Technology Overview

AVC-Intra (H.264 Intra) Compression

H.264/AVC Intra-only Compression for P2 applications

1. Introduction

The use of High Definition (HD) in most television program production has been rapidly increasing over the last few years. Thankfully, recent technological advances have lowered the cost of HD production and post-production equipment to be in line with the cost of yesterday's standard definition hardware. The same technological advances that make cost effective HD possible have also introduced new creative processes and changed workflows, while also enhancing efficiency. The HD of today has borrowed heavily from the "IT" industry, bringing networked data workflows, non-linear HD editing, and the introduction of solid-state field recording and associated tapeless workflows. One example of an IT tapeless system is the P2 system[1]. P2 uses solid state memory to record a variety of content which includes MXF essence files and associated metadata. The adoption of flexible recording formats like P2 provides a welcome break from the inherently "locked" formats of tape and other "physical" media.

The advent of high-speed processors and affordable memory has also spurred similar quality and efficiency gains in the area of video compression. Earlier video compression schemes, such as MPEG-2 introduced in the early 1990s, were seriously constrained by the processing capability of the hardware available at the time. Today however, we can now take full advantage of the power and speed of modern digital processing and leverage that technology to produce more efficient modern compression schemes.

Based on the above background, P2 HD products, which have already supported the DVCPRO HD compression, will be expanded to the product line with the introduction of the latest and highly efficient video coding standard, H.264/AVC compression. The use of H.264/AVC provides production quality HD at bit rates more normally associated with ENG applications by enabling full resolution, 10 bit field capture of high quality HD imagery for the first time in one piece camera-recorders. This paper outlines the concept and key features of "AVC-Intra", which is the term used to represent the implementation of the H.264/AVC Intra-only compression in P2 HD products, describes the essence file format on a P2 Card and also introduces some of the AVC-Intra capable P2 products.

2. Basic concept of AVC-Intra

The requirements of professional HD applications, along with the introduction of the concept and specification of AVC-Intra in order to meet these requirements, are summarized in **Table 1**.

Table 1 – Application requirements and concept of the AVC-Intra

Requirements	Concept and specification of AVC-Intra
IT affinity / Tapeless	P2 file recording
Guarantee interoperability	Adoption of International video coding standard and MXF file format
Higher picture quality	Significant improvement in coding efficiency using H.264/AVC
Multi-generation performance	Intra-only compression
Editing / Operation	Intra-only compression with fixed coded frame size
Full Resolution HD mode	100Mb/s mode (1920x1080 / 1280x720 resolution, 4:2:2 with 10 bits)
Economy HD mode	50Mb/s mode (1440x1080 / 960x720 resolution, 4:2:0 with 10 bits)

With existing recording schemes, e.g. tape, the physical recording format and file/codec compatibility are guaranteed by the physical media itself, which may be considered a closed system. With the more flexible IT file-based systems, e.g. P2, full compatibility of a compressed bit stream and a file format needs to be ensured, as this is a open system which means an essence can exist in different medias and be exchanged between different systems. To guarantee interoperability, therefore, it is very important that the compression scheme and a resulting compressed bit stream conform to international video coding standards.

Figure 1 illustrates the evolution of the various compression schemes. For the past 10 years, the main target of research and development was the improvement of compression efficiency at the relatively lower bit rates. MPEG-2 has been very successful through providing bit rate savings in recording and transmission of SD DVDs and DTV. After MPEG-2, work on more advanced compression continued leading to the development of MPEG-4 Visual. After the completion of the MPEG-4 Visual standard, the *Joint Video Team* (JVT) of ITU-T VCEG and ISO/IEC MPEG was established to develop an even more efficient compression scheme. As the result of the efforts by JVT experts, H.264/AVC, formally known as ITU-T Recommendation H.264 [2] or as ISO/IEC 14496-10 (MPEG-4 part 10) Advanced Video Coding[3], was developed with significant improvements in coding efficiency. In order to meet the demand for coding of higher-fidelity video material, the first amendment of H.264/AVC, named FREXt (Fidelity Range Extension), was created with new High profiles.

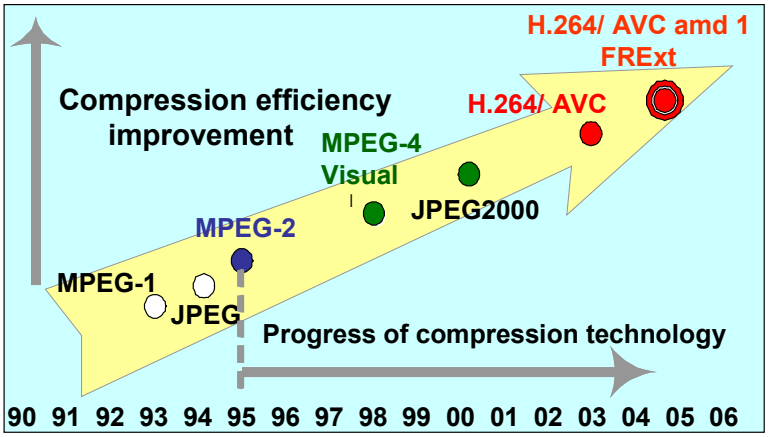


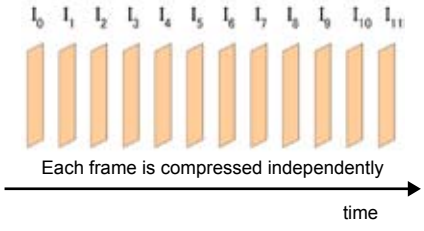
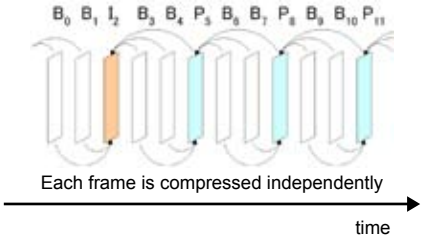
Figure 1 – Evolution of compression technology

Since professional HD applications require not only higher picture quality, including the full resolution and the extension of bit depth etc. at reasonable bit rates, but also require multi-generation performance and frame accurate editing capability, highly efficient coding using Intra-only compression is utilized in order to satisfy these requirements. The latest H.264/AVC compression fulfills such requirements while providing significant improvements in picture quality compared to existing compression schemes. The AVC-Intra implementation of H.264/AVC within select P2 products is flexible to user demands by virtue of its ability to switch between the AVC-Intra 100 mode and the more economical AVC-Intra 50 modes. The AVC-Intra 100 mode provides the full resolution (no-subsampling) HD using 4:2:2 sampling, while the AVC-Intra 50 mode provides a more economical advantage using 4:2:0 sampling. Both compression modes support 10-bit depth and the coded data size is fixed on a frame-by-frame basis which eases the frame accurate editing.

3. Advantages of Intra-only Compression

Video compression may be divided into two basic schemes: Intra-only compression that completes the compression processing within an individual frame, and Inter (Long GOP) compression in which the processing is completed over multiple frames. As summarized in **Table 2**, there are differences in certain characteristics of the video compression system due to the processing of an individual frame versus multiple frames.

Table 2 - Comparison between Intra-only compression and Long GOP compression

	Intra-only compression		Long GOP compression	
Compression Scheme	Individual frame 		Multiple frames (e.g.15 frames) 	
Bit rate saving	Smaller	Use spatial correlation only	Greater	Use spatial and temporal correlations
Processing delay	Smaller	1 frame	Greater	Multiple frames
Editing easiness	Easier	frame by frame	More Difficult	GOP
Multi-generation deterioration	Smaller	Intra structure	Greater	Long GOP structure
Error propagation	Smaller	Max. 1 frame	Greater	Multiple frames
Parallel processing	Easier	Max. 1 frame	More Difficult	Multiple frames

Long GOP compression schemes utilize temporal correlation in order to generate lower bit rates than Intra-only schemes by using the assumption that the picture content of the adjacent frames is similar. However, if the sequence has a low frame correlation between adjacent frames, the bit rate savings generated by using Long GOP compression would be reduced, making it closer to the bit rate generated by using Intra-only coding. Examples are press events with many “still-camera”

strobes, fast motion sports images, camera zooms and pans, special effects or graphics with short duration events and high intensity motion, e.g. animation and Music Videos.

Because multiple frames are utilized to exploit temporal correlations when coding a sequence with Long GOP coding, there is a greater processing delay associated with Long GOP coding. In contrast, the processing delay is lower in Intra-only compression because each frame is coded independently. Editing within postproduction is more difficult for Long GOP coding because access to individual frames is complicated since multiple frames are used within the coding. Since Intra-only compression codes each individual frame, recording, editing and manipulation are easily accomplished because the access to each individual image is easy and image quality is kept stable while being totally immune to adjacent frame content influence, which also leads to a lower multi-generation generation deterioration. The quality of a coded sequence using Long GOP coding will worsen much faster than using Intra-only coding over multiple coding generations leading to a greater multi-generation deterioration for Long GOP coding due to the dependency between coded frames. As stated previously, because Intra-only compression codes each frame independently, the quality of a coded sequence over multiple coding generations can be kept higher using Intra-only coding.

An error within a frame using Long GOP coding has the possibility to affect several frames leading to greater error propagation when comparing to Intra-only coding. In comparison, an error within a frame using Intra-only coding is contained within a single frame leading to lower error propagation. While parallel processing is used for both coding schemes, parallel processing is more difficult for Long GOP coding due to using multiple frames in the coding process. Intra-only compression is very suitable for use with parallel processing architectures, i.e. multi core CPUs, and processing with software based codecs.

4. Higher coding efficiency of H.264/AVC

H.264/AVC compression video coding is based on the traditional hybrid concept of block-based motion-compensated prediction (MCP) and transform coding. Within H.264/AVC, a number of powerful tools have been developed and incorporated into the standard. According to the experiments, the aggregation of the various efficiency enhancement tools makes it possible to achieve the potential bit rate savings up to around 50% over MPEG-2 depending on the video sequence and implementation[4,5] . In order to improve the compression efficiency of Intra-only compression, the following two coding tools provide major contributions to the significant bit rate savings:

- Spatial Intra prediction conducted by using spatially neighboring samples of a target block which have been previously coded.
- Entropy encoding improvement, CAVLC and CABAC

4.1. Spatial Intra prediction

H.264/AVC uses both spatial and temporal predictions to increase its coding gain. The intra-only compression uses spatial prediction and the prediction only occurs within a slice. Figure 2 shows examples of some prediction options for 8x8-block intra prediction. Each luminance sample in an 8×8 block is predicted from the neighboring constructed reference samples, where 8 different prediction directions and a DC prediction can be selected by the encoder. In the case of chrominance block, four different prediction methods are available. The key to improving coding performance when using spatial intra prediction is to select the proper prediction mode for each block. The AVC-Intra implementation for P2 products not only decides the best prediction mode with minimum processing complexity, but also uses the mode optimization algorithm to prevent flicker and any multi-generation deterioration.

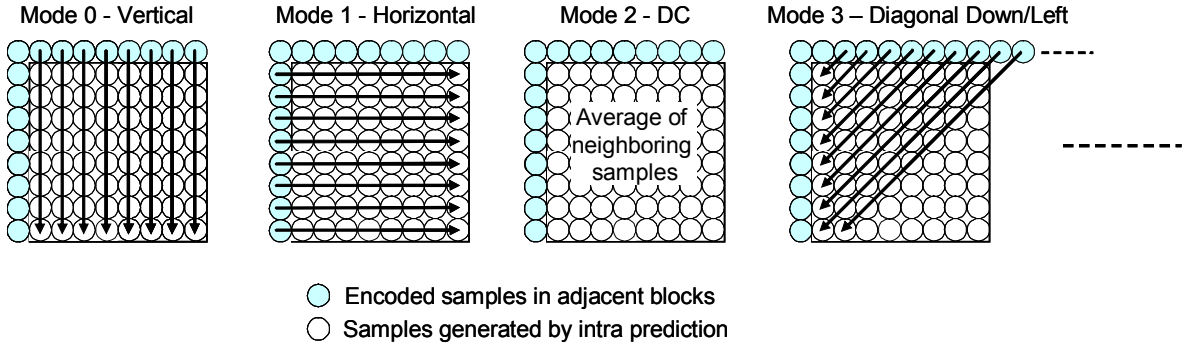


Figure 2 – Examples of spatial intra prediction modes

Figure 3 shows the original input image and the intra prediction image generated from the input image. Due to the high accuracy of the prediction, the intra prediction image is very similar to the original input image.

(a) Original input image (b) Intra prediction image

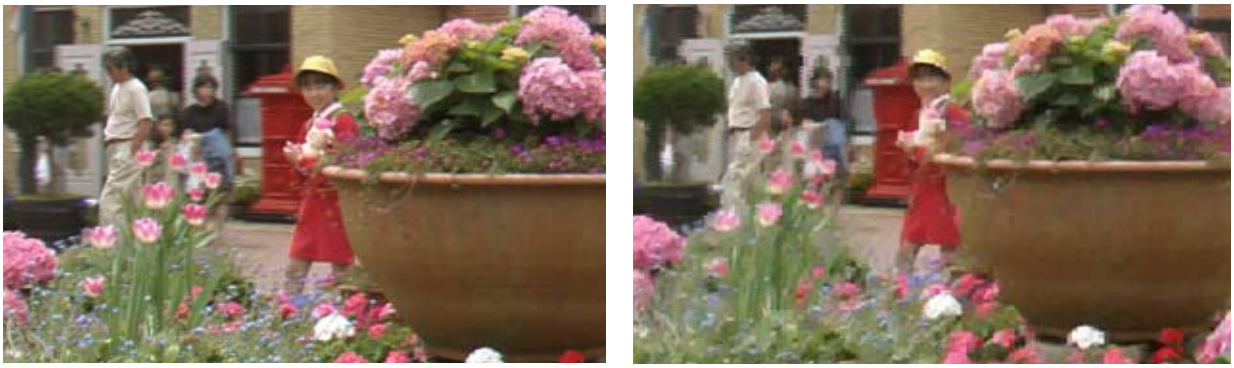


Figure 3. - Original input image and Intra predicted image

By subtracting the intra frame predicted image from original input image, the result, a “difference” or residual image, is generated and is shown in Figure 4. An integer transform is applied to this residual image with the resulting coefficients being adaptively quantized and entropy coded. The prediction mapping information is stored in a bit stream along with compressed residual image. Because the amount of data required for the residual image can be reduced by highly accurate intra prediction, higher efficiency compression can be achieved even when using Intra-only compression. In contrast to inter frame prediction employed in long GOP encoding, spatial intra prediction is performed within the confines of a single frame, which means that the prediction accuracy and subsequent compression efficiency does not deteriorate with motion as it would with long GOP.

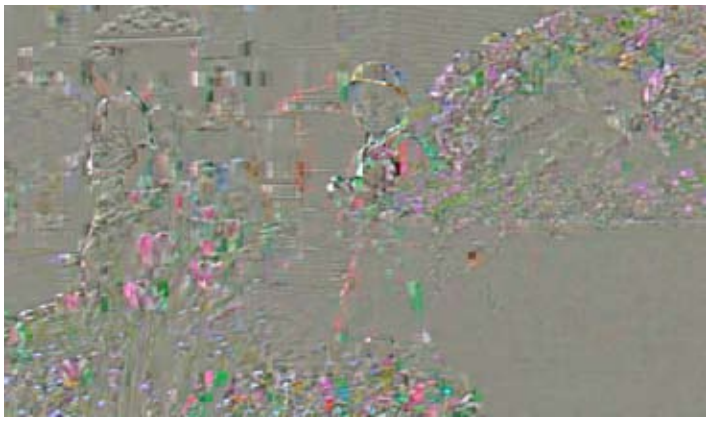


Figure 4 – Residual image

4.2. Enhanced entropy coding method

The entropy encoding method can be selected from either Context Adaptive Binary Arithmetic Coding (CABAC) or Context Adaptive Variable Length Coding (CAVLC). These context based entropy coding methods use coding information from surrounding areas to achieve high compression efficiency by adjusting the entropy encoding parameters in order to best match the content of the image. Table 3 shows the comparison of entropy encoding methods. Simple VLC employed in MPEG-2 is not always optimal for all pictures, since compression efficiency may decrease when a predetermined VLC table does not match the content of a target picture. Conversely, CAVLC and CABAC can entropy encode quantized components with high efficiency by adjusting the operation precisely to match the statistics of the target picture, which leads to a much lower bitrate when compared to the non-adaptive MPEG-2 VLC. Significantly, CABAC is able to perform “text-book” entropy encoding almost to the limit of the theory due to the combination of the arithmetic coding and context adjustment. Even though its complexity is higher than CAVLC, CABAC provides a very significant contribution to the coding efficiency most likely leading to even wider utilization of the tool in the future.

Table 3 - Comparison of Entropy Coding Methods

	MPEG-2 VLC	H.264/AVC	
		CAVLC	CABAC
Encoding method	Non-adaptive VLC	Context Adaptive VLC	Context Adaptive Arithmetic Coding
Context Adjustment process	No	Transformed coefficient based	bit by bit
Encoding efficiency	Moderate	Very good	Excellent

5. MXF File format for AVC-Intra

The structure of the content on a P2 card consists of logical “clips” that each contain a video MXF file, one or more audio MXF files, and an XML clip metadata file, as well as implementation dependent optional files, i.e. a Bitmap thumbnail file, a WAVE voice memo file, and an MP4 proxy AV file. These files are stored under directories within the P2 card, as shown in Figure 5. As a video essence file, P2 products have already implemented a DV-DIF video MXF file, which contains a DV/DVCPRO compressed video stream. AVC-Intra’s compressed byte stream is encapsulated in a MXF file conforming to SMPTE 381M, which is commonly used for mapping MPEG-2 and MPEG-4 Streams into the MXF Generic Container. As shown in **Figure 5**, the structure of the content and XML metadata are the same between the DV/DVCPRO essence and the AVC-Intra essence with the exception of the essence stream wrapped in the MXF essence container and relevant structural metadata. In addition, coded frame sizes for the AVC-Intra stream are selected so that the total bit rate for the AVC-Intra stream fits into the DV-DIF stream. These features provide benefits for users and implementers such as a common operation, a common recording time and a common access performance to a video essence file.

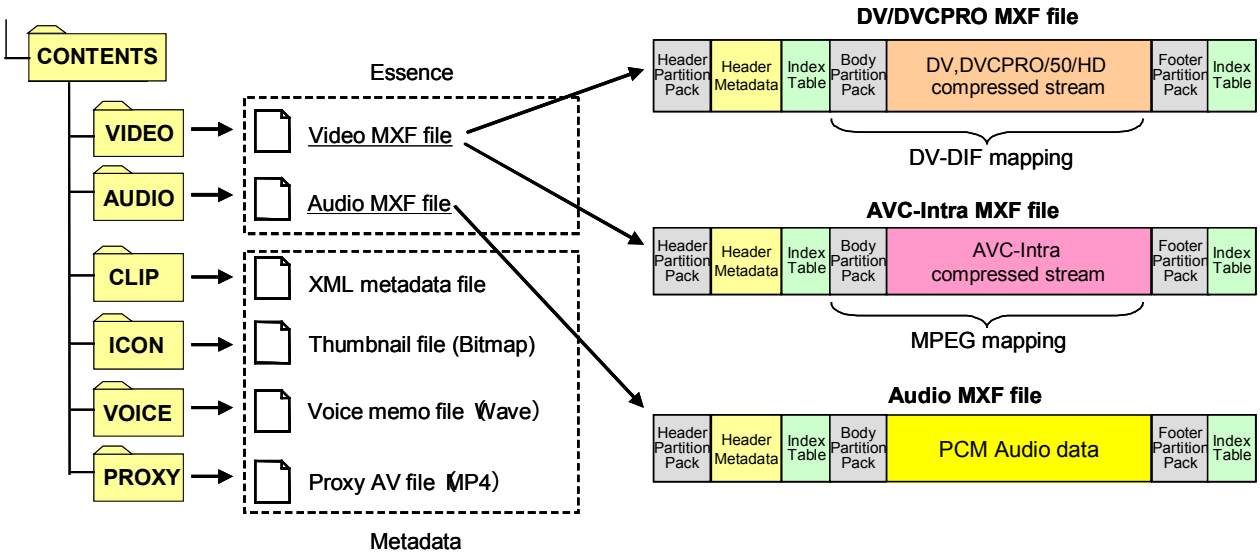


Figure 5 – Content structure on P2 Card

6. Products Lineup supporting AVC-Intra

6.1 Camera recorder (AJ-HPX2000)

The AJ-HPX2000 P2 HD shoulder-mount camcorder integrates native HD progressive 2/3” 3-CCD performance with the ultra-high reliability and speed of P2 solid-state recording. As one of the most flexible, full production-quality cameras available, the AJ-HPX2000 records pristine high-quality images in over 30 HD and SD formats ranging from 1080p, 1080i, 720p, 480p, 480i and 576i. With the new AVC-Intra codec option board (AJ-YBX200G), the AJ-HPX2000 can deliver 10-bit, 4:2:2 master-quality video for outstanding video production and news acquisition. AVC-Intra, the industry’s most advanced

compression technology, is a professional intra-frame video codec with bit rates of 50 and 100Mbps, utilizing the High-10 and High-422 profiles of H.264 respectively. AVC-Intra provides high-quality 10-bit intra-frame encoding in two modes: AVC-Intra 100 for full-raster mastering video quality, and AVC-Intra 50 Mbps for DVCPRO HD quality at half the bit rate, thereby doubling the record time on a P2 card.

6.2. Camera recorder (AJ-HPX3000)

AJ-HPX3000 is the industry's first native 1080p one-piece camcorder to acquire mastering-quality high definition video. With three 2/3" high-density 2.2-megapixel CCDs, the HPX3000 captures cinema-quality images in full-raster 1920 x 1080 resolution with 4:2:2 10-bit sampling, utilizing the powerful AVC-Intra codec. It offers intuitive film camera-like operation and its superb performance is enhanced with advanced 14-bit A/D conversion and a 12-pole matrix color correction function. Additional high-end features include six advanced gamma settings, including Film-Rec mode (made popular by the VariCam); a Chromatic Aberration Compensation (CAC) function that corrects for lateral chromatic aberration in lenses; film-like shutter controls; built-in scan reverse and a proxy video encoder. It has a high sensitivity of F10 at 1,000 lux in 1080i, and a minimum illumination of .064 lx (at +56db gain-up).

6.3 Portable recorder (AJ-HPM100)

Called the P2 Mobile, this portable, rugged 4:2:2, 10-bit capable solid-state memory recorder/player is ideal for field production, postproduction as well as ENG applications. With the new AJ-YBX200 AVC-Intra codec board (option) installed, the P2 Mobile can record full-raster 1920 x 1080 or 1280 x 720p images with 10-bit sampling, which makes it well suited for "video village" use in the production of movies, TV series, documentaries, commercials and more.

The P2 Mobile features multi-format recording and playback with a six-slot P2 card reader, versatile inputs/outputs (HD-SDI, IEEE 1394, USB 2.0), an SD memory card slot, job/shuttle dial and up/down/cross conversion between 1080i and 720p and between high definition and standard definition formats. Plus, the P2 Mobile combines professional editing controls with audio faders, a 9-inch widescreen LCD monitor with stereo speakers, and a compact, magnesium die-cast body. It's a versatile and powerful mobile recording/editing solution for field recording (including pool feeds) and video production, as well as for use in mobile vans or in desktop non-linear/linear editing systems. The P2 Mobile allows a user to record in DVCPROHD/50/25 and in AVC-Intra.

7. Summary

Since emerging as an IT tapeless system three years ago, the P2 system has been developing to meet user demands for HD applications. The adoption of the latest and highly efficient video coding standard, H.264/AVC compression, along with the DVCPROHD compression fulfills further demands, and provides production quality HD at bit rates more normally associated with ENG applications by enabling full resolution, 10 bit field capture of high quality HD imagery for the first time in one piece camera-recorders. It also provides excellent multi-generation performance and the frame accurate editing capability in subsequent editing applications by utilizing Intra-only compression. Due to the increasing prevalence of flexible and open IT file-based systems, conformance to international video coding standards and utilization of the standardized MXF file format is also very important to guarantee interoperability.

In due course, new products in the Panasonic lineup supporting AVC Intra will be delivered soon. The ability to record very high quality HD with a significant reduction in storage/networking requirements while working in an IT infrastructure will greatly benefit HD users.

References

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