



Research Department Report

A digital HDTV recorder using a cluster of four D1 DVTRs

P.R. Burfield, B.Sc.(Eng), A.C.G.I., A.M.I.E.E.

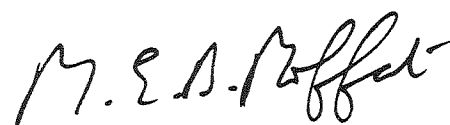
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Summary

This Report outlines the design philosophy of a digital HDTV video recording system that has been constructed from four conventional D1 digital video component recorders. Technical Specifications of the recorder are given with explanations of how the system can be used to edit source material into good quality programmes. At present, the HDTV recorder is housed in a mobile laboratory together with other HDTV equipment, and has been used by the BBC to make programmes for both itself and other members of the Eureka 95 consortium.

Issued under the Authority of



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BRITISH BROADCASTING CORPORATION

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1.	Introduction	1
2.	Specifications of the Digital HDTV Recorder.....	1
3.	The Dedicated Video Electronics	1
	3.1 General	1
	3.2 Digital/analogue conversion	2
	3.3 Demultiplexing and multiplexing	3
	3.4 Sharing the data between the four recorders	3
	3.5 Synchronisation within the HDTV recorder	4
4.	Housing the Recorder within the Mobile Laboratory	5
	4.1 General	5
	4.2 Ancillary recorder outputs	5
5.	Video Editing	6
6.	The Audio System	6
	6.1 General	6
	6.2 Audio editing	6
7.	Future HDTV Recorders.....	7
8	Conclusions.....	7
9.	References	7

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1. INTRODUCTION

As part of the British Broadcasting Corporation's contribution to the Eureka 95 project on High Definition Television (HDTV) it has built an HDTV mobile laboratory. This vehicle contains all the equipment needed to produce and replay programme material using the 50 Hz-based Eureka HDTV standard. As part of this set-up the BBC decided to build a prototype digital HDTV recorder, using a cluster of four D1 digital video component recorders, in order to provide all the advantages of digital recording. Also, by re-routing the digital video connections to run between the D1 recorders, editing and copying can be performed without the need for a second HDTV recorder.

This Report contains details of the method used to turn the four D1 recorders into the one digital HDTV recorder, and how it has been built into the mobile laboratory, all the work being done within a six-month period. The Report also explains how the recording system is operated by a user conversant with a conventional video editing suite. Already, operational experience has been gained from using the mobile laboratory during programme production and presentation at the International Broadcasting Convention, IBC 88, in Brighton; during a demonstration to President Mitterand in Paris one month later; and in support of numerous other HDTV demonstrations.

2. SPECIFICATIONS OF THE DIGITAL HDTV RECORDER

The digital HDTV recorder has been designed to work with equipment that conforms to the Eureka 95 standard of 1250 lines, 50 fields per second, 2:1 interlace, 16:9 aspect ratio. The video signals between the recorder and other equipment are sent via analogue *RGB* connections. The recorder normally locks to the syncs that accompany the input video, but the output video timing can be adjusted to provide replay synchronisation. In the stand-alone mode, the recorder runs off an internal synchronising pulse generator to produce its own syncs for the output video signals.

Most of the recording system's specifications are defined by the use of the four D1 digital video component recorders. The actual construction of a

digital HDTV recorder has been possible because each D1 machine can record an externally applied digital video signal, conforming to CCIR Rec. 656¹. This input is an alternative to the internally generated digital signal, complying with CCIR Rec. 601², that is produced from analogue inputs. A D1 machine records only 720 samples of each line and only 600 lines of every picture that arrives at the digital input channel. By utilising four D1 machines it is possible to record 1440 samples from each of the 1152 active video lines in every HDTV picture.

Sampling frequencies of 54 MHz for the luminance and 27 MHz for the two chrominance channels were chosen for their simple relationship to the sampling rates of the individual D1 recorders. In modelling CCIR Rec. 601 as much as possible, the analogue characteristics have been extended by four to give a luminance bandwidth of 23 MHz and chrominance bandwidths of 11 MHz.

An advanced video edit controller is used with the four D1 recorders. No special software was required as all the functions needed are used in a conventional editing environment. For simplicity of operation, the recordings are usually made in the 'insert' mode with pre-striped tapes and the four machines recording on identical time-codes. To play material back, the edit controller plays the four D1 machines making sure that the time-codes are kept in synchronisation.

3. THE DEDICATED VIDEO ELECTRONICS

3.1 General

A photograph of the bays containing the video electronics, a digital video matrix, and associated power and cooling system of the recorder is shown in Fig. 1. This part of the recording system has been designed to be both compact and of low power consumption (less than 500 W) to enable it to work within the mobile laboratory. All of the video electronics are housed in the two upper racks of the left hand bay. The top rack contains the HDTV analogue/digital codec and system synchronisation circuitry, whilst the lower rack performs the task of sharing out and recombination of the digital video between the four recorders using their CCIR Rec. 656 interfaces. Fig. 2 shows a block diagram of the video system.

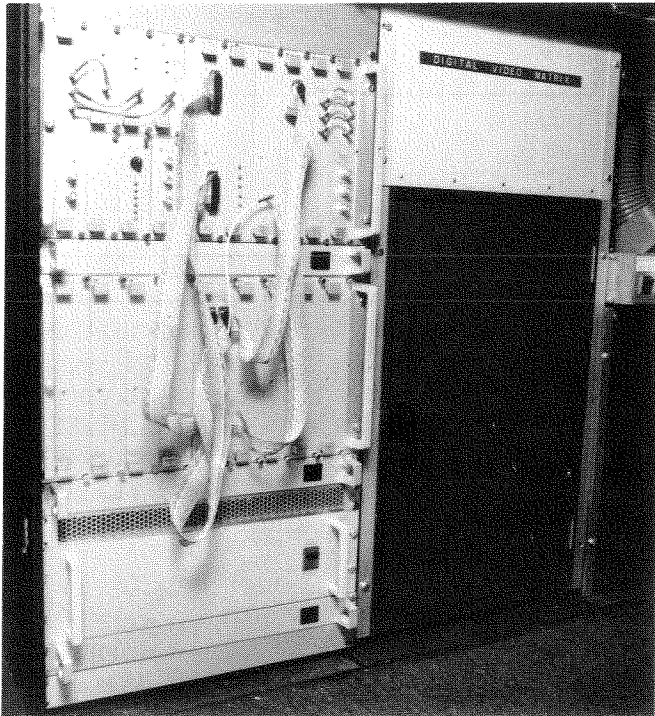


Fig. 1 - A view of the bays that house the dedicated video electronics and the digital video matrix.

3.2 Digital/analogue conversion

Referring to the upper left part of Fig. 2, the recorder takes in the source RGB signals and converts them to Y , P_R and P_B through an analogue matrix that has a bandwidth of over 30 MHz. Table 1 shows the values used within the matrix; these are presently based on System I. All three signals are then passed through the analogue-to-digital converter. The luminance is band limited to 23 MHz and 8-bit sampled at 54 MHz to produce 1440 samples during the active period of each picture line. The two chrominance signals are band limited to 11 MHz, 8-bit sampled at 54 MHz, and then 2:1 sub-sampled. These two chrominance channels are then multiplexed to form a single 8-bit 54 MHz $C_R C_B$ channel, co-timed to the luminance signal. Both luminance and chrominance signals are routed to the front panel of the top unit to facilitate connection to the lower rack.

Table 1

$$\begin{bmatrix} Y \\ P_B \\ P_R \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

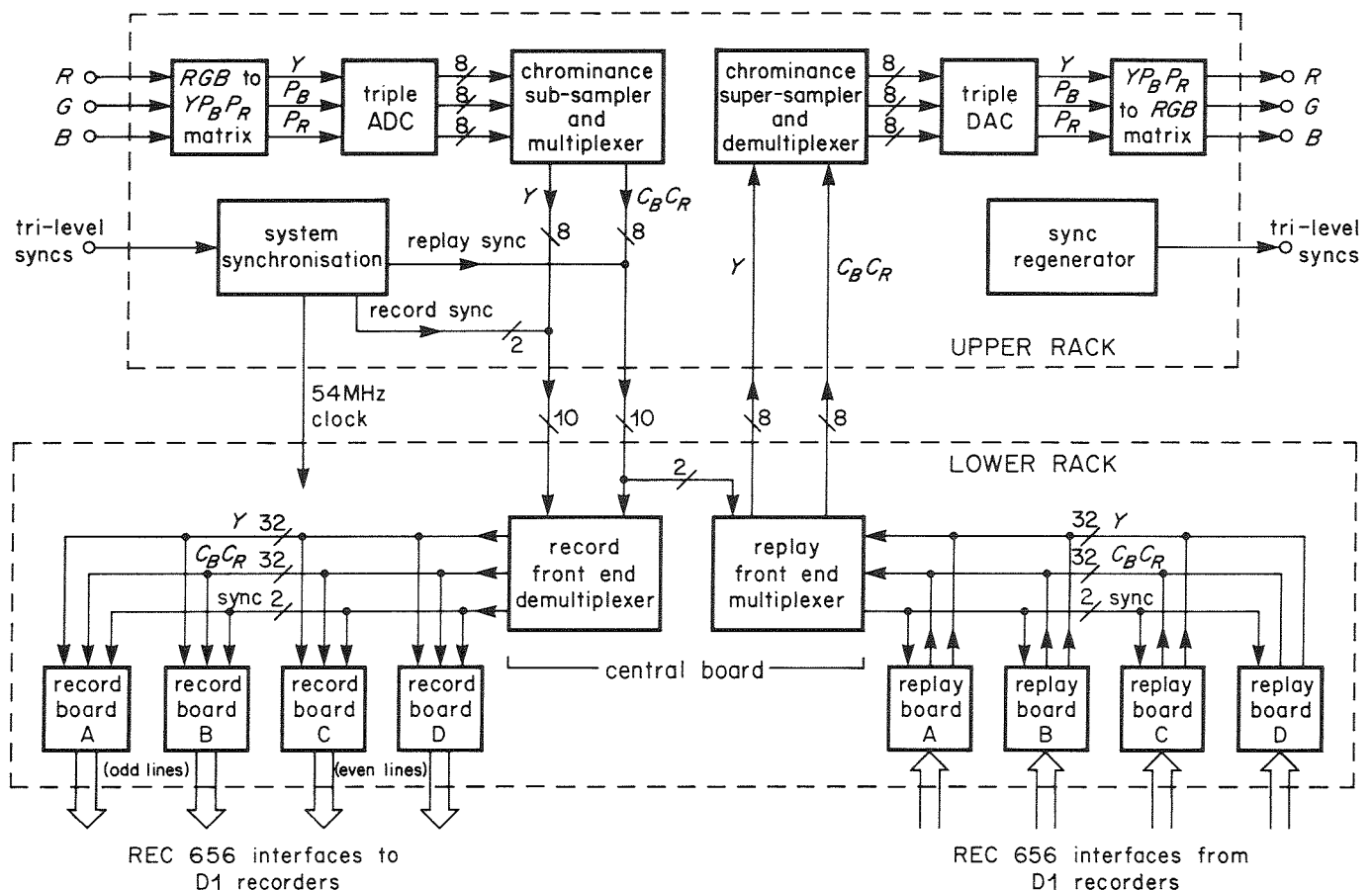


Fig. 2 - A block diagram of the dedicated hardware.

The replay path (top right of Fig. 2) contains a chrominance demultiplexer and super-sampler that holds each value for two 54 MHz clock periods. The three digital signals are then sent to a triple 54 MHz digital-to-analogue converter board whose chrominance filters have been designed to take account of the super-sampling structure. The three analogue signals Y , P_B , P_R , are finally converted back to RGB using an inverse matrix.

3.3 Demultiplexing and multiplexing

The left hand side of the lower rack holds the digital video record demultiplexer, while the right hand side holds the replay multiplexer (lower part of Fig. 2). Both sides contain sufficient memory to store one HDTV frame. The compact design and low power consumption has been possible due to the use of $64K \times 4$ -bit Dual Port Video RAMs³. The computer port of these memory devices behaves like conventional dynamic RAM, allowing a computer to address locations randomly, but with the penalty of slow access times. The serial port permits the storing or recall of data only from sequential addresses within the memory device, but at clock rates of up to 25 MHz.

At 54 MHz, the luminance and chrominance 8-bit wide channels are too fast to be applied directly to the memory serial ports. Therefore, a central board within the lower rack performs a front-end demultiplexer/multiplexer operation. The two incoming video channels, Y , $C_B C_R$, are slowed down in the record demultiplexer to 13.5 MHz by converting four consecutive samples of each into one parallel 32-bit wide sample. These new samples are placed onto two 32-bit wide record busses.

The replay, multiplexer, section performs the reverse function by taking the two 32-bit 13.5 MHz replay busses and reforming them into the 8-bit wide 54 MHz luminance and chrominance output channels that feed the upper rack.

The record backplane, along which the two 32-bit record busses travel, accommodates four record boards, each of which contains two 625-line field stores that take one quarter of every HDTV picture from the backplane. By careful selection, each board stores a different part of the picture. The two field stores on each board alternate, at field rate, between collecting video data from the backplane and sending the data to their respective D1 recorder. The field stores on each board use only the memory's serial ports to provide a 'first in first out' operation, so are unable to re-order the video data. The change from HDTV to 625 lines is made by adjusting the clock waveforms that are sent to the field stores between loading in and playing out of the video data.

Similarly, four replay boards are plugged into the replay backplane. These are similar to the record boards in operation, but now the field stores are loaded from the D1 recorders and played out onto the two 32-bit wide replay busses where they are multiplexed to reform the Y , $C_R C_B$ signals as explained above. To place data from any of the four replay boards onto the backplane at exactly the right time in order to recombine the HDTV picture, requires the field stores of each board to run in synchronism when playing out data. However, each of the field stores must lock to its D1 machine when loading video data in. Therefore, the HDTV and 625-line control systems on each board run asynchronously.

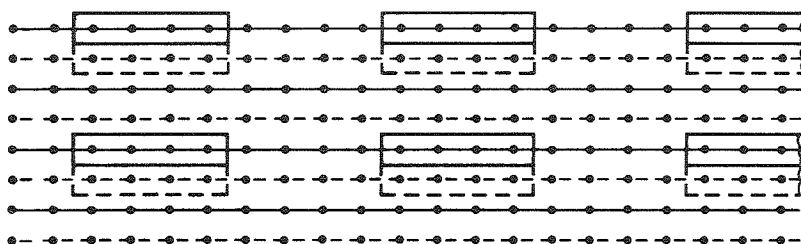
Again, the memory on the replay side is large enough to hold one complete frame of the replayed HDTV signal. This has been used to provide a still store facility for the programme maker. The four recorders can replay an HDTV picture off tape, or pass a signal via the electronics only (known as E - E). This picture is held by the replay multiplexer and appears frozen on the HDTV recorder's output. However, the HDTV recorder is still able to record the signal placed on the input, which could include parts of the picture held on the output.

3.4 Sharing the data between the four recorders

Considerable thought went into how the video data was to be shared between the four recorders. The format chosen sends to each recorder a 625-line signal that looks like the original HDTV picture when viewed from a reasonable distance*. To have 625-line pictures with complete artistic content greatly enhances the editing process. The format also succeeds in getting the error concealment properties of the individual D1 recorders to continue to be beneficial in hiding the errors in the reconstructed HDTV picture.

Fig. 3 shows the sampling structure from a small part of the HDTV picture. The four record boards and their accompanying D1 recorders are designated A, B, C, and D. They are paired together so that alternate lines of the HDTV picture are stored by alternate pairs of record boards. Boards A and B store odd numbered lines while boards C and D store even numbered lines. The 1440 samples from each line are shared in groups of four between each pair of boards. The first board of each pair stores the first

* Another member of the Eureka 95 consortium has also built a digital HDTV recorder from four D1 machines. However, this recorder splits the HDTV picture into four quarters, where each D1 machine records one of the quarters. To provide some compatibility, the BBC's HDTV recorder can be programmed to replay a set of tapes recorded on this other machine. Unfortunately, however, it has not been possible to record material in this alternative format on the BBC recorder. Other members of the consortium have shown great interest in the BBC's preferred technique.



field 1
field 2
etc.

Fig. 3
A small segment of an HDTV image that shows the samples that are sent to one of the recorders.

The solid blocks are sent during field 1, while the dashed blocks are sent during field 2. The other samples are sent to the other three recorders using the same sampling pattern but with a different phase.

group of four samples and the second board stores the second group. The first board then stores the third group and so on, this alternating process continuing until the end of the line.

3.5 Synchronisation within the HDTV recorder

Synchronisation circuitry is housed within the top rack, between the two halves of the analogue/digital codec. Fig. 4 shows a block diagram of the system.

The heart of the system is a genlockable 625-line sync pulse generator (SPG) integrated circuit. The incoming HDTV sync is separated and used to produce 625/50 line-rate and frame-rate pulses that lock up the internal 625-line SPG. External 625-line mixed sync can be used as an alternative, enabling locked replay to conventional equipment, or the SPG can be allowed to free-run.

The outputs of the SPG are used to lock both

the HDTV and 625-line sides of the digital recorder system. A 500 kHz line-locked clock is sent to phase lock the 54 MHz system clock. HDTV line pulses and frame pulses are produced and sent to the waveform generator board, which generates all the waveforms needed to operate the various parts of the HDTV side of the recorder. Similarly, the 625-line mixed sync output of the SPG is sent to the edit controller and the four recorders via a distribution amplifier, to synchronise the 625-line side of the HDTV recorder.

The 625-line SPG has been set to be on the opposite field from the incoming HDTV sync. This allows the four record boards in the bottom rack to present their outputs on the CCIR Rec. 656 channels co-timed with the 625-line mixed sync reference used by the edit controller and the four D1 recorders. The field delay and asynchronous ability of the replay boards allows the recombined HDTV video signal to be moved by up to a few lines either side of the incoming HDTV sync. This is performed by adjusting the output timings from the waveform generator board that controls the replay system.

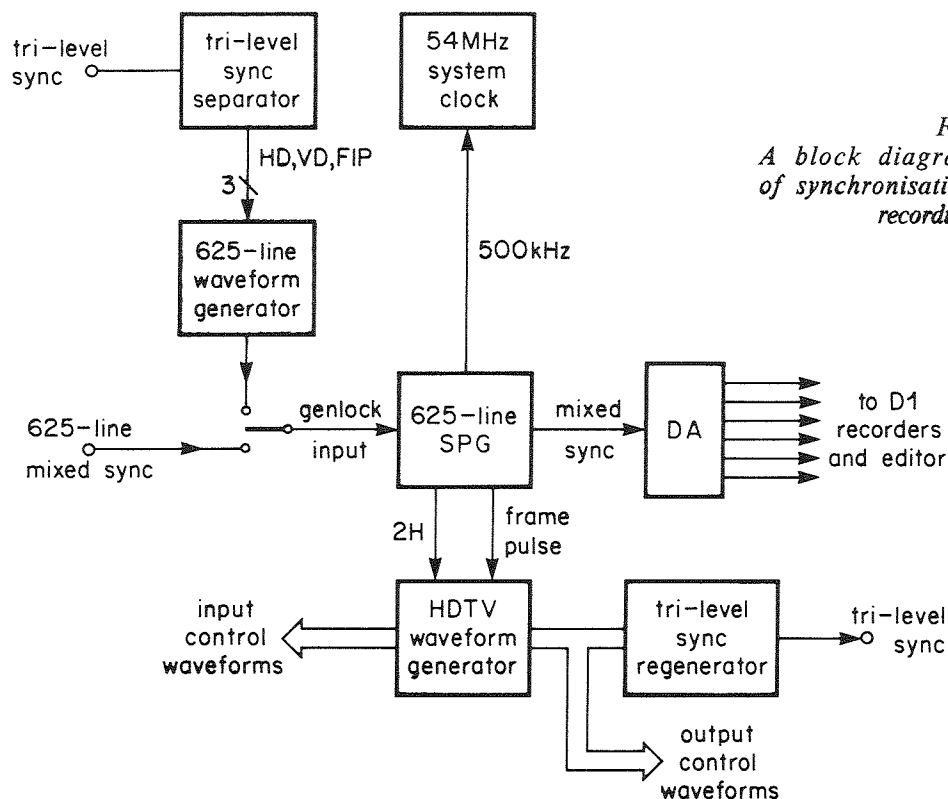


Fig. 4
A block diagram of the method of synchronisation used within the recording system.

4. HOUSING THE RECORDER WITHIN THE MOBILE LABORATORY

4.1 General

The mobile laboratory has been built into the shell of a redundant colour outside broadcast vehicle, which would otherwise have been scrapped. The inside of the vehicle was completely gutted and divided into three similarly sized areas as described next.

The forward, programme production, area contains a number of HDTV monitors, an HDTV mixing desk, and the facility to control up to two HDTV cameras. The HDTV mixer is a 525-line component mixer that has been modified by increasing the channel bandwidths to over 20 MHz and reprogramming the internal timings for HDTV. All these pieces of equipment work with analogue *RGB* signals.

The rear section, Fig. 5, is soundproofed and has a controlled lighting system to provide a suitable environment for demonstrations and editing. This section houses one HDTV monitor that shows either the input to or the output from the HDTV recorder. Four other monitors, above the HDTV monitor, are connected to the four D1 recorders and provide 'confidence' pictures of individual machines during recording and replay of the HDTV material. The four D1 recorders are controlled from this area via the edit controller keyboard. A pair of speakers are mounted either side of the HDTV monitor to enable the accompanying high quality audio to be fully appreciated.

The centre section is where the equipment is housed. It contains two sets of bays, each approximately 2 m high by 2.5 m wide. The forward set is

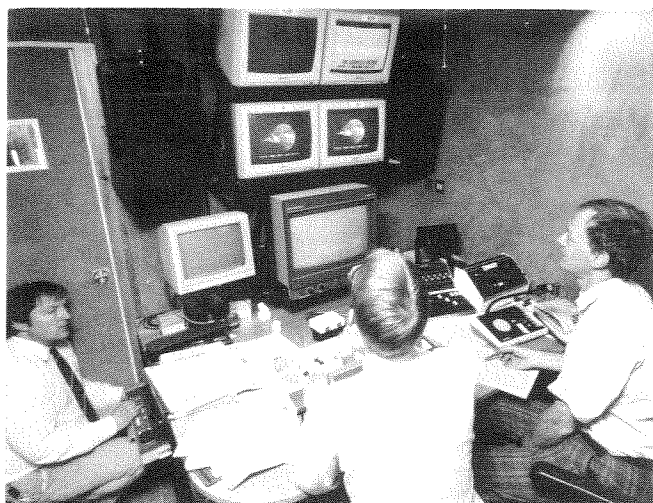


Fig. 5 - A view of the rear section of the mobile laboratory during an early editing session.

concerned with HDTV, and holds the mixer, camera control units, and the video electronics of the HDTV recorder. A manually operated 8×8 digital video switcher has been placed next to the recorder bay; in the normal mode this connects the four D1 machines to the video electronics, but is replugged for editing.

The rear set of bays, shown in Fig. 6, contains the four recorders and all the associated 625-line equipment. The whole set is enclosed from the rest of the vehicle, but has sliding transparent doors for access. The enclosure is for both noise reduction in the rest of the vehicle, and to provide an operational environment for the D1 machines. A closed-loop air conditioning unit, capable of removing 7 kW, has been fitted and the air is filtered to keep it clean enough for the four tape mechanisms. These mechanisms are also susceptible to mechanical damage when the vehicle is in transit and have, therefore, been fitted on damped mountings to reduce any damaging effects.

4.2 Ancillary recorder outputs

The HDTV recorder also provides a PAL signal output to increase the system's capabilities at some of the sites that the mobile laboratory may be used at. The monitor output of one of the D1 recorders is encoded to provide this signal, which is

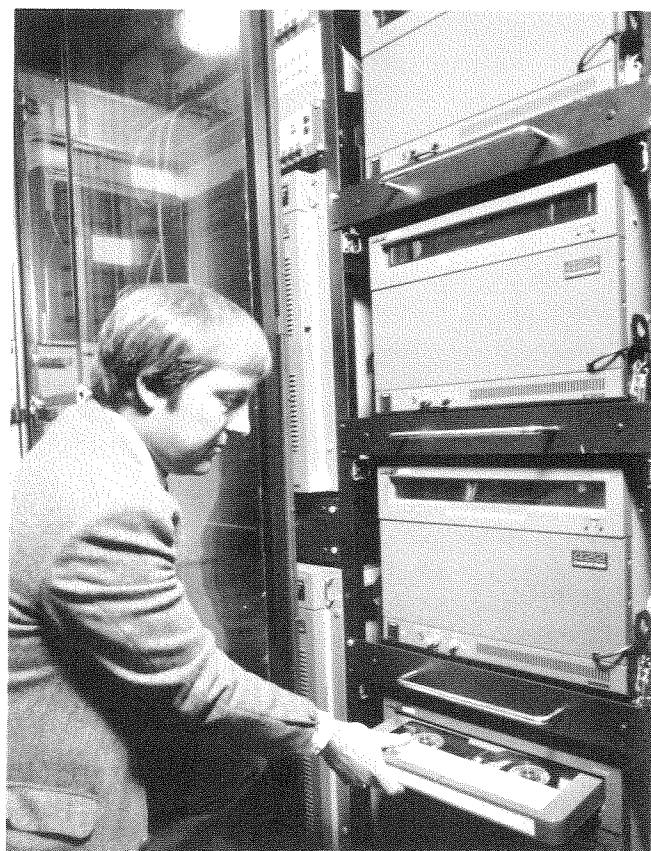


Fig. 6 - Loading one of a set of four tapes into the D1 recorders that are housed in the rear bays of equipment.

available to the user for viewing on any conventional monitor. For optimal viewing, such monitors should have their picture height reduced to convert the picture from a 4:3 aspect ratio to the 16:9 aspect ratio of HDTV. The PAL signal can be fed into a studio gallery to provide an artistically accurate picture, with imbedded time-code, for both lighting and sound control.

Within the vehicle the PAL signal, together with accompanying sound, is recorded on a semi-professional VHS recorder. This provides an independent means of viewing the source material and making provisional editing decisions from the visual time-code.

5. VIDEO EDITING

Normally, to put together even the simplest of programmes, two recorders are needed for post-production. For more advanced effects, such as wipes and fades, three recorders would be required. However, a post-production area working with full HDTV pictures, thus needing more than one HDTV recording system, was not a viable proposition. Within the digital HDTV recorder, however, enough 625-line equipment exists to make a simple 4:2:2 digital post-production unit that can be used to edit HDTV programmes as four sequential 625-line operations. With the addition of a digital video effects unit (DVE), a full 625-line post-production environment is possible, many of whose facilities have valid effects on the HDTV picture. Fig. 7 shows the rear section of the mobile laboratory following the addition of a digital mixer.

All edits on one of the four 625-line pictures are initiated via the edit controller, which makes an edit decision list containing full details of each edit; these can be saved later on a floppy disc. The edits are then recalled and made to perform identical actions on the other three 625-line pictures that go to make up the complete HDTV picture. A fair amount of care must be taken when 'cleaning-up' the edit decision list, a normal event during programme making, as some forms of change affect the way the first tape is made compared with the other three during this 'conforming' operation.

During field trials of the equipment, a new way of performing 'two-machine' edits was discovered. In this new mode, the two tapes that share the same HDTV line are placed into two D1 players, their outputs then being connected to the other two D1 recorders, whose own outputs are connected to the multiplexing equipment. The edit controller performs the two 625-line edits in synchronism. However, the

multiplexer has combined the two edited signals into one HDTV image, where alternate lines are set to black. This image enables much better judgement of the technical quality of the source material over a single 625-line image. This process has become known as 'double two-machine' editing. As a bonus, it enables conforming to be carried out in half the time.



Fig. 7 - A later editing session, now including a digital video mixer and larger audio mixing desk.

6. THE AUDIO SYSTEM

6.1 General

Each of the D1 machines is capable of recording four audio channels using 48 kHz sampling with between 16- to 20-bit resolution. The HDTV recorder could therefore provide a high quality 16-track audio system. Normally, the audio channels of only one recorder are used. The audio system within the mobile laboratory was originally built for only four channels, but since it has been decided to carry out experiments with Surround Sound, the system has been extended to accommodate more channels.

Stereo delay lines are placed in the input and output audio channels of the recorder. These are set to match the delay of the video during the sharing out and recombination process. This is important, as the sound must be accurately laid down over the video to prevent lip-sync problems at the editing stage.

6.2 Audio editing

A small audio mixing desk has been installed in the editing area. This greatly improves the facilities compared to the simple audio cut of the edit controller. In practice, completely different techniques seem to have been used each time a programme has been made.

For the first programme, the sound was initially cut edited with the video. One of the four edited tapes was then sent to a post-production audio edit suite at BBC Television Centre, where the sound track was lifted off and sound effects added before being placed back onto the video tape. With the second programme, the audio from different parts of the source material was mixed together in the audio mixing desk. This was possible because the D1 recorder can lift off, and reinsert the audio during one pass of the tape. The sound that was mixed with this real-time sound came from the other recorder that was playing a different part of the source material. The third programme laid down the audio tracks first and the video was then edited in time with this.

7. FUTURE HDTV RECORDERS

The HDTV digital recorder described in this Report, records, edits and subsequently replays material to a very high standard. As a result, it is expected to have a life of 3-4 years, when a new generation of digital HDTV recorders should have become available. At this point, all the material will need to be transferred and the old system dismantled, many of the parts being usefully redeployed elsewhere within the BBC.

Any new digital HDTV recorder will sample at an effective rate of 72 MHz, and place the information onto just one tape. To record the full data rate demands a very large tape usage, and thus increases the mechanical stresses. It is likely, therefore, that some form of data reduction strategem will be

used to make a more cost-effective machine. Within the BBC, research continues in this area.

8. CONCLUSIONS

The recorder described has been remarkably useful to the Eureka 95 project. The good quality of its first few programmes, both technically and artistically, can be put down to the care taken in producing a reliable digital system that can record and replay without any loss in quality the images sent to it. Due credit must also be given to the Sony D1 recorders which have seemed to be well suited to this application. The ease with which professional VT editing staff can control the system, and the post production facilities made available to the producer, have permitted many intricate edits to be practised with ease. In addition, the flexibility built into the video electronics has allowed many new ideas and extra facilities to be tried out. Many of these were not even thought of at the time the equipment was built.

9. REFERENCES

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3. NICOULD, J.D., 1988. Video RAMs. *IEEE Micro*, Feb 1988, pp. 8-27.