KUNIMARO TANAKA

The Mitsubishi Digital Audio System

Hand-in-hand with the current surge in digital technology is the speculation that PCM will become audio's wave of the future.

AN EXAMINATION OF THE complete audio recording/reproduction chain, from microphone to speaker system, immediately reveals that the quality of the reproduced sound is subject to a number of limitations, including noise, distortion, cross-talk, and so forth.

The last few years have seen numerous attempts to achieve significant improvements in equipment performance, by the introduction of pulse-code modulation, or PCM, techniques. The introduction of PCM technology has been supported by contemporary developments in semiconductor technology, and has been making real progress which indicates that it will become the mainstream of audio engineering in the 1980s.

The potential of PCM for improving the performance of tape recording equipment was recognized by Mitsubishi Electric, and an R & D program resulted, in September 1976, in the world's first PCM tape deck operating on 6.3mm (¼-inch) tape at a tape speed of 38 cm/sec. (15 in/sec.). By October of the following year we had developed a PCM recorder for the amateur, based on use of a VCR unit, and another world first in the form of a digital audio disc (DAD) system. Since then our on-going R & D program has been directed at; a self-contained PCM recorder and DAD player for home use, featuring a semiconductor laser, and, a two-channel fixed-head professional-type tape recorder, featuring tape-cut editing. The latter received a most enthusiastic reception when it was unveiled at the New York AES Convention in November, 1979. Mitsubishi Electric is actively pursuing the adoption of PCM in audio equipment.

HOW DOES PCM RECORDING EQUIPMENT ACHIEVE HIGH QUALITY?

Conventional analog recording equipment records the original audio input signal waveform in the form of remanent magnetization of the recording tape. This means, of course, that the non-linearities of the magnetic tape distort the waveform, with noise also arising from inhomogeneities in the distribution of the magnetic domains in the tape. In addition, wow and flutter, etc. caused by inadequate mechanical precision in the tape-transport mechanism, also distorts the waveform. The result is a degradation of the original signal at playback, as shown in FIGURE 1.

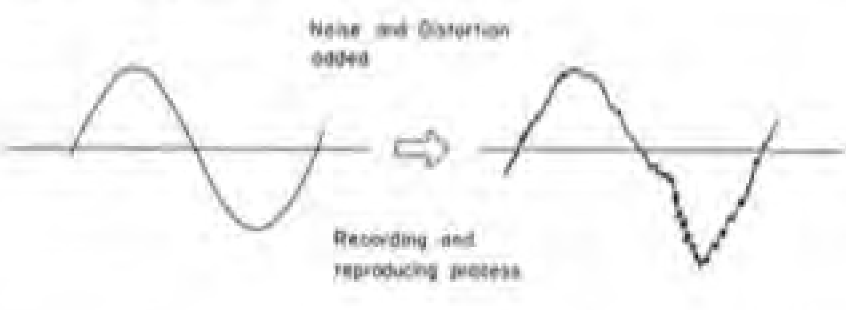
With a PCM recorder, the input signal is converted into numbers and groups of pulses, which are then recorded on the tape. Of course, the waveform of these pulses is also subject to the above-mentioned influences of noise and distortion, but these do not affect the numbers and groupings of the pulses, and so the recorded information is preserved without degradation. The original waveform is faithfully reproduced, as shown in FIGURE 2. This is the most important and basic principle of PCM recording.

The coding of the signal is performed as follows. First, the input signal is sampled at a frequency of some 45 to 50 kHz. According to Shannon's sampling theorem, a given sampling frequency permits the recording of audio frequencies up to one half of the sampling frequency. The choice of 45 to 50 kHz therefore enables recording up to 20 kHz.

Next, each sample is measured, and expressed as a binary number, consisting of a series of "0" or "1" digits. "1" is represented by a pulse and "0" by the absence of a pulse. Since errors in the measurement of the sample will appear as noise, it should be measured as accurately as possible, and expressed by a binary number with as many digits as possible. In general, the signal-to-noise ratio for a signal coded with N bits is given by:

$$S/N = 6N + 1.8 \text{ (dB)}$$

Figure 1. Degradation of analog signal.



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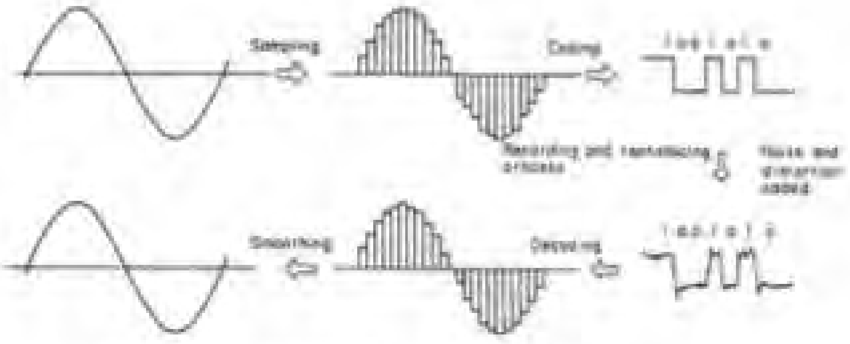


Figure 2. Principle of PCM recording.

Thus, whereas the performance of conventional analog recorders is determined by the characteristics of the magnetic recording tape and the performance of the heads, the performance of the PCM recorder is determined by the electrical circuit design.

The density of the information in PCM recording and playback equipment is generally extremely high, so that dust, etc., adhering to the surface of the magnetic recording medium (disc or tape) very readily generates error signals. Error-correction codes are therefore normally added to the signal so that, should an error arise, it will be automatically detected and corrected. If the errors are too numerous to be corrected in this way, error-concealment techniques are brought into use. These measure the error-free samples immediately before and after the error sample and substitute their average value in place of the error sample. Obviously, the effectiveness—or otherwise—of these error-correction and error-concealment functions is critically important for the stable and reliable operation of the equipment.

JUST HOW GOOD IS PCM EQUIPMENT PERFORMANCE?

As an example of the level of performance that can be obtained by the introduction of PCM techniques, we turn to a professional fixed-head recording deck, using a sampling frequency of 50.35 kHz and 16-bit coding.

FIGURE 3 gives the performance specifications, FIGURE 4(A) the frequency response, FIGURE 4(B) the distortion characteristics, and FIGURE 5 shows the changes in the amplitude of a 20 kHz sine wave. In an analog recorder, the high-frequency playback output is subject to variations in level due to varying degrees of contact between the tape surface and the heads. This is completely absent in the PCM recorder.

By incorporating a buffer memory in the playback circuit, the effects of wow and flutter are eliminated. In a PCM recorder, wow and flutter is no more than the "inaccuracy" of the quartz-crystal oscillator clock. This means that a one-hour recording program will play back over precisely the same length of time, to within the order of one milli-second.

Dubbing is performed with the digital signal itself, so that there is very little degradation of the signal. Even after 40 or 50 repeated dubbings, there is no detectable change. The reproduced sound is also free of print-through, and no ghosts are left after erasure. There is negligible crosstalk, and no difference between the characteristics of the left- and right-hand channels. These are advantages of a very high order indeed.

(For more on PCM, see **Digital Modulation For High-Quality Audio**, in the June, 1978 **db**—Ed.)

Figure 3. Performance specifications of fixed-head PCM recording deck.

Dynamic range	Better than 90 dB
Frequency response	10 Hz-20 kHz (±0.5dB)
Total distortion	0.02% (at peak level)
Crosstalk	-85dB (1 kHz)
Wow and flutter	Only limited by quartz-crystal oscillator
Playback signal level variation	None
Print through	None
Residual level after erasure	None

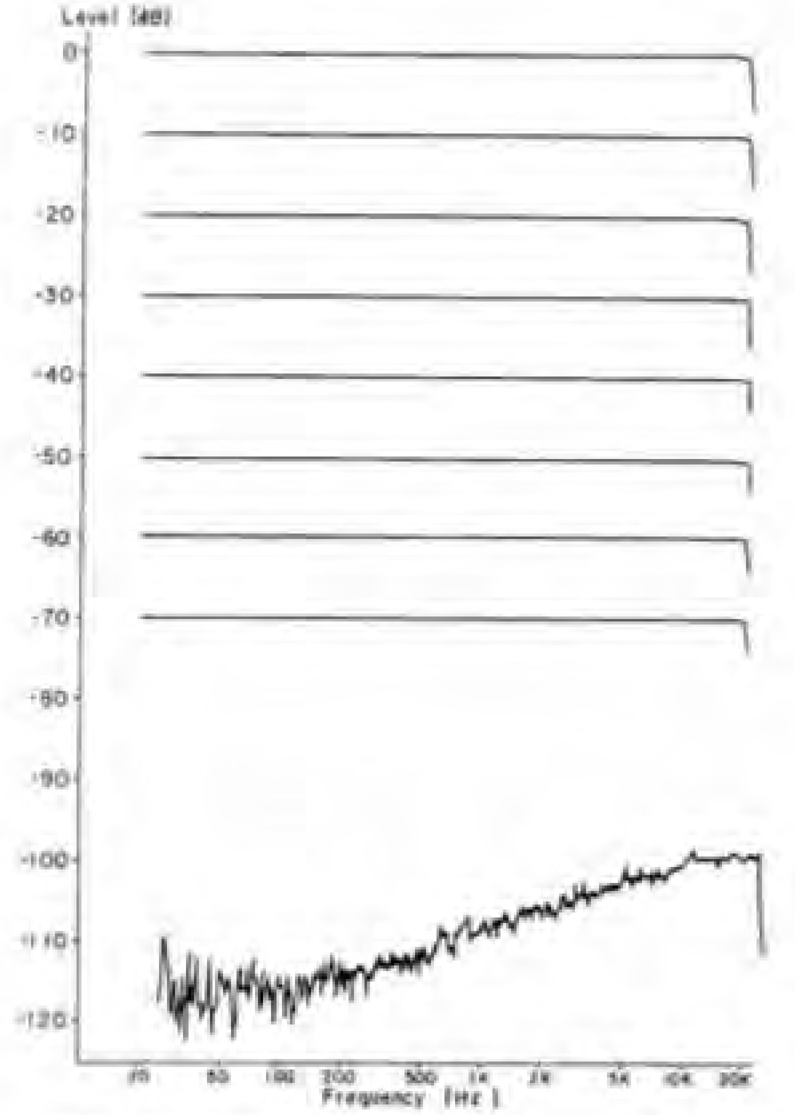


Figure 4(A). Frequency response.

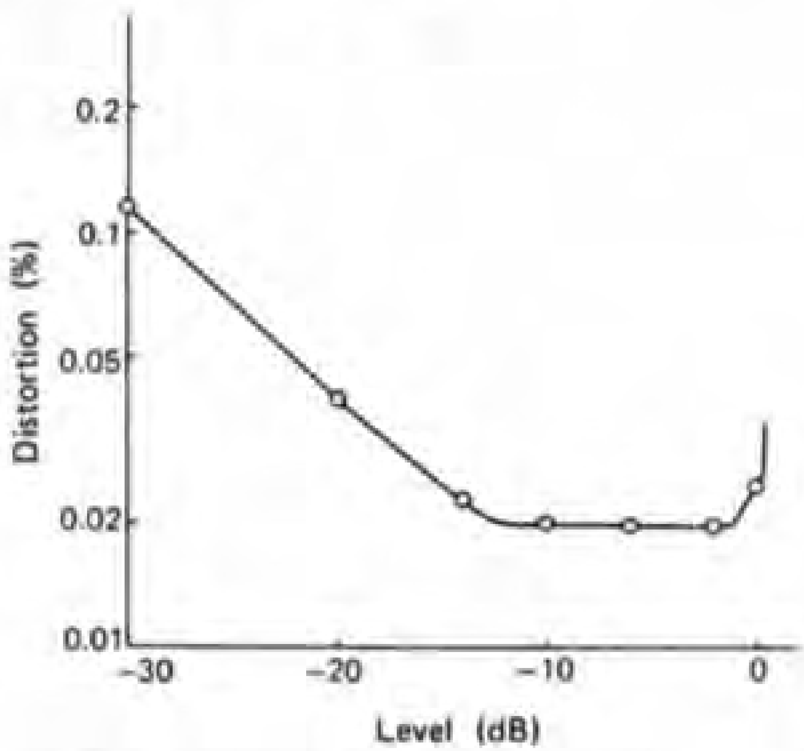
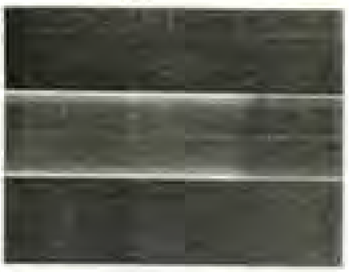


Figure 4(B). Output level distortion characteristics.



(A) Analog recorder (B) PCM recorder

Figure 5. Amplitude fluctuation.

WHAT KINDS OF PCM RECORDING AND PLAYBACK EQUIPMENT ARE CURRENTLY AVAILABLE?

PCM recording and playback equipment may be divided into PCM decks for recording, and digital audio disc equipment (the latter corresponding to conventional analog audio discs). PCM recording decks may be further subdivided into fixed-head and rotating-head equipment. The features of the fixed-head and rotating-head equipment are given in FIGURE 6. The fixed-head types are suitable for professional use, and the rotating-head types, because of the comparative simplicity of the circuitry used, are more suitable for domestic use.

FIXED-HEAD PCM RECORDING DECK

FIGURE 7 shows the external appearance of a two-channel professional recording deck. Specifications are listed in FIGURE 8.[1] As is clear from the photograph, it is similar in appearance to current analog decks. It offers simultaneous monitoring and tape-cut editing functions, and can be operated in virtually the same way as a conventional analog deck. The choice of a tape speed of 38 cm/sec. (15 in/sec.) means that, for audio channels, the PCM signal must be distributed between eight tracks. This keeps the recording density along each track at some 20 kbit/inch.

(For more on PCM track formats, see **A Proposed Digital Audio Format,** in the November, 1978 **db**—Ed.) Errors originating in the tape will generally affect some 100 to 200 bits of data along a signal track. However, the use of multi-track recording means such errors are distributed more-or-less randomly along each track, so that the addition of an error-correction code across the width of the tape is highly effective for correcting errors. This deck uses a Reed-Solomon error correction code across the width of the tape, with a cyclic-redundancy check along the length of the tape. The extremely powerful error-correction utilized in this deck ensures uniformly high performance as follows:

1. Even if one track fails, almost all error signals are corrected with no resultant deterioration in the quality of the reproduced sound.

Figure 6. A comparison of fixed- and rotating-head decks.

Rotating-head type	Fixed-head type
+ High recording densities possible	+ Splice editing possible
+ Can be compact	+ Error correction using multi-track feature
+ Few circuit elements	+ Little operating noise
− High operating noise level	+ Fast duplication possible
− Fast duplication difficult	+ SIM.SYNC possible
− SIM.SYNC difficult	− Current models have many circuit elements
− Some equipment has slow start-up	− Currently high price

Note: a "+" indicates an advantage, a "−", a disadvantage.

Figure 7. Two channel fixed-head PCM recording deck.

Sampling frequency	50.349645714 kHz
Bit number	16 bits (linear)
Recording tracks	8 PCM (= 2 audio) 1 Auxiliary analog 1 SMPTE
Recording bit density	797 bit/mm (20240 bpi)
Tape speed	38.1 cm/sec (15 in/sec)
Magnetic tape	6.3 mm high-density tape

Figure 8. Specifications for a two channel fixed-head PCM recording deck.

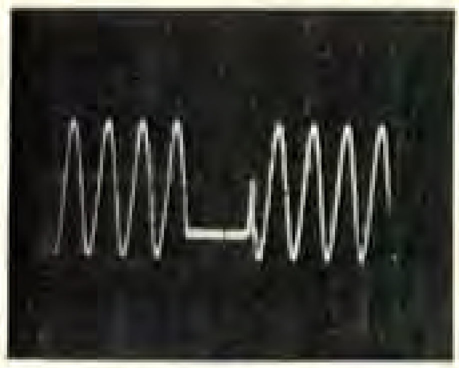


Figure 10(A). Zeroth order extrapolation.

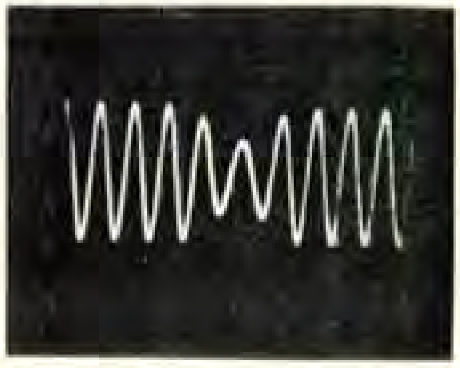


Figure 10(B). Cross fading.

2. Even when errors are too numerous for correction, error concealment by interpolation is performed. Computer simulation studies indicate that with the usual type of tape in normal use, the need for error concealment should only arise about once a year, and that it would be about 10,000 years before this could be expected to give rise to audible noise!
3. Even with tape-cut editing and splicing, the errors associated with the splice will be corrected.

There are two methods of editing recordings made with PCM recording decks: the tape-cut editing that is used with conventional analog decks, and the electronic editing that has become possible for the first time with the introduction of PCM equipment. The comparative advantages and disadvantages of these two methods are listed in FIGURE 9.

The method of tape-cut editing employed in this PCM deck is almost identical with that used for current analog equipment. There is no need to "develop" the recorded pattern as with, for example, the Quadraplex video tape recorder. FIGURE 10A shows an example of zeroth order extrapolation at the splice, and FIGURE 10(B) shows the join achieved with cross-fading. Our deck naturally uses the latter.

FIGURE 11 shows an electronic editor with automatic editing facilities. It controls one recording deck and three playback decks, so as to store instructions for 99 different editing points that are edited automatically in succession.

Figure 9. Comparison between tape-cut editing and electronic editing.

Item	Electronic Editing	Tape-Cut Editing
Method	To copy original tape selectively to slave tape.	To cut tapes physically and splice them with splicing tape.
Equipment needed	Two or three PCM recorders and editing adapter.	One PCM recorder and splicing block.
Editing time required for one hour program	One hour + time required for editing procedure times number of edits.	Time required for editing procedure, times number of edit.
Readjustment of sound quality	Possible	Impossible
Technique needed	Editing is performed by pushing button.	Identical to the analog type.

ROTATING-HEAD PCM RECORDING DECK

The Electronic Industries Association of Japan, in order to stimulate the distribution of PCM recorders for home use, produced standards designed to ensure the interchangeability of PCM recording equipment based on the use of VCRs, in June of 1979. The time of home PCM recording equipment is rapidly approaching. FIGURE 12 shows a PCM adaptor[3] which conforms to the EIAJ standards, and FIGURE 13 lists the specifications.

For this adaptor to become popular, prerecorded cassettes must become available. If the master recordings for these cassettes are prepared on the professional PCM deck introduced above, the difference in the sampling frequencies means

Figure 11. Electronic editor.

Figure 12. PCM adapter.

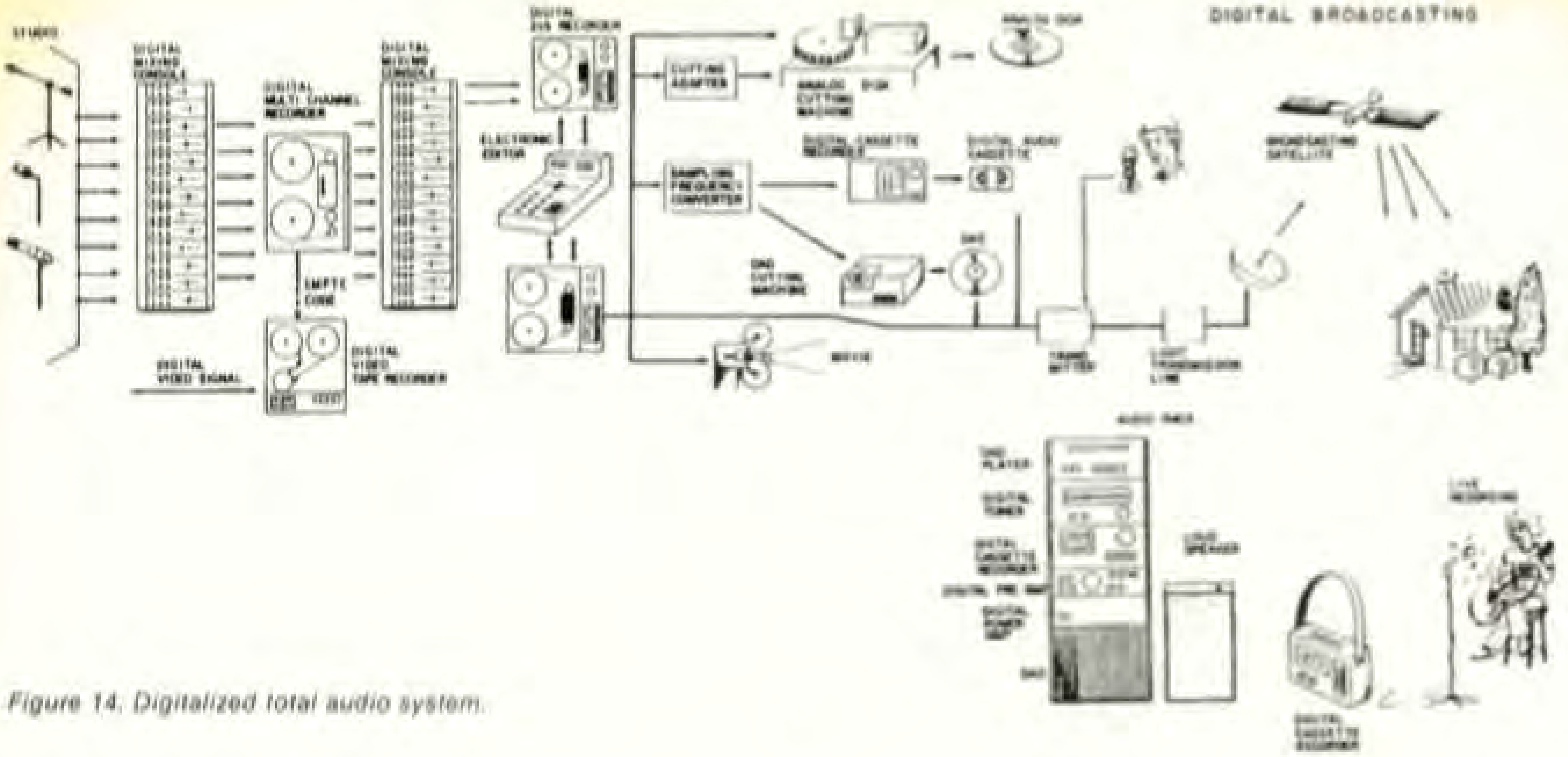


Figure 14. Digitalized total audio system.

Sampling Frequency	44.056 kHz
Transmission Rate	2.643 Mbps
Quantization (Both Encoder and Decoder)	D-I: 3 segment 12 bit companding D-IL: 14 bit linear
Wow and Flutter	Undetectable
Dropout Compensation	Correction by interleaved b-Adjacent error correction code with CRC
Signal Format	Based on the EIAJ Technical File STC-007
Conforming VTRs	VHS, β, U etc.

Figure 13. Specifications of PCM adapter.

that the digital signal cannot be dubbed as is, but must be converted back to an analog signal before dubbing, with an unavoidable slight loss of quality. However, if a sampling frequency converter is connected, the output supplies a signal in the video format, with the 44.056 kHz sampling frequency, and can be recorded as it is for VCRs.

FUTURE PROSPECTS FOR PCM IN AUDIO ENGINEERING

In addition to the above equipment, Mitsubishi Electric is also developing a multichannel fixed-head PCM recording deck, and tentative specifications include the use of 25.4mm (1-inch) tape moving at 76 cm/sec. (30 in/sec.), and giving 32 audio channels. We are directing our efforts at the development of a total audio system based on PCM technology, and are pursuing an active research and development program. The underlying concept of the total audio system is as shown in FIGURE 14, involving conversion of the signal from the microphone into a PCM signal so that mixing, recording, transmission, etc., will eventually result in reproduction of the very highest quality from the speaker system. ■

REFERENCES

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2. T. Inoue, "Comparison of Performances Between IPC Cord and RSC Code When Applied to PCM Tape Recorders," Preprint of AES 1541 (H-5), 1979.
3. Yoshinobu Ishida et al, "A PCM Digital Audio Processor for Home Use VTRs," Preprint of AES 1528 (G-6), 1979.

ROBERT J. YOUNGQUIST

Electronic Digital Editing For Multi-track Comes of Age

With digital recording comes the requirement for a new method of editing. Electronic editing now available for this purpose offers something more than just a replacement for the cut-and-splice technique of analog.

It was just a year ago this month that recording studios began installing 3M's 32-track digital mastering system. But even before those historic first deliveries, it had become obvious that an electronic editing system was needed, not only to advance the state-of-the-art, but to protect the data recorded on the digital tapes. As artists, producers and engineers began recording digitally, it soon became clear that studio acceptance and day-to-day use of the new digital recording technology could not be expected, until a viable editing system was made available. As converts to the multiple benefits of digital recording, studios wanted to preserve the full quality of their tapes by avoiding the transfer to analog for conventional editing.

Today, an electronic digital editing system is available which offers—according to those who used and critically evaluated the preproduction prototype—exceptional precision, risk-free preview capability, splice-free masters, digital's lack of degradation throughout the process, plus a new vista for editing creativity.

DEVELOPMENT OF THE SYSTEM

Initially, 3M contracted ITX to help it develop a system. At the Winter '78 Audio Engineering Society convention, a preliminary prototype of a deluxe automated system was shown which incorporates a graphic video representation of the music to verify those points that, in theory, are most suitable for editing. Work on this system, however, was later set aside in favor of a much simpler, easier-to-use system developed in 3M's St. Paul laboratory. A working prototype of this second system was completed late last summer.

This latter unit took into account studio preference for an editing system whose operation would be relatively simple and easily learned. The system also needed to be of compact size, feature semi-automatic edit-point cueing and fine tuning for smooth transitions, be of reasonable cost and adaptable to possible future options.

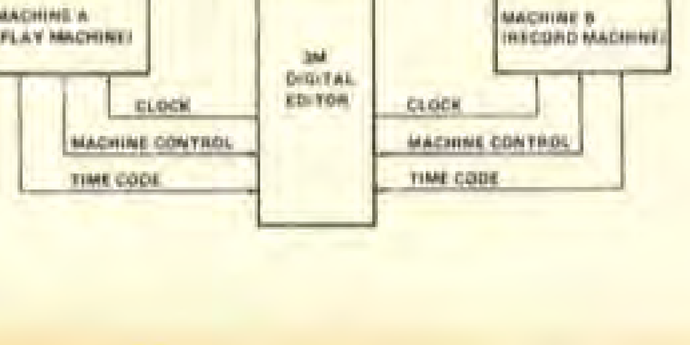
The prototype was employed in several major projects during the fall, to permit some critical field evaluation and constructive user-feedback. As a result, a number of refinements were made, primarily involving the human interface. Control functions were combined, repositioned and relabeled to make identification of the contents and their operation more convenient and natural. This streamlining also had the side benefits of making size reduction of the console possible and reducing its basic cost.

DESCRIPTION OF THE SYSTEM

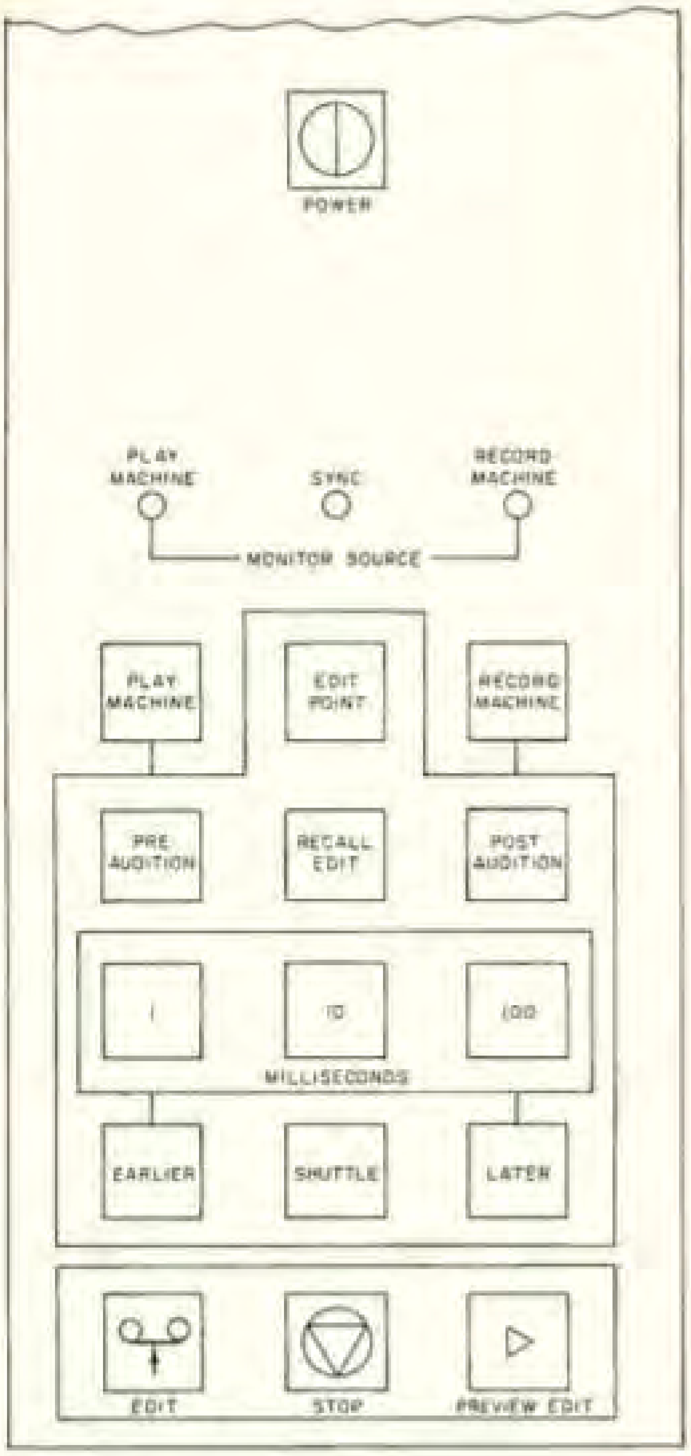
Digital editing has a number of advantages over the traditional razor blade-and-splicing-tape editing necessary with analog masters. The most obvious one is that, with electronic editing, the original tapes remain physically unaltered, so their structural integrity is never compromised by potential physical or magnetic damage.

But, perhaps more importantly in the view of the producer is the ability to select tentative edit points, and preview them repeatedly, separately or as the proposed edit. Any edit point may be refined by moving it in either direction as little as one-thousandth of a second. Then, the final aesthetic choice of an edit-point may be executed upon command of a single button.

Digital editor block diagram.



Robert J. Youngquist is the research manager responsible for the development of digital audio equipment in 3M's Mincom Division, St. Paul, MN.



3M's digital editor control panel.

3M 32- and 4-track digital mastering system.

This precise and easy control is in part achieved by the microprocessor, the miniature dedicated-computer system or the brain, that performs the logic and a number of housekeeping chores on behalf of the operator.

The key to electronic editing is a time code—the mileposts, if you will—recorded on one track of both recorders. This code, laid down automatically during recording, writes a 24-digit binary number every 320 microseconds; thus, every three-ten thousandths of a second, there's an electronically identifiable location on the tape.

As the tapes are reviewed for potential edit points, the time code is constantly monitored by the editor's circuitry. When the human editor punches the Edit Point button for the machine he's monitoring, the time code number is captured and stored, ready for reference.

The tape adjacent to each edit point can be auditioned as many times as desired, before finalizing the edit. Use of the Shuttle button with either Pre-Audition or Post-Audition continually shuttles the selected segment through a two second sequence, muting the sound either before or after the edit point, as appropriate. Activation of the Edit Recall button alone recalls the last edit made on the play or record machine.

At this stage, it is quite likely that the producer will want to move one or both edit points slightly; it's easily done, forward or backward, in increments of 1, 3, 10, 30 or 100 milliseconds. For this operation, the producer commands the direction with either the Earlier or Later button, then the time through one, or a combination, of the time commands. For example, pressing the one-millisecond button three times moves the tape a distance equivalent to three milliseconds in the designated direction. However, this may be shortcut, because pushing the 1 and 10 buttons simultaneously will also move the edit point three milliseconds. Likewise, pushing the 10 and 100 millisecond buttons simultaneously results in a 30-millisecond move.

When both edit points are thought to be final, the edit can be previewed in full by punching the Preview Edit button, which causes both tape machines to rewind to a point ten seconds before the selected edit point. Then, the record machine plays back the first take to the edit point, where it mutes its sound, while the music is heard starting from the second edit point on the tape of the play machine. These segments of the two tapes will shuttle back and forth across the edit point in sync without the actual edit being recorded. Each time, the producer hears how the final edit will sound.

If satisfactory, then all that remains is to push the Edit button. This also starts the recorders 10 seconds before the edit point; where the point is reached, the record machine is automatically put into the recording mode and the dubbing begins. When the end of the second take is reached, the Stop button halts the tape motion of both machines and the next source can be cued up.

Obviously, there is a transition from the old to new program data at the edit point. The error-correcting method which permits the 3M mastering system to record 32 tracks on a one-inch tape has been designed so that the signal transition can be smoothly accomplished. If at a later time, an error (drop-out) were to develop at this location, however, it is conceivable that incorrect reconstruction would occur, since some of the non-adjacent error-correcting data has been removed by the edit.

To avoid this remote possibility, it is recommended that the completed master tape be digitally dubbed. This will recreate new error-correction data for all program material.

Block diagram of 3M's digital preview system.

EXPERIENCE

At the time of this writing, studio experience has involved the prototype unit, with the exception of continuous demonstrations of the first production unit during the most recent Winter AES. The applications were varied, involving several major popular and classical music projects. The editor was used to edit prior to mix-down—16 track to 16 track—and during mix-down of a Columbia Masterworks album. It was also used during a 32 to 2-track mix-down of a tune at Sound 80, Minneapolis, and for editing after mix-down of a single and an album at Record Plant, Los Angeles.

Reactions of producers and engineers who used the system were positive. They collectively concurred that, while proficiency naturally increased with familiarity and practice, electronic editing didn't require learning a new technology. As with analog, the editing job still consists primarily of artistic organization of takes, selection of edit points and decisions as to the other creative criteria by the professional's ear.

Rather than paraphrase user comments, it is perhaps more informative to discuss specific applications and include their exact comments.

The first user was Andrew Kazdin, producer of a Columbia Masterworks recording of the New York Philharmonic Orchestra playing "Petrouchka," conducted by Zubin Mehta. After recording the work at New York's Avery Fisher Hall, on 16 of the digital pre-mix machine's 32 tracks (with the other 16 tracks used as backup), Kazdin awaited completion of the editing equipment.

The prototype editor was used for fine-editing work before and during mix-down. What was his reaction? "Electronic editing offers additional creative flexibility and potential. It wouldn't be honest to say it was all easy; however. As a new technique involving unfamiliar equipment, there were obviously certain things to learn and explore.

Seated before a portable mixing console and a prototype of 3M's electronic digital editing system (foreground) is Andrew Kazdin, producer of a New York Philharmonic Orchestra recording. The editor, since refined as production equipment, was used during a multi-track editing session at 3M's St. Paul research facility. Bob Youngquist observes.

"For instance, I was a bit surprised to discover that some edits, that would have been relatively easy conventionally, were a bit more difficult to achieve in the digital domain. But, conversely, many that would have been difficult or impossible in analog were made with relative ease. This all points out that this is a new technique with some similar and different capabilities," Kazdin said.

Kazdin went on to comment upon digital in general, as he had not heard the "Petrouchka" tapes since a brief playback at the recording sessions. He indicated that reviewing the tapes reconfirmed digital's unexcelled sound purity, and the absence of noise and distortion. The absence of wow and flutter was a particularly notable benefit on stringed passages.

Herb Pilhofer, composer/musician/producer and principal of Sound 80, Minneapolis, referred to electronic digital editing after his brief experience with it as "more than just a substitute for cutting and splicing." In fact, he noted with surprise, "It becomes a very-useful musical tool. We wanted to overlap certain sections and to make some fairly-precise edits of a musical nature where I would usually hesitate to do that with a blade. The ability to rehearse edits and sample the results of an edit in several locations is a new luxury."

Pilhofer said, "I see a trend; electronic editing opens up some new avenues for music production not before feasible, and I predict that a lot of things are made possible for which we haven't yet found any practical application."

His viewpoint was echoed by Scott Rivard, producer and chief engineer of Sound 80, who used the editing system during mix-down. "We were assembling some very complicated mixes on the 4-track and the editor allowed us to do this very effectively." He also indicated that he was able to use the system after very little practice, although real proficiency came later.

At Record Plant, engineer Mike Stone began his sequence for the Bonnie Pointer editing sessions following mix-down, using the 4-track master recorder as the playback source. Assembly then took place on two tracks of the 32-track pre-mix machine. After the assembly was complete, the recorder's roles were reversed; the tape was played back by the 32-track recorder for one continuous dub onto the 4-track unit. As the 4-track recorded the program material, it also automatically generated new error-correcting parity code blocks to protect against possible future dropouts at edit locations.

Stone used a metronome to sync the performance on individual tracks. Because of that perfect tempo, he could feel when very slight timing adjustments were necessary. "Since we could adjust in milliseconds, we could get exactly what we wanted—and you can't get that kind of accuracy with analog editing." Stone also felt it was relatively easy to learn digital editing. "If you have a good feel for punching in, your proficiency can develop fairly readily," he said. He added that he feels a practiced engineer can soon learn to edit digitally as rapidly as he can in analog—and, of course, with more precision.

The two tracks were then used to feed the new, optional 3M Digital Preview Unit, which digitally delays program material to the cutting lathe by a selected amount (from 5 milliseconds up to 1.96 seconds). The undelayed signal is fed to the automatic pitch-control mechanism and the delayed signal to the lathe cutting head. Since the signal is digitally delayed, no loss of quality occurs.

SUMMARY

As a result of the field experience and refinements thus incorporated, production editing equipment is now installed in studios for use on a day-to-day basis. This fills in the missing link critical to the ultimate viability of digital recording for many producer and artist groups.

In the process of creating this editing system, we have learned of additional studio needs and have begun development work in some of these areas. One of these may be a cross-fade option; a prototype of this is just about ready for evaluation. And, with the enthusiasm toward digital production techniques increasing and 3M's commitment to make conversion to digital complete, there is even more to come. ■