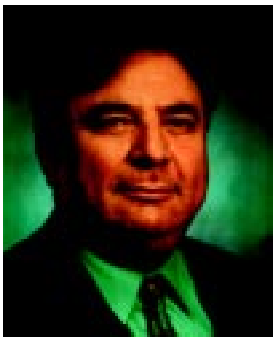
Anthony Caruso *obtained a degree in Telecommunications Engineering at Buenos Aires University in 1972 and joined the development group of PYE Telecommunications Argentina, as an engineering assistant. He was transferred to PYE Telecommunications Canada in 1975 where he continued his post-graduate studies. He then joined the Engineering Department of the Canadian Broadcasting Corporation in 1981.*

Mr Caruso - a professional engineer licensed in Canada - is presently a Senior Specialist Engineer in a group within the Delivery Technology Department of the CBC. He is concerned with the investigation of new digital technologies that are applicable to the contribution, distribution and transmission networks of the CBC. He represents the CBC in such matters on several international technical committees.

Anthony Caruso's most recent achievement was the planning and deployment of the first MPEG-2 4:2:2 Profile system to be used for the satellite/terrestrial transmission of the Winter Olympic Games (Nagano 98, Japan). He is currently responsible for the digitalization of the CBC's terrestrial and satellite networks.

Louis Cheveau *qualified as a Physics Engineer from the University of Liège, Belgium, in 1967 and obtained a Ph.D. in Physics from the University of Montreal, Canada, in 1974. That year, he joined the EBU Technical Centre in Brussels as head of the computing department and, initially, worked in the field of terrestrial television broadcasting. In 1977, the emphasis of his work changed to satellite broadcasting.*

In 1984, Dr Cheveau was detached for two years to the CBC in Canada. There, he worked in International Relations with a special emphasis on satellite broadcasting and HDTV matters. In 1986, he returned to the EBU Technical Centre, this time to work on Eurovision transmissions. Since 1989, he has been Head of Transmission Technologies within the EBU Technical Department in Geneva.



Brian Flowers *studied Engineering at the University of Southampton, UK. In 1960, after serving two years in the Royal Air Force (RAF), he joined BBC Television News. Then, in 1962, he was detached to the Eurovision Control Centre (EVC) in Brussels.Mr Flowers worked at all levels of responsibility in the EVC – technician, supervisor, engineer-in-charge, and as the project leader for the new EVC in Geneva.*

Prior to his retirement in 1997, Brian Flowers was a Senior Engineer in the Transmission Technology division of the EBU Technical Department, Geneva.

- After two cycles of compression / decompression, with the composite NTSC interface, the video encoded using the 4:2:2 P@ML remained on average “Slightly Better” than the reference MP@ML, for all the bit-rates tested.
- The results for the two cycles of compression / decompression were mainly due to the deterioration in vertical chrominance resolution, caused by the four A / D and D / A conversions and filtering.
- At data-rates of 6 Mbit / s and below, video artefacts were observed on certain programme sequences. However, these artefacts were equally observed on both profiles. This result led to a secondary conclusion: the deterioration in the video quality starts to occur for both profiles at rates starting at 6 Mbit / s.

As a final conclusion, it can be stated that the sequences encoded and decoded using the 4:2:2 P@ML were never rated “Slightly Worse” than those coded using the MP@ML at all the bit-rates investigated. This clearly indicates that a “crossover point” where 4:2:0 is better than 4:2:2 does not exist.

Acknowledgements

The Authors would like to thank NDS for their co-operation and assistance in providing their laboratory facilities in Southampton (UK) for performing these tests. Special thanks go to Mike Budge, Noel Matthews and Alois Bock (all of NDS UK) and Richard Shea (NDS Americas).

Bibliography

[1] http://www.ebu.ch

[2] http://www.cbc.ca

Abbreviations

A/D	Analogue-to-digital
CBC	Canadian Broadcasting Corporation
D/A	Digital-to-analogue
DVB	Digital Video Broadcasting
DVC	Digital video coding
DVD	Digital video (versatile) disc
GoP	Group of pictures
IEC	International Electrotechnical Commission
IRD	Integrated receiver/ decoder
ISO	International Organization for Standardization
ITU-R	International Telecommunication Union, Radiocommunication Sector
MPEG	(ISO/IEC) Moving Picture Experts Group
NTSC	National Television System Committee (USA)
SDI	Serial digital interface
SMPTE	(US) Society of Motion Picture and Television Engineers

[3] L. Cheveau: **Switching to digital**
EBU Technical Review No. 276, Summer 1998.

[4] http://www.ndsworld.com

[5] ITU-R Recommendation BT.500: **Methodology for the subjective assessment of the quality of television pictures**
http://www.itu.int/publications/itu-r/iturbt.htm