Pro-MPEG Forum

Pro-MPEG Code of Practice #1
April 2001

MPEG-2 Operating Ranges and Applications

Prepared by

Operating Ranges Working Group of the Pro-MPEG Forum.

For Information Only

This documentation was proposed to the Society of Motion Picture and Television Engineers (SMPTE) for standardisation.

The SMPTE split the document into two parts and assigned them the following SMPTE designations.

SMPTE RP213 – MPEG-2 Operating Ranges

SMPTE EG38 – MPEG-2 Operating Range Applications

These SMPTE documents therefore represent the final output of the Pro-MPEG Forum's Operating Ranges Working Group. Consequently, this document is provided for information only.

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Contents

1. Scope

The aim of this document is to provide practical guidelines to users of MPEG-2 in the Studio & in other Professional applications by specifying the structure and parameters of the data for interfacing MPEG-2 4:2:2 Profile and digital audio in the professional environment.

The purpose of the document is to ensure video and audio bitstream interchange between MPEG-2 compliant equipment.

The document provides a system overview, detailing the elements to be considered when choosing an MPEG-2 Operating range and how this may be configured to meet a selected Operating point. This is achieved by giving specific, but representative implementation examples planned or in use around the world.

Examples are included from both Intra-frame and temporal predictive coded MPEG -2 for both 4:2:2 Profile and Main Profile @ Main Level and High Level.

Appendix 1 provides an overview of other Pro-MPEG documents designed to meet specific operating requirements.

This code of practice is limited to the video and audio parameters of such a system

This code of practice specifies MPEG-2 Operating Ranges which are defined to be subsets of ISO/MPEG profiles and levels. This should, therefore, be understood to augment the ISO/MPEG standards, and is not intended as a modification of those standards. This code of practice currently defines two Operating ranges for standard definition television and three Operating ranges for high definition television.

All the data structures defined in this Code of Practice are ISO/IEC 13818-2 amendment 2: 4:2:2 profile compliant and as such decodable by MPEG-2 4:2:2 profile compliant stand-alone decoders at the appropriate level. As the MPEG-2 4:2:2 profile requires stand-alone decoders to decode Main Profile structures, existing main profile sources can be accommodated.

2. References to Standards

2.1 Pro-MPEG Code of Practice #1

This Code of Practice is based upon work performed within Pro-MPEG. The documents were in parallel proposed to SMPTE for standardisation and after due process were given the following SMPTE designations:

SMPTE RP213 – MPEG-2 Operating Ranges

SMPTE EG38 – MPEG-2 Operating Range Applications

All SMPTE documents are subject to revision, and parties to agreements based on these documents are encouraged to investigate the possibility of applying the most recent edition of these documents.

Consequently, these SMPTE documents and any subsequent versions thereof, must be regarded as the definitive version of this Pro-MPEG Code of Practice.

2.2 Referenced Standards within this Code of Practice

The following documents contain provisions, which, through reference, constitute provisions of this code of practice:

ANSI S4.40-1992, Digital Audio Engineering - Serial Transmission Format for Two-Channel Linearly Represented Digital Audio Data (AES-3)

ISO/IEC 13818-2:2000 (MPEG-2) - Generic Coding of Moving Pictures and Associated Audio: Video

ITU-R BT.601-5 - Encoding Parameters of Digital Television for Studios

ITU-R BT.709-3 - Parameter values for the HDTV standards for production and international program exchange.

SMPTE 274M - 1920 x 1080 Scanning and Analog and Parallel Digital Interfaces for Multiple Picture Rates

SMPTE 293M -1996, 720 x 483 Active Line and Digital Representation

SMPTE 296M -1997, 1280 x 720 Scanning, Analog and Digital Representation and Analog Interface

ITU-R 1356:2000, 720 x 576 progressive sampling structure

SMPTE 302M - Linear PCM Digital Audio in an MPEG-2 Transport Stream

SMPTE 308M - MPEG-2 4:2:2 Profile at High Level

SMPTE 312M - Splice Points for MPEG-2 Transport Streams

SMPTE 327M - MPEG-2 Video Re-coding Data Set

SMPTE RP202 2000 - Video Alignment for MPEG-2 Coding

SMPTE 328M - MPEG-ES Editing Information

3. Other References

EBU / SMPTE Task Force for Harmonised Standards for the Exchange of Program Material as Bit-streams - 1998.

Digitalisation of the EUROVISION network, Final Report, EBU, November 1998.

EBU Statement D84 - Use of 50 Mb/s MPEG compression in television programme production

EBU Statement D85 - Constraints on MPEG 4:2:2 P@ML compression to ensure interoperability in television production

EBU Statement D89 - Quality and Interoperability in a 625/50 digital television production environment using MPEG compression

Pro-MPEG Code of Practice #2 - WAN Operating Points

4. Introduction

The flexibility of MPEG-2 compression allows MPEG-2-based equipment to meet the diverse economic and operational requirements of a broad range of professional television applications. While some applications might be served by choosing specific Operating points, end-to-end systems can benefit significantly from the broader scope of MPEG-2 capabilities. Although some applications may be best served by choosing a specific Operating point, different users have different constraints and objectives, so may choose different operating parameters.

Recognising these considerations, this code of practice specifies the following:

Operating ranges including constrained bit-rates and group-of-pictures (GOP) structures
Operating Ranges created for random access and editing capability
Spatial alignment of coded images
Use of 48 kHz sampled digital audio

This code of practice defines general operating categories, called Operating ranges, within which bitstreams from a variety of manufacturers will inter-operate. These Operating ranges, in conjunction with application-specific compression parameter settings will facilitate design and application of flexible MPEG-2-based professional television equipment. The Operating ranges include those specifications necessary to ensure that the design and construction of equipment conforming to this code of practice will enable broadcasters and professional MPEG-2 users to define and configure audio and video systems using equipment from multiple vendors.

Users who wish to select encoding parameters unique to their specific requirements can do so with confidence. As a minimum, decoders that comply with this specification should be capable of spanning the entire applicable Operating Range. Specific operating parameter choices will depend on the individual application requirements, including editing capability, storage capacity, contribution feeds and distribution / emission bandwidth.

For Audio, no single world-wide compressed standard has been adopted; various transmission systems are in use depending upon geographic area. Global interoperability can therefore only be achieved by specifying a non-compressed audio format.

5. MPEG-2 Video Parameters

5.1 Operating Ranges

Within professional applications of MPEG-2, including the HDTV extensions to MPEG-2 as defined by SMPTE 308M; five Operating ranges are defined in this section as shown in Figure 1. Separate long and short-GOP ranges are defined for both Main Level and High Level Systems. Additional Operating ranges may be added as required to meet future HDTV requirements.

Operating ranges 1 and 2 cover the MPEG-2 4:2:2P@ML options including the standard 525-line and 625-line SDTV formats.

Operating ranges 3 and 4 cover the MPEG-2 4:2:2P@HL including:

480-line progressive-scan
576-line progressive-scan
720-line progressive-scan
1080-line interlaced-scan
1080-line progressive-scan (up to 30Hz Frame rate)

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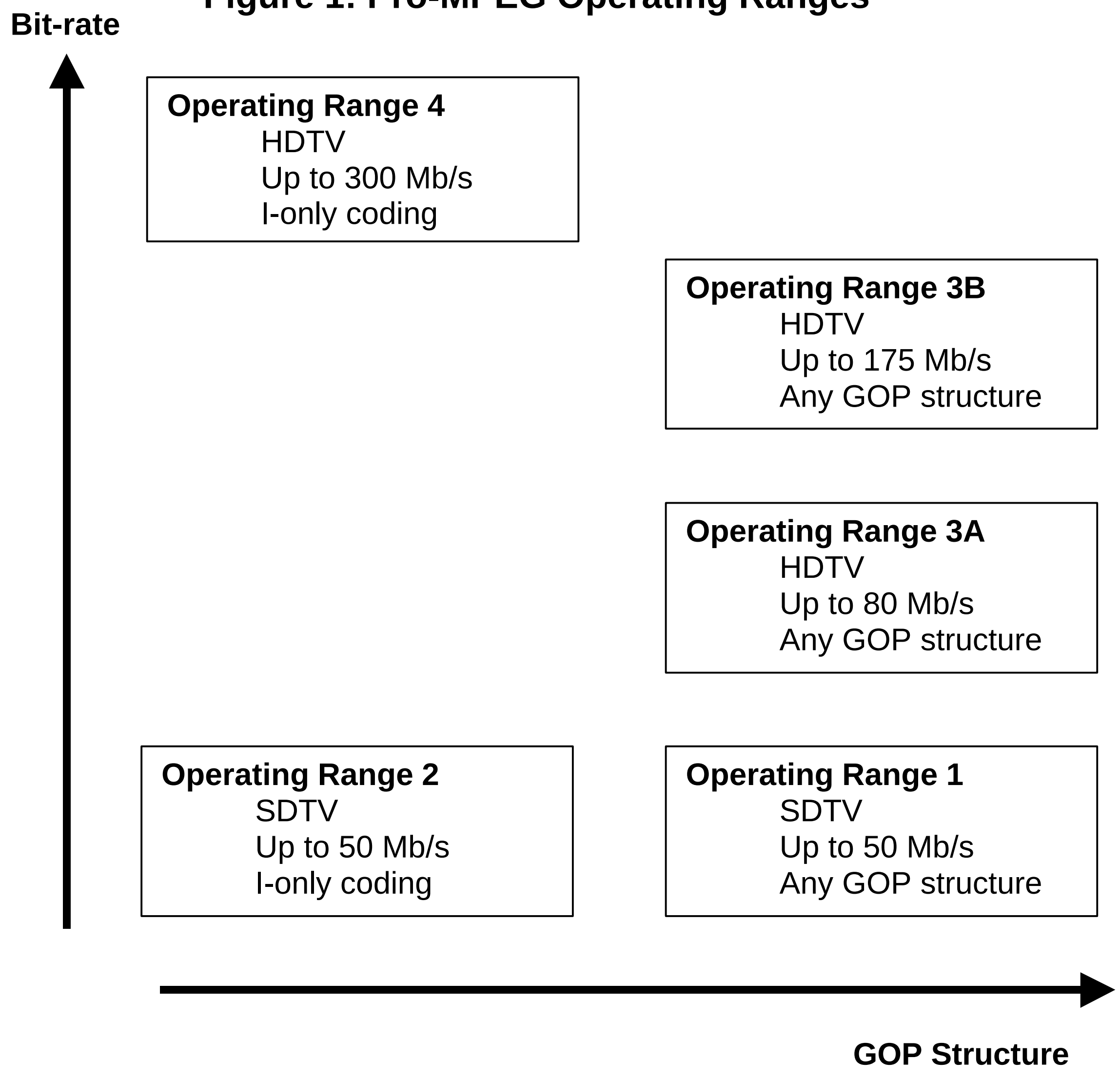
Net bit-rates specified for each Operating Range are maximum video bit-rates and should include all data that is included in VBV (Video Buffer Verifier) calculation.

Figure 1: Pro-MPEG Operating Ranges



5.1.1 Operating Range 1: (SDTV, Any GOP)

Operating range 1 covers SDTV coded at up to 50 Mb/s, and may use temporal predictive coding.

For GOP structures greater than one, future equipment designs should conform to this Operating range. This will facilitate bitstream interchange over the full range of MPEG-2 Main Level compliant equipment.

5.1.2 Operating Range 2: (SDTV I-Only)

Operating range 2 covers SDTV coded at up to 50 Mb/s, using no temporal predictive coding. For this Operating range, an encoder rate control should ensure that no frame exceeds a limit of 50 Mb/s divided by the number of frames per second. For example, at 29.97 I-frames per second, no frame can have more than 1,668,328 bits net data, or at 25 I-frames per second, no frame can have more than 2,000,000 bits net data.

For I-only applications, future equipment designs should conform to this Operating range. When coupled with the bitstream constraints defined in section 5.4, this will facilitate bitstream interchange over the full range of MPEG-2 Main Level Compliant equipment.

5.1.3 Operating Range 3A and 3B (HDTV, Any GOP)

Operating range 3A covers HDTV coded at up to 80 Mb/s, and may use temporal predictive coding.

Operating range 3B covers HDTV coded at up to 175 Mb/s, and may use temporal predictive coding.

5.1.4 Operating Range 4 (HDTV, I-Only)

Operating range 4 covers HDTV coded at up to 300 Mb/s, using no temporal predictive coding. For this Operating range, an encoder rate control should ensure that no frame exceeds a limit of 300 Mb/s divided by the number of frames per second. For example, at 29.97 I-frames per second, no frame can have more than 10,010,000 bits net data.

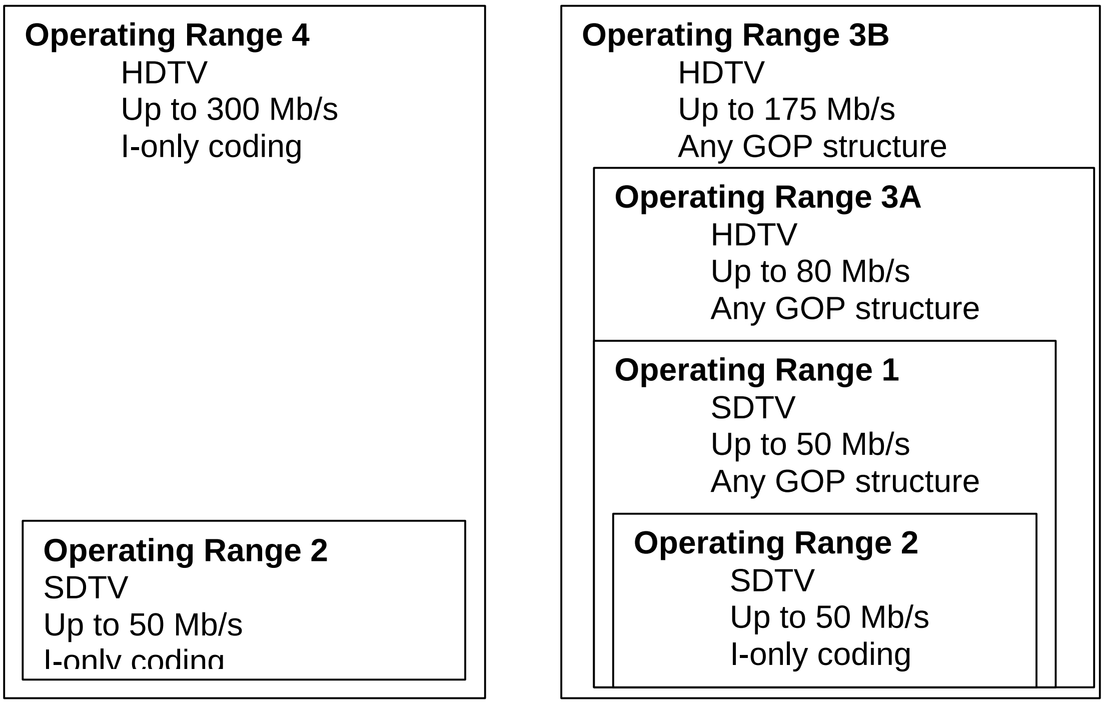
For I-only applications, future equipment designs should conform to this Operating range. When coupled with the bitstream constraints defined in section 5.4, this will facilitate bitstream interchange over the full range of MPEG-2 compliant equipment.

5.1.5. Relationships between Operating Ranges

Relationships between different Operating ranges are illustrated in Figure 2.

Operating range 2 is a subset of Operating ranges 1 and 4.
Operating range 1 is a subset of Operating ranges 3A and 3B.
Operating range 3A is a subset of Operating range 3B.

Figure 2: Relationships between Operating Ranges



5.2 Compatibility with ISO/IEC 13818-2 Specification

For all Operating Ranges, the MPEG-2 buffer model defined in the ISO-IEC 13818-2 (MPEG-2) must be respected. Bit-rates specified are all maximum bit-rates, and include all data that is included in MPEG-2 buffer (VBV) calculation.

For Operating Ranges 2 and 4 using I-only GOP structure, the video elementary stream is also constrained such that no frame exceeds the additional limits specified in sections 5.1.2 and 5.1.4.

Devices operating in Operating Ranges 2 and 4 may have constraints that preclude processing a VBR input directly. For interoperability in the case that a CBR device cannot process a VBR input, that CBR device should pad the incoming VBR signal up to the appropriate maximum bit-rate. If any constant bit-rate device has inserted such padding, it should remove this padding at its interoperable output interface[1].

5.3 Spatial Alignment of Coded Image

To ensure optimal multi-generation picture performance, the spatial alignment of coded images specified in SMPTE RP202 - Video Alignment for MPEG-2 Coding, applies to both MPEG-2 encoders and decoders.

5.4 MPEG-2 Bitstream Parameters

Operating ranges 2 and 4 (Intra Frame coding) are primarily defined to facilitate bitstream interchange within an I-frame only MPEG-2 Video Tape Recorder environment. The key requirements of such recorders are listed below:

a) A fixed number of coded-bits (bytes) per I-frame

b) To facilitate the random access features normally associated with analogue Video Tape Recorders, the following additional constraints are required.

- a defined slice structure
- the repetition of sequence headers on each frame
- the repetition of non-default quantization tables on each frame

Moreover, to facilitate conversion of elementary streams to transport streams, an accurate vbv_delay value should be carried in the video elementary stream. The value of '0xffff' (i.e. Variable Bit Rate) is not allowed. The vbv_delay value may be relied on for re-multiplexing elementary streams into transport streams.

6. Audio Interchange

For Audio, no single world-wide compressed standard has been adopted; various transmission systems are in use depending upon geographic area. Global interoperability can therefore only be achieved by specifying a non-compressed audio format.

All equipment should at minimum support the use of two AES/EBU audio data streams (four audio channels) of 16-bit minimum resolution plus VUC bits. These audio data streams should utilise 48 kHz sampling.

[1] ISO/IEC 13818-2 (MPEG-2), treats constant bit rate (CBR) systems to be a constrained version of variable bit rate (VBR) systems, consequently all systems specified by this Code of practice should be capable of interoperation within a VBR environment.

7. MPEG-2 Operating Range Applications

7.1. Introduction

The picture quality obtained when decoding a MPEG-2 encoded signal is largely dependent upon the combination of bitrate and the GOP structure. The results of tests made by the SMPTE and EBU are shown in figure 3 and are as reported in the EBU/SMPTE Task Force Report (for full details of the test procedures please refer to the report).

This figure illustrates that for a given sequence of images, the same image quality can be obtained by various combinations of bitrate and GOP structure.

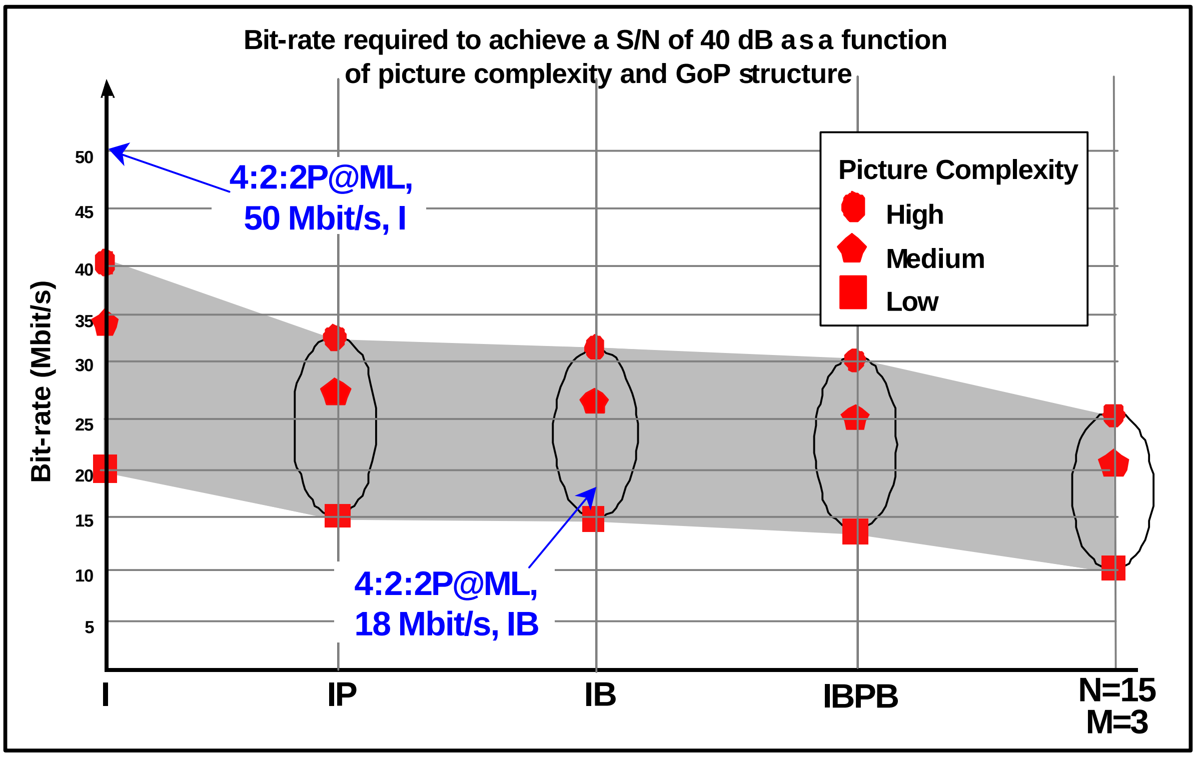


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Figure 3 - Basic characteristics of compression for News and Sports – MPEG-2 4:2:2P@ML

The curves shown in the diagram should be taken as an indication of first generation performance within the wide span of MPEG-2 encoding options only. Taking signal differences as a measure of picture quality only allows coarse evaluation of actual quality performance. The variance of encoding parameters allowed in MPEG-2 encoding structures to achieve the desired flexibility will require subjective testing of each individual encoder design to determine the actual quality performance at a given data rate and GOP structure. The arrows indicate possible members of the MPEG-2 4:2:2@ML compression family envisaged for Mainstream Broadcasting, News and Sports for Contribution, as implemented in current industrial designs.

Since this figure was produced, the temporal predictive coding efficiency has been improved allowing lower data rates than those given in the figure 3.

7.2. Introduction to Operating Points

The first section of this document defines the MPEG-2 Operating Ranges. These ranges constrain characteristics of the MPEG-2 4:2:2 P bitstreams to ensure bitstream interchange in the professional environment.

This section analyses the production system data flow, describes the Operating Range applicable for each main production stage and gives examples of Operating points. For each stage in the production system data flow, the document discusses considerations that influence selection of an Operating range and within it, an Operating point or points. Specific considerations include quality of video and audio, efficiency, technology, and existing equipment and services.

This document elucidates choice of Operating points to enable bitstream interchange within professional applications. It enhances the user's ability to purchase equipment and set application-specific parameters. The sections that follow will inform and help guide the users to an optimum choice for their applications.

Section 8 describes the production system data flow and defines its stages.

Section 9 gives, for each stage, example data rates and Operating range are given. This is done separately for SDTV and HDTV. Further considerations for each stage follow.

Section 10 lists applications that use the production system described in Sections 8 and 9 and identifies issues that need to be considered when implementing a system.

7.2.1. Glossary of Terms

The following definitions will be used in the clauses that follow:

Term	Definition
Net data rate	The data rate of the video elementary stream
Total data rate	The Net Data Rate plus audio, data, and any system overhead
Acquisition data rate	The (net or total) data rates used in field acquisition recording
Contribution data rate	The (net or total) data rates used to back-haul signals to a network centre or station operating facility
Editing data rate	The (net or total) data rates used for a reasonable number of post-production generations, not including the most demanding high-end post-production applications.
Distribution data rate	The (net or total) data rates used to pass network signals to regional or local stations
On-air operations data rates	The (net or total) data rates used for local storage prior to master control in an on-air playout facility, and may be subsequently re-coded for analogue transmission or lower bit-rate digital transmission.
Emission data rates	The (net or total) data rates used in digital television broadcasting, either by terrestrial or satellite paths
Transcoding	The process of converting one MPEG-2 format to another
Naïve Transcoding	the conversion between two MPEG-2 formats using only uncompressed video and audio in the recompression. The formats may differ in GOP structure, bit rate, frame rate, or frame size
Intelligent Transcoding	is the conversion between two MPEG-2 formats using MPEG-2 Recoding Data Set in the recompression to maximise quality. The formats may differ in GOP structure, bit rate, frame rate, or frame size
Naïve Compression Family Conversion	is the conversion between the MPEG-2 and non-MPEG families (DV, JPEG, etc) of compression using only uncompressed video and audio in the recompression
Intelligent Compression Family Conversion	is the conversion between the MPEG-2 and non-MPEG (DV, JPEG, etc) families of compression using non-essence data (such as bit-rate allocation and quantization) in the recompression to minimise quality loss.
Headroom	The additional data rate necessary to permit a naïve transcode or naïve compressed family conversion whilst retaining an acceptable picture quality.

8. Professional Production System Data Flow

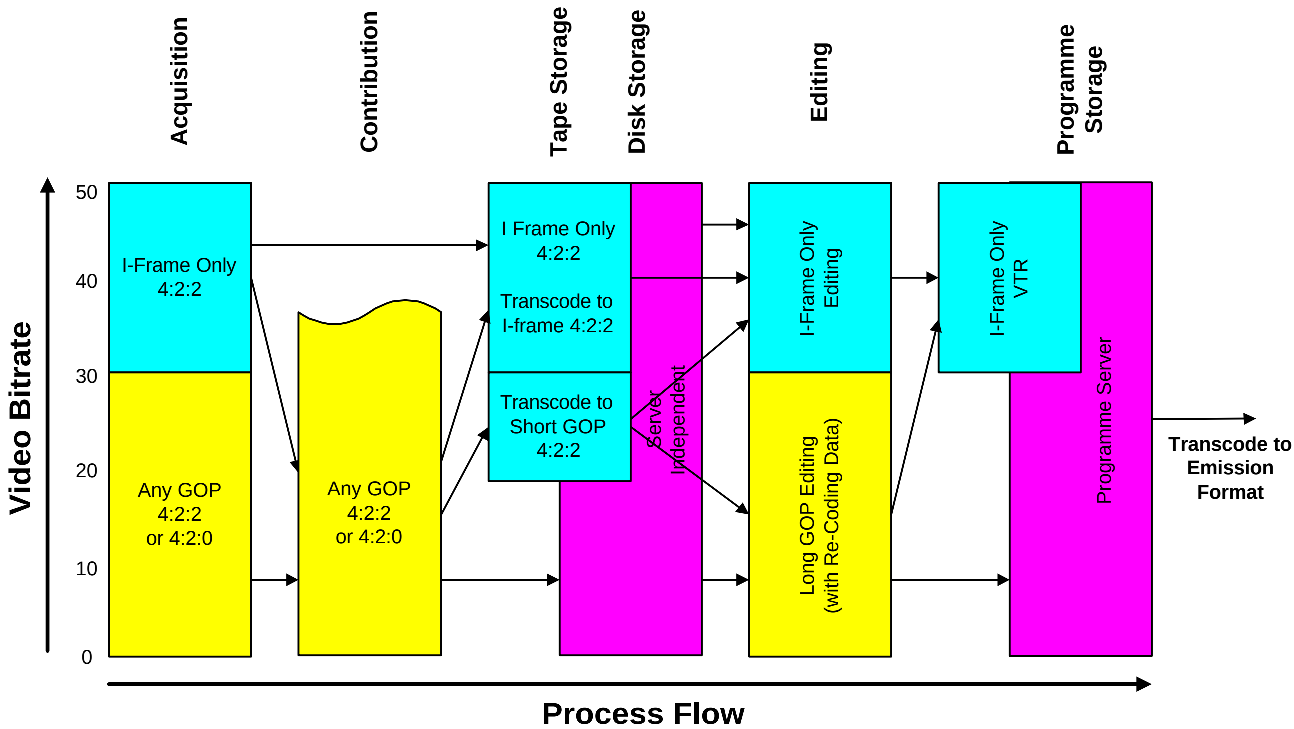

Figure 4 - The Compressed Video Process Flow - Current Practice - SD example

The above diagram illustrates the various strategies available to broadcasters when designing a compressed video production flow process. In this example, the split between Long GOP and I-frame only systems at 30Mb/s reflects the point of approximately equal performance for Long GOP systems at 30Mb/s and I-frame only systems at 50Mb/s.

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Acquisition	The program may be captured in I-frame only or using Long GOP MPEG-2 to provide higher storage capacities (principally Camcorders)
Contribution	Where there is a need to electronically transmit the captured information over a network (Satellite / Telco / Wireless Camera), the Long GOP MPEG-2 format is more likely to be used as this provides for higher transmission efficiency.
Source Storage	Ideally the signal should be stored in its received format, that is I-frame only for I-frame only systems and Long GOP for Long GOP systems to maintain the highest possible quality. It is also possible to transcode the incoming feed to permit a standard native storage format, however, care must be taken to ensure that the quality is not degraded.
Editing	Cuts only editing is simple to perform in the MPEG-2 domain in the case of I-frame only VTRs or servers. Where more complex editing is required, the signal has to be processed at video baseband. This can be achieved using either I-frame or Long GOP MPEG-2 provided that the system has sufficient headroom. Where this headroom does not exist, it is necessary to use the MPEG-2 re-coding parameters as defined in SMPTE 327M if MPEG concatenation artefacts are to be avoided.
Program Storage	Program storage should also be made in the editing format or in the transmission format so that the number of transcoding stages are reduced to a minimum.

The key options available to the program maker can therefore be summarised as:

An I-frame only or Long GOP system with a sufficiently high data rate to allow multiple naïve decoding / recoding processes whilst maintaining the overall quality.

A Long GOP system using lower data rates but passing forward re-coding information as described in SMPTE 327M to minimise MPEG concatenation artefacts.

8.1. System Issues

To maintain quality throughout the production chain, the following issues should be taken into consideration:

The same GOP structure should ideally be maintained throughout the transmission chain in order to minimise the number of transcoding stages required.

The alignment of the MPEG-2 video should conform to that defined in SMPTE RP 202.

For long GOP inputs or systems, re-coding data should be used to minimise concatenation artefacts by feeding forward previous encoding decisions as defined in SMPTE standard 327M.

In practical systems and for economic reasons, it may be necessary to transcode between one form of MPEG-2 and another, for example to pass through a Telco or Satellite contribution circuit.

8.2. Transcoding Issues

Multiple stages of compression encoding and decoding will introduce artefacts in the program content. Some conversions between different bit-rates or compression structures will also introduce artefacts. Where practical, compressed program material should be transported and stored in the original compression format to minimise the number of cascaded encoding and decoding stages in the production chain. However, for many applications, it is necessary to mix sources derived from different MPEG-2 compression parameters to create a final program. In these instances some form of transcoding will be required.

A method for reducing the number of transcoding stages is to define a set of encoding parameters to be applied as consistently as possible within an applications area. To ensure the consistent operation of encoders between different manufacturers, it is necessary, as a minimum, for the coded picture area to be the same for a given MPEG-2 level so that the MPEG-2 macro-blocks within the picture are correctly aligned as defined in SMPTE RP202.

Transcoding techniques now exist to optimally convert compressed video bit-streams from one bit-rate to another either via digital video baseband or through an I-frame only stream. These techniques are defined in the MPEG-2 Re-coding Data Set - SMPTE 327M. Using recoding information enables the next encoder to follow the same decisions as the previous encoder, thereby minimising or eliminating concatenation artefacts.

8.3. Analogue Legacy Issues

SMPTE RP202 also makes reference to the 512-line and 608-line formats, which were introduced into the MPEG-2 4:2:2 profile to accommodate processing of vertical interval data through the compressed video path. This was done with analogue television systems in mind, in advance of substantial digital television broadcasting deployment. Particularly in confined data rate environments, mixing data and video paths (composite analogue inputs to encoders) has resulted in sub-optimal processing of both signals. With increased emphasis on digital broadcast emission, there is new motivation to pass only video through the MPEG-2 compression process and pass data via a separate data path. In this case, only the 480-line and 576-line formats would be used for standard definition television. Consequently, the phasing out the use of these MPEG-2 formats, which are based only on legacy analogue requirements, is recommended.

Digital high definition systems do not have the burden of the analogue heritage of standard definition systems. HDTV does not therefore have a legacy of analogue and digital vertical intervals being carried with compressed video. It is imperative that HDTV systems maintain their clear distinction between video data and ancillary data.

8.4. Standards Conversion Issues

There is frequently a requirement during international electronic program exchange to have both an MPEG-2 Long-GOP link coupled with a frame rate standards conversion process.

MPEG-2 relies on smooth motion rendition for the accuracy of its predictive modes. Where this motion is modified, as in the case of standards conversion, temporal disturbances will be introduced. These disturbances are minimised by the use of motion compensated rather than linear standards converters.

Ideally, the contribution link would be MPEG-2 compressed at the source frame rate and standards converted at the receiving end, thereby allowing the contribution link to work at its maximum efficiency. This assumes that the contribution link has a sufficient overhead for the subsequent processing and MPEG-2 recoding for emission.

Whilst the above situation is preferred, it is acknowledged that in the case of point to multipoint contributions, the alternative solution of standards conversion before the MPEG-2 contribution link may be chosen for economic reasons.

8.5. Historical Process-related Metadata

As source content is moved through the transmission chain, it is likely to undergo a series of conversions such as coding to MPEG-2 for a contribution link, standards conversion, conversion from MPEG-2 4:2:2 to 4:2:0 or vice-versa. Each new modification is typically performed without reference to what has happened previously.

To retain the maximum signal quality at the end of the chain, it is advisable to retain the knowledge of what has been done to the content during its progress through the chain. Although this information may be of limited use at present, future process control systems should allow the interrogation of this information in order to optimise the next content modification from editing to colour balancing.

9. MPEG-2 Application Examples

The tables below provide examples of actual bit-rates and GOP structures being used in current real-time streaming applications. The first table shows HDTV application examples; the second table shows SDTV application examples. Application examples are derived from representative implementation examples planned or in use around the world.

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9.1.1 MPEG-2 Application Examples: HDTV

	Acquisition (Camcorder)	Contribution and Distribution	Editing	On-Air Operations	Emission
IR 4 (I-Only)	300 Mbit/s net (note 1)	(Note 6)	300 Mbit/s net (note 1)	300 Mbit/s net (note 1)	
IR 3A (any GOP)		40 Mbit/s net (note 2) 45 Mbit/s total (note 2) 52 Mbit/s net (note 7) 68 Mbit/s (note 3) (Note 6)		40 to 80 Mbit/s net (notes 2 / 4)	19.4 Mbit/s total (note 5)
IR 3B (any GOP)	Non-MPEG solutions exist at these bitrates	(Note 6)			

Note 1 300 Mbit/s I-only is specified in SMPTE/EBU Task Force report.
Note 2 40 Mbit/s net, 45 Mbit/s total is capacity of DS3 - commonly used by US Broadcasters for this application. 39Mbit/s net is used in Japan.
Note 3 68 Mbit/s is approximate capacity of Ku-band satellite.
Note 4 Data rates up to 80 Mbit/s are being used in on-air playout servers.
Note 5 19.4 Mbit/s is the total payload rate. (US ATSC HDTV Standard).
Note 6 Possible when 622Mbit/s ATM becomes widely available
Note 7 52Mbit/s net, 59.684Mbit/s TS+RS rate - ARIB standard for Contribution Satellite (ARIB STD-B26:HDTV Digital SNG Transmission Systems) and / or Microwave Link (ARIB STD-B11: Portable Microwave Digital Transmission System for Television Program Contribution)..

9.1.2 MPEG-2 Application Examples: SDTV

	Acquisition (Camcorder)	Contribution and Distribution	Editing	On-Air Operations	Emission
IR 2 (I-Only)	25 -30 Mbit/s (Note 1) 50 Mbit/s (Note 2)	30 Mbit/s net 40 Mbit/s net (notes 3 / 4) 50 Mbit/s net (Note 2)	50 Mbit/s net (Note 2)	20-50 Mbit/s net	
IR 1 (any GOP)		2 Mbit/s net (note 5) 7.5 Mbit/s net (note 6) 10.5 Mbit/s net (note 9) 20.5 Mbit/s net (note 7)	Contribution rate to 30 Mbit/s net	Emission rate -20 Mbit/s net (note 8)	3-8 Mbit/s

Note 1 25 Mbit/s -30 Mbit/s I-only is being used in Japan
Note 2 50 Mbit/s I-Only - EBU Technical Statement D84/D85 -1999

Note 3	30 Mbit/s net (34 Mbit/s total) on E3 links
Note 4	40 Mbit/s net (45 Mbit/s total) on DS3 links
Note 5	Data rates as low as 2 Mbit/s net (3 Mbit/s total) are used in limited bandwidth applications.
Note 6	7.5 Mbit/s net is specified for ENG by the Inter-Union Satellite Operations Group (ISOG) and is currently using MP@ML. (also in standardisation in ITU)
Note 7	EBU 4:2:2 - 22.3 Mbit/s rate used by Eurovision Network
Note 8	8 to 20 Mbit/s is commonly used for on-air playout servers in NTSC or PAL transmission. Coding for on-air playout servers may be at emission rate in the case of digital transmission.
Note 9	EBU 4:2:2 - 12Mbit/s rate used by Eurovision Network

All the above examples are for streaming formats. Where file transfer is the preferred method of moving information, the data rates remain unchanged, however the real time constraints are removed. Thus signals may be transferred over lower bandwidth communication channels than listed above, but at rates slower than real time or alternatively over higher bandwidth channels at faster than real time.

10. Key Issues by Application Area

10.1. Acquisition

Ideally the acquisition format would be chosen to match the predominant format of the following processes. However, for practical reasons, this is frequently not the case.
Where transcoding is likely, the choice of acquisition or process formats should take into account the availability of intelligent transcoding.

The first compression system will determine the maximum quality attainable in chain. This issue becomes critical where the contribution link is of a very low bit-rate.
The use of an unfortunate combination of systems / equipment may create a situation where the low bit-rate contribution link performance, whilst providing acceptable quality when received, becomes degraded to an unacceptable point by subsequent studio processes.

The following areas, which apply to both SD and HDTV services, should be considered:

10.1.1. Video Sampling Structures

To ensure optimal system performance, all sources should ideally have the same luminance and chrominance sampling structures. In both MPEG-2 and non-MPEG systems there exists the possibility of different sample structures being mixed. Where such mixing is required, it is important to retain the history of the signal so that any subsequent processing can take these filtering processes into account.

10.1.2. Frame rates

Although mixing frame rates can introduce well-known temporal artefacts, MPEG-2 offers a substantial coding efficiency improvement when dealing with 24 or 25 Hz progressive frame-rate source material. The successful use of such techniques is not only dependent on the type or genre of the source material but also on the choice of the correct equipment and the operational settings downstream of the acquisition process.

10.1.3. Non-MPEG systems

This is not an ideal starting point for an MPEG-2 based core system, but there will inevitably be a need to accommodate such systems. High-bit rate acquisition minimises any problems but lower bit-rate, non-MPEG acquisition will benefit from intelligent family transcoding to minimise artefacts which could otherwise become unacceptable in later re-use or with special picture processing such as chroma-key.

It should be noted that non-MPEG systems frequently use an alternative sampling structure, where this is the case, care must be taken to ensure that sufficient headroom is provided to allow for a naïve family transcoding.

10.1.4. Latency

Where a program requires a real time link between two or more sites, the time delay for live contributions and / or two-way exchanges is critical as this may damage the continuity of the program or even make a two-way interchange impossible.

MPEG-2 provides the flexibility to implement low latency coders in both I-frame and Long-GOP formats. There is, however, no standard specification for such usage. The temporal predictive modes of MPEG-2 require a higher latency for their operation than I-frame only systems, but in practice this has to be weighed against the higher bitrate requirement for the same quality.

10.1.5. Consumer Formats in News

Frequently the only source of material available is from a consumer camcorder. Whilst these machines produce acceptable first or even second generation quality, they were not designed for the broadcast environment and cannot therefore be treated as professional sources.

The consumer camcorders in the market today do not have a sampling structure conforming to broadcast standards and were not designed with sufficient overhead for decoding and recoding to an MPEG-2 emission format. Nonetheless by careful manipulation of the images, intelligent family transcoding and the avoidance of multiple decode / recode cycles, acceptable news transmission quality can be obtained

10.2. Contribution

In Studio-to-studio applications, the highest possible quality is required within cost constraints. Often the available transport media determines what kind of bitrate can be achieved, but for a given bandwidth, the quality will always be optimised.

Long GOP always gives you the best quality – be it at 4Mb/s or 50Mb/s video rate. As reported in the SMPTE EBU Task Force Report, the quality of 40Mb/s I-frame only is comparable with 25Mb/s Long GOP.

The following are different examples, very much driven by the transport medium.

10.2.1. Satellite

The EBU, for example, uses transport stream rates of about 24Mb/s (video rate ~21.5 Mb/s) for their Satellite based contribution network. This gives a good trade-off between cost and quality, as satellite space is costly.

For News Gathering an alternative set of parameters has been defined, known as DSNG (Digital Satellite News Gathering). The most popular set of parameters used in DSNG is the "ISOG[2]-mode".

This mode specifies the following parameters:
TS rate: 8,448Mb/s excluding Reed-Solomon coding.
Video bit rate: 7,5Mb/s
Audio data rate: 256kbit/s (stereo)

ISOG frequently conducts test between equipment from various manufacturers and has achieved acceptable results. Some DSNG operators use slightly lower and higher bit-rates, but MP@ML, Long GOP and QPSK is prevalent, as it fits in a 9MHz Satellite slot.

In future, higher order modulation schemes like 8PSK and 16QAM will enable higher bit-rates and the use of 4:2:2P@ML.

10.2.2. PDH/SDH

For some time, broadcasters have used 140Mb/s links for "uncompressed" video transmissions and many of these links are still in use today, as it achieves a very high quality level.
However, increasing use is being made of dedicated 34 or 45Mb/s connections, consequently the broadcaster / telco is able to obtain an effective video bitrate of 32 or 43 Mb/s respectively.

For example, a large contribution network in the Pacific region uses a video rate of between 25-35 Mb/s Long GOP together with Linear Audio (~2Mb/s) and some data channels which completely fills the DS-3 link. Several other E3 and DS-3 networks are in operation world-wide using these "high" video-bitrates (>30Mb/s) with Long GOPs.

[2] Inter-Union Satellite Operators Group

10.2.3. ATM

Physical connections to ATM networks suitable for compressed contribution / primary distribution applications are commonly available at the following rates:

OC-3 / STM-1	155.52Mb/s
E-3	34.368Mb/s
DS-3	44.736Mb/s

These bitrates represent ceiling values. ATM offers the flexibility to allocate any lower data rate, and to support multiple channels and data types.[3]

188byte packets are used to match MPEG-2 to the ATM payload area, consequently the Transport Stream with FEC which requires 204 byte packets is not used and error monitoring at the Transport Stream level is not possible. The adaptation layer, normally AAL-1, must therefore provide this FEC function for MPEG-2 streams transported over ATM.

10.3. Editing

Editing alters the time order of video and audio samples. Editing may also alter the content of the video and audio samples. In order to perform these two tasks it is useful to exchange video and audio elements in a format that is either not multiplexed, or one which can be easily demultiplexed.

General consideration:
- Format needs to be easily demultiplexed
- Random access needs to be achieved.
- Quality of the compressed media must be preserved.

Two Operating ranges are required for SDTV and two for HDTV. One of these ensures interoperability by simplicity, the other by flexibility.

Considerations for simple interchange:
- Constrained bytes per GOP
- I-only
- Select single bit rate with sufficient headroom for multiple generations. 50 Mb/s is sufficient for SDTV.
- Repeat sequence headers on every frame
- If non-default quantization tables are used, repeat quantization tables on every frame
- Carry a valid vbv_delay in each picture header

Considerations for flexible interchange:
Compressed video and audio elements should be recompressed as few times as possible. This minimises quality loss due to multiple generations of compression. Efficient use of bandwidth dictates that flexible GOPs be allowed

- Leave compressed elements in their original form.
- Support multiple formats, flexible GOP, bitrates.

[3] Refer to Pro-MPEG Code of Practice #2 - WAN Operating Points

- Preserve timing information that exists in the compressed stream (either implied, or vbv_delay, or PCR/PTS/DTS)
- Use of Re-Coding Data to ensure the minimum picture degradation throughout the process
- Disallow intra_slice_update for MPEG-2 coding

10.4. On-Air Operations

There are currently two methods in common use,

- the use of Play to Air Servers often using a high data rate, followed by real time MPEG-2 encoder.
- the alternative is to encode onto the server at the play to air bitrate and to stream out directly.

Today. the first solution is primarily used for broadcast stations that have a major interest in live program material such as Sport or News, whereas the second solution is preferred where the majority of the content is pre-authored before transmission.

10.5. Emission

To permit the insertion of local programming and advertising, two different techniques are currently in use:

- A hierarchical system, which has sufficient headroom to permit the naïve, decode and re-code of the Video and Audio signal before the final emission.
- A play to air system using the same bitrate as the emission bitrate:

To enable the downstream insertion of local content or advertisements, the distribution stream requires authoring to add SMPTE / SCTE splice points to allow for these insertions. In addition, care must be taken to ensure that the SI / PSIP and data essence information is suitably modified to take into account the emission point.
A more flexible solution may be achieved by decoding the MPEG-2 signal to baseband, mixing with other baseband sources and re-coding. To avoid MPEG-2 codec concatenation losses, it is desirable that the parameters defined in the MPEG-2 Re-Coding Data Set are passed from the decoder to the encoder.

Both systems can also provide the necessary flexibility to allow for logo or bug insertion by an affiliate.

10.6. Archiving

The choice of archive strategies is highly dependent on the user's business needs. As such there is no single recommendation that can be made for the selection or format to be used for a facility's archive. Applications that may determine specific requirements include:

- long term storage of material in a "master" quality format
- temporary storage of material used in production (work in process)
- short or long term storage of finished program material
- as-aired recordings of material transmitted to air (for legal confirmation)

Additional requirements may also need to be considered:

- the need for browse copies that provide a visual "index" to the content
- the need for access by users that may be located off-site
- the choice of a single format or a multi-format archive
- the need to access a segment of material from within a stored program file
- access time (search and fetch time)
- speed of delivery (how fast the material can be delivered from the archive format)
- file transfer vs. streaming delivery

In many facilities, users will be faced with a variety of different audio and video coding formats. In addition, facilities today generate a wide variety of valuable information that is associated with the audio and video material. This may include scripts, EDLs, captioning files and other data essence. Archive systems should ideally be format independent and allow storage and access to all these data types.

When selecting a format for archiving, users may choose to archive material in either its native coding format (D5, HD-CAM, DTF, DV, MPEG-2 etc) or they may select a single format, such as MPEG-2 for all stored material. For MPEG-2-based facilities, the latter approach allows access from a wide variety of equipment without the need to transcode to the house format at the time of access.

The MPEG-2 toolbox offers the flexibility to work at a variety of data rates and GOP structures, which can be selected as appropriate for the quality supported by the source format. For example if archiving material originated on U-matic, the user may select to use main profile @ main level, while material that originated on a higher quality format such as D1 might be archived using the higher quality 4:2:2 profile.

Similar considerations exist for selection of compressed or uncompressed audio formats.

10.6.1. Video formats

Transcoding techniques provide a means of moving from between different GOP structures and data rates. When transcoding, it is important to select a data rate that minimises loss of quality in the copy.

Experimental results showing equivalent picture quality for different data rates and GOP structures are shown in the figure 3. These tests were reported as part of the work of the EBU/SMPTE task force. It should be noted that the current state of the art provides considerably better pictures at the data rates than shown in the table. Users should carefully consider where and when transcoding takes place in their facility based on their specific application.

In a production environment, (where the material will subsequently be used in the editing process), if frequent re-use is anticipated users may choose to transcode all source material to a single Operating point such as 50Mb/s I-frame only as the material is ingested. Where high speed transfer of material over networks or other compressed interfaces, users should consider the speed of any required format conversion and/or transcoding processes as these may limit the speed of transfer.

10.6.2. Audio formats

New audio compression formats allow for efficient transport of multi-channel audio within and between facilities. In a production environment, audio and video will typically be handled separately. Audio processing is normally performed in the uncompressed environment. Just like video, audio de-compression is a real time process and should be accomplished at the same time as and in synchronism with any video transcoding that occurs.

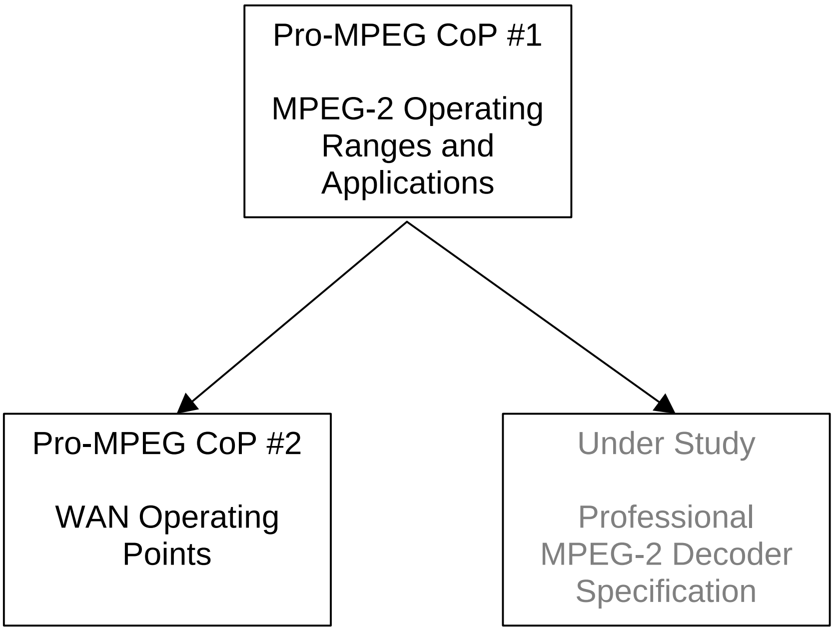
10.6.3. MPEG-2 Transport Streams

If material arrives as a transport stream, specific applications will dictate whether the material should be stored in its native transport stream format or decomposed to elementary streams. For facilities that process incoming material before retransmission, the transport stream must be decomposed to separate audio and video elementary streams before post-production processing takes place. For processing within the facility, material is best stored in an elementary stream format. Examples of such processing may include the production of promos in an edit suite, or mixing, keying and audio voice-overs that may be added in master control.

In the event that metadata and/or data essence is carried in the TS, users are advised to determine the value of such data and to select equipment that preserves this data for re-use or re-insertion in the facilities emission stream.

Informative Annex 1 - Overview of related documents

The relationships between related Pro-MPEG documents are shown below:



Bibliography

Pro-MPEG Code of Practice #1 – MPEG-2 Operating Ranges and Applications
Pro-MPEG Code of Practice #2 – WAN Operating Points

Under Study:

Professional MPEG-2 Decoder Specification

Informative Annex 2 - Variable Bit-rate and Constant Bit-rate

Some devices have a great deal of flexibility to deal with bursts of data, as might happen when coding a difficult video scene. These devices use variable data rate by increasing data rates when necessary to preserve quality, and decreasing data rates with easier content to improve efficiency. These devices, therefore, are sometimes referred to as providing constant-quality operation.

Other devices inherently operate with data rate constrained to a constant value. When data rate is fixed, there will be some picture quality variation, which will be a function of the picture complexity. If data rates are sufficiently high, these variations can be imperceptible. The ease of processing constant bit-rate streams is therefore attractive in some applications.

Whatever type of compression (VBR or CBR), all practical systems need some limits on allowable bit-rate variations. To address this, MPEG-2 specifies a buffer model for both compression and transport. It is the responsibility of the compression encoder to manage the data rate, through varying quantization granularity, to avoid buffer over-flow or under-flow.

Perhaps the most familiar example of VBR implementation is DVD, where storage efficiency is especially critical. The average bit-rate on a DVD is around 4.8Mb/s while the peak rate may reach 9.8Mb/s. Professional television equipment has used both VBR and CBR; VBR is popular with some disk recorders, while CBR compression has generally been used on tape and in some editing disk recorders.

With clear applications for both VBR and CBR in the professional domain, this code of practice facilitates an approach to interconnect VBR and CBR components in a system. This approach is based on an interface in which VBR signals are padded up to CBR by those devices which must use CBR processing, then the padding is removed when returning to a VBR environment. In addition, new techniques are being developed for changing compressed signal data rates. Together, these techniques will allow best benefits of both VBR and CBR operation.

Informative Annex 3 - Interoperability

There is a confusion in the minds of many people who use systems about the interoperability between system components. One of the reasons for this is that the degree of interoperability varies in different situations.
This is a recommended approach to creating a common language that allows users and providers to understand more clearly what is meant by interoperability.
The idea behind the approach is to define four levels of interoperability. These levels bear a resemblance to the OSI model in that the lower level of interoperability is about interoperation at the physical layer and the link layer, the middle level is about interoperation at the transport layer and the highest level of interoperation is about interoperation at the presentation and application layers. This approach assumes that interoperability is about the interconnection of a sender and a receiver connected by a transport mechanism. Thus levels of interoperability may be changed by altering the capabilities of any of the three components.

Interoperability Level 1- COMMUNICATION LEVEL

This is the lowest level. If equipment is interoperable at this level then that equipment can communicate but is not able to understand the internal content of the file.
An example of operation at this level is FTP of files, where servers are used as a store of files.

Interoperability Level 2- STRUCTURE LEVEL

Interoperability at level 2 requires that equipment can communicate at level one and in addition understand the internal structure of the signal.

- Thus signals can be passed between devices but need to be interoperable at level 2 in order to be able to process the signals. Examples are: SDTI SMPTE305, SDI ITU-R BT.656, ATM etc.
- For example if two VTRs are connected in a record/playback configuration, and the record machine displays an error message to say that it had an incoming signal but cannot record it, then we would regard these machines as being interoperable at level 2. (The machines can understand that a signal is arriving but it is of a format that the record machine cannot handle)

Interoperability Level 3 - FILE AND STREAM LEVEL

Equipment operating at this level can understand and process essence and parse data, but there may be distortions in the essence or some of the data may not be understood fully or not map onto the receiving equipment's data structures.
Thus for example when a file is transferred from word processor A to word processor B the result is that all the text is readable and imported. However often the drawings do not come out correctly and there are errors in the layout. This interconnection is therefore a level 3 connection.
In the broadcast world, in order to achieve interoperation at level 3 equipment must understand detailed information about the bit structure of the Essence, packetization structures, and file formats that are used to convey essence and metadata. Examples are: SDTI-CP, DV DIF blocks, MXF.

Interoperability Level 4 - SIGNAL LEVEL

Level 4 interoperability is achieved when all the essence and metadata is available to be used.
In order to understand this level it is easiest to introduce the concept of the 'value' of a signal or data. This is an adaptation of standard economic concepts. As a signal undergoes processing, work is put into the essence and the metadata thus sorting and developing the information communicated by the signal. We say that value of the signal is increased. However if a signal is processed in a way that reduces its appeal to the intended end-user, for example distorted through the application of compression then we can say that the value of the signal is decreased.
For equipment to be interoperable at this level then all essence and metadata must be handled in a way that does not diminish its value after allowance has been made for any value added by the processing within the unit.
This level is therefore most applicable to the essence. Every broadcasting organisation has an intrinsic view of the minimum quality that it requires, an important component of the value, and therefore needs to understand the quality delivered by a connecting two items of equipment. Thus for an organisation to regard equipment as interoperable at level 4 then that equipment must be capable of delivering the organisation's minimum quality
Within this level, standards are applied which define e.g. the signal generation (e.g. ITU-R BT.601) as well as encoding and decoding algorithms for compression. This level also includes the definitions of Metadata and Data essence types.

It is recognised that levels 1, 2 and 3 are easier to confirm than level 4. However the user group agree that level 4 is the area that causes most of the difficulty when building systems and therefore must be part of a user requirement.

This Code of Practice, MPEG-2 Operating Ranges & Applications, is located in the interoperability Levels 1 and 2.

In order to meet the requirement for a minimum predictable picture quality and to guarantee full interoperability through a chain of different equipment, specifications may be required which are located in interoperability level 4 as well as level 3, 2 and 1.