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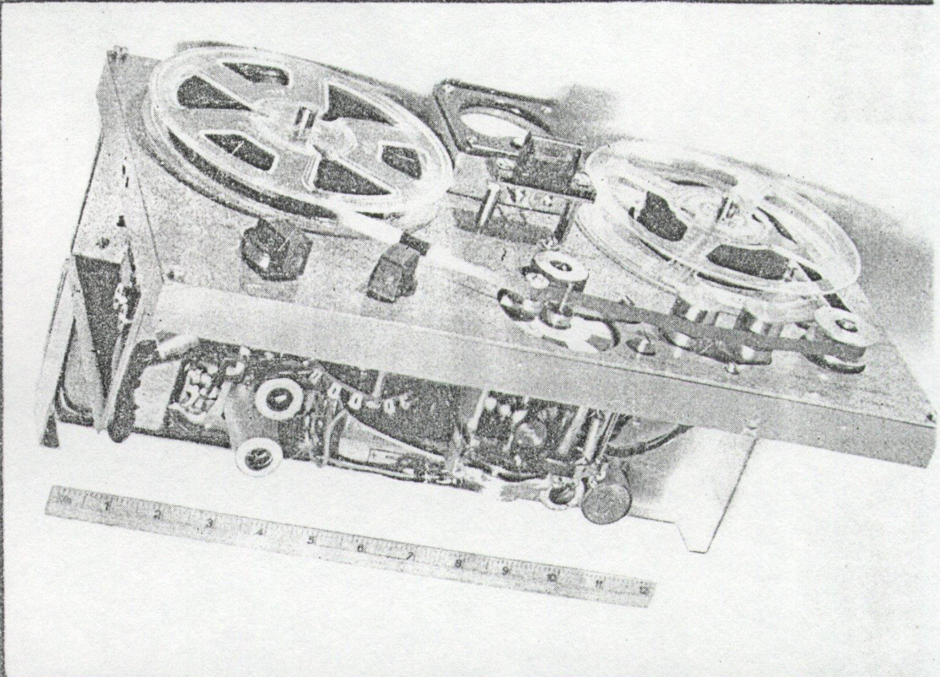

Portable Battery Operated Tape Recorder

The Development of a Miniature Battery-Operated Tape Recorder*

W. R. Nicholas†, A. D. Hildyard‡

Summary

The widespread use of magnetic recording in the production of broadcast programmes has produced a demand for a small self contained battery-operated tape recorder. The general requirements for such a recorder are discussed, followed by an outline of the development of both the mechanical and electrical design of a suitable machine.

1. Introduction

The production of high quality tape recordings is generally effected by mains operated equipment of either portable or stationary design. It is frequently found that in the sphere of broadcasting in particular a light weight battery-operated recorder will find many uses for short duration recordings of interviews, sound effects, etc. With these thoughts in mind it was decided to attempt to develop a suitable machine which would comply with the requirements as closely as possible.

As the proposed recorder was to be used primarily for broadcasting the specification naturally fell into the professional class, and it was soon realised that some of the requirements would be difficult to achieve and that some compromises would be inevitable.

2. Mechanical Design

Before proceeding with any design details the requirements were listed in the form of a specification which had to be met as closely as possible. The following was considered to be a suitable mechanical specification,

(1) Tape speed $7\frac{1}{2}$ inches per second full track recording.
(2) Total playing time 15 minutes.
(3) Playing time per wind of spring motor not less than 6 minutes.
(4) Spool size 5 inch holding 600 feet.
(5) Wow and flutter not to exceed 0.35 per cent rms total.
(6) Weight not to exceed 20 lbs complete with batteries.
(7) High speed rewind.
(8) Robust construction.

In the design it was decided to make the tape drive mechanism the starting point, and a decision had to be made between a purely mechanical system using a spring motor or an electro-mechanical system using an electric motor and suitable governor. As it was considered essential to keep battery replacement costs low, it was decided to utilise a spring motor in the form of the highly developed double spring phonograph motor as used for many years in acoustic phonographs.

The next step was to design a suitable method of coupling the motor to the capstan and take-up assembly. The first system made up followed conventional practice as shown in Fig. 1. The capstan "A" was fitted directly to the original turntable spindle, it was therefore necessary to choose a capstan diameter to provide the correct tape speed of $7\frac{1}{2}$ inches per second when revolving at the designed speed of 78 rpm.

The capstan diameter was calculated from the following formula

$$D = \frac{TS}{RPS} \times \frac{1}{3.142} \qquad (1)$$

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where

D = capstan diameter in inches

TS = tape speed in inches per second

RPS = capstan speed in revolutions per second

$$D = \frac{7.5 \times 60}{78 \times 3.142} = 1.836 \text{ inches.}$$

This looked good so far, a capstan diameter approaching two inches indicated no trouble with machining or with tape slip.

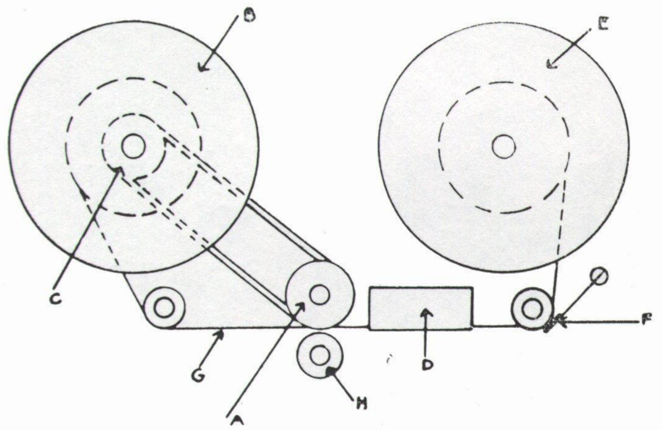

Figure 1.—Original tape driving system. A, capstan; B, take-up spool; C, slipping clutch; D, head assembly; E, supply spool; F, tensioning device; G, tape; H, pinch roller.

The take-up spool " B " was driven by means of a belt and slipping clutch from a pulley mounted integral with the capstan. The head assembly " D " was mounted between the capstan and the supply spool " E " and a constant tensioning device was fitted at " F " to provide approximately constant tape tension throughout the entire spool. A normal pinch roller " H " was used to apply the tape " G " to the capstan.

This system was put on test and the following troubles were experienced.

(1) Flutter from the governor drive gear was very bad at approximately 90 c/s.

(2) Variations of friction in the take-up clutch reacted on the motor governors thus causing random low frequency wow.

(3) When the take-up clutch was set tightly enough to spool the tape satisfactorily the playing time per wind was reduced to around 3 minutes.

Before proceeding further with practical efforts to reduce the wow and flutter some brief references were made to the theory of flywheels.

It was known that the performance of the spring motor was very satisfactory when playing records as the flywheel effect of the 12 inch steel turntable plus the record was sufficient to filter out the gear flutter and to store sufficient energy to eliminate low frequency wow due to variations of the needle drag on the record. It was felt that a somewhat similar amount of stored energy would be required to filter out the variations of tape tension which would be expected to occur.

The kinetic energy of a flywheel may be calculated from the following

$$\text{Kinetic Energy} = \tfrac{1}{2} I\omega^2 \qquad (2)$$

where ω = speed in radians per second

I = moment of inertia

$$\text{moment of inertia of a wheel} = \tfrac{1}{2} MR^2 \qquad (3)$$

Where M = mass

R = radius.

From (2) and (3) it will be seen that the kinetic energy of the flywheel varies directly as the square of the rotational speed and as the square of the radius of the wheel.

As the recorder had to be of small dimensions it was not possible to accommodate a flywheel of a size approaching that of the original turntable so it was decided to instal a wheel of 5 inches diameter fitted with a large section rim to make up as far as possible the loss of kinetic energy due to the reduction of flywheel radius.

The installation of this wheel brought about a partial cure for the troubles but at the expense of a considerable increase in the weight of the complete recorder. The work was carried a stage further by the installation of a mechanical filter consisting of a neoprene coupling between the motor shaft and the flywheel/capstan assembly. The gear flutter was now completely cured, but it was found that the low frequency wow was still present in sufficient quantity to prevent satisfactory recording of music or certain sound effects. In addition it was found that the recorder could not be moved appreciably during recording without the inertia of the heavy flywheel reacting on the motor governors and causing violent speed variations.

Further difficulties were encountered with the manual tape rewind mechanism which had to engage with the appropriate spool, release the pressure roller from the capstan and release the clutch tension on the take-up spool. The provision of all these mechanical functions proved to be somewhat complicated and expensive, and added considerable weight.

Progress so far indicated that further development along these lines was not justified, and an alternative tape drive system was worked out and made up for test.

The work done so far plainly showed the need for a flywheel which would store sufficient energy without being large and heavy. Further reference to equations (2) and (3) provided the answer, by increasing the rotational speed of the flywheel the stored energy could be greatly increased and the physical size and weight correspondingly reduced, with the added advantage that the machine would be less sensitive to external movements.

The next step was to evolve some means of revolving the flywheel at a high speed without the introduction of additional gearing to cause losses and flutter troubles. This was achieved by a complete reversal of normal practice in that the tape was made to drive the capstan instead of the latter driving the tape as in normal practice.

The operation of the system was very simple (Fig. 2); the take-up spool " A " was driven via a belt from a pulley on the motor spindle " C," thus placing a tension in the tape " G " which is held against the capstan " E " by the pinch roller " F " thus causing the capstan to revolve at a speed determined by the governor and flywheel to which it was directly coupled. The record and playback head assembly was now situated at " D."

A study of the system showed it to possess several advantages over the original system as follows

(1) Small flywheel revolving at 1000 rpm; advantages already explained.
(2) Full torque of motor was available to wind tape on take-up spool. This completely eliminated loose spooling and spilling of tape.
(3) No slipping clutch needed.
(4) Section of tape between take-up spool and capstan carried ample tension at all times to provide good head contact without recourse to additional tensioning devices which would cause further losses and a consequent loss of playing time.
(5) High speed forward motion of the tape was instantly available by releasing the pressure roller from the capstan and high speed rewind by unthreading and changing the spools over.

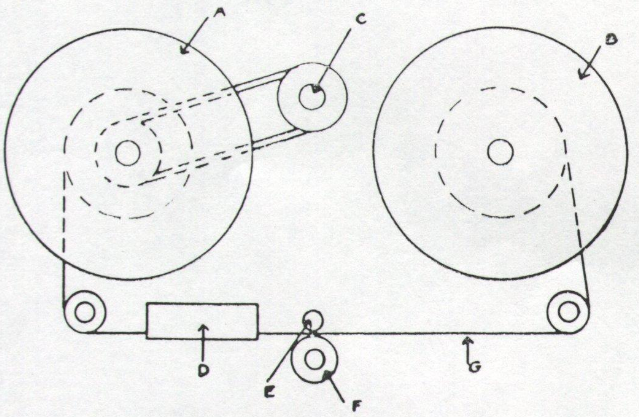

Figure 2.—Modified tape driving system. A, take-up spool; B, supply spool; C, motor spindle; D, head assembly; E, capstan; F, pinch roller; G, tape.

The latter point was considered to be a definite drawback but of less evil than the complication and expense of a separate manual rewind system. It was also felt that most " on the spot " recordings for broadcasts would be taken back to the studio for rewind and editing if required.

In the practical application of the idea the first point to be decided was the rotational speed of the capstan assembly, the object being to utilise the original governors from the spring motor which were designed to run at 1300 rpm. Calculation from equation (1) showed that the capstan diameter for this speed to be inconveniently small and the problem of machining such a capstan to the required standard of accuracy to be too difficult. A compromise was made for a speed of 1000 rpm giving a capstan diameter of 0.143 inches still rather small but within reason.

It was realised from the start that friction in the capstan bearings would be a problem, and this proved to be the case. Ball races were absolutely essential, and careful selection and fitting of the races was necessary.

Difficulty was also experienced with tape slip on the small capstan and quite high pinch roller pressures had to be used. It was also found that considerable losses occurred in the pinch roller tyre and some form of servo mechanism appeared desirable, arranged in such a way that the pinch roller pressure was controlled by the tape tension itself. In this way the pressure could be made high when the tape tension was high such as occurred when the motor was fully wound and the take-up spool empty, similarly the pressure would be low when the tape tension was low.

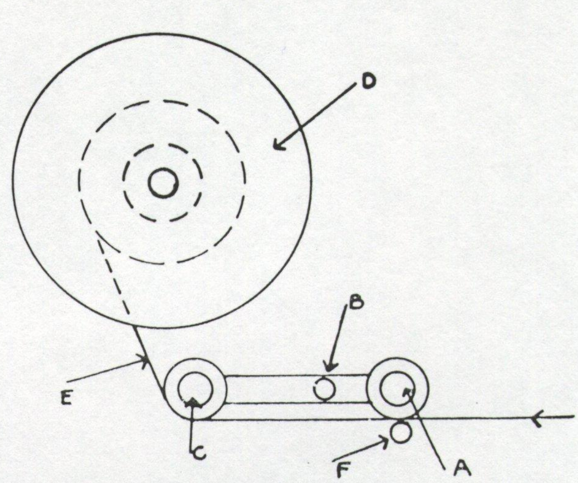

Figure 3.—Mechanism for providing pinch roller pressure proportional to tape tension. A, pinch roller; B, pivot; C, guide roller; D, take-up spool; E, tape; F, capstan.

Fig. 3 illustrates one suitable servo arrangement where the pinch roller " A " is carried on one end of an arm pivoted at " B," a guide roller " C " is mounted at the other end of the arm and the tape " E " passes over this as it comes from the take-up spool " D." The capstan is at " F."

Another arrangement is shown in Fig. 4 in which the pinch roller " A " is allowed to float between the idler roller " B " and the capstan " C." The tape " E," guide roller " F " and take-up spool " D " being arranged as in normal practice. Operation of this system depends on the tape tension wedging the pinch roller between the capstan and idler roller.

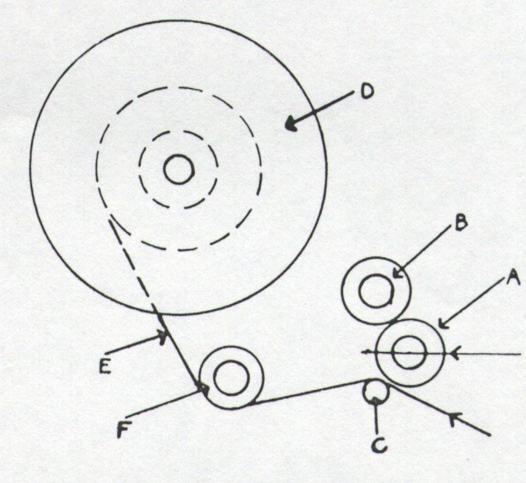

Figure 4.—An alternative mechanism making pinch roller pressure proportional to tape tension. A, pinch roller; B, idler roller; C, capstan; D, take-up spool; E, tape; F, guide roller.

After fitting the arrangement shown in Fig. 3 the mechanical losses of the tape mechanism were quite low and a playing time of 7-8 minutes could be had per wind of the spring motor. Some tests made on the prototype showed results satisfactory for the class of work for which the machine was intended, the rms total of wow and flutter was around 0.3 per cent and the long term speed variation better than + or − 2 per cent.

Some form of indication of the necessity to rewind the motor before the speed dropped was found desirable and a great deal of thought was put into this before a successful system was evolved. Several methods of indication were possible, both visual and aural, and it was decided that an aural warning in the form of a "buzz" in the monitoring headphone would be the better.

The mechanical portion of the system was operated from the torque of the main spring in the following manner. The main drive pinion bearing of the motor was removed from the motor frame and fitted to a pivoted lever which was allowed a very small movement (insufficient to upset the meshing of the gears), the lever was then spring loaded and arranged to operate a microswitch when the main spring torque dropped below that required to balance the spring tension on the lever.

The final mechanical design of the recorder consisted of details such as layout, position of controls, etc. The more important controls such as "start stop" lever, gain, winding handle were located in the ends of the machine to allow operation with the lid closed.

Fig. 5 will make clear the layout where the spool hubs are shown at "A," tape guide rollers at "B," the capstan at "C," pinch roller at "D," heads at "E," record/play and meter switches at "F," amplifier gain, start stop lever, microphone and headphone sockets at "G," microphone compartment at "H," level indicator at "I" and the winding handle on the end of the case at "J." The batteries were mounted on a removable panel in the bottom of the case. A removable lid with an observation panel was provided to cover the tape deck.

Due to the necessity for accurate alignment of the heads etc., it was decided to use an aluminium casting for the deck assembly, suitable brackets being provided to support the amplifiers, etc., as sub assemblies. The complete assembly was then arranged to fit into a light plastic covered plywood carrying case fitted with carrying handle and webbing shoulder strap for use when making recordings while standing or walking.

To sum up the mechanical features it was felt that a design had been evolved, which was simple, reliable, light in weight, cheap to produce, and capable of satisfactory performance in the field for which it was intended.

3. Electrical Design

The electrical design was taken as a completely separate problem and the requirements for this section were set down as for the mechanical section. The following was considered to be a suitable electrical specification:

(1) Frequency response 50-7000 c/s + or − 2 db when replayed on typical professional studio recorder.
(2) Distortion not to exceed 3 per cent at 1000 c/s at full recording level when replayed as in (a).
(3) Signal to noise ratio not less than 40 db below full recording level measured at 1000 c/s when replayed as in (b).
(4) HF erasure.
(5) Sufficient gain to allow operation from 50 ohm high quality microphone at −70 dbm.
(6) Separate replay head and amplifier to allow monitoring from tape while recording.
(7) Aural warning for motor rewind.
(8) HT voltage not to exceed 135 volts, LT 1.5 volts.
(9) Battery drain not to exceed 12 ma HT and 450 ma LT.
(10) Preferred tube types.
(11) Good accessibility to components.
(12) Level indicator and battery test.

In making a tentative design for the amplifier it was thought best to follow common practice in mains operated

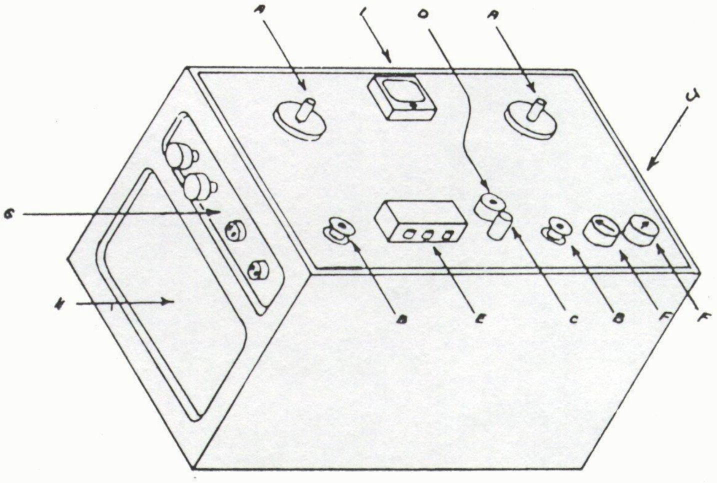

Figure 5.—Final layout. A, spool hubs; B, tape guide rollers; C, capstan; D, pinch roller; E, head assembly; F, record-play and meter switches; G, controls; H, microphone compartment; I, level indicator; J, winding handle.

recorders whereby the high frequency equalisation was obtained from a tuned circuit in the plate load of the first stage of a three stage amplifier. The recording head was to be fed via a constant current resistor from the pentode output stage, inverse feedback to be applied over the last stage.

This amplifier was made up for test, tapes were recorded and checked against calibrated test tapes, it being found comparatively easy to meet the frequency response and distortion requirements. However the signal to noise ratio was poor owing to microphony of the first and second stages. Shock mount type sockets were fitted and this trouble cleared up, the signal to noise ratio then being around —43 db. The gain of the amplifier was insufficient due to the combined losses of the equaliser and feedback network. The amplifier in this form was rather complicated, containing the equaliser tuned circuit, feedback loop components and a bias trap circuit in the record head coupling circuit.

During these experiments earlier fears about the power requirements of the bias oscillator were borne out, it was found necessary to use 180 volts of HT and a drain of around 15 ma to provide adequate HF bias for a normal mu metal recording head and high coercivity tape.

Before going further with the project it was decided to investigate the use of the ferrite materials as a core material for the record head, and some experimental heads were made up. Great difficulty was found in lapping and assembling the heads, but finally these troubles were overcome and more tests were made on the recorder.

The results as far as efficiency at the bias frequency was concerned, were quite surprising, as the optimum bias could now be obtained with an oscillator input of 90 volts at 3.5 ma. The results were quite similar in other respects to the mu metal head except that the high frequency recording losses (above 5 kc/s) were somewhat greater due to a less perfect gap edge than that on the mu metal head; however, by adjusting the equalising circuit the specification could be met.

During the research work on the record head considerable time was saved by establishing the relationship between the impedance Z and the number of turns T. The relationship was found to be approximately $Z = T^2/100$ at the highest recorded frequency of 8 kc/s. A constant current resistor of five times the head impedance at 8 kc/s was chosen and the value of the resistor made to equal the proper load resistance for the 3V4 tube. This ensured that the tube was operating into its correct load at the lowest frequency, where the head impedance dropped to a low value.

It was also found that due to the decreased losses of the ferrite cores at high frequencies the head windings showed higher value of Q and could be tuned quite sharply at both the bias frequency and high audio frequencies. This led to an investigation on the possibility of obtaining the necessary high frequency equalisation by resonating the record head at the highest recorded frequency of 8 kc/s.

The Authors:

William Rupert Nicholas was born at Hobart, Tasmania on November 16, 1913, and educated at the Friend's High School, Hobart.

He joined the staff of Findlays Pty. Ltd. in 1930, and also acted as Junior Engineer to Broadcasting Station 7HO. He was appointed Chief Engineer to 7HO in 1935, and resigned in September 1939.

In January 1940, Mr. Nicholas became Chief Engineer of Broadcasting Station 7HT, resigning in 1951 to join Commonwealth Electronics Pty. Ltd. as Chief Mechanical Engineer.

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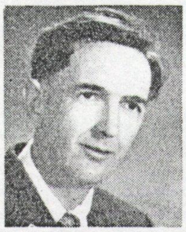

Athol David Hildyard was born at Hobart, Tasmania on June 21, 1919, and educated at the Hobart Technical College.

He joined the staff of Oldham, Beddome & Meredith Pty. Ltd., Radio Department, in 1936 and resigned to become Junior Engineer of Broadcasting Station 7HT in 1938. He was promoted to Technician in 1939 and joined the R.A.A.F. in 1942 as Radar Technician.

Mr. Hildyard returned to 7HT in 1946, and was appointed Chief Engineer in 1951, from which position he resigned to join Commonwealth Electronics Pty. Ltd. as Design Engineer.

A new amplifier was designed with this idea in view using preferred type tubes in the 1.4 volt series. A 1S5 pentode in the first stage was resistance capacity coupled to a similar tube as a triode in the second stage, the latter also resistance capacity coupled to the last stage using a type 3V4.

Fig. 6 is a schematic of the head coupling system. The output stage V_3 has a conventional plate load resistor R_1, and coupling condenser C_1. Audio is fed to the record head RH via the constant current resistor R_2. The number of turns on the secondary of the oscillator coil L_1 was chosen to provide a little over the optimum bias required, final adjustment being obtained by varying the oscillator HT voltage.

The condenser C_2 serves the dual purpose of bringing the junction of the constant current resistor R_2 and the record head to ground potential at the bias frequency of 50 kc/s, thus preventing the 50 kc/s component from appearing at the anode of V_3. The value of C_2 was chosen to resonate the record head plus the oscillator coil secondary at the highest recorded frequency of 8 kc/s. Due to the comparatively high Q of the record head and oscillator coil combination quite a spectacular rise in head current was achieved at resonance and the equalisation so gained was not at the expense of amplifier gain as in the first system tried.

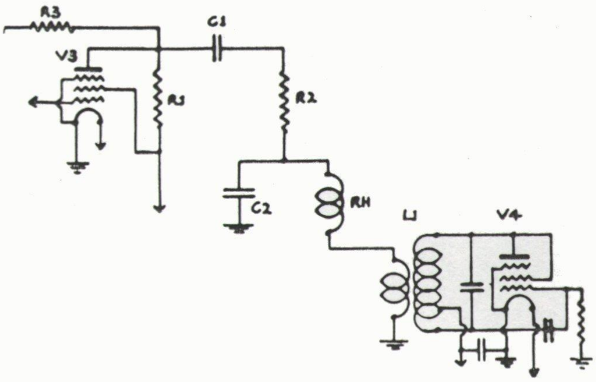

Figure 6.—*Record head coupling circuit.*

In order to provide some control of the degree of equalisation a feedback resistor R_3 was added from the anode of V_3 to the anode of the second stage, this was found to give excellent control of the resonant peak at 8 kc/s. The oscillator V_4 was designed as a conventional Hartley circuit also using a 3V4 tube the various values being selected to give a good bias wave form.

As mentioned previously, a separate playback head and amplifier were provided, the amplifier consisting of a pentode connected 1S5 resistance capacity coupled to a second 1S5 as a triode feeding the monitoring headphone. This amplifier also provided the " buzz " for the rewind indication, positive feedback being applied to the screen of the first stage via the microswitch operated from the main spring as described earlier in the mechanical section.

A small 0-100 microamp meter was provided to read recording level and HT and LT battery voltages, the various functions being selected by a rotary switch on the tape deck. The recording amplifier and bias oscillator was designed as one subassembly and the monitoring amplifier as another, both units being screwed to the side of the aluminium tape-deck casting in such a position that all components were accessible when the recorder was withdrawn from the case.