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APPLICATION OF THE MODULARIZATION CONCEPT TO SATELLITE TAPE RECORDERS

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SUMMARY

A program is underway at Goddard Space Flight Center to adapt the widely accepted concept of modularization to magnetic tape recorders for satellite application. Prior to this program, special recorders were custom-designed for the particular requirements at hand. Even long lead times often were insufficient for development of good designs with assurance of reasonable reliability. Reduction of recorders to discrete mechanical modules offered an attractive solution to this problem. Slight design variations in modules would then make possible a series of recorders to operate at different speeds, operate over different frequency ranges, and perform different functions. This modularization concept is being applied in the design and development of the recorder for the United Kingdom No. 2 satellite with considerable success.

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INTRODUCTION

Early in the course of development of satellite magnetic tape recorders it was realized that there was a genuine need to supplant the empirical "trial and error" approach subscribed to in many quarters in the design of recorders. Each recorder application was met by a custom design often embodying many untried techniques. This course led to disruption of schedules, introduced unknown factors affecting overall reliability, and, in short, courted trouble.

Work at the Goddard Space Flight Center in magnetic tape recording has been directed toward the goal of a truly modularized recorder. In the past, some degree of recorder modularization has been claimed by considering the entire tape transport as a single module and dividing the electronic circuits into other modules. However, recorder requirements for a wide range of functions, involving changes in parameters such as speed, recording time, bandwidth, etc., indicate that the logical course is toward further refinement in modularization. The concept that is being developed involves the fabrication of a recorder by arranging a number of standard mechanical modules in a suitable configuration. This concept should facilitate the compilation of a recorder reliability history through use of the histories of the individual modules.

The many difficulties experienced in previous programs involving the custom design technique added considerable impetus to the work for a modularized satellite recorder. The United Kingdom No. 2 Satellite project presented an ideal opportunity to put into practice some ideas on modularization of the tape recorder. In order to maintain sufficient control in the development of the modularization concept as applied to the recorder, preliminary work was undertaken "in-house". This preliminary work consisted of the design and development of the breadboard, engineering test model, and prototype recorders for the U.K. No. 2 program.

FUNCTIONAL REQUIREMENTS

The orbit selected for the U.K. No. 2 is such that the required record interval is 110 minutes. The playback time must be limited, of course, to the period during which data can be transmitted from the spacecraft to a telemetry acquisition station. Also, it is desirable to hold playback time to a minimum in order to minimize the amount of data lost (not recorded) during playback. In addition and most important, the playback-to-record speed ratio P/R must be such that the information rate during playback is equal to the rate at which unstored (real-time) data are transmitted. The P/R that best meets these requirements is 48:1 (±0.5 percent). It is required that the recorder remain continuously in the record mode without interruption until it is switched into playback by a command signal. It is further required that the recorder remain in the playback mode long enough to play back all recorded data, and then automatically return to the record mode; thus a playback timer is needed.

The signals to be recorded are in the form of bursts of frequencies in the range 93.8 to 321 cps with an amplitude of approximately 1 volt peak-to-peak. It should be noted that upon playback the required frequency response range of the recorder is 48 times that of the record mode or 4.5 to 15.4 kc. The output signal from the recorder in playback is required to have an amplitude of approximately 2 volts peak-to-peak. Since the intelligence in this signal is contained only in the frequency and not in the amplitude, the recorder can be operated in the magnetic saturation region of the tape and thus provide a maximum signal-to-noise ratio. The dynamic signal-to-noise ratio must be at least 30 db.

The power available to operate the recorder is severely restricted by the limited capacity of the spacecraft power source. The power consumption of the recorder and associated electronics must be restricted to 0.75 watt in the record mode and 1.5 watts in the playback mode. The supply voltage available to operate the recorder is nominally 12 volts dc and may vary, depending on the charge condition of the batteries, from 11 volts to 14.5 volts.

Further requirements are that the recorder occupy a space no greater than 7.25 inches in diameter and 3 inches in height, and that its weight not exceed 4 pounds. Flutter during playback must be no greater than 1 percent peak-to-peak for any one discrete flutter frequency component, or for any 200-cps band between 2500 and 17,000 cps. Amplitude uniformity at the highest recordable frequency is to be such that the maximum deviation from the maximum peak output does not exceed 10 percent. The recorder's long-term speed stability must be within 1 percent over the temperature range from -15 ± 2 to $+45 \pm 2\,^\circ C$.

This brings up the question of environment. The recorder is to be housed in a pressure-tight container in a dry atmosphere of 90 percent (by volume) nitrogen and 10 percent helium at a pressure near 1 atmosphere. The purpose of the pressurized container is to preclude bearing lubrication problems that would arise in a vacuum and to forestall possible deterioration of the magnetic tape. Nitrogen was chosen as the atmosphere because of its relative chemical inertness and helium as a tracer to test for leaking of the container.

The recorder, while in the non-operating state, will be expected to withstand temperatures of -30 °C and +60 °C for six hours each without suffering any permanent damage as determined by performance tests. It must withstand temperatures of -17 °C and +47 °C for 24 hours each while operating, without suffering any degradation in performance at these temperatures. The maximum sinusoidal vibrations which the recorder is expected to undergo are summarized in Table 1: The recorder is expected to withstand the vibration test indicated in Table 1 along three orthogonal axes, one of which is parallel to the thrust axis. In addition, the recorder must withstand Gaussian random vibration along the three axes for 4 minutes each at an rms acceleration level of 11.5 g and a power spectral density of 0.07 g^2/cps in the frequency range 20-2000 cps.

Table 1

Recorder Sinusoidal Vibration Test

Frequency Range* (cps)	Duration (min)	Zero to Peak Acceleration (g)
5-50	1.66	2.3
50-500	1.66	10.7
500-2000	1.00	21.0
2000-3000	0.30	54.0
3000-5000	0.36	21.0

*The time rate of change of frequency is proportional to the frequency at the rate of two octaves/minute.

The recorder must, of course, withstand shock due to igniter or booster ignition without damage. This should not exceed in effect the shock due to three half sine pulses of 30 g peak amplitude applied parallel to and in the direction of the thrust axis, the total period of each shock pulse being between 10 and 15 milliseconds. It should be noted that all shock and vibration occur during powered flight and that the recorder operates in the record mode during this period. The recorder may suffer in performance during shock and vibration but must suffer no permanent damage as determined by performance after the shock and vibration is over. Along the thrust axis the maximum unidirectional acceleration level which the recorder must withstand without damage is 28 g applied for 5.0 minutes. Along any other axis orthogonal to the thrust axis, the maximum expected unidirectional acceleration is 12 g applied for 0.5 minute.

The operational life design goal for this recorder is one year.

Figure 1 shows the engineering test model of the recorder that evolved from the above specifications.

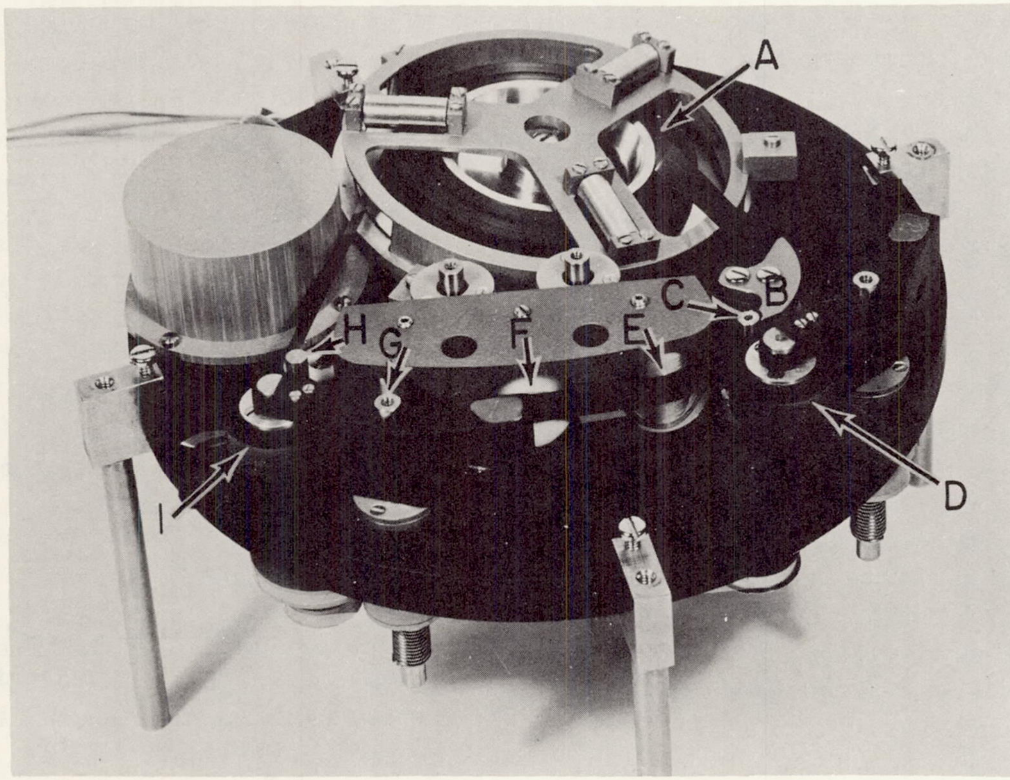

Figure 1—The UK-2 magnetic tape recorder

DRIVE SYSTEM

The recorder drive system is located on the under side of the recorder as shown in Figure 2. The system consists of the motor, two idler assemblies, and two capstan assemblies, all interconnected by means of Mylar belts* with the exception of the connection between the two idler assemblies, which is accomplished by means of a Mylar-rimmed drive wheel. The modules comprising the drive system or transmission are shown individually in Figure 3 along with the two pinch roller assemblies which, though not integral components of the transmission, are nevertheless essential elements in the overall tape drive system. Two spring clutches are utilized to provide slip or to transmit drive, depending on the direction of rotation. These clutches are located on the entrance capstan assembly and the first idler assembly as shown in Figure 3 at A and B, respectively. Briefly, the operation of the drive system is such that in one direction of rotation of the motor the two capstans operate at record speed (1/4 inch per second) and in the opposite direction they operate at playback speed (12 inches per second). Both capstans, of course, always rotate in the same direction. Figure 4 is a sketch of the drive system showing the

*Licht, John H., and White, Arthur, "Polyester-Film Belts," NASA Technical Note D-668, May 1961. Also published in *Machine Design*, 32(22):137-143, October 27, 1960

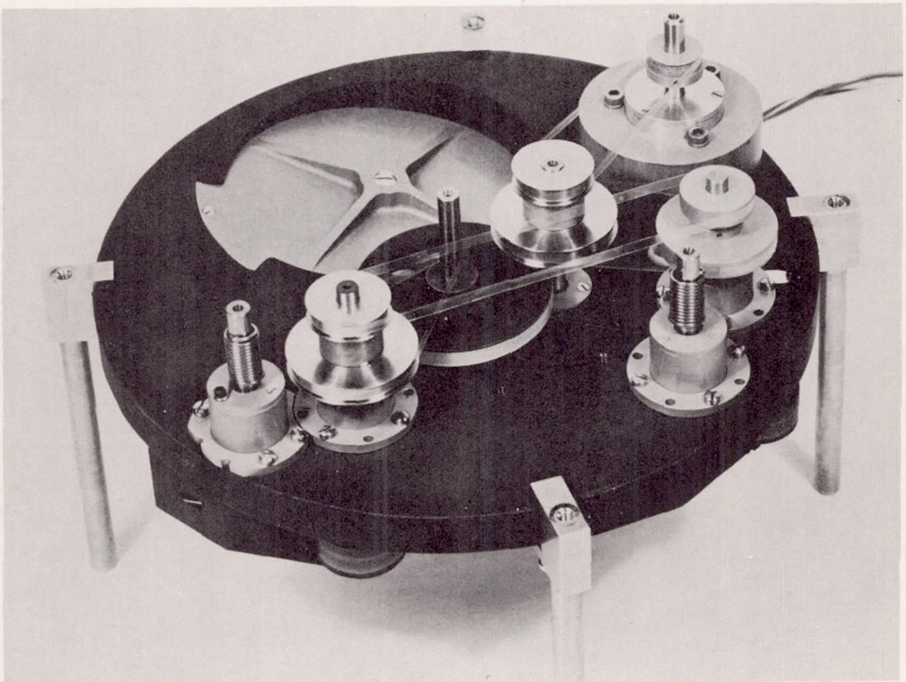

Figure 2—Bottom view of the UK-2 recorder

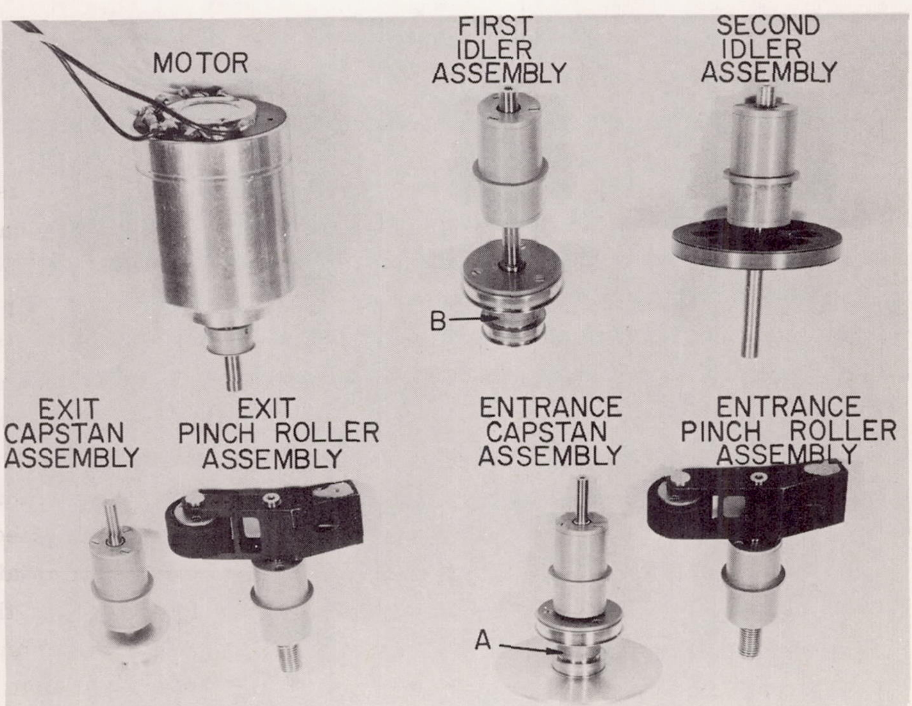

Figure 3—Drive system modules

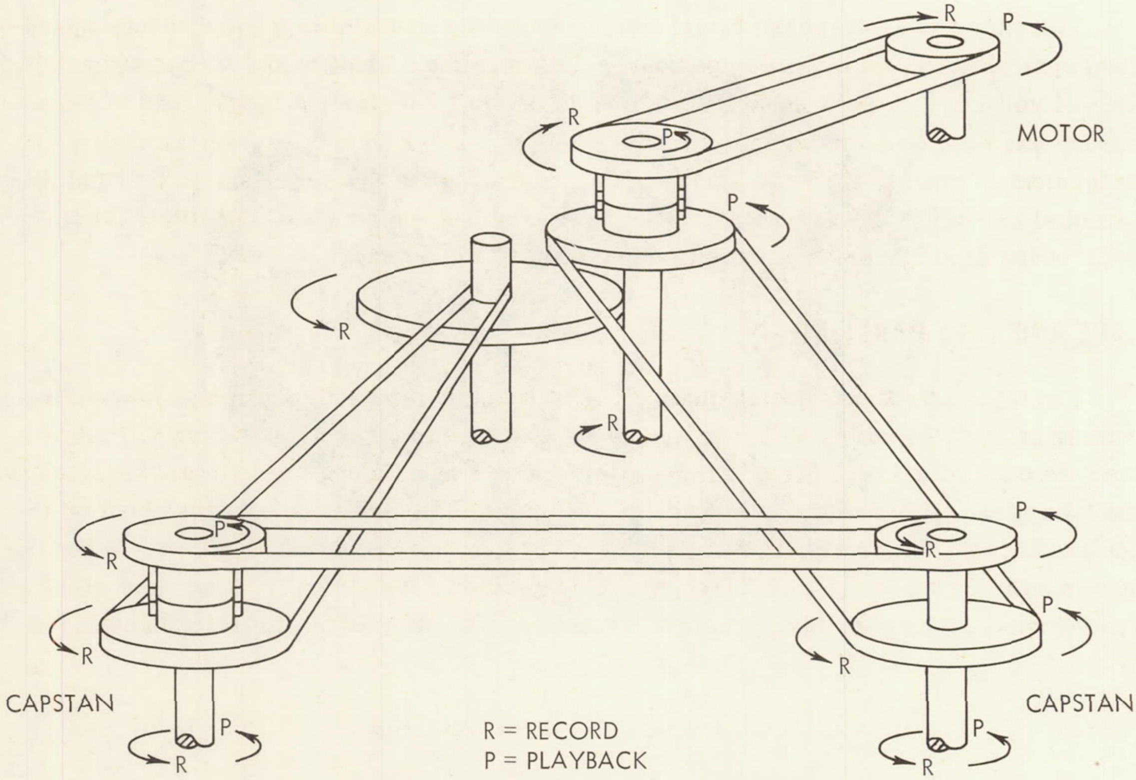

Figure 4—Drive system

direction of drive for each module with "R" indicating the record mode and "P" indicating playback mode.

Figure 5 shows the two basic modules that are used in the two capstan assemblies; in the two idler assemblies, and in the two pinch roller assemblies. These two basic modules are identical except for the location of the mounting flanges. It should be noted that the bearings for all rotating parts are preloaded duplex pairs. This is essential to minimize bearing noise and to safeguard against environmental vibration damage to the bearings.

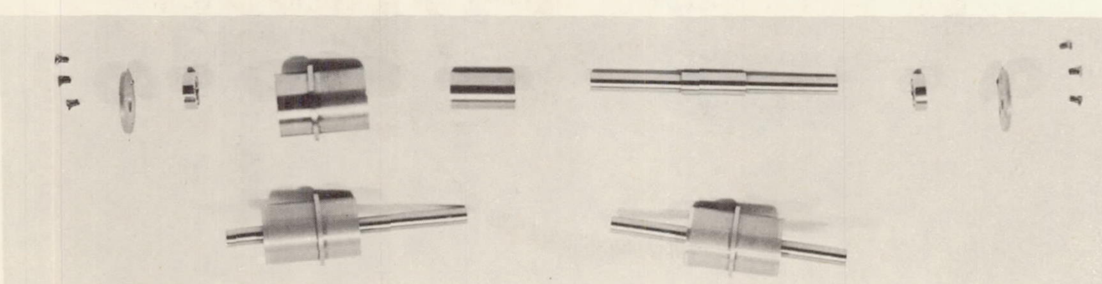

Figure 5—Basic modules

The motor is a two-phase hysteresis synchronous motor with a synchronous speed of 2000 rpm when driven by a 100 cps source. Its maximum shaft output torque when driven by a 24 volt peak-to-peak square wave is 0.20 oz.-in.; the starting torque load of the recorder has been found to be approximately 0.05 oz.-in. A unique bearing mounting arrangement is used to preclude variations in loading within the motor due to thermal differential expansion or contraction. Two flat Belleville washers that constitute the end bells of the motor are used to position and preload the bearings.

TAPE AND TAPE HANDLING

The tape is instrumentation quality 1/4 inch Mylar tape with a graphite lubricating coating on the back side. The tape supply is contained in a cartridge shown in Figure 6, the free ends of the tape being spliced together to form a closed loop. It will be noted that the tape feeds off of the hub at the center of the cartridge and back onto the spool on the outside at the opposite side of the cartridge. The closed loop lends itself well to the requirements placed on the recorder. By selecting the proper length of tape for a given record speed, it is possible to record data during the entire orbit, arriving back at the

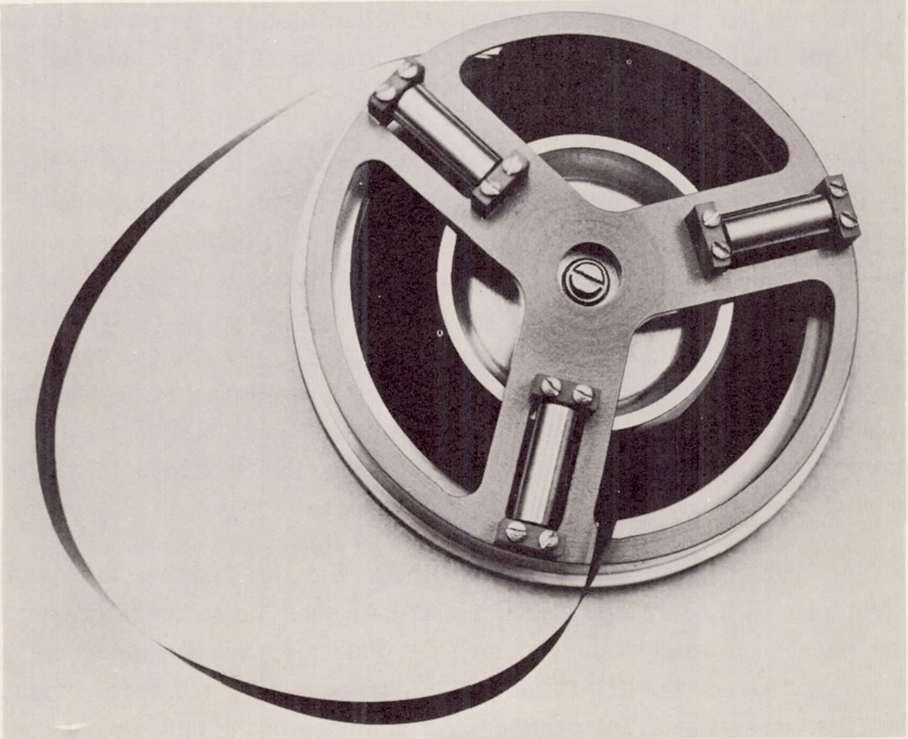

Figure 6—Tape cartridge

starting point on the tape and being ready immediately for playback. An equally important advantage is the simplicity of programming that the closed loop configuration makes possible: it is necessary only to command the recorder to play back, with provision having been made for a timer to return the recorder to the record mode after the tape has been played through completely.

Since adjacent layers of tape in the cartridge must rub against one another, the use of a tape having a relatively hard oxide is essential to minimize deterioration due to ruboff. In addition, lubrication is necessary on the back side of the tape to restrict the frictional load due to rubbing of the adjacent layers, so that the maximum power limitations may be met. At present the only type of lubrication commercially available is the powdered graphite coating. Since this coating has rather limited life (being subject to considerable ruboff) development is underway on improved lubricating coatings.

The requirements placed on the tape in this application are primarily physical. The oxide and lubricant should be hard enough and should adhere to the Mylar well enough to minimize ruboff and provide reasonable tape life. A highly conductive coating on the back side of the tape is desirable to eliminate loading due to buildup of a static electric charge on the Mylar. The tape should have sufficient stiffness to enhance the lubricating properties by reducing any tendency of the tape to bind if it is physically distorted at the hub or within the wind. This all but rules out the extra-thin 0.5 mil tapes with presently available lubricating coatings. Requirements on the magnetic properties of the oxide coating are minimal; any good instrumentation quality coating will serve.

The profile of the spool on which the tape is wound in the cartridge is shown in Figure 7. The angle of the wall of the hub as shown has been found to provide the smoothest tape flow off the hub with the least expenditure of power. The angle of the floor of the spool offsets adjacent tape layers, so that any tendency of the jagged edges of the tape to mesh and thus add to the load is minimized. It should be noted that there are three rollers in the roof of the cartridge canted at the same angle as the floor of the spool, to restrict lateral movement of the tape under zero gravity. To provide smooth flow of tape, the tape cartridge is canted with respect to the recorder base plate at an angle of 8 degrees in a direction perpendicular to the path of the tape entering and leaving the cartridge. This results in the least physical distortion of the tape as it leaves the cartridge.

Reference back to Figure 1 will clarify the tape path. The tape leaves the cartridge at the hub (A); passes through a slotted guide (B); passes the entrance capstan (C) and pinch roller (D); passes the head module housing the playback head (E), the erase head (F), and the record head (G); passes the exit capstan (H) and pinch roller (I); and then goes back onto the outside of the tape spool in the cartridge. Tensioning of the tape across the heads to provide the necessary intimate contact of the oxide coating with the head gaps is accomplished by means of a 2 percent speed differential between the two capstans. This differential

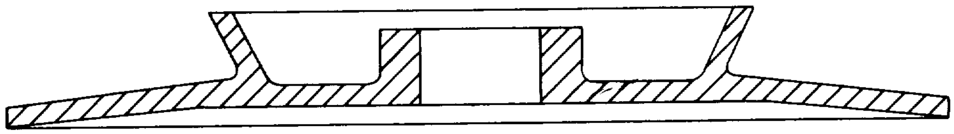

Figure 7—Cross-section of tape spool

is obtained by appropriate sizing of the capstan assembly drive pulleys. The pinch roller assemblies are adjusted to provide forces against the capstans of approximately 65 grams for the entrance roller and 30 grams for the exit roller, by means of springs located at the bases of the pinch roller assemblies. It should be noted that the pinch roller arms are statically balanced about their pivot points so as to minimize deleterious effects due to excitation under vibration. The guide block is provided in the tape path to smooth out the line of flow of the tape from the cartridge to the trailing capstan and to direct the tape in accordance with the centerline through the head gaps.

ELECTRONIC CIRCUITS

Motor Driver

The motor driver electronics furnish a two-phase 100 cps square wave of 24 volts peak-to-peak amplitude to the motor. A 400 cps reference oscillator whose frequency is determined by a tuning fork is used as the frequency source; the accuracy of the frequency supplied is ±0.1 percent. Two frequency-divider stages are used to step down from 400 to 100 cps. A phase-shifter circuit is used to convert the 100 cps single-phase signal to a 100 cps two-phase signal, with an amplitude of 2 volts peak-to-peak. This is fed to two complementary-symmetry switch-type amplifiers which switch at the 100 cps rate between +12 volts and -12 volts supplied by a converter. This two-phase switched voltage is then applied to the two phases of the motor. All stages of the motor driver are powered by 12 volts dc from the satellite battery pack. A block diagram of the motor supply is shown in Figure 8.

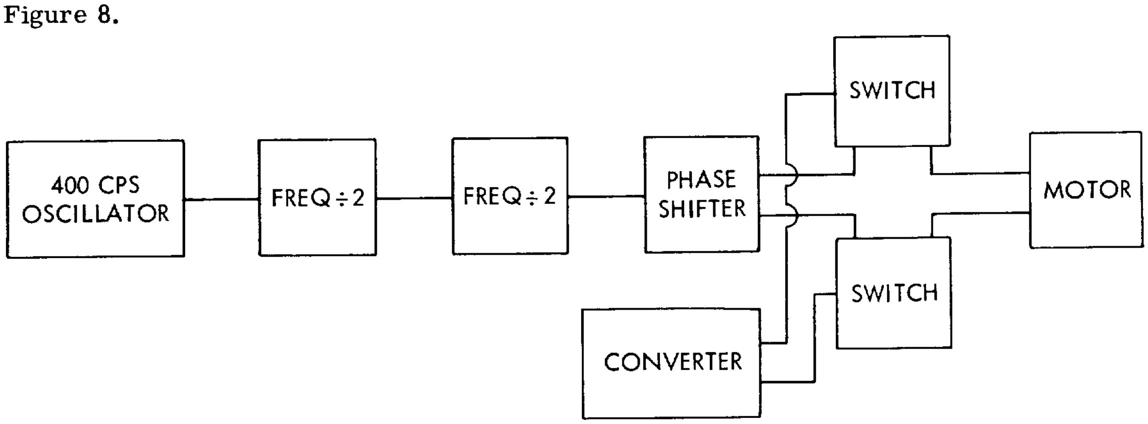

Figure 8—Motor driver supply

Record and Playback Amplifiers

The record amplifier provides constant current to the record head so that the tape is magnetized at a point just below saturation for a 1 volt peak-to-peak input signal over the frequency range 93.8 to 321 cps. A bias oscillator in the record circuit supplies a bias frequency of 2430 cps which, of course, is not critical as long as the frequency is at least three times the highest record frequency. The playback amplifier is equalized to provide an output signal of 2 volts peak-to-peak over the frequency range 4.5 to 15.4 kc, with an output signal-to-noise ratio of 40 db. The power consumption of the record and playback circuits is 88 mw on record and 63 mw on playback.

Figures 9 and 10 show the card containing the record and playback amplifiers. This card is mounted to the base plate on the under side of the recorder, just below the tape cartridge.

Heads

The head module is shown in Figure 11. The record head is indicated at "A", the playback head at "B", and the erase head at "C", and it should be noted that the tape passes the heads in that order. After recording, the tape passes through the tape cartridge and back to the head module for playback and erasure.

The gaps of the record head and playback head are 250 microinches and 150 microinches, respectively. The erase head is of the permanent magnet type. As the tape passes over the erase head it passes three progressively weaker magnetic poles, the polarity of the center pole being opposite that of the outer two. This erase head reduces the previously recorded signal to a level sufficient to meet the 30 db signal-to-noise requirement on subsequent recordings.

Playback Timer

When playback is desired the command receiver, triggered from the ground, supplies a pulse to the playback-timer mode relay which switches the record-playback circuit into playback. At the same time, this pulse turns on a unijunction oscillator which feeds a 10^3 pulse divider. At the end of 140 seconds the pulse divider supplies a pulse to the mode relay, throwing the recorder back into the record mode in which condition it remains until again commanded to play back. The mode relay switches the record amplifier off and the playback amplifier on, and also switches the motor connections to reverse the direction of motor rotation, thus obtaining the proper speed change (see "Drive System").

It should be noted that of all the aforementioned circuits, only the record and playback amplifiers are housed in the recorder case. All other circuits are located externally.

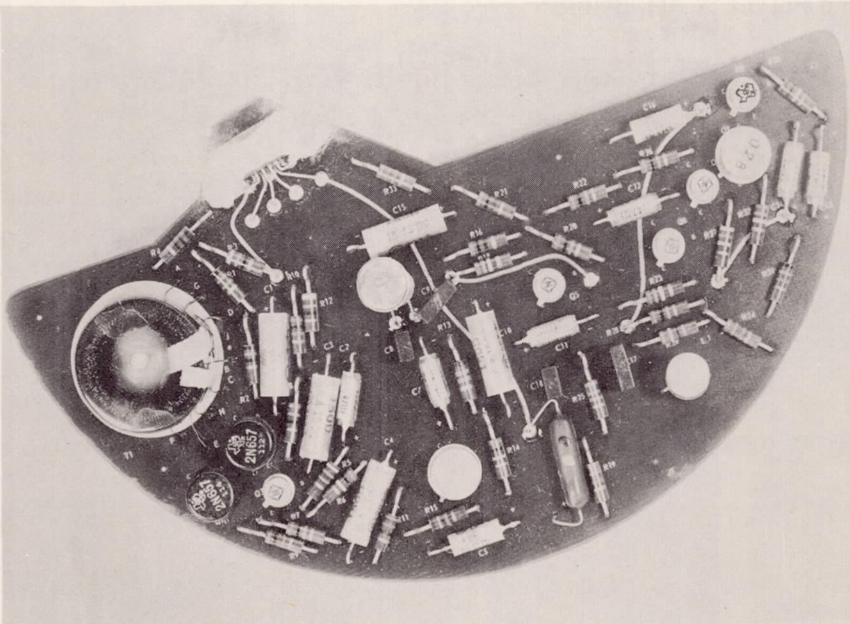

Figure 9—Record-playback card, top side

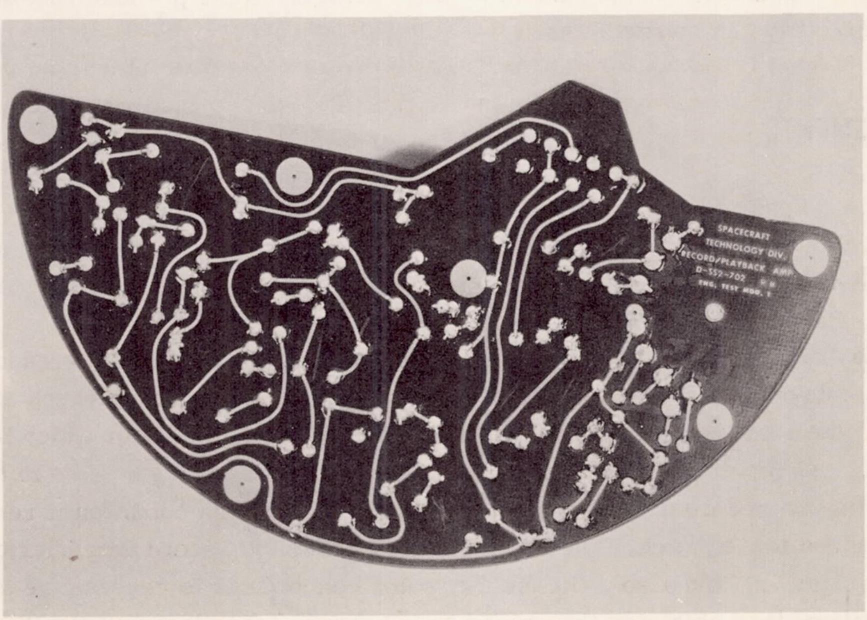

Figure 10—Record-playback card, bottom side

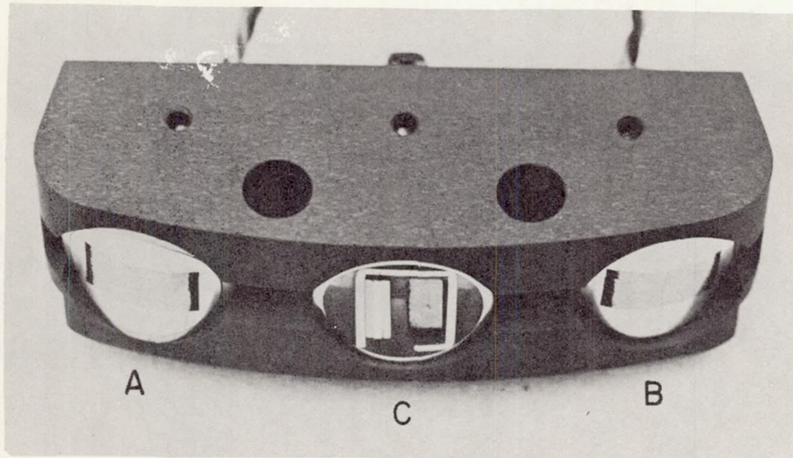

Figure 11—Head module

CONCLUSION

From a fabrication standpoint, the modularized satellite tape recorder has been shown to be feasible. Preliminary study of the three recorders constructed thus far indicates that they should live up to all expectations in regard to performance. This modularization technique will be applied in future programs with the great advantage of a reliability history on the component modules. Hence, when the next variation on the present recorder is designed, its reliability can be predicted.

ACKNOWLEDGMENTS

The Goddard Space Flight Center personnel who have contributed directly to this program are as follows: Electronic system design — Lib C. Rogers, Justin C. Schaffert, and Thomas D. Clem. Mechanical system design — Paul W. Uber and Raymond W. DiSilvestre. Fabrication — Carl L. Walsh and Charles W. Heerd.

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