The Fox Movietone News Preservation Project: Electronics

By Gerry G. Taylor and Graeme Little

This paper describes the electronics package that controls the camera, synchronizes the projector, digitizes and formats the video and audio information, and provides both high-resolution and 525/60 or 625/50 format outputs.

When this Fox Movietone News Preservation Project began, there was no standard for converting film images in real time to a digital data format at the required resolution. The system format was largely determined by the availability of a Kodak high-resolution, black-and-white charge-coupled device (CCD) camera capable of the 24 frame/sec frame rate and strobe shuttering requirements.

To preserve as much of the original image quality as practical it was decided to digitize the camera output with 10-bit resolution. This results in a 250 Mbit/sec serial digital data rate. Fortunately, digital data tape machines (ID-1 format) capable of recording 256 Mbits/sec were available, allowing the audio and identification information to be embedded in the data stream along with the image data.

Scanner System

The complete system, as shown in Fig. 1, consists of the film transport mechanism, camera, strobe illumination, sound head, input processor, digital tape recorder, and output processor. The film is moved past the camera and strobe at a constant velocity equivalent to a 24 frame/sec exposure time. The film transport servo is locked to a 24-Hz reference supplied by the input processor. The strobe system optically senses the sprocket holes in the film and fires on every fourth hole. The phase of the 24-Hz reference from the input processor is such that the strobe fires during the open shutter period of the camera. The camera takes about 32 msec to output a frame of data so the shutter remains open for about 9 msec, during which time the strobe may fire.

The CCD sensor used in the camera uses a square pixel 1024 x 1024 array; the film is projected onto the sensor using an anamorphic lens to convert from the 4:3 aspect ratio of the film to the 1:1 ratio of the sensor. The CCD is an interline device that outputs two adjacent lines simultaneously. The dual analog image outputs and the sound signal are fed to the input processor for digitizing and formatting. The output from the input processor is fed to the digital tape machine and the output processor to provide an electronic-to-electronic (E-E) feed. The output processor provides a 1024 x 1024 image in an 1124-line, 48-Hz format for monitoring purposes. This output can also be used to make kinescope recordings. A second analog output provides a user-selectable 525/60 or 625/50 composite monochrome format.

Data Format

The data format of the ID-1 digital data machine at 256 Mbits/sec consists of 8-bit bytes at a 32-MHz clock rate. The camera resolution is 1024 x 1024 pixels, and the camera output is digitized by the electronics package to 10 bits at 20 MHz (the camera clock rate). Since the projector output is at 24 frames/sec none of the existing digital video formats were exactly compatible; therefore, a new format was developed to optimize the interface between the projector, the camera, and the recording machine. This format is shown in Fig. 2 and described below.

Each frame of data consists of 1024 lines, each containing 1024 ten-bit pixels, two 16-bit audio words, and synchronizing data. The first line of each frame contains an identification code in place of the video information. Each line consists of a total of 1302 eight-bit bytes, starting with a sync

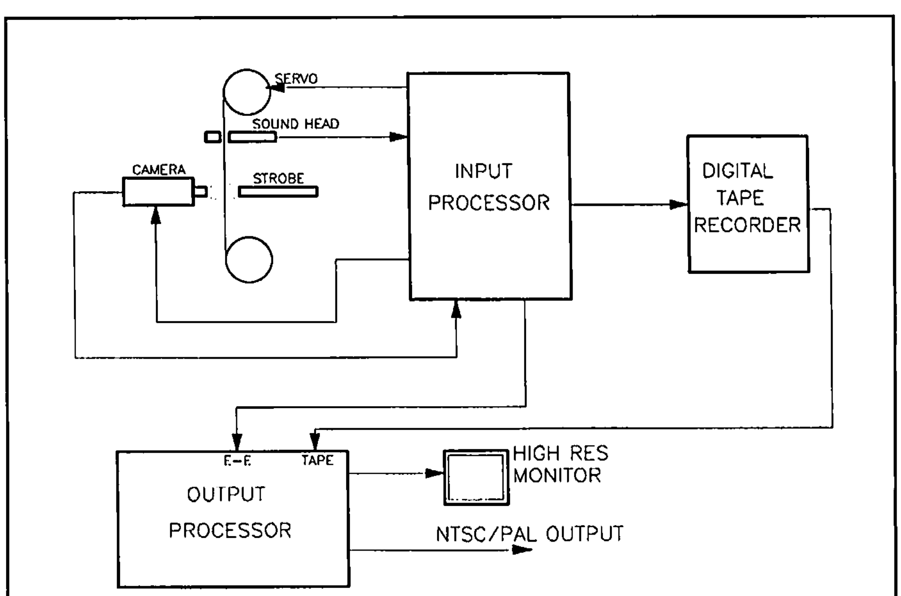

Figure 1. The Fox Movietone restoration system.

A contribution received from Gerry G. Taylor, Questel, Inc., Grass Valley, CA 95945; and Graeme Little, Graeme Little Design, Nevada City, CA 95959.

BYTE 0	BYTE 1	BYTE 2	BYTE 3	BYTE 4	BYTE 5	BYTE 6	BYTE 7	BYTE 8	BYTE 9	BYTE 10	BYTE 11	BYTE 12	BYTE 13	BYTE 14	BYTE 15	BYTE 16	BYTE 17	BYTE 18	BYTE 19	BYTE 20
SYNC	SYNC	SYNC	SYNC	SYNC	SYNC	HDR	UNU	AUDM	AUDM	AUDL	AUDL	AUDM	AUDM	AUDL	AUDL	UNU	VIDM	VIDM	VIDM	VIDM

BYTE 21	BYTE 22	BYTE 23	BYTE 24	BYTE 25	BYTE 26	BYTE 27	BYTE 28	----------	BYTE 1286	BYTE 1287	BYTE 1288	BYTE 1289	BYTE 1290	BYTE 1291
VIDL	VIDM	VIDM	VIDM	VIDM	VIDL	VIDM	VIDM		VIDM	VIDM	VIDM	VIDM	VIDL	-

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SYNC - DATA = 0
HDR  - DATA = CCH        HORIZONTAL SYNC
       DATA = 0FH        VERTICAL (LINE 0) SYNC

AUDM - DATA = MSB OF AUDIO WORD
AUDL - DATA = LSB OF AUDIO WORD

VIDM - DATA = MSB OF VIDEO WORD
VIDL - DATA = LSB'S OF PREVIOUS FOUR VIDEO WORDS
              FIRST WORD IN LSB, LAST WORD IN MSB
UNU - UNUSED AT THIS TIME
```

Figure 2. FMTR data format.

interval consisting of 6 zero bytes (00H). Both the audio and video signals are limited in the negative direction at a data level of one (01H), so that a string of zeroes does not occur during the active part of the line.

The audio information is recorded in offset binary instead of the more usual two's complement format in order to avoid clipping the zero crossings. The 6 sync bytes are followed by a header byte that identifies the following line as containing either video or identification information. The next byte is unused at present. The next 8 bytes represent the audio information. The 16-bit audio data is formatted into two 8-bit words, each of which is repeated to form 8 bytes. This allows for a second audio channel, should it become necessary. The next byte is unused. The audio information is followed by the 10-bit video information formatted into blocks of 5 bytes, the first four of which represent the most significant eight bits and the last representing the least significant 2 bits of the previous four 10-bit words.

The first line of each frame contains the same sync and audio patterns and a different header, followed by the identification block. This block consists of 10 double bytes of straight ASCII data. The bytes are doubled to ease the timing constraints on the identification code generator.

No error correction information is contained in the data stream. Since the tape recorder is located adjacent to the electronics package and implements its own error correction, further correction was considered unnecessary. Also, as the tape format has adequate storage capability to handle the 1024 x 1024, 10-bit image, no compression is used.

Input Processor

The input processor (Fig. 3) contains the master timing generator, the video input processor, the audio input processor, and the identification code generator.

Timing

The master timing generator contains the 32-MHz master clock from which all other timing signals are generated. It provides a 24-Hz reference for the projector and time code generator and a shutter control signal for the camera. The master timing generator also provides all of the timing signals necessary for the video, audio, and identification code multiplexing. A 525/60 sync signal is provided for locking external time code generators requiring composite sync inputs.

Input Video

To achieve the required pixel rate the Kodak camera uses a CCD, which outputs simultaneous line pairs at a 20-MHz rate on two separate channels. The video input processor consists of two clamped, adjustable gain video channels, each followed by an anti-aliasing filter and a 10-bit analog-to-digital (A/D) converter. The line pairs from the A/D converters are fed to a frame buffer, where they are subsequently clocked out sequentially by the 32-MHz clock. The frame buffer output is fed to an image flip circuit that inverts the image horizontally to correct for the fact that the image is being projected directly onto the sensor rather than viewed on a reflective medium.

The corrected image data is then connected to a Normal/Invert circuit that inverts the video when recording negative film. This circuit also limits the negative excursion of the 10-bit data to exclude all-zero (00H) data.

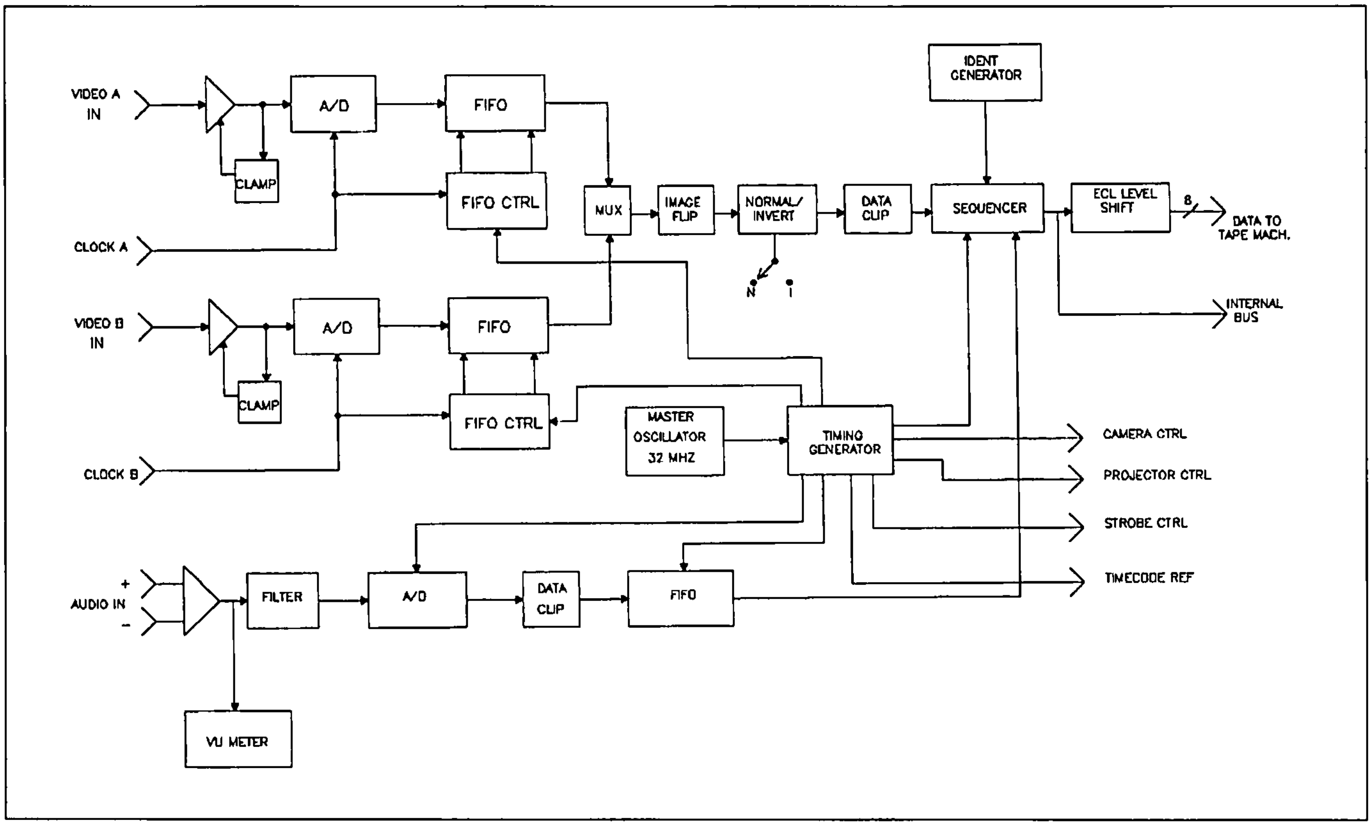

Figure 3. The input processor.

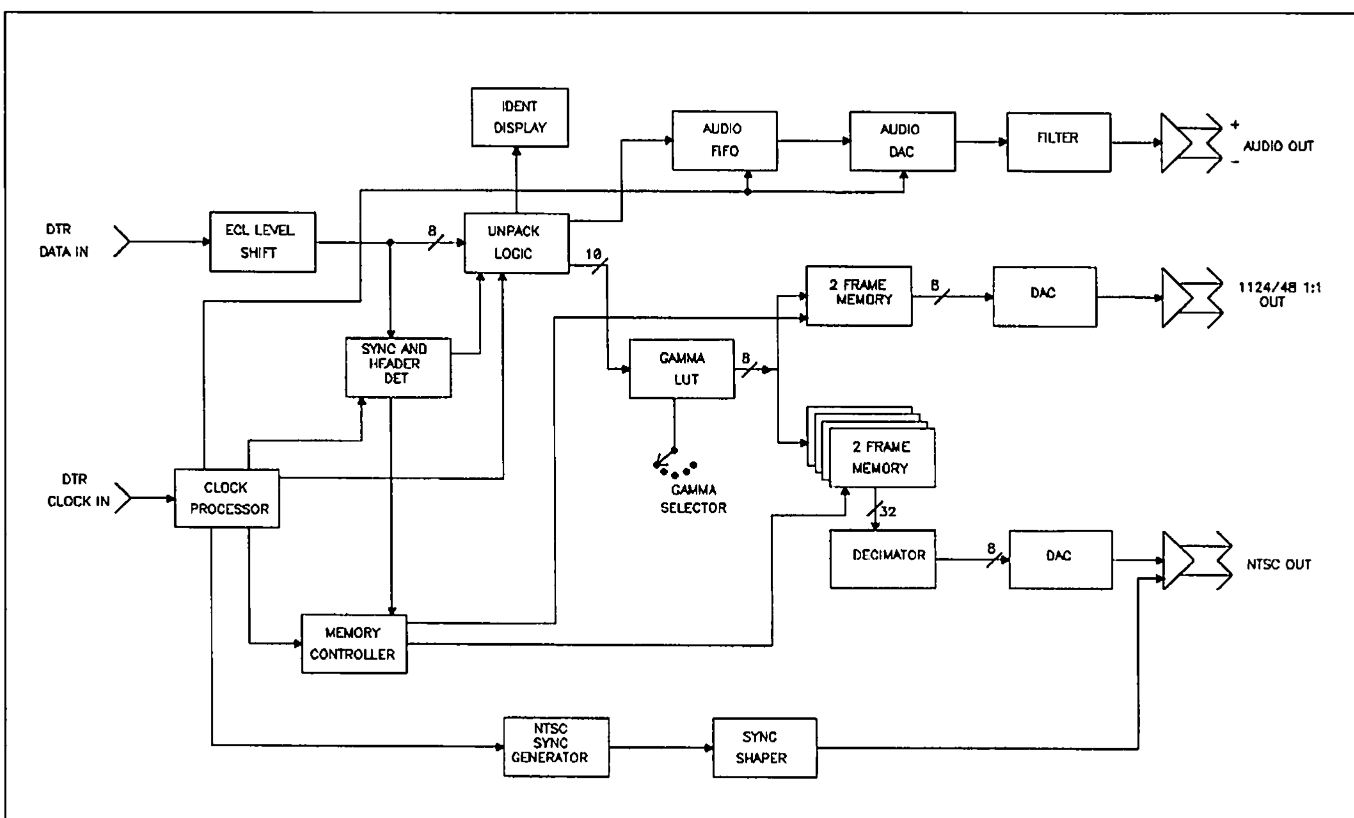

Figure 4. The output processor.

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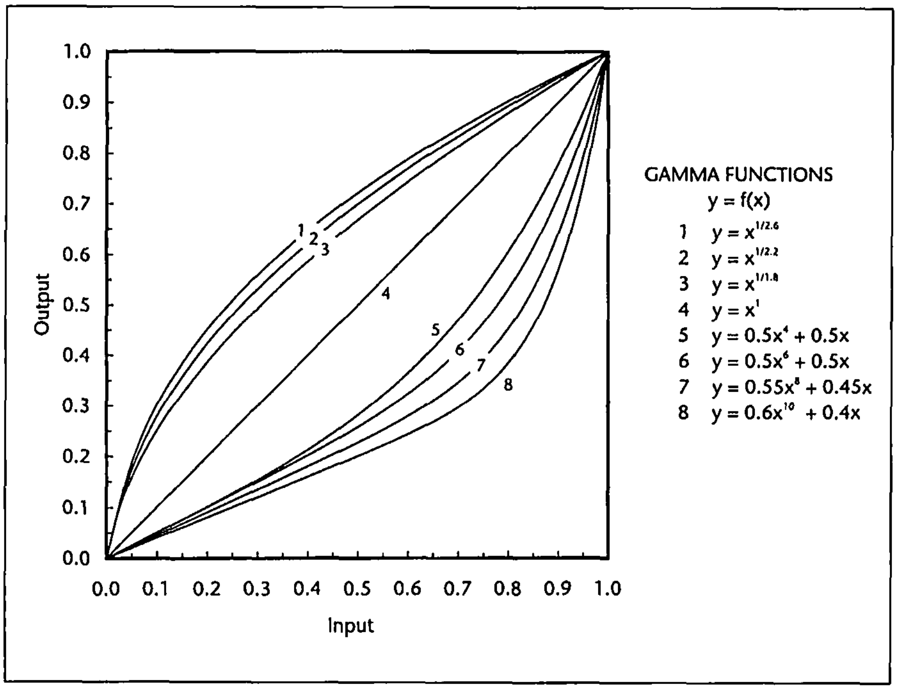


Figure 5. Curves for gamma functions, including curves for negative film.

The two least significant bits (LSBs) are then stripped off the 10-bit image data and packed into the fifth byte of the video sequence. The video stream is then combined with sync, header, and identification code information and provided as an output to the tape machines, together with the 32-MHz clock reference.

Input Audio

Because of the limited audio quality of the film material it was decided to use 16 bits to digitize the audio in this version of the system. However, extra bytes were made available in the format to accommodate 24-bit audio.

Although the format can accommodate 48-kHz audio it was decided to simplify the audio buffering by storing exactly two samples on every line resulting in a 49.152-kHz audio clock rate. This avoids having to store a whole frame of audio on both input and output processors and also simplifies the clocking.

Audio from the projector is first filtered by a six-pole Butterworth filter with a 15-kHz cut-off frequency. This combination was chosen to provide optimum performance with the limited spectrum of the input signal. The filtered audio is then digitized by a 16-bit A/D converter at the 49.15-kHz clock rate. The converter is sampled twice per video line and the information stored in a buffer to be output at the appropriate time to be multiplexed into the data stream. Input level monitoring is provided with both volume unit (VU) and peak program meter (PPM) characteristics.

Identification Code Generator

Media identification information is provided by the identification code generator, which consists of a microprocessor and first-in, first-out (FIFO) buffer. The ten-character media identification code is entered, either from a keypad on the front panel or remotely via an RS-232 port. The microprocessor writes this identification data to the FIFO buffer, where it is subsequently clocked into the data stream by the video board during the first line of each frame.

Output Processor

The output processor (Fig. 4) contains the desequencing logic, the audio output processor, the 1124/48 output processor, the NTSC output processor, and the identification code reader. The desequencer monitors the data stream from the tape machine and extracts the clock and sync information. It then provides all of the timing information for the subsequent output functions including the desequencing of the video, audio, and identification code data.

Video Processing

The video data is extracted from the data stream and reformatted into 10-bit words. The data is then fed to the gamma correction look-up table (LUT), which provides a choice of eight gamma correction characteristics. The gamma curves are based on CCIR 709 and include curves for negative film (Fig. 5). The positive curves are slope limited to a gain of four to prevent excessive noise in black areas of the image. The negative curves are generated from a polynomial of the form $Y = aX^{\gamma} + bX$, where $a + b = 1$. These negative curves were chosen empirically to correct for the variations in transmittance characteristics of the film stock. The gamma corrector provides 8-bit output data to the two video output boards.

Monitoring Output

Output video monitoring is provided by the 1124-line, 48 frame/sec, high-speed video output system. The 24 frame/sec video data is stored in a dual frame buffer and read out at a 48 frame/sec rate to provide an 1124-line, 48-Hz vertical rate picture with a 64-MHz pixel rate. This output is normally connected to a high-resolution black-and-white monitor and can also be used for rerecording onto film.

525/625 Output Generation

The 525-line output is generated by storing the 24-Hz data in two frame buffers and reading them out in a 2:3 pulldown sequence. The 625/50 output is generated by playing back the data from a variable-speed machine running at a 25-Hz rate and then using a 2:2 pulldown sequence. The system can also accommodate film shot at 15 frames/sec by using a 4:4 pulldown sequence. The 1024 x 1024 image is scan-converted to produce either a 1024 x 575, 50-Hz (625-line) or 1024 x 485, 60-Hz (525-line) output image. The scan converter (Fig. 6) consists of a frame buffer memory, a decimator, a digital-to-analog (D/A) converter, and sync and blanking processing.

To facilitate the decimation process the frame buffer is divided into four

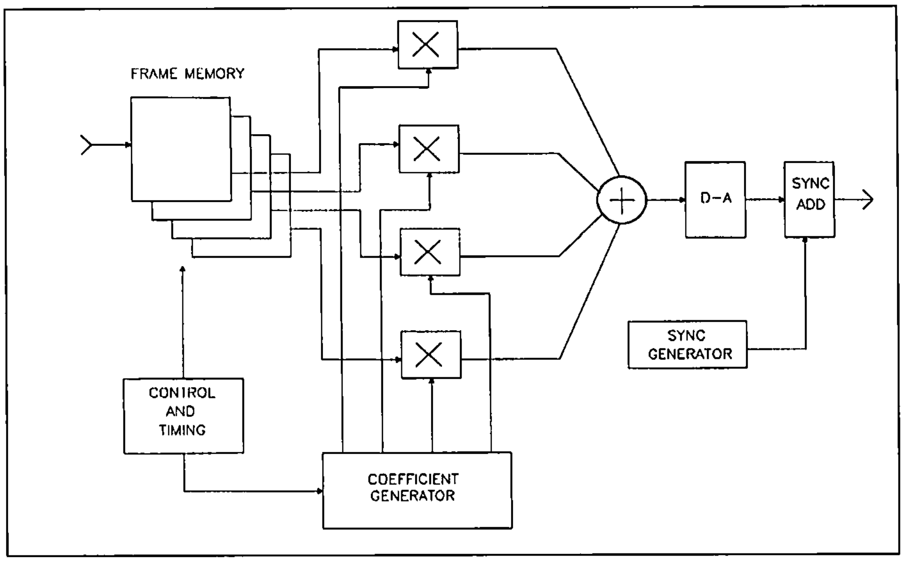


Figure 6. The scan converter.

planes. The incoming data stream is written into each memory plane one line at a time so that four lines may be simultaneously read into the decimator filter. Since there is not a simple integer relationship between the number of input lines and the number of output lines, it is necessary to continuously change the filter coefficients in the decimator. This is achieved by storing the coefficients in programmable read-only memory (PROM) and changing the PROM addresses on a line-by-line basis.

Since both the input and output frame rates and the input and output pixel rates are the same, it is only necessary to scan convert in the vertical (line-to-line) direction. As the input resolution is over twice the output resolution, it is possible to achieve very good results with a relatively simple filter. The memory control is somewhat more involved, since there is not a 4:1 relationship between the input lines and the output lines in each field and the line numbers need to track the rolling coefficients in the decimator. The decimator output is converted to analog by a D/A converter clocked at approximately 19 MHz. The analog video is then filtered and has sync and setup (525/60 only) added.

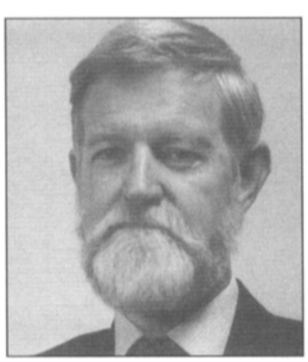
Output Audio

The audio signal is extracted from data stream by reversing the process used to embed it. The two audio samples at the start of each line are sampled and passed to a circular buffer that provides compensatory delay for the video delay through the frame buffers. The output of the circular buffer is clocked at the output data rate (49.152 kHz), which is exactly twice the line rate. The D/A converter output is filtered and fed to the audio output driver. Level monitoring is provided at this point.

Conclusion

This system provides a means of digitally archiving black-and-white film material, in real time, with a limited loss in resolution and dynamic range. The use of a standard data recorder avoided the necessity of designing a special-purpose recording machine. The simple data format allows easy translation of the archived data into other formats or rerecording onto film.

THE AUTHORS



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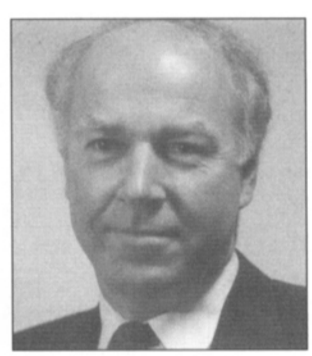

Graeme Little

Gerry Taylor is president of Questel, Inc., a Grass Valley, Calif., research and development company specializing in television product development. He was educated in the U.K., where he studied telecommunications engineering before joining the Independent Television Authority in 1961. He subsequently worked for the Canadian Broadcasting Corp. at its engineering facility in Montreal, where he was involved in the conversion of the CBC network to color in 1966. Taylor also worked as a staff engineer at the Grass Valley Group, where he participated in the design of various products, including the GVG 300 switcher. After leaving the Grass Valley Group, he started Questel, Inc., in 1983.

Graeme Little is president, Graeme Little Design, in Nevada City, Calif., which offers a range of audio, video, and control system design consulting services to the radio and television broadcasting and motion picture industries. Prior to starting his own company, Little held design engineering and engineering management positions at Central Dynamics, Ampex, Sony, and the Grass Valley Group. He has served on a number of SMPTE committees, most significantly T14.10 (Es-Bus), and is the author of several papers that appeared in the *SMPTE Journal.*