NASA Standard 4 x 10^9 Bit Spacecraft Tape Recorder

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Summary .— The concept of employing standard spaceborne hardware to meet the needs of present and future spaceborne missions is the beginning of a new era. In this paper, attention is focused on describing the functional characteristics of a 4 x 10^9 bit magnetic tape recorder that will become the standard tape recorder for future satellite missions. The recorder development was directed by NASA Goddard Space Flight Center.

Introduction. — The concept of a standard tape recorder design capable of satisfying the requirements of existing as well as future spacecraft missions implies by definition that the performance boundaries set by the initial design must encompass all possible future mission profiles without incurring substantial development costs and its associated schedule impacts. Prior to entertaining the notion of standardization, each recorder was designed to satisfy unique performance requirements with emphasis placed on minimizing size, weight and power simultaneously with maximizing reliability. The common denominator between all of these unique recorder designs is the recorder function. In essence, the tape recorder has five general functions to perform. These functions are listed below in increasing order of contingencies associated with development.

1. Telemetry Interface

2. Power Interface and Internal Power Distribution

3. Command Interface and Internal Mode Control Distribution

4. Speed Control Range

5. Signal Conditioning Required for Input/Output Transfer Rates

The above suggests that a major objective toward standardization would be achieved if emphasis is placed in a prudent selection of upper and lower boundaries for the latter two functions, in conjunction with maintaining the internal interface between all recorder functions constant. This objective could be implemented in one of two ways. The first approach considered involves developing a performance matrix for all possible combinations of user requirements and then design the recorder hardware to satisfy any solution that the matrix unveils. Although this solution is feasible, the end product would be so complex, not to mention the recurring costs, that almost every case would fall outside the limits of acceptable power, weight and size requirements which still are a driving force for acceptable recorder utilization.

The second approach is more attractive. In this approach the design objective is to modularize the recorder functions and therefore, provide user flexibility by using an adaptive concept whereby only selected solutions to the performance matrix previously cited need be satisfied for any given mission. Using the statistics accumulated from recorder developments over the past decade as a basic premise for this argument, the latter approach is acceptable to the users. Also, this approach minimizes the development, and of equal importance, reliability risks incurred in satisfying the best overall design for each unique requirement. In the subsequent sections, the major goals to be achieved for a standard recorder system will be stated and then followed by discussion of each recorder function. Included in the discussion will be the limitations of recorder flexibility based on the assumptions used as design criteria for each function.

System Description. — The 10^9 standard tape recorder is capable of storing 4 x 10^9 bits of digital data distributed over 16 tracks on 2,400 feet of 1/2 inch tape. This data may be stored in either a serial mode by sequential track switching or a parallel mode in which case the track switching occurs in pairs of two, four or eight tracks. The number of tracks used in the parallel mode is predetermined at the time of recorder assembly. The recorder tape speed range is controlled over a dynamic range of 160:1 by a clock coherent to the input/output data rate. This external clock, in conjunction with serial/parallel mode control, allows the data to be recorded on tape at a constant bi-phase level packing density of 8.5 Kb/in. By combining the capabilities of serial and parallel mode operation, the maximum dynamic range of the input data transfer rate is 1,280:1. The upper transfer rate is limited to 8.192 Mb/s (parallel by 8 at 120 ips) and the lower transfer rate is limited to 6.4 Kb/s (serial at .75 ips). Readout of the stored data on tape is always opposite to the direction recorded in the parallel mode but has a bidirectional readout in the serial mode. Unlike the record mode, constraints are imposed on the dynamic range of reproduce mode. The total dynamic speed range of the reproduce mode is 160:1; however, for any one given mission, this speed range is restricted to one of three overlapping speed ranges that is predetermined at the time of recorder assembly. Another benefit of the modular approach is it allows considerable simplification of the amplifier, phase equalizer and bandwidth normalization electronics necessary to preserve the signal-to-noise ratio of low level analog signals detected by the reproduce heads. Control of the tape recorder is accomplished through the use of a 16-bit serial command word. This command word is subdivided into five data fields which, when decoded, describe specific operation for any one of eight recorder modes. Real time performance as well as diagnostic monitoring is structured to be compatible with the standard spacecraft telemetry system. The recorder is powered from a conventional 28 V DC unregulated power bus.

System Configuration. — A block diagram of the 10^9 STR is shown in Figure 1. Physically, the recorder is divided into two units, the transport unit (TU) and the electronic unit (EU). The TU is hermetically sealed and consists of a coaxial reel, negator spring tensioned, tape transport mechanism. It also includes all of the associated electronics necessary to provide speed control, power distribution, transport telemetry, track-select logic and signal conditioning for the record and reproduce heads. The EU consists of the main power supply, control logic, master synchronizer, record/reproduce signal conditioning electronics and EU telemetry. The interface between the TU and the EU is designed to allow cross-strapping of like units. All physical and electrical interfaces to the spacecraft, however, are accomplished on the EU.

Data Recording. — Two distinct recording techniques are provided by the recorder—serial and parallel. In the serial record mode, the input data is buffered and converted into a bi-phase level format prior to being recorded sequentially on up to 16 data tracks. The serial record mode is used for input data transfer rates ranging from 6.4 Kb/s to 1.024 Mb/s. A clock coherent with the input data bit stream is used to generate a capstan servo reference frequency such that data is recorded on tape at a constant packing density of 8.5 Kb/in. This serial mode is always initiated at the beginning of Track 1 such that the full width DC erase head can erase all previously recorded data as well as record a servo reference track for tapelock speed control on either succeeding recording tracks or during the reproduce mode. In the parallel record mode, the input bit stream is demultiplexed into two, four or eight parallel bit streams depending on the predetermined parallel mode desired at the time of recorder assembly. Each of these bit streams are then formated into a 792-bit data frame prior to recording on tape; 768 bits are used for data block with the remaining 24 bits used for synchronizing the recorded characters in the reproduce mode. This tape format is shown in Figure 2. The gapping of the input data stream is accomplished by using a 32-bit RAM for each data track. Clocks for loading and unloading the RAM are generated by a phaselock loop that is coherent with the input data clock and 33/32 times the input data rate. The parallel mode may be used to either extend the upper bit rate limit of the serial mode previously described or extend the recorder life by recording lower bit rates at a lower tape speed and consequently fewer tape passes for a given mission life. A summary of the recorded data rate flexibility afforded by the record mode of operation offered by the 10^9 standard tape recorder is illustrated in Table I.

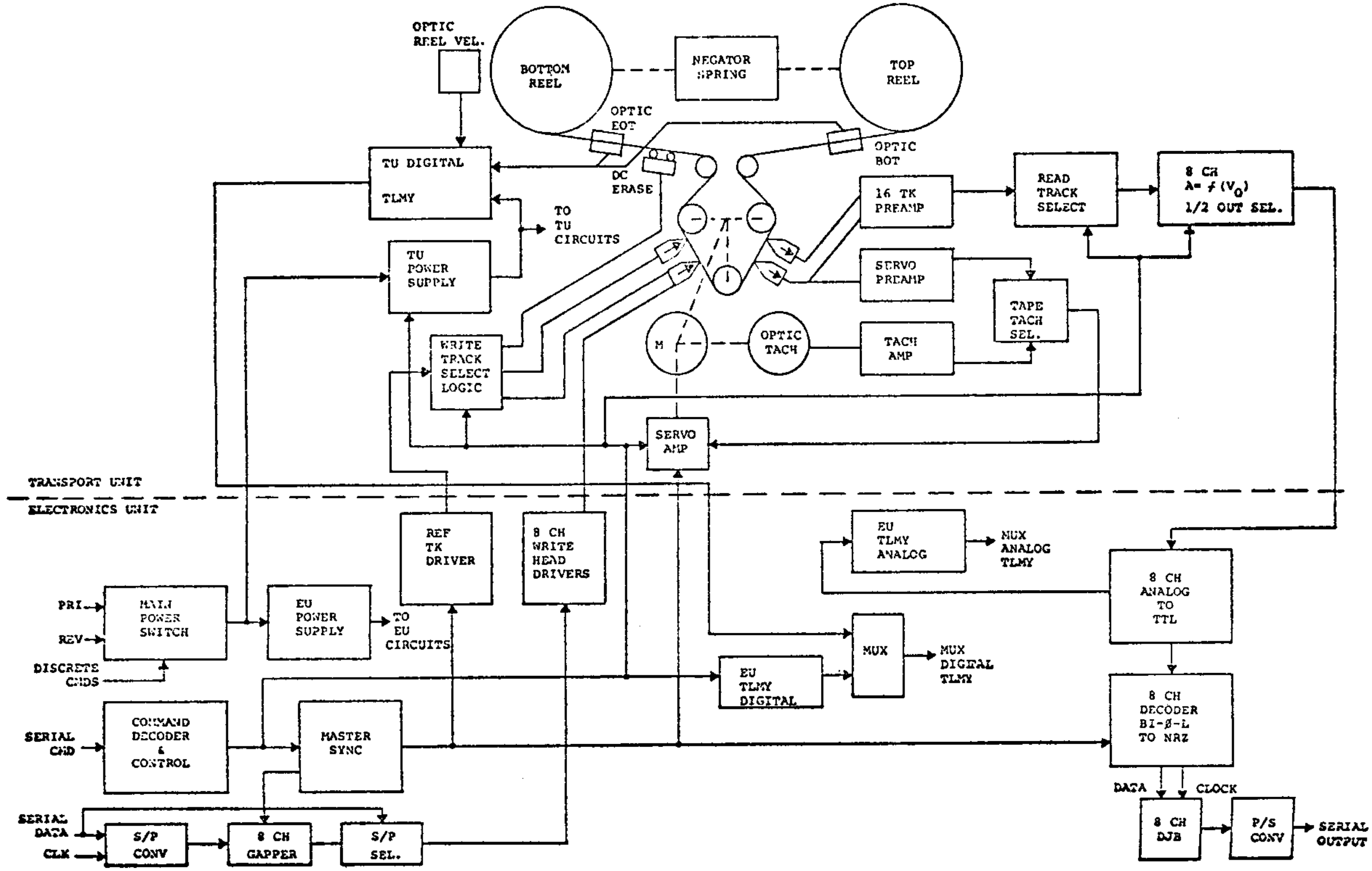


Figure 1
Block Diagram of 10^9 STR

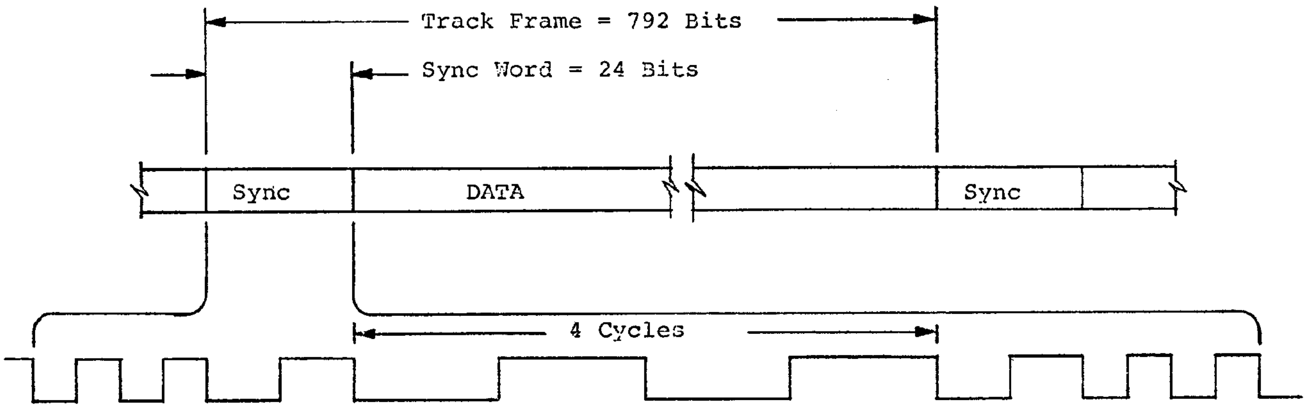


Figure 2
TAPE FORMAT

Table I
Summary of Data Rates

Octave	Serial (Kb/s)	Two Channel Parallel (Kb/s)	Four Channel Parallel (Kb/s)	Eight Channel Parallel (Kb/s)
0	513 - 1024	1025 - 2048	2049 - 4096	4097 - 8192
1	257 - 512	513 - 1024	1025 - 2048	2049 - 4096
2	129 - 256	257 - 512	513 - 1024	1025 - 2048
3	65 - 128	129 - 256	257 - 512	513 - 1024
4	33 - 64	65 - 128	129 - 256	257 - 512
5	17 - 32	33 - 64	65 - 128	129 - 256
6	9 - 16	17 - 32	33 - 64	65 - 128
7	6.4 - 8	12.8 - 16	25.6 - 32	51.2 - 64

Data Reproduction. — In order to preserve the signal-to-noise ratio of the reproduce signal with an acceptable amount of hardware, the dynamic range over which any recorded data may be reproduced has two basic constraints; TU signal conditioning and EU signal conditioning. In the TU, the 160:1 dynamic speed range is divided into three speed groups with each speed group being further divided into eight commendable 1/2 octave increments as shown in Table II. Eight channels of reproduce signal conditioning electronics are provided. Although all 16 tracks have a dedicated 50 dB reproduce head preamplifier, the appropriate track in the serial mode and track groups in the parallel mode are switched to their corresponding data channel by the transport control logic. A two-stage speed equalizer is used to normalize amplitude and phase response over the 1/2 octave increment selected. The output of the TU is an analog signal that ranges from 1.5 to 3.0 V RMS depending on the absolute speed within the speed range selected. In the EU, another constraint is imposed on flexibility. In this case, the bandwidth of the TU output analog signals must be limited in the EU prior to convertion into TTL logic levels. For the EU and TU to be completely compatible, eight filters would be required for each data track; one for each selectable 1/2 speed octave. In the interest of trading off flexibility for simplicity, only two filters are used with each filter spanning a full octave of data rates. Thus, all possible data rates for a given TU are covered, but with limitations set for a given mission.

Table II

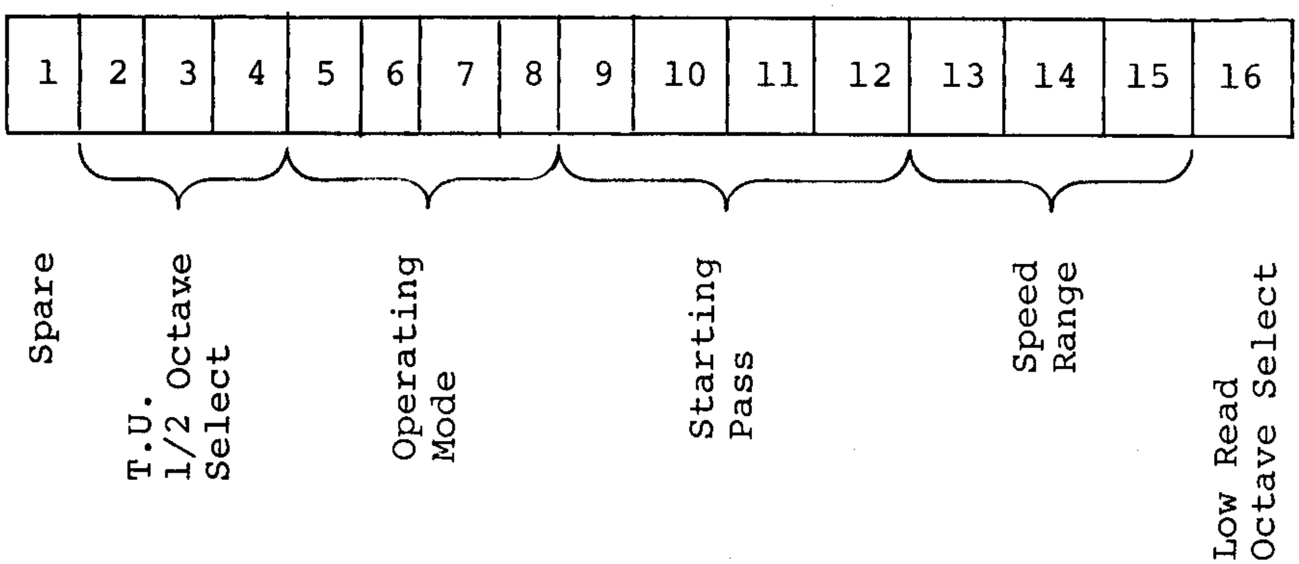
Speed Group			Half Octave Command
III	II	I	
120-85 ips	30-22 ips	7.5-5.3 ips	0
85-60	22-15	5.3-3.75	1
60-43	15-11	3.75-2.7	2
43-30	11-7.5	2.7-1.875	3
30-22	7.5-5.3	1.875-1.35	4
22-15	5.3-3.75	1.35-.9375	5
15-11	3.75-2.7	.9375-.75	6
11-7.5	2.7-1.875	.9375-.75	7

Once the data signals are converted into TTL logic levels, they are decoded and fed to the dejitter buffer. When operated in the serial mode, the only function of the dejitter buffer is to remove the ill-effects of the timebase error built up by the tape transport. However, in the parallel mode, the buffer is also used to remove interchannel timing errors as well as strip out the sync word inserted during data recording and remove the gap between recorded data blocks. The output of the dejitter buffer is then multiplexed into a serial output bit stream. Provisions are made to supply either NRZ or biphase level format at the recorder output interface.

Tape Speed Control. — Speed control of the capstan drive assembly is accomplished by a phaselock servo that consists of a brushless DC motor, current mode driver, phase detector and mode control logic. The motor is a delta wound, optical commutated, brushless DC type. There are three capstans redundantly belt-coupled to the motor shaft in a symmetrical arrangement called Delta Drive. An optical tachometer is also connected to the motor shaft as a means of indicating motor shaft position when in the tach mode. The motor is driven from a current mode driver that employs motor current feedback as a means of obtaining uniform speed performance over the 160:1 speed range required. This wide operating speed range accounts for a great deal of the flexibility afforded by the recorder. The phase detector compares the phase difference between a servo speed reference frequency and the feedback obtained from either the tach or the tape. A sample-and-hold technique is used to remove the carrier frequency prior to being fed to the current mode driver. The servo has three modes of operation: accelerate/decelerate, tach and tape. In the accelerate/decelerate mode, the servo loop employs rate feedback until the final speed is achieved. The tach mode is used during the data recording mode and in the reproduce mode as a means of making a smooth transition between the acceleration profile and tape lock. The tape lock mode, on the other hand, is always used during the playback of the recorded data.

Command Interface and Mode Control Logic. — The command interface is structured for a 16-bit serial command word that is present during a command gate interval. Line receivers are used to interface the command data and clock signals while a single ended TTL line is used for command gate interval. The command is stored in a command register within the recorder until a new, valid command has been received. All other functions associated with the command detection are physically located on one P.C. board within the TU. In the event a nonstandard command interface requirement should arise, the unique command-decoder could be designed to adapt to the pre-sent decoder output that link all recorder functions. A detailed format of the command word is shown in Figure 3. The eight operational modes are described below:

Fast Forward - The recorder will shuttle tape at 120 inches per second to the end of tape (EOT).



Command Word Format
Figure 3

Rewind - Same as Fast Forward except that tape will shuttle toward beginning of tape (BOT).

Record Serial - The unit will record data at a speed determined by the commanded speed octave and the external bit rate clock. Data will be recorded in a serial track-sequencing format starting with the commanded track incrementing to Track 16. Erasure of all data tracks will occur only during the recording of Track 1. Record direction is forward on odd tracks and reverse on even tracks.

Record Parallel - The unit will demultiplex the serial input data to two, four or eight parallel record channels as a function of the number of channels predetermined at the time of recorder assembly. Data is to be recorded at a speed determined by the commanded speed octave and the external clock. Data will be recorded in a parallel track-switching format starting with the first group of tracks or the commanded track group incrementing to the last group. Erasure of all data tracks will occur during the recording of the first group of tracks only (i.e., Track 1). Recording will continue until an operational mode command is changed or end of sequence is detected.

Reproduce Reverse Serial - The unit will reproduce data at a speed determined by the commanded speed octave and the external clock. Data is to be reproduced in a serial track-sequencing format starting with Track 16 or the commanded track decrementing to Track 1. Reverse serial playback shall reproduce the data opposite record. Playback will continue until the operational mode command is changed or the end of sequence is reached.

The 16 bits are utilized as follows:

Bit Position	Functional Description
Bit 1	Spare
Bits 2-4	These bits are effective in the reproduce mode and are used in conjunction with bits 13-16. They establish which 1/2 octave speed range of eight available will be selected as a function of a predetermined speed group (Table II).
Bits 5-8	Select one of eight functional modes (see text).
Bits 9-12	This command field defines the starting pass from which an operation is initiated. In the serial mode, the starting pass equals the track I.D. In the parallel mode, the pass count shall be a function of the selected parallel tracks.
Bits 13-15	Selects any one of eight speed octaves in reproduce mode, the speed octave must be compatible with predetermined T.U. speed group.
Bit 16	A one in this bit selects the low band filter in the E.U. A zero in this bit selects the high band filter in the E.U.

Playback Parallel - The unit will reproduce data at a speed determined by the commanded speed octave, predetermined number of parallel channels and the external clock. Data is reproduced in the parallel track switching format the same as described for the record parallel mode except that both the order in which groups of tracks are reproduced and the tape direction of any group of tracks is opposite of that of record. Reproduce will continue until the operational mode is changed or the end of sequence is reached.

Playback Forward Serial - This mode is identical to the reverse serial reproduce except the direction of the tape motion and track switching are reversed.

Stop/Standby - The primary power supply will be turned off and tape motion stopped. The standby power supply will remain energized and provide power through the control logic interface. The recorder will be receptive to commands while in this mode and will output analog and digital telemetry signals.

Power Interface and Internal Power Distribution. — The recorder is powered from a conventional 28 V ±9 VDC power bus. The internal power supply converts this bus into two regulated voltages. One regulated bus is used to distribute, through an isolation inverter, power to all functions within the EU. The second bus is fed to the TU and, in like manner, uses this voltage to distribute power to all TU functions.

The internal power supply is designed as a module and hence, if a spacecraft requirement has a power interface that is not within the present design limits, sufficient space is available for redesign without affecting any other recorder function.

Telemetry Interface. — The standard tape recorder has provisions for four classes of telemetry signals: discrete analog, discrete digital, multiplexed analog and multiplexed digital. In previous spacecraft applications, tape recorder telemetry was limited to temperature, pressure, EOT/BOT indications and some form of mode responses. More often than not, little emphasis was placed on implementing diagnostic telemetry signals. However, the spacecraft design of the future has a complex telemetry structure that can accommodate many diagnostic telemetry points in an efficient manner. For this reason, the telemetry design of the standard recorder has four multiplexed analog outputs as well as one multiplexed digital output. The telemetry interface, like the command interface, has a telemetry gate and telemetry clock signals that are interfaced to the recorder by line receivers. A major frame sync signal is in a single ended TTL compatible signal used to index the internal multiplexer to a known state.

Conclusion. — This paper has analyzed each of the five basic functions of a spaceborne tape recorder. As predicted, the telemetry function has the least impact and the signal conditioning in the reproduce mode is the critical function for limiting recorder flexibility. The ultimate goal is to provide sufficient balance between flexibility and adaptability such that no single mission is required to pay the size, weight, power and reliability penalties for the sake of standardization.

For future applications, an additional expansion of speed ranges is available because of the unique Delta Drive design. Speeds as low as 0.19 ips during record are achievable.