Destination Digital: Description of the Role of Component Digital Video in the Transition to HDTV

By Don Thompson and Michel Proulx

A full HDTV facility overhaul is expensive, and the cost is hard to justify without accurate viewer-count estimates. On the other hand, using a bitstream splicer to insert local content into a passed-through network signal greatly restricts local branding. The most economical and flexible option is to operate in component digital, a format fully compatible with MPEG-2 compression. Remaining in component digital from start to finish allows local broadcasters to avoid conversions and maintain signal quality, and is, therefore, the clear choice for facility design.

As the U.S. moves toward digital television, broadcasters are burdened to find the right digital television (DTV) equipment. Should they ready their facilities to simply pass through the network's transmission-ready digital signal? Simple pass-through is far too restrictive, and a full high-definition television (HDTV) facility overhaul is quite costly. To satisfy function and cost demands, the entire DTV system, from acquisition to transmission, begs to be component digital.

The equipment for a full HDTV facility is produced by very few manufacturers and is therefore prohibitively expensive. That expense is difficult to justify, because few viewers will be able to receive DTV in its early years.

A second, more affordable option allows local stations to transmit some HDTV just by receiving and passing through the network signal, with locally produced sources (IDs and promos, for example) spliced into the bitstream. This system requires a bitstream splicer and greatly limits local branding. Only full-screen images can be spliced in, and the local station cannot add transparent keying, text crawls, or sophisticated video effects like digital video effects (DVE) pull-backs and transitions (other than cuts). Cuts are possible only on designated splice points and last up to 1 sec. Further, all local insert material must be precompressed, which prohibits insertion of live programming like news. These limitations make the pass-through option primitive and undesirable.

After carefully analyzing costs and benefits of various options, Leitch believes that facilities operating in component digital will be best equipped for the DTV future. Buying component digital is the more economical, more flexible option, and in light of the following considerations, is currently the clear choice for broadcasters and studios.

- Component digital signals maintain a higher quality when upconverted for local insertion.
- Component digital equipment allows broadcasters to begin their digital transition with small master control facilities and add one edit suite at a time.
- With component digital equipment, portions of local plants can operate in 525 16:9 and avoid a difficult aspect ratio conversion, which affects content.
- A full range of 4:2:2 equipment is widely available from various manufacturers.
- AES/EBU audio is better than AC-3 for use within the studio.
- Cameras are inherently component. Many feature component digital outputs.
- The Advanced Television Systems Committee (ATSC) DTV transmission format relies on MPEG-2 compression, which processes component digital signals.
- Any component digital distributing or routing equipment purchased now can be used in the future with mezzanine-level compression (4:1/5:1 compression) using SMPTE's proposed SDTI standard, SMPTE 305M.

Content acquired with component digital cameras and effects and graphics created with component digital equipment are of the highest quality possible within the 525-line interlaced format. Further, all MPEG-2 compression, including MPEG-2 19.39 DTV transmission, requires component digital signals. Therefore remaining in component digital from start to finish, avoiding conversions to maintain high signal quality, is the clear choice for facility design.

Is DTV High Definition?

Perhaps the most important debate that has occurred since the FCC announced the DTV schedule has been whether DTV would be high definition. In its announcement the FCC cleverly left the capital "H" out from what had formerly been known as the HDTV standard, choosing instead to call it DTV. Rather than selecting a single standard, the U.S. Congress offered 18 different picture formats, which were recommended by the ATSC and are described in Table 1.

Some interpreted this move as the government's inability to make up its mind, but the table actually reflects the power and flexibility of the ATSC (formerly known as Grand Alliance) standard. The standard provides a transport system that is format independent, allowing broadcasters to choose different formats depending on their application and needs. This flexibility allows one broadcaster, whose mandate is educational, to transmit multiple, lower resolution channels, and another broadcaster, whose business is entertainment,

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Table 1 — ATSC Image Formats

Number of Active Lines (Total Lines)	Number of Horizontal Pixels per Line	Aspect Ratio	Scan Rate and Type
SDTV			
480	640	4:3	60I, 60p, 30p, 24p
480 (525)	704	4:3 and 16:9	60I, 60p, 30p, 24p
HDTV			
720 (750)	1,280	16:9	60p, 30p, 24p
1,080 (1,125)	1,920	16:9	60I, 30p, 24p

to offer fewer, but higher definition programs.

The ATSC DTV system is a flexible, extensible system designed to carry one or more television programs in a 6-MHz channel. The key to the system is that broadcasters choose the picture format and number of services, and the ATSC compliant television set adapts to the transmitted format and displays the picture. The system even allows broadcasters to change the image throughout the day, and again the DTV set adapts.

Many major networks soon capitalized on the issue of flexibility and publicly declared their intention to use the flexibility and multicasting capability of the DTV system. Hearing these announcements, the press focused on the multichannel aspect and accused broadcasters of wanting to exploit the new spectrum solely to make money. Soon thereafter, the U.S. congress declared mutiny and called the broadcasters to Washington where they reaffirmed their intention to broadcast at least some HDTV. The bottom line is that we will see a mix of implementations and that broadcasters will use the flexibility of the ATSC standard and alternate between standard and high definition.

What Is the FCC DTV Timetable?

Table 2 shows the FCC's timetable, presented to the broadcast community in April 1997.

Our research has revealed that broadcasters are planning a tempered and gradual move to DTV and HDTV. It is clear that many of the plans are deeply rooted in a continuation of the upgrade of their current standard definition facility to serial digital component (4:2:2).

The Network DTV Facility

Initially most HDTV material will originate at the network headquarters. Networks have stated that for some time most material aired will be prerecorded. Live production will be limited to special events, and the notion of live news in HDTV will lag until the logistics and economics of field production and random access editing are practical.

The facilities that networks are currently building consist of a simple "play-to-air" master control. All processing will be performed in baseband (noncompressed) digital component. The role of the initial network DTV facility will be to insert promos, commercials, and logos. Most networks will transmit by satellite at least two time-shifted DTV feeds. These DTV feeds will either carry a single high-definition (HD) signal or multiple standard definition (SD) signals depending on the time of day.

Live insertion to allow simulcast during non-HD times and emergency insertion during HD programming will be based on upconverting outputs from the SDTV plant. Most networks have already upgraded their SDTV plant to serial 4:2:2, maximizing the quality of the locally upconverted insert.

Most networks have indicated that they will transmit the HDTV program feed to their affiliates using a higher quality, 4:2:2-based, 40 to 60-Mbit/sec MPEG-2 bitstream. The higher data rate (45 to 60 Mbits/sec versus 19.4 Mbits/sec) is necessary to support a higher quality contribution (less compressed) feed to the affiliate, which allows the affiliate to decode, process, and reencode for actual transmission to the home. (Fig. 1)

Local Station Setup Scenarios

Scenario 1: Network Pass-through with Limited Local Insertion

Some networks have determined that initially they will deliver their signals to affiliates as a "transmission ready" ATSC 19.4 Mbit/sec bitstream because local stations will not be able to afford

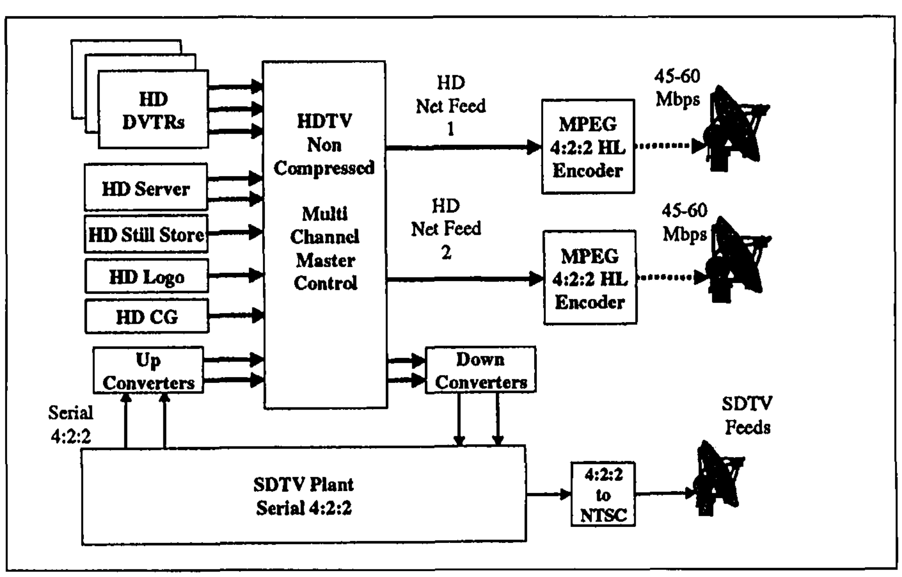

Figure 1. Network HDTV origination facility.

Table 2 — FCC DTV Timetable

Date	On Air With DTV	Total Number of Stations Affected	Percentage of Viewers Affected
Nov 1, 1998	24 network owned and operated commercial stations in top 10 markets	24	30%
May 1, 1999	All commercial stations from ABC, CBS, NBC, FOX in top 10 markets	40	30%
Nov 1, 1999	All commercial stations from ABC, CBS, NBC, FOX in top 30 markets	120	70%
May 1, 2002	All commercial stations in all markets	1,000	100%
May 1, 2003	All stations commercial and noncommercial in all markets	1,500	100%

their own HDTV ATSC encoder. Local insertion can be achieved by splicing compressed local sources into the compressed network bitstream using a specialized bitstream splicer. Logos and local promos can be stored on disk-based servers as precompressed bitstreams. Because all locally inserted HDTV sources must be precompressed, they cannot be live.

The local station can compress the local SDTV signal using a lower cost SDTV ATSC encoder. This is not upconversion in that, during local insertion, the transmitted bitstream will be a standard-definition (SDTV), rather than high-definition (HDTV) signal. The switch of video format will be handled by the home receiver, which will automatically detect the change in format. The switchover may involve a brief (0.5 to 1 sec) freeze or insertion of black. (Fig. 2)

The Case for Component Processing in the SDTV Plant

For the locally inserted SDTV material to be of a quality suitable for transmission as DTV, the signal should originate in component rather than composite video. One of the important advantages of MPEG-2-based digital transmission is that higher quality component images are delivered to the final display rather than composite encoded images. At reasonable data rates (>4 Mbits/sec for SDTV), compression artifacts are less objectionable than the NTSC artifacts that we have lived with for so many years.

A serial 4:2:2 SDTV plant also offers the capability of operating in 16:9 aspect ratio. If local insertion of SDTV material will be used extensively, configuring part of the SDTV facility for 16:9 production will be beneficial. This could be as simple as running the one studio that will feed the DTV channel in 16:9 while the rest of the facility operates in 4:3.

The true value of using 16:9 in an SDTV serial 4:2:2 environment is that existing, widely available and affordable 4:2:2 equipment including production switchers, video effects, character generators, routers, distribution devices, and all disk-based and tape-based recorders can be used. The overall data rate of the 16:9 image is still 270 Mbits/sec; 16:9 and 4:3 processing can be used interchangeably. Minor modifications may be necessary to accommodate the change in aspect ratio; in most cases this can be done with a change of software or firmware. The 525-line interlaced 16:9 production format is defined in SMPTE 267M. (Fig. 3)

Scenario 2: Local HDTV Encode with Full Local Insertion

Many broadcasters feel that the pass-through scenario described in the previous section does not provide adequate local branding capability. The limitations of the processing of a compressed bitstream include the following:

- The bitstream splicer is not currently available.
- The bitstream splicer does not allow any transparent keys and all transitions are cut-only.
- The cut cannot occur on any frame, only on a specially designated splice point.
- There is no capability to key in text crawls useful for local alerts.
- There is no capability for incorporating sophisticated video processing (such as a video effects unit to perform DVE pull-backs) to allow nonpreemptive

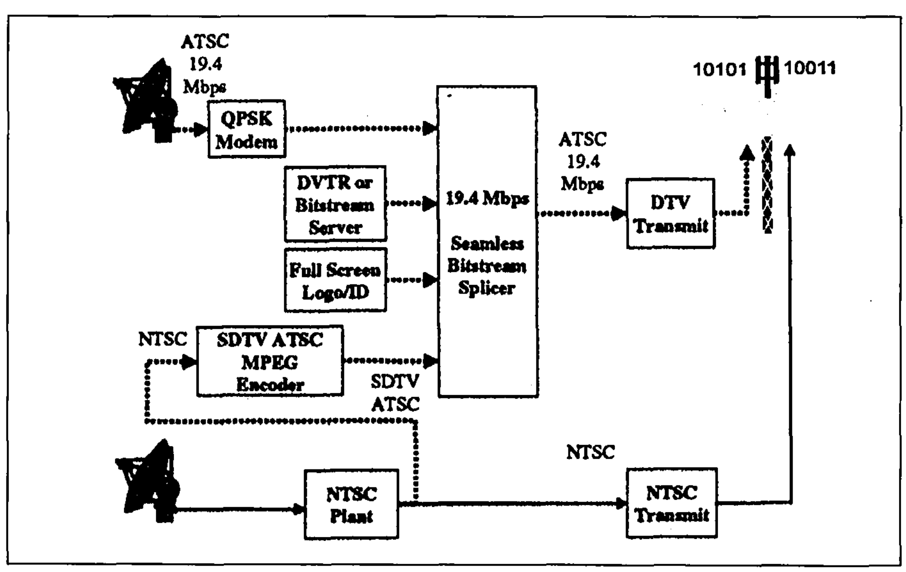

Figure 2. Network signal pass-through.

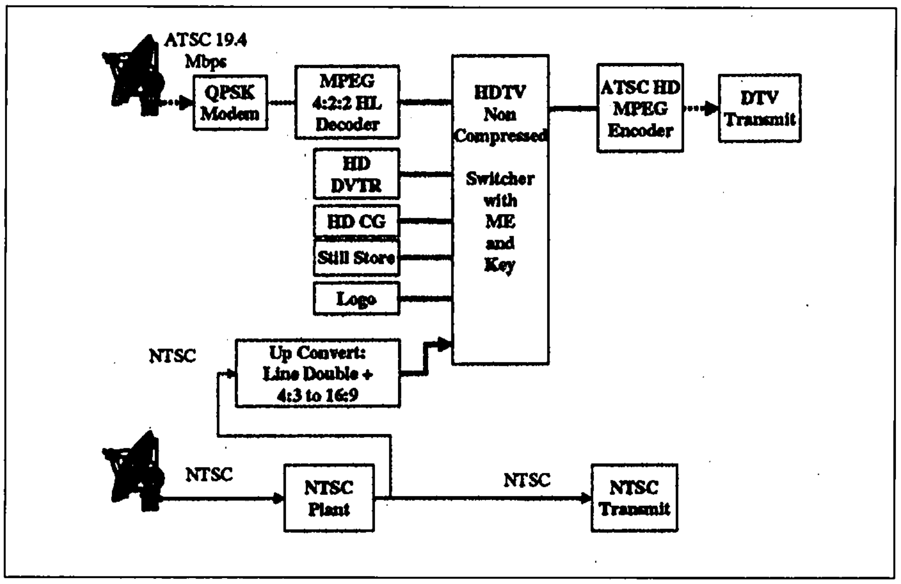

Figure 3. Part of 4:2:2 SDTV plant can operate in 525 16:9.

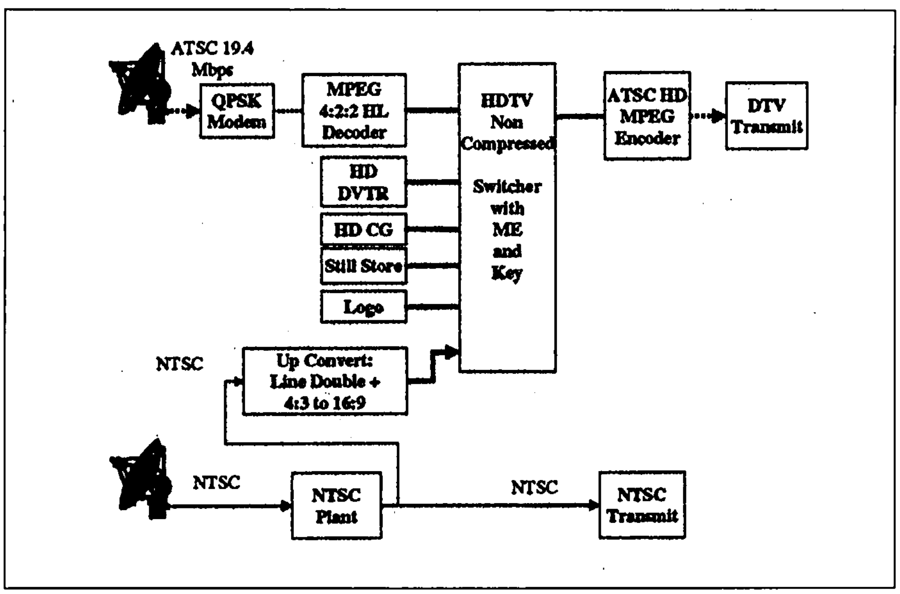

Figure 4. Local HDTV encode with full local insertion.

breaking news updates or weather warnings.

• Locally inserted HDTV material must be precompressed.

These broadcasters consider the higher cost of a local HDTV ATSC encoder to be a better investment than a bitstream splicer, which is expensive and offers limited functionality. They are proposing an alternate facility in which the incoming contribution-quality network signal is decoded back to baseband HD, and all switching is done in the uncompressed domain. A modest and economical HDTV master control switcher provides the desired video and audio mix and key capability. The switcher allows unrestricted local insertion of logos (full screen or keyed) and storage of local material in a variety of formats, including tape- and disk-based record/playback devices. (Fig. 4)

Material produced in the NTSC plant may be upconverted for live local insertion. The upconversion involves changing the aspect ratio from 4:3 to 16:9 and creating the correct line rate and frame refresh format. The upconverter outputs a baseband HDTV signal that can be integrated with the network material and other local HD sources using the master control switcher.

The Case for Component Processing in the SDTV Plant

Again the use of a component digital SDTV plant offers a number of advantages. The upconversion device is an image-processing-intensive device that functions in the component domain. Upconversion can magnify artifacts present in the input signal. Using the upconverter with a signal that originates in the component domain can significantly improve the resulting signal's quality. (Fig. 5)

In converting the SDTV signal to HD, the upconverter must convert the images from 4:3 to 16:9. This is usually accomplished either by adding side panels, cropping the top and bottom of the image, or distorting the image, or a combination of the three methods. Some have suggested creative ways of using the side panels by introducing graphics, financial data, or sports scores in the panel space. This scheme may be appropriate during informational programming slots (e.g., news) or in between shows, but it may be too distracting or inappropriate when trying to air an entertainment piece.

An alternative, once again afforded by the use of serial component digital in the SDTV plant, is to configure part of the SDTV system to operate in 16:9 and economically produce the programming destined for transmission on the DTV channel in 16:9. In this case the upconverter is now simplified, charged only with the task of providing line rate and picture rate conversion. This will improve the appearance of the locally inserted material and likely mask the transition between network and locally inserted material. (Fig. 6)

Scenario 3: Component Digital in the SDTV Plant

A number of issues have become clear as broadcasters formulate their early DTV plans.

• It is critical that local stations be able to contribute local content to the DTV program feed provided by the network. Capabilities such as transparent corner logos, insertion of news, unrestricted determination of insert points, text crawls, and DVE pull-backs are absolutely required.

- It is important that the quality of the locally contributed material be worthy of being intermixed with the network DTV and HDTV programming.
- Unfortunately, it is not economically feasible for local stations to do much production in HDTV.

It is clear that there has to be some way for broadcasters to contribute to the DTV signal economically, without disregarding quality.

As illustrated in the network and local station scenarios described earlier, component digital processing can greatly and economically enhance the capability and quality of locally contributed material. Component digital provides a number of significant benefits:

- Component digital processing yields a far superior image to NTSC because images are stored, transmitted, and processed in their native component form. The fact that images are component is more important than the fact that they are digital. (Fig. 7)
- All HDTV production, recording, and transmission formats are based on component processing. To maximize the quality of the upconversion, it is important to maintain component processing.
- Component digital equipment can be configured to operate at an aspect ratio of 16:9. This allows broadcasters to edit and produce material destined for upconversion in 16:9. The use of the more economical SDTV facility to produce 16:9 can continue until true HDTV production equipment becomes economical. (Fig. 8)
- ATSC DTV transmission is based entirely on MPEG-2 video compression. MPEG-2 processes only component video signals. If presented with a composite signal, the MPEG-2 encoder converts the signal to component before compressing it. (Fig. 9)

Extending the Life of SMPTE 259M Infrastructure

Another potential benefit of investing in a component digital infrastructure is the widely held notion that 270 and 360-Mbit/sec infrastructure and storage equipment will one day play a role in distributing and storing mildly compressed (4:1 compression) HDTV signals. This concept has been dubbed "mezzanine" compression because it

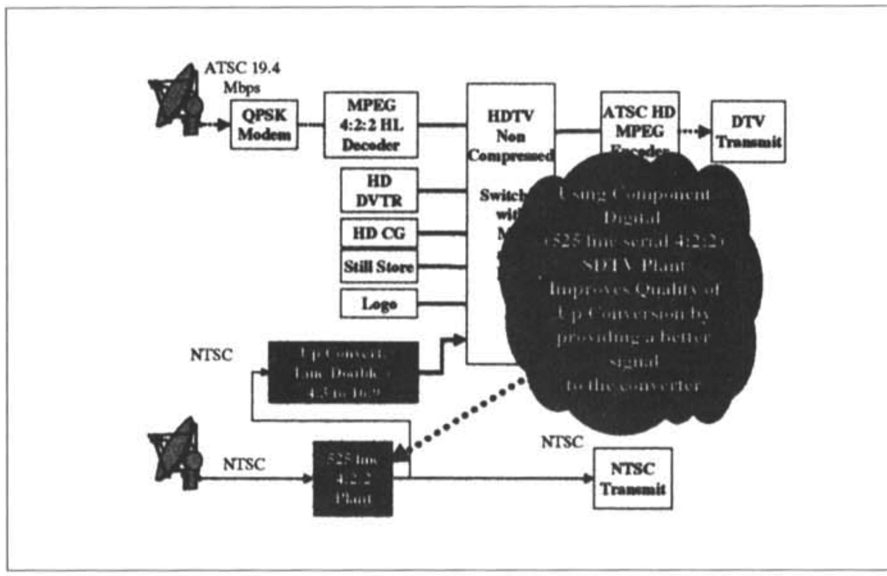

Figure 5. Using component digital in the SDTV plant to improve upconversion.

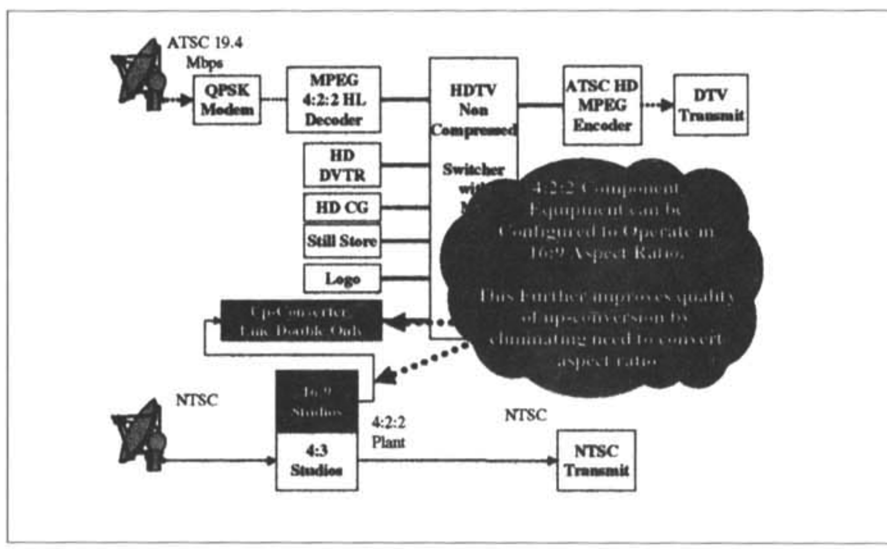

Figure 6. Configuring component digital equipment to operate in 16:9 aspect ratio.

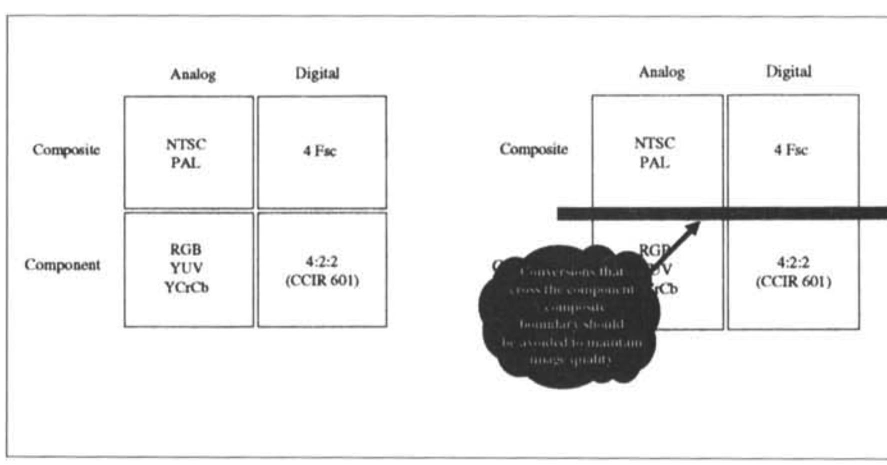

Figure 7. Conversions that cross the component/composite boundary harm image quality.

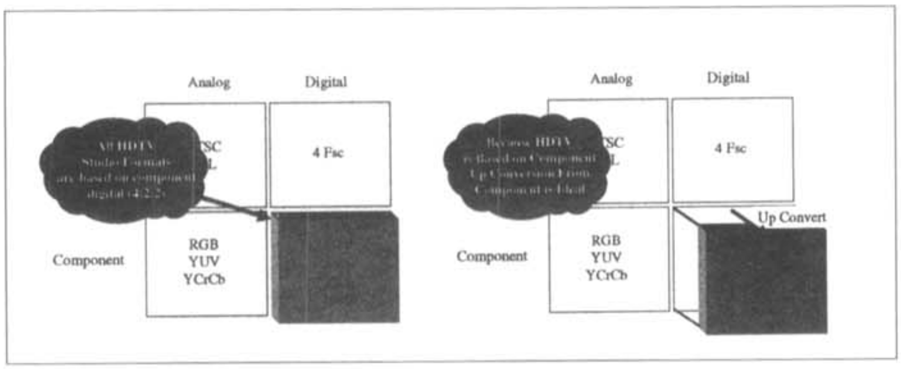

Figure 8. Because HDTV studio formats are component digital, upconversion from 4:2:2 is ideal.

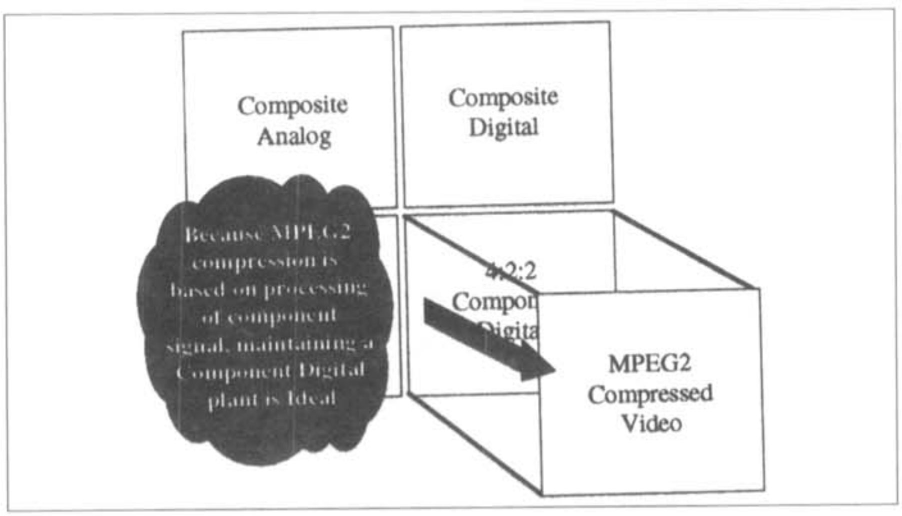

Figure 9. Component digital is ideal because MPEG-2 compression requires component signals.

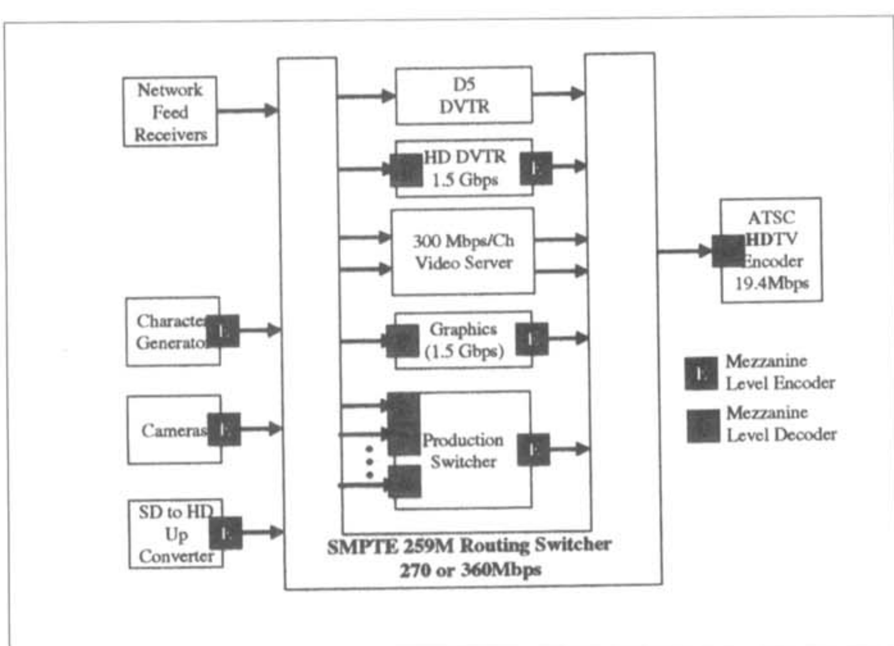

Figure 10. SMPTE 259M routing switcher.

offers a data rate that is somewhere between uncompressed HDTV at 1.5 Gbits/sec and transmission level compression at 19.4 Mbits/sec. If this scheme were to be adopted in a facility, the following 270 to 360 Mbit/sec equipment could be reused:

- SMPTE 259M (270 or 360 Mbit/sec) distribution amplifiers
- SMPTE 259M (270 or 360 Mbit/sec) routing switchers
- Recorders and playback devices capable of storing 200 to 300 Mbits/sec without further, internal compression (e.g., D-5 machines can store 288 Mbit/sec uncompressed data)
- Existing coaxial wiring and patching

Reusing these devices for HDTV is attractive because they represent the underlying infrastructure that is expensive and disruptive to remove and replace.

There are two developments necessary in order for mezzanine-level distribution to be a reality in the studio: new levels of compression and decompression devices must be developed, and an interface that allows lightly compressed bitstreams to emulate SMPTE 259M signals must be established.

Mezzanine Compression and Decompression

To implement mezzanine distribution and routing in the HDTV plant, our first needs are for an industry standard and equipment that can compress the SMPTE 292 signal to fit within the data rate capability of SMPTE 259M equipment. Each HDTV source device (e.g., camera, character generator, still store) would have to include a compression encoder to do the compression from 1.5 Gbits/sec to 200 to 300 Mbits/sec. Each HDTV destination device (e.g., recorder, production switcher input) would have to include a corresponding decoder to decompress the mezzanine signal back to baseband.

MPEG and SMPTE are in the process of standardizing a higher MPEG-2 level that provides 4:2:2 color sampling and I frames only at the higher rates (230 to 300 Mbits/sec). The 4:2:2 color sampling is to preserve image quality. The I frame-only group of pictures (GOP) is designed to reduce the cost of the mezzanine encoders/

Table 3 — SMPTE Formats

SMPTE Format	Normal Serial Data Rate	Number of Samples Per Line Available For SDTI Payload	Approx. Max Packetized Video Payload Capacity	Resulting Compression from 1.5 Gbits/sec
259M-C	270 Mbits/sec	1,440 10 bit words	225 Mbits/sec	5.3 to 1
259M-D	360 Mbits/sec	1,920 10 bit words	300 Mbits/sec	4 to 1

Table 4 — Summary Comparison of Local Station Setup Scenarios

Local Station Setups	Capabilities	Drawbacks
1. Pass-through Network ATSC "Antenna Ready" Stream	• Network pass-through • Local insertion of promos/interstitials • Local insertion of full screen logos • Network delay/program time shift • Insertion of local programming converted to DTV	• Insertion too limited – No key or voice over (full screen insert only) – No live HDTV insert – Can insert only on designated splice points • Bitstream splicer costly • Network bitstream must be processed to include splice points • All HDTV local insert material must be precompressed off-site
2. Local HD Insertion with HD ATSC Encoder	• All above-mentioned capabilities • Local insertion of keyed logos • Local insertion of weather crawls and alerts • Full bandwidth audio processing • Unconstrained switch point selection • Datacasting • Squeeze & Tease and combined local and network display (with HD DVE added) • Local insertion of live programming and news from SDTV studio (with upconverter)	• Requires costly HDTV equipment (some not yet available) for all processing (HD DVTR, HDCG, still store, logo generator) • Upconverter costs 100K • HD ATSC encoder costs 360K • Only practical on very small scale; little short-term payback for large expense
3. Local Plant using 4:2:2 component digital equipment for processing	• All above-mentioned capabilities • 4:2:2 equipment readily available • 4:2:2 processing better than current formats for upconversion and MPEG compression • Early and economical local insertion of live programming and news into DTV channel (when 4:2:2 operated in 16:9) • 4:2:2 equipment good for future, mezzanine compression • Can add HD processing equipment gradually	• Expensive HDTV equipment still needed (but can replace some HDTV processing equipment with 4:2:2 equipment)

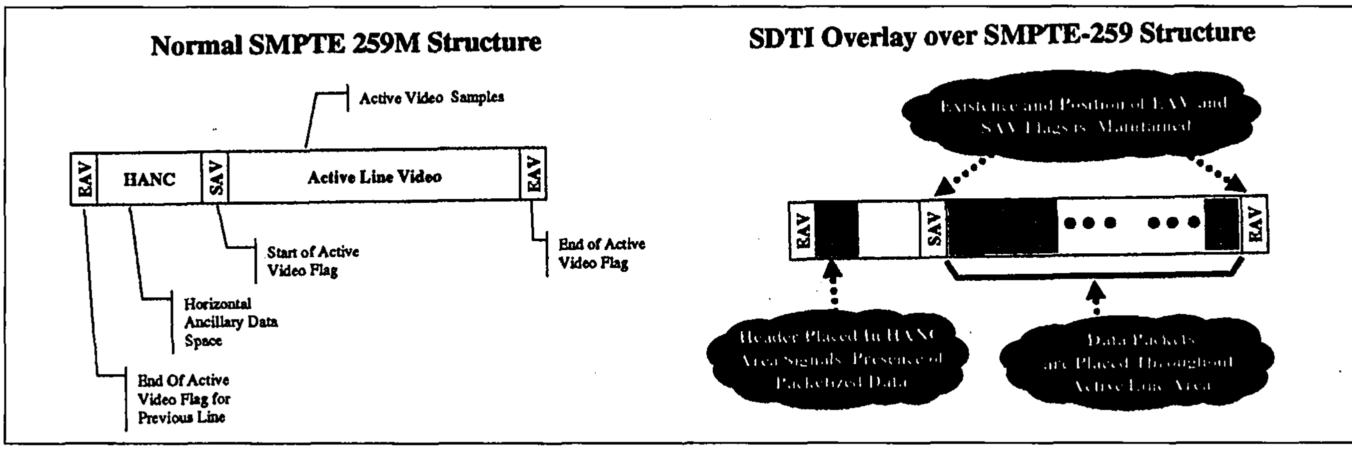

Figure 11. Comparison of SMPTE 259M structure with and without SDTI overlay.

decoders and their latency or delay. SMPTE's proposed standard is SMPTE 308M. (Fig. 10)

Currently mezzanine encoders and decoders are not available. It is our belief that in order for mezzanine compression to be a reality, the cost of an encode/decode pair will have to be less than $10,000. This may seem low given the current costs of MPEG-2 devices; however, mezzanine encoders and decoders will not require the motion estimation capability normally associated with MPEG-2. If the encode/decode combination does not reach the $10,000 price point, the cost saved by reusing existing SMPTE 259M equipment will be outweighed by the cost of the many encode and decode devices needed.

Making the Mezzanine Compressed Bitstream Compatible with SMPTE 259M Equipment

Second, the lightly compressed bitstream must be compatible with the SMPTE 259M data stream in order to implement mezzanine distribution and routing in the HDTV plant. This disguises compressed bitstreams as standard serial digital signals then routes, distributes, and potentially stores them using serial 4:2:2 equipment sold today. (Table 3)

SMPTE has recently finished defining a standard that allows transport of compressed bitstreams on a serial digital (SMPTE 259M) data stream. The new standard, aptly named SDTI for serial data transport interface, specifies that compressed video packets be placed where video and other data samples normally reside. By maintaining the coding structure of a regular 259M signal, the SDTI signal travels through distribution and routing devices without any modification or configuration of the equipment. This proposed standard is SMPTE 305M.

By maintaining the nonreturn to zero inverse (NRZI) coding, data scrambling and protocol details, such as Start and End of Active video flags (SAV and EAV), the signal is indistinguishable from a normal 270 or 360-Mbit/sec SMPTE 259M signal to these devices. Unlike the DVB-ASI (Digital Video Broadcast Standard-Asynchronous Serial Interface) developed in Europe for compressed video signals, the SDTI can be processed with the reclocking and buffering stages commonly found in distribution and routing equipment. Error detection and handling (EDH) coding and decoding can be added to an SDTI signal to verify its integrity through the system. (Fig. 11)

Conclusion

Table 4 compares capabilities and drawbacks of three setup options. It shows component digital in the local plant (item 3) to have the fewest drawbacks and to be the best option for compression, upconversion, and insertion, as well as for a station's budget.

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