The Cure for Concatenation

Preserving 4:2:0 chroma integrity in concatenated operations

Since the early days of transcontinental and intercontinental networking of television content, several intermediate communication links have generally been required to complete end-to-end delivery. This is referred to as "concatenation" and has been an area of significant attention in regard to maintaining video and audio quality and integrity. In earlier analog systems, demodulation and re-modulation of the television signal at each en-route microwave or satellite terminal contributed to signal degradation particularly video signal-to-noise, which in many instances reduced the image at the point of delivery to less than that normally acceptable for broadcast.

The transition to video compression and digital networking has created new challenges in mitigating the effects of degradation caused by concatenation in the multiple encode-decode process associated with digital turn-around over satellite, wireless and terrestrial links. One particular problem is that of maintaining integrity of the 4:2:0 chroma component where an HD-SDI interconnect is used between concatenated decoders and encoders. This relates equally to both the widely used MPEG-2 and newer MPEG-4 (H.264 / AVC) codec standards.

HD-SDI is inherently a 4:2:2 interconnect which requires that a 4:2:0 stream be up-sampled and then down-sampled at each digital turn-around. This can, within as little as 4-5 concatenated links, result in visual blurring of the color image to the point where the quality and integrity of High Definition content can be severely compromised.

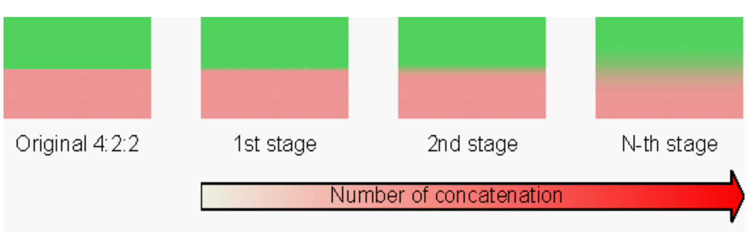


Fig 1: Degradation of the 4:2:0 chroma component in concatenated operations

This is of particular importance in applications such as HD-Digital Electronic News Gathering (HD-DENG) where the use of lower data rate encoding and 4:2:0 chroma sampling can provide operational and economic advantages. In HD-DENG a significant number, possibly as many as 10 or more concatenated operations can take place before final delivery to network affiliates and others.

The two most widely used chroma encoding formats in broadcast television applications are 4:2:2 and 4:2:0.

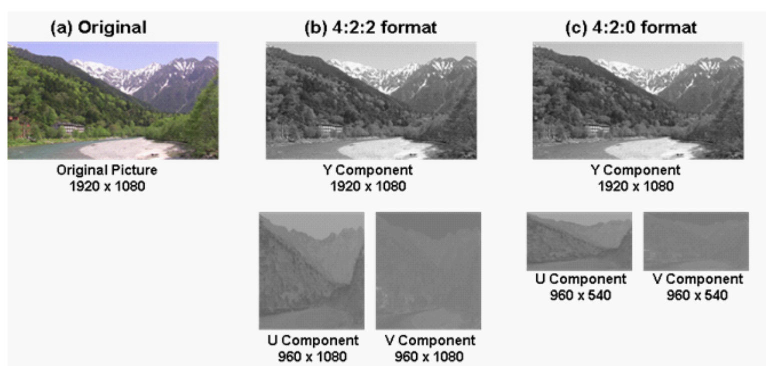


Fig 2: Comparison of 4:2:2 and 4:2:0 formats

The original high definition 1080i picture shown in this example has 1920 pixels in the horizontal and 1080 pixels in the vertical scan. The components of the picture comprise the Luminance or "Y" component, plus the two "U" and "V" chroma components. It is well accepted that the human eye is less sensitive to chroma than it is to luminance, which enables chroma resolution to be reduced to less than that for luminance in the encoding process.

In a 4:2:2 format, the two chroma components are therefore down sampled by a factor of two from the horizontal luminance component resulting in a pixel ratio of 960 x 1080; whereas, the 4:2:0 format the "U" and "V" chroma components are down-sampled by a factor of two in both the horizontal and vertical resulting in a pixel ratio of 960 x 540.

The recent introduction of MPEG-4 (H.264 /AVC) compression standard has delivered yet another improvement in digital network utilization. Most MPEG-4 content can be carried in less than 50 percent of the bandwidth required for similar MPEG-2 encoded content. MPEG-4 High Definition video performance at encoded data (bit) rates below 10Mbps is generally accepted as sufficient to meet many broadcast television operations including HD-DENG.

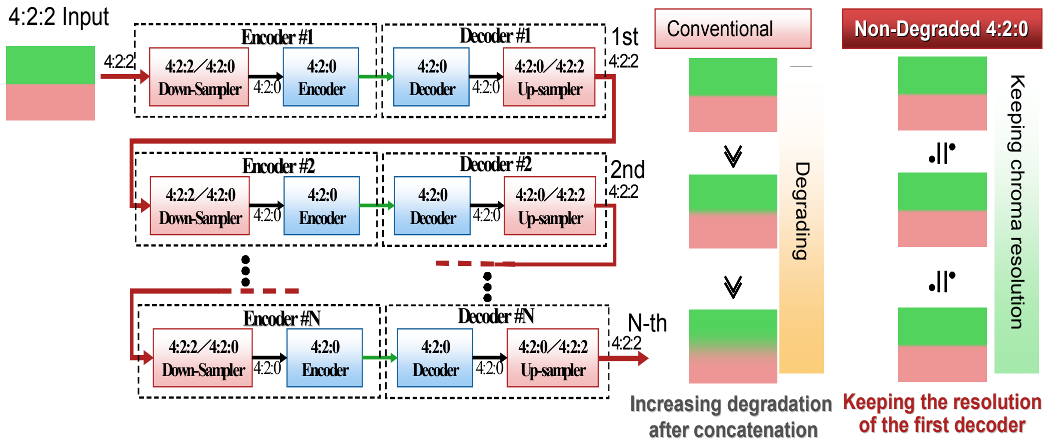


Fig 3: Conventional and Non-Degraded 4:2:0 concatenated links.

It is widely agreed for lower encoded video data rates, those at or below 10Mbps in MPEG-4 (H.264), that 4:2:2 chroma sampling will not produce a significant improvement in performance over that of 4:2:0, and also requires more bandwidth for a specific encoded data rate. Content encoded at 10Mbps 4:2:0 requires approximately 20 percent less bandwidth than 4:2:2 encoded content.

This presents both opportunity and problem. Whether to use 4:2:2 chroma sampling and accept the some 20 percent more bandwidth cost, or to use the more efficient 4:2:0 format with potential chroma degradation in concatenated links. Thankfully, this consideration is no longer an issue, due to work recently done by Akira Nakagawa and the engineers at Fujitsu Laboratories in Japan.

In order to provide a solution to the degradation of 4:2:0 streams carried over concatenated links and using HD-SDI interconnects, Mr. Nakagawa and his team of engineers have created an advanced technology, chroma down-sampling and up-sampling filter set that they refer to as the "Perfect Reconstruction Filter". We have been informed that this new filter technology will soon be implemented in Fujitsu MPEG-4 products including the IP-9500 HD-SD encoder shown here.

In a conventional 4:2:0 encoder and decoder design, without the perfect reconstruction filter set, the chroma component will suffer loss of resolution during each concatenated operation from the necessary up-sampling and down-sampling in the HD-SDI (4:2:2) interconnect. This unwanted degradation can be totally eliminated by fitting each encoder and decoder with the prefect reconstruction filter set as demonstrated in Fig 3.

In order to achieve the objective of maintaining non-degraded 4:2:0 chroma resolution throughout the concatenated chain it is necessary that all encoders and decoders are fitted with the same "Perfect Reconstruction Filter" set.

The second objective of maintaining compatibility with conventional MPEG-4 decoders has also been achieved to enable a Fujitsu non-degraded 4:2:0 stream to be decoded without errors or color displacement by other manufacturers' conventional decoders as shown in Fig 4.

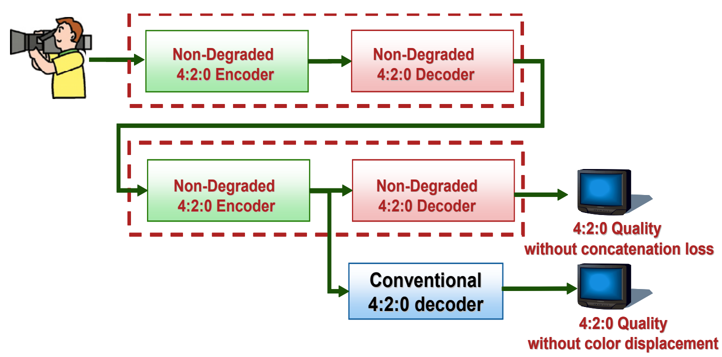


Fig 4: Compatibility with conventional MPEG-4 (4:2:0) decoders

Several key conditions had to be met in the design of a Perfect Reconstruction Filter set to enable multiple concatenated operations. As many as sixteen (16) encode /decode concatenations were conducted in testing without degradation of the 4:2:0 chroma component. The filter set is designed to accurately separate the chroma component of an original HD-SDI (4:2:2) video input and down-sample it by using a low pass filter and a 2:1 vertical sampler. The 4:2:0 output is then created by combining the down-sampled chroma with the luma component as shown in Fig 5.

The MPEG-4 (4:2:0) encoded output can then be carried efficiently over any digital communications link; Satellite, Wireless, Telco, VPN or Internet to an intermediate destination or digital turn-around point. Then by using a decoder fitted with a perfect reconstruction filter the 4:2:0 / 4:2:2 up-sampling process is performed to connect the second encoder in the concatenated link using the HD-SDI interconnect, at the same time preserving 4:2:0 chroma integrity.

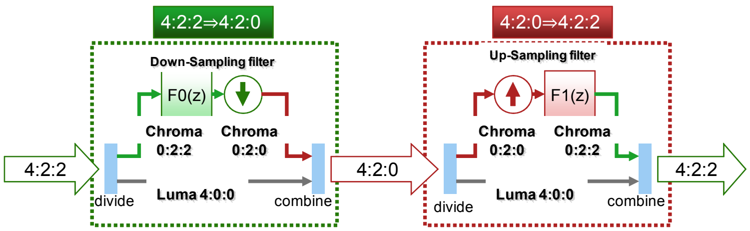
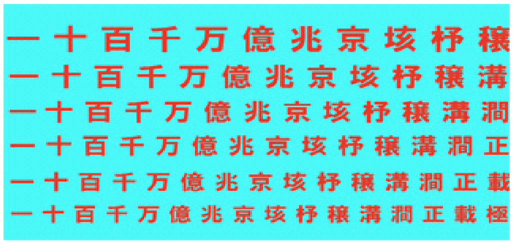


Fig 5: The Perfect Reconstruction Filter

In field testing the new filter technology, it was reported that up to sixteen encode and decode concatenations were performed to compare results of Fujitsu filter technology with conventional MPEG-4 encoders and decoders. Comparisons included routine tests such as PSNR, standard industry video clips and subjective evaluation. It is widely recognized that color degradation tends to be more visible in screen text and computer graphics (CGs) which tend to have sharper transitions. This is clearly visible in 4:2:0 video that has been degraded by concatenated operations. Fujitsu engineers used several independently created visuals in testing, including those shown here:

(A) Characters with sharp transitions



(B) CCETT Mobile and Calendar; saturated color sequence with high resolution characters

C) RAI - Italian Television formula one racing

In these tests, a comparison of the chroma PSNR of the 1st 4:2:2/4:2:0 conversion was made with that at the output of the 2nd; 4th; 8th and 16th concatenation of the 4:2:2/4:2:0 conversions. Test results shown in Fig 6, clearly demonstrate chroma degradation in conventional concatenated operations and protection provided by the Non-degraded 4:2:0 solution that maintained PSNR close to that of the original 4:2:2 source.

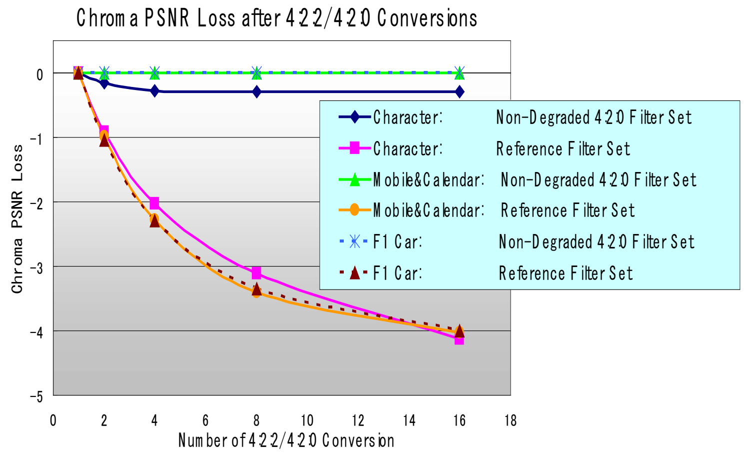
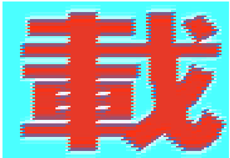


Fig 6: Chroma PSNR in conventional and non-degraded concatenation

It is generally recognized that down-sampling and up-sampling is more difficult for Interlace than for progressive video largely because of non-linear phase characteristics. The generation of unwanted artifacts is also more pervasive. These factors were considered in providing a solution equally valuable to either interlace or progressive video. The following test sequence in Fig 7 demonstrates protection of the chroma component in a concatenated operation employing non-degraded filter technology.

Conventional technology


1st Conversion


4th Conversion


16th Convension

Non-degraded technology


1st Conversion

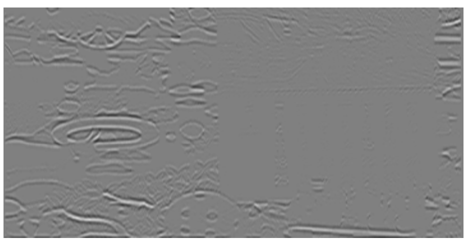

4th Conversion


16th Convension

Fig 7: Character test sequence

Another important test revealed the “V” chroma differential using conventional and non-degraded filter technology. Fig 8 shows the “V” component differential between the first 4:2:2/4:2:0 conversion and the sixteenth 4:2:2/4:2:0 conversion and concatenation. It can be seen clearly that using a conventional filter set the differential is obvious, and almost no difference can be seen when the non-degraded 4:2:0 filter set is used.

It therefore appears that a long time problem with concatenated encode-decode operations is now a thing of the past, solved effectively through the work of Mr. Akira Nakagawa and the engineers at Fujitsu Laboratories. Importantly their solution does not create an incompatibility with the MPEG-4 standard. It allows full interoperability with other manufacturers’ decoders although these will not provide protection of the 4:2:0 chroma integrity in concatenated operations as do those equipped with the “Perfect Reconstruction Filter” technology.



Conventional technology

Non-degraded technology

Fig 8: “V” chroma component differential atbetween the 1st and the 16th concatenation.

For more information please visit
http://us.fujitsu.com/video

Fujitsu IP-9500 offers real-time H.264 High Profile at Level 4 encoding with data rates from 4 to 27 Mbps for High Definition Television Contribution and Distribution. With its Best-in-Class picture quality, the IP-9500 also supports an industry leading 300ms total encode/decode latency for exceptional HD Satellite News Gathering and Sports broadcasting.

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