A HIGH CAPACITY, HIGH DATA RATE INSTRUMENTATION TAPE RECORDER SYSTEM

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Summary. A 240-megabit/second, serial bit stream recording system using a longitudinal (fixed-head) magnetic recording technique called HDMR (High Density Multitrack Recording) has been developed. This system provides maximum bits per square inch of tape at reliable in-track packing densities. Unique “unitized” fabrication techniques have been used to construct single stack magnetic heads (record/play on the same head) at track densities of over 100 tracks per inch. Commercially available tape is accommodated by the use of error detection and correction. HDMR technology, applied to the implementation of a typical ground instrumentation recording system, allows key performance parameters of: 240 Mb/s serial data input, 108 in/s tape speed, a 142-track head, a bit error rate of 1×10^{-6} and 240 Mb/s serial data output.

Introduction. Sensor outputs, whether synchronous scan (TV, radar, electro-optical) or non-formatted (IF, RF, telemetry) are basically analog at the data source. The trend is to use A/D converters to digitize data from these analog sources for processing because of the relative ease of handling data in digital form. A digital format typically: 1) provides minimal performance degradation during data processing, multigeneration copying or editing; 2) allows easy detection and correction of errors and dropouts; 3) accommodates very high data rates through parallel processing; 4) drastically reduces operational adjustments; 5) is the most easily encrypted form of data; and 6) can be computer compatible.

Until recently, A/D Converters were limited to low bandwidth and/or low dynamic range applications. With the advent of A/D systems capable of adequately processing such complex signals as broadcast quality color TV and high resolution radar, a need for recording and processing digitized data at rates in the hundreds of megabits per second has emerged.

To address this need, a longitudinal recording technique called HDMR (High Density Multitrack Recording) has been developed. HDMR provides maximum storage of data bits on a minimum quantity of tape; in other words maximum bits per square inch (BPI^2). To achieve this goal, both the in-track packing density, or bits per inch along tape (BPI), and the track density across tape (tracks per inch) have been increased. HDMR is unique, however, in the degree of extension of track densities. This feature permits extended area packing density at reliable recorded wavelengths. An alternate approach which has been widely promoted uses IRIG track format heads with in-track densities extended up to 35,000 BPI. This approach yields an area packing density of 0.980×10^6 BPI^2 with an IRIG track density of 28 tracks per inch. Experience has shown that sensitivity to head-to-tape separation losses at such short wavelengths results in high bit error rate (BER), low reliability of the head-to-tape toward extending the track density while maintaining reliable in-track density.

A successful video head technology led directly to unique fabrication techniques for ultrahigh track density longitudinal heads. Applications of this technique have successfully demonstrated track densities of more than 80 tracks per inch, yielding an area packing density of over 2×10^6 BPI^2 with an in-track density of only 25,000 BPI.

Typically, the two-inch, 164-track HDMR head (shown in Fig. 1), operating at 30 inches per second, records at the same data rate as a 28-track IRIG version operating at 120 inches per second, but the HDMR version requires only 2/3 the in-track density. This means a more reliable head/tape interface plus increased tape utilization, i.e., less tape used, or more record time available.

For example, a requirement to record 60 Mb/s for 1 hour can be satisfied by HDMR with a 4500-foot roll of tape. IRIG format at 40/35,000 BPI requires a tape length of 18,000 feet (a reel greater than 16" in diameter, with a dreaded tape splice).

Experience has also shown that 28 tracks per inch provides “overkill” in signal-to-noise ratio even at high BPI figures. A 5-mil (0.005-inch) track operating at 25,000 BPI reliably produces a measured BER of less than 1×10^{-8} if tape imperfections are ignored, and 1×10^{-4} with tape imperfections included. The latter effect is the reason wide tracks are normally used. An EDAC[1] [2] [3] (error detection and correction) system for HDMR has been developed which effectively circumvents the tape dropout errors, thereby providing a BER

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[1] This system requires very little overhead (implementation), does not require that the data be blocked or formatted, and can be utilized to correct errors generated during data processing external to the recorder. For details see references 2 and 3.

[2] C. M. Melas, “A New Group of Codes for Correction of Dependent Errors in Data Transmission”, IBM Journal, January 1966, pp.

[3] J. S. Griffin (RCA), “Ultra High Data Rate Digital Recording”, Proceedings of SPIE Conference 1973, Dayton, Ohio.

of better than 10^{-6} at packing densities of over 2×10^6 BPI^2. With this system, standard instrumentation tape can be used direct from the factory without burnishing and cleaning.

HDMR thus provides a tape utilization capability which allows the recording of ultrahigh data rates at reasonable tape speeds by spreading the high rate signal over many parallel tracks on tape. The development of high density heads was the prime element in HDMR technology. Other important elements contribute substantially to the performance reliability:

HEADS	No gap scatter, 1000 hours life
HEAD-TAPE INTERFACE	Commercial tape, reliable in-track packing densities, accurate tracking
BER	Error detection and correction
BPIZ	Double density code, unique equalization, high track density, incremental operation
SIMPLE ELECTRONICS	No equalizer to adjust, only 20 active elements per channel
DESKEW	No overhead, no static skew, simple system

HDMR System. The block diagram in Fig. 2 depicts the major elements of a typical HDMR system. Although this diagram shows an analog-to-digital converter at the system input, the digital signal to be recorded can actually be derived from various sources:

- A serial or parallel digital input
- A digitized analog input
- A “Self Test” signal

The selected input data is demultiplexed to many parallel lines and parity checked by the EDAC encoder. All data and EDAC NRZ signals are phase encoded and equalized for optimum record bandwidth. Each channel is then amplified to a suitable record level and applied to the multitrack magnetic head.

The reproduce portion of the HDMR system utilizes the same HDMR head to read out the stored data. Each head output is amplified, filtered and limited by analog circuitry. These circuits and the final stage of the record amplifier are the only analog circuits associated with the basic HDMR record/reproduce system. These analog circuits contain only 20 active devices per channel and require only one adjustment: record current. No playback equalizer is required since this function has been replaced by a simple and unique equalizer on the record side. Thus, the normal complications associated with equalizer adjustment have been eliminated and the analog reproduce electronics are reduced to 50% of the normal requirement.

The outputs of each limiter are decoded independent of clock circuitry. After decoding, clock information is extracted from some of the data channels and used to strobe the data out of the decoders and into the deskew/deflutter buffers.[4] The lack of "gap scatter" in HDMR heads (no interchannel time displacement error between adjacent tracks) allows this minimal implementation of clock circuitry. Typically, only one clock is needed to strobe out 10 track s, the limit being determined by the amount of dynamic skew. A VCXO (voltage controlled crystal oscillator) or an external reference can be used to control the data output stability. The source selected serves as the reference for the recorder capstan and the output clock for the deskew/deflutter buffer. Digital time base correction is accomplished in the deskew/deflutter buffer with a single digital integrated circuit (random access memory) which replaces all the functions normally accomplished by sophisticated analog time base correctors such as MATC, CATC, and EVDL.

The coherent data lines derived from the buffers are error checked and corrected by the EDAC system, and multiplexed for D/A conversion or further digital processing.

HDMR Applications. HDMR systems are available in one- and two-inch versions. Both versions use standard instrumentation tapes and have a 2:1 data rate ratio. The one-inch version has exactly 1/2 the signal processing electronics and records up to 120 Mb/s or exactly half that of the 240 Mb/s version. HDMR applies equally well to ground, airborne and space data storage requirements. Low power, small size and weight and high reliability are accomplished by simplified channel electronics and transport design. An aerospace version of HDMR can be implemented in a configuration weighing less than 250 pounds and occupying less than 5 cubic feet, storing and reproducing digital data at a rate of 200 Mb/s and requiring less than 350 watts of power.

HDMR provides computer compatibility for analysis of high speed and wideband data. Eight or sixteen output lines may be chosen, with output rates of 4 megawords per second or less, for dumping into present minicomputers or main frame input buffers. Incremental reproduce capability is available with HDMR to allow data reduction/processing at transfer rates which are normally too high to process serially. In this mode the HDMR system would play back a sufficient number of bits to load a memory (e.g., 1.2 megabits), then stop, rewind a short distance to index the following data, and wait for another playback command. Bit error rates of 10^{-4} to 10^{-7} are typical for standard HDMR systems. This range encompasses the requirements for most system applications. For instance NTSC broadcast video, which has been A/ D converted with 8-bit quantizations[5] and recorded, will produce a reconverted (D/A) video signal with a 47 dB signal-to-noise ratio

[4] C. R. Thompson (RCA) and J. M. Hayes (NASA-Goddard), "High-Data-Rate Spacecraft Recorders", Proceedings NTG Conference, 1972, Houston, Texas.

[5] A. J. Viterbi, "Principles of Coherent Communications", McGraw Hill: New York, 1966, p. 257.

(S/N) for BERs less than 10^{-5} (refer to Fig. 3). The basic HDMR system operates at 240 megabits/ second. This is considered a typical bit rate for today's needs. In addition the system reflects the capabilities of present A/D converters and covers the required rates for present and near future systems. HDMR provides the capability to record a serial 240-Mb/s bit stream as might be available from a very wideband data link, or to record multiple, synchronous data outputs (typical of AID converters) at line rates of 240/N megabits per second for each of N lines. An illustration of such a 240-Mb/s recorder/ reproducer is shown in Fig. 4 and typical specifications are listed in Table I.

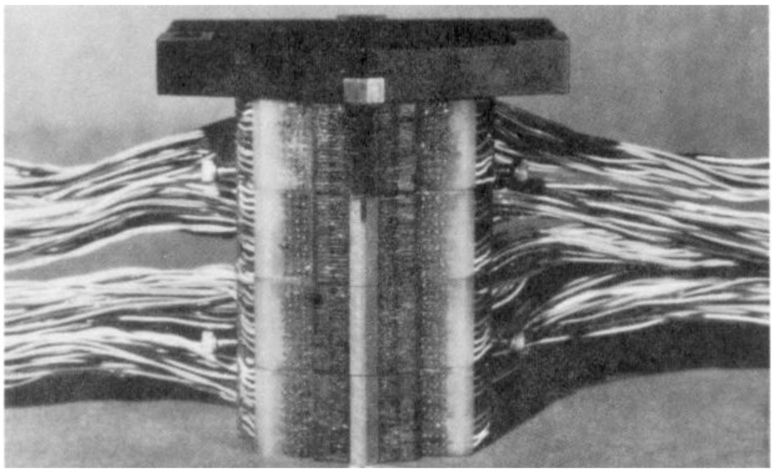

Fig. 1. 164-track High Density Multichannel Recording head.

TABLE 1. TYPICAL SPECIFICATIONS -- HDMR-240G

Data Rate (1)	Record 40- 240 Mb/ s continuously variable Reproduce 40-240 Mb/s fixed, selectable
Data Format	Serial NRZ-L in/out
Auxiliary Data Inputs	Up to 12 lines @ 2 Mb/s digital (or other signal formats)
Record Time	23 minutes @ 240 Mb/s 138 minutes @ 40 Mb/s
Start Time	50 milliseconds record 100 milliseconds reproduce
Error Rate	2 x 10^{-6} maximum
Magnetic Tape	2-inch on NAB reel 16-inch (12,500-ft) maximum

Tape Interchangeability	Tape recorded on one HDMR-240G can be reproduced on a second HDMR-240G
Packing Density	20, 000 BPI in-track density 1.4 x 10^6 b/in^2
Total Storage	Primary data 3.3 x 10^{11} Bits
Capability	Auxiliary data 3.3 x 10^{10} Bits
Head Life	1,000 hours
Size	65 cubic feet
Power	115 Vac, 60 Hz, 1 phase, 2 kW
Number of Tracks	112 data, 14 EDAC, 12 AUX
Head Stacks	One record/play (2)
Head Construction	Alfecon II Unitized HDMR
Track Width Spacing	0.008-inch 0.014-inch
Transport	Vertical with waist level tape loading, vacuum bins for fast start/stop
Tape Speed	107 in/s at 240 Mb/s (18 in/s at 40 Mb/s)
Cabinet	Welded EMI design on castors, pneumatic drop door for clean tape compartment
Special Effects	Edit, auto search and other special features also available

(1) Also available at 120 Mb/s on 1-inch tape.
(2) Read while write available (two head stacks, plus increased deskew electronics)

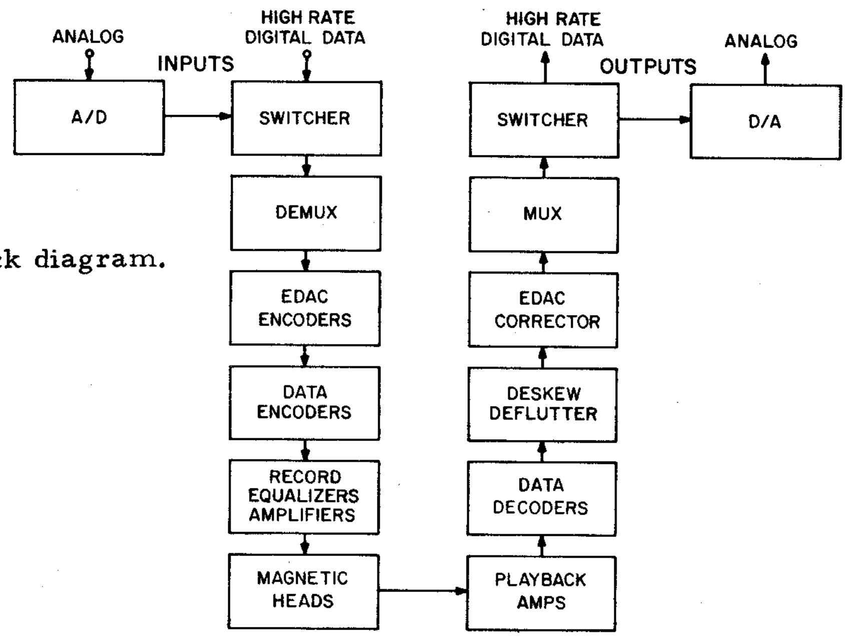

Fig. 2.

HDMR system block diagram.

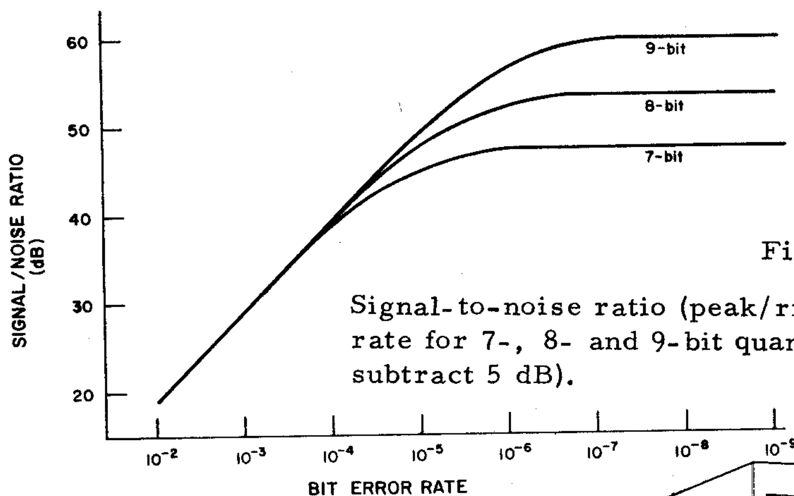

Fig. 3.

Signal-to-noise ratio (peak/rms) as a function of bit rate for 7-, 8- and 9-bit quantization (for rms S/N subtract 5 dB).

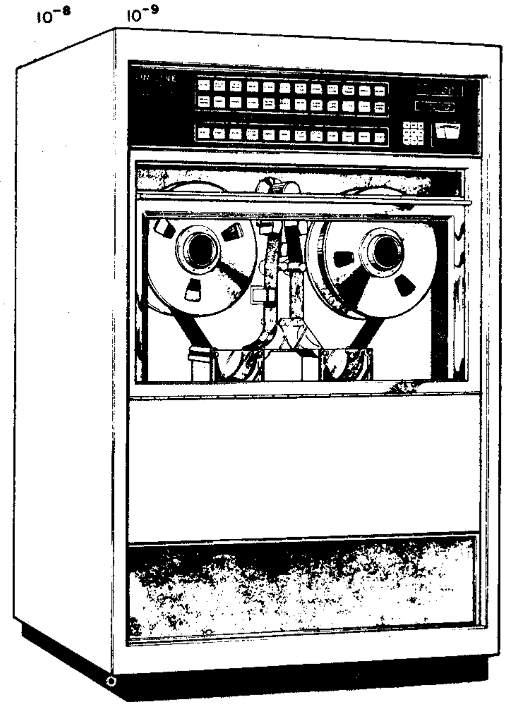

Fig. 4. HDMR system configuration.