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**AZIMUTH DATA RECORDER-REPRODUCER  
SET AN/FSH-1 (XB-1)**

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Radio Division**

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ABSTRACT

The research, design, development, and fabrication of Azimuth Data Recorder-Reproducer Set AN/FSH-1 (XB-1) are described. This is a shore-based equipment designed to record and reproduce bearing information from direction finders employing synchronous-motor driven goniometers. The equipment is intended to improve the accuracy of reported bearings and to increase signal capture probability, especially for flash transmission, by allowing an operator to observe repeated reproduction of the recorded d-f signal while adjusting the playback gain for optimum bearing determination. Magnetic recording on gear-driven drums is utilized in conjunction with a frequency-modulated carrier system. Characteristics of the AN/FSH-1 (XB-1) equipment are presented in detail and the results of a 2000-hour life test are described. The recorder-reproducer fulfills all performance requirements set forth in the original problem request.

PROBLEM STATUS

This is a final report; this problem will be considered closed ninety days from mailing date of this report unless the Bureau requests otherwise.

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AZIMUTH DATA RECORDER-REPRODUCER SET  
AN/FSH-1 (XB-1) [REDACTED]

INTRODUCTION

The AN/FSH-1 (XB-1) Recorder-Reproducer Set, Azimuth Data, is a shore-based equipment designed to record and reproduce bearing information from direction finders. This equipment is intended to improve the accuracy of reported bearings and to increase signal capture probability, especially for flash transmissions by allowing an operator to observe repeated reproduction of the recorded d-f signal while adjusting the playback gain for optimum bearing determination. The recorder has been specifically designed to operate with the AN/GRD-6 direction finding equipment but is easily adapted for use with any goniometric direction finder employing salient-pole synchronous-drive motors for the goniometer and indicator. [REDACTED]

Recorder performance characteristics requested by the problem details are as follows:

- (a) Bearing error due to recorder action shall not exceed  $\pm 0.5$  degree and bearing pattern distortion due to recorder action shall not exceed 5%.
- (b) Storage time to be from one to three minutes.
- (c) Repeated use of recording material, retention of received signal intelligence, and repeated scanning of any portion of a recording are to be provided. [REDACTED]

The first phase of the problem was begun in January 1952 and consisted of original investigations of several recording techniques such as precision drive-systems for recording media, and wide dynamic-range frequency-modulation systems. A tentative recording-system design based on these investigations was then adopted; a working breadboard model was constructed; and its performance capabilities were carefully ascertained. Information obtained from this model served as a guide for the mechanical and electrical design of a final developmental recording equipment which was completed in August 1953 and to which the AN/FSH-1(XB-1) nomenclature was assigned. [REDACTED]

This equipment is intended to be used for extensive operational evaluation. Its performance characteristics equal or exceed all requirements of the problem details. Considerable attention was devoted to design details in order to permit the production of limited quantities with current manufacturing techniques and with very little additional engineering. The AN/FSH-1 (XB-1) equipment has been operated for a period of 2000 hours. This operation has provided a limited life-test and has established standards for a schedule of maintenance and repair. [REDACTED]

CONSIDERATION OF REQUIREMENTS

The signal to be recorded is the detected video output of the AN/GRD-6 direction-finder receiver. The receiver input is modulated by a goniometer driven by a salient-pole synchronous motor rotating at 20 revolutions per second. This goniometer produces a

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"figure eight" antenna pattern so that reception of a steady radio-frequency carrier produces a receiver video-output waveform corresponding in appearance to a full-wave-rectified, 20-cps, sine wave. Any modulation present on a carrier is superimposed on this waveform. The AN/GRD-6 indicator is of the mechanically rotated deflection-coil type and is driven by a 20-rps salient-pole synchronous motor which is accurately locked both in rotation rate and in phase with the goniometer drive motor. The receiver output produces the usual "propeller" pattern on the indicator. (Increasing amplitude of detected signal produces deflection toward the center of the indicator.) [REDACTED]

The minimum recorder-reproducer frequency response required for satisfactory reproduction of the receiver output waveform is from dc to 2000 cps. The dc requirement is necessary in order to maintain phase accuracy and to maintain the no-signal pattern position, or "circle diameter." The minimum upper frequency is determined by the required sharpness of the propeller pattern points. [REDACTED]

The nulls of the receiver video waveform, which corresponds to the tips of the indicator propeller pattern, remain at ground potential regardless of the r-f signal level (within the limits of the depth of the antenna null) and maintain constant circle diameter and/or propeller length. The loops of the video waves are formed by a unidirectional swing with respect to ground, and their amplitude is dependent on the r-f signal input level and receiver sensitivity adjustment. The receiver output waveform is available in either polarity from cathode follower output stages. The indicator utilizes only the positive waveform. Thus, either polarity is available for the recorder input, but the recorder output must be positive. [REDACTED]

Received signals normally have a greater dynamic range than is available in the receiving equipment for a fixed sensitivity adjustment. When no knowledge of the expected signal level is available, it is necessary to operate the receiver at a relatively low sensitivity level to prevent overload by strong signals. However, during such operation, signals are encountered at levels of 30 db or more below that required to produce a properly closed pattern. When there is insufficient time to adjust the receiver sensitivity, as for short transmissions, it would be desirable to have a large dynamic range capability in the recording system to enable weak recorded signals to be sufficiently amplified during reproduction to produce a closed pattern. Although no specific recorder dynamic range requirement was stated in the problem, for the above reasons consideration was given to methods of obtaining a large dynamic range within the recording equipment. Another feature which might add considerable value to the final recorder, though not specifically required, is the ability to record continuously while a previously recorded signal is being reproduced. Methods of providing this type of operation were investigated throughout the development of the recorder. [REDACTED]

The bearing error introduced by the recording system was specified not to exceed  $\pm 0.5$  degree. This translates into a maximum time deviation of  $\pm 69.5$  microseconds being introduced by the combined record-reproduce process. This deviation must include all synchronization errors between the rotational motions of the goniometer and recorder, and between the reproducer and indicator. Proper operation of the AN/GRD-6 equipment requires accurate phase and velocity synchronization of the goniometer and indicator drive motors. Thus, in addition to the video signal, both phase and velocity information from the goniometer motor must be stored by the recording system in a form such that it can be used during reproduction for phase and velocity synchronization of the indicator drive motor. [REDACTED]

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## BASIC CHOICES AND DECISIONS

In any recording system, one of the first and most basic decisions to be made is the selection of the type of recording to be used. The requirement for repeated use of the recording medium would seem to be best fulfilled by a magnetic system. Consideration of the remaining requirements did not reveal any required characteristics for which magnetic recording was not suitable; therefore, this type of recording was tentatively adopted. [UNCLASSIFIED]

Two approaches to a method of storing goniometer phase and velocity information were considered as follows: (1) simultaneous recording of goniometer position information and receiver video output on two channels having very small relative timing error, and (2) recording the receiver video on a medium which always has a known position and velocity with respect to any goniometer position and velocity. Use of the first method requires precise translation of the goniometer azimuth position into an electrical signal suitable for recording and, upon reproduction, use of this signal to control precisely the physical rotation of the indicator deflection coils. Thus, an electro-mechanical servo system is required for proper indicator synchronization. The high inertia of such a system, particularly since the AN/GRD-6 indicator does not use a low-inertia motor, would result in a slow initial phase-synchronization of the indicator to the reproducer, and this would be particularly disadvantageous when repeated scanning of short signals is performed. In addition, the precise positioning required necessitates a servo system having high gain and very low following error, and the virtual elimination of recording-system flutter rates which the servo system cannot correct. [REDACTED]

The second aforementioned approach seemed more adaptable to the AN/GRD-6 equipment. The synchronous motors which drive the goniometer and indicator utilize the same power source and are equipped with a system for locking them in precise relative phase. Thus, if a synchronous motor is used to drive the recording medium it can be phase-locked to the goniometer motor during recording and to the indicator motor during reproduction, and can use essentially the same phase control system which already exists in the AN/GRD-6 equipment. The recording medium must then be phase-locked to the drive motor. This can be achieved by such methods as the use of a gear-driven magnetic drum or a gear-and-sprocket-driven magnetic-oxide-coated film. Gear-driven systems tend to produce excessive flutter amplitudes but it appears that, in a phase-locked system such as this, a design could be achieved in which a large amount of the motion instability during "record" would be repeated in the same amplitude and phase during "reproduce" and would thus be effectively cancelled. [REDACTED]

The requirement for repeated scanning of any portion of a recording and the relatively short storage time desired indicated that a helical recording path on a magnetic drum would be preferable to sprocket-driven magnetic film. In view of these considerations, a tentative decision was reached to use a magnetic drum, gear-driven by a synchronous motor. Whereas the second approach described is considered more suitable for use with the AN/GRD-6, the first approach is thought to be preferred for use in an azimuth-data recording system utilizing an all-electronic indicator, and in which the required system accuracy is somewhat less as, for example, on shipboard. [REDACTED]

Longitudinal magnetic recording offers greater resolution (response to shorter recorded wavelengths) and greater ease of application to a helical recording path on a drum than either the "transverse" or the "perpendicular" method. However, direct-current response is not attainable with "longitudinal" recording unless some type of a carrier system is used. This is true even when special direct-current, flux-reading reproduce-heads are used because of

the formation of available flux from extremely long longitudinally recorded wavelengths. A tentative decision was made to adopt longitudinal recording in conjunction with a wide-deviation, frequency-modulated carrier system. A significant reduction in the effect of the amplitude dropouts, which are typical of magnetic recording, can be achieved by the use of amplitude limiting of the carrier in the reproduce-amplifier. Wide deviation and amplitude limiting were both proposed in order to increase the potential dynamic range of the system. [UNCLASSIFIED]

The carrier to be modulated must have a minimum frequency which is about three times the maximum frequency component contained in the modulating waveform in order to reduce interaction between the carrier and the modulating signal to an acceptable minimum. The upper limit of recorder frequency response was set at a minimum of 3000 cps to assure an adequate safety factor above the requirements. On this basis the minimum carrier frequency was chosen to be 9000 cps. A maximum carrier deviation of somewhat less than 2 to 1 was adopted in order to permit removal of second and all higher order harmonics of the carrier frequency by use of a low pass filter. Accordingly, a carrier swing of 9000 to 15,000 cps was proposed. [UNCLASSIFIED]

To accommodate the maximum carrier frequency, a tentative decision was made to operate the recording heads in contact with the recording medium and at a speed of approximately 15 inches per second. A storage time of one minute was assumed. This indicated a track length of about 900 inches. To enable repeated scanning of any small portion of a recording, a track consisting of a 60-turn helix on a 5-inch-diameter drum was proposed as a suitable form factor. It was further proposed to consider using two 35-turn tracks, each scanned by a separate set of magnetic heads in such a manner as to provide time overlap and thus enable continuous recording. Such a drum would rotate at one rps and require a 20-to-1 gear reduction when driven by the 1200-rpm synchronous motor used in the AN/GRD-6 equipment. [REDACTED]

It was decided to pay particular attention to the design of the recorder control circuits and control panel so as to achieve a simple, foolproof and, to a high degree, automatic system which would require a minimum of operator attention. [UNCLASSIFIED]

#### PRELIMINARY INVESTIGATION OF RECORDING MEDIUMS AND HEADS

Operation of the magnetic heads in contact with the recording medium achieves about ten times the resolution (or "packing factor") of noncontact heads, and thus permits use of a much shorter track and smaller drum. Also, precise drum concentricity is required for noncontact operation to permit small and relatively constant head-to-medium spacing. A major disadvantage of contact recording is the occurrence of head and medium wear. This wear is of particular importance in the recording system being designed since continuous operation for long periods of time is required. Three types of magnetic recording material were considered: (1) a red iron oxide coating, (2) a nickel-cobalt plating, and (3) a synthetic rubber belt impregnated with red iron oxide. Preliminary study indicated the recording rubber might have wearing qualities superior to the other materials. Recording rubber was a relatively new development and very little information concerning its useful life or its application to recording systems was available. To provide additional information on the application of recording rubber to this problem and to compare its characteristics with those of a hard magnetic plating, the test structure depicted in Fig. 1 was designed. A commercially available nickel-cobalt plated brass drum five inches in diameter was friction driven at a speed of one revolution per second. A neoprene sleeve approximately 1/16-inch thick, homogeneously impregnated with red iron oxide and designed to fit this drum was also commercially available.\* [UNCLASSIFIED]

\*Recording sleeve and nickel-cobalt plated drum manufactured by Brush Electronics Co., Cleveland, Ohio

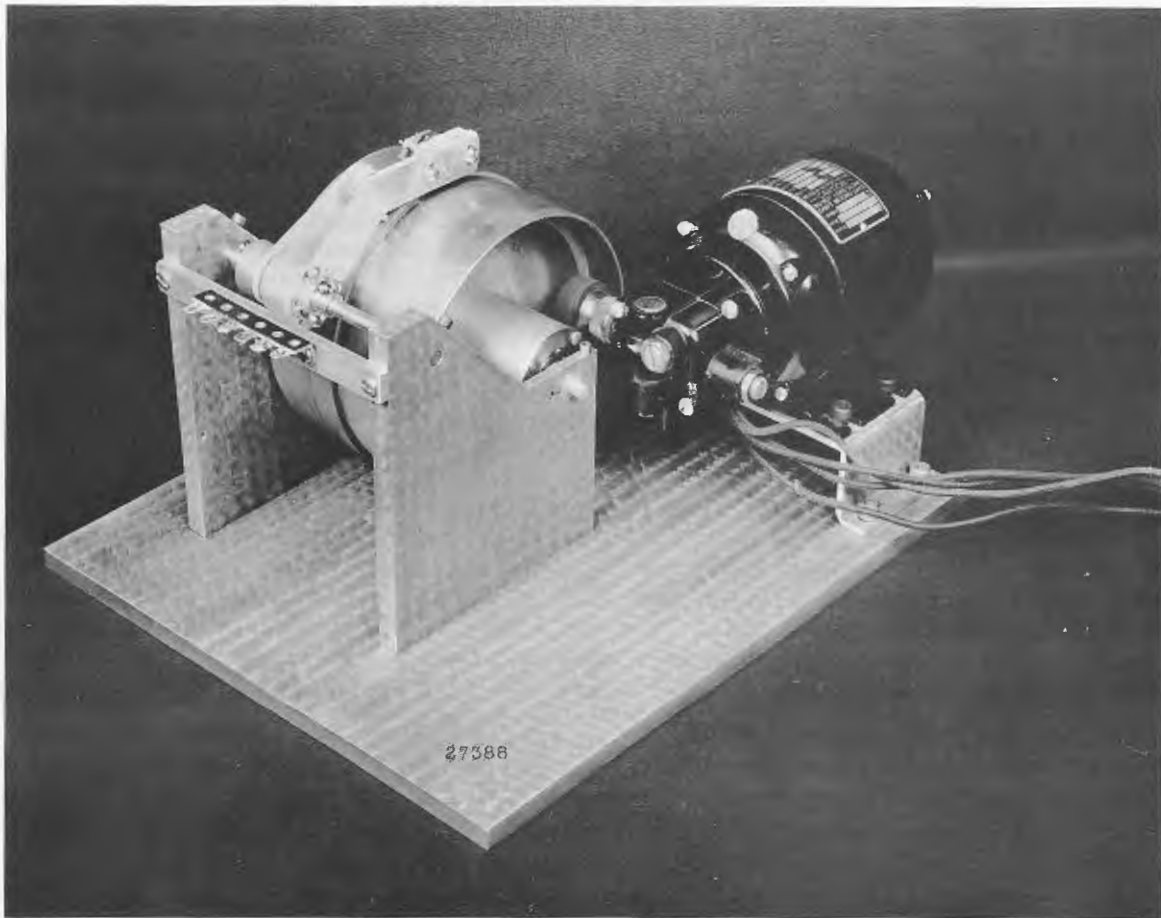


Fig. 1 - Test drum for recording components [Unclassified]

Conventional ring type erase and record-reproduce heads of an uncased design suitable for contacting a drum surface were mounted as shown in Fig. 1. A circular recording path of one second duration was provided. Erasure was performed just prior to recording and repeated playback of any one second recording was available. [UNCLASSIFIED]

The erase head\* has a track width of 0.050 inch and a gap length of 0.010 inch as compared to a 0.030-inch track width and a 0.0005-inch gap length of the record-reproduce head. † [UNCLASSIFIED]

Bias-erase and recording signals were obtained from Laboratory sources and a comparative examination of the magnetic and wear characteristics of both the plating and the rubber was performed. Signal-to-noise ratio, wavelength resolution, output level, and amplitude stability were similar and deemed to be satisfactory for both materials. The head arms were provided with slotted mounting holes to permit rotation of the heads to position the gap at the line of contact with the drum. This adjustment was much more critical on the magnetic plating than on the rubber. The slight cushioning effect of the rubber would, it was believed, alleviate damage to the heads or medium when the heads are repeatedly raised, retraced and lowered by an automatic handling system. A wax lubricant impregnated in the magnetic rubber tended to accumulate on the surface of the medium and on the heads after several days of operation. Most of the excess wax accumulated in ridges on each side of the recording path, but some lumps of wax formed directly on the path and caused erratic operation. It was then necessary to remove excess wax by washing with soap and water. [UNCLASSIFIED]

Many weeks of continuous operation are required to obtain complete and conclusive results from these recording head and medium life-tests. Owing to the high priority placed on rapid design of the recording system, it was decided to adopt tentative conclusions from the results obtained during the first few days of the test and to continue the life test throughout the duration of the problem. The rate of head wear was noted to be greater on the plating than on the rubber during the preliminary portion of the test. This did not include a sufficient period of time to determine maximum useful head life or relative wear rates of the two magnetic materials. The useful life of either medium was indicated to be much greater than that of the heads when using the proposed track length of approximately 525 inches per head. Upon the basis of these preliminary results, the recording rubber was tentatively chosen as the recording medium. Consideration of methods for improving the recording rubber, the use of more satisfactory rubber lubricants, and the use of ferrite head cores were included in the continuing life tests. Conclusions are summarized later in this report. [UNCLASSIFIED]

#### THE EXPERIMENTAL MODEL

The decision was made to design, build, and test an interim experimental model of the recording system in order to establish whether the required timing accuracy could be obtained by use of gears. This would also provide a complete system with minimum expenditure of time and effort from which to gain experience with reproduced displays and to master details involved in the production of a final model free from operational defects. Since most of the circuits and techniques appearing in the interim test model are duplicated in either an exact or very similar form in the final model, only a brief general circuit description supported by a simple block diagram will be presented for the interim model. [UNCLASSIFIED]

\*Brush Electronics type 986 erase cartridge

†Brush Electronics type 975 record-reproduce cartridge

Since this was an experimental model in the strictest sense, and due to the urgent priority placed on the over-all equipment, no time was taken for physical dress up of this model. All automatic controls were eliminated and only basic mechanical and electrical features were examined. The electrical portion was mounted in a standard enclosed rack cabinet 28 inches high and the magnetic drum assembly was mounted on top of the cabinet as shown in Fig. 2. A rear view of the complete experimental recorder-reproducer is shown in Fig. 3. [UNCLASSIFIED]

A 1200-rpm, salient-pole synchronous motor\* identical to those used for both indicator and goniometer drive in the AN/GRD-6 was used. It was believed that the use of the same motor would facilitate use of the same phase control system, and would in general be desirable since fewer spares would be required for the combined direction finding and recording equipment. [REDACTED]

The same type of five-inch-diameter magnetic drum as used in the head and media test setup was also used in this model; therefore, a 20 to 1 speed reduction was required. A two-stage helical spur gear reduction system was used as shown in Fig. 4. Integral reductions of first 4 to 1 and then 5 to 1 were used in order to eliminate hunting gear teeth and thus further reduce nonrepetitive flutter to a minimum. The gear box was fabricated by welding together steel plates 3/8-inch thick to provide extreme rigidity. The gears were cut with precision equipment, the minimum shaft spacing which could be used was determined by careful measurement of the actual pitch diameter of each gear, and these dimensions were used to locate the centers of the gear-box bearing bores. Precision sleeve bearings were used throughout. Shaft collars were provided on the inside and an adjustable collar including a double locking nut arrangement on the outside of one bearing of each shaft for control of end play. [UNCLASSIFIED]

The gear box output shaft is twenty times more critical with respect to any nonrepetitive speed variation than the input shaft and therefore a precision pin-driven steel coupling was used to connect the output shaft to the magnetic drum. The slow speed of this shaft eliminates the occurrence of bounce within the coupling and only light spring loading of the coupling drive pins against the driven surfaces is required. A stiff rubber coupling used to connect the motor to the high-speed input shaft achieved quiet operation and reduced angular acceleration to an acceptable minimum. [UNCLASSIFIED]

The magnetic-drum assembly is shown in Fig. 5. In order to reduce design and fabrication time, no head scanning mechanism for producing a helical recording path on the drum was provided. A circular recording path is used and the maximum storage time is one second. This recording time was sufficient for checking the over-all system. It was realized that some additional timing errors would be introduced by whatever head scanning system was used in the final model and this fact was borne in mind. Head pressure is adjustable and the heads can be positioned at any location chosen along the drum length. Heavy supports are used for both the drum and the head assembly to reduce all unwanted movement to a minimum. The head arms are formed of stamped aluminum sheet and were designed to achieve high rigidity with minimum weight. The entire motor, gear-box, and drum assembly was bolted to a 3/8-inch-thick steel plate which had been machined to achieve a flat surface. Complete design drawings of this mechanical unit are available. [UNCLASSIFIED]

A simplified block diagram of the experimental recorder-reproducer equipment is shown in Fig. 6. The basic system-features adopted in the previous discussion were included in the design. [UNCLASSIFIED]

\*Electric Indicator Co., type 572 1/15 horsepower



Fig. 2 - Experimental recorder-reproducer, front view [Unclassified]

Fig. 3 - Experimental recorder-reproducer, rear view [Unclassified]



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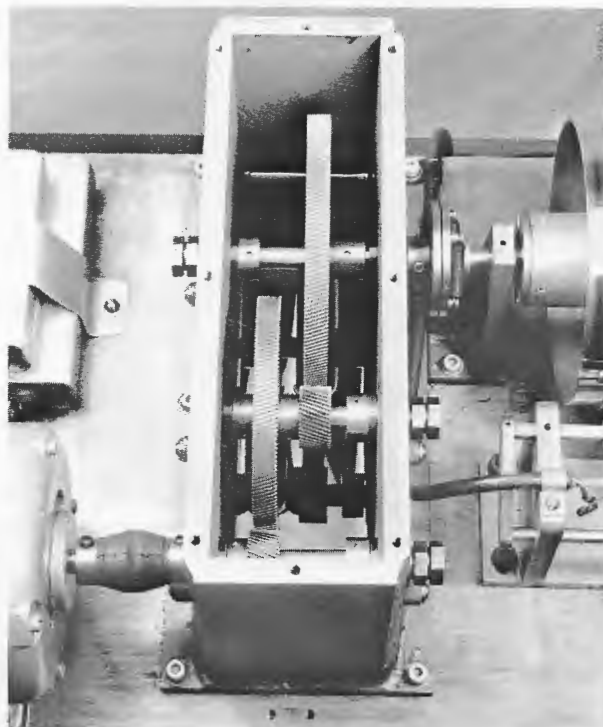


Fig. 4 - Gear box of the experimental recorder-reproducer [Unclassified]

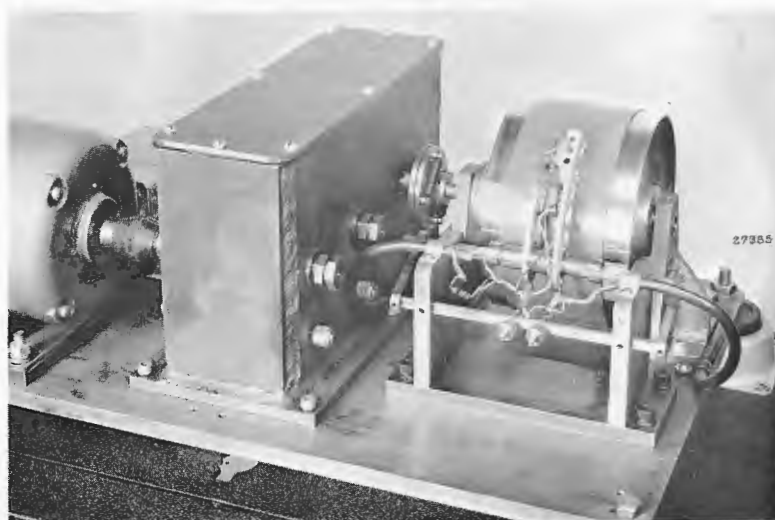


Fig. 5 - Drum assembly of the experimental recorder-reproducer [Unclassified]

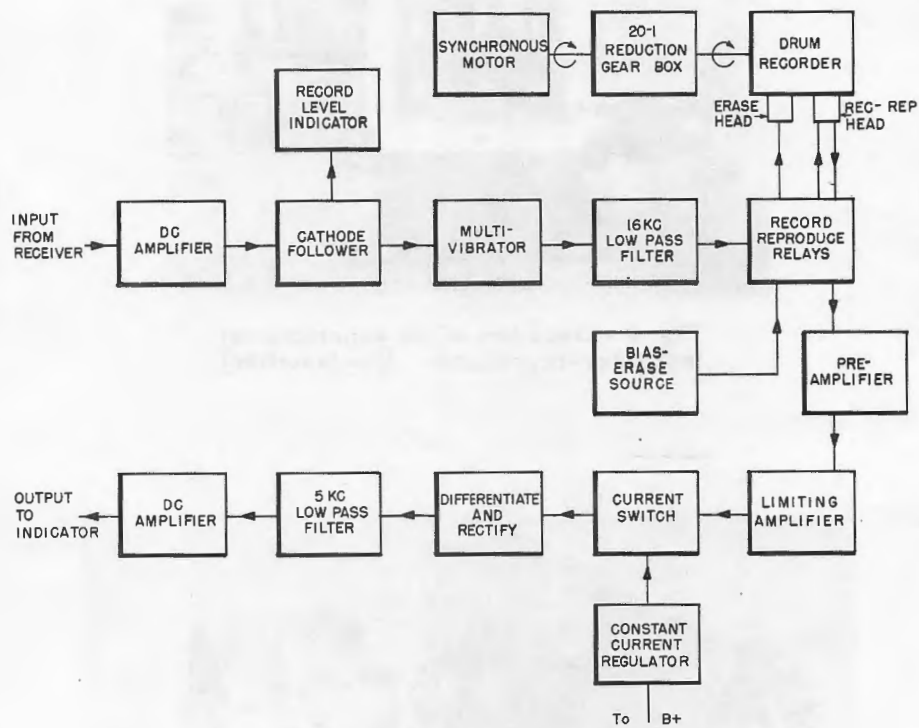


Fig. 6 - Block diagram of the experimental recorder-reproducer [Unclassified]

The input signal is applied to a dc amplifier and cathode follower which then frequency-modulates a positive-grid multivibrator. One hundred percent modulation is defined as a unidirectional carrier swing from 9 kc to 15 kc. The 9-kc point represents zero signal and 15 kc represents a maximum modulation level. A limiter prevents the frequency from exceeding 15 kc. A two-inch cathode-ray tube having a direct-coupled vertical amplifier is employed as a modulation indicator to show the correct record level. [UNCLASSIFIED]

The multivibrator output is passed through a 16-kc low pass filter to produce essentially a sine wave which is then recorded on the magnetic rubber. The rubber has a linear speed of approximately sixteen inches per second. A source of supersonic bias-erase energy is provided and is variable both in frequency and amplitude. Erasure is effected immediately previous to recording, thus providing a storage time of slightly less than one second. The bias-erase oscillator and the positive-grid multivibrator run continuously in order to reduce frequency instability. Since a combination record-reproduce head is used, a high degree of isolation is necessary between these circuits and the head during playback. [UNCLASSIFIED]

During playback the reproduced carrier is fed to a low-noise preamplifier, followed by a limiting amplifier and then a counter-type detector. This detector converts successive half cycles to pulses of constant energy by means of a current gate, a constant current source, and a differentiating network. These constant-energy pulses are fed to a 5-kc low-pass filter which produces an output voltage proportional to the frequency of the input pulses, and thus reproduces the modulating wave form. This signal is applied to a stable push-pull dc amplifier having a maximum voltage gain of approximately 320. Ten db of this gain is required to raise the output signal to the level of the input signal to the modulator. The remaining gain is necessary to utilize the dynamic range of the over-all recording system, which is approximately 40 db. [UNCLASSIFIED]

Attention was paid to the use of stable circuitry throughout to aid in obtaining a wide dynamic range. A signal 40 db below that required for 100 percent modulation produces a frequency swing of 9000 to 9060 cps, or only 0.67 percent of the carrier frequency. Thus, if a s/n ratio of 40 db is to be achieved, all system noise, due to both the electronics and the mechanical instability, must not exceed this value. The problem is accentuated by the dc response requirement, which means that reasonably long term drift must be included as noise. Accordingly, carefully regulated plate-voltage supplies and, where necessary, regulated heater supplies were used. Particular attention was given to the design of all dc amplifiers. The frequency stability of the modulator was such that, with the recorder input grounded, the frequency of the positive-grid multivibrator varied less than  $\pm 0.1$  percent during a 30-minute period. Most of this slight error was caused by drift of the preceding dc amplifier rather than by the multivibrator itself. A linear relationship was achieved between input voltage and multivibrator frequency, thus assuring low amplitude distortion in the modulator. [UNCLASSIFIED]

Low-mass, unshielded heads were used, permitting optimum head-following of the slight irregularities that are characteristic of the recording rubber. Measurements were made of the voltage induced in a reproduce head by energized record and erase heads in order to determine the magnetic shielding necessary to permit simultaneous recording and playback on adjacent drums. It was concluded that simultaneous recording and playback could be better achieved by the use of separate, shielded, drum compartments rather than attempting to shield each individual head. This compartment shielding would also serve to attenuate all external magnetic fields as well as those of an adjacent compartment. [UNCLASSIFIED]

Supersonic bias and erase were used. A common oscillator was employed to insure that both the bias and the erase frequency would be the same, thus eliminating the formation of undesirable beat notes between them. The 16-kc, low-pass filter following the multivibrator removes harmonics of the carrier wave form and prevents the formation of any spurious tones which fall within the frequency passband of the system. The bias-erase frequency and the bias and erase amplitudes were adjusted for optimum performance. [UNCLASSIFIED]

The bias-erase oscillator and the positive-grid multivibrator of the interim model were designed to run continuously during both recording and reproducing in order to achieve improved frequency stability. The use of a combination record-reproduce head was adopted to simplify the head-handling mechanism of the final model. Special switching circuits were designed to provide a high degree of isolation between the continuously running oscillators and the combination head during playback. [UNCLASSIFIED]

The reproduce preamplifier has an equivalent input noise voltage of 10 microvolts. The limiting amplifier which follows greatly reduces the effect of the typical amplitude dropouts encountered in magnetic recording, particularly when the magnetic heads and medium are worn. Great care was taken to achieve a high degree of stability in the constant-current source and in the high-gain, dc reproduce amplifier. [UNCLASSIFIED]

The interim experimental recorder-reproducer was designed specifically to operate with the AN/GRD-6 equipment, but the latter equipment was not available for use in testing and evaluating the recorder. Therefore a type-DAJ direction-finding equipment was altered to permit its use with the recording system. This alteration included installation of a synchronous drive motor for the indicator and goniometer and an additional amplifier stage for the indicator. Azimuth recordings of one-second duration were made from the DAJ indicator. When signals producing 100 percent modulation were recorded and reproduced, experienced operators concluded that any bearing error or jitter introduced by the recording system was definitely less than 0.5 degree. [REDACTED]

The f-m modulation and demodulation process of the recording system produces a constant time delay of 330 microseconds, which can be compensated by indicator adjustment. When signals 40 db below the value required for 100 percent modulation were recorded and amplified 40 db on playback, the signal and noise, as observed on the indicator, were essentially equal in amplitude. Thus, the usable dynamic range of the over-all recording system was judged to be approximately 40 db. [UNCLASSIFIED]

The operators also judged that no appreciable or deteriorative pattern-distortion resulted from the recording process. On completion of the interim recording equipment, laboratory tests were conducted to determine over-all characteristics. Such things as nonrepetitive flutter, phase shift, signal-to-noise ratio, and amplitude stability were checked. Full results of these tests are not included here since a similar but more detailed performance study was made on the final model and is described in the section on Over-All Performance of the Final Model. [REDACTED]

Thus, on the basis of the laboratory measurements of the recorder, and the d-f operator evaluation of reproduced bearings, it was concluded that the general approach to the problem as used in the interim model would be entirely satisfactory for use in the design of the final developmental version of the azimuth-data recording system. [SECRET]

## BASIC DESCRIPTION OF THE FINAL MODEL

The final model of the azimuth-data recording system, to which the AN/FSH-1 (XB-1) nomenclature has been assigned, was designed to fulfill the requirements deemed most important, as previously discussed. The basic circuitry and drive mechanism are similar to the experimental model; the controls, recording-head automatic-handling mechanism, and over-all packaging are entirely different. Considerable effort was expended to produce an engineering model which was simple, foolproof, and automatic in operation, and which incorporated a largely trouble-free design that would lend itself to production in limited quantities with little re-design. A concise general description of the final model will be presented first, and will be followed by a more detailed treatment. [UNCLASSIFIED]

The AN/FSH-1 equipment is housed in two cabinets. One is a table cabinet, designated "UNIT 2, CONTROL, RECORDER-REPRODUCER" (Fig. 7), and is designed to be mounted beside a direction-finder indicator of the type used in the AN/GRD-6 equipment. This unit includes all controls necessary for normal operation of the recording system and contains a portion of the electronic circuitry. It is 15 inches wide, 12-1/2 inches high, and 22 inches deep. [REDACTED]

The cabinet (Fig. 8) designated "UNIT 1, RECORDER-REPRODUCER" contains all the remaining mechanical and electronic components of the system. It is a floor console cabinet, equipped with retractable casters for ease of movement and designed for remote placement at distances up to 30 feet from the control unit. Unit 1 is 34 inches wide, 47 inches high, and 22 inches deep. The two units are joined by a cable assembly thirty feet in length. All connector sockets are mounted on the rear of the cabinets as shown in Figs. 9 and 10. Connections to the AN/GRD-6 receiver and indicator and to the primary power source are made at Unit 2. [REDACTED]

The block diagram of the final model is presented in Fig. 11. All components in the left portion, as indicated, are located in the control unit, and all remaining parts are in the recorder-reproducer unit. [UNCLASSIFIED]

Two complete recording channels designated A and B, each of which can accept the video output of a d-f receiver, are provided in the system. In the control unit, video signals from the recorder inputs are passed through the dc amplifiers and cathode followers, and may be separately monitored with respect to the recording levels by a single two-inch cathode-ray-tube indicator. From the cathode followers, the video signals pass through coaxial cables to the recorder-reproducer unit, where each is used to frequency-modulate a carrier. A linear relationship between the modulating voltages and the resultant frequencies is obtained by grid modulation of positive-grid multivibrators. In the system used, one hundred percent modulation is defined as a carrier swing from 9 kc to 15 kc. The 9-kc point represents a dc level corresponding to the circle diameter and 15 kc represents full deflection to the pattern center. A single oscillator provides appropriate bias and erase signals for the two record-channels. [REDACTED]

The recorder mechanism consists of two electrically independent drum recorders, A and B, mounted on a common shaft and driven by a 20-rps synchronous motor through a precision 20 to 1 gear reduction drive. Each recorder is enclosed in a mu-metal shield. A phasing mechanism is provided for rotation of the drive motor stator to maintain the proper phase position of the recorder motor with respect to the associated goniometer and indicator drive motors. Magnetic heads are operated in contact with synthetic rubber belts impregnated with magnetic oxide and stretched over five-inch-diameter drums. Each recorder is equipped with two sets of record-reproduce and erase heads and associated



Fig. 7 - Recorder-reproducer control unit [Unclassified]



Fig. 8 - Recorder-reproducer unit [Unclassified]

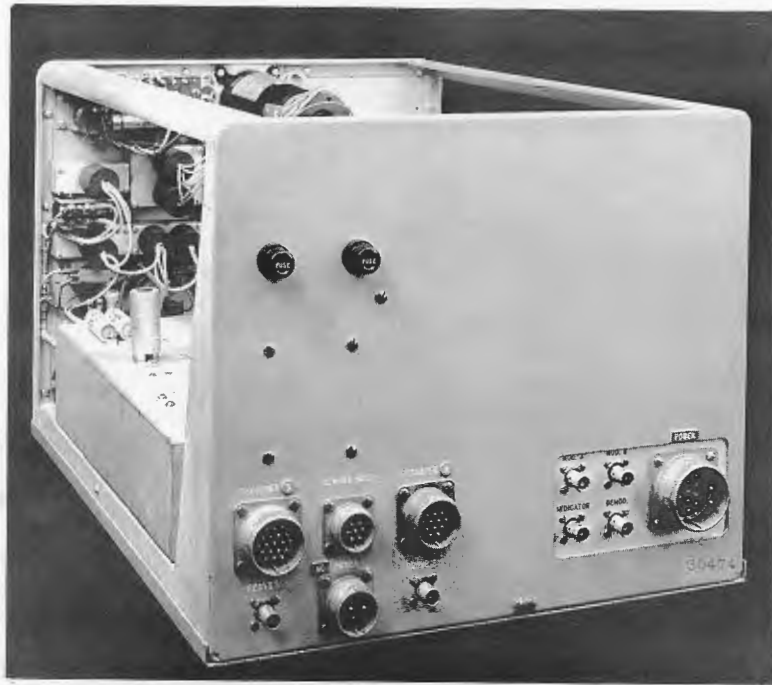


Fig. 9 - Control unit, rear view [Unclassified]

Fig. 10 - Recorder-reproducer unit,  
rear view [Unclassified]



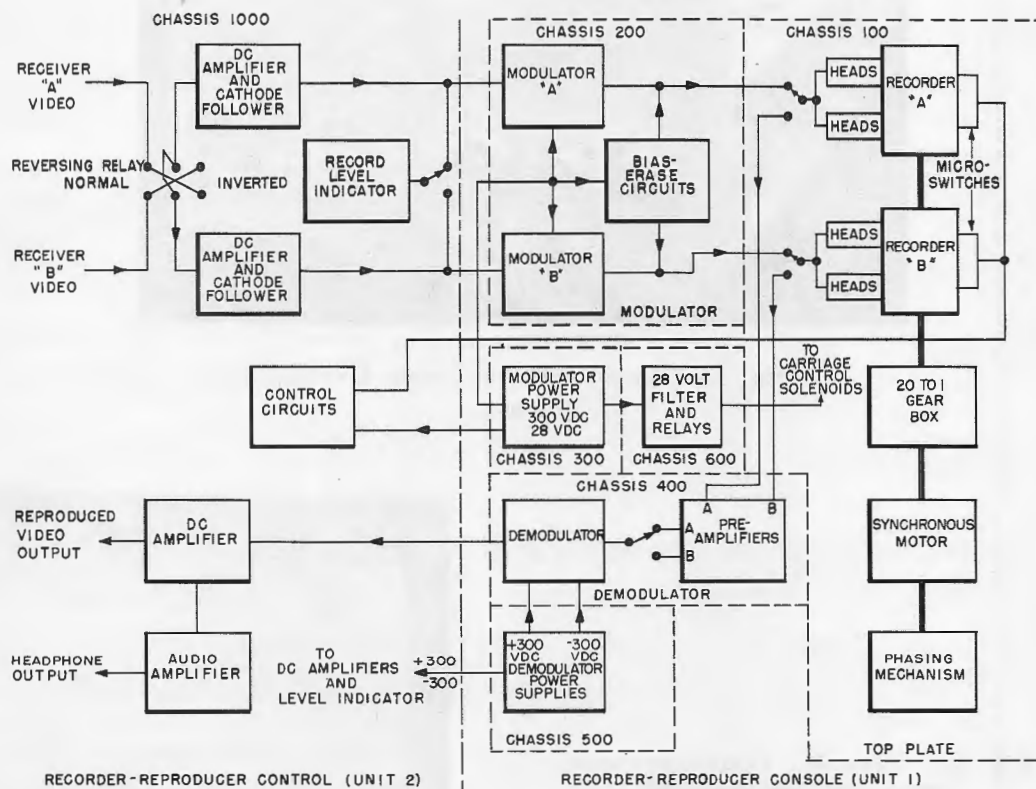


Fig. 11 - Block diagram of complete recording system [Unclassified]

head-handling carriages. Each of these head sets traces a 35-turn helical path on a zone of the drum surface with 14 tracks per inch of drum length. The operation of the two head carriages of each recorder is automatically controlled during record in such a manner as to achieve continuous recording and continuous storage of the last 60 seconds of recorded material. Dead time is eliminated by the alternate starting of the two recording-head carriages at 30-second intervals with each head recording for 35 seconds on its associated zone and thus providing a 5-second overlap period. [REDACTED]

The basic reason for furnishing two recording channels is to permit continuous monitoring of one receiver at all times, even when one recorder is being used for reproduction of previous signal activity. However, during long periods of signal inactivity the second recorder is not needed. Therefore, the second modulator was added, at the expense of relatively slight increase in complexity, to permit utilization of the second recorder for monitoring an additional receiver during such inactive periods. In normal operation, "Receiver A" is monitored by "Recorder A" and "Receiver B" is monitored by "Recorder B." [UNCLASSIFIED]

A signal can be saved for future playback by pushing a "HOLD" button of the associated recorder at any time up to one minute after the signal was recorded. These buttons are prominently located on the front panel of the control unit. In addition, external connections are provided for remote operation of this function. If desired, the holding function will also operate the receiver-input reversing relay shown in Fig. 11, thus automatically continuing uninterrupted recording of a chosen receiver on the other recorder. Such is termed a "master" receiver. A four-position "RECEIVER PRIORITY" switch for selection of the master receiver is provided on the front panel of the control unit. This switch has one position which assigns master control to whichever receiver is first "held" as described above. A second position assigns master control only to Receiver A, a third position assigns master control only to Receiver B, and a fourth position, by preventing operation of the reversing relay, does not permit either receiver to become a master. [UNCLASSIFIED]

Normal operation of the recorder-reproducer system requires the reproduction of only one recording at a time. In order to be of any value, simultaneous reproduction of both recorders would require two rather complicated playback electronic systems, two operators, and two AN/GRD-6 indicators. Therefore, only a single reproduce channel which can be switched to either recorder is provided. During the playback function, control circuits for the head carriages are used which achieve automatic repeated reproduction of either 35-second zone of one recorder. An alternate playback procedure permits manual selection of any small portion of a zone for reproduction. [REDACTED]

Separate reproduce preamplifiers are used for each recorder for improved record-reproduce isolation. Demodulation of the reproduced signal is performed by a linear counter-type detector which is followed by a high-gain, dc amplifier to achieve proper reproduce level of weak recorded signals. An audio amplifier is provided for aural monitoring of reproduced signals. [UNCLASSIFIED]

Twenty revolutions of the AN/GRD-6 goniometer are recorded on one turn of the recording path. Precise motion of the drum and the head-handling carriages is required, since one-half degree of bearing error would result from any motion imperfection during the combined record and reproduce process which creates 0.001 inch of head position error on the drum surface. [REDACTED]

Figure 11 indicates the power supply arrangement. All plate supplies and some filament supplies are regulated. Most of the circuits and relays for automatic remote control

of the recording head carriages and record-hold-reproduce functions are located in Unit 2 as also shown in Fig. 11. [UNCLASSIFIED]

Figure 12 shows Unit 1 with lid and doors opened and the location of major components is indicated. The basic items included in each of these are shown within the dotted rectangles of Fig. 11. The lid, doors, side and rear panels of Unit 1 are readily removable for inspection and service. Front and rear views of the recorder-reproducer (Figs. 13 and 14) are presented to show such items as interconnecting cables, chassis slides, framework details, and over-all views of the recorder mechanism. [UNCLASSIFIED]

A special effort was made to use JAN-approved components and procedures throughout the entire final model whenever possible. [UNCLASSIFIED]

#### COMPREHENSIVE DESCRIPTION OF THE FINAL MODEL

A more detailed description of the operation of each unit follows. For the most part, circuit description will be general, but complete schematic diagrams are included for readers having a particular detailed interest. [UNCLASSIFIED]

#### Top-Plate Mechanical Assembly

The top plate of the recorder-reproducer console is an anodized aluminum casting of a heavy ribbed design to provide a very high degree of rigidity. The entire mechanical assembly of the recorder, as well as portions of the control circuits, are mounted on this casting. Arrangement and identification of the major components making up this assembly are shown in Figs. 15 and 16. [UNCLASSIFIED]

The salient-pole synchronous-drive motor is identical to that used in the interim model, but the end bells have been modified for installation in an adjustable mount. To the rear of the drive motor are the two motor-capacitors (one for running, the other for start) and the motor on-off switch and fuse. The plugs adjacent to the capacitors are for the drive motor voltage and phasing circuits. They connect to the rear of the console. The drive motor is assembled in a mounting so constructed as to allow its stator to be rotated in order to maintain accurate phase relationship between the recorder and goniometer or indicator. Rotation is affected by a small control motor and gear linkage located beneath the main drive motor. A generator to produce phasing pulses is mounted on one end of the motor shaft as shown in Fig. 17. It consists of a small, soft-iron slug mounted in the arm of a propeller in such a way as to pass through an iron core carrying a pickup coil and supplied with a magnetic field by a permanent magnet. In this way a single pulse is produced for each revolution of the drive motor. [REDACTED]

Pulses from this generator are compared in a phase-control unit included as part of the AN/GRD-6 equipment with similar pulses from a generator on the goniometer or indicator. The signal derived from this unit then operates the control motor in the recorder or indicator to maintain it in the proper phase with the goniometer or recorder. Also included in the phase control unit is a provision for selection of the proper quadrant on the synchronous drive motor if a motor should be stopped. The electronic portion of the phase-control system has not been included in the recorder-reproducer equipment, but the mechanical portion which is included is identical to that of the AN/GRD-6; thus, the recorder can be used with the servo-control chassis of this equipment if desired. [SECRET]

Fig. 12 - Front view of recorder-reproducer unit, doors and lid opened [Unclassified]

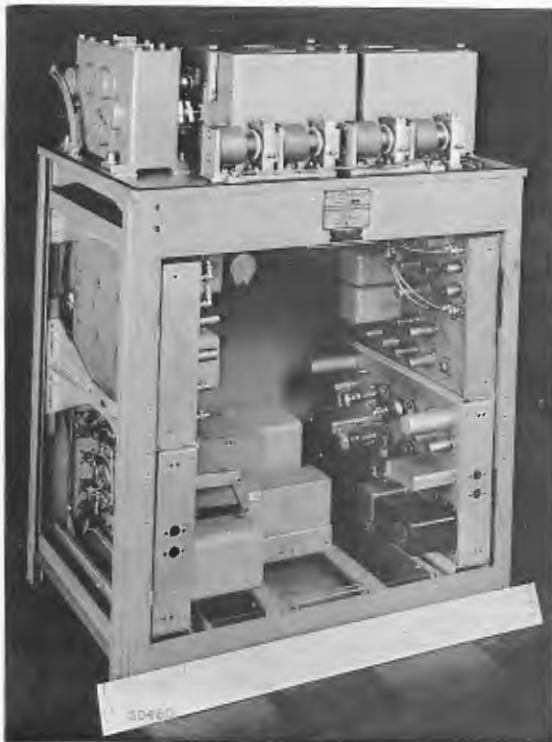
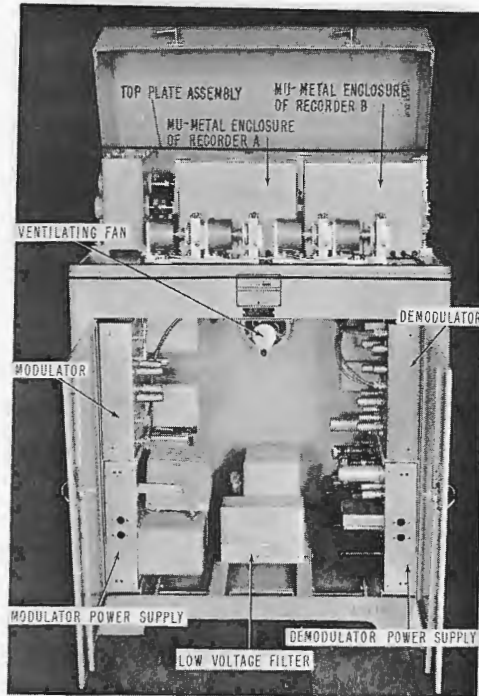


Fig. 13 - Front three-quarter view of recorder-reproducer unit; lid, doors, and sides removed [Unclassified]

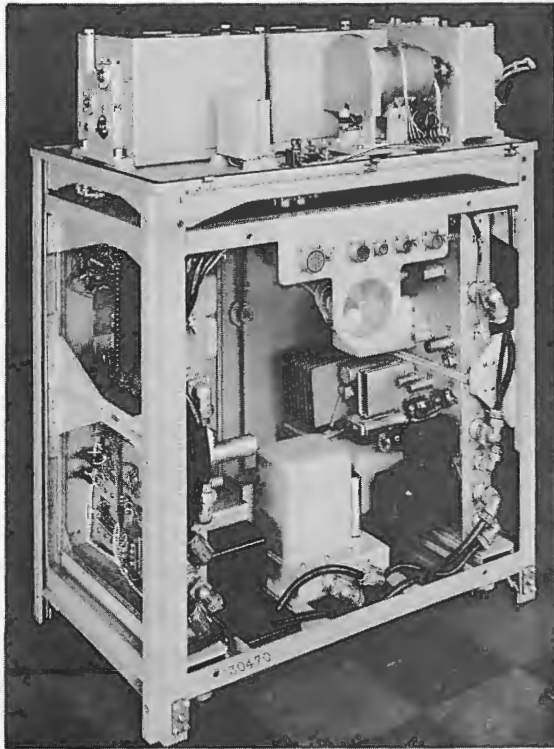


Fig. 14 - Rear three-quarter view of recorder-reproducer unit; lid, back, and sides removed [Unclassified]

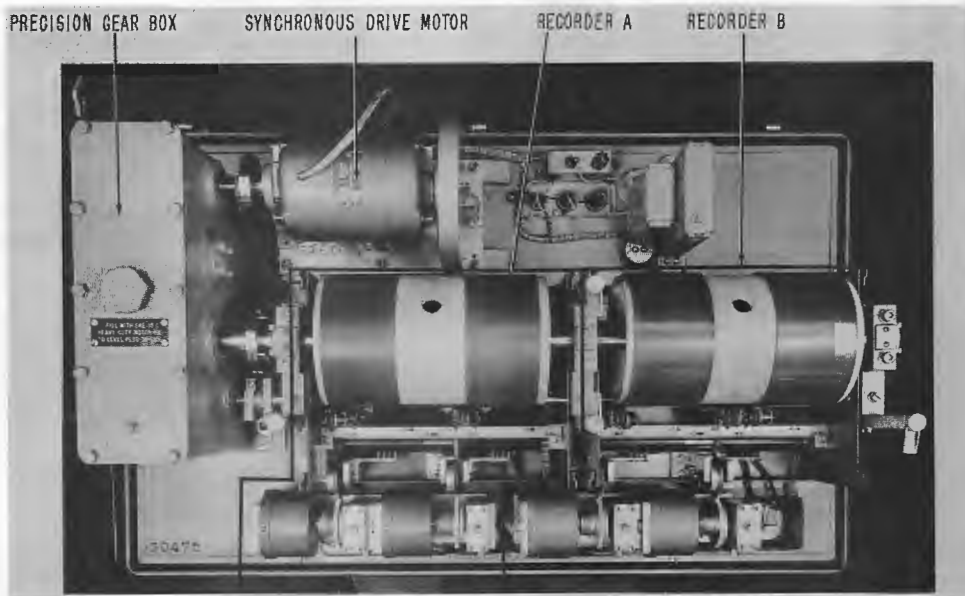


Fig. 15 - Recorder-reproducer mechanical assembly, top view [Unclassified]

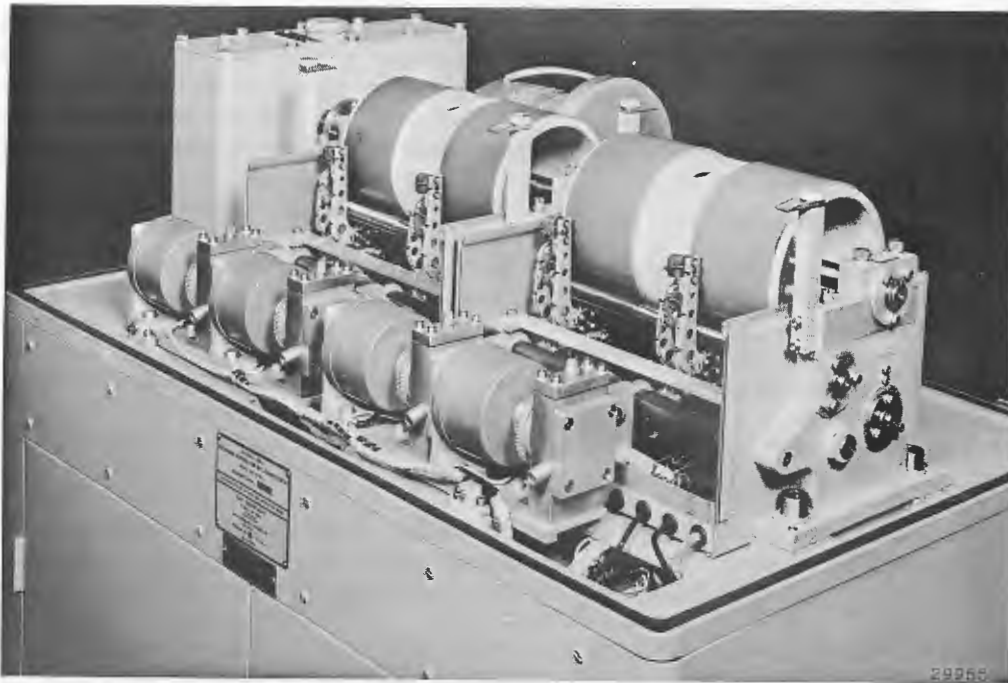


Fig. 16 - Recorder-reproducer mechanical assembly, front view [Unclassified]

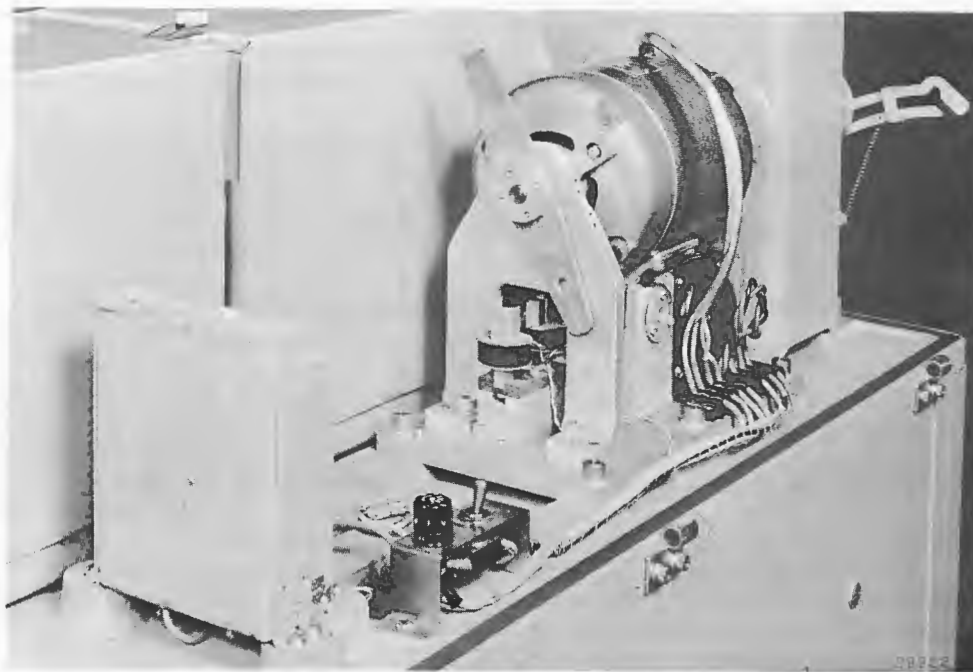


Fig. 17 - Phase pulse generator [Unclassified]

Some tests were run on the relative phase variation between the recorder and a synchronous-motor-driven goniometer and indicator, and the bearing shift caused by small variations of the common line voltage supplying simultaneously operated motors was found to be very slight. It was concluded, therefore, that the recorder equipment would operate satisfactorily without the phase control system, provided none of the drive motors were stopped and if only slight variable loads were applied to any portion of the system. [REDACTED]

The motor rotates the drums holding the recording medium at one revolution per second by means of the 20-to-1 reduction, precision gear-box shown in Fig. 18. The motor is connected to the input shaft of the gear box by a precision pin-type coupling, and a similar coupling is used to connect the output shaft to the recording drums. Two additional output shafts are provided, one for driving a carriage lead-screw which rotates at the same speed as the drums, and the other for driving a carriage return-roller which rotates at two and one-half times the drum speed. Bellows-type couplings are used on these shafts. [UNCLASSIFIED]

The gear box is made of cast steel; components and assembly procedures are of the same high precision and similar to those described for the interim gear box. All gears are pinned on the shafts and the shaft-end-play adjusting nuts are enclosed in oil-tight caps to prevent leakage. Oil seals consisting of a synthetic-rubber sealing member, a serrated finger-type metal spring, and a composition filler ring—all enclosed in a metal case—are used on all input and output shafts. An automatic oiler located near the top of the gear box (Fig. 18) collects oil from the large gear on the output shaft. This oil is then guided by small wires to all bearings not adequately lubricated by oil splashing from other high-speed gears. An oil-level plug is provided on the side of the gear box for maintaining the correct oil level and an oil filler plug is located on the lid. The gear box is vented to outside air to eliminate pressure differentials harmful to the oil seals. SAE No. 10 motor oil is used for lubrication. A small magnetic rod is located near the bottom of the gear chamber to collect any steel particles which flake off the gears. [UNCLASSIFIED]

As previously mentioned, the recorder mechanism consists of two electrically independent drum recorders designated A and B which utilize a common drum shaft as was seen in Fig. 15. Each recorder is completely enclosed in a mu-metal shield and all components other than the heads and recording medium are of nonmagnetic material to eliminate the possibility of interference from stray magnetic fields. [UNCLASSIFIED]

The drums which carry the synthetic rubber recording belts are made of cast aluminum and are mounted on a 3/4-inch-diameter nonmagnetic stainless steel shaft. All shafts which carry any portion of the recorder mechanism are large because of the extreme rigidity required to maintain head-position accuracy. The two recording-drums, the supporting shaft, and the precision shaft bearings are easily removable by disconnecting the drive coupling, removing the three bearing caps and lifting out the assembly. This feature is included to provide easy replacement of the recording medium at any time it becomes worn or damaged, since installation of new recording rubber belts requires adequate shop facilities including the use of compressed air. A spare dual drum assembly is provided with the equipment and is shown complete with carrying case in Fig. 19. Lubrication of each bearing is provided by a small felt wick located in the bearing cap. All other rotating shafts are lubricated by means of felt wicks in a similar manner. A high-grade light-weight instrument oil is the lubricant used. [UNCLASSIFIED]

The carriages which control all head movement during record, hold, or playback are shown in detail in Figs. 20 and 21. They are made up of two major parts and mounted on

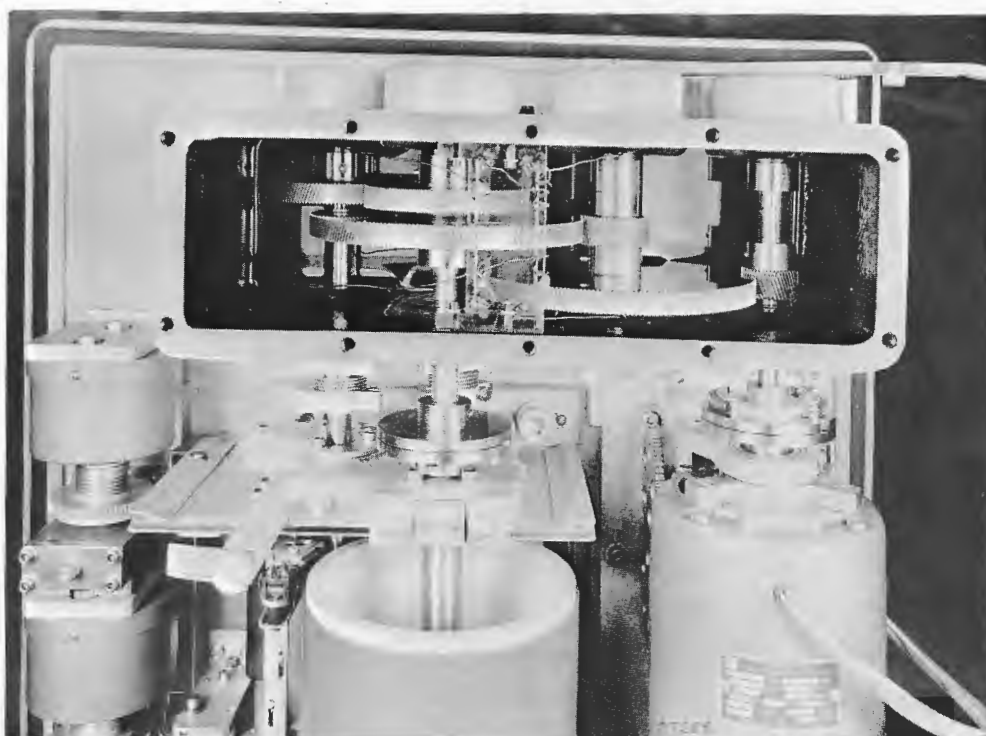


Fig. 18 - Precision gear box [Unclassified]

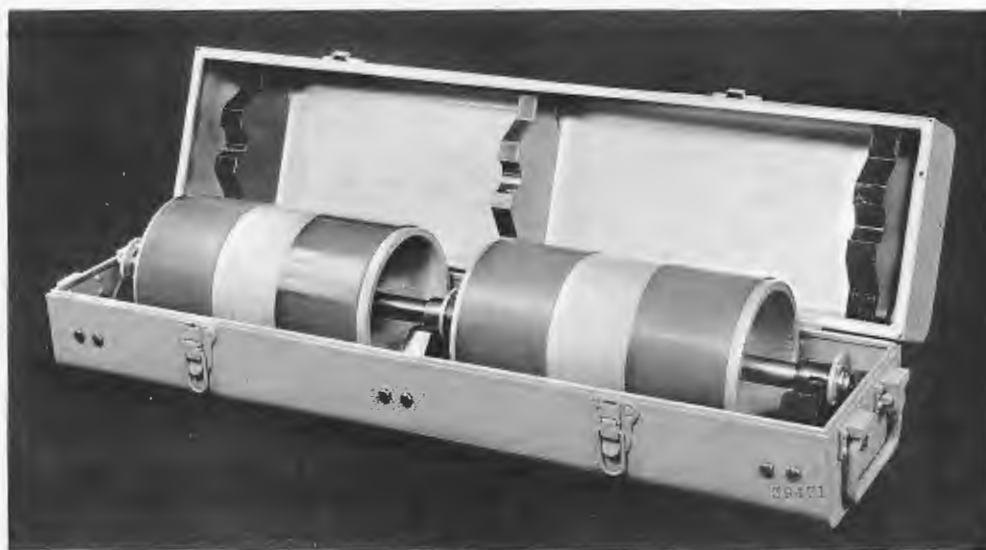


Fig. 19 - Dual drum assembly and carrying case [Unclassified]

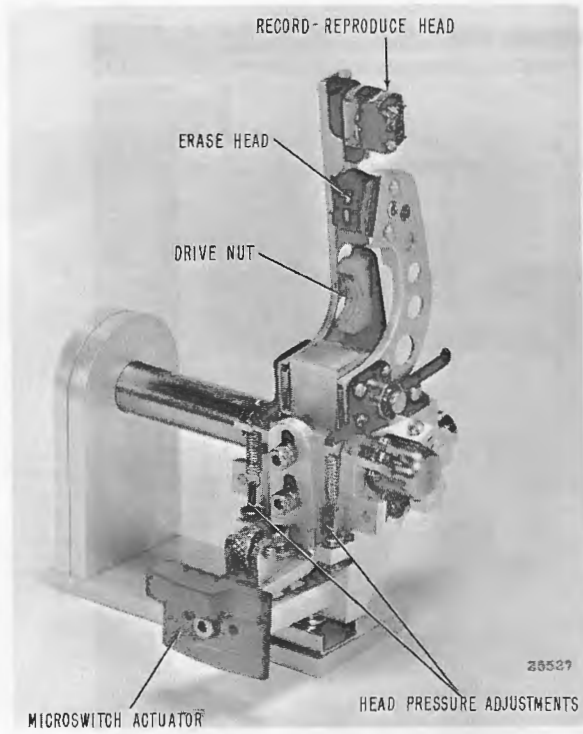
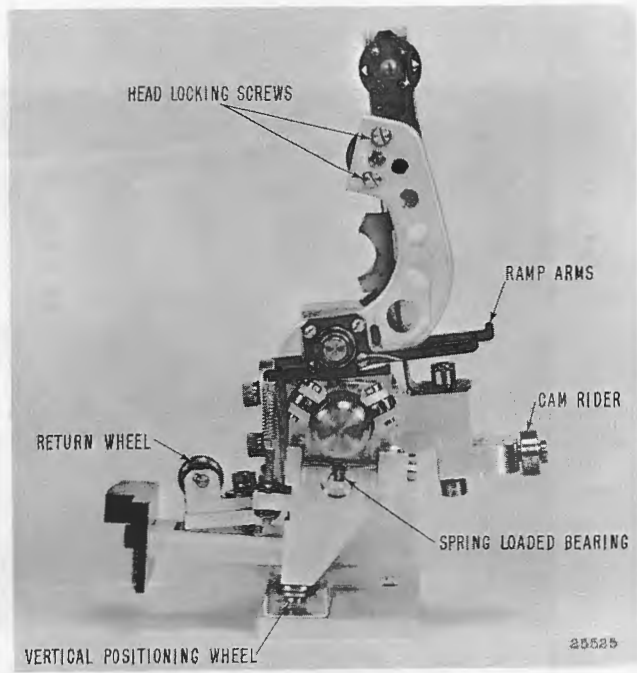


Fig. 20 - Head carriage, front view, [Unclassified]

Fig. 21 - Head carriage, end view [Unclassified]



a 5/8-inch-diameter nonmagnetic stainless steel shaft and move back and forth on 6 small precision ball bearings, the lower two of which are spring-loaded against the shaft to eliminate all play. These ball bearings are mounted on the outer portion of the carriage, which is positioned vertically by a small ball bearing attached to its lowest point and traveling in a channel-shaped guide located in the bottom of the recorder compartment. Also mounted on this portion of the carriage is a cam which operates three control-circuit microswitches. [UNCLASSIFIED]

The inner portion of the carriage can be rotated around the guide rod and carries the record-reproduce head, the erase head, and the carriage drive-nut. The head arms rotate independently on a shaft through the inner portion of the carriage and the head pressure is set by means of small adjustable springs attached from the head arms to the outer portion of the carriage. Precision sleeve bearings are used throughout and close tolerances are maintained to minimize head positioning error. The heads are attached to the head arms with mounts which may be rotated for positioning the gap tangential to the recording medium and are held in this position by locking screws. The carriage is moved laterally by engaging the drive nut with the lead screw. [UNCLASSIFIED]

The position of the carriage in the recorder assembly along with the lead screw, carriage control solenoids, dash pots, gears, and cam are shown in Fig. 22. Also to be seen in this figure are the small cavities in the casting which contain the record-reproduce switching relays. The carriage control solenoids are located outside of the shielded recorder compartments and are encased in mu-metal shields to reduce magnetic interference from their operation to a minimum. [UNCLASSIFIED]

In actual operation, the rotary solenoid associated with a particular carriage is energized and its rotary motion applied through a chain of three gears to a cam which tilts the center portion of the head carriage. The solenoid is connected to the first gear of the chain by a flexible bellows-type coupling to allow freedom for axial motion of the solenoid armature when rotation occurs. Also attached to this first gear is a dash pot which utilizes a moving vane to force oil through a small orifice. The size of this orifice is adjustable and is varied to achieve a suitable maximum speed of gear rotation, thus preventing rapid solenoid action from damaging the head carriage assembly. The second gear of the chain is spring-loaded for returning the cam to its original position when the solenoid is de-energized. The cam is best seen in Fig. 23 and the return spring in Fig. 22. [UNCLASSIFIED]

As the center portion of the carriage is tilted, the drive nut is first brought into contact with the lead screw, causing the carriage to move from left to right, and the heads then contact the recording medium. When the carriage reaches a point 5 seconds from the end of its travel it operates a microswitch which starts the second carriage in the recorder, thus providing continuous recording of an incoming signal. On reaching the end of its travel, the carriage operates a second microswitch which de-energizes the solenoid, causing the cam to return to its original position, raising the heads from the medium, disengaging the drive nut, and engaging the return wheel and roller. The return roller engages a small knurled wheel, cocked at a slight angle and mounted on the back of the carriage. The action of the return roller against this wheel returns the carriage to its starting position. At this position, the cam is undercut to release the wheel from the roller and thus stop the carriage. The angle at which the knurled wheel is set determines the carriage return speed, and is adjustable. At the starting position, a third microswitch is operated which allows the carriage to be recycled at the proper time. The microswitches, return roller, and knurled wheel are shown in Fig. 24. [UNCLASSIFIED]

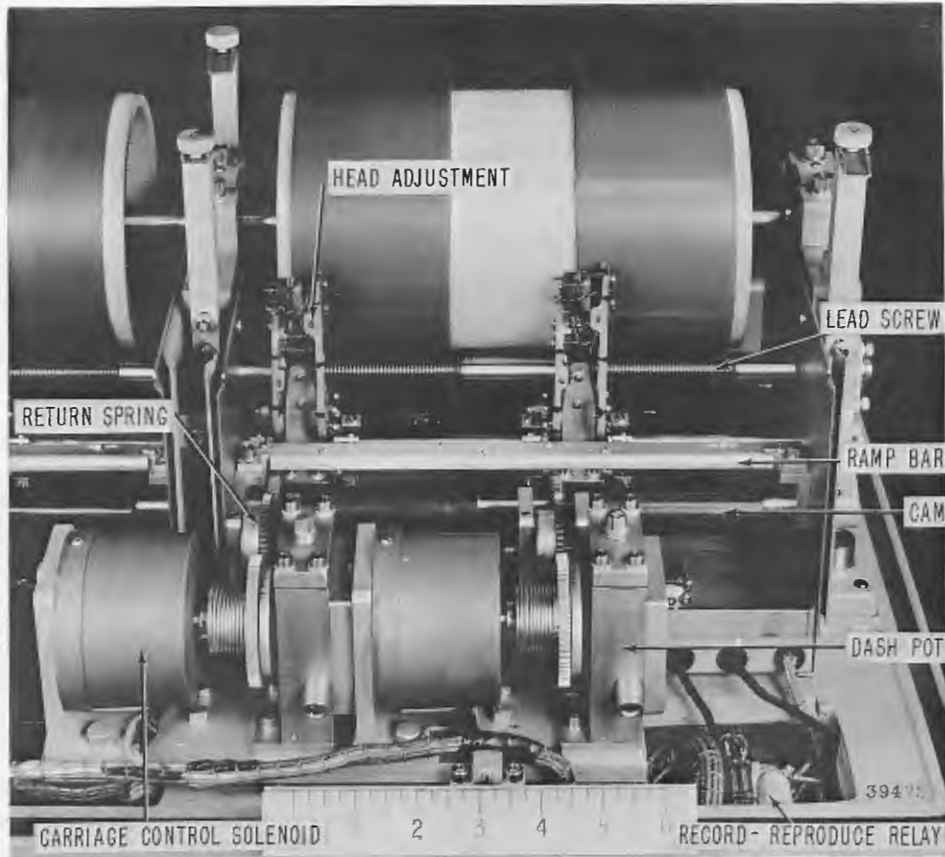


Fig. 22 - Front view of one recorder assembly [Unclassified]

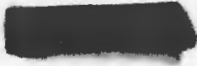




Fig. 23 - Closeup view of head carriages mounted in recorder [Unclassified]

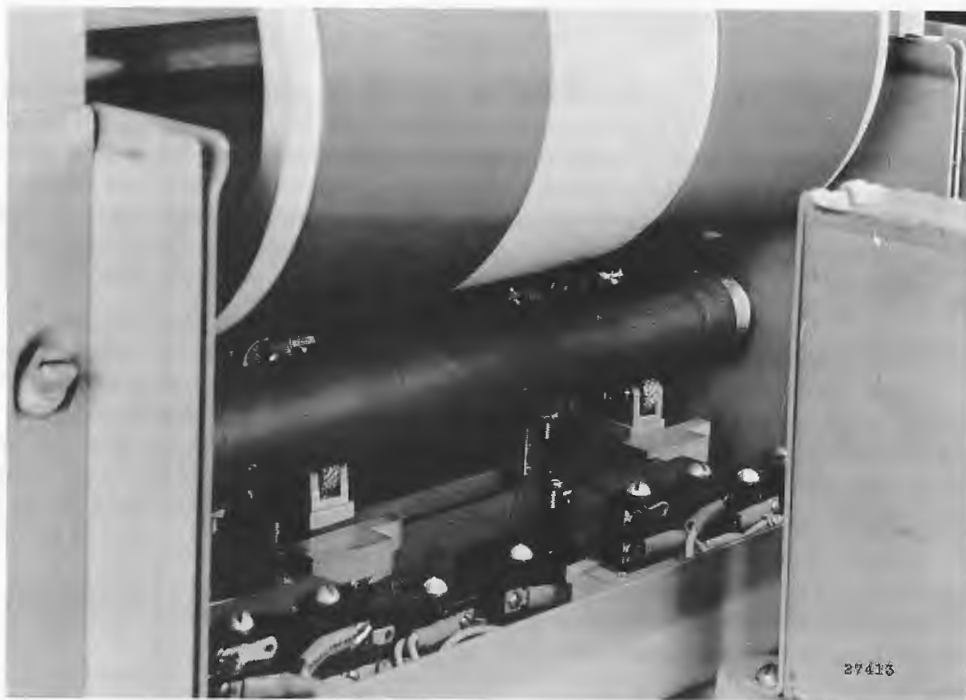


Fig. 24 - Return roller and control switches [Unclassified]

To protect the carriage from damage by overrunning in the forward direction, should the cam fail to operate, the lead screw is terminated a short distance beyond the normal end of travel, causing the carriage to stop. Ramps are provided, as shown in Fig. 22, for raising and lowering the heads at precisely the same point on the medium to minimize difficulty with the wax lubricant used in the original recording medium. [UNCLASSIFIED]

All components making up the mechanical assembly, with the exception of those made of stainless steel or plastic, were given a protective coating. All steel parts were cadmium-plated or painted. Aluminum parts were either anodized, hard-coated, or given an iridite finish. The iridite process was used on parts having extremely close tolerances, since this process does not alter their physical dimensions. In several instances paint was applied over anodized surfaces. All mu-metal shields received only one coat of paint on their outside surfaces. Further protective coating was not applied since any processing of mu-metal after heat treating tends to reduce its effectiveness as a magnetic shield. All panels, doors, and covers of both units of the recorder system were aluminum, anodized, and painted. [UNCLASSIFIED]

The mechanical assembly on the top plate of the recorder console is maintained as dust-free as possible to minimize wear. This is done by providing a rubber gasket against which the top cover seals when it is closed, and by using gaskets to maintain airtight seals between all plug mounting-plates and the top casting. Further, since the heat generated by the drive motor and carriage solenoids is insufficient to cause harmful effects to the mechanical assembly, no air is circulated through the top-plate compartment. A ventilating fan located at the top rear of the lower part of the console exhausts the warm air from this section and draws cool air over the chassis by way of screened openings in the bottom of the cabinet. [UNCLASSIFIED]

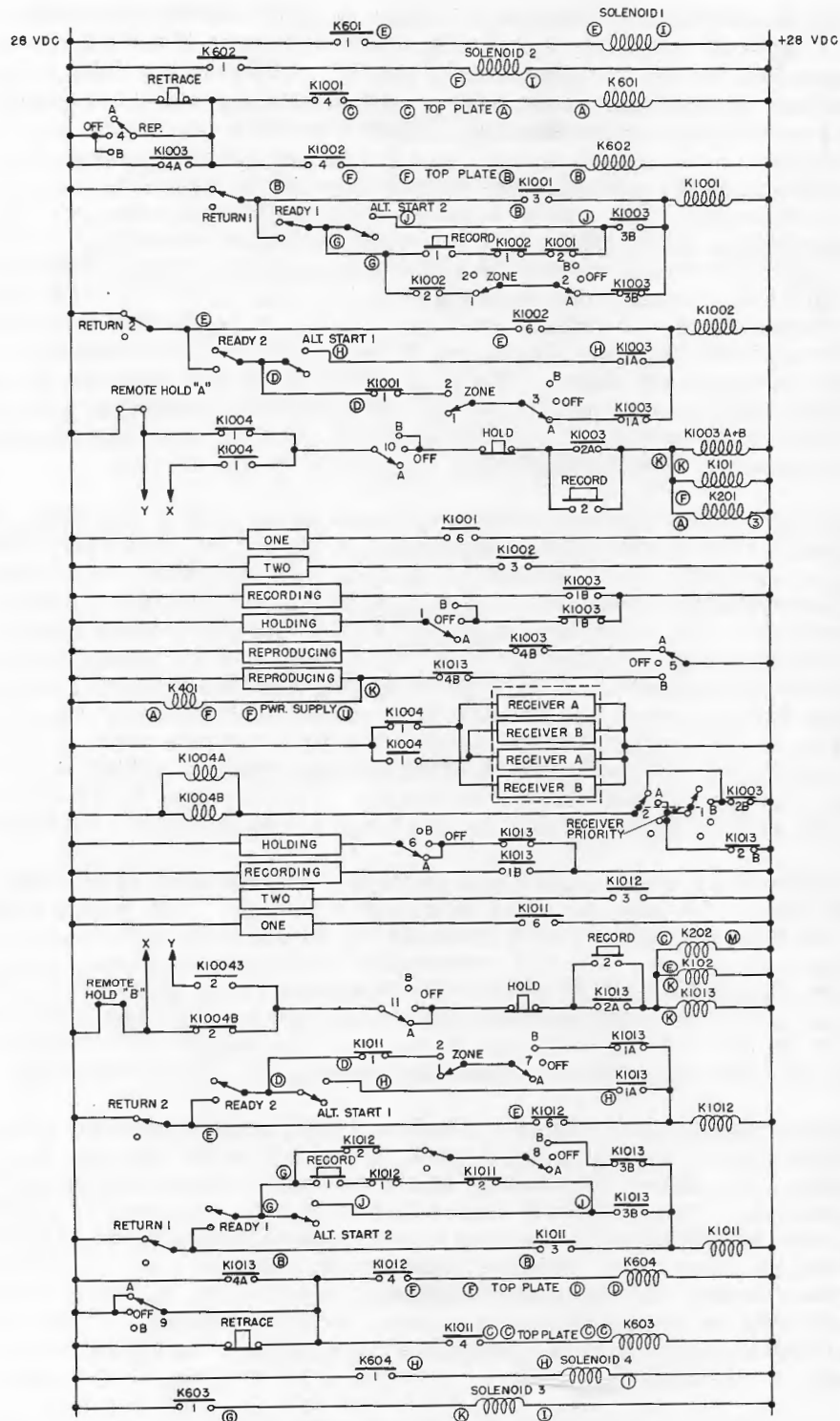
#### Control Circuits

The control circuits are included for the purpose of maintaining all automatic functions and for adjusting the mode of operation of the equipment in accordance with operator commands. The components which make up these circuits are for the most part located on or directly to the rear of the front panel of the control unit. The remaining control components are located in various portions of the recorder unit. All solenoids, relays, and indicator lights operate from 28 volts dc. Controls necessary for the operation of the complete equipment, along with panel lights that indicate its mode of operation, are mounted on the front panel of the control unit and are shown in Fig. 7. As can be seen from this figure, those controls and indicator lights pertaining to Recorder A are grouped together at the left of the panel, those for Recorder B to the right, and those common to both recorders in the center. Reproduce gain, circle diameter, power input, and audio controls are located across the bottom of the panel. Certain of these controls having no direct action on the mechanical operation of the recorder, such as the modulation-level-indicator switch, receiver-priority switch, and reproduce gain control, will have their function explained in that portion of the report describing the operation of the basic components of which they are a part. [UNCLASSIFIED]

The recorder is almost entirely automatic and is designed to be as foolproof and simple to operate as possible. Interlocking of functions is provided to protect against faulty operation, accidental erasure, or injury to the equipment should improper operation be attempted. Since both recorders are identical, operation of only one will be explained in detail. To aid in this explanation, a simplified schematic diagram of the control circuits is included as Fig. 25. [UNCLASSIFIED]

SECRET

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NOTE: CIRCLED LETTERS INDICATE PLUG PINS  
 OTHER NUMBERS INDICATE RELAY AND SWITCH CONTACTS.

Fig. 25 - Simplified schematic diagram of control circuits [Unclassified]

Recording is effected alternately on two zones in each recorder to provide continuous recordings as has been previously mentioned. For the purpose of this discussion the zones will be numbered one and two, the zone closest to the gear box being number one and the other zone number two. When the record button is depressed, recording begins and continues as a fully automatic function. If both carriages are in their starting position (to the left of the recording zone) when the record button is pushed, zone one commences recording, the head carriage moving from left to right. As it reaches a point near the end of zone one it operates an alternate-carriage start microswitch which starts the zone-two carriage, thus providing the 5-second overlap in recording during zone changeover. As the carriage reaches the end of zone one the carriage-return microswitch is operated which de-energizes the operating solenoid, causing the carriage to return to its initial position. Here, a carriage-ready microswitch is operated which allows it to start when the zone-two carriage approaches the end of its travel and operates its associated alternate carriage start switch. The zone-two carriage then operates its return microswitch and returns to its initial position. This sequence continues, providing retention of the last 60 seconds of recorded material, until the recording operation is stopped by an operator. [UNCLASSIFIED]

Indicator lights are provided to show at all times which zone is operating. Recording is always effected first on zone one if both carriages are at rest. However, if the zone-two carriage is operating, having previously been used on reproduce, then recording commences immediately on zone two when the record button is depressed, and the sequence continues from there. If, at any time during record, the primary power fails and then comes back on, the carriages return to their rest position and the holding indicator light on the front panel is energized. To resume recording, the record button must be depressed. If at any time during record the hold button is pushed, the recorder immediately stops recording and any carriage in operation at that time continues until it operates its carriage-return microswitch and returns to the starting position. Under these conditions, however, the alternate carriage will not be started. The carriages then remain at rest until either the produce or record function are begun by the operator. [UNCLASSIFIED]

When reproducing a signal from either recorder, only one zone or the other will operate, depending on the position of the zone selector switch. This switch is inoperative on record. When the reproduce switch is turned on, the carriage of the zone indicated by the zone-selector switch starts and continuously reproduces the chosen zone until the zone switch is changed to the other zone or the reproduce switch is turned off. When the zone switch is transferred from one zone to the other, the carriage operating at the time continues to do so until it triggers the carriage-return microswitch and returns to its starting position. The newly selected zone then commences. [UNCLASSIFIED]

A momentary retrace push-button is provided which, when depressed, causes the carriage to retrace until the button is released, at which time the carriage resumes its forward motion. This allows "bracketing" of a short signal without waiting for the complete carriage cycle. This function is inoperative on record. It should be noted that the momentary retrace function cannot be used to return the operating carriage for the purpose of starting the other zone. Only one recorder can reproduce at a time, as indicated by the reproduce switch. At any time a recorder is reproducing, it cannot be made to record or hold until the reproduce switch is placed in the off position. If the primary power is removed during reproduce, the recorder continues to reproduce as soon as primary power is returned. [REDACTED]

A rear view of the operating controls and indicating lights located on the front panel of the control unit can be seen in Fig. 26. The carriage-control relays are located in the



Fig. 26 - Control unit, top view, cover removed [Unclassified]

small chassis directly to the rear of the front panel. Interference-reducing capacitors, used with the carriage operate relays, can be seen on top of this chassis. The carriage-control solenoids are energized by means of these relays through power relays located in the recorder unit. These relays are also filtered by capacitors. Only those controls which function during the continuous record cycle, or those which are used frequently during reproduce, are so equipped. A further view of the operating relays is shown in Fig. 27. Those relays to the left are for Recorder A and those to the right for Recorder B. Relays common to both recorders are located in the center of the chassis. A simplified control schematic was shown in Fig. 25 and a complete schematic diagram of the control components located in the control unit is shown in Fig. 28. Control components located in other units of the recorder are shown in the circuit diagram of the unit in which they are located. Those located on the top plate are shown in Fig. 29. [UNCLASSIFIED]

### Direct-Coupled Amplifiers

The two record dc amplifiers, the record-level monitor and its dc driving amplifier, the reproduce dc amplifier, and the reproduce audio amplifier are located in the control unit shown in Figs. 26 and 27. The complete schematic diagram of these items is included in Fig. 28. [UNCLASSIFIED]

The two recorder-input connections go first to the reversing relay (K1004a) of the receiver priority-control circuits as previously described. Section K1004b of this relay performs the necessary switching of the remote-hold lines. Following these switching circuits, each video channel consists of a 12AX7 tube (V1001 and V1003). One half of this tube serves as a high-gain stable dc amplifier and the second half is diode-connected to effect clipping at a referenced voltage so adjusted as to prevent overmodulation. The frequency response of these amplifiers is shown in Fig. 30 and the amplitude linearity, including the clipping action, is shown in Fig. 31. Cathode follower stages (V1002 and V1004) are placed after each amplifier to obtain a low-impedance source from which the video passes through the interconnecting cable to the recorder-reproducer unit. A dc level adjustment and test point are provided for each cathode follower. These controls are adjusted so that the proper voltage to swing the multivibrator frequency from 9 kc to 15 kc is obtained from an input signal amplitude that should produce 100 percent modulation. The proper test point value is +65 vdc when the recorder input terminal is grounded and +165 vdc when an input voltage of -2.25 vdc is supplied. [UNCLASSIFIED]

The modulation-level indicator used for adjusting the input signal level can be switched to the output of either modulator amplifier. The indicator consists of a dc amplifier (V1005), a sweep generator (V1006), and a two-inch cathode-ray tube (V1007). The horizontal sweep is synchronized with the power line, thus assuring synchronization with the goniometer output waveform. One to three cycles of this waveform can be displayed. The cathode-ray tube is provided with an illuminated scale of ten divisions. The trace is positioned opposite the top line of the scale for zero recorder input and the gain of the indicator amplifier is adjusted so that full scale deflection is produced by a signal which will cause 100 percent modulation of the carrier. The zero signal position is adjusted by the vertical positioning control and the gain control can be set when the modulator amplifier dc level is being adjusted. The level indicator controls, including vertical and horizontal positioning, intensity, focus, and sweep frequency, are located behind the small door on the upper right-hand corner of the control panel. The level-indicator gain control and the dc-level controls for both modulator channels are located on the chassis as shown in Fig. 26. [UNCLASSIFIED]

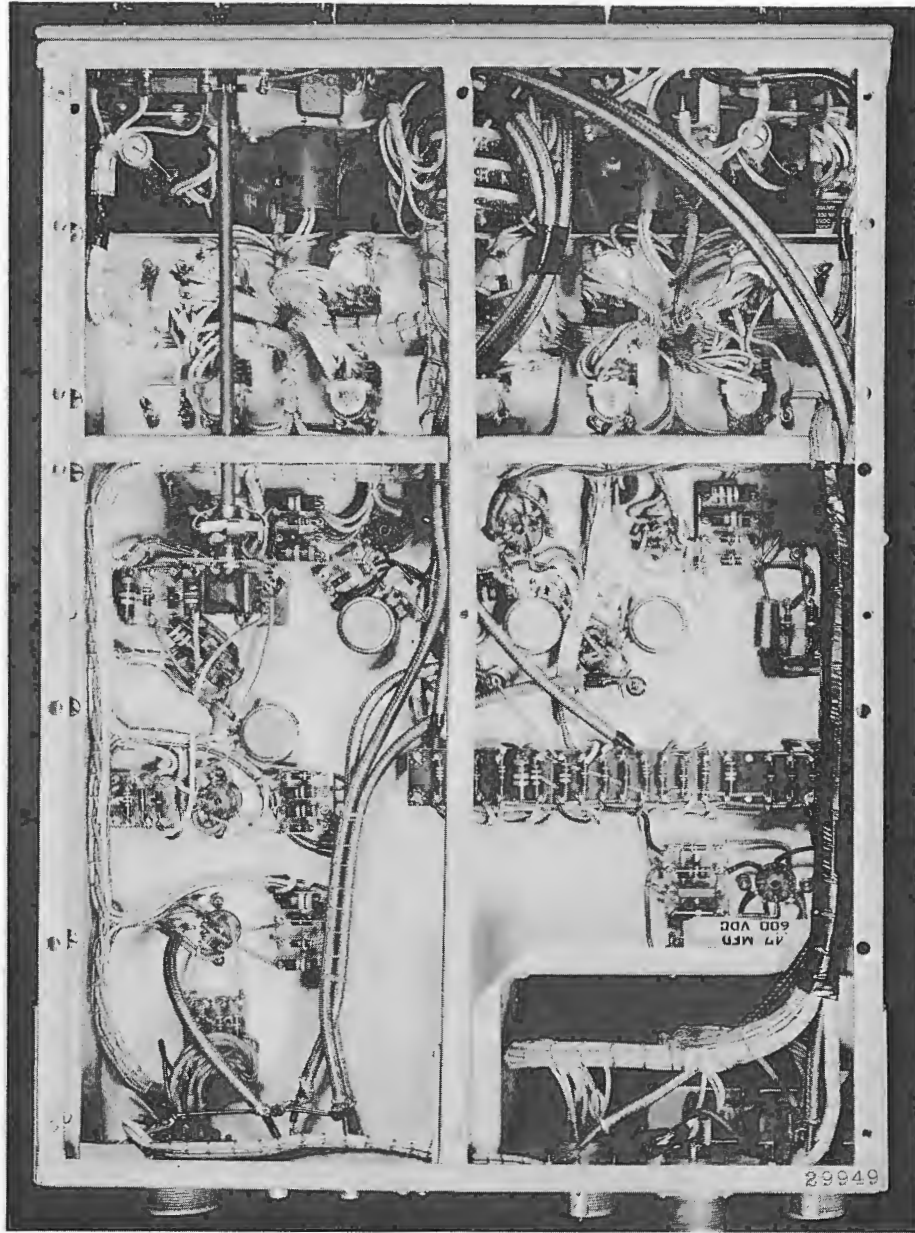


Fig. 27 - Control unit, bottom view [Unclassified]





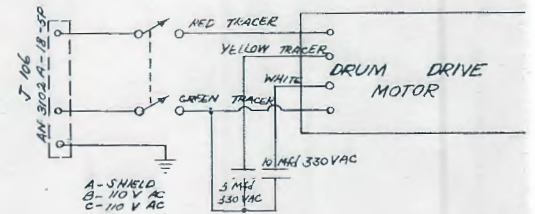
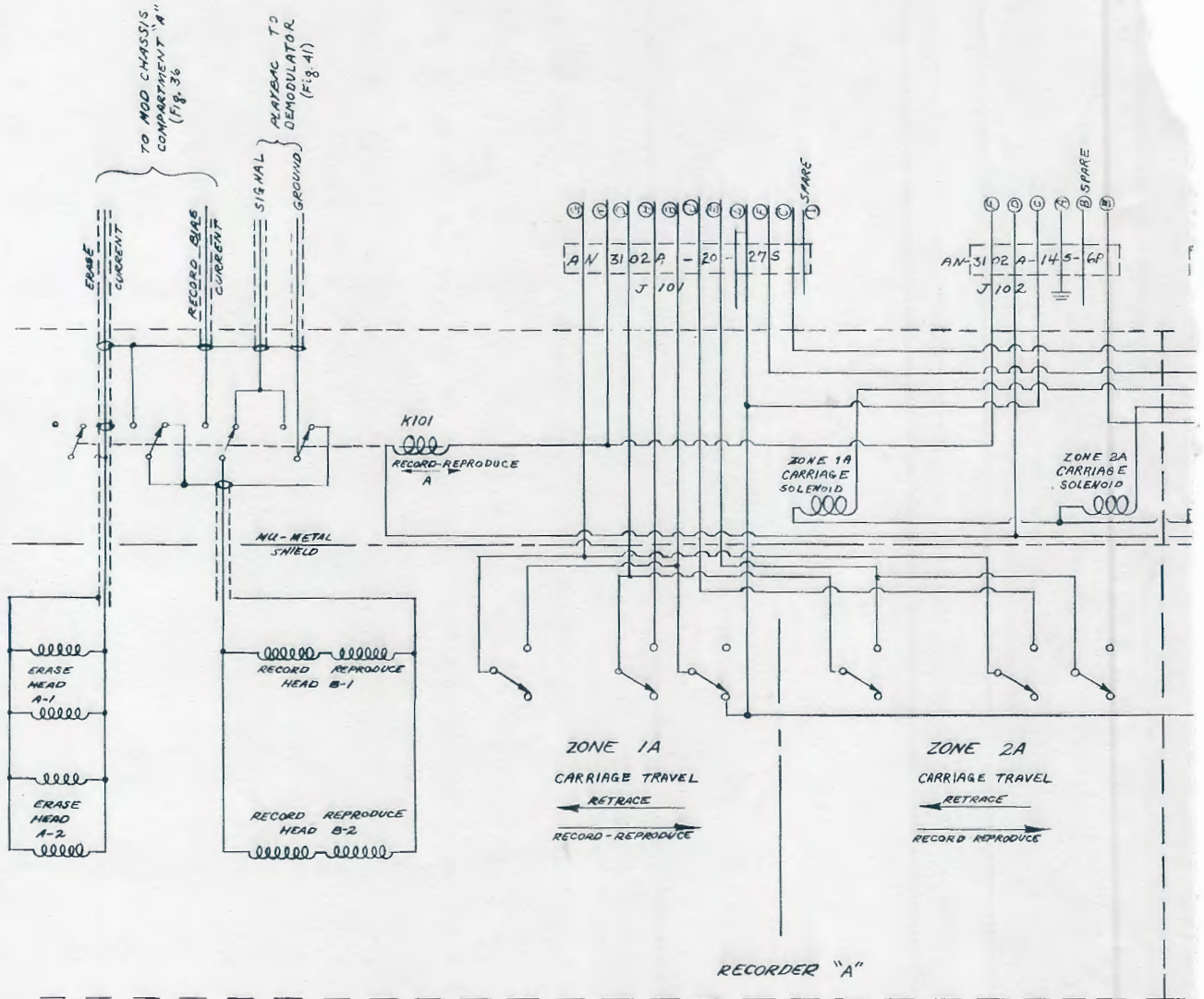
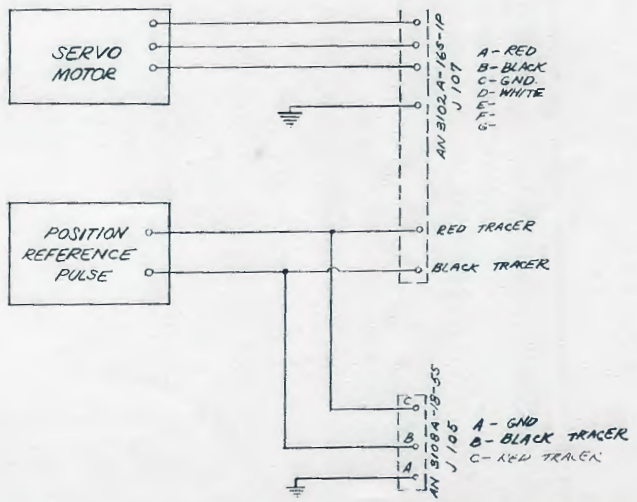
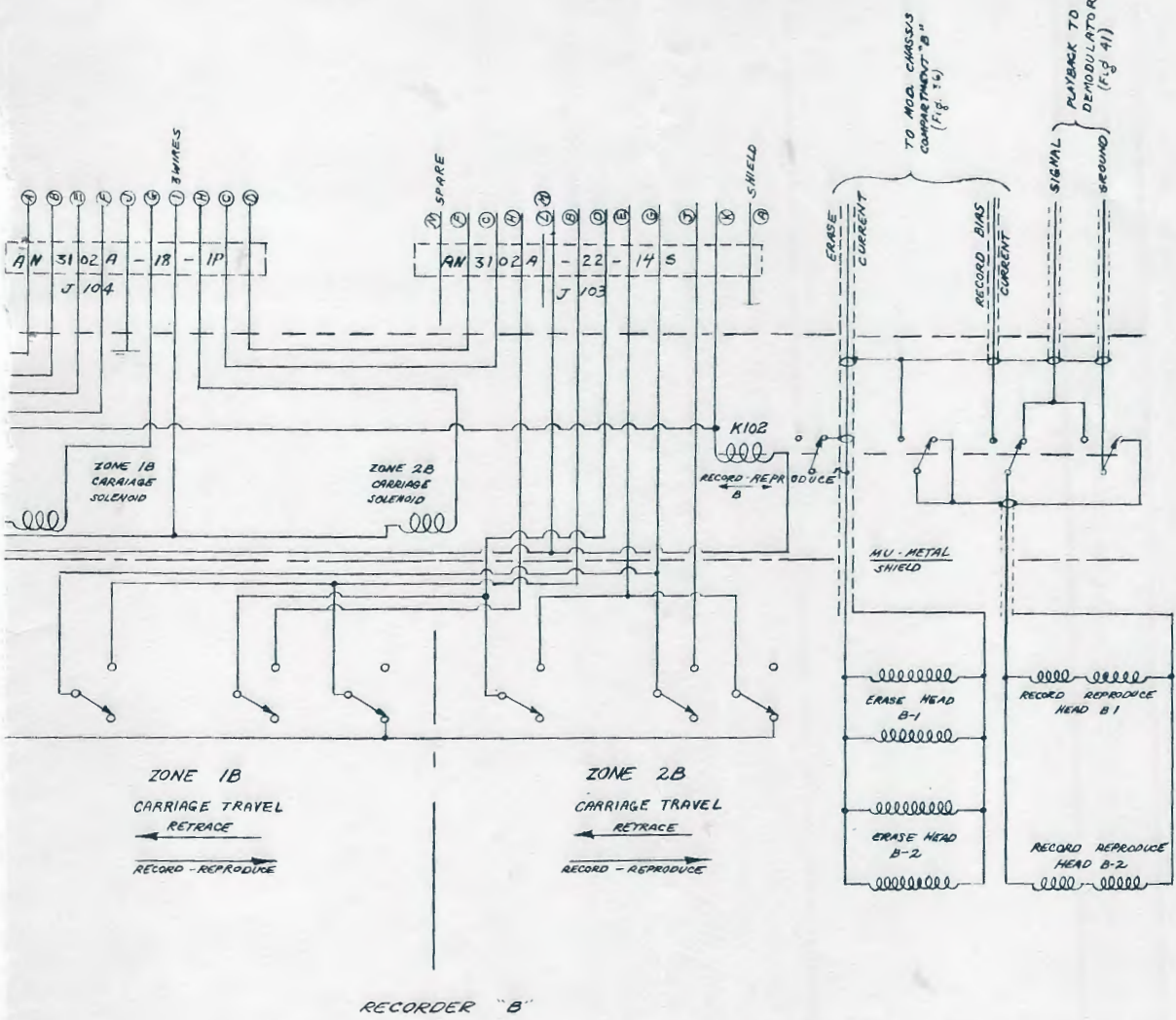


Fig. 29 - Top plate schem



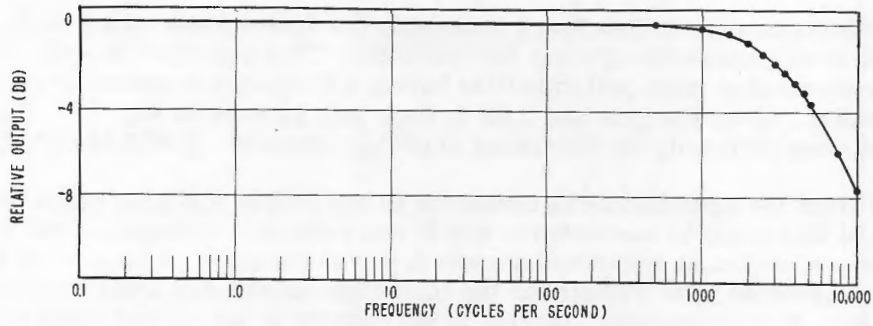


Fig. 30 - Frequency response of modulator dc amplifiers [Unclassified]

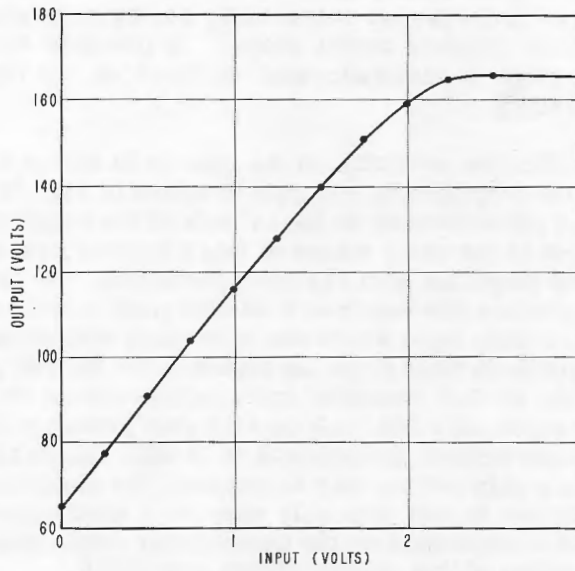


Fig. 31 - Amplitude linearity of modulator dc amplifiers [Unclassified]

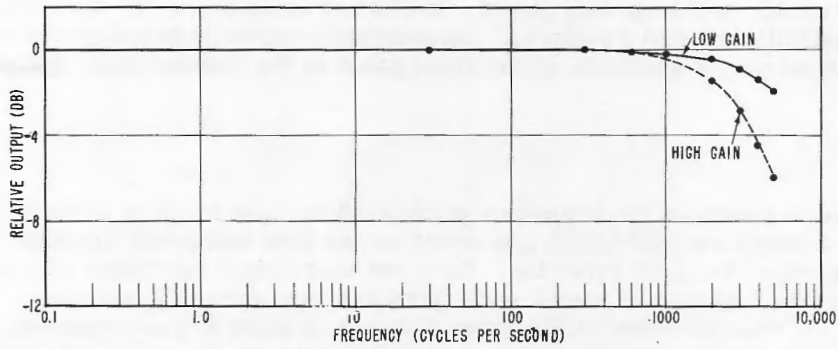


Fig. 32 - Frequency response of reproduce dc amplifier [Unclassified]

The reproduce amplifier is necessary to amplify the demodulator output to the 2.25-volt peak signal level required to operate the indicator. This amplifier is a stabilized three-stage direct-coupled push-pull amplifier having a frequency response from dc to 3000 cps flat within 1 db on low gain and 3 db on high gain as seen in Fig. 32. The push-pull circuitry is used primarily for increased amplifier stability. [UNCLASSIFIED]

The signal from the demodulator is connected to one grid of the input stage (V1008). The other grid of this stage is connected to a 0.9-volt reference voltage and the cathode coupling produces a push-pull output voltage which drives the grids of the second amplifier stage (V1009). Lowered plate voltage for the first stage is obtained from a cathode follower (V1011a). A potentiometer, located in the cathode of the second stage and available on the front panel, adjusts the dc balance of the amplifier and is used to set the circle diameter of the pattern. Output from the second stage can be used directly to drive the output cathode follower (V1011b) when the "coarse reproduce level" switch is in the low position, or can be connected to the grids of the third amplifier stage (V1010) when this switch is in the high-gain position. The "reproduce level" switch also transfers the grid of the output cathode follower to the proper output tube, and by reversing channels in the push-pull amplifier maintains constant output phase. A low-gain zero adjustment is provided in the second stage to maintain equal dc level on the high- and low-gain positions. [UNCLASSIFIED]

Maximum voltage amplification available on low gain is 32 and on high gain is 500. The amplitude linearity of the amplifier on low gain is shown in Fig. 33. The fine reproduce level is controlled by a potentiometer in the cathode of the output cathode follower. Since there is no gain control in the early stages of this amplifier, care must be exercised to prevent overloading of the amplifier with resultant distortion. On low gain, the minimum input voltage necessary to produce the required 2.25-volt peak output to the indicator is 0.070 volt peak, and the maximum input which can be handled without undue distortion is 1.6 volt peak. Normal maximum input from the demodulator for 100 percent modulated carrier is only 0.6 volt peak, so that excessive input voltage cannot occur on the low-gain setting. A minimum input signal of 0.0045 volt on high gain produces the required output signal, and the maximum input without distortion is 0.13 volt. Since signals which will overload the amplifier on this gain setting may be present, the amplifier should normally be used on low gain and switched to high gain only when very weak signals are encountered. Adjustment of this amplifier is dependent on the demodulator output and will be explained in a paragraph in a later section of this report. [UNCLASSIFIED]

An audio amplifier and output stage are provided to allow the operator to monitor any modulation on the recorded signal. The input circuit of the audio amplifier tube (V1012) is designed to attenuate the 20-cycle goniometer modulation on the signal and derives its input from the reproduce dc amplifier output. In this way a constant audio input signal level is obtained for all fully closed d-f patterns. An audio gain control is provided and output suitable for head phone use is available on the front panel of the control unit. [SECRET]

#### Modulator

The modulator produces the frequency-modulated carrier which is recorded. It is constructed on a single chassis which also contains the bias and erase circuits. One modulator is provided for each recorder. Only one bias-erase oscillator is used but separate bias-erase voltage and power amplifiers are used for each recorder. Figure 34 is a top view of the chassis showing the general layout of tubes and components. Considerable effort was required to provide adequate isolation between the carrier and bias-erase



voltage of a recorder that is recording and the input of the other recorder when it is reproducing. Care was also taken to prevent external radiation or conduction of bias-erase and carrier signals. Figure 35 is a bottom view of the chassis showing the shielding used. Complete circuit details are shown in the circuit diagram, Fig. 36. [UNCLASSIFIED]

The modulators for each recorder are identical and utilize a degenerative positive-bias multivibrator of the type described by Bertram<sup>1</sup> for the source of the f-m carrier. The frequency of this multivibrator depends upon the grid bias voltage and can be made linear over a frequency range of one octave. A curve of the output frequency versus grid bias voltage is shown in Fig. 37. Frequency of the multivibrator is controlled by applying the signal from the input dc amplifier to the grid return lead. The multivibrators are tubes V206 and V207. A 50-K dual potentiometer is provided as a portion of the grid resistor for adjusting the frequency of each multivibrator to 9000 cycles when no input signal is present. These controls are available on the top of the chassis and are labeled Carrier A and Carrier B Adjust. Adjacent to each of these controls is a test point for use in determining when the frequency is correct. An oscilloscope and an accurately calibrated audio oscillator should be used in making the adjustment. Full details on adjustment procedure are to be found at the end of the demodulator description. [UNCLASSIFIED]

Each multivibrator is followed by a cathode follower (V208 and V209) which drives a 16-kc low-pass filter. This filter removes all components of the multivibrator wave form above 16 kc from the output to prevent higher order harmonics from beating with the 112-kc bias-erase frequency. The frequency response of this filter drops off very rapidly at approximately 16 kc as is shown in Fig. 38. The output of the filter is applied to the record heads by way of a record-reproduce relay (K101 and K102) located in the top plate of the recorder unit. A contact on the appropriate isolation relay (K201 or K202) grounds the output lead of the filter and another contact removes plate voltage from the cathode follower and grounds the plate when the recorder is on hold or reproduce. To minimize frequency drift, the multivibrators are run continuously whenever the equipment is on. [UNCLASSIFIED]

The bias-erase oscillator (V201) is an inductance-capacitance oscillator of high frequency-stability similar to that described by Clapp.<sup>2</sup> This oscillator also runs continuously to improve frequency stability. Oscillator output, which is derived from the cathode circuit, is divided into two branches, one for each recorder, and amplified first by a stage of voltage amplification and then by a power amplifier to provide sufficient output for adequate erasure. The voltage amplifiers (V202 and V203) have LC circuits used as plate loads and tuned to the oscillator frequency to aid in improving the output wave form. The plate voltage for these stages is supplied from the same contacts on the isolation relays that supply the modulator cathode followers; therefore, the plate voltage is removed and the plate grounded when the recorder is on reproduce. Output from the plate of the voltage amplifiers drives the power-amplifier stages (V204 and V205). The plate loads for these stages are also LC circuits tuned to the oscillator frequency. Total harmonic distortion of the bias-erase wave form is approximately 0.1 percent. [UNCLASSIFIED]

Output from the plates of these stages is used for both bias and erase functions. The erase output goes through 1000 $\mu$ f blocking condensers to the erase heads via the record-reproduce relays located in the top plate of the recorder unit. In order to obtain adequate

<sup>1</sup>Bertram, S., "The Degenerative Positive-Bias Multivibrator," Proc. IRE, 36 (No. 2): 277-280, February 1948

<sup>2</sup>Clapp, J. K., "An Inductance-Capacitance Oscillator of Unusual Frequency Stability," Proc. IRE, 36 (No. 3): 356-358, March 1948

voltage of a recorder that is recording and the input of the other recorder when it is reproducing. Care was also taken to prevent external radiation or conduction of bias-erase and carrier signals. Figure 35 is a bottom view of the chassis showing the shielding used. Complete circuit details are shown in the circuit diagram, Fig. 36. [UNCLASSIFIED]

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Each multivibrator is followed by a cathode follower (V208 and V209) which drives a 16-kc low-pass filter. This filter removes all components of the multivibrator wave form above 16 kc from the output to prevent higher order harmonics from beating with the 112-kc bias-erase frequency. The frequency response of this filter drops off very rapidly at approximately 16 kc as is shown in Fig. 38. The output of the filter is applied to the record heads by way of a record-reproduce relay (K101 and K102) located in the top plate of the recorder unit. A contact on the appropriate isolation relay (K201 or K202) grounds the output lead of the filter and another contact removes plate voltage from the cathode follower and grounds the plate when the recorder is on hold or reproduce. To minimize frequency drift, the multivibrators are run continuously whenever the equipment is on. [UNCLASSIFIED]

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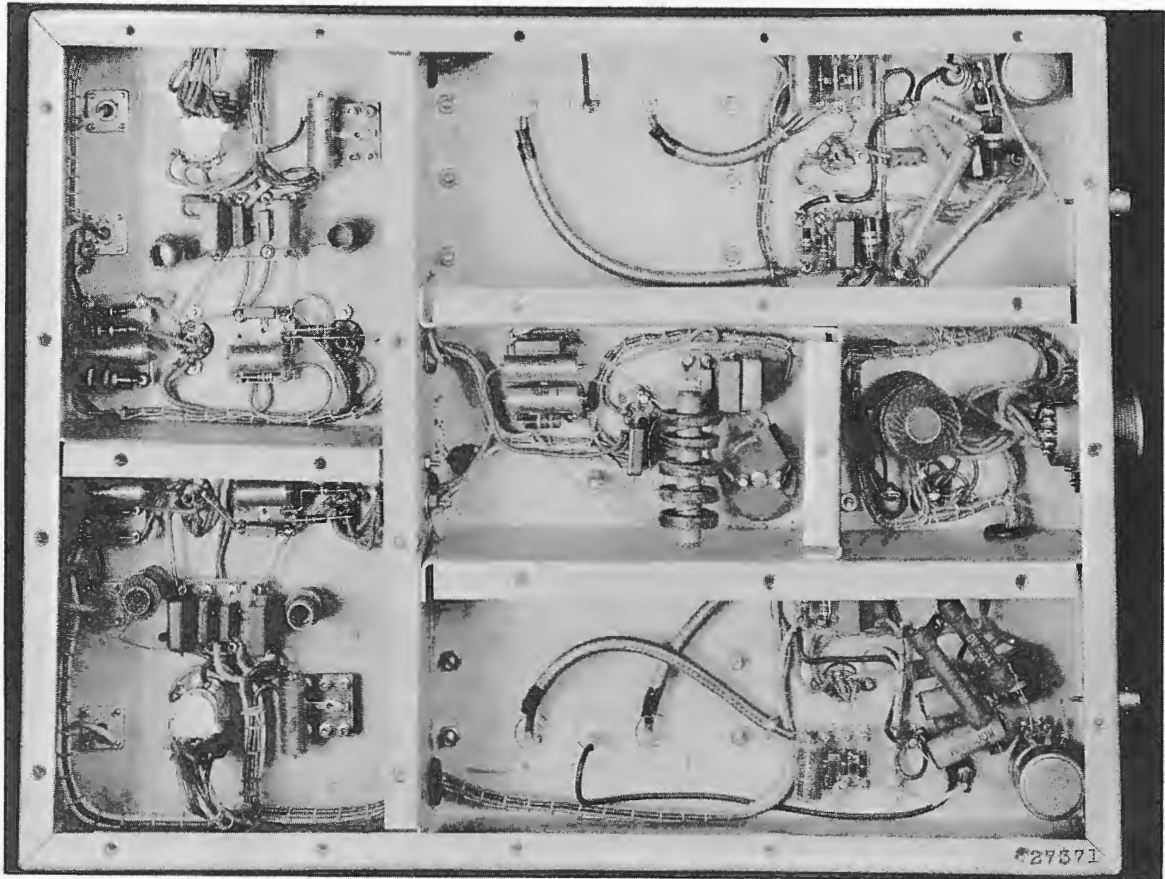


Fig. 35 - Modulator chassis, bottom view [Unclassified]

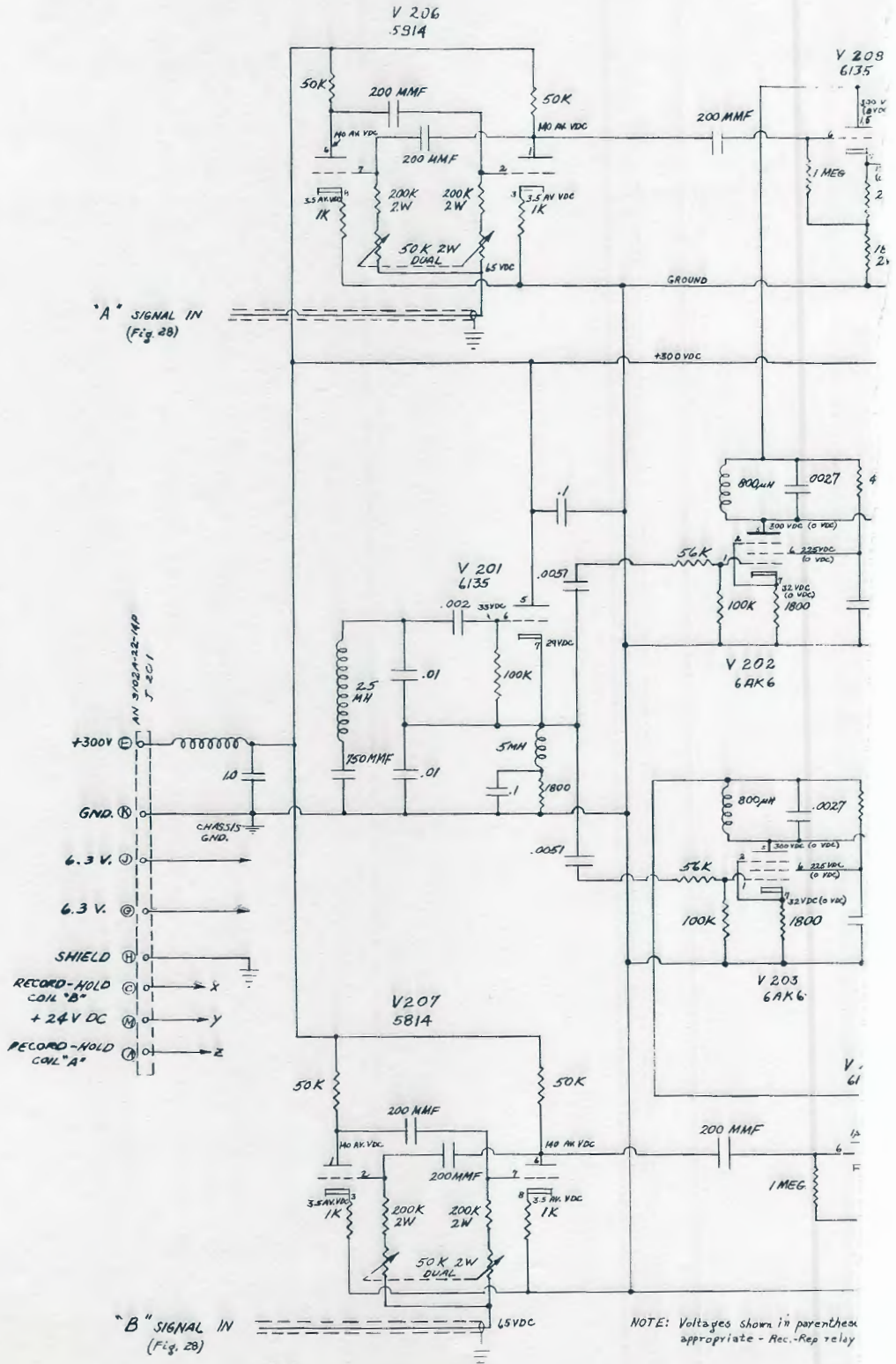
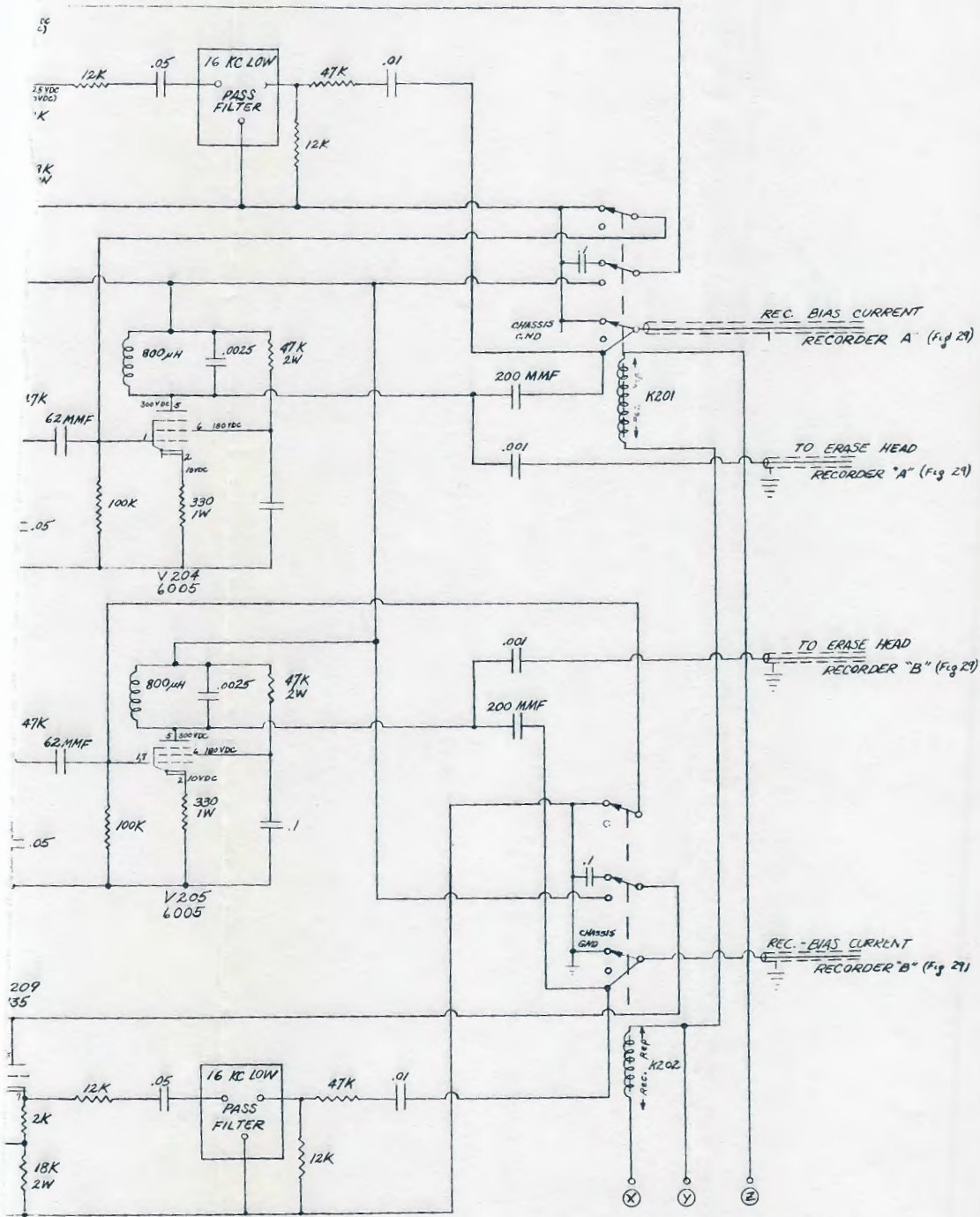


Fig. 36 - Modulator



209  
135

20 are present when  
(K201 or K202) is unenergized.

schematic diagram [Unclassified]

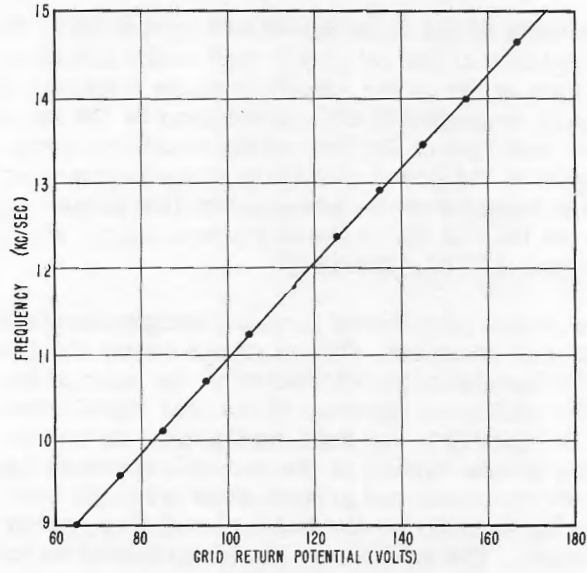


Fig. 37 - Multivibrator linearity [Unclassified]

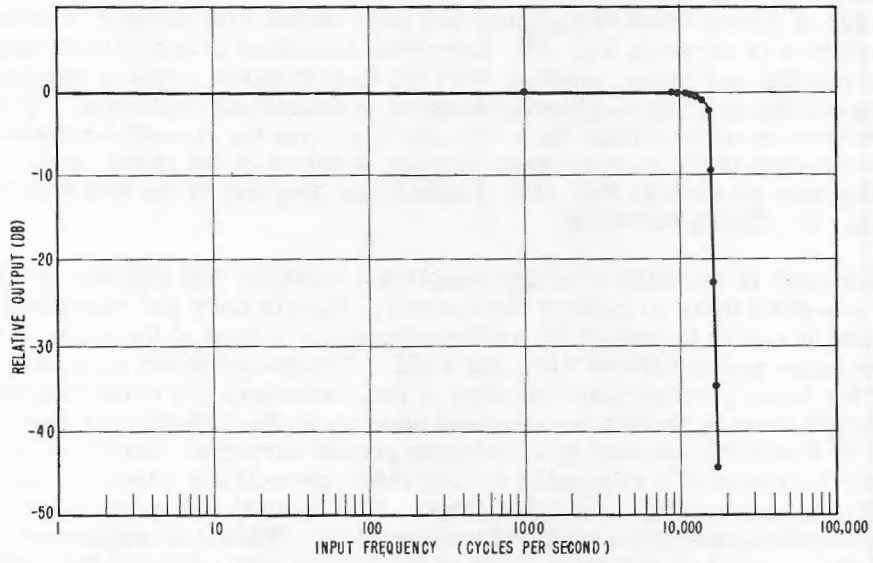


Fig. 38 - Sixteen kilocycles low-pass filter characteristic [Unclassified]

erase energy transfer, the coils of the erase heads are connected in parallel to provide a sufficiently low head-impedance at the relatively high erase frequency used. The bias voltage is taken from the plate of the power amplifier stage through a 200- $\mu$ f condenser to lower its amplitude, and is connected to the record head by the record-reproduce relays. To provide further isolation of the bias-erase oscillator from the reproduced output of a recorder, the grid of the power-amplifier stage is grounded on reproduce. The plate and screen voltage remains on the power-amplifier stages even during reproduce to maintain a more even load on the modulator power supply since sufficient isolation is effected without its removal. [UNCLASSIFIED]

The record-reproduce relays are located in small compartments in the top-plate casting directly in front of each recorder. These relays switch the record-reproduce heads from the output of the modulator during record to the input of the demodulator during reproduce, and also provide additional isolation of the bias signal when reproducing. They are de-energized in both the reproduce and hold conditions. As can be seen from the circuit diagram in Fig. 29, the ground circuit of the record-reproduce head is isolated from the chassis ground, and both the signal and ground leads from the head go directly to the demodulator when reproducing in order to eliminate circulating ground currents in the input to the preamplifier stage. The erase head is also grounded to further reduce input interference. The erase voltage of approximately 600 volts peak appearing on the erase head of one recorder is reduced to an equivalent value of about 10 microvolts peak at the reproduce head of the alternate recorder by the isolation provided. This is an attenuation of approximately 150 db from one recorder to the other and allows reproduction of even the weakest signals with negligible interference from the bias-erase and carrier voltages of either recorder when the alternate recorder is reproducing. [UNCLASSIFIED]

#### Demodulator

The demodulator reproduces the video signal which was used to modulate the recorded carrier. A total of eleven tubes is required and their layout with respect to other components and controls is shown in Fig. 39. Individual low noise preamplifiers are used for each recorder channel and these, together with the first common stage of voltage amplification, are assembled on a shock-mounted chassis to reduce microphonics. To further reduce interference from vibration, the relay which selects the recorder channel to be reproduced is attached to the main chassis through a cutout in the shock-mounted assembly. This may be seen in Fig. 40. A schematic diagram of the demodulator is included as Fig. 41. [UNCLASSIFIED]

The demodulator is basically a voltage amplifier, clipper, and counter-type detector, followed by a low-pass filter to remove the carrier. Signals from the reproduce heads of Recorders A and B arrive by way of the record-reproduce relays at the grids of their respective low-noise preamplifiers V401 and V402. Triode-connected type 5879 tubes are employed for these preamplifiers because of their excellent low noise characteristics. The ground circuit from the heads is connected directly to the cathode bias resistor return of these tubes to minimize hum due to circulating ground currents. Selection of the recording channel to be demodulated is effected by a relay which connects the output of either preamplifier to the input of the first voltage-amplifier stage. This relay also disconnects the plate voltage from the alternate preamplifier for increased isolation. The relay is operated by the reproduce selector-switch on the front panel of the control unit. [UNCLASSIFIED]

A pentode-connected 5879 (V403) is used for the second stage of voltage amplification to maintain low tube noise and hum level. The third stage of voltage amplification (V404)

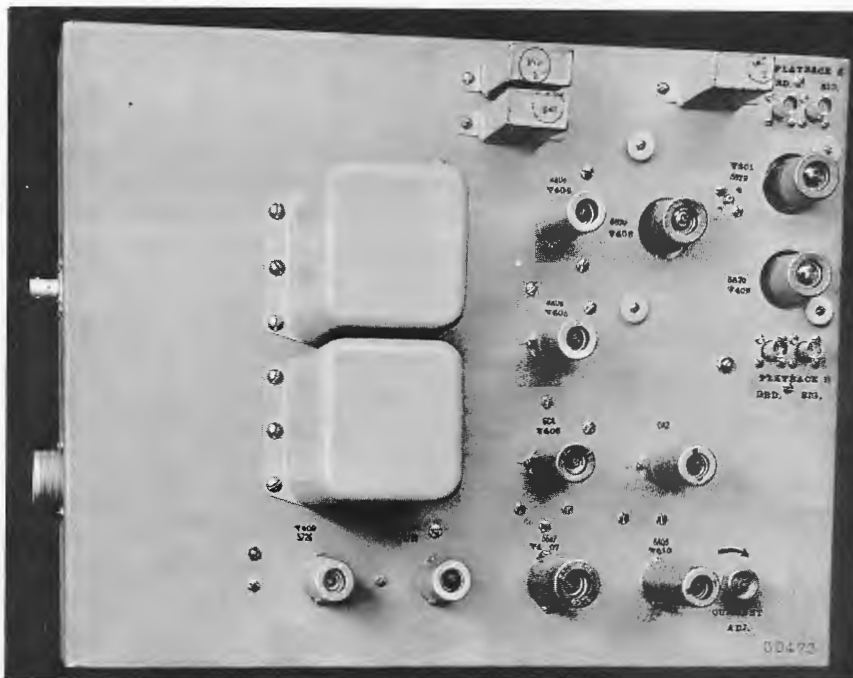


Fig. 39 - Demodulator chassis, top view [Unclassified]

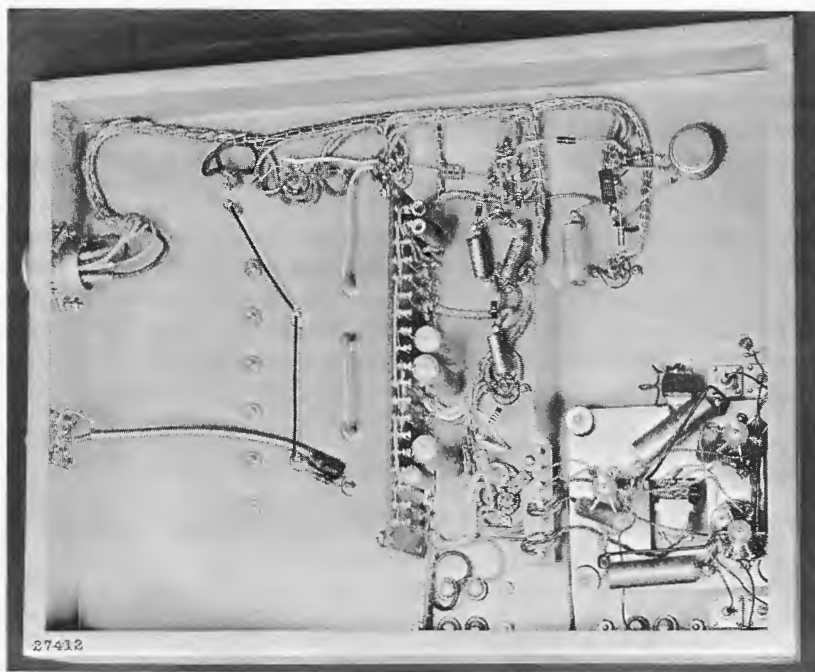


Fig. 40 - Demodulator chassis, bottom view [Unclassified]

is followed by a 6AU6 clipper (V405). All interstage coupling capacitor values are selected to reduce low-frequency response and thus reduce the effect of any hum or low-frequency noise. Frequency response of the demodulator carrier amplifier is shown in Fig. 42. The output of the clipper drives a cathodyne phase-splitter (V406) which in turn applies square waves 180 degrees out of phase to each grid of a 5687 dual triode (V407) used as a current switch. The current drawn by the switch tube is controlled by a pentode (V410). The current which this pentode passes is adjusted by the 50-kilohm potentiometer in its grid circuit, labeled "CURRENT ADJUST" as seen in Fig. 39. An OA2 (V411) maintains constant screen voltage on the control tube. [UNCLASSIFIED]

The output of each section of the switch tube is in the form of a constant-amplitude square wave, the amplitude depending on the current value. The frequency of these square waves is that of the modulated carrier. Each square wave is rectified and differentiated by two diodes (V408) and (V409), their driving capacitors and output load. The driving capacitor, switch-tube load resistor, and diode load must have values such that essentially full recovery of the differentiated wave form is effected at the highest carrier frequency in order to produce a demodulator output voltage which is linear with respect to carrier frequency. The output pulses from the rectifier diodes occur at twice the carrier frequency and are filtered by the 5 kc low-pass output filter, whose frequency response characteristic is shown in Fig. 43. The sharp cutoff of this filter is required to provide sufficient attenuation of any 9-kc carrier component which might be present in the output waveform owing to slight asymmetry of the differentiated square wave. [UNCLASSIFIED]

The output of the demodulator varies from approximately -0.9 volt for a 9 kc carrier to -1.5 volts for a 15-kc carrier and is very linear as illustrated in Fig. 44. The magnitude of this output voltage can be varied by adjustment of the current in the switch tube. A fully modulated carrier produces an output signal of 0.6 volt peak to peak and, for a carrier modulated by an input signal 40 db below that required to produce 100 percent modulation, the resultant output voltage is only 0.006 volt peak to peak. To provide satisfactory operation with signals of this level it was necessary to bias the cathodes of the rectifier tubes at least three volts positive to eliminate noise and hum resulting from the cathodes and heaters. The clamping diodes obtain this bias voltage from a dropping resistor in the cathode of V411. It was further necessary to isolate the ground lead of the low-pass filter and rectifier circuit from the chassis and run it on a separate conductor to the direct-coupled amplifier at the control unit in order to reduce hum due to circulating ground currents. This was achieved by insulating from the chassis of the recorder unit the shield and connectors of the co-axial cable which carries this signal between the recorder and the control unit and by grounding the shield only at the control unit. The low-pass filter is encased in mu-metal shields to reduce hum pickup from neighboring power transformers. It is made in two sections to improve isolation and facilitate mounting. [UNCLASSIFIED]

#### Electronic Alignment

Adjustment of the modulator, the demodulator, and the direct-coupled amplifiers is accomplished as follows. With the reproduce dc amplifier on "High" gain, set the "CIRCLE DIAMETER" control to its center position. Next, adjust the record dc amplifiers as has been previously explained and ground their input to place plus 65 volts on the multivibrator grid returns. Set the "CARRIER ADJUST" potentiometers on the modulator chassis so that the multivibrators are operating at 9000 cycles per second, and make a one-minute recording of either 9-kc carrier. While reproducing this recording, adjust the "CURRENT ADJUST" potentiometer on the demodulator chassis until the reproduce direct-coupled

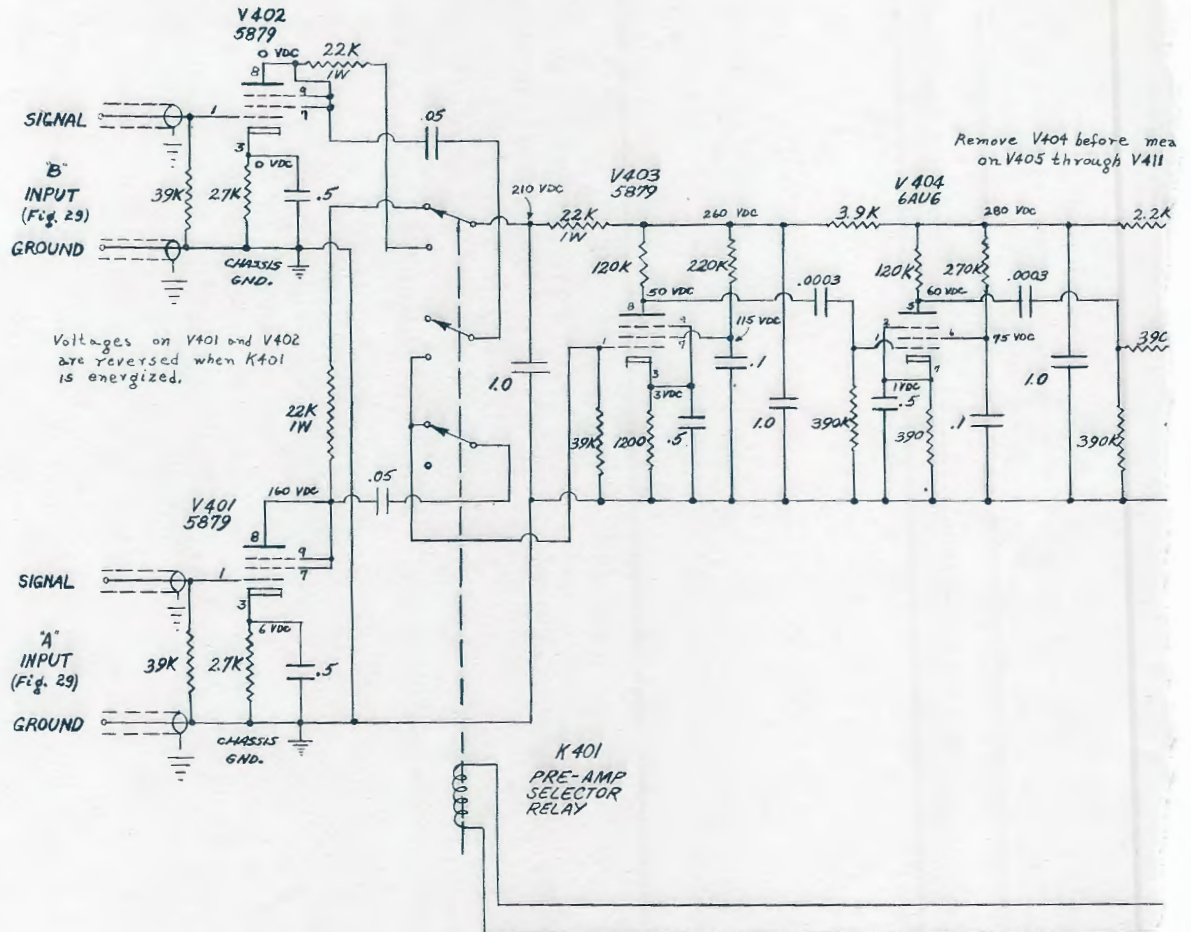
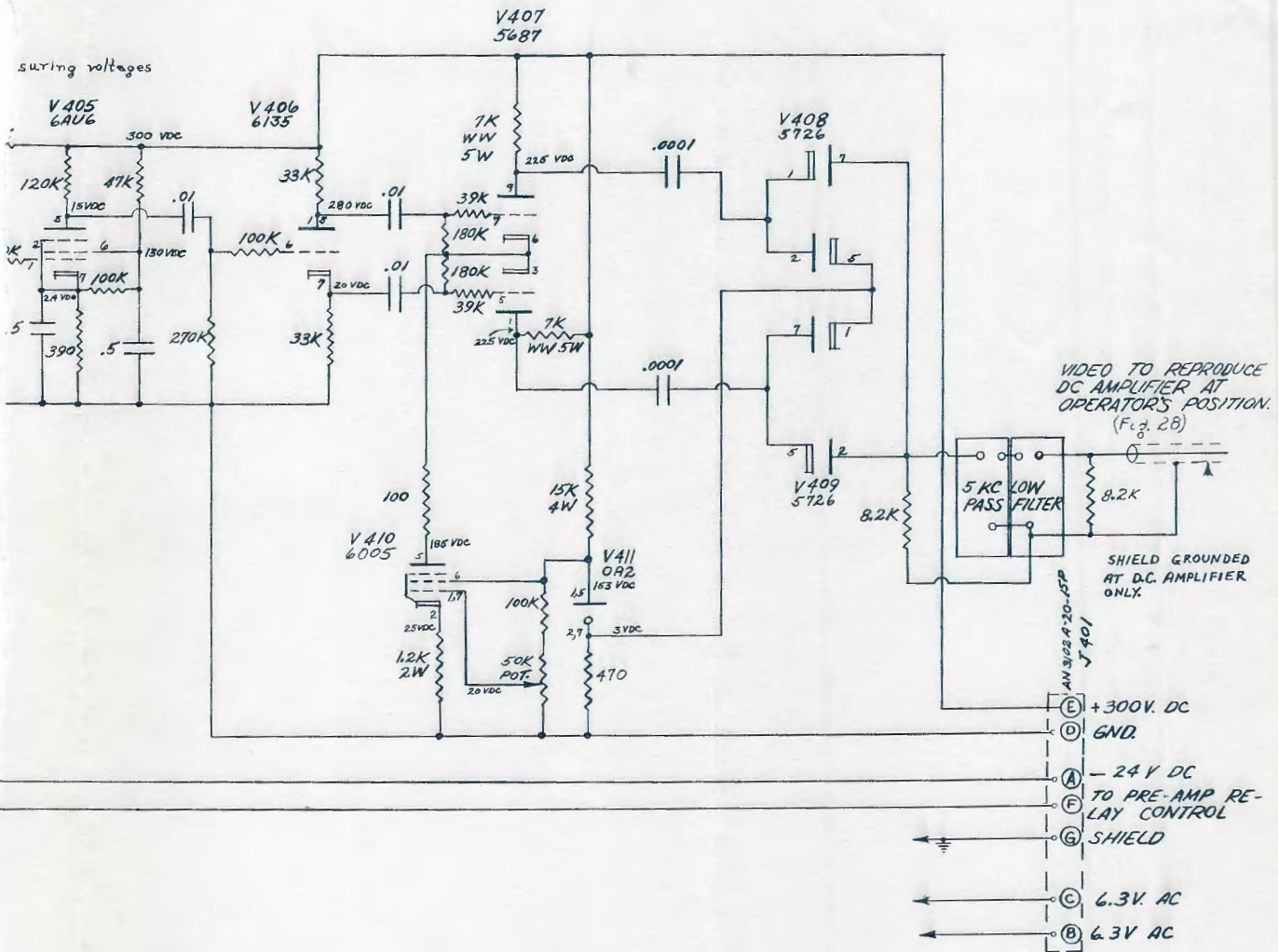


Fig. 41 - Demodulator sc



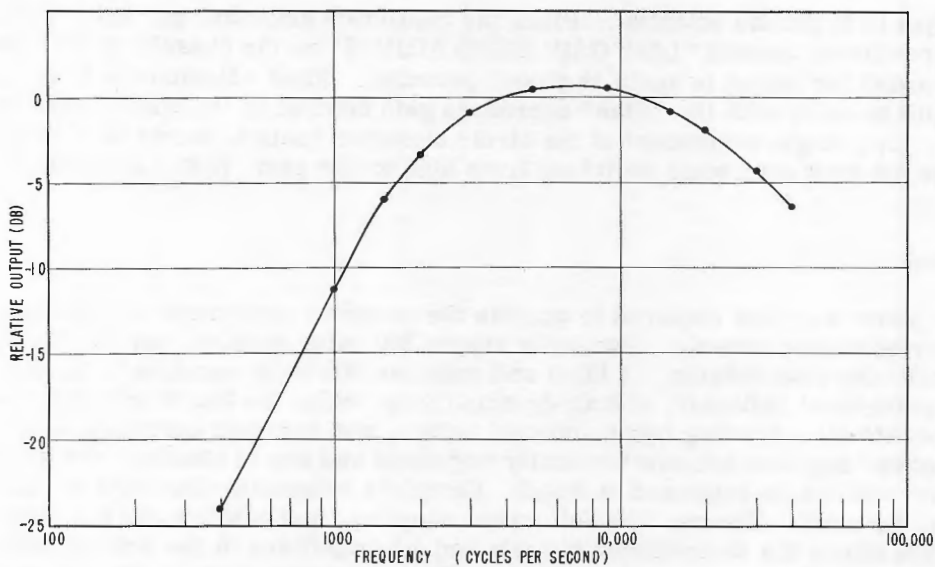


Fig. 42 - Demodulator carrier amplifier frequency response [Unclassified]

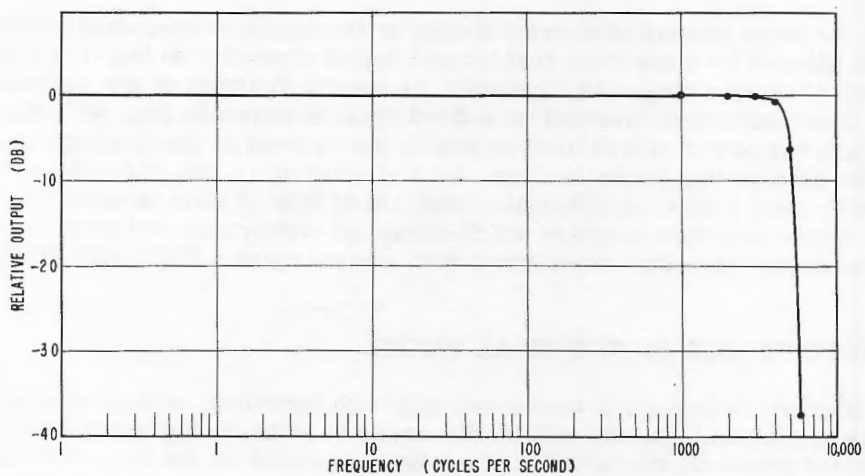


Fig. 43 - Demodulator filter characteristic [Unclassified]

amplifier output is at ground potential. Place the reproduce amplifier on "Low" gain. Adjust the screwdriver control "LOW GAIN ZERO ADJUST" on the chassis of the control unit until the amplifier output is again at ground potential. Final adjustments to ground potential should be made with the "Fine" reproduce gain control on the control panel set at maximum. Only slight adjustment of the circle diameter control should be necessary to compensate for drift even when switching from high to low gain. [UNCLASSIFIED]

### Power Supplies

The four power supplies required to operate the complete equipment are located in the recorder-reproducer console. Two units supply 300 volts positive, one for the modulator and one for the demodulator. A third unit supplies 300 volts negative to the demodulator, modulation-level indicator, and all dc amplifiers, while the fourth unit supplies 28 volts dc to operate all indicating lights, control relays, and carriage operating solenoids. All 300-volt power supplies are electronically regulated and are of standard design; consequently, they will not be explained in detail. Complete schematic diagrams of each unit are, however, included. The two 300-volt power supplies, one positive and the other negative, which supply the demodulator chassis and all amplifiers in the control unit, are mounted on the single chassis shown in Fig. 45. The schematic diagram for this chassis is Fig. 46. [UNCLASSIFIED]

On a second chassis, pictured in Fig. 47 and shown schematically in Fig. 48, the 300-volt power supply for the modulator and the transformer, rectifier, and low-current filter for the 28-volt supply are mounted. This filter section supplies all voltage to the indicator lights and control relays. Because of the high currents involved with this power supply, no direct connection to ground is made. This reduces circulating ground currents which might cause interference in the low-noise preamplifier of the demodulator and in the input circuit from the demodulator to the reproduce dc amplifier. Both sides of this supply are grounded through 330-ohm resistors, and bypass condensers are necessary to prevent bias or erase voltages from appearing on the control leads and passing from one recorder to another. The location of these bypass condensers was found to be critical; their exact location is shown in Fig. 48. [UNCLASSIFIED]

Because of the large amount of current drawn by the carriage-operating solenoids, their power was filtered by a separate reactor and output capacitor to improve the regulation of the control relay voltage and to prevent excessive dimming of the indicator lights. This additional filter section is mounted on a third chassis shown in Fig. 49. Also mounted on this chassis are the power relays used to switch the current to the carriage solenoids. These relays are used so that leads carrying the high current to the solenoids are not a part of the remote-local cable. A schematic diagram of this chassis is shown in Fig. 50. Figure 51 is an interconnection diagram which shows all connections between the individual chassis and between the recorder-reproducer and control units. [UNCLASSIFIED]

### OVER-ALL PERFORMANCE OF THE FINAL MODEL

The discussion which follows is concerned only with technical, and not operational evaluation. The operational aspects will be discussed in forthcoming separate reports. A number of performance characteristics of various segments of the recorder-reproducer system have been presented in the previous section where their operation was outlined. The data given here concerns over-all performance characteristics of the final engineering model

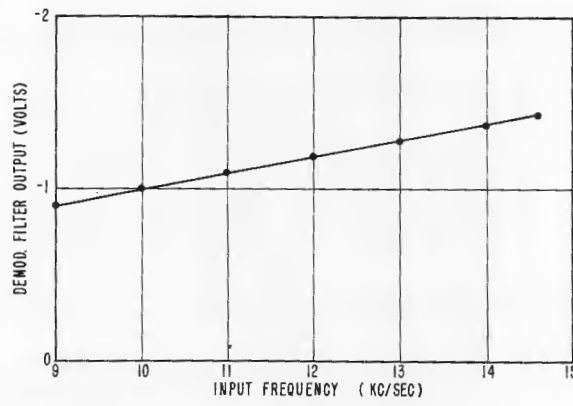


Fig. 44 - Demodulator output amplitude linearity [Unclassified]

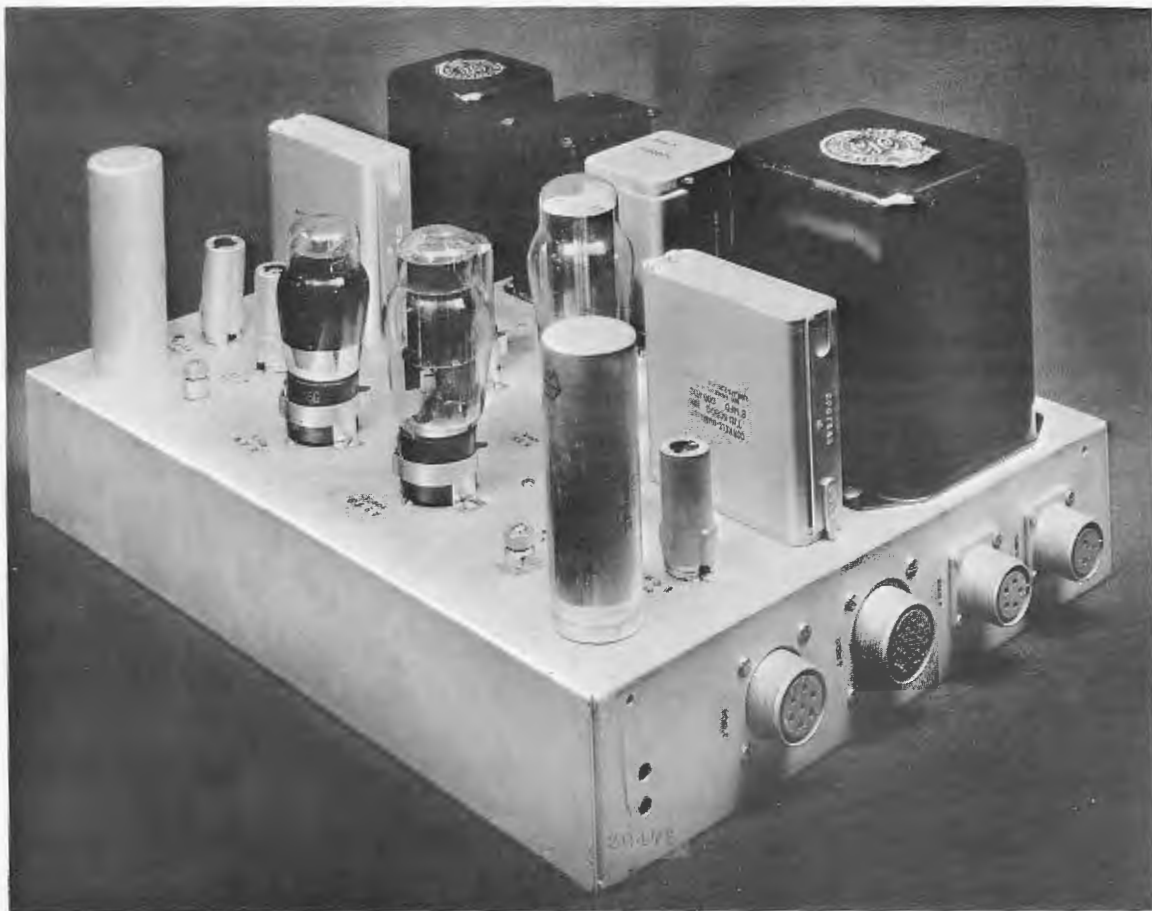
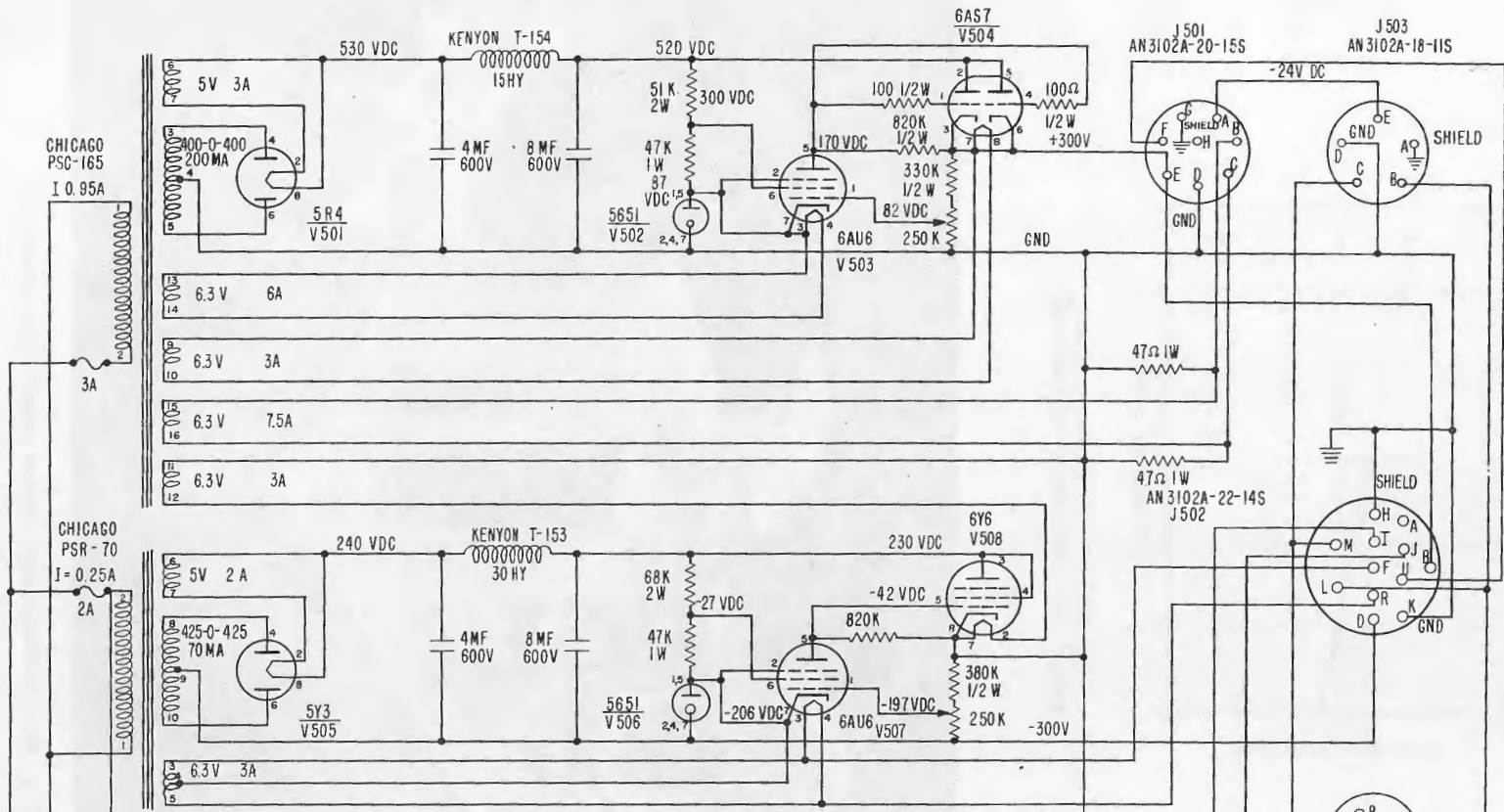


Fig. 45 - Demodulator power supply [Unclassified]

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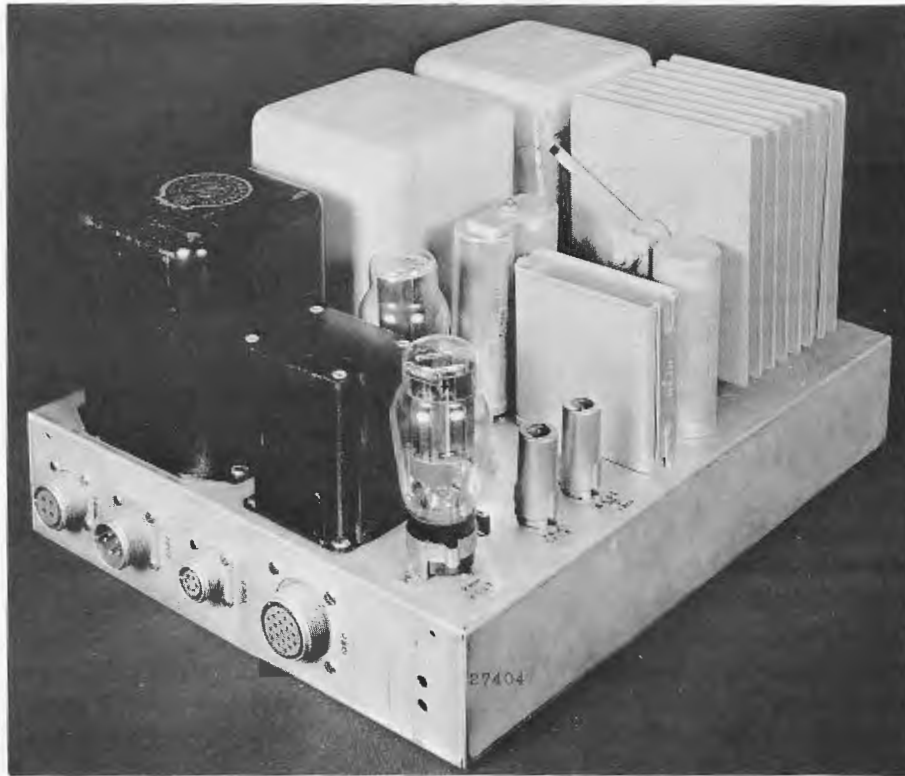


Fig. 47 - Modulator power supply [Unclassified]





Fig. 49 - Solenoid filter chassis [Unclassified]

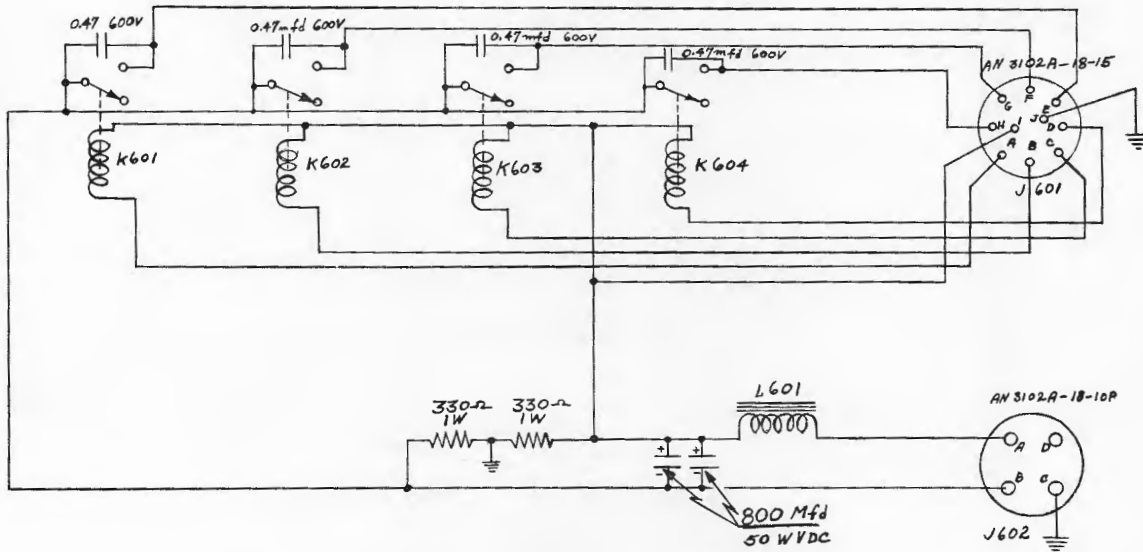


Fig. 50 - Solenoid filter chassis schematic diagram [Unclassified]

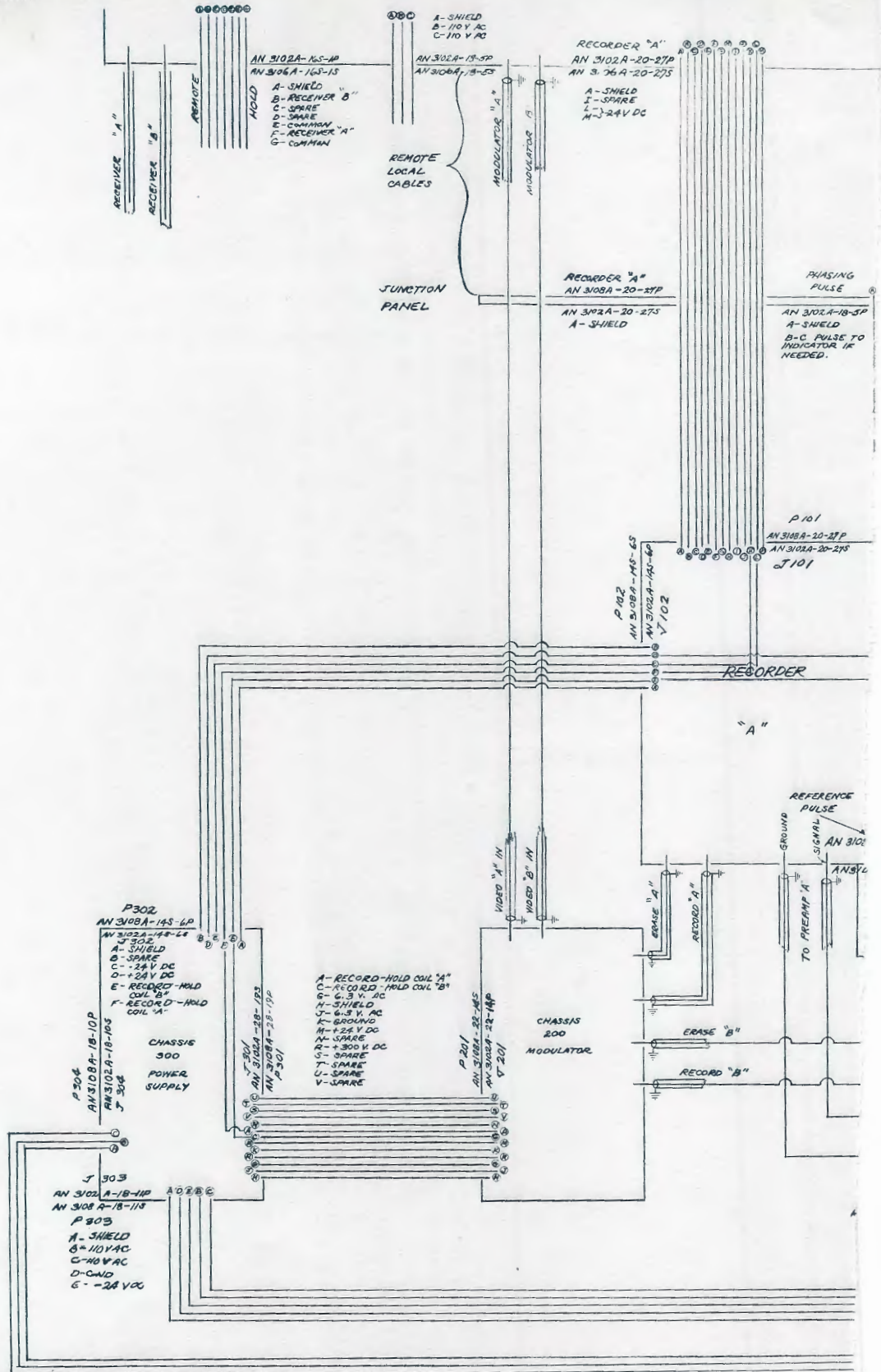
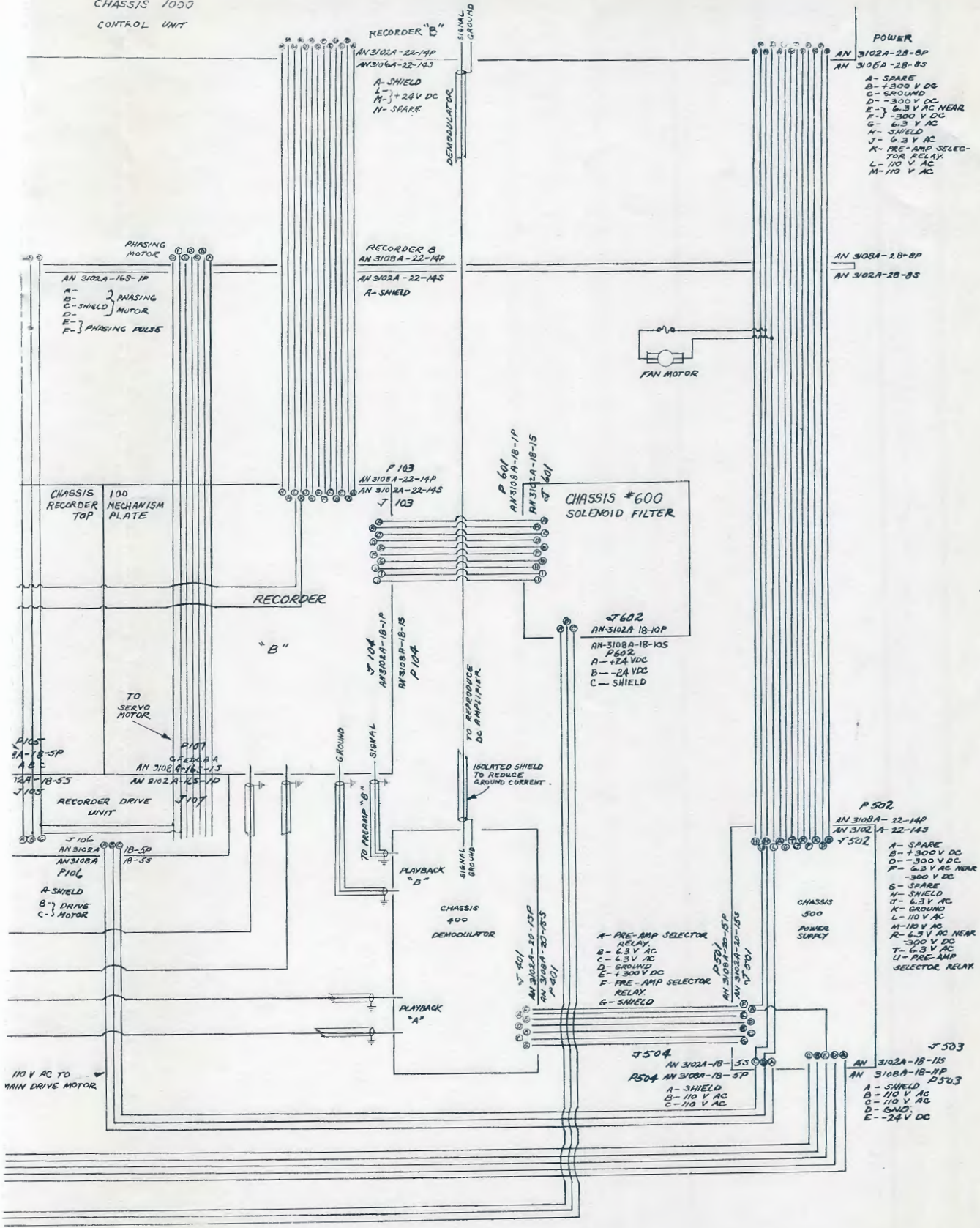


Fig. 51 - Complete

CHASSIS 1000  
CONTROL UNIT



interconnection schematic diagram [Unclassified]

which have not been heretofore presented. All performance data presented here were made when "watch oil" lubricated synthetic rubber (neoprene) recording bands were used. A detailed treatment of recording head and medium lubrication is to be found in the Life Test section of this report. [REDACTED]

The signal-to-noise ratio of a frequency-modulated carrier recording system is determined by several factors including hum, drift, noise, and unfiltered carrier introduced by the electronics; spurious frequency modulation introduced by unreplicative (and therefore noncancelling) flutter of the relative head to medium velocity; and phase modulation resulting from amplitude variations of the reproduced carrier such as result from the typical amplitude dropouts of magnetic recording. Each of these sources of noise will be discussed in turn with respect to the azimuth-data recorder. Hum is particularly undesirable since it is synchronized with the d-f pattern and causes a twist which alters the correct bearing, and the error so introduced is difficult to estimate. For these reasons, great care was exercised to reduce hum to a minimum, and a signal-to-hum ratio of 60 db was achieved. All noise, including spurious carrier, produced by the electronics of the system is at least 45 db below a fully modulated signal. This determination is made by omitting the recording function and introducing a portion of the modulator output, minus bias, directly to the demodulator. Spurious signals, such as carrier and tube noise, which have primary energy concentration in a frequency range much higher than the goniometer rotation rate appear as fuzz on the pattern and permit accurate determination of bearings, even for a one-to-one signal-to-noise ratio of this type. [REDACTED]

The signal-to-noise ratio of the complete recording system, which varies somewhat depending on the condition of the head and recording medium and the accuracy of head alignment, ranges from 40 to 45 db. Some of the nonreplicative flutter introduced by the recording motion is of a frequency similar to that of the goniometer rotation rate, and this flutter is, by a narrow margin, the limiting factor in the over-all signal-to-noise ratio. [REDACTED]

Since the flutter characteristics of gear-driven recording mechanisms have seldom been described in the literature, the motion error noted will be further examined here. If noise due only to the electronic portion of the recorder is subtracted from the over-all noise, then that remaining is due to frequency modulation caused by imperfect motion. Thus, this equipment can serve as a high-quality flutter meter for its own mechanism. The amplitude of all nonreplicative flutter in the recording mechanism is about 0.2 percent rms. The wave form of this flutter was carefully examined to determine any predominate rates. A large portion appeared quite random but two fairly well defined frequencies were noted, one in the range of 33 to 36 cps and one of 150 to 160 cps. No shaft rotation rate or gear mesh rate or any harmonic thereof corresponded to these frequencies. Mechanical resonances of the system were measured by both acoustic and vibration pickup methods. When excited by a blow perpendicular to its surface, Drum A resonated at 2485 cps and Drum B at 2490 cps, indicating a very high degree of similarity between the two castings. The top-plate casting of the assembled recorder resonated at about 90 cps. An attempt was made to determine torsional resonance of the entire drum assembly including both drums, their shaft, and the coupling and driving shaft. This proved difficult and the results were questionable, but an indication of a resonance in the range of 150 to 200 cps was obtained and this rate might be responsible for the 150 to 160 cps flutter rate noted. A drum shaft three quarters of an inch in diameter was included in the original design to reduce any torsional instabilities to a low level. [UNCLASSIFIED]

Friction loads were applied, one at a time, to each side of the four couplings attached to the gear box shafts. It was noted that all points of application which loaded the four gears

between the input shaft and the drum drive shaft had a common effect consisting of increasing the amplitudes of both the 36- and the 160-cps flutter rates and also of superimposing a 1-cps modulation on them. This result causes the 1-rps gear which rotates the drum shaft to be suspect. Such is, of course, a logical conclusion since if the same degree of precision were incorporated in all gears, those on the input and idle shafts would have their errors reduced by 20 to 1 and 4 to 1, respectively. The 36-cps flutter rate is the most objectionable of all recorder noise because it is only 4 cps different from the second harmonic of the indicator rotation rate, and thus causes a slow circular motion of the over-all pattern. It should be borne in mind, however, that this flutter amplitude is 45 db below a fully modulated pattern and is visible only when very weak signals are recorded. [REDACTED]

Another interesting loading effect was noted when recordings 45 db below full modulation were being studied. The reader will recall that there is a five-second overlap during recording when both head sets of a recorder are in use. The reproduce controls are such that only one set is in use at any time. Slightly increased flutter was observed when reproducing the first and last five seconds of each zone, thus indicating that the loading of one instead of two carriages on the drive gears results in a slightly different flutter characteristic. This loading changes the head position on the drum by a small fraction of 0.001 inch and introduces flutter which normally would be repetitive and cancel out. This hypothesis is borne out by the fact that by altering the control circuits and operating both carriages during reproduce, as during record, returns the noise level to normal, as does the exclusive use of a single carriage for both record and reproduce. It should be emphasized that this effect is slight and, on the average, decreases the S/N ratio from about 45 to about 40 db during the first and last 5-second portions of a zone. The 5/8-inch stainless-steel carriage guide-bar was included in the original design in anticipation of rigidity requirements such as these, and the effect noted above is not caused by bending of the guide bar. [REDACTED]

It was thought that the salient-pole drive motor might develop different flutter modes for different operating voltages. Accordingly, a recording was made with a 95-volt motor potential and played back first with a 95- and then with a 135-volt motor potential. Essentially, no change in flutter was noted between the two reproduce conditions. [UNCLASSIFIED]

Repetitive flutter was examined briefly by prerecording a carrier on a precision tape-transport mechanism and then wrapping the tape around the drum and using the gear-driven mechanism for reproduction. The resultant flutter was somewhat greater than that of normal operation, and there was considerable repetition of flutter wave form at a 1-cps rate. Flutter frequencies related to the shaft and gear tooth rates were noted. Further flutter measurements after the life-test period were made to study the bounce and twist of various motor-to-gear box couplings, and are described later. [UNCLASSIFIED]

Limiting action by the carrier amplifiers which are used prior to detection in frequency-modulation systems greatly reduces but does not eliminate the effect of amplitude modulation of the carrier. In particular, relatively high-frequency amplitude variations of the carrier result in appreciable phase modulation. In order to evaluate the effects of the typical amplitude dropouts in the magnetic recording process, the susceptibility of the demodulator to AM was determined. [UNCLASSIFIED]

An unmodulated carrier was injected at the input to the second stage of the demodulator at the same level that the reproduced carrier would have had at this point (70 millivolts peak), and the resulting demodulator output noise was found to be more than 50 db below the output produced by 100 percent FM of the carrier. The carrier was then subjected

to AM of various rates and amplitudes and the noise level was observed. The peaks of the modulation envelope were maintained at 70 millivolts. Amplitude modulation of 50% at 600 cps; 75% at 80 cps, and 90% at 60 cps each increased the noise level 6 db. Amplitude modulation of 25% at 2400 cps; 50% at 1800 cps; 75% at 600 cps, and 90% at 300 cps each produced a noise increase of 16 db. [UNCLASSIFIED]

With these data as a guide, it was possible to predict accurately the effects of dropouts encountered on the various recording zones by estimating their average time length and depth. As previously observed, noise due to these dropouts is not the limiting item of the dynamic range. A very slight improvement is possible by increasing the amount of clipping in the carrier amplifier, but this is not deemed advisable because of the more critical amplifier which would result. [UNCLASSIFIED]

The frequency-versus-amplitude response of the complete electronic portion of the recording system with the record and playback functions omitted is shown in Fig. 52. A portion of the modulator carrier output was fed to the demodulator input through a suitable dividing network. A relatively low input test signal producing about 10 percent of full frequency modulation is required to obtain the high frequency portion of this over-all response curve because wide-frequency excursions at a high rate produce sidebands which are restricted by the 16-kc low-pass filter in the modulator, thus producing distortion. The d-f receiver video wave form is such that no injurious effect is produced by this filter. [REDACTED]

The frequency-amplitude response of the over-all system including the recording process is essentially the same as Fig. 52 but slight variations are noted among different recording zones. It is interesting to note that, for the average of the zones, the high-frequency response appears somewhat improved when the record-reproduce functions are included in the measurement. This effect results from a somewhat nonlinear frequency-versus-amplitude characteristic of the reproduced carrier, which produces a small amount of AM, particularly when the reproduce heads are worn or improperly adjusted. The rate of this AM is the same as the FM being applied, and phase modulation resulting from this AM becomes noticeable at the higher frequencies, as previously explained, and actually increases the amplitude of the demodulated signal slightly in this instance. [UNCLASSIFIED]

Figure 53 shows the phase shift-versus-frequency characteristics of the entire recording system caused by the modulation and demodulation processes. This characteristic results in a constant and compensable bearing shift, equivalent in time to 330 microseconds, and representing 2.5 degrees for an indicator such as that of the AN/GRD-6 turning at 20 rps. When an indicator is used exclusively for reproduced bearings, this 2.5-degree correction can be compensated by indicator zero adjustment permitting all reproduced bearings to be read directly from the indicator scale. When the recorder drive-motor voltage is changed from 95 to 135 volts, a reproduced pattern will shift 3 degrees. However, if the same voltage variation is applied to the goniometer motor during record and to the indicator motor during reproduce, they shift a similar amount, so that the resulting error is less than one degree. As previously mentioned, it was therefore, concluded that the recorder equipment would operate satisfactorily without use of the motor phase-control system provided no motors were stopped and if the same voltage were applied to simultaneously operated motors. [REDACTED]

The linearity of the input-level versus output-level of the complete recording system is shown in Fig. 54. One-hundred-percent modulation level, as defined, produces some compression of the upper portion of the input signal just prior to the occurrence of the

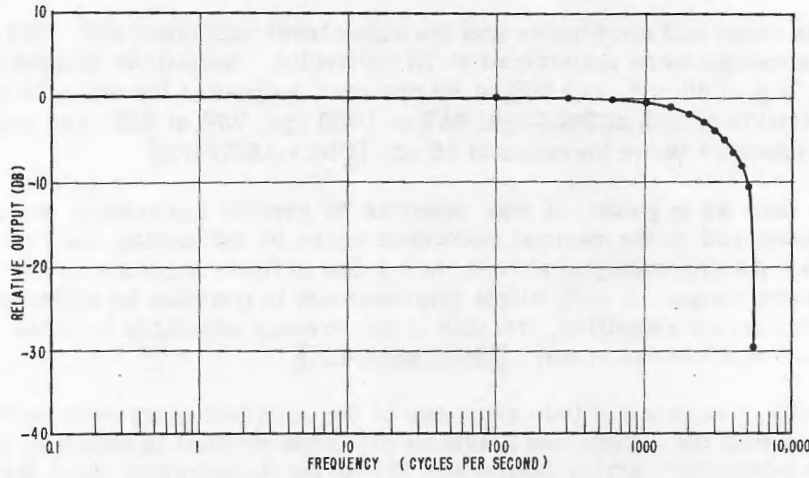


Fig. 52 - Frequency response of electronic portion of the system [Unclassified]

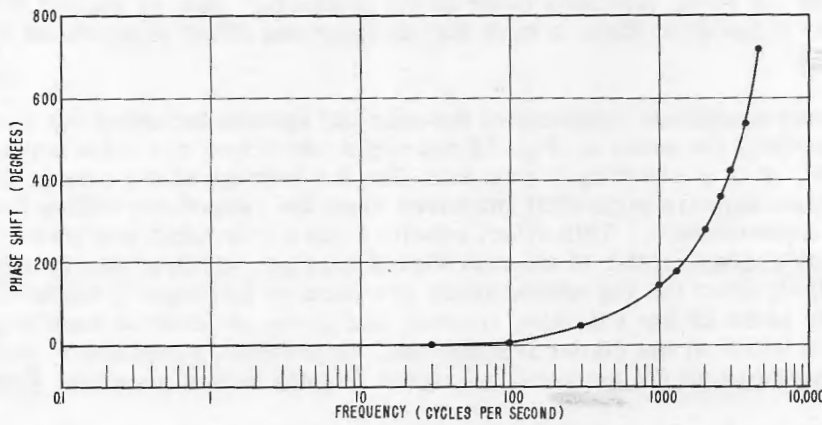


Fig. 53 - Phase shift of over-all system [Unclassified]

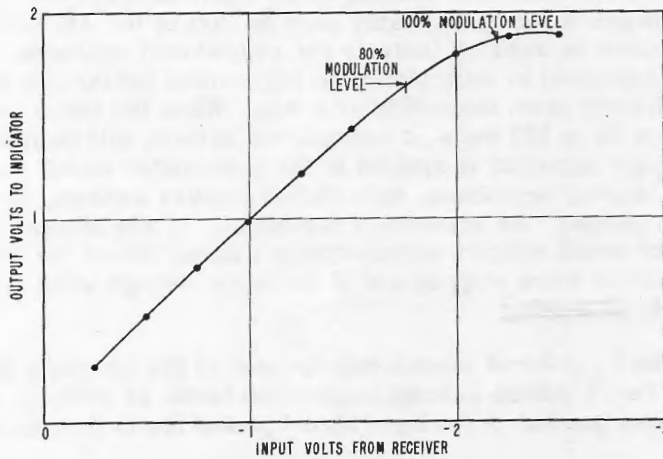


Fig. 54 - Amplitude linearity of over-all system [Unclassified]

clipping action employed to prevent overmodulation. However, this compression results in only a slight slimming of the propeller and does not introduce bearing error. Modulation values of 80 percent and less result in essentially perfect over-all system amplitude linearity. Actually, bearings are readable even when highly clipped, provided the amount of clipping does not exceed the depth of the video-pattern null. [REDACTED]

Figures 55 and 56 show various d-f propeller patterns as they appear on the indicator directly from the receiver and after being recorded and reproduced. To obtain these patterns the receiver gain was first adjusted so that receiver noise created about 1/16th inch of grass on the indicator trace. This gain setting will, hereafter, be referred to as "normal search gain." A cw signal was applied from a laboratory generator and the level of this signal input was adjusted so that a properly closed propeller pattern was obtained on the indicator using the normal search gain setting on the receiver. This signal input level was then noted and is hereafter termed "zero db signal input." It will be noted that Figs. 55 and 56 each consist of two horizontal rows of a series of three pictures. Fixed signal input levels, both above and below zero-db signal-input level were used for each row of three pictures (one value for Fig. 55a, b, and c; another value for Fig. 55d, e, and f; etc) and the actual value used in each instance is noted on the figures. [REDACTED]

The left hand picture of each row (Fig. 55a, and d and Fig. 56a and d) was taken when the receiver output was applied directly to the indicator and normal search gain was used. Thus, these pictures show the appearance of the pattern for varying received signal strengths, and it should be noted that in the case of short duration signals, time to properly adjust the receiver gain would not be present. The record gain of the AN/FSH-1 was adjusted so that 100 percent recorder modulation was achieved coincident with a fully closed indicator pattern when normal search gain was used. At this recorder gain setting, recorder saturation occurred only 6 db prior to receiver saturation, and the null indication of strong signals vanished simultaneously on both direct and reproduced patterns. The recorder gain was left in this position while the video of each of the left hand pictures was in turn recorded. The middle picture of each row shows the respective recorded patterns being reproduced. The reproduce gain has been adjusted in each instance to produce a properly closed pattern. The right hand picture of each series once again shows the receiver output applied directly to the indicator, but in each case the receiver gain has been adjusted to produce an optimum pattern. [REDACTED]

The quality of these direct patterns, when compared with the quality of recorded and reproduced patterns indicates that receiver noise is essentially the limiting factor in providing usable bearings and that very slight pattern depreciation is introduced by the record-reproduce process. Comparison of the direct pattern produced when the receiver is used on normal search gain with the reproduced patterns having properly adjusted gain indicates that considerable improvement in bearing readability is effected by use of the recorder when insufficient time is available to adjust the receiver gain. Further improvement in bearing accuracy may often be obtained by the use of several replays of the recorded signal. [REDACTED]

The receiver and recorder gain settings used for the photographs in Figs. 55 and 56 were chosen in order to prevent receiver noise from excessively masking the recorder dynamic-range characteristics. It is probable that an even higher receiver gain setting would be optimum for actual search operation, and that the recorder gain should be adjusted so that 100 percent recorder modulation is achieved coincident with receiver saturation. When the recorder gain is so adjusted, no operator could detect any pattern depreciation due to the record-reproduce process. [REDACTED]

DECLASSIFIED



a.  
DIRECT PATTERN  
NORMAL RECEIVER GAIN



b.  
REPRODUCED PATTERN  
PROPER REPRODUCE GAIN



c.  
DIRECT PATTERN  
CORRECTED RECEIVER GAIN

SIGNAL LEVEL: 0 DB



d.



e.



f.

SECRET

DECLASSIFIED

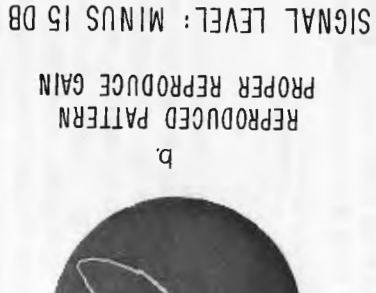
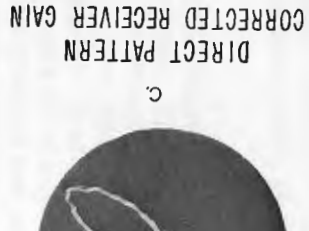


Fig. 56 - Photographs of direct and reproduced patterns

Retrace of the head carriages during reproduction causes a momentary absence of the carrier, and the demodulator produces a high amplitude noise output which disturbs viewing of the indicator for the first few seconds after playback is resumed, particularly when long-persistence phosphors are used in the indicator cathode-ray tube. This effect can be eliminated by use of a squelch relay, which places the input to the reproduce direct-coupled amplifier at ground potential whenever the reproduce head is removed from the recording surface. This squelch relay can be operated by a contact on the appropriate carriage-control relay. Squelch operation should be simultaneous with the carriage relay operation when the head is raised but it should be continued a sufficient length of time after carriage relay operation when the head is lowered to permit rotation of the control cam to effect contact of the recording head and medium. Such a circuit was designed and used in breadboard form and was satisfactory. The required delay in removing the squelch action was achieved by placing a capacitor in parallel with the squelch relay, thus providing rapid closing and delayed release action. The squelch circuit was not incorporated in the present model because of the difficulties attendant upon rewiring a completed unit. [UNCLASSIFIED]

As previously mentioned in the comprehensive description of the final model, steps were taken to minimize any spurious external signals emanating from the recording system. Arc-suppression capacitors were used on all frequently operated relay contacts and switches, and both electrostatic and magnetic shielding were used in various portions of the equipment. A quantitative measurement of the actual spurious signal level was not made, but the recorder-reproducer system was placed in a shielded room and a qualitative check performed. A group of communication receivers having normal sensitivity and covering the frequency band from 100 kc to 140 Mc were used with both loop and straight-wire antennas placed within one foot of the recorder units. Maximum receiver sensitivities were used, and each receiver was tuned over its frequency coverage several times as various recorder operating conditions were employed. No signals from the recorder exceeded the noise level of any receiver, thus indicating the recording system to be satisfactory for use even in sensitive receiving locations. [UNCLASSIFIED]

#### LIFE TESTS

The AN/FSH-1 (XB-1) equipment has been operated for a total period of 2000 hours as of the date of this writing. The first 1000 hours of use were on a continuous basis whereas the second 1000-hour period was intermittent with an average daily operating period of six hours. The operating notes included as Appendix A were furnished to the attending personnel during the 1000-hour continuous run. No electronic failure has been encountered. All tubes were tested after 1200 hours of operation. Of the total number of 46 tubes, six had one or more sections with below-standard emission but none exhibited shorts or other defects. The tubes having low emission were V201, V206, V406, V407, V409, and V1008. These tubes were replaced, although their weakness had not produced any noticeable degradation in equipment performance. The durability of the mechanical portion of the recorder-reproducer system, as observed during the entire life test, was judged to be excellent, since only a few failures in the entire complex mechanism were encountered. [UNCLASSIFIED]

The metal drive-coupling between the motor shaft and gear-box input shaft worked satisfactorily for the first 1400 hours, after which time it became noisy and started to introduce slight additional flutter. The design of the coupling was such that it would tolerate only very slight shaft misalignment when operated at the relatively high speed of 1200 rpm.

SECRET

DECLASSIFIED

A slight amount of wear occurred in the sleeve bearing of the gear-box input shaft, thus accentuating the misalignment and inducing chatter. A commercial rubber coupling as used in the interim model was not sufficiently stiff to drive the greater load of the final model and slow torsional flutter of such a coupling existed. A more rigid rubber coupling could be obtained only by initiating a special development. Therefore, a search was made of other types of commercially available couplings and the one which appeared to be the most suitable was obtained. This coupling\* was installed between the motor and gear-box shafts and preliminary tests indicate it to be entirely satisfactory. It is quiet in operation and removes the flutter introduced by the original pin-type coupling. [UNCLASSIFIED]

The gear box operated satisfactorily during the entire period except for the loosening of one taper pin which required refitting, and the development of an oil leak around the input shaft seal which necessitated replacement of the seal. It is believed the seal failure was hastened by a slightly high oil level resulting in excessive spray against the bearing, and also by bearing wear. [UNCLASSIFIED]

The only remaining failure of the mechanism was a freezing of the recording-drum-shaft sleeve bearings caused by inadequate lubrication resulting from improper seating of the lubrication wicks. The wick oilers were redesigned to assure proper contact with the shaft, and operation thereafter was satisfactory. Lubrication of all wick oilers on the drum assembly and associated shafts was necessary every 200 to 300 hours of operation. The head handling carriages were carefully lubricated during their assembly and thus far have not required reoiling. [UNCLASSIFIED]

Recording medium and head wear tests were continued throughout the course of the project and a brief summary of the results is given here. The record-reproduce and the erase heads used in all models were formed of 0.006-inch-thick mu-metal laminations. These thin laminations gave less high frequency loss and seemed to wear more uniformly than the 0.015-inch laminations used in the corresponding commercial heads. [UNCLASSIFIED]

During the first 1000 hours of operation, watch oil<sup>†</sup> was used for lubrication of the synthetic-rubber recording bands and gave a consistently good signal-to-noise ratio with no measureable wear of either heads or medium. This oil was adopted at the beginning of the test when the lubricating wax in the rubber was found unsatisfactory with respect to signal-to-noise ratio and increased wear and maintenance. The main disadvantage in the use of such an oil is the frequent application necessary when the recorder is used intermittently, since reoiling is necessary after each period of approximately 12 hours of recorder nonuse because the oil drains to the bottom of the drum. However, for continuous recorder operation, reoiling is required only twice a week. The design of several types of automatic oilers was considered, but no attempt was made to incorporate them in the final model owing to the extensive revisions required. Any one of several oils is satisfactory. Numerous types of oils were used for recording trials and samples of the recording medium were soaked in these oils to observe any deteriorative effects. The details of these tests are lengthy and will not be presented here. It is of particular interest to note that only oils of rather low viscosity were satisfactory since high viscosity prevented intimate head-medium contact. Oils having synthetic bases were unsatisfactory because they produced excessive softening of the recording medium. [UNCLASSIFIED]

\*One-half simplex type, manufactured by Thomas Flexible Coupling Co., Warren, Pa.

†Marco Watch Oil c. & e., manufactured by the Marshall Company

Recording bands of a new synthetic-rubber type of recording material called "hypalon" by the manufacturer\* and not intended to require a wax or other lubricant were obtained. The final model of the recorder was fitted with these bands, and operated for 1000 hours without lubrication. The signal-to-noise ratio obtained at the beginning of the test was, on the average, better than that obtained with the original wax-lubricated neoprene, but was 3 to 5 db poorer than that of the oil-lubricated neoprene. The signal-to-noise ratio had decreased about 6 additional db to a value of about 34 db by the end of the 1000-hour run and the heads were seriously worn and needed replacement at that time. The hypalon itself showed little wear. A similar test made on the interim model indicated the hypalon material would greatly outwear the heads. [UNCLASSIFIED]

The use of hypalon with mu-metal heads was considered unsatisfactory except for intermittent recorder use, but hypalon could possibly be used with heads of new types of core material to achieve long life and reasonably good signal-to-noise ratios. New magnetic-core materials are discussed in the conclusions and recommendations of this report. All of the oil tests were repeated with the hypalon material. The signal-to-noise ratio of oil-lubricated hypalon was similar to that of the oiled neoprene, and several oils were found to be satisfactory for use with the hypalon although some reacted differently to the hypalon than to the original neoprene. [UNCLASSIFIED]

When oil-lubricated recording bands were used with unworn heads, the over-all signal-to-noise ratio of the complete recorder-reproducer system was essentially unchanged after the 2000-hour life test, indicating the normal equipment life to be far in excess of the test period. [UNCLASSIFIED]

#### CONCLUSIONS AND RECOMMENDATIONS

On the basis of the over-all performance characteristics and results of the life tests, it is concluded that the AN/FSH-1 (XB-1) equipment meets or exceeds all specifications stated in the problem details and that it is entirely suitable for operational evaluation. The life tests have shown the equipment to be exceptionally free of defects and capable of extended trouble-free operation. It is recommended that future models incorporate the following minor changes from the present model. [UNCLASSIFIED]

The ramps for raising and lowering the magnetic heads and the control circuit feature which always causes any heads in operation to complete their mechanical cycle were both incorporated in order to minimize difficulties associated with the wax lubricant used in the original recording rubber. Since the wax is no longer used, both of these items can be eliminated. In addition, the choice of fourteen recording tracks per inch was predicted on the allowance of sufficient "land" for the accumulation of excess wax. If desired, approximately a 30 percent increase in recording time can be obtained by replacing the present lead screw with one having eighteen threads per inch. Since the maximum recorded wavelength is about 0.002 inch, very little fringing flux is encountered during playback. [UNCLASSIFIED]

A squelch circuit should be added to eliminate the noise output of the reproduce amplifier during retrace of the head carriages. A suitable circuit for this purpose has been described in the Performance section of this report. [UNCLASSIFIED]

\*Brush Electronics Co., Cleveland, Ohio

The slight wear of the gear-box bearing on the input shaft next to the motor coupling can be alleviated by replacing the present sleeve bearing with a ball bearing. The sleeve bearing on the other end of this shaft has a smaller load and should be retained to control endplay. [UNCLASSIFIED]

It is believed that future study of the magnetic head wear problem should include tests of core materials having a greater physical hardness than mu-metal. The use of ferrites has been considered, but the resolution of ferrite head gaps is, in general, rather poor, and the narrow-gap open-core type of head cartridge necessary would subject the brittle ferrite to mechanical injury. A more suitable material appears to be "alfenol," a magnetic alloy developed by the Naval Ordnance Laboratory, White Oak, Maryland. Preliminary information indicates this material has about ten times as long a life as mu-metal when used with magnetic tape. To date, no commercial source of "alfenol" is available but it is understood that it will be obtainable from a manufacturer in the near future. The use of some hard-core material with "hypalon" recording bands is suggested for intermittent operation, and may prove to be acceptable for continuous operation. As an alternate possibility for continuous operation, the use of either "hypalon" or the regular neoprene recording bands and mu-metal head cores in conjunction with biweekly oil lubrication is believed to be entirely satisfactory. Automatic application of the oil could be considered if desired. [UNCLASSIFIED]

The AN/FSH-1 recording system, as described herein, is believed to be entirely suitable for use as a model for the limited production of more units with very little additional design or development work. The equipment has been described at some length herein but many additional detailed data including complete engineering drawings of all mechanical details, parts lists, and further performance, test and construction information are on file at the Naval Research Laboratory and can be made available to properly cleared and authorized personnel. [UNCLASSIFIED]

#### ACKNOWLEDGMENTS

The successful and rapid completion of the research, design, fabrication, and testing of this complex and precisely engineered electronic and mechanical equipment was facilitated by the aid and close cooperation received by the authors from many NRL personnel. It is desired, in particular, to mention the following. Valuable comment on the over-all system design and application was contributed by Mr. H. K. Weidemann. Mr. M. J. Sheets furnished consultative services concerning the field of direction finding. Supervision and coordination of mechanical design items and construction procedure were performed by Mr. J. W. Burkert. Many design features and all final layout and design drawings of the top plate mechanism were contributed by Mr. C. R. Shuler and Mr. R. S. Rovinski of the Engineering and Design Drafting Branch. Assembly and adjustment of the top-plate mechanism was done by instrument makers R. F. Henley, J. H. Collier, and T. R. Bailey of the Naval Research Laboratory Engineering Service Shop. [REDACTED]

\* \* \*

APPENDIX A  
Operating Instructions for AN/FSH-1 (XB-1)  
Azimuth Data Recorder

GENERAL DESCRIPTION

The AN/FSH-1 (XB-1) recording equipment consists of a recorder unit and a control unit. The recorder unit is housed in a console cabinet and includes the recording mechanism and most of the associated electronics. No controls necessary for the operation of the recorder are included in this unit. To facilitate positioning, the console is equipped with four retractable casters which can be lowered to the floor by turning each of the two acorn nuts located at the lower front corners of the cabinet one-half turn in either direction. After the recorder has been rolled into position, these casters should be retracted by turning the acorn nuts an additional one-half turn, which permits the console to rest on four domed feet. [UNCLASSIFIED]

The control unit, containing all remaining electronics of the recording system and all controls necessary for normal recorder operation, is housed in a table-type cabinet designed to be placed side by side with the indicator of the AN/GRD-6 equipment. [SECRET]

The two units are connected by a multiple cable assembly thirty feet in length. This cable assembly consists of three shielded cables plus three co-axial leads. The three shielded cables are labeled RECORDER A, RECORDER B, and POWER, and are equipped with plugs which fit only the proper sockets. The three co-axial leads are labeled MOD A, MOD B, and DEMOD, and are connected to the identically marked sockets on the units. The cable assembly is provided with straight plugs for connection to the control unit and right-angle plugs for connection to the recorder unit. The connector sockets located on the rear of the recorder unit and labeled PHASING MOTOR and PHASING PULSE are not necessary for operation of the recorder. They have been provided to permit the connection of servo circuitry for phase control of the recorder motor by the goniometer motor and/or phase control of an indicator motor by the recorder motor. All other connections to the recording system are made at the rear of the control unit. These include the primary power input labeled AC POWER, recorder inputs from two separate receivers labeled RECEIVER A and RECEIVER B, one recorder output for an indicator labeled INDICATOR, and a socket labeled REMOTE HOLD for connection of an external recorder-hold circuit. The jumper furnished for the remote-hold socket must be left in place when external hold circuits are not used. The holding function of the recorder is described in the section of these instructions entitled "Operation of the Recorder-Reproducer System." [REDACTED]

PRIMARY POWER REQUIREMENTS AND FUSE LOCATIONS

The recorder operates from a 115-volt, 60-cycle, single-phase supply and requires 620 watts. Two 10-ampere fuses are used in the primary power-input leads and are located on the rear of the control unit. Six additional fuses are located in the recorder unit as follows. When the front doors are opened, two fuses are visible on the front of the lower left-hand chassis. The upper fuse has a value of 3 amperes and protects both the positive 300-volt supply and the heater supply for the modulator located in the upper left-hand chassis. The lower fuse has a value of 3 amperes and protects the 24-vdc supply which furnishes power for all relays and solenoids. Two fuses are visible on the front of the lower right-hand chassis. The upper fuse has a value of 3 amperes and protects both

the positive 300-volt supply and heater supply for the demodulator located in the upper right chassis, and for all direct coupled amplifiers and the monitor oscilloscope, both of which are located in the control unit. The lower fuse has a value of 2 amperes and protects the negative 300-volt supply and the heater supply for the direct-coupled amplifiers and the monitor oscilloscope. The fuse which protects the ventilating fan motor is mounted on a bracket attached to the motor frame and has a value of 1 ampere. The fuse which protects the main recorder drive motor has a value of 3 amperes and is located on a bracket near the motor. [UNCLASSIFIED]

#### BASIC OUTLINE OF RECORDER MECHANISM

Access to the mechanical portions of the recorder is achieved by opening the hinged lid of the recorder console. A drum-type recorder mechanism is rotated 1 rps by a 20-rps synchronous motor through a precision gear-reduction drive. The recording heads trace a helical path on the drum surface with 14 tracks per inch of drum length. The drum consists of two sections which are mounted on a common shaft. Each section is a separate recorder and is enclosed by a mu-metal shield. These shields must be in position when the recorder is in operation in order to exclude external magnetic fields and to permit reproduction on one section while the other section is recording. In addition the shields protect the delicate recording mechanism from mechanical injury and dust accumulation. [UNCLASSIFIED]

#### FUNDAMENTAL OPERATION OF RECORDER MECHANISM

The recorder closer to the gear box is designated RECORDER A and the other is designated RECORDER B. Each recorder has two recording zones designated as ZONE ONE and ZONE TWO. In each case, zone one is closer to the gear box. In each zone are included the following basic items: (1) a magnetic recording band capable of storing 35 seconds of recorded material, (2) a record-reproduce head, (3) an erase head, and (4) a carriage for automatic handling of these heads. Each recorder is capable of continuous recording and continuous storage of the last 60 seconds of recorded material. This is achieved by alternate operation of the two zones with a 5-second overlap between zone changes. During this 5-second period, the signal is recorded on both zones. In normal operation, a receiver output is continuously monitored by one recorder. A signal can be saved for future playback by pushing a hold button at the control unit any time up to one minute after the signal was recorded. Provision for both local and remote operation of the holding function is furnished. This function normally transfers the receiver from the first recorder to the second recorder in order that continuous recording of the channel may be maintained. The last minute recorded on the first recorder may be held or reproduced as desired. The playback circuits are arranged so that either zone one or zone two, whichever is selected, is reproduced repeatedly. In addition, any small segment of a zone can be reproduced by pushing a MOMENTARY RETRACE button, which causes the carriage to retrace as long as the button is depressed. The retrace speed of the carriage is about 5 times the record-reproduce scan rate so that depressing the retrace button for 1 second allows the last 5 seconds of recording to be replayed. The electrical functions of HOLD, RECORD, and REPRODUCE are initiated immediately when the respective controls are operated, but any carriage which has started to scan a zone when a command is given will complete that scan and retrace before coming to rest or obeying other mechanical commands. [UNCLASSIFIED]

## OPERATION OF THE RECORDER-REPRODUCER SYSTEM

All controls necessary for operation of the recorder are located on the front panel of the control unit. These controls and their functions are described below. [UNCLASSIFIED]

The POWER ON switch and pilot light are located on the lower-right portion of the panel. [UNCLASSIFIED]

The controls for RECORDER A are grouped within a rectangle on the left side of the control panel. The recording function is initiated by pushing the RECORD button. The RECORDING indicator light remains on whenever recording is being accomplished. The INPUT indicator lights, RECEIVER A or RECEIVER B, show which receiver is connected to RECORDER A. The HOLD pushbutton stops the recording function and saves the last 60 seconds of recorded material. Existence of the holding function is shown by the HOLDING indicator light. The ZONE IN USE indicator lights, ONE or TWO, show which zone of RECORDER A is in operation regardless of whether recording or reproduction is being performed. The zone selector switch labeled ZONE ONE and ZONE TWO is operative only during reproduction and determines which zone is played back. The REPRODUCING indicator light is on when RECORDER A is reproducing. The MOMENTARY RETRACE pushbutton is operative only during reproduction and causes whichever head carriage is in use to retrace while the button is depressed. [UNCLASSIFIED]

All of the controls listed above for RECORDER A are duplicated on the right side of the control panel for RECORDER B. [UNCLASSIFIED]

The recorder input controls are as follows. The RECEIVER A RECORD LEVEL control adjusts the recording level of the output of the receiver connected to the RECEIVER A input terminal. The RECEIVER B RECORD LEVEL control adjusts the recording level of the output of the receiver connected to the RECEIVER B input terminal. [UNCLASSIFIED]

A RECORD LEVEL monitor oscilloscope is provided. The vertical scale of this monitor is divided into 10 equal divisions. When the appropriate RECORD LEVEL control, RECEIVER A or RECEIVER B, is turned to zero, the oscilloscope trace will coincide with the top line of the scale. When this RECORD LEVEL control is turned to maximum and the sensitivity control on the associated receiver is turned to its minimum position, the oscilloscope trace should remain coincident with the top line of the scale. If this does not occur, the receiver output is not at ground potential, and must be adjusted to ground potential. As the receiver sensitivity is increased, the receiver noise and/or a received signal deflect the oscilloscope downward. When the peaks of the noise or signal deflect the oscilloscope to the bottom scale line, 100 percent recording level is achieved. Any attempt to record signals at an amplitude greater than that required to produce 100 percent recording level results in sharp clipping of the excessive signal amplitude. [UNCLASSIFIED]

A DIMMER control for adjusting illumination of the monitor oscilloscope scale is mounted to the left of the cathode ray tube. [UNCLASSIFIED]

As previously noted, provision has been made for connecting the outputs of two separate receivers to the recording system. This has been done to enable RECORDER A and RECORDER B each to record the output of a separate receiver at times when neither recorder is required to be holding or reproducing. Therefore, the LEVEL MONITOR INPUT switch has been provided to connect the monitor oscilloscope to either receiver.

The receiver input to which the monitor is connected is determined by observing the illuminated INPUT indicator light to which the bar knob of the switch is pointed. [UNCLASSIFIED]

When the RECEIVER PRIORITY SWITCH is placed in either the RECEIVER A or RECEIVER B position, the designated receiver becomes the "master," and its output is automatically switched to the alternate recorder and continues to be recorded when its original recorder is placed in the holding or reproducing condition. When this switch is placed in the FIRST SIG position, master control is automatically given to whichever receiver first produces a signal that is held. It should be mentioned that the FIRST SIG notation applies to whichever recorder is first held after both recorders have been placed on record; no memory of any previous "first signal" is retained. Therefore, if a receiver detects a "first signal" and it is desired to make this receiver remain a master, the switch should be placed in the appropriate position. When the RECEIVER PRIORITY switch is placed in the NONE position, neither receiver is permitted to become a master, and thus, RECEIVER A is always connected to RECORDER A and RECEIVER B is always connected to RECORDER B. [REDACTED]

The controls for reproducing are on the lower portion of the panel. When the REPRODUCE switch is in OFF position, no reproducing functions can be performed. When it is turned to the "A" position, information on RECORDER A (either ZONE ONE or ZONE TWO, depending on the setting of the ZONE switch) is reproduced. No further recordings can be made on RECORDER A until the REPRODUCE switch is removed from "A" position. Likewise, the above statements apply to RECORDER B when the REPRODUCE switch is placed in the "B" position. [REDACTED]

The CIRCLE DIAMETER, COARSE REPRODUCE LEVEL, and FINE REPRODUCE LEVEL controls affect the output dc level and output amplitude of the direct-coupled reproduce amplifier and must be adjusted to obtain the proper reproduce pattern on the indicator. Always use the LOW position of the COARSE REPRODUCE LEVEL control unless maximum clockwise setting of the FINE control will not produce a fully closed pattern. This is important in order to prevent overloading of the high-gain amplifier used in the HIGH position of the COARSE REPRODUCE LEVEL control. It will be necessary to use the HIGH position only when very low level recordings (more than approximately 25 db below 100 percent record level) are being reproduced. A suggested operating sequence of these reproduce controls is as follows: (1) turn the COARSE REPRODUCE LEVEL to LOW, (2) turn the FINE REPRODUCE LEVEL fully counterclockwise to assure that the reproduce amplifier output (indicator input) is at ground potential, (3) make any necessary initial adjustments of the indicator to produce the correct circle diameter, and (4) while reproducing a recording, turn the FINE REPRODUCE LEVEL control slowly clockwise, at the same time correcting for any changes in circle diameter by adjusting the CIRCLE DIAMETER control on the recorder panel. Continue to advance the FINE level control until a fully closed pattern is obtained when the desired signal is reproduced. If a fully closed pattern is not achieved when the FINE level is advanced fully clockwise, it will then be necessary to use the HIGH position of the COARSE level control. The position places a 20-db additional gain in the reproduce amplifier and will probably necessitate decreasing the FINE level control. In addition, the CIRCLE DIAMETER control may require slight readjustment. [REDACTED]

A headphone jack labeled PHONES and an audio volume control labeled A. F. GAIN are provided for aural monitoring of reproduced signals. [UNCLASSIFIED]

#### ALIGNMENT ADJUSTMENTS

Numerous screwdriver adjustments are located on the chassis of both the recorder unit and the control unit. These controls should not require adjustment during normal

operation of the recorder. The proper adjustment of these controls requires special test procedures and equipment and should not be attempted under any conditions without specific instruction. All of these controls are equipped with locking nuts. In addition, five screw-driver adjustments for the record-level monitor oscilloscope are located behind a small door on the upper-right corner of the control unit front panel. The VERTICAL POSITIONING control, which is one of these adjustments, is equipped with a locking nut. It affects the calibration of the recording level and should not be adjusted without special instructions. The remaining four oscilloscope controls should not require adjustment, but may be adjusted if necessary. [UNCLASSIFIED]

#### RECORDER PHASE LAG

The frequency modulation and demodulation processes of the recording system produce a constant time-lag of 330 microseconds. If a separate indicator is used for reproduced signals, the time lag can be corrected by adjustment of the indicator. If the same indicator is used for both live and reproduced signals, it is necessary to apply a constant correction to the indicated bearing of all reproduced signals to obtain the correct bearing. This correction is 2.5 degrees for an indicator turning 20 rps and 3.5 degrees for an indicator turning 30 rps. When the direction of the indicator trace rotation is clockwise, the correction is subtracted from the indicated bearing to obtain the correct bearing. [UNCLASSIFIED]

#### ROUTINE MAINTENANCE

The mu-metal shields enclosing each recorder must be removed for routine maintenance of the recorder mechanism. Extreme caution should be used in the removal of these shields. Before starting to remove the shields, make certain that the toggle switch (located behind them at the rear of the main casting) is turned off, thus insuring that the drive motor cannot be turned on at the control unit. The shields are labeled RECORDER A and RECORDER B (RECORDER A is nearer the gear box) and should not be interchanged. Do not force, bend, strike, or drop the shields since such action destroys their magnetic shielding ability. [UNCLASSIFIED]

The recording heads should not require cleaning over an extended period of use. If an accumulation of material occurs on the head surfaces, it may be removed by wiping the gaps gently with a clean, lint-free cloth. Handle the head arms and carriages very carefully; do not pull the heads back from the recording bands any further than necessary. Do not force the head arms in any respect and do not turn the head-adjusting screws because head alignment is very critical and requires special equipment. Do not attempt to clean heads unless the power is turned off, thus assuring that all carriage-control rotary solenoids are de-energized. [UNCLASSIFIED]

Information concerning lubrication of the recording mechanism has been included in the main body of this report. [UNCLASSIFIED]

#### ADAPTATION OF THE RECORDER-REPRODUCER FOR USE WITH THE DAJ OR SCR-502 TYPE EQUIPMENT

As previously mentioned, the recorder input signal must "zero" at ground potential. The output of the receiver used with the DAJ or SCR-502 equipment is taken directly from the second detector and does not quite reach ground dc potential when the receiver sensitivity

is turned completely down. The ac component of the signal goes to zero, but the dc component does not owing to the characteristics of the thermionic diode used. For this reason, a special adaptor unit must be inserted in the lead from the receiver output to the recorder input. This unit must be capable of adjusting the recorder input voltage to dc ground potential when the receiver sensitivity is turned all the way down. This adjustment can be made by switching the recorder-level monitor to the appropriate receiver input, turning the associated record-level control (RECEIVER A or RECEIVER B) to maximum (fully clockwise) and adjusting the control on the added unit until the monitor oscilloscope trace coincides with the top line of the scale gradation. The two 10-k record-level controls, labeled RECEIVER A and RECEIVER B, must be replaced with 500-k controls due to the high impedance receiver output. The recorder inputs accept only signals negative with respect to ground. [CONFIDENTIAL]

The output of the reproducing amplifier is positive with respect to ground. The indicators used with the DAJ or SCR-502 equipment have only one amplifier stage and require input signals which are negative with respect to ground. For this reason, an auxiliary phase-inverting amplifier must be provided for connection between the reproducing amplifier and the indicator. This phase inverter should be provided with a dc level control which can be adjusted so that the output is at ground potential when the amplifier input is grounded. The gain of this phase-inverting amplifier should be adjusted to produce an amplification of 6 or 7. This setting is not critical. [CONFIDENTIAL]

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