EXCEPTIONALLY HIGH-DENSITY DATA RECORDING

Digital recording on magnetic tape at unusually high data rates and packing densities has been achieved with transverse rotary-head recorders and a special FM recording mode. Data losses are greatly reduced through the use of 100% redundancy recording.

Designers of modern digital data systems have dramatically increased the capabilities of high-speed systems in the recent past to the point that tens of megabits per second are within the state of the art, and hundreds of megabits per second are within sight. The requirements of data processing problems have also increased, and increasingly larger volumes of data need to be handled and stored.

Transverse-scan rotary-head recording techniques, in use since 1956 and developed now to a high degree of perfection, are ideally suited to rise to the challenge of high data rate and high data density requirements. With the incorporation of a new technique, unusually-high bit reliability can be obtained.

ROTARY-HEAD RECORDING

Wideband rotary-head recorders for instrumentation are available with one or two wideband data channels, and one or two longitudinal channels for auxiliary data. Four magnetic heads mounted in quadrature around a rotating drum constitute one data channel. Another set of four heads, interspersed at 45° angles between the heads of the first set, provides a second data channel. In the two-channel case the speed of tape motion must be doubled, or the track width reduced to one-half, with respect to the single-channel case. Figure 1(a) shows the arrangement of heads on the drum, while Figure 1(b) shows the tracks on the tape for a two-channel machine.

The head-to-tape writing speed used for most instrumentation applications is approximately 1500 inches per second; recorders having up to twice the speed and as low as one hundredth of it have been built for special applications. The tape has a width of 2 inches, the track width is usually 0.010 inch, and the guard band between tracks is one-half or one-fourth of the track width. These parameters determine a tape speed of 15 or 12.5 inches per second for a single-channel machine.

Information signals are usually recorded in FM form.[1] Carrier frequencies of approximately 9 MHz are used, offering a data input bandwidth of 4.5 to 6 MHz, which is reproduced with a signal-to-noise ratio of 43 to 40 db (peak signal to rms noise). At normal writing speed of 1600 inches per second, the magnetic wavelength on tape of a carrier cycle is 180 microinches. Recent advances in head design have made possible the recording of approximately twice the above carrier frequency with twice the input data bandwidth.

In the reproduced process, electronic time-base correction brings the FM carrier from the four rotating heads, which make up one signal channel, very nearly in phase

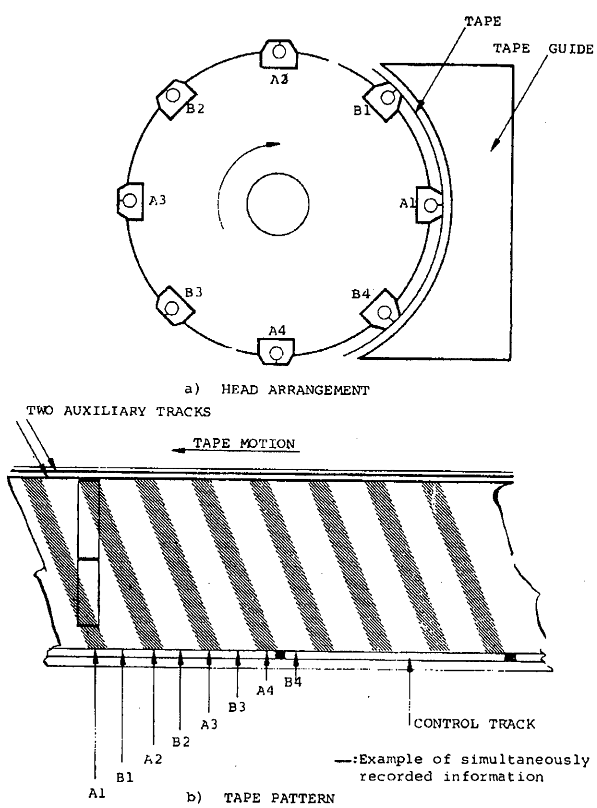

Fig. 1 Two-channel rotary-head recorder

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with each other so that a gradual switchover from one head signal to the following results in an uninterrupted FM carrier, thus making possible the detection of a completely continuous and transient-free data signal.[2] The introduction of rotary transformers to replace the sliprings and brushes, formerly used to couple the signals to and from the rotating heads, has greatly improved reliability and maintenance and has eliminated contact-failure transients.

Thirty-two of the new high-efficiency transducers can be mounted around the periphery of the head drum so that an eight-channel recorder with 10- to 12-MHz data-bandwidth per channel can be built.

HIGH BIT-RATE DIGITAL RECORDING

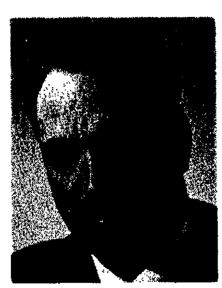
The input signal to the wideband channel(s) of a rotary-head instrumentation recorder can have any form which is compatible with the bandwidth and dynamic range of the recorder. It can consist of radar signals or telemetry signals either in detected or in predetection (but frequency-translated) form, or a television signal of any scanning format compatible with the recorder bandwidth. Alternatively, the input could be pulse trains representing digital data. If the digital signal is in a self-clocking format, there is no problem in recording the data asynchronously without relationship to the recording speed. If the data is coded in 3-level RZ, for instance, the recorder accepts, like any other information-carrying channel, a maximum serial bit rate equal to the bandwidth in Hertz, i.e., approximately 5.5 to 6 MHz in standard equipment, 10 to 12 MHz in advanced recorders.

The digital input signal is handled in the rotary-head system in the same fashion as analog pulse information is handled; after limiting the signal bandwidth to the specifications of the recorder by passing it through a low-pass filter, it frequency-modulates a carrier, which is recorded. After recovery of the carrier from the tape, an electronic time-base correction by means of a pilot signal which was frequency-multiplexed and recorded with the carrier, the signals from the four magnetic heads are sequentially recombined, limited, and demodulated. The resulting pulses are re-shaped into the desired form by reconstitution circuitry.

The transient-free and time-base-corrected rotary-head recorded offers a unique feature for the recording of serial NRZ data. An NRZ-coded signal can theoretically be transmitted at 2 bits per cycle of channel bandwidth, and a practical value which does not result in mutual interference of successive pulses is (bandwidth in Hz) = 0.6 x bit rate. Since the recorder contains a frequency standard and the reproduced information is time-base corrected with reference to this standard to within less than one-half bit period by way of the pilot signal, it follows that the frequency standard can serve as an error-free clock. In some cases, of course, it may be possible (or preferable) to synchronize the recorder from an external data clock.

An oscillogram is shown in Fig. 2 of a 10 MHz NRZ signal. Fig. 2(a) displays the input signal fed into an Ampex FR-900 rotary-head instrumentation recorder in its 6-MHz version. Fig. 2(b) shows the reproduced signal without any reconstitution process applied. The actual packing density on tape for this signal is 490,000 bits per square inch. The linear packing density along the recorded tracks in this example is 6.3 Kbit/inch.

As a senior staff engineer at Ampex, Erhard K. Kietz has participated in the development of tuning fork and crystal clocks, early television systems, a 1000-line television system, very large video display devices, and rotary-head magnetic tape recorders including the application of such recorders for high-reliability, high-transfer rate digital systems. He holds a PhD in Natural Sciences from the University of Leipzig, Germany.



Mr. Damron is presently Manager of the Rotary Instrumentation Section of the Instrumentation Engineering Dept. at Ampex. He has served as project engineer in advanced video and instrumentation technology studies and product development programs, primarily in the field of rotary-head recording. Preceding his association with Ampex, Mr. Damron was with the Instrument Div. of Varian Associates performing engineering development of graphic recorders and spectrometers.

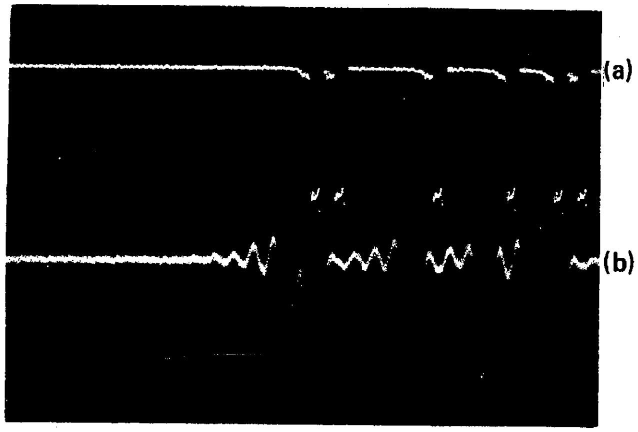


Fig 2 Digital data recorder at 10 MHz: (a)input to recorder; (b)output of recorder

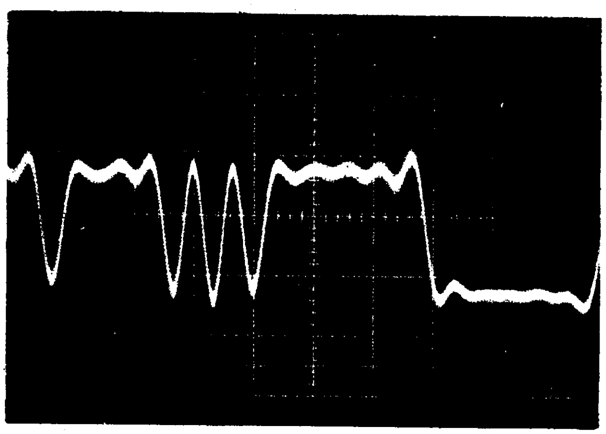


Fig. 3 Digital data recorder at 6 MHz

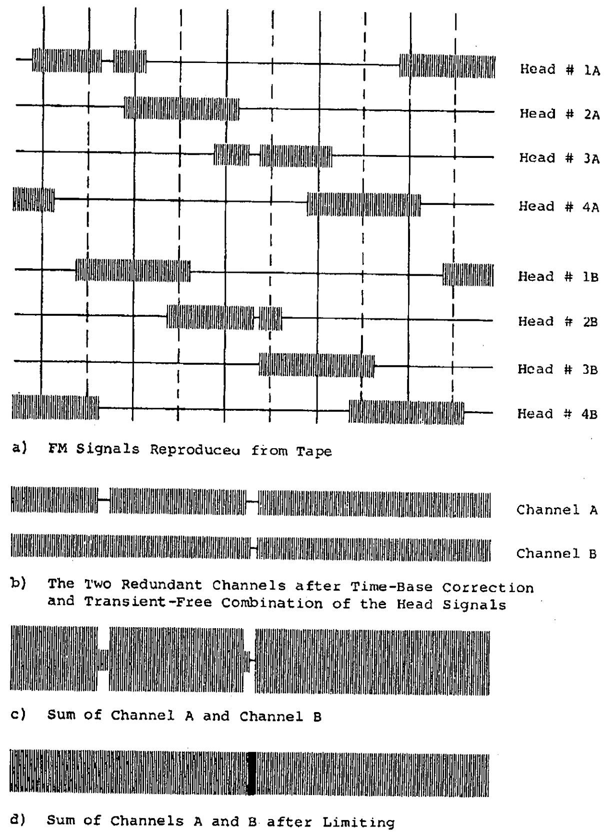


Fig. 4 Digital FM recording with high reliability

Figure 3 is an oscillogram of a 6 MHz NRZ signal reproduced with a recorder having a bandwidth of 3.75 MHz, a ratio of bit-rate-to-bandwidth of 1.6. The area storage density for this recorder is 1.0 Mbit/in^2, and the linear packing density in the direction of head travel is 11.25 Kbit/in. The multichannel recorder referred to previously will operate at the same densities and, with eight bits recorded in parallel, will be able to handle bit rates up to 144 MHz.

INCREASING BIT RELIABILITY

In the digital recording mode described above, the digital signal is applied to an unmodified single-channel or multichannel rotary-head instrumentation recorder. The recording takes place either asynchronously, or in synchronism with the recorder clock. Commercial video-tape is used and the recording is made with no redundancy, unless redundancy is provided in the coding scheme. Under these conditions, the bit reliability will be only moderate, i.e., one error in 10^4 or 10^5 bits, depending upon the packing density used. This is satisfactory for some applications. The area packing density could be doubled with respect to the figures given above, with a concurrent reduction of reliability, by reducing the track width written on tape from the standard 0.010 inch to one-half that value. It is known from tests that very nearly 100% of the bit errors occur due to tape dropouts.

A simple method for greatly increasing the reliability without affecting the packing density consists of using two recording channels for one digital data channel, thus providing a 100% redundant recording, and reducing the track width to one-half of the standard value of 0.010 inch. A distinct advantage of the FM recording mode is demonstrated in Fig. 4. The FM signals reproduced from each of the four heads in each of the two redundant recorder channels are illustrated in Fig. 4(a). One of the channels has two dropouts, shown with zero signal level during the dropout period; the other channel contains one dropout. Fig. 4(b) shows the signals after time-base correction and transient-free combination. The two channels are now added together, before limiting and demodulation takes place, as shown in Fig. 4(c). The limiter serves to eliminate data losses due to all dropouts which occur in only one of the two channels [see Fig. 4(d)], and the demodulated signal will not even change in amplitude.

Only dropouts which occur simultaneously in both channels will cause bit errors, and these can occur only when two tape deficiencies are located exactly 0.8105 inch apart in the direction of the head travel (this dimension represents a 45° section of the head drum periphery, see Fig. 1). This redundancy technique thus eliminates the data losses which would otherwise result from the majority of tape dropouts: even a longitudinal scratch on the tape does not cause bit errors. This method brings the bit error rate to the region of one bit in 10^{-8} or better.

SELECTIVE UPDATING ON ROTARY-HEAD RECORDERS

Selective updating comprises the processes of erasing a predetermined block of information, which was recorded under a certain address, and of recording a block of new information in this place on the tape without affecting neighboring blocks.

A similar process has been developed for television recording. It is known as "Electronic Editing"[3] and is based on the following sequence of events. At the instant the operator wishes to initiate editing, he pushes a button. Starting with the next following television frame, the recorded information is erased. The exact number of frames which the tape has to move from the erase head to the rotary heads are counted automatically and recording starts for the required number of frames.

The process is easily adaptable to digital recording of blocks whose periods are any multiple of one head-drum rotation. An address track, uniquely identifying each block, is recorded simultaneously with the data block by a stationary head along the upper edge of the tape, and the head rotations are marked by a control track near the lower edge of the tape, as shown in Fig. 1(b). The updating process is initiated automatically when a preset address is read. At the next following control track pulse, erasing begins for a preset number of head rotations, and a preset number of control track pulses are counted during the movement of the erased section of the tape to the rotary heads. At that moment, recording takes place automatically for the same number of control track pulses which occurred during the erase process.

Rotary-head wideband recorders, with the special FM system used in television recorders, are well suited for digital applications at data rates of up to 18 MHz per channel. Standard instrumentation recorders are presently available with a capability of 10 MHz per channel. With certain modifications of a standard rotary-head-instrumentation recorder, a 100% redundant recording can be achieved, yielding error rates of 10^{-8} or better.

REFERENCES

1. M.O. Felix and H. Walsh, "F.M. Systems of Exceptional bandwidth," *Proc. IEEE*, Vol. 112, No. 9, pp. 1659-1668, Sept. 1965.
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3. N.F. Bounsall, "Electronic Editing, A Dramatic New Technique for Videotape," *Broadcast Engineering*, Vol. 4, No. 9, pp. 10-16, 27, Sept. 1962.