DIGITAL AUDIO EDITING:
The development of a random access editor

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Summary

Whilst digital audio techniques offer many advantages over their analogue counterparts, the difficulty of editing digital recordings has detracted from the widespread adoption of this technology in broadcasting. The BBC has continued its research in this field with the development of a disc-based Digital Audio Editor to assess the capabilities of this type of equipment in a broadcast environment. This equipment became operational in September 1987 and has since been used for a wide variety of programmes with differing requirements.

This Report describes some of the editing techniques implemented and the advantages and disadvantages of disc-based editing which have become apparent under operational conditions.

Index terms: Digital audio signals; magnetic disc recording; editing

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1. INTRODUCTION

Whilst digital audio recorders of various designs have been available for several years, difficulties in using such equipment have restricted their widespread introduction in broadcasting. Perhaps the most limiting of these is the difficulty in editing the material once recorded in digital form. Although cut-tape editing techniques are available for some of the digital recording formats, they still have a number of disadvantages over analogue methods. The relatively recent availability of high capacity magnetic disc drives, each capable of storing about 30 minutes of stereo audio, has promoted the development of alternative editing systems based on these devices.

Early research work in the BBC identified various techniques for implementing such a system and led to the development of prototype equipment to demonstrate its potential. Prior to further work, a review of the few commercial products which were beginning to emerge concluded that none would address the requirements of basic stereo editing as an alternative to cut-tape editing. These products were either intended as multitrack machines or simple desktop editing systems. On cost grounds alone, the multitrack approach would be prohibitively expensive for stereo editing. On the other hand, the simple editing systems, which were generally based on a desktop computer, were awkward to use and inconvenient since they relied on a graphics display, keyboard and 'mouse' to provide waveform editing. As a result it was decided that a fully operational stereo editor should be developed to allow a wide appraisal of its potential. This would also allow operational techniques to be explored and give a better understanding of the advantages and disadvantages of this approach.

A disc-based editing system was therefore developed to fulfill these requirements. After successful proving experiments, the Editor, shown in Fig. 1, was installed in BBC Radio's main London production centre in September 1987 and has since been used for a variety of programme work. This Report describes some of the experience gained from its use and aspects of its implementation which have evolved as a result.

2. DESIGN CONSIDERATIONS

As a major reason for the development of a Digital Audio Editor was to assess its capabilities in a broadcast environment, it was important that many potential users should have access to the equipment. Furthermore, they should be able to use the system interchangeably with their conventional editing work. It was not intended that the Digital Audio Editor

![Fig. 1 - The Digital Audio Editor installed in Broadcasting House, London.](image-url)
would become a specialised item of equipment operated only by a few highly trained staff. Its operation would therefore have to appeal to a wide range of users each with their own demands for their particular work.

An important goal in the design of the control system was therefore that it should be as simple as possible to use without restricting the capabilities of the equipment. Wherever possible controls were to be similar to those on a conventional tape machine, unless this imposed undue restrictions.

Another important feature is the method of edit point location. Traditionally this is performed by manually rocking spools of tape on a tape machine. Whilst there are other methods that can be used, this ‘reel-rocking’ approach is considered to be superior in many respects. It was therefore felt necessary to provide this function in the Digital Audio Editor.

With these considerations in mind, a dedicated control panel was designed with a relatively straightforward layout, shown in Fig. 2. It incorporates the familiar tape transport controls for the play, record and rewind functions, etc., and a control wheel for ‘scrubbing’ or ‘reel-rocking’ operations during edit point location. In addition, a few simple screen displays are presented to the operator on a visual display unit (VDU). The keyboard for the VDU is used where optional titling, etc., is to be entered but is otherwise unused in controlling the equipment.

The required operational features could therefore be summarised as follows:

- The equipment must be easy to use without undue training
- All of the present analogue editing facilities should be available
- Edit point location should be by ‘reel-rocking’
- It must be possible to rehearse edits as adjustments are being made
- The equipment should provide both analogue and digital audio input and output
- The discs should have a minimum capacity of one hour of stereo audio at 16 bits per sample, 48 kHz sampling rate

3. OUTLINE OF HARDWARE

Broadly speaking the Editor has two types of function to perform, supervisory and real-time audio processing. The structure of the hardware, shown in Fig. 3, reflects this division, with the audio kept completely separate from the control hardware. The audio path, shown in the upper half of the figure, contains four elements: the audio storage discs, the real-time audio Input/Output transfer system (RIO), the vari-speed processor and other input/output units. The control system, shown in the lower half of the figure, uses a standard Motorola computer system and communicates with each of the audio processing functions through a separate control bus, the Motorola ‘IO channel’. The control panel is supervised by a separate microprocessor which, in turn, is controlled by the main computer.

The function of each of these units is described in the following subsections.

3.1 Computer system

The computer system is a standard Motorola product, the MVME 110, which uses a 68000 processor and is based on the VME bus. It is equipped with 1 Mbyte of memory, a 20 Mbyte Winchester disc and a floppy disc drive for software exchange. It runs the VersaDos* operating system in order to achieve short and predictable response times as demands are made by the real-time audio hardware. The 20 Mbyte disc is used solely for the operating system and control software and is not used for audio storage.

* Trade mark of Motorola

Fig. 2 - A closer view of the Editor control panel.

Note the familiar ‘transport’ controls on the left, the control wheel for edit point location and the two faders for gain adjustment at edit points.
3.2 Control panel

The control panel, shown in Fig. 2, is controlled by a dedicated Motorola 6809 microprocessor. Communication between control panel and MVME 110 processor is via the I0 channel. This is used to send commands to the panel, for example, to illuminate push-buttons, as well as receiving details of key presses, etc., back from the panel. Key presses and wheel movements are communicated to the remainder of the system over a separate bus, the SYNC bus. This is a simple byte wide bus which allows units to respond rapidly to changes at the control panel by avoiding the delays which would be introduced in handling such real-time requests through the main control system.

3.3 Audio storage discs

The audio data is stored on two 310 Mbyte Winchester discs, equivalent to a total capacity of 42 minutes of stereo at 48 kHz. Whilst this falls short of the design requirement for one hour of storage, additional discs could easily be added to give several hours of recording capacity. The discs are accessed via a controller, through the standard SCSI (Small Computer Systems Interface) bus. The use of the SCSI bus allows other drives to be used on the system with only minor changes, if any, being needed. The 5 1/4" format was chosen as it optimised storage capacity versus size and had adequate performance.

3.4 The Real-time audio Input/Output system (RIO)

The transfer of audio to and from the discs is carried out by RIO, the dedicated controller, shown schematically in Fig. 4. This subsystem consists of two circuit boards, one containing two digital signal processors (Texas Instruments TMS320E15) and the other 2 Mbytes of RAM for audio buffering. Direct memory access (DMA) control allows audio data to be transferred between this memory and the discs, whilst the pair of signal processors manipulate the audio and perform the replay and editing functions. At the time of the design (1986), one processor could not handle the processing required in real time and so two were used, working in tandem. One of these deals with the control of the SCSI bus and addressing of the audio buffer. The second handles the audio data, crossfading between sections of audio as edits are made and adjusting the gain when necessary. The two processors share a common bus to access the audio buffer memory, with hardware to synchronise their operation.
These processors are controlled by command packets sent from the main control computer. Such commands include information on disc addresses to be used for audio transfer and the position of edits in the replayed audio.

3.5 Varispeed processing

The varispeed processor board implements the reel-rocking function for edit point location. To achieve this, speed information is derived from the wheel on the control panel and this determines the rate at which audio samples are replayed from disc. The function of the varispeed processor is to up-convert this sample rate to the standard output sampling rate of 44.1 or 48 kHz.

Speed data is sent directly to the varispeed processor from the control panel via the dedicated SYNC bus so that its operation is locked directly to the movement of the wheel.

The varispeed processor itself operates in two stages. The first up-converts the incoming variable rate signal by a factor of eight in sampling rate. The second stage applies linear interpolation between the two up-converted samples which straddle the desired sampling point. The result of this final interpolation is the value of the waveform at the instant of the fixed rate output clock. This function is implemented in software running on a Texas Instruments TMS 32010 signal processor. A detailed description of the operation of the varispeed processor is given elsewhere².

3.6 Audio input and output

As well as analogue inputs and outputs, the Editor is provided with an AES/EBU digital port and a digital interface for a Sony PCM701 recorder. When an input is selected, the incoming signal is output for monitoring. This provides some confidence that the signal is being received correctly, although it is not a full confidence replay since the signal is looped back prior to recording it on the disc.

When either of the digital inputs is selected the Editor will lock to the incoming signal and output in the same phase. In addition, a second AES/EBU port is provided to receive a reference feed to which the equipment can lock and hence minimise the problems of locking multiple systems within a studio.

4. THE OPERATION OF THE EDITOR

4.1 The Transport controls

The recording and replay operations on the Editor are controlled using the conventional ‘transport’ controls (to the lower left in Fig. 2) in much the same way as on a tape recorder. Thus the play, stop, record, fast forward and fast rewind functions behave as a
user might expect. In addition to their normal function of double speed replay, the fast forward and rewind functions provide a means of jumping to a particular time in the replayed material.

The varispeed function, controlled by the wheel on the panel, has two operating modes: reel-rocking mode for edit point location or shuttle mode where the wheel becomes a speed control. When used in shuttle mode, two speed ranges are available: up to unity or double speed. The former is useful in locating gaps in recording, or other intended edit points, as rapidly as possible since speech, for example, is usually intelligible at these speeds.

4.2 Recording

A recording is made on the Editor by first displaying the Recorder page on the VDU. This prompts the user to enter a title for the recording and allows an optional comment to be included. The recording operation can then be started, and subsequently paused or stopped, by using the transport controls. As the recording is in progress, cue points can be marked to which the user can later return. By using a display of cue points, the user can immediately return to any of these marked points. This provides a convenient way of marking potential edit points or other points of interest, as the recording is made. Furthermore, the 'in' and 'out' points of edits (described later) can also be marked at this stage. This means that the first steps in editing the material can be made at the time of the recording, leading to more efficient use of the otherwise wasted time during this initial transfer phase.

After the recording is completed, its details are added to the list of recordings and the new material is then available for editing.

4.3 Editing

Editing work tends to fall into two categories for which the terms 'assembly editing' and 'cut editing' have been adopted. Assembly editing allows various sections of material, identified from recordins or other programmes, to be assembled together in any order. A news bulletin, for example, would make extensive use of this form of editing. The alternative form of editing, cut editing, as its name suggests, allows sections of material to be removed from a programme, for example, intrusive noises or mis-spoken words. Cut editing resembles the cut tape editing process with which the majority of users are familiar and can be carried out without reference to any of the display pages. It is only when the more advanced editing features are required that these displays become essential.

In practice, both these forms of editing are used together. Where the original recording is not correctly ordered for the programme or several recordings are being used, rough editing is first performed by the assembly editing technique. Cut editing is subsequently used to remove the excess material left after the initial rough edit stage. Finally, edit adjustment is performed to trim any edits which are judged artistically not to be entirely satisfactory.

It should be stressed that during these editing operations audio data is never copied, only edit details are created or updated. Thus editing does not create additional audio data and hence does not need extra audio disc space.

4.3.1 Assembly editing

Assembly editing takes place in two operations. In the first of these, material is selected by replaying the recordings and marking both the start and end of each of the required sections to form a 'slice'. As these slices are marked their details appear on a separate display page, shown in Fig. 5, and each can be given a label, for example, 'bar 18' or 'take 34', entered from the keyboard, for later identification. With the required slices identified in this way, the second stage of the assembly process is to place them in their required position in the programme. This is carried out by first creating a new programme and giving it a title. The appropriate slices can then be picked from the slice display and stored in the programme details. There is no restriction as to where a slice may be placed, it can be appended to a programme or inserted

Fig. 5 - A VDU display showing several 'slices', or sections of material, selected from various recordings.

Each slice is identified with the name of the recording from which it was taken and the times of the recording at which it starts and ends. A comment can also be added to indicate the content of the slice. The highlighted bar can be moved to select different slices; once selected, a slice can be played individually or stored in a programme.

(PH-300)
at any point within it. When an insertion is made, the transport controls and the control wheel are first used to replay the programme to locate the exact point for the insertion of the new material. As slices are inserted, edits of the default duration are made at both ends of the new section. After the slices have been stored in the programme, a page showing the programme contents can be displayed as shown in Fig. 6. Here the source recording and duration details of each slice are shown in order, together with the overall duration of the programme.

After the assembly operation has been performed, the programme can be replayed to ensure that its order and content are acceptable. If not, then individual sections can be removed or re-arranged until correct. Where necessary, the edits can then be refined by using either cut editing, described in the next section, to remove the excess material around the rough edit, or the edit adjustment facility.

![Fig. 6 - A display page listing the slices included in a programme.](image)

As the programme proceeds, the highlighted bar moves from line to line indicating which section is currently being replayed.

4.3.2 Cut editing

A cut edit removes a section of material from a programme between two points, the 'out-point' and the 'in-point'. In practice, this edit is made by first playing the programme and using the control wheel to identify the 'out-point', i.e. the point from which material is to be discarded. This point is marked by pressing the 'out' button and the transport controls or wheel are then used to find the associated 'in-point', i.e. the point from which replay is to continue after the edit. When this point has been located, the rehearsal facility can be used to audition this trial edit without committing it to the programme details. The rehearsal will play a short section of material, typically four or eight seconds, centred on the edit. Alternative rehearsal durations ranging from two to 32 seconds may be selected to suit the material being edited. A rehearsal of either the 'out' (leading) side or the 'in' (trailing) side alone can also be performed. This is particularly useful where an edit is not correct and it is difficult to identify which side requires adjustment.

If, after rehearsal, the edit is unsatisfactory, then adjustment of the wheel on the control panel will continue to move the 'in-point' as before. Hence this may be trimmed repeatedly and each time the edit heard with the rehearsal facility.

At this stage, the duration of the edit may also be changed. Eight values in the range 0 to 500 ms are provided and these are stepped through by pressing a single button. In practice, it has been found that edit durations from 10 to 200 ms are most frequently used, depending on the material being handled. In some cases, where an edit is required between dissimilar recordings which are at high levels, the 500 ms duration edit is extremely useful since this can avoid the use of an external mixer in making an acceptable cross-fade between them.

When recordings which were made at different times are being edited together there may be a slight, but significant, change in level between them. To compensate for such differences in level across edits, a gain adjustment facility is provided. This allows the gain of the material following an edit to be varied between +6 dB and -6 dB and this change remains in force until the next edit.

If the 'in-point' is satisfactory but the initially selected 'out-point' now requires adjustment to perfect the edit, then the 'in' button on the control panel is pressed. This fixes the 'in-point' at its current setting and regains control of the 'out-point'. Adjustment of this point can now be carried out by rocking the wheel and the rehearsal facility again used to audition the edit.

This toggling between adjustment of the 'in' and 'out' points may be continued until both are satisfactory. At this point, the edit is stored by pressing the 'store' button, whereupon it will be entered into the list of edits in its appropriate position. If, during adjustment, a satisfactory cut edit is unattainable then the 'clear' button can be used to delete the edit entirely and reinstate the discarded material.

A cut edit can span any number of previous edits in the programme, thus the discarding of the material between the cut marks may also involve removing corresponding edits from the edit list. This operation is carried out automatically by the control
system and the operator need not be aware of the modifications to those details.

4.3.3 Edit adjustment

As editing on a disc-based Editor is performed non-destructively, all aspects of an edit may be manipulated after it has been made. Parameters which may be altered include edit position, edit (cross-fade) duration and gain adjustment across the edit for each channel.

Edit adjustment is achieved by entering an ‘unedited’ mode after the edit to be adjusted has been replayed. The display, shown in Fig. 7, will then show the full details of the immediately preceding edit. The material on either side of the edit can be selected for adjustment and the transport controls and wheel are used to adjust that half of the edit, working in the original, unedited recording. Irrespective of which side of the edit is being adjusted, the duration of the edit and the gain adjustment across the edit may also be varied. As with cut editing, the edit duration can be varied over the range of 0 to 500 ms with gain adjustment between +6 dB and −6 dB. The gain for each of the two channels may be adjusted individually to correct for differences in image position across an edit.

It is also possible to move the leading and trailing sides of an edit simultaneously through their respective material. This is useful where the timing of the material on either side of the edit has been established but the optimum position of the edit between them has to be determined. This technique, which has no counterpart in tape editing, is frequently referred to as sliding the edit.

Rehearsal of the edit, to check its quality, can be performed at any time as adjustments are being made. This function operates in the same way as previously described for cut editing, allowing the rehearsal of the full edit or either its leading or trailing half in isolation.

After the adjustment of an edit is completed, the new settings may be stored, replacing the previous values. However, if the adjusted edit is not satisfactory, then the new settings can be discarded and the original edit details will be restored, unchanged.

4.3.4 Gain variation during replay

A facility to vary the gain of the material during replay is also provided. This allows a gradual change of gain of up to +6 dB or −6 dB to be applied at any point in the programme. The gain will change to its new value over a preselected period up to 5 seconds. This is intended for use where a change in level is required to bring the overall level back to an average value. This may be required to compensate for gain adjustment applied at an earlier edit. Care must be taken when applying such gain since signals at a high level may clip if there is insufficient headroom for the gain being applied.

5. EXPERIENCE TO DATE

To date, this equipment has been used to edit a variety of programmes, typically containing classical music, popular music and speech. From an early stage, it was clear that the facilities offered by such an Editor were extremely powerful and that the system would have a great deal to offer. The expectations of many users, in terms of edit capability and simplicity of use, have been surpassed. Experienced studio managers, who have several years of tape editing experience, find the system extremely rapid to use and achieve high quality edits with ease.

The non-destructive nature of the editing and in particular, the ability to make small adjustments to the position of an edit and vary its duration and gain offset, has proved to be a major advantage over cut-tape editing. As a result, a superior edit can be achieved in many cases. Furthermore, it is possible to place edits at points which would not give acceptable results with cut-tape editing. There are several other benefits which arise from this flexibility. From an artistic point of view, a better overall result can be achieved, since the improved edits more closely approach the ideal of a ‘perfect performance’,
apparently without edits. A practical benefit is that acceptable edits can be achieved more quickly although it may be tempting to spend excessive time striving to improve an edit which is already quite acceptable. A less obvious benefit is that retakes during a recording session can be made shorter since the ‘overlap’ at either end of the retake can be reduced, perhaps to one or two bars of music. It is unlikely that a good edit cannot be achieved within that interval.

It has also become clear that difficulties encountered with limited audio storage capacity on the discs could soon erode the advantages gained by rapid editing. Although capable of supporting up to 28 disc drives, the system was initially equipped with two 310 Mbyte discs, giving a capacity of approximately 45 minutes of stereo at a sampling rate of 48 kHz. Where a large amount of source material is being used this has resulted in transfers to and from the discs being necessary as completed sections of a programme have to be saved temporarily to free disc space for further editing. When all these sections are completed, they are transferred back to the Editor and assembled together to complete the programme.

The ratio of material prior to the editing session to that in the final programme is typically 3 or 4 to 1, e.g. for a 30 minute programme, 1.5 to 2 hours of original recordings may have to be edited. Where prestigious productions are involved, this ratio may be far higher. If the time spent in transferring audio to and from discs during editing is to be avoided then a storage capacity of about 3 to 4 hours of stereo is required. If a storage capacity of less than this is provided then the equipment will be restricted in its applications.

Generally, digital recordings are now being more widely used since editing can be performed without difficulty. Previously, digital recording was used mainly for ‘live’ concerts, etc., which would require little, if any, subsequent editing. This is no longer the case and there is an increasing preference towards digital recording because of the benefits obtained at the editing stage. Furthermore, the equipment is attracting conventional analogue editing work as this can be carried out more easily and to a higher standard than with cut-tape editing.

6. CONCLUSIONS

Whilst there was little doubt that a disc based editing system was feasible, the results that are attainable have impressed all who have come into contact with it. A period of use convinces most users that the future of audio production certainly lies with equipment of this type.

The experienced operator can usually make perfect edits first time, as he can with tape, but the non-destructive nature of the disc-based system engenders a feeling of confidence and hence encourages greater speed of working. The less experienced find using the system an ideal training experience, as full concentration can be given to the artistic task in hand without needing simultaneously to develop a faultless technique for making (and un-making!) joins in tape.

There is no doubt that the major limitation of the system, which will preclude its more widespread application until it is overcome, is the limit on the speed of transfer in and out of the system to real time. This is imposed mainly by the digital audio recorders currently available and the sampling rate limitations of broadcast quality analogue to digital converters.

It is particularly important, therefore, if productivity is to be maintained, that it should be possible to perform as many operations as practical whilst the recording proceeds, uninterrupted, in the background. Ideally, it should be possible to perform editing on the material as the recording is in progress but this may place excessive demands on the disc system. The minimum that is acceptable is the ability to mark cue points as the recording is made, allowing passages to be located quickly during the later editing phases. As a compromise, it has proved very useful to be able to mark, not only cues, but also edit points, ‘on-the-fly’, whilst recording. When the recording has been completed, a rough edited version of the final programme can be assembled quickly from these marked sections. This helps significantly to offset the limitation of only real-time transfer to the Editor.

During the course of this development, several commercial disc-based editors have become available, offering a variety of editing features. Broadly speaking, these systems are either based on desktop computers or are dedicated systems capable of multitrack operation.

Further experience with the desktop editors has confirmed that users are unhappy with the approach of using a mouse and graphics display to select edit points. Here there is a very strong preference for the reel-rocking facility, since it allows users to hear the recording during edit point location.

Whilst the multitrack systems generally do not suffer from this drawback their cost tends to be prohibitive, particularly where the major part of their use would be for stereo editing. Nevertheless, a few of these systems have been acquired by the BBC for special applications and experience with them has been equally encouraging. However, their use is likely
to be on a much smaller scale than with the stereo editor envisaged by this Report.

Despite the limitations of transfer time and storage capacity, encountered during the appraisal of the Editor described here, the majority of users feel that there is undoubtedly a significant application for this generation of equipment. Furthermore, its speed and ease of use has confirmed that this approach will certainly replace cut-tape editing in many situations.

7. FUTURE DEVELOPMENTS

The availability of removable media, both optical and magnetic, opens up several possible enhancements to the basic system as described. The immediate advantage of such an addition would be the ease of interchange of recordings without the delay in recording material to and from the Editor. If recordings in the studio were made on these discs, then the initial transfer to the Editor would also be eliminated.

At present, the cost of removable magnetic discs detracts from their widespread use and optical discs are therefore more attractive for this role. Unfortunately, the relatively low data transfer rates attainable with current erasable optical discs make them difficult to use in this application. Write-once optical discs, whilst faster in data transfer rates, still fall short of Winchester disc performance and may therefore not be able to perform dense clusters of edits whilst replaying the material.

Another area of interest leading from this work is the interconnection of several audio Editors to form a network. In this application, perhaps most useful in a newsroom environment, all recordings would be held on one or more centralised stores and users could access any of these from their own Editor. In this way, incoming recordings would be available to all users simultaneously without the need to make duplicate recordings for later distribution. Furthermore, edited versions could also be stored centrally, allowing a user to access the material from different places and pass it on to others in the editorial chain prior to broadcast. This arrangement would be similar to the present electronic newsroom systems but would handle the recorded audio rather than text.

8. REFERENCES

