High frame rate conversions
November 2014

Introduction

UHDTV will benefit from a higher frame rate than 60 Hz, due to the enhanced motion rendition which is so critical to picture quality at higher resolutions. Therefore 120 Hz has already been included in the UHDTV1 systems definition (3840×2160 pixels per image), as published in SMPTE ST 2036-1 and recommended by ITU in Rec. BT 2020.

Some broadcasters would like to add 119.88 Hz (120/1.001) to UHDTV standards for apparently easier integration with today's fractional standards. There is a thought that conversion between today's fractional standards and future higher frame rates could be achieved via frame drop/insertion, leading to lower complexity conversion products. However, avoidance of fractional frame rates in the standard (e.g. allowing only 100Hz and 120 Hz) would allow for easier handling of audio and metadata, and avoids the need for drop-frame timecode[1].

In this paper, we show that complexity of frame rate conversion is similar, whether converting to integer or fractional higher frame rates, and that excellent picture quality can be achieved with a low complexity motion compensated converter, for conversions between today's fractional and tomorrow's integer higher frame rates.

High frame rate UHDTV workflows

UHDTV needs more than just higher spatial resolution to offer a significant new market appeal to viewers who are still investing in HDTV home equipment. Artifacts associated with typical film and TV frame rates such as motion judder and motion blur are even more visible on UHDTV screens. High quality presentation of fast moving objects depends on both appropriately fast camera shuttering and high frame rate acquisition.

Integration of UHDTV high frame rate material into an existing HD workflow requires format and frame rate conversion as shown in Figure 1. In a future UHDTV high frame rate workflow, similar conversions are needed for the HD material, as shown in Figure 2.

As users will transition to UHDTV production over a period of time, due to the high capital investment needed, hybrid workflows will exist for some time. Therefore careful consideration needs to be given to the rescale/frame rate up/down conversion elements shown in Figures 1 and 2, which is the subject of this white paper. High quality conversion is essential since temporal artifacts in frame rate conversion are extremely undesirable, and can particularly affect viewer enjoyment of premium content such as live sports and movies.

[1] For more discussion on the fractional vs integer discussion, please see the InSync White Paper "Fractional vs integer frame rates in UHDTV standards" (http://www.insync.tv/documents/2014-03-17-supporting-4K-UHDTV-standards-development-final.pdf)

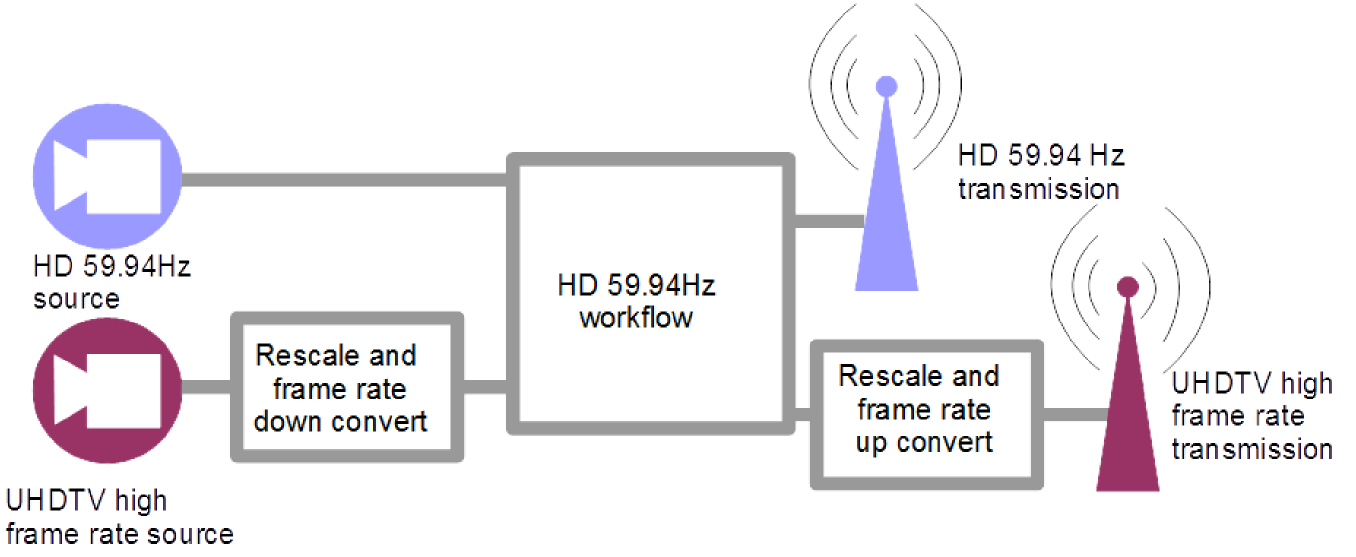

Figure 1 : Accommodating high frame rate material into today's HD workflow

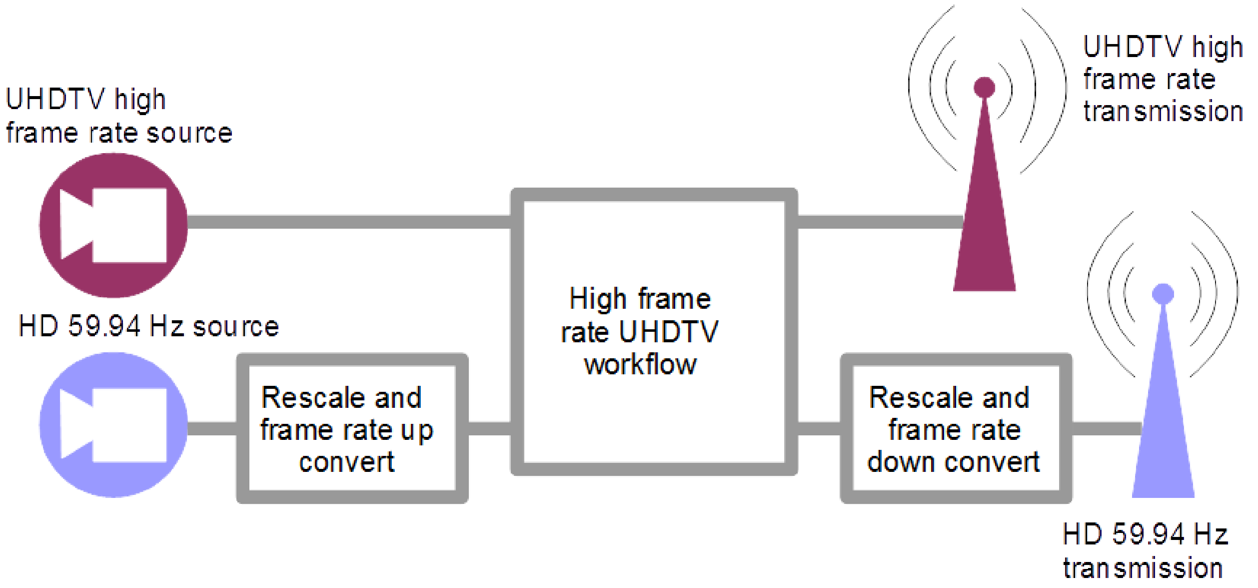

Figure 2 : Using HD material in a future UHDTV high frame rate workflow

Frame rate upconversion

Frame rate upconversion from HD to UHDTV1 at a high frame rate, as shown in Figures 1 and 2, requires creation of new video pixels and lines, at new spatial positions and new temporal intervals. The typical process chain for conversion of HD interlaced material at current frame rates (1080 59i or 1080 50i) to UHDTV1 is shown in Figure 3.

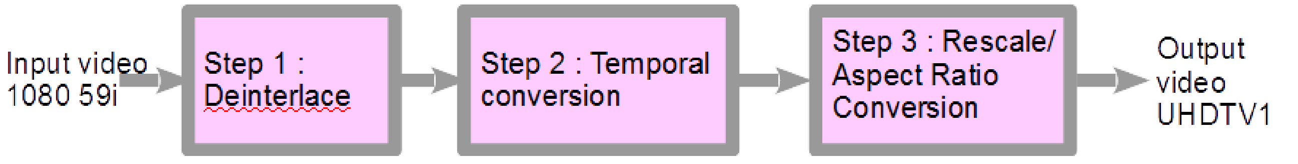

Figure 3 : Typical frame rate upconversion process chain

As shown in Figure 3, the first step in standards conversion of HD interlaced material at current frame rates (1080 59i or 1080 50i) to UHDTV at 120 Hz or 119.88 Hz is deinterlacing. In deinterlacing, it is absolutely essential to retain as much resolution as possible without introducing spatial (e.g. jagged diagonals) or temporal (e.g. smearing of moving objects) artifacts. Quality of the frame rate upconversion is critically dependent on suitable deinterlacing, which is independent of the output frame rate, so the complexity of this step is the same for both fractional and integer output frame rates.

At the input to step 2, therefore, the content is available in a progressive format at 59.94 frames per second. At this stage, the frame rate is to be increased to 120 or 119.88 Hz. In the case of conversion from 59.94 Hz to 119.88 Hz, the simplest notional option is frame doubling, which any broadcaster would discard due to the introduction of double imaging. An alternative "simple" method would carry out interpolation of every other frame i.e. where input and output frames are coincident in time, the input frame is copied to the output, but where they are not coincident in time, it is assumed that the closest two input frames would be used to interpolate an output frame.

In practice, unless completely flawless interpolation of the non-coincident frames is achieved, this method will lead to undesirable artifacts such as picture strobing or edge twitter, where an element or area of the image is in perfect resolution in one frame, but is softened or blurred in the next frame due to the effects of the interpolation. Even using the very best motion compensated frame interpolation, differences between the copied and the interpolated frames would be visible, thereby ruling out this method in practical systems.

In the case of conversion between 59.94 Hz and 120 Hz, input and output frames are only coincident in time every 2002 frames, so all output frames are interpolated, as shown in Figure 4. Very efficient motion compensated interpolation can be used to generate the best results, meaning that output frames would be of consistent quality at low complexity.

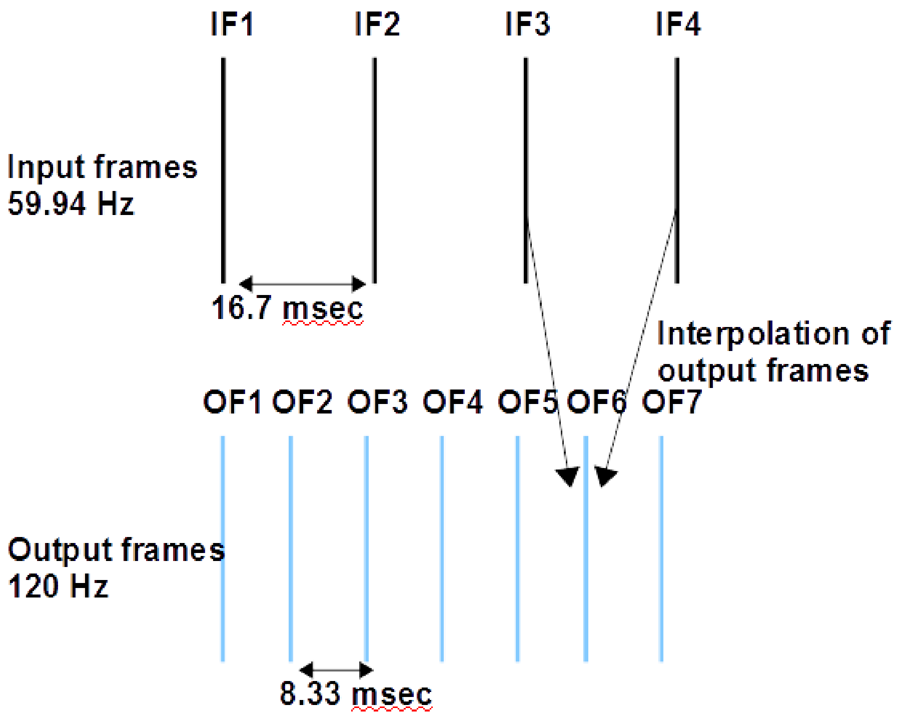

Figure 4 : Frame rate upconversion 59.94 Hz to 120 Hz

In the case of frame rate upconversion from 50 Hz to higher frame rates, all output frames would need to be interpolated (as in the method of Figure 4) whether the desired output frame rate is 100 Hz, 119.88 Hz or 120 Hz, so choice of fractional or interlaced frame rates does not impact system complexity.

In Figure 5 below we see the results of a high quality, low complexity frame rate conversion from 59.94Hz to 120Hz. It can be seen that the results are very consistent, so the viewer would see smooth motion portrayal without any visible artifacts. This type of processing is suitable for live broadcast workflows and for situations where no program length change is permitted.

Figure 5a : Extract from Frame 304 of source at 59.94Hz

Figure 5b : Extract from Frame 608 of 59.94Hz source converted to 120Hz

Figure 5c : Extract from Frame 609 of 59.94Hz source converted to 120Hz

Frame rate downconversion

We have focused mainly on frame rate upconversion, as this is the most technically challenging operation in hybrid workflows. However, frame rate downconversion is also required, as shown in Figures 1 and 2.

It is tempting to imagine that simple frame dropping could be used to create 59.94 Hz output from 119.88 Hz material. However, the subjective effect of this process on the output picture depends on the source shuttering. For material shot using very fast shutter speeds, frame dropping can lead to unnatural motion effects (sometimes described as "choppy" or "jittery" motion) which are highly undesirable.

Since typical TV programming material will have a range of shutter speeds, it is advisable to use motion compensated processing to create slower frame rate outputs, and therefore frame rate downconversion from 120 Hz to 59.94 Hz is unlikely to be any more complex than 119.88 Hz to 59.94 Hz.

Reducing conversion complexity

For both frame rate up and downconversion, highly efficient motion compensated processing can be used, as described in the InSync White Paper "How more efficient motion processing can save you money" (http://www.insync.tv/documents/Efficient-motion-compensation.pdf). As that paper describes, processing savings can be achieved by careful pre-processing stages, aimed at data reduction, combined with identification of redundancy in the sequence which allow data condensing, and limiting the set of motions over which the converter will operate to the set of motion profiles contained in most TV and film productions.

Conversion examples

The following two examples (Figures 6 and 7) demonstrate the conversion quality available from InSync's efficient motion compensated converter. It is impossible to show motion portrayal in a print document, but both examples show consecutive frames of the output, which enable the reader to see the clarity and quality of the individual objects in the picture, as well as the consistency in picture quality from frame to frame.

In Figure 6, we have converted a 50Hz source to 120Hz, and in Figure 7, the conversion is from 59.94Hz to 100Hz. In both cases we have chosen challenging sequences with a high level of detail and fast motion. In both cases, it can be seen that the conversions are reliable and of excellent quality.

Figure 6a : Extract from Frame 959 of 50Hz source

Figure 6b : Extract from frame 2302 of 50Hz sequence converted to 120Hz

Figure 6c : Extract from frame 2303 of 50Hz sequence converted to 120Hz

Figure 7a : Extract from Frame 1720 of 59.94Hz source

Figure 7b : Extract from frame 2870 of 59.94Hz sequence converted to 100Hz

Figure 7c : Extract from frame 2871 of 59.94Hz sequence converted to 100Hz

Conclusion

Modern motion compensated standards conversion has been refined to such an extent that low complexity methods are available which produce high quality results, whatever input and output frame rates are required.

In this white paper, we have shown examples of conversions between today's fractional frame rates and future integer frames, with both frame rate up and downconversion. In all the examples, excellent quality results are obtained, suggesting that restriction of future UHDTV higher frame rates to integer rates only could be achieved without complexity or quality issues.