A Unified Hybrid Recorder: Combining Hard Disk Drives, Betacam SX, and Analog Betacam

By I. Sato, K. Hyodo, C. Golson, and J. P. Creignou

The transition of the broadcast industry to an all-digital environment for the operation of television news programming poses some unique challenges. Harnessing the best of contemporary digital compression technology with an efficient total video/audio data rate that supports higher quality (than the best of current analog ENG systems) while also facilitating novel new networked system concepts (that introduce crucial new efficiencies to the total broadcast news operation), formed a core design imperative. This new high-speed digital system streamlines the production of broadcast news to service the existing analog NTSC service, but also fully anticipates the imminent 4:2:0 MPEG-2 SDTV digital U.S. broadcasting standard by being squarely based on the 4:2:2 digital component signal format. At the same time, the recognition that broadcasters must transition at their own pace — oftentimes in incremental steps spanning some years — dictates a system approach that assigns an equally high priority to maintenance of a crucial compatibility with the predominantly component analog Betacam environment (presently the mainstay of ENG acquisition and news program editing).

Digital video and signal compression technologies have created an increasing demand for high-performance, efficient systems with the promise of streamlined operations and increased productivity. The transition of the broadcast industry to an all-digital environment for the creation of television news programming and television broadcast operations poses some unique challenges. For a new system to satisfy these requirements, the core design imperative has to incorporate novel networked system concepts and the best of contemporary digital compression technology with an efficient total video and audio data rate that supports higher quality than that of current analog electronic news gathering (ENG) systems.

Based on the 4:2:2 digital component signal format, this new high-end digital system streamlines the production of broadcast news programs to service the existing analog NTSC delivery services, but also fully anticipates the imminent 4:2:0 MPEG-2 standard-definition television (SDTV) digital U.S. broadcasting standard. At the same time, recognizing that U.S. broadcasters must transition at their own pace — oftentimes in incremental steps spanning years — the introduction of new technologies dictates a system approach that assigns equal importance to maintaining compatibility with the vast majority of existing analog Betacam equipment.

This paper describes the operation of the Betacam SX Hybrid Recorder (Fig. 1), a unique component of the Sony Betacam SX family specifically aimed at connecting today's analog environment to tomorrow's digital future. Several examples of the applications where this new type of editing machine will be found are also presented.

System Concept

The idea of a Hybrid Recorder (HBR) originates from the duality of addressing the needs for nonlinear systems and their inherent benefits while preserving present investments in tape libraries and people's expertise. It introduces a unique new concept in video technology: a high-performance nonlinear recording system that incorporates both digital videotape and digital recording to hard disk drives. The implementation of this concept is realized in an HBR, that is, the Sony DNW-A100 — a single five-rack unit component.

This self-contained 1/2-in. videotape recorder/player operates in the MPEG-2 4:2:2 Profile@ML digital video compression system. This compressed video signal, along with four channels of uncompressed audio and other control data, constitute the Betacam SX signal format that is laid on tape. The Hybrid Recorder down-

Figure 1. Sony Betacam SX Hybrid Recorder (DNW-A100).

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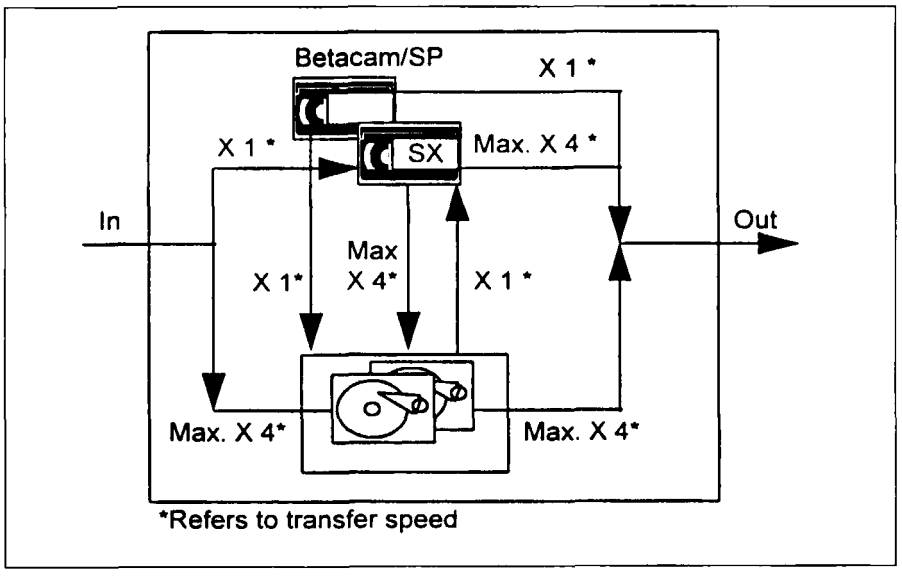

Figure 2. Betacam SX Hybrid Recorder (DNW-A100) signal flow.

loads Betacam SX videotape recordings to the built-in hard disk drives (HDDs) at up to four times normal play speed. The internal HDDs facilitate standalone, full resolution, nonlinear disk-based editing (Fig. 2).

The HBR provides high-speed multiplexed video/audio/data input and output through a serial digital data interface (SDDI), and it can play back 1/2-in. analog Betacam or Betacam SP (i.e., oxide or metal particle) videotapes that can also be digitized in real time to the Hybrid's HDDs.

System Interconnections

To ensure interconnectivity in today's evolving broadcast equipment environment, the Hybrid Recorder provides a comprehensive set of signal inputs and outputs (I/Os). For analog interfacing, outputs for component video with four channels of audio (two selectable monitoring channels) are standard with three composite outputs (one composite output can display superimposed character data). Optional component or composite video input is also available. Digital interfacing is done through a serial digital interface (SDI) I/Os (baseband, real-time 4:2:2 as defined in SMPTE 259M).

Transfer of audio and compressed video data at real time or faster than real time is done through the SDDI output; there is an optional SDDI input. An AES/EBU audio interface is also available as an option that replaces the standard analog audio I/O.

A SCSI-2 interface is provided to expand the disk storage capacity by attaching additional storage units. For example, a 68-Gbyte storage capacity array may be added for an additional 6.4 hr of HDD operation.

525/59.94 or 625/50-Line System Switchable

The HBR's great versatility allows it to be used in both 525/59.94 and 625/50 component systems by providing dual standard component analog, SDI, and SDDI digital I/Os. This greatly facilitates the exchange of tapes between crews traveling around the world by switching between 525/59.94 and 625/60 operation. Prerecorded analog tapes can only be played back in their respective 525/59.94 or 625/60 standard machines.

In addition, a composite PAL signal is available at the output of the 525/59.94 machine, for monitoring purposes only, when replaying a 625/50 recorded videotape. (In a similar manner, the 625/50 machine offers a monitor quality NTSC output.)

MPEG-2 4:2:2 Profile@Main Level (MPEG-2 P@ML) Video Compression

The Betacam SX family of products adopts the MPEG-2 4:2:2 Profile @ML video compression standard. This new standard represents a major achievement by meeting all the requirements necessary to operate in demanding broadcast environments — from television news to program and commercial production and playout.

4:2:2 video is maintained within the compression system ensuring high picture quality throughout the processing chain. This is especially important when including effects, chroma keying, and multigeneration processes. Furthermore, the entire 507 lines of the active video frame and vertical blanking interval are carried through. This gives the broadcaster access to embedded signals such as vertical-interval time code (VITC), closed captioning, and vertical-interval reference signals (VIRS).

By utilizing the spatial redundancy within the video frame and the temporal redundancy between frames, the MPEG-2 style compression system can achieve a higher picture quality for the same bit rate as compared with intraframe-only compression systems, such as JPEG.

As an implementation of the MPEG-2 4:2:2 Profile@ML, Betacam SX adopts a two-frame group of pictures (GOP) consisting of only an intraframe (I) and a bidirectional (B) frame at a raw video bit rate of 18 Mbits/sec. Four uncompressed audio channels at 16 bits per sample and 48 kHz sample rate result in an additional 3.072 Mbits/sec of raw bit rate.

SDDI

SDDI is employed to facilitate point-to-point transport of the compressed video and audio data. The data carried by the SDDI bitstream represent compressed data, and they share the same mechanical, electrical, and synchronization syntax of the SDI interface as defined in the SMPTE 259M standard.

It is important to note that, since SDDI is designed to carry bitstreams representing various compression systems, only equipment using the same compression system can freely exchange data without the need for transcoding between the different compression schemes.

SDDI is used to transfer Betacam SX encoded signals at up to four times normal speed. Also, the SDDI interface can share existing SDI routing and any switching equipment that does not decode the embedded video or

Table 1 — Format Characteristics

Robustness of Format	Betacam SP	Digital Betacam	DVCAM	Betacam SX
Magnetic property	Oxide/MP	MP	ME	MP
Videotape thickness	14.5 µm	14.5 µm	7 µm	14.5 µm
Track pitch	80.5 µm	22 µm	15 µm	32 µm
Min. rec. λ	0.9 µm	0.69 µm	0.49 µm	0.74 µm
ECC V	N/A	22.7%	19.2%	42%
Redundancy A	N/A	122.2%	71.7%	159%
Tape speed	118 mm/s	96.7 mm/s	28.2 mm/s	55.9 mm/s
Drum rotation	29.97 Hz	89.91 Hz	149.85 Hz	74.925 Hz

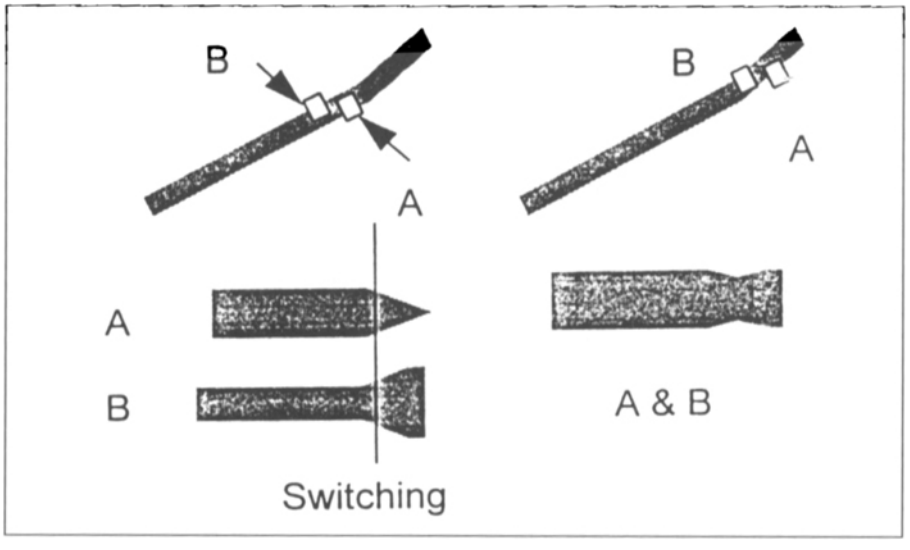

Figure 3. Multitracking concept.

audio data. SDDI has been submitted to SMPTE for a Standards proposal and has now been published for comments.

Hybrid Recorder Videotape Transport

Betacam SX Footprint

A videotape system used in broadcast operations must be robust in order to endure the rigorous physical environment of the ENG application, as well as repeated play, and high-speed shuttle. It must also allow for long-term archiving. The 1/2-in. videotape footprint of Betacam SX is designed to meet those criteria with its wide 32-µm track pitch. In addition, the low signal bit rate translates into a long recorded wavelength of 0.74 µm, giving additional headroom for the carrier-to-noise ratio needed to replay the on-tape signal (Table 1). This additional headroom is used in several ways to make the transport even more robust. For example:

- Playback head width is increased, which improves tracking performance.
- A high ratio of redundancy is applied to audio and video data for better error correction coding (ECC), which means that a typical drop-out (videotape scratch) or momentary head clog will be completely recovered with no effect on the output picture or sound.
- Wear-resistant material is used for the rotary heads to give extended head life.
- Proven metal particle tape technology in an economical new format.

Multitracking System

The HBR employs a multitracking system utilizing two sets of staggered rotary heads to allow the playback of the radio frequency waveform even in the extreme case where the track on the videotape is not straight. The playback head is wider than the track, and, because the second head is offset to the side, the second head can replay the skewed part of the track. This unique system eliminates the need for sophisticated dynamic tracking (Fig. 3).

Furthermore, thanks to the multitracking system, high-speed playback of the videotape is also performed reliably.

High-Speed Videotape Playback

Betacam SX recorded tapes can be played back at up to four times normal speed for video/audio material transfer to the internal HDD, or output through the SDDI interface to a server, for example.

This is accomplished by increasing the longitudinal videotape speed and using four sets of playback heads to capture all the required data. This method does not require an increase in the rotational speed of the drum, which remains at 74.925 Hz in the 525/59.94 system. The results are good transport stability during high-speed mode with less overall wear of the scanner.

Betacam SX Videotape

The Betacam SX HBR uses a new lower cost metal particle videotape for digital recording that has an equivalent running cost to current oxide videotape.

This new advanced videotape technology utilizes ultrafine metal particles (Hi-Packing™ Technology) giving a high carrier-to-noise ratio (CNR) and a strengthened binder for high videotape stability as proven in BCT-MA-type videotape used with

Table 2— Master File Record/Playback Maximum Speed

	Frame Switch	GOP Switch
Simple Edit	4 X	4 X
Full Edit 3	X	

Table 3— Program File Maximum Playback Speed

	Frame Switch	GOP Switch
Simple Edit	1 X	2 X
Full Edit 1	X	

Betacam SP. While this new videotape is particularly suited for Betacam SX format recording, the current Betacam SP metal particle tapes (the BCT-MA and UVW-T-type tapes) may also be used reliably for recording and playback. The analog Betacam oxide-type videotape is only used for the playback of prerecorded material.

As the Betacam SX's normal linear videotape speed is half that of Betacam, longer duration recordings of up to 184 min may now be achieved for full length programming, live remotes, or sporting events.

Videotape cassettes come in two sizes, a small "S" cassette with up to 60 min record time and a large "L" cassette for up to 184 min of operation.

Disk Subsystem

The DNW-A100 HBR is equipped with two built-in HDDs that provide 90 min of record playback time. This record time can be expanded incrementally up to 6.4 hr by connecting additional HDD storage units to the SCSI-2 port.

The internal storage, combined with an external redundant array of inexpensive drives (RAID) 3-level HDD storage array, further protects the audio/video (A/V) data, which is a significant benefit for on-air application. With this added array, it is also possible to replay fully edited programs while simultaneously recording source material. Simultaneous recording mode and playback is also done with the internal HDD, producing assembled scenes that have no audio/video split.

Simple Edit and Full Edit Modes

Independent editing of the video and all, or any, of the four audio channels is available on the Hybrid's HDD. This operation requires access to multiple files and restricts certain functions like simultaneous recording and playback of a programmed sequence.

To maximize functionality, the HBR introduces two main modes of editing.

- The *Simple edit* mode, which is used when the video and audio material of each scene is kept together throughout the edited program (no audio split from the video). The benefit of this mode is that it is possible to perform simultaneous recording of a source signal while editing by previewing a program, or playing out a program or master file.
- The *Full edit* mode is used when any video or audio channel material is edited independently, as in an audio channel insert. In this mode, simultaneous playback of a program while recording is only possible with the optional external hard disk drive array connected.

Edit Accuracy

The Hybrid Recorder uses a dual decoding method. Frame-accurate editing accomplished by switching at the transition between each edit point is made in the decoded baseband domain (Fig. 4).

The edited program of the HBR may always be played out in real time or recorded back to the disk, or on videotape with complete frame accuracy.

Frame Switch/GOP Switch

While the HBR is capable of frame-accurate editing with full picture quality, it may also be desirable to directly play out the simple edit mode program at high speed (2x normal speed) before

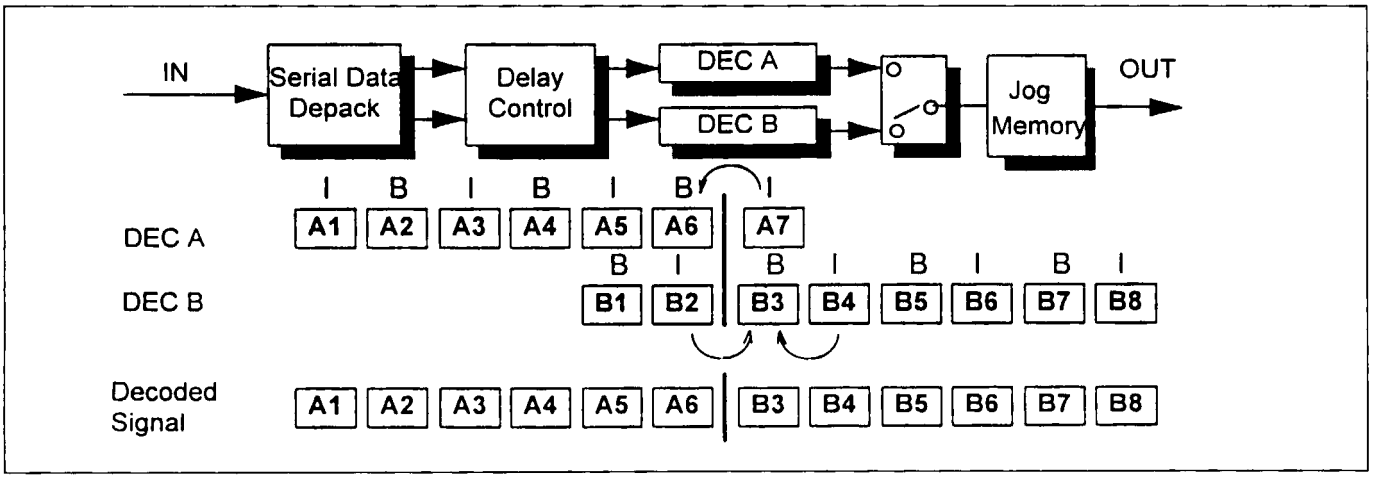

Figure 4. Dual decoder system.

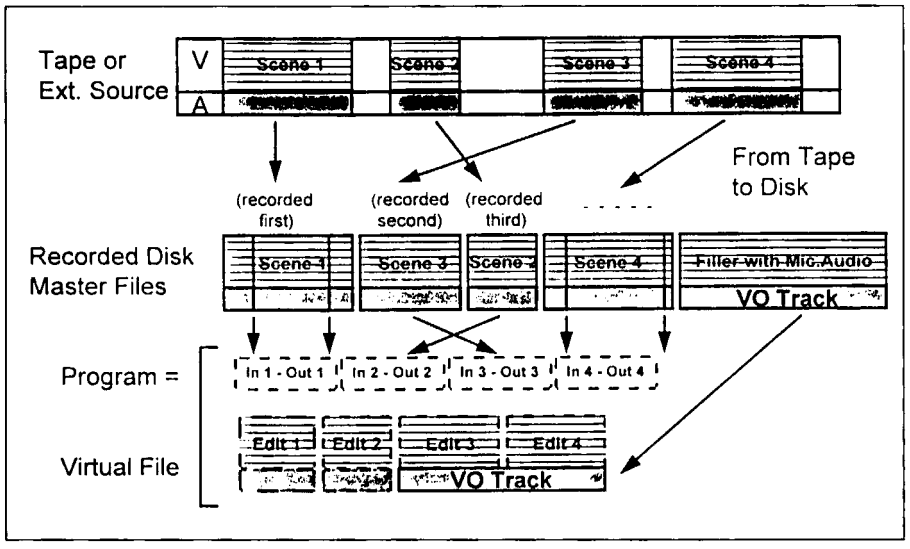

Figure 5. HBR files and program.

first recording it on the disk or videotape. This is useful when feeding the digital satellite news gathering system, for example.

In this case, the GOP switch mode is used to enable the 2x transfer at the SDDI port. In this mode, the edit accuracy becomes plus or minus one frame as the encoded bit stream is switched at a GOP boundary. The Bidirectional "B" frame at the edit point is treated as a Predictive (P) coded frame resulting in unnoticeable changes in the picture. If not in GOP switch mode, the HBR is then in the frame switch mode with frame accurate editing (Tables 2 and 3).

It should also be noted that any programmed sequence or program can always be recorded back to the videotape or disk as a master file for high-speed playback.

Jog Playback Mode

The HBR utilizes a ring buffer called "Jog Memory," which stores multiple frames of past and future decoded frames. This method allows the HBR to replay video and audio at a variable speed within the range of ±1 normal speed.

Shuttle Playback Mode

Videotape Shuttle

In shuttle mode, the video head crosses several tracks, resulting in bursts of data picked up randomly. Since a video frame is encoded by blocks of 16 (H pixels) x 16 (lines), the HBR can scan the videotape at up to ±75 times normal speed and still capture entire video blocks for the decoding process. The result is a mosaic picture on the video monitor made of 16 x 16 blocks of different adjacent frames. The picture in shuttle is recognizable at up to ±75 times normal speed.

Disk Shuttle

The data on the disk are read in blocks containing entire GOPs, with the buffer memory managing the played out frame sequence to achieve the desired playback speed. At higher than normal speed, some frames are skipped, while complete frames in between are decoded and displayed. This eliminates the mosaic-type effect seen on the shuttle videotape playback. Playback in shuttle from the disk is possible at up to ±100 times normal speed.

Editing Functionality

The most innovative aspect of the Hybrid is its ability to combine various editing methods from the most simple control panel editing to the more sophisticated and specialized applications using a dedicated controller. The main appeal of the front control panel editing is the straightforward approach that gives the user the comfort of familiar VTR-like control with the added flexibility and speed of the disk operation.

Exploiting the features of the HBR, a number of nonlinear controllers are targeted at specific applications with a specialized graphical user interface (GUI). For example, there is a field editor based on a laptop configuration with scripting and good shot marker capability. Additionally, there is a "live" editing system, with two overlaid video windows in order to simultaneously monitor the incoming feed to mark the highlights and prepare, or to replay a sequence with motion animation on the other window. Even a studio editing workstation will be able to use the HBR as local storage.

In the disk file system, an A/V recording on the HBR disk is called a Master file. There can be up to 256 master files of any duration. Once recorded on the HBR disk, master files may easily be browsed by using the Index function to skip from file to file, similar to skipping between the songs of an audio compact disc player. Master files are recorded back-to-back sequentially as shown in Fig. 5.

An edited sequence is called a Program, and it is composed of a selection of any portions of chosen master files. The program by definition is not a recording on the HBR disk, but rather it exists as a list of In and Out points or markers referring back to the original material of the master files. The program can be revised in many ways with no danger of altering any of the original master files. Once a program is completed, it can then be played out, recorded back to disk as a new master file, or to videotape for archival. A program may contain up to 1,000 events.

Control Panel Edit Process

Editing from the Hybrid Recorder's control panel is very much like machine-to-machine editing with conventional VTRs. You simply select the source such as "Tape," mark the in and out points of the material, switch to "Recorder," set the Record In point, and press "Auto Edit" (Fig. 6).

Disk Editing Process

The editing process consists of recording master files onto disk by selecting scenes from a source videotape, either from the HBR or from an external VTR. Trimming, rearranging, overlaying, or inserting new scenes are then performed to create a program. The created program can then be

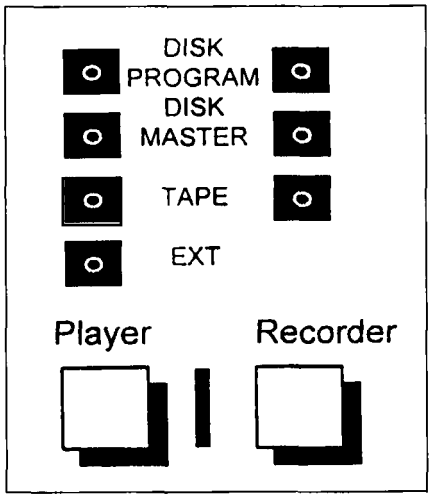

Figure 6. Source and destination selection.

played out or recorded back to SX videotape for later high-speed transfer or archival.

This represents only one of many possible methods, as the HBR also allows a program to be built directly from the source videotape to disk (as it is commonly done in machine-to-machine editing) creating an edited sequence as you go.

Yet another method consists of recording the entire source videotape to disk as a first step, and then creating a program exclusively utilizing the disk. In any of the above cases, the program may always be revised by changing the desired events at any point.

Multievent Memory

When selecting the scenes from the source videotape, each scene can be recorded sequentially to disk, or a multievent memory may also be used to memorize a series of scenes (maximum 100 scenes). This allows a "batch" recording of the corresponding master files to disk. A feed auto edit function will transfer the selected scenes from a Betacam SX videotape to the disk at up to four times normal speed resulting in notable time savings. The master files recorded onto the disk have excess A/V material recorded before the in point and after the out point to facilitate later trimming of each scene.

Overlay and Insert Mode

The HBR supports both Overlay mode, where the new material is overwritten to replace existing material, or Insert mode, where the new material is added by sliding the existing material to the side. When audio split editing is performed at the control panel, the overlay mode is always selected to avoid loss of "lip sync."

Revising a Program

When creating a program, the Auto Edit function saves the list of in and out points that define the edited program to disk. In this way, the edited program may be recovered in case of a power failure or user error. Any event from the program may be recalled and revised by changing the in and out points, inserting a new scene, or reordering the existing scenes.

Videotape Controlled by Conventional Edit Controllers

The HBR can be controlled as a videotape player by conventional linear edit controllers to play source Betacam, Betacam SP, or Betacam SX tapes. Assemble editing on a Betacam SX videotape is only available from the HBR's control panel.

Typical Applications

The following applications for the HBR have been suggested based on current broadcast operations, but it is easy to imagine that in our evolving environment, users will soon discover even more uses for this unique and versatile tool.

Integration in Current Edit Systems with Videotape Playback

Current edit suites can immediately benefit from Betacam SX recorded material on videotape because the HBR can be controlled as a source deck to replay Betacam, Betacam SP, or Betacam SX videotapes.

Standalone Editing

The Hybrid Recorder is the most natural application to replace two VTRs in a machine-to-machine editing configuration. The HBR's front control panel gives simple access to the nonlinear editing functions for quickly assembling cuts-only stories.

Nonlinear Editing Workstation

The primary benefit of today's disk technology is clearly demonstrated in the nonlinear editing application. A nonlinear edit system has typically limited storage capacity and must therefore be connected to a high-capacity A/V server system or to a VTR for downloading and uploading the finished program. The HBR is used for both local disk storage and videotape program material uploading and downloading in a variety of editing configurations, from simple cuts-only workstation to fully configured nonlinear edit systems with effects.

Digital Satellite News Gathering with 2x Transfer Speed

Using the high-speed transfer capability of the HBR, a reporter in the field can edit the story using the HBR. As soon as the program is completed, the story can be played out at 2x normal speed back to the station through a satellite uplink or microwave transmission realizing significant cost savings and maximizing transponder time allocation.

Live Events With Simultaneous Recording and Editing

When used in conjunction with the Sony DLE-110 Live Editor, the HBR can be used to simultaneously record the live feed to its HDD (and to the videotape for backup or archival) while instantly recalling highlights for replay.

Variable speed effects are also available, including learning a Dynamic Motion sequence, for later replay. While the live feed is still being recorded, a sequence of highlights may be assembled as a program that can then be played out at any time.

A protection mode allows the user to save selected events so that in case the disk fills up and more capacity is needed, recording over the old material is done without destroying the protected events.

Time Shifting or Program Delay with Endless Loop Recording

Network time shifting is easily accommodated using the simultaneous recording and playback capabilities of the Hybrid's HDD. During this operation, a videotape can also be recorded for backup or archival. Protection of chosen events is also available to prevent overwriting the selected events. Only master files are recorded in this mode.

Field Editing with Portable Editor

A laptop computer-based portable edit controller is used for on-line editing in the field. The videotape and the disk are controlled by the user, who can also perform a quick scan of preselected scenes from the videotape by detecting and highlighting corresponding stamp pictures.

A batch transfer of the highlighted scenes can also be executed at four times normal speed from the Betacam SX videotape to its internal HDD. This application, which is designed for journalists "on the go," also features scripting synchronized to video for voiceover and directing notes.

On-Air Playback

The random access capability of the disk with the additional videotape playback for last-minute story insertion make the HBR an excellent candidate for play-to-air. In addition, the optional extended storage unit can provide the protection of a redundant disk array system.

Server Feeder with High-Speed Transfer

The four times transfer speed capability of the HBR is specially suited to feed A/V servers at high speed through a SDDI interface.

Conclusion

The Betacam SX format presents the clear prospect of efficient picture coding with high picture quality for the demanding infrastructure of a modern all-digital broadcast facility. The HBR is a key component to this new digital facility, but more importantly, it provides a practical path between today's analog-based infrastructure and tomorrow's digital world.

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Ichitaro Sato joined Sony Corp. in 1966 after graduation. His first job at Sony was in magnetic tape development at the Sendai Technology Center. After seven years in tape development, he moved to the Atsugi Technology Center, where he works on the development of various types of professional video equipment (U-Matic, Betacam, Betacam SP, Digital Betacam) for broadcast and industry. He is currently the project manager for the development of Betacam SX.

Kenji Hyodo joined Sony Corp. in 1973. His first assignment was as a designer of video circuit development for the U-Matic format VTR. After that, he developed a series of Betacam formats for the broadcast and professional video industry. He has participated in the design and development of renowned products such as Betacam, Video Disc Player, Betacam SP, Digital Betacam, and Betacam SX. Hyodo is currently the project leader for Betacam SX.

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