

# AN ULTRAHIGH RATE DIGITAL TAPE RECORDER FOR SPACECRAFT APPLICATIONS

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**Summary** Spaceborne digital recorders must satisfy the conflicting requirements of maximum data storage of high rate data (particularly for high resolution sensor data) and a long life with high reliability (meaning rugged design and moderate head-to-tape speeds). The multitrack longitudinal (fixed head) recorder can successfully resolve this conflict and satisfy both requirements. The evolutionary machine described herein was originally designed to store and reproduce 30 min of 39.9-Mb/s sensor data, for mission lives on the order of 1 year; newer designs have surpassed these parameters by significant amounts.

**Introduction** Longitudinal tape recorders for storage of wideband digital data on unmanned satellites offer the most promise for a long life of continuous or near-continuous use throughout the mission duration. The tape handling associated with longitudinal recording does not impose excessive overstressing of the tape at the tape-head interface or elsewhere in the tape path. Video recorders such as rotary head machines, on the other hand, must exert excessively high head-to-tape pressures to accommodate the required high head-to-tape speeds. Multitrack longitudinal tape recorders in a regime of low tape stresses can be expected to survive one- and two-year mission durations.

With the advent of high speed, low power digital logic and very narrow parallel pole heads, 160-track machines are in the offing. The development of such a longitudinal multitrack tape recorder was undertaken by NASA's Goddard Space Flight Center in September 1970. This paper will primarily deal with the technology of that effort, which was the forerunner to the larger capacity machines referred to above and now under development at RCA. The aforementioned GSFC-RCA task was completed in January

1972 and culminated in a report which provides the basis for this paper. Recent advances have extended the technology beyond the original Goddard effort, so this paper concludes with an update.

Multitrack tape recorder development was undertaken at the onset of the high resolution sensor development planned for large unmanned Earth Observatories. With the sensory data digital in format, and the technique of multiplexing/demultiplexing so amenable to the concept of multitrack recording, it was inevitable that such a recorder would emerge as a potential storage medium. When ultrahigh rate digital data is divided by a significant number of tracks, the individual track input rate is reduced to a frequency which can be recorded at relatively low tape speeds. Life expectancy is further enhanced by the transfer of precision performance from the electromechanical transport to electronic circuits; transports can be built ruggedly, and the needed precision obtained from well derated electronic circuits.

**System Description** The multitrack tape recorder provides more than data storage; it is the complete transfer mechanism from sensor to transmitter, performing all the necessary signal processing to maintain the quality offered by the sensors.

As shown in the block diagram of Fig. 1, the system has a record function with playback at higher speed. The capacity of  $8 \times 10^{10}$  bits permits 30 minutes of recording at a sensor output of 39.9 Mb/s. Playback at a rate of 129.16 Mb/s dumps the entire contents in 10 minutes.

**Record Electronics** The system as originally configured in the Goddard program employs a single read-write head with 112 tracks across 2-inch wide tape. The input, NRZ(L), is converted to a double density format and BCH encoded for error correction at the ground site. Ninety-eight tracks are assigned encoded data which, when loaded at a density of 20 kilobits per inch, contains the flux reversal pattern of 10 kilobits per inch biphasic data. The remaining 14 tracks contain the recorded clock and synchronization signals for servo motor control of the tape drive and for electronic dejitter and deskew on playback. A block diagram depicting the record electronics is presented in Fig. 2.

The recording method is constant current, near saturation without ac bias. To deskew on playback, input data at 39.9 Mb/s is gapped every 91 bits, laced with seven synchronization and error correcting bits, and reclocked into the serial-to-parallel demultiplexing logic at 43 Mb/s. Decommuation provides 98 parallel paths for each frame of 98-bit data.

Each of the 98 lines of NRZ data is converted to high zero axis transition, double-density code; with the low frequency components removed, the resulting spectrum is more suited to magnetic recording.

**Playback Electronics** Clock and synchronization are redundantly recorded on seven pairs of adjacent tracks to prevent a single failure from affecting a sync track and thereby to improve the ability to reconstruct the recorded data.

A block diagram of the playback electronics is shown in Fig. 3. A basic clock at twice the data rate is used for converting the recorded double density code to NRZ(L) prior to deskewing, dejittering, and multiplexing the data. The basic timing is recovered in seven phase-locked loops from the “OR’d” sync track pairs.

On playback, the 98-track data is first equalized to minimize zero-crossing errors. These zero-crossing errors in playback at high packing densities arise from two conditions: 1) time base line shift due to pulse crowding effects (i.e., pulse interference in playback caused by a very close spacing between two adjacent flux reversals recorded on the tape using saturation recording), and 2) a time base shift caused by the small but not insignificant dc component in the delay code waveshape.

A computer simulation program, used to predict the zero-crossing errors expected, calculated the effect of passing NRZ-type data waveshapes through band-limited networks. (Both the magnetic record-reproduce process and the equalizer were characterized as bandpass filters with known transfer functions. ) A 44-bit delay code word with the characteristic 101101 inserted in the center and a half-bit rate centered at 225 kHz simulated a bit packing density of 20 kilobits per inch.

The results of the computer simulation program indicated that the 20 kb/i delay code is adequately processed by use of a playback gap of 35 microinches and a 3-stage R-C type amplitude-phase equalizer. A linear phase filter restores the pre-equalized signal-to-noise ratio which has been degraded by high frequency peaking in the equalizer.

Each of the 98 equalized data streams is fed to a separate deskew buffer, and the buffers output 98 in-phase parallel data streams. The buffers are composed of circulating registers with separate read-in, read-out logic. Data tracks blocked into sets of 14 are read in to their respective buffers at clock rates derived from the assigned sync track. For the buffer to operate properly, the maximum displacement across 14 data tracks must be small enough so that all of the tracks can be clocked from the clock track pair located between two sets. From experimental data which showed a maximum edge-to-edge tape skew of 40 microinches, it was calculated (prior to transport breadboarding) that the maximum displacement from bit to bit would be 0.01 bit per track. Allowing a factor of three for additional time base error yielded a maximum displacement of  $\pm 21\%$  of a bit period from

the clock track. In addition to this, the buffer had to be large enough to accommodate maximum skew across the entire tape, which was calculated to be 0.8 bit. Again using a factor of three for time base error margin, the resulting maximum displacement was estimated at  $\pm 3$  bits. On this basis, an 8-bit circulating buffer was selected.

A parallel-to-serial converter reformats the deskewed data from one parallel 98-bit word occurring every 760 ns to two 66.58-Mb/s serial data streams. (The RF link for use with the multitrack tape recorder was proposed as a four-phase PM transmitter. ) The parallel-to-serial converter employs two parallel-input/serial-output shift registers with a relative delay of one-half bit in phasing to convert and reclock the parallel data into serial form. In addition, the clock tracks at the tape center are compared with a master clock frequency to provide error signals to the capstan motor servo when phase differences occur, thereby reducing the jitter magnitude.

**Tape Transport** The tape transport, outlined in Fig. 4 and photographed as a breadboard in Fig. 5, is coplanar, capstan driven, and negator spring tensioned. A dc brushless motor, servo-controlled by means of an optical encoder on record and from the tape-extracted clock on playback, is directly coupled to the capstan shaft.

The single- stack multitrack head serves to record and play back; another, noncontacting dc-powered head provides erase to zero remanence before record. The read-write head (Fig. 6), which uses ultrahard Alfecon II pole tips, has a track spacing of 0.02 inches, a track width of 0.012 inches, and a gap length of 35 microinches. A single turn inductively couples each pole to a miniature toroidal ferrite transformer having multiple turns on the output.

The transport weighs 51 pounds; the total power consumed (including the electronics) is 29 watts in the write mode, 107 watts in the read mode.

**Update** Since the Goddard study effort, the multitrack tape recorder has grown up technically into a more versatile and more polished system. In a feasibility model experiment the recorder has recorded and reproduced the equivalent of 150 Mb/s. The head has been increased to 164 tracks while maintaining tape width at 2 inches. The electronics have undergone changes and simplifications; the previously mentioned equalization, and in fact all of the playback analog functions, have been eliminated. Phase and amplitude correction are no longer required. The recording remains direct, but with newly developed techniques equalization is now accomplished prior to recording.

In test, feasibility models have been operated at 100 inches per second and bit packing has been successfully increased to 25, 000 bits per inch per track. Analytical models have been calculated and dimensioned for handling 6500 feet of tape to allow for increasingly long periods of ultrahigh rate recording.

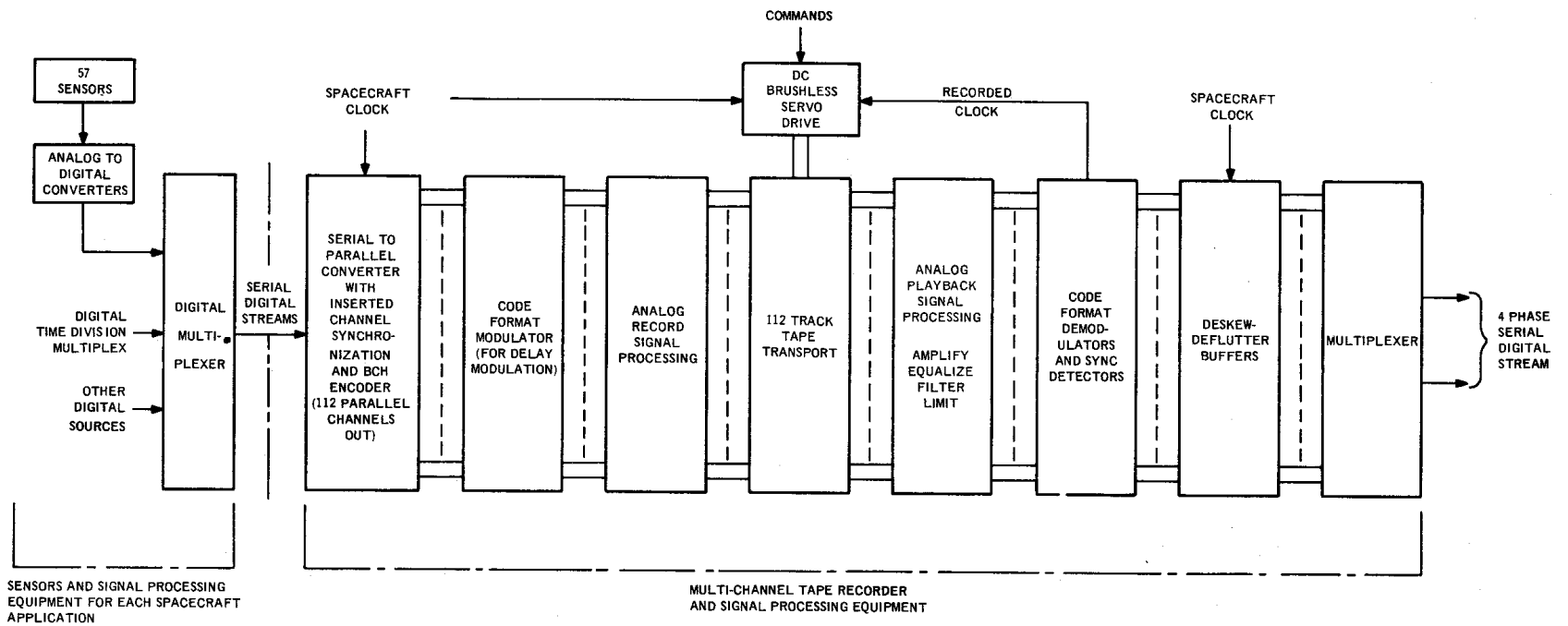


Fig. 1. Multichannel recorder system functional block diagram

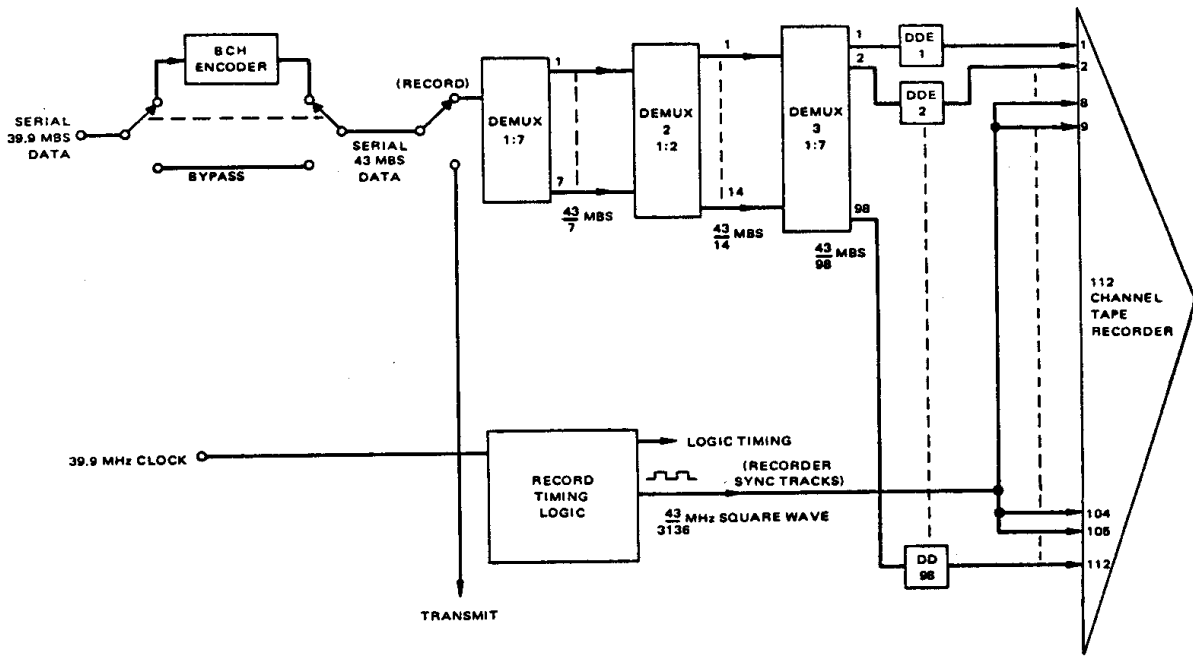


Fig. 2. Record electronics block diagram.

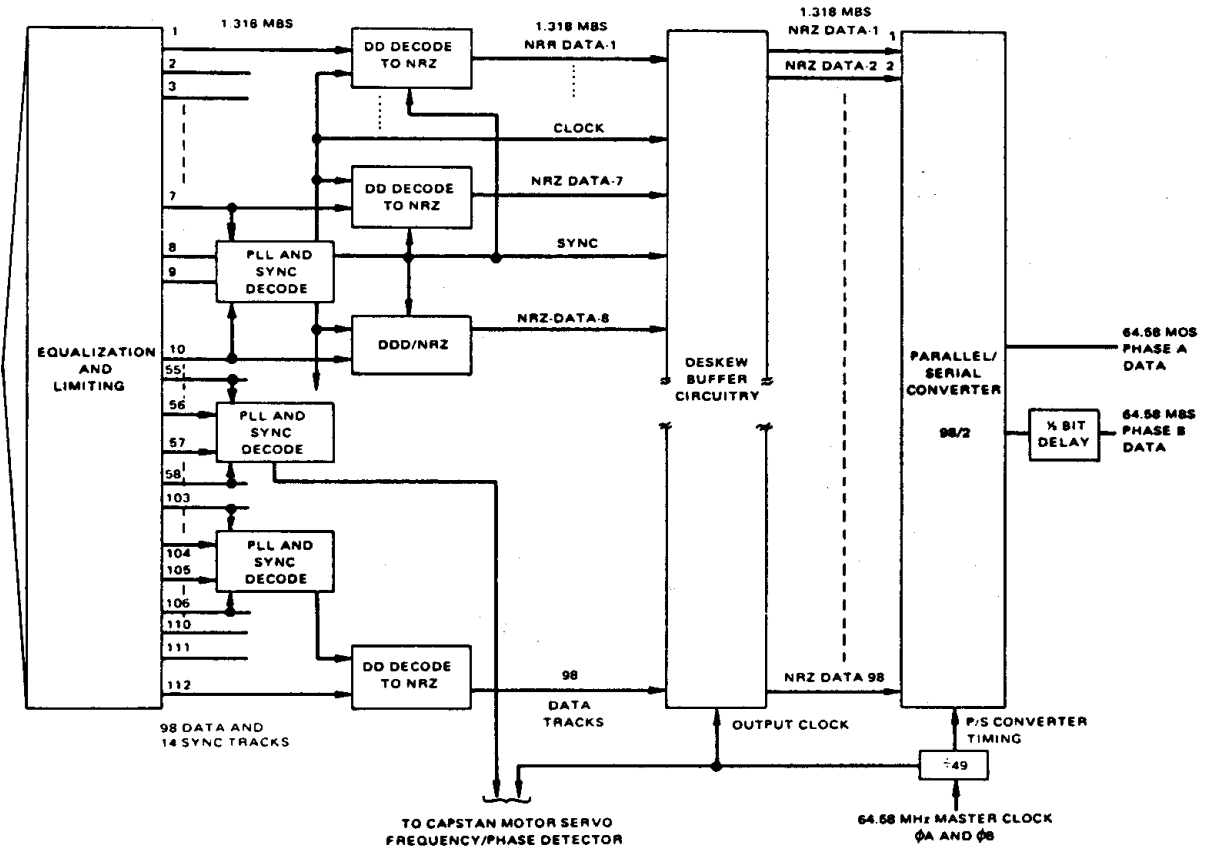
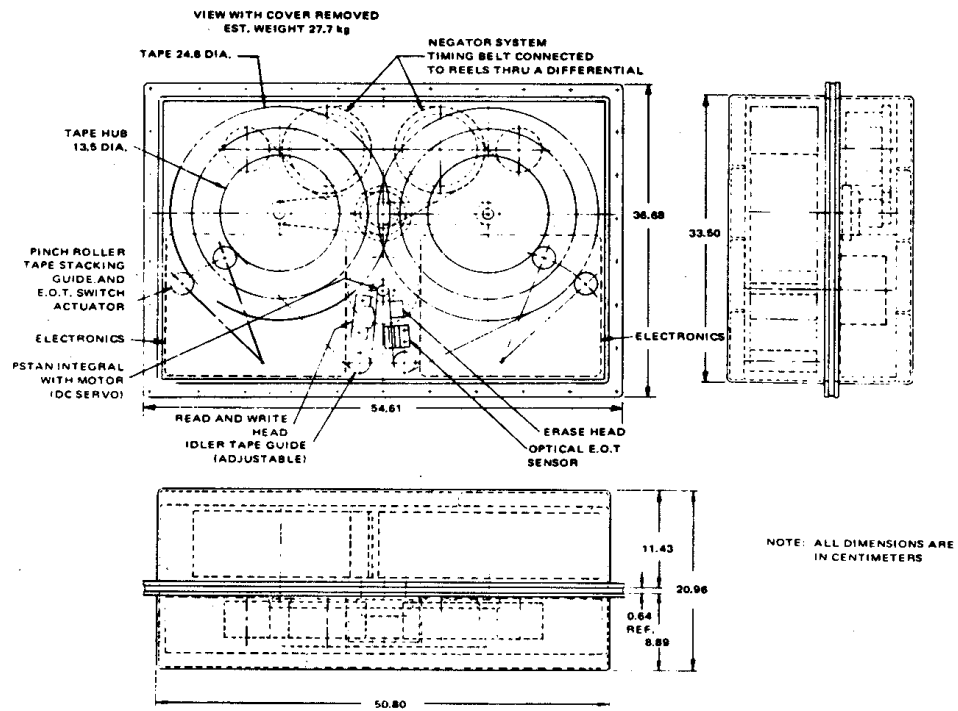
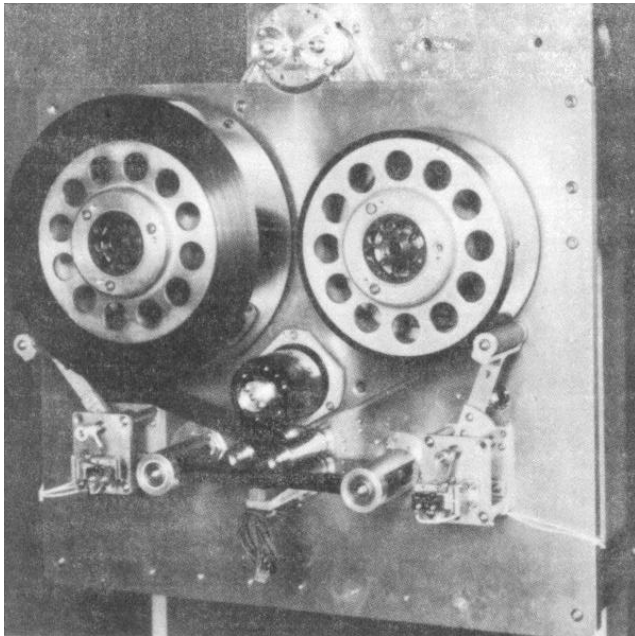


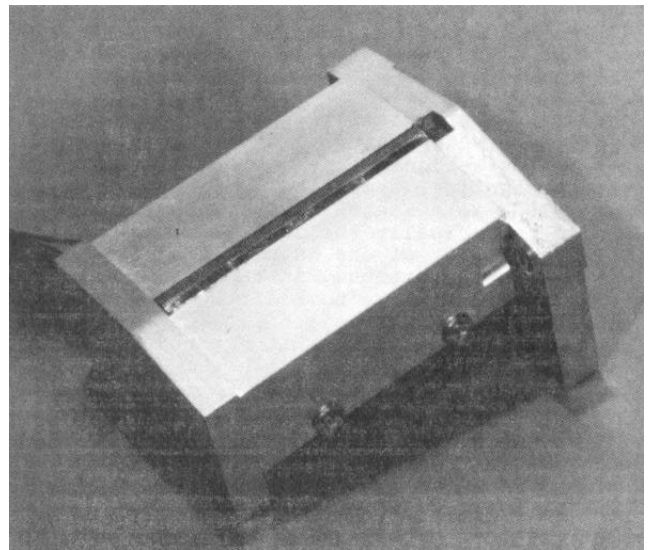
Fig. 3. Playback electronics block diagram.



**Fig. 4. Primary tape transport configuration.**



**Fig. 5. Transport breadboard.**



**Fig. 6. High density single stack multitrack head.**