Combined Upconverter & Pre-Compression Processor For Best End-to-End Picture Quality

by

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Abstract

One of the biggest challenges facing the broadcaster in the transition to DTV is providing a sufficiently high quality signal to the home viewer to justify the purchase of expensive DTV/HDTV receivers. In practice, there can be numerous cascaded compression, scaling, and decompression stages that can degrade the quality of the signal chain. Much care must be taken to ensure the fidelity of the video signal throughout this process.

Compressed capture, storage, and transmission systems provide significant benefits in bit efficiency by limiting high spatial frequencies and removing redundancy in the image. However, if there is significant high frequency detail in the image, the compressor will be forced to severely quantize the image, often resulting in blockiness. For the compressor to preserve detail in one part of the image, it must sacrifice quality somewhere else. Unfortunately, noise appears as detail; and since it is uncorrelated, it is not seen by the compressor as redundant. Consequently, without noise reduction, the compressor is spending bits on the noise instead of actual image detail.

The solution to this problem is to provide high quality pre-compression noise reduction before the compression process. Combining this necessary filtering with an integrated DTV upconverter eliminates multiple de-interlacing and re-interlacing steps, and enables the upconverter to operate on a clean, noise reduced source.

The performance and flexibility of the Teranex Video Computer platform enables these two complex functions to be combined into a single compact, cost-effective platform.

Introduction

Digital television makes the promise of delivering ultra-high quality images to the public. In the case of video produced in HDTV, or telecine transferred to HDTV, the promise is a reality. Unfortunately, there is a shortage of such ultra-high quality content, although production is ramping up rapidly. In the interim, broadcasters are forced to upconvert standard definition television material to HDTV. This process typically consists of many "hidden" conversions that can degrade the image quality. For example, news footage captured on Beta SX at 18Mbps must be decompressed to baseband 270 Mbit SDI, recompressed on a news server, and cycled through an editing process to add overlays which includes further decompression and recompression. The video is then decompressed on play-out and upconverted to HDTV at 1.5Gbps with subsequent re-compression to 19 Mbps for transmission. Then, at the set-top box, the signal is decompressed to baseband HD and sent to the television receiver where it is often re-scaled to match the resolution of the DLP or LCD device in the display. Clearly, there are many opportunities to degrade the signal quality in the processing chain.

Upconversion can provide high quality results assuming the source is of very high quality, such as Digital Betacam, camera video or telecine transferred films. Digital component transmission will always look better than analog composite transmission if a sufficient bit-rate is allocated for the digital signal. The problem arises when "cost effective" compressed tape formats are used in the production process, and composite sources are incorporated. The result is an infusion of "noise" that can be traced to compression/decompression processes and composite encoding/decoding. This noise level may be acceptable in standard definition analog transmissions, but is amplified in digital transmissions. Remember that the goal of digital television is ultra-high quality images - so that requirement must constrain every part of the production chain. New production techniques will need to be developed to complete the transition to digital, but nonetheless there needs to be a good solution for existing material to ease the transition.

The most important thing to remember in HDTV upconversion is the principal of "rubbish in - rubbish out." If the source is noisy or degraded, the upconverter will amplify all of the artifacts, generating an often unviewable picture. The result will certainly not attract DTV viewers. The application of noise reduction prior to other processing is essential to achieving a better quality end-to-end result. Otherwise, the opportunities for noise identification and reduction are very limited. Fortunately, there are proven techniques for improving image quality before compression.

DTV System Solutions

The HDTV upconverter and downconverter are essential elements in a DTV television station. A typical application, as diagrammed in Figure 1 below, begins with the collection and demodulation of HDTV and SDTV source video from the satellite. The HD-SDI video may be downconverted to SDI and fed to the SDTV master control switcher along with the SDTV feed. Alternatively, the HD-SDI video can bypass directly to the HDTV Encoder via the HDTV switch.

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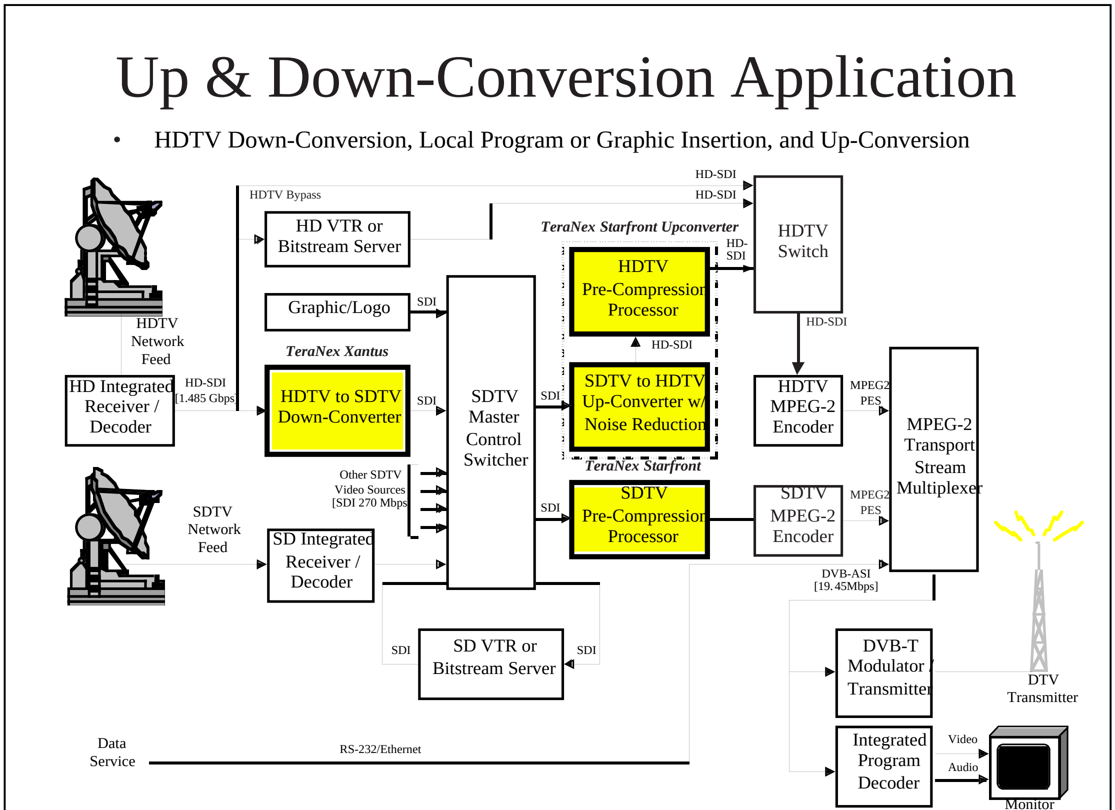

Figure 1: DTV Broadcast Example

The master control switcher selects the desired SD source video to be pre-compression processed, MPEG-2 encoded, and broadcast. The selected SD source is also fed to the upconverter. The source video may come from SD satellite feed, downconverted HD feed, bitstream server, archival videotape, or live studio feed. The SDTV source is converted to the desired HDTV format by the up-converter and fed to the HDTV Compression Pre-Processor where the data is prepared for MPEG-2 encoding. The output of the Compression Pre-Processor is fed to an HDTV switcher where it is switched with HDTV source material to produce the HDTV master feed. Next, the HDTV master feed is MPEG-2 encoded and multiplexed into the 19.45 Mbit Transport Stream. Finally, the stream is DVB-T modulated to fit within the bandwidth of a single television channel, and broadcast.

The above described process of downconverting the HDTV network feed to later upconvert it may seem counter-intuitive, but many broadcasters have adopted this plan so they can take advantage of their existing SDI or Composite plants for distribution, effects processing and local program or graphic insertion.

It is important to note that although the Pre-Compression Processor is located after the upconverter in Figure 1, high quality noise reduction is required *before* the upconversion, in order to prevent input noise from being amplified. Typical compression pre-processors perform both noise reduction and pre-compression processing in one box, relying on the upconverter's built-in noise reducer to clean up the input. Unfortunately, traditional upconverters have very limited noise reduction capability, insufficient to handle the myriad of noise sources that can corrupt standard definition video. If the advanced noise filtering is performed only after the upconversion, it is much more difficult to remove unwanted noise, and compression artifacts may result.

Another problem with separating the upconverter from the pre-compression processor is that the very complex de-interlace process will have to be done twice, multiplying the possible errors introduced by that process. In order to locate the noise reduction components in the proper place and to remove the redundant de-interlace, a combined upconverter plus pre-compression processor is required. This is exactly what Teranex has developed with Starfront. Refer to Figure 2.

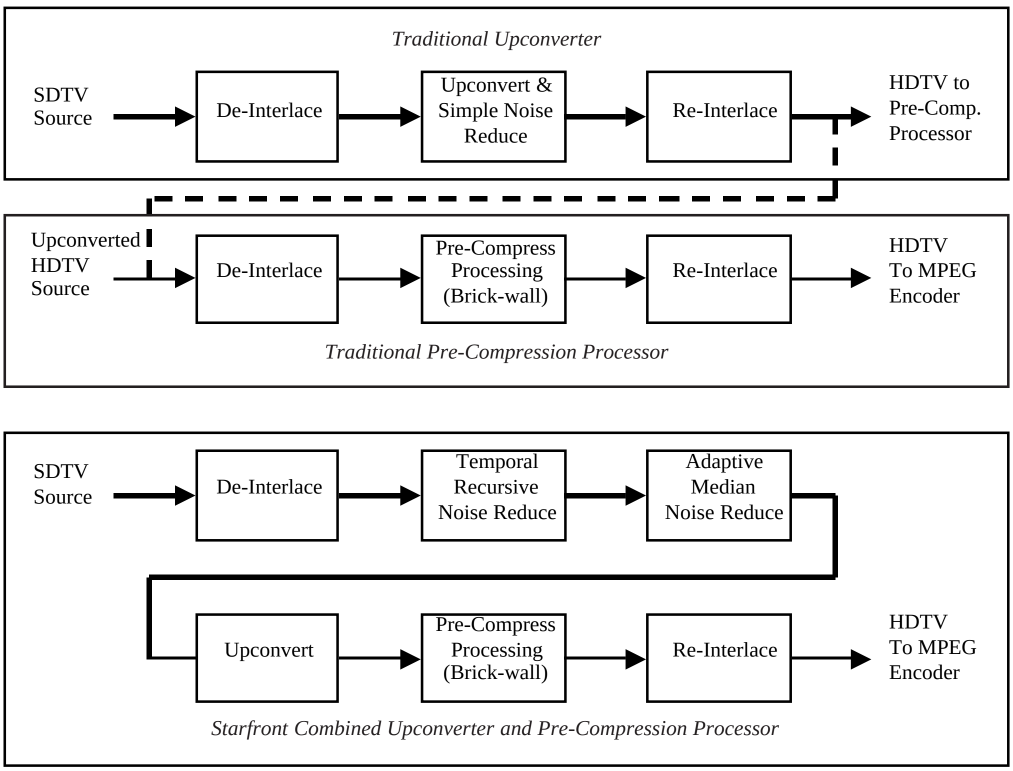

Figure 2: Processing Chain Alternatives

Pre-Compression Noise Reduction

Unlike simple noise reducers employing spatial averaging, pre-compression noise reduction encompasses motion adaptive Temporal Recursive Filtering, adaptive Spatial Medial Filtering and Brick-Wall Filtering. The purpose for this type of processing is to assist MPEG-2 encoders by removing or attenuating random and impulse noise, and to reduce the total energy in the output stream via the reduction of high frequency signal content. In order for the broadcaster to minimize the "rubbish in, rubbish out" scenario, it is necessary to apply such advanced noise reduction in two places in the video path.

First, the source SDTV video must be filtered to remove any undesired noise. This stage of pre-compression processing consists of removing impulse noise and attenuating the impact of random noise. Examples of random noise are listed below.

Random Noise Sources:

- Residual noise and grain - archival or generational
- Low contrast film dirt and scratch noise, horizontal or vertical
- Film grain
- FM sparkle
- Compression artifacts
- Cross color from composite decoders

Random noise is removed and/or attenuated by motion adaptive Temporal Recursive Filtering. Motion adaptive temporal recursive filtering compares adjacent frames, classifying each pixel into one of three categories: noise, motion, or no motion. Pixels whose comparisons are less than a threshold are categorized as having no motion. For those pixels whose comparisons are greater than the threshold, spatial processing is employed to determine if the pixels belong to an object in motion, or if the pixels are to be categorized as random noise.

To minimize artifacts that may be introduced due to improper handling of objects in motion, pixels that are on the boundary of these motion objects are not temporally filtered. Pixels classified as not being in motion receive temporal filtering via an average value, median value, or some other mathematical combination of temporal pixels to smooth out peaks and valleys in the data stream. This attenuates the effects of low level random noise that has been introduced into the image. Pixels that have been categorized as noise are replaced with spatial filtering techniques, again via some mathematical and/or morphological combination of neighboring pixels.

The second kind of noise of interest is impulse noise. These artifacts are not as detrimental to compression as random noise because they are non-periodic and appear typically less often in the video stream, but they need to be removed nonetheless. Examples of impulse noise are listed below.

Impulse Noise Sources:

- Tape drop out
- Satellite glitches
- Analog clamping errors
- Bit errors in digital transmission

Impulse noise is removed by specialized algorithms that locate the desired artifact and replace the affected pixels with surrounding information. These artifacts are typically much more difficult to locate, and are harder to mask since they may affect numerous pixels in the frame. Adaptive Median filtering solves this problem by comparing adjacent pixels in the video frame.

The Adaptive Median Filter performs spatial processing to determine which pixels in an image have been affected by impulse noise. Strictly applying a median filter may destroy small structure (e.g., whiskers on a cat), as well as eroding away edge boundaries. Replacing strictly a maximum or a minimum valued pixel may remove structurally sound pixels as well, or not remove all of the noise when the impulse noise is spread across more than one pixel.

The Adaptive Median Filter classifies pixels as noise by comparing each pixel in the image to its surrounding neighbor pixels. The size of the neighborhood is adjustable, as well as the threshold for the comparison. A pixel that is different from a majority of its neighbors, as well as being not structurally aligned with those pixels to which it is similar, is labeled as impulse noise. These noise pixels are then replaced by the median pixel value of the pixels in the neighborhood that have passed the noise labeling test. A prime benefit to this adaptive approach to median filtering is that repeated applications of this Adaptive Median Filter does not erode away edges or other small structure in the image.

The second place noise reduction is important is at the output of the upconverter. This is where Brick-Wall Filtering becomes important. It has many times been proven that bandwidth reduction prior to compression has substantial benefits. This is true particularly as the bit-rates are reduced. MPEG encoders begin to create artifacts such as blockiness and "mosquito noise" if they are tasked to encode high detail video at low bitrates. The compression process indiscriminately "chops off" frequencies, via DCT quantization, generating significant compression artifacts. To prevent this catastrophic breakdown of the imagery, brick-wall filtering may be applied.

A brick-wall filter is typically a very high-order low-pass filter with a sharp cut-off above the designated frequency that removes excessive detail in a controlled fashion - detail that would be otherwise eliminated by the compressor resulting in visible artifacts. By controlling the manner in which the detail is removed, compression artifacts can be minimized.

De-Interlacing and Re-sampling

The most important evaluation criteria for an upconverter, by far, is image quality. Once the input has been properly noise reduced, the conversion quality is driven by two variables: the quality of the de-interlacing algorithm, and the quality of the re-sampling algorithm. Ultimately, the final quality of the video stream is dependent upon the type and the refinement of the image processing algorithms that are applied to it. For instance, with respect to up-conversion from 576i50 to 1080i50, the first and most complex step is to convert the interlaced image to progressive (576p50). This is necessary because the odd lines of the image are spatially shifted from the even lines, due to inter-field motion. This misalignment must be compensated for in order to create visually pleasing progressive images.

There are many different varieties of de-interlacing algorithms in use, ranging from linear interpolation to motion adaptive interpolation to the high-end motion compensation techniques. It is important to remember that the quality of the de-interlace algorithm is directly proportional to the amount of processing power available. With ultra-high performance real-time software-based converters, very elaborate and compute intensive algorithms may be implemented.

Once the image has been properly de-interlaced, it must then be re-sampled, or re-sized, to the desired output format. This process requires interpolation filters. There are two basic classes of interpolation filters: optimal, and non-optimal. Optimal filters are precisely designed in order to preserve the detail of the input imagery throughout the scaling process, whereas non-optimal filters are an approximation to the ideal (optimal) filter curves. Interpolation filter quality may also be characterized by the filter size, or number of taps. As the number of taps in an interpolation filter increases, more surrounding pixels are used to generate the resultant pixel value, increasing the accuracy of the interpolation. With respect to filter size, there is a practical limit to the number of taps required to perform the re-sampling, after which adding additional taps has negligible effects.

The Flexible Teranex Video Computer Platform

One important feature to look for when selecting a DTV format converter is flexibility. Since the number of DTV formats in use is increasing rather than decreasing, there is a significant advantage in converters that are updatable to emerging formats, so as not to obsolete the substantial investment into a converter. This "future proofing" approach is the concept behind the Teranex real-time software-based converter, which can be updated via CD-Rom to support new formats as they emerge.

The Video Computer platform hosts the Starfront Upconverter application, as well as many other video processing and conversion applications. The programmable nature of the processing engine enables the system to run multiple applications and be updated with additional features or enhanced algorithms with a simple CD-ROM update. The Video Computer platform is capable of processing standard definition and/or high definition video with exacting quality in real-time. This platform is field-proven and provides a lower cost of ownership by combining multiple processing functions, such as upconversion and pre-compression processing, in the same box.

Conclusion

The end-to-end quality possible in a digital television system is limited by the weakest link in the processing chain. Until such time as producers are able to generate program material in high definition, or at least lightly compressed standard definition, it will be difficult to convince viewers to make the leap. In the interim, it is possible to provide acceptable quality upconverted images by using the right combination of upconversion and pre-compression noise reduction. Traditional systems employ separate components for these two functions, which results in redundant de-interlacing and misplacing of the noise reduction components. By combining the pre-compression processor and upconverter in the same box, the Teranex Starfront Upconverter (Star-Up) eliminates the redundant de-interlace step and places the noise reduction and brick-wall filtering in the proper places in the processing chain. This cost-effective solution will ease the transition to HDTV by providing the best possible picture quality from standard definition archives and highly compressed news footage.

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