Instruction manual for model C conjugate point auroral photometer

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RADIO AND ELECTRICAL ENGINEERING DIVISION

INSTRUCTION MANUAL FOR MODEL C CONJUGATE POINT AURORAL PHOTOMETER

- M. D. WATSON -

OTTAWA

NOVEMBER 1969

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INSTRUCTION MANUAL FOR MODEL C CONJUGATE POINT AURORAL PHOTOMETER

– M.D. Watson –

Introduction

The National Research Council of Canada has operated auroral photometers as part of a conjugate point program at Great Whale River, Quebec, and Byrd, Antarctica, since the austral winter of 1966. Between that time and the present, the details of the instrumentation used have changed gradually, as experience has been gained in recording and analyzing the data. Two previous NRC reports, ERB-718 and ERB-775, form a record of these changes. (An earlier report, ERB-674, describes an older but similar photometer system, which was used in the Canadian Arctic during the IQSY.) This manual describes the NRC photometer at its present state of development. As the two earlier conjugate point photometers were designated Model A and Model B, the apparatus described below will be referred to as Model C.

A radical change in instrumentation at the northern station is occurring, and has not been mentioned in previous reports. During the past few years, experimental and theoretical evidence has been accumulating that indicates that the point in the northern hemisphere which, at any given time, is exactly conjugate to Byrd does not remain stationary, but in fact traces a path on the surface of the earth which varies in size and shape with the season and the degree of geomagnetic disturbance. The inverse phenomenon occurs, of course, for the conjugate point with respect to Great Whale (or any other point on the earth's surface). It was decided in late 1966 to try to observe this 'wandering' of conjugate points using the aurora as a visualization technique. Because of the relative difficulty and expense of operations in the Antarctic, it was planned to establish a network or chain of unattended, automatic stations in the vicinity of Great Whale River. The design and testing of a prototype photometer station has been going on since 1967. The data recording system for the stations involves the sampling of auroral brightness at each of three optical wavelengths (5577, 4861, and 3914 Å) at a sample rate of once every 5.4 seconds.

In order to allow for a drift in timing accuracy at the automatic stations, the recording process at Byrd must be a continuous one, or, at least, a sampling process with a data rate high enough to permit interpolation to coincide with the sampling times at each northern station. To make a meaningful correlation, it is necessary for the timers at Byrd and Great Whale to be kept fairly accurate. Considering the bandwidth of the photometer electronics (about 0.3 Hz) and the stability and ease of reading of the timers, an accuracy of $\frac{1}{4}$-sec is probably a reasonable limit. Any timer error less than this is acceptable. The data rate requirement, and the technical requirements of the tape recording process, have led to the choice of an analog recording mode, using pulse duration modulation (PDM) as the actual coding technique to store information on the tape.

The manual describes in turn the photometer detector head, with its component modules, the low-speed tape recorder, the timer unit, and the high and low voltage power supplies.

Description and Operation of Apparatus

Photometer Detector Head

The photometer head is the same as the one described in the 'Instruction Manual for Multichannel Auroral Photometer' (NRC Report ERB-718, November 1965), and is installed in the insulated, roof-mounted housing already existing at both Byrd and Great Whale. Three detector modules are mounted on the head, sensitive to the three auroral emissions at 5577 Å (OI), 4861 Å (Hβ), and 3914 Å (N_2^+ first negative system (0,0) band). The modules have a field of view about 40° square, centered on the zenith. The optical system is shown diagrammatically in Fig. 1 and in the photograph of Plate I.

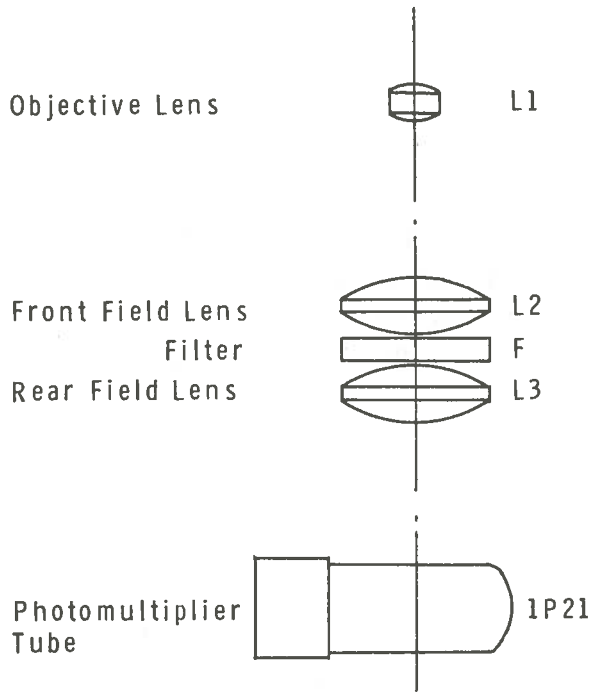


Figure 1 Optical system of detector module

The objective lens, L1, forms an image of the sky approximately at the position of the interference filter F (which acts as the field stop for the system). The front field lens, L2, has a focal length equal to that of L1, and hence light coming through L1 is formed into a parallel beam before passing through the filter. The rear field lens L3 re-focuses the light which has been transmitted by the filter and forms an image of the objective L1 upon the cathode of the 1P21 photomultiplier tube. The net effect of the lens system is that, although the field of the photometer is 40° by 40°, the filter is working at a maximum divergence angle of about 4°, and hence broadening and shifting of its passband are kept fairly small.

The circuit diagram of the module is shown in Fig. 2. The integrated-circuit operational amplifier (generic type 741) is connected in the so-called 'current transducer' mode, so that

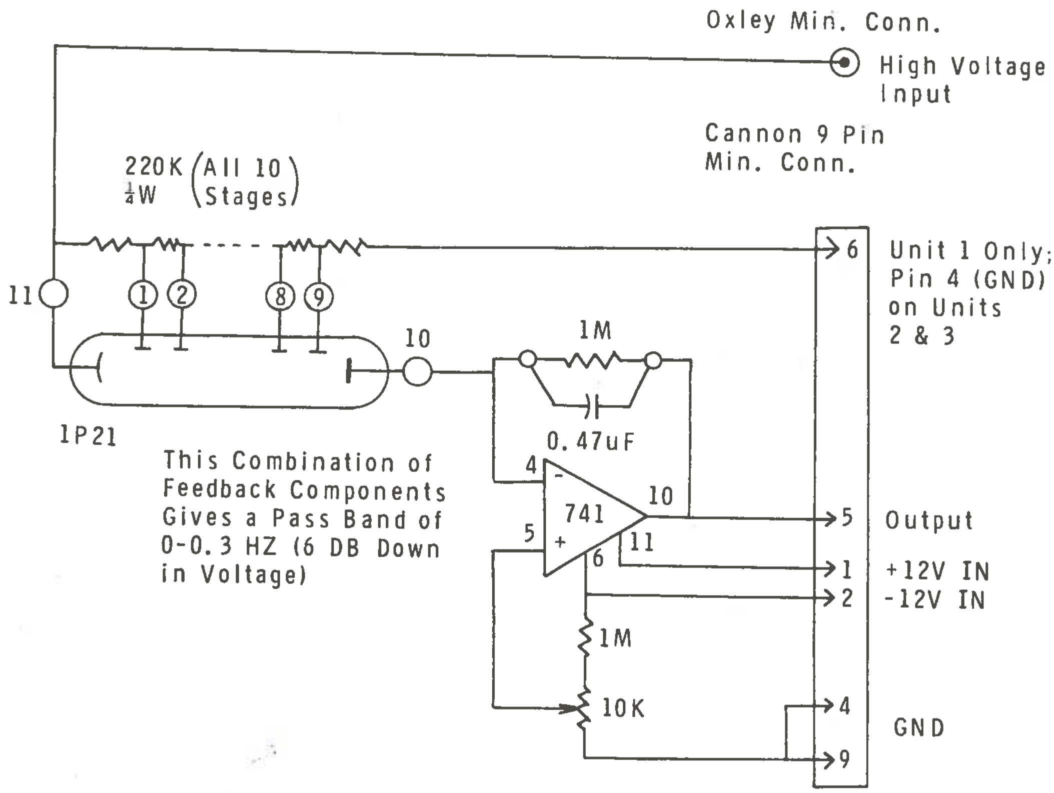


Figure 2 Circuit diagram of detector module

its output voltage is equal to the product of the photomultiplier anode current and the amplifier feedback resistor. With the external current input at zero (i.e., the input floating) the 10-kΩ potentiometer is adjusted to give less than 1 mV output. The capacitor in parallel with the feedback resistor gives low-pass filtering; the response is 6 db down (voltage) from dc at 0.3 Hz for the 1-MΩ/0.47-μF combination shown. The output impedance of the 741 amplifier is only a few hundred ohms, so no trouble should be experienced in driving the 30 feet of cable supplied.

Tape Recorder

This unit is a custom-built record-only instrument using $\frac{1}{4}$-inch tape on 7-inch reels. The tape speed is 0.026 inch per second, giving a maximum continuous recording time of 9.6 days (for 1800-foot reels). Four channels are used simultaneously (one for time information and three for data). The channel widths and spacing for the Nortronics type 5602 head stack used are 0.037 and 0.071 inch, respectively. The mode selected for recording is pulse-duration modulation (PDM). The three analog voltage inputs to the recorder (0 to +10 V, bandwidth from dc to 0.3 Hz) are first passed through an amplifier stage whose gain is dependent upon the input voltage level (see block diagram, Fig. 3): for inputs between 0 and +1 V, the stage gain is approximately 3.5, while for inputs

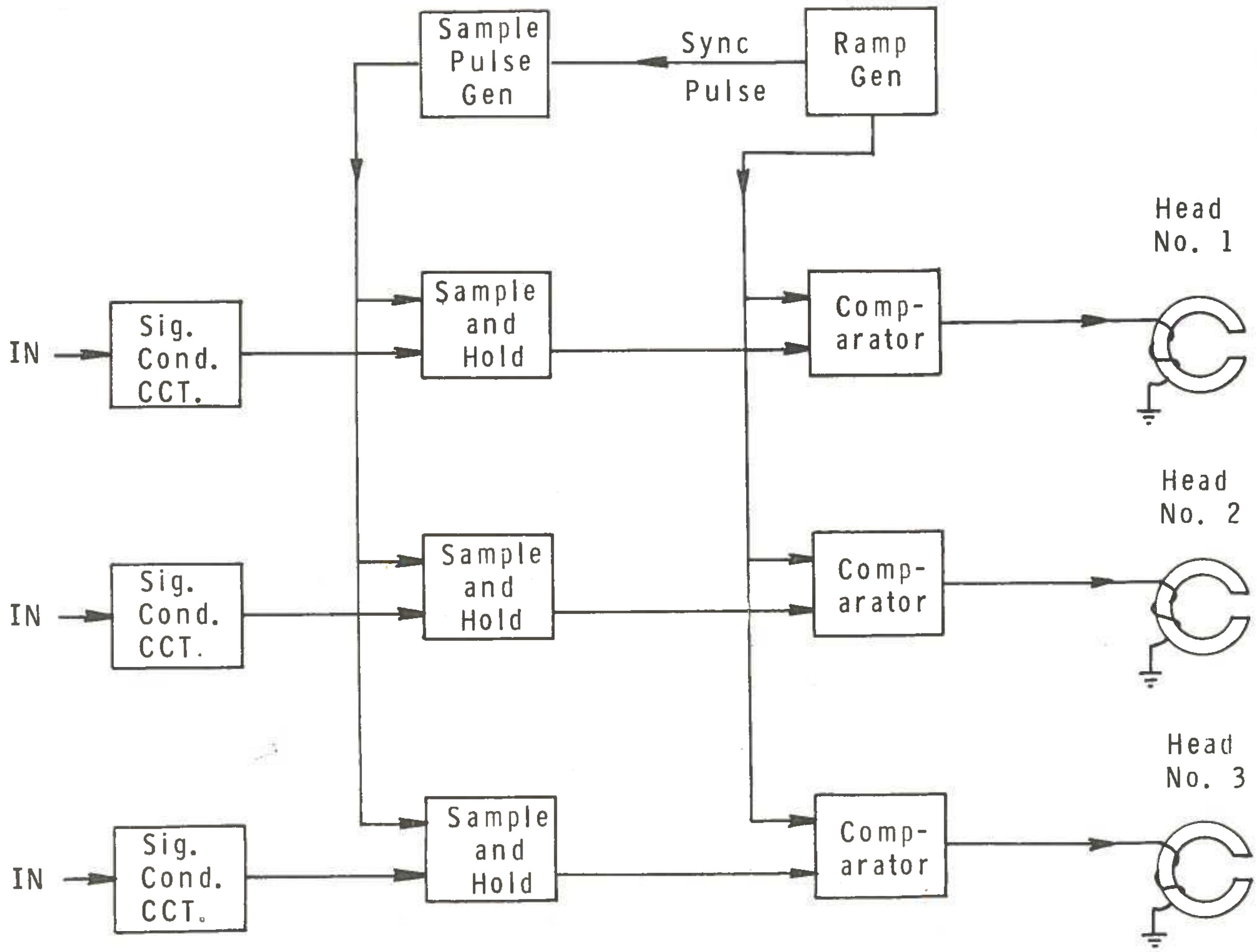


Figure 3 Block diagram of tape recording electronics

between +1 and +10 V, the gain is about 0.3. The response of this signal-conditioning stage is shown graphically in Fig. 4.

From the input stage, the analog voltage signal goes to a sample-and-hold circuit, and the sampled voltage is then applied to one side of a comparator (see the enclosed circuit diagram, Drawing No. UAR-119-35E). The other input to the comparator is a triangular waveform with a frequency of about 6 Hz and peak-to-peak amplitude of about 22 volts (-11 V to +11 V). The output of the comparator is a train of rectangular pulses with a pulse repetition frequency of 6 Hz. The length of the negative-going part of each pulse is determined by the amplitude of the sampled analog input voltage, since the output of the comparator remains at -11 V until the triangular ramp input rises to the value of the other (analog) input. The sample-and-hold circuit prevents undesirable multiple triggering of the comparator, which might occur if the input signal contained frequency components higher than a few Hertz. (In the photometer system described here, the limiting of the bandwidth of the module preamplifier to 0.3 Hz is an extra precaution against multiple triggering.)

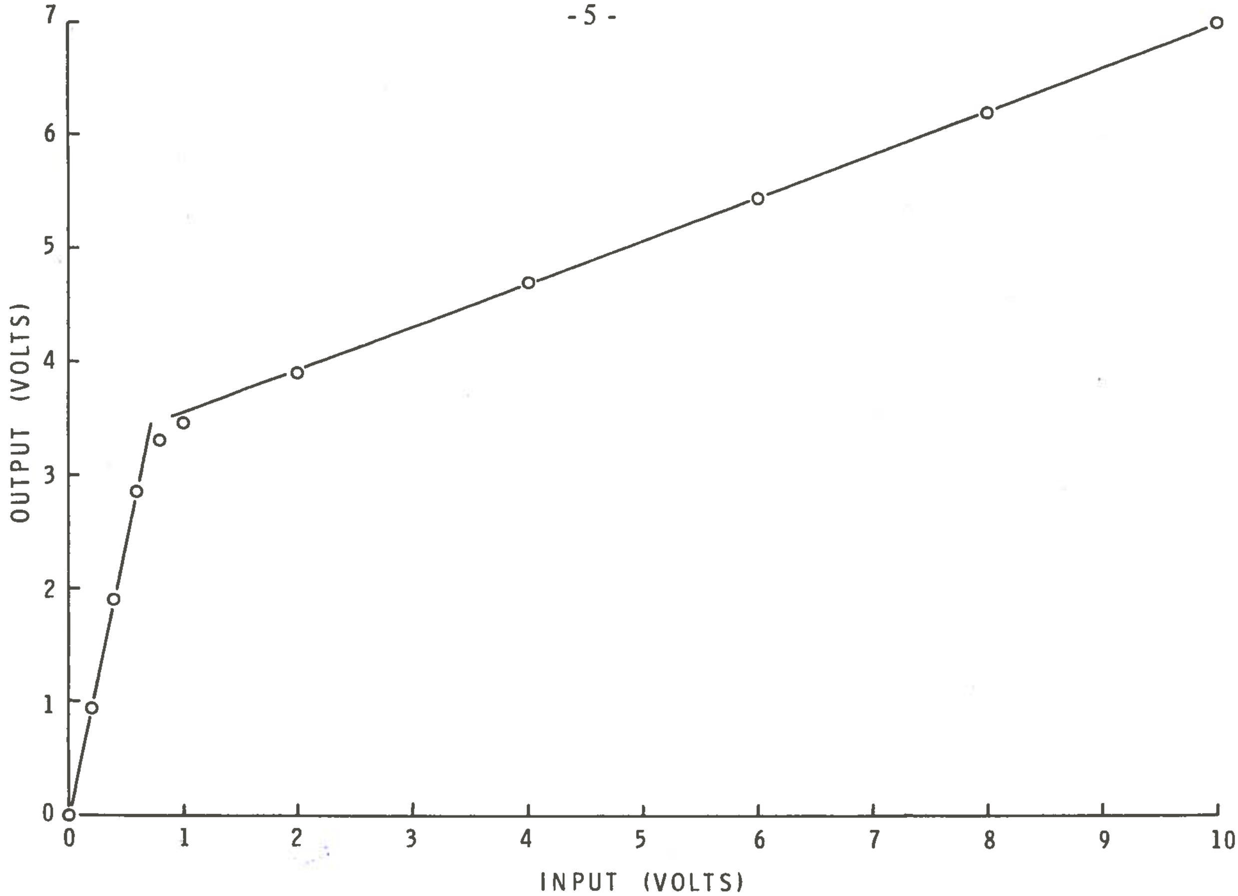


Figure 4 Response curve of signal-conditioning circuit

Typical pulse waveforms for analog inputs of 0, +1, and +10 V are shown in Fig. 5. The design duty cycle is 15% for 0 V input and 85% for 10 V input. Figure 6 shows a graph of pulse duty cycle versus analog input voltage. The similarity to Fig. 4 is evident.

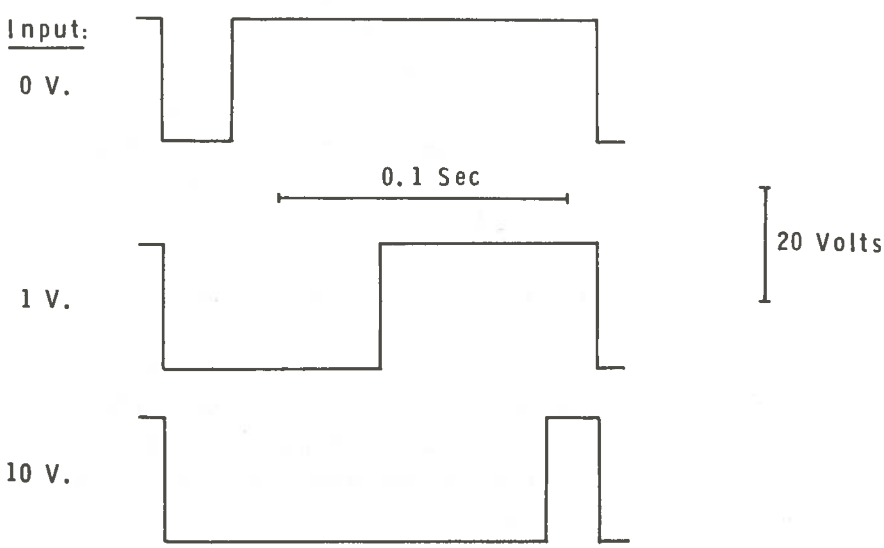


Figure 5 Typical pulse waveforms

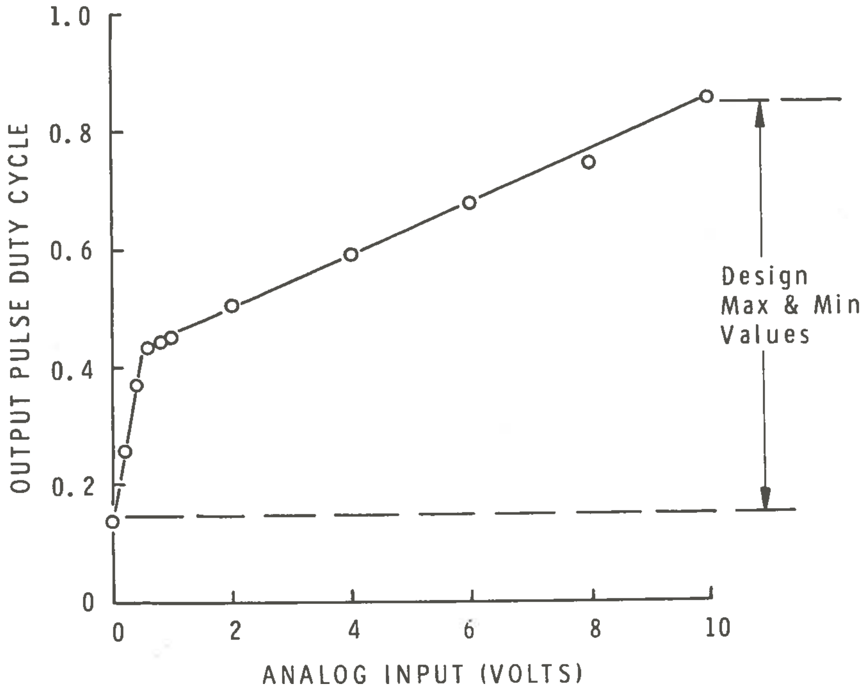


Figure 6 Response curve of PDM circuit

The pulse train is fed via a series current-controlling resistor to the recording head. Since only the leading and trailing edges of the pulses are of interest, distortion of the pulse shape is immaterial and no high-frequency bias is required. Timing pulses are fed, via a series current-controlling resistor, directly to No. 4 head, again with no high-frequency bias.

The controls of the recorder may be seen in Plates II, III, and IV. The front panel carries a 12-position rotary switch labeled INPUT which connects all three data channels to either the input connector or to a series of calibration voltage levels ranging from zero to +10 V in appropriate steps. The test-point and potentiometer immediately below the INPUT switch permit the initial adjustment of the over-all calibrating voltage. Under the label SIGNAL CHANNELS, there are six test points and six potentiometers. The test points labeled ANALOG OUTPUTS are connected to the outputs of the sample-and-hold circuits, and indicate the magnitudes of the three sampled analog signals presented to the three comparator stages. If an analog input voltage is changing with time, the voltage observed at the corresponding ANALOG OUTPUT test point will appear as a 'stair-case' waveform with six steps per second, corresponding to the basic 6-Hz pulse repetition frequency. The waveforms observed at the PULSE OUTPUTS test points are the pulse trains generated at the outputs of the comparators. The ZERO ADJUST and FULL-SCALE ADJUST potentiometers are used to set the limits on the pulse duty cycle to their design values, as follows.

(1) With the INPUT switch set at 10 V, adjust the FULL-SCALE ADJUST potentiometers to give readings of +7.5 V at the ANALOG OUTPUTS test points.

(2) With the INPUT switch at GROUND, set the ZERO ADJUST potentiometers to give a pulse duty cycle (observed at the PULSE OUTPUTS test points) of 15%.

(3) With the INPUT switch at 10 V again, check that the pulse duty cycle is 85%.

The role of the ZERO ADJUST potentiometers is to balance the duty cycles for zero and 10-V inputs (i.e., 15% *on* time for zero input and 15% *off* time for 10-V input). If the balanced condition gives *on* and *off* times less than 10% or more than 20%, one of the feed-in resistors in the comparator circuit (an 8.2-kΩ resistor indicated on the circuit diagram) should be changed to give the desired nominal limits of 15%. (To reduce the *on* and *off* times, the resistance should be reduced – or increased to increase the times.)

The test point labeled TIME monitors the timing pulses (one per second) applied to head No. 4. The large red-jewelled warning light labeled TAPE TRANSPORT ALARM, when lit, indicates a malfunction of the tape drive. The operation of the alarm circuit is described on page 8. On the rear of the chassis are located input and output connectors (each one unique to avoid mistaken connections), a 1-ampere fuse protecting the 110-V, 60-Hz circuit, and a push-button switch labeled RESET ALARM whose function will be described later.

The mechanical design of the recorder is intended to provide a rigid and stable structure which will maintain reliable tape alignment and uniform tape motion over long periods of time. The chassis consists of a $\frac{5}{16}$-inch aluminum plate welded to $\frac{1}{4}$-inch thick aluminum stiffeners on the underside. After it is welded, the top surface of the chassis is machined flat. The massive tape guides are machined from stainless steel bar stock and screwed firmly to the chassis to define the tape path (see Fig. 7 for an outline drawing showing the tape-threading path). The head stack is mounted upon a brass plate, which is in turn supported by three screws and compression springs above the chassis. The feed reel spindle is free-turning, with tape tension on the feed side of the capstan being provided by a spring-loaded drag brake consisting of a nylon split-bearing rubbing on the feed reel spindle shaft beneath the chassis. The capstan is a brass rod 0.496 inch in diameter slipped over the shaft of a 1-rpm synchronous motor mounted beneath the chassis. The tape is pinched against the capstan by a commercial rubber pressure roller on the end of a spring-loaded lever arm. During shipping, storage, and other periods of disuse, this arm is held back by a stop threaded into a hole in the chassis, to prevent deformation of the pressure roller. Tape tension on the take-up side of the capstan is provided by passing a tape loop around a guide mounted at the end of a lever arm. (The $\frac{1}{2}$-turn twist in the tape shown in Fig. 7 and Plate III is necessary because of the unavailability of a CCW take-up motor at the time of construction.)

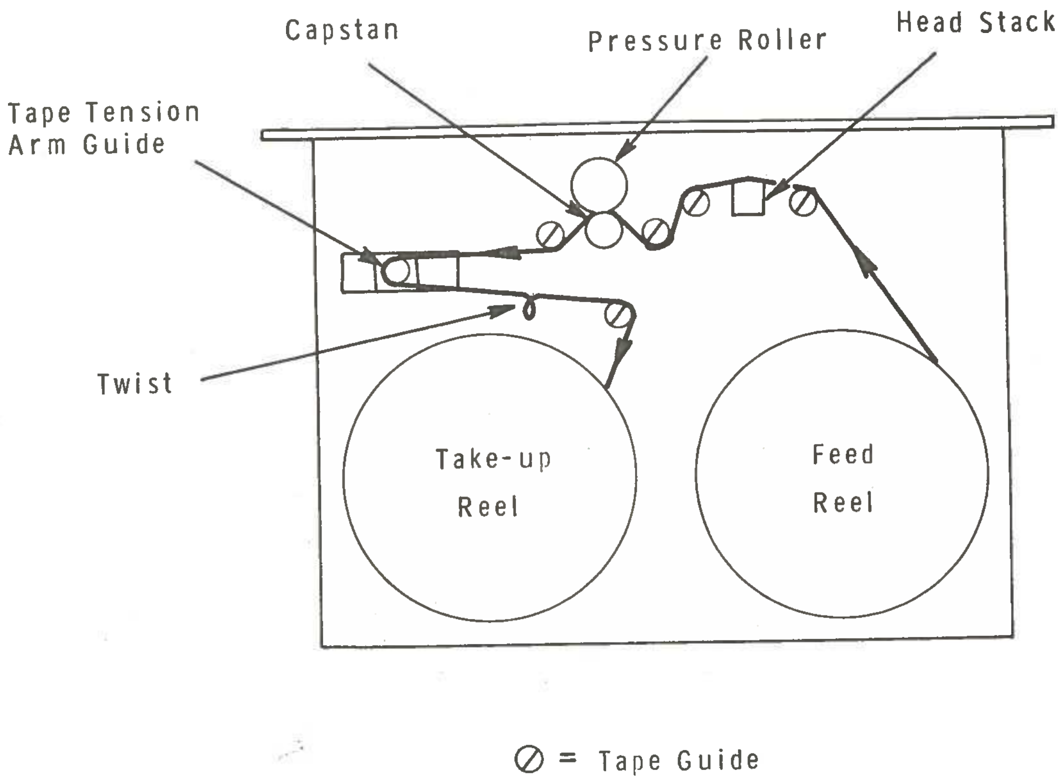


Figure 7 Threading guide for tape recorder

The loop is kept taut by a Nega'tor constant-torque spring motor pulling on the lever arm. When enough tape has been fed through the capstan – pressure roller mechanism to allow the tape tension arm to reach its extreme position, a microswitch is actuated (MSW1 on the circuit diagram). This in turn operates a self-holding relay which turns on the 1-rpm take-up motor. The tape loop is partially wound onto the take-up reel, pulling the tape tension arm over against the restraining force of the Nega'tor motor until a second microswitch (MSW2) is activated. This removes power to the self-holding relay, shutting off the take-up motor. The cycle then repeats.

The tape drive alarm circuit mentioned earlier operates as follows. When the self-holding relay is in its unenergized condition, capacitor C2 is being charged through resistor R1 (the transistor-capacitor combination Q1–C2 acts as a so-called 'capacitor amplifier': the effective capacitance of the combination is approximately $\beta C2$, where β is the current gain of Q1). When the self-holding relay is energized, C2 and C1 are connected in parallel, and the voltage at the collector of Q1 drops to a lower value determined by the combined capacitance. When the self-holding relay is de-energized again, the voltage at the collector of Q1 begins to rise exponentially once more. Under normal operating conditions a graph of Q1 collector voltage versus time resembles that shown in Fig. 8. If, however, a fault should occur in any part of the tape drive mechanism, the

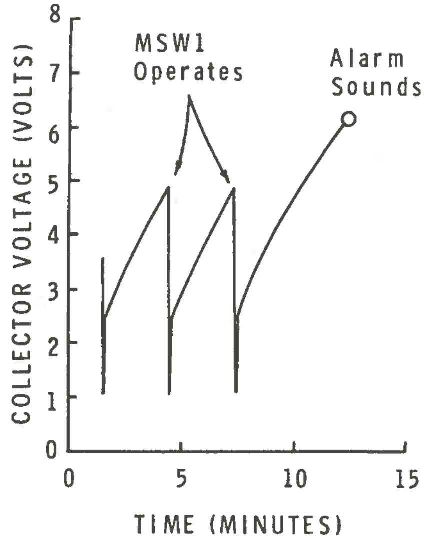


Figure 8 Q1-collector voltage for tape transport alarm

tape tension arm does not operate the microswitches in its normal manner, and the Q1 collector voltage continues to rise until the 6-V zener diode D2 breaks down and permits the transistors Q2 and Q3 to energize the 12-V alarm relay. This relay disconnects 110-V 60-Hz power from the recorder, and activates the alarm warning light and (via a 6.3-V filament transformer) a 6-volt dc relay, used as a noisemaker. Pressing the RESET ALARM push-button at the rear of the chassis disconnects the alarm circuit from its 12-V power source and simultaneously discharges all capacitors through a 47-ohm resistor. About $6\frac{1}{2}$ minutes will elapse after start-up before the alarm sounds again.

Every day, between the hours of 1100 and 2300 UT, a calibration recording must be made. The following steps are to be followed:

(a) Note, in the log book, the time of the last minute preceding the start of the calibration. Label this minute on the E.A. recorder chart.

(b) Set the INPUT switch to the positions marked GROUND, 0.2, etc., in sequence up to '10', pausing 1 minute at each step. Label the input voltage at each step on the E.A. recorder chart.

(c) Set the INPUT switch to GROUND, following the '10' volt step, for one more minute.

(d) Return the INPUT switch to OPERATE.

(e) Note, in the log book, and on the E.A. recorder chart, the time of the first minute following the end of the calibration.

(f) Record the date of the calibration in the log book and on the E.A. recorder chart. *Please note* that recording the date and time accurately in the log and on the chart is absolutely essential, since there is no other way of identifying the data.

As mentioned at the beginning of this section, an 1800-foot reel of tape should have a continuous running time of 9.6 days. However, the reels supplied are not full, and it is suggested that each reel be used for 8 days only, to avoid possible loss of data due to reaching the end of a reel while the equipment is unattended. Tape should be changed only between the hours of 1100 and 2300 UT, when Great Whale River is in daylight. When removing tapes from the recorder, DO NOT REWIND THE TAPE, to avoid confusion during subsequent data analysis. Remove both the feed and take-up reels from the machine, wind about 10–20 feet onto the take-up reel and cut and discard the remaining tape on the feed reel. The empty feed reel is to be used as the take-up reel for the next tape.

Timer

As in the previous photometer systems used in the Great Whale – Byrd conjugate point program, the timer serves a number of functions. It acts as a charger for a 12-V lead-acid storage battery, and hence as a source of 'brute force' low-voltage dc power for other apparatus. It acts as a power amplifier to produce a stable 60-Hz source (for timing motors, recorders, etc.) whose continuity depends only on that of the external oscillator originally generating the 60-Hz signal, and not on the continuity (or otherwise) of the 115-V, 60-Hz mains. Finally, and most important, it generates time pulses coded in various ways, whose precision depends upon the precision of the external 60-Hz oscillator. In the present timer (installed in 1970) the external oscillator is that in the NRC DA-3 all-sky camera (see NRC/REED document ERB-806, by M.J. Neale).

The circuit diagram of the timer is shown in Drawing No. UAR-104-47D. The battery charger and 60-Hz amplifier portions of the circuit are self-explanatory. The circuit labeled FREQUENCY CONTROL BOARD is a phase-shift oscillator and buffer stage whose operating frequency is controlled by a front-panel-mounted 3-position lever switch (spring-loaded to the center position). The nominal operating frequencies for the phase-shift oscillator are 50 and 70 Hz, so that the electro-mechanical clock can be speeded up or slowed down for convenient adjustment to the correct time.

The electro-mechanical clock is driven by a synchronous timing motor, and contains various magnetically operated reed switches (5 closures per minute and 1 closure per minute) and cam-operated microswitches (1 closure per hour and 1 closure per day). In addition, a photoresistor periodically illuminated by a light beam shining through holes in a rotating disk generates a voltage pulse once per second. These pulses (each about 0.1 sec long) are fed into pin 12 on the PULSE GENERATOR BOARD where they are lengthened to 0.2 sec, are used to operate a Schmitt trigger circuit, and, after final buffering, are fed back into the electro-mechanical clock (pin 5 on the Blue Ribbon connector). The pulses are gated through the series of reed switches and microswitches to produce pulses at intervals of 1 minute, 1 hour, and 1 day (appearing, respectively, at pins 6, 7, and 8 on the Blue Ribbon connector, and at pins 18, 20, and 22 of the

PULSE GENERATOR BOARD). Each of these pulses is further stretched in the PULSE GENERATOR, to pulse lengths of 0.4, 0.6, and 0.8 sec for the minute, hour, and day pulses, respectively. The waveforms for the various time pulses are shown diagrammatically in Fig. 9. The gated and stretched minute, hour, and day pulses are available on parallel output lines (pins 2, 3, and 4 of the Cannon 5-pin connector), as well as serially, mixed in on the seconds-pulse line (pin 5 of the Cannon 5-pin connector). The minute pulse is also used to operate a series-switching transistor (the 2N3053 on the PULSE GENERATOR BOARD) which energizes the 12-V dc side pen of the Esterline-Angus recorder used as a monitor and back-up recorder in the present photometer system.

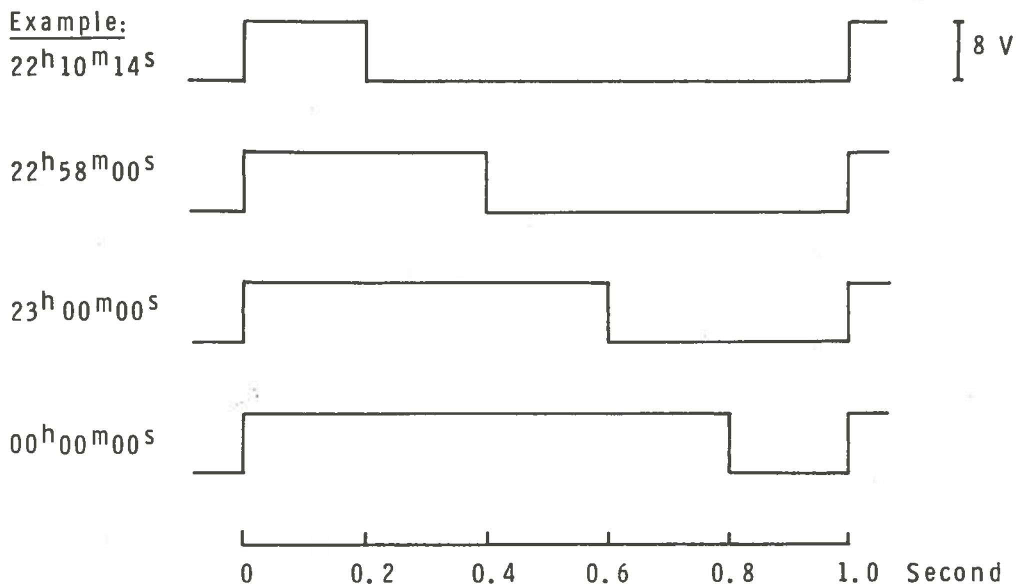


Figure 9 Time pulse waveforms

Typical front-panel meter readings, when the timer is in operation with the complete photometer system, are as follows: the CHARGE RATE meter should read 100–200 mA charging; the AC VOLTS meter should read 90–120 V; the DC VOLTS meter should read 12–14 V. The CHARGE RATE control and the STD FREQ GAIN potentiometer are mutually interactive to a certain extent, and alternate adjustment will probably be necessary. Re-adjustment after several hours will be required if the 12-V storage battery is in a low-charge condition when the equipment is first turned on.

High-Voltage Supply

A minor modification has been made to the high-voltage supply which was used in previous years. Originally, the output signal from a detector module sensitive to light at a wavelength of 5400 Å (where no auroral emissions exist) was used as the input to a negative-feedback loop to control the magnitude of the high voltage applied to all of the photomultiplier tubes. Any increase in ambient light level which was not due to aurora would cause a drop in the high voltage. In the present system the feed-back signal is derived simply from the low-voltage end of the photomultiplier bleeder chain in No. 1 module (the 5577-Å detector) and the circuit is thus a simple regulated power supply. The value of P2 in Drawing No. UAR-104-06D has been changed to 10 kΩ (from 5 kΩ) and potentiometer P1 is disconnected. The left-hand end of P2 is grounded as shown in the drawing.

Initial adjustment of the high-voltage supply is accomplished as follows. Starting with all switches turned off and all knobs counter-clockwise, connect all the cables. If the adjustment is performed during daylight, cover the photometer detector head with opaque material to avoid damage to the photomultiplier tubes. Remove the 6-pin Cannon male connector from the high-voltage supply, to close the shutter on the head. Turn on the POWER switch. Set the MANUAL–PHOTOCELL switch to MANUAL. Using a high-impedance voltmeter to monitor the high voltage, adjust the GAIN ADJ potentiometer P2 to give −1000 V output. Return the MANUAL–PHOTOCELL switch to PHOTOCELL, reconnect the 6-pin Cannon male connector, and uncover the photometer head.

Low-Voltage Supply

The low-voltage supply is the ±12 V supply described in NRC/REED document ERB-718. No changes have been necessary.

Maintenance

Tape Recorder

The head stack, capstan, and all tape guides should be cleaned with a Q-tip moistened with Xylene, at each tape change (i.e., every 8 days). The Bodine motor should be oiled at every other tape change. Using the hypodermic syringe and lubrication oil provided, place a few drops of oil into each of the two red holes on the motor. (The yellow hole is for greasing the gear train and should need no attention.)

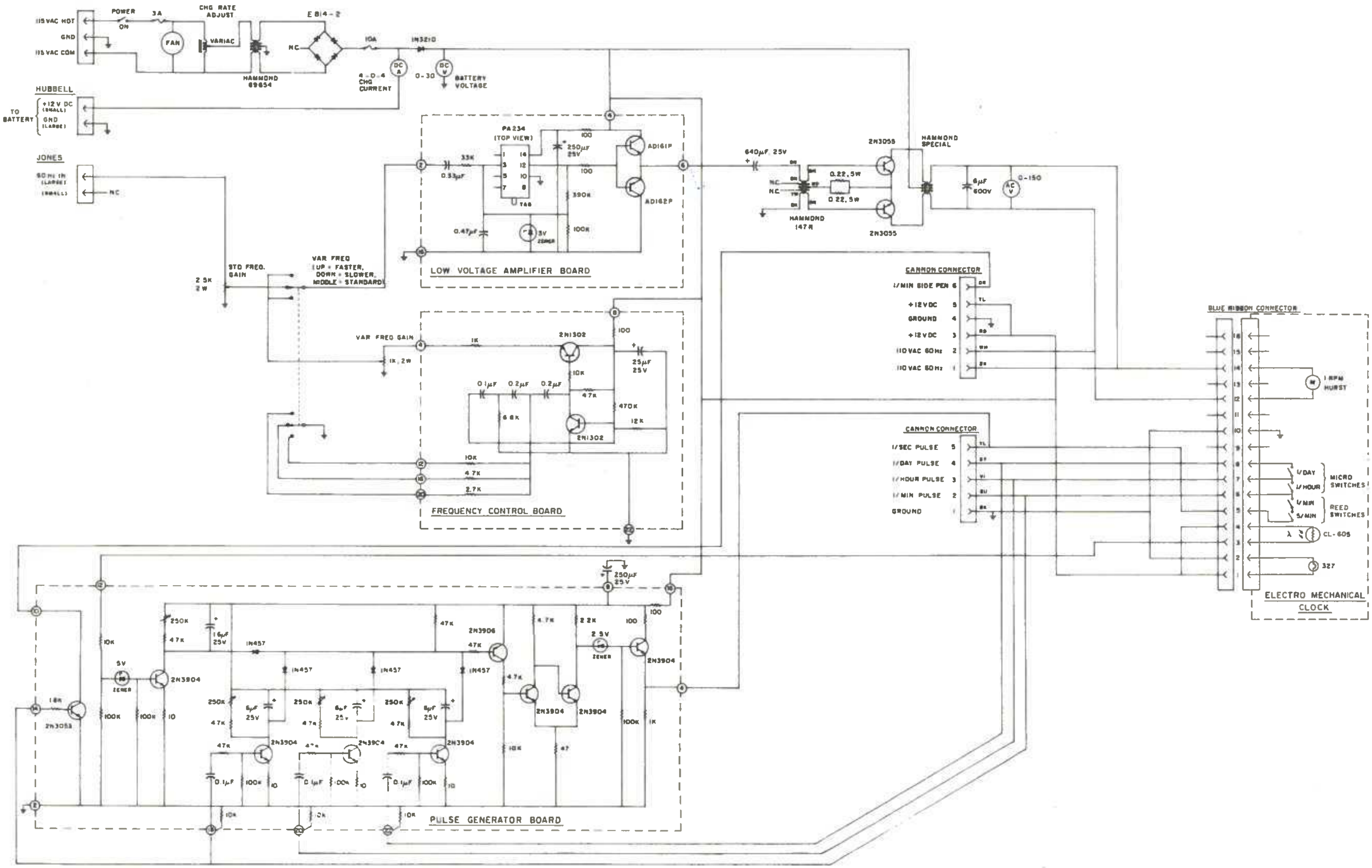
If it is desired to check the alignment of the tape as it passes over the head stack, remove the four socket-head cap screws which hold the two front panel handles in place. The handles may be removed, and the entire front panel swings forward and down, remaining attached to the chassis only by the cable harness.

Timer

The electro-mechanical clock should be kept clean. The ball bearings used in the clock should not need lubrication. The acid level in the storage battery should be checked regularly. Cells with low electrolyte levels should be topped up with distilled water (melted snow or rainwater).

Acknowledgment

The author expresses his appreciation to A. Staniforth and J. McDougall, of the Data Systems Section of REED, for their indispensable help in developing the tape recorder electronics, and to B.E. Bourne, J.T. Cooke, and V.F. Cyr, of the Upper Atmosphere Research Section of this Division, for their fast and accurate work in the design and construction of the entire photometer system.



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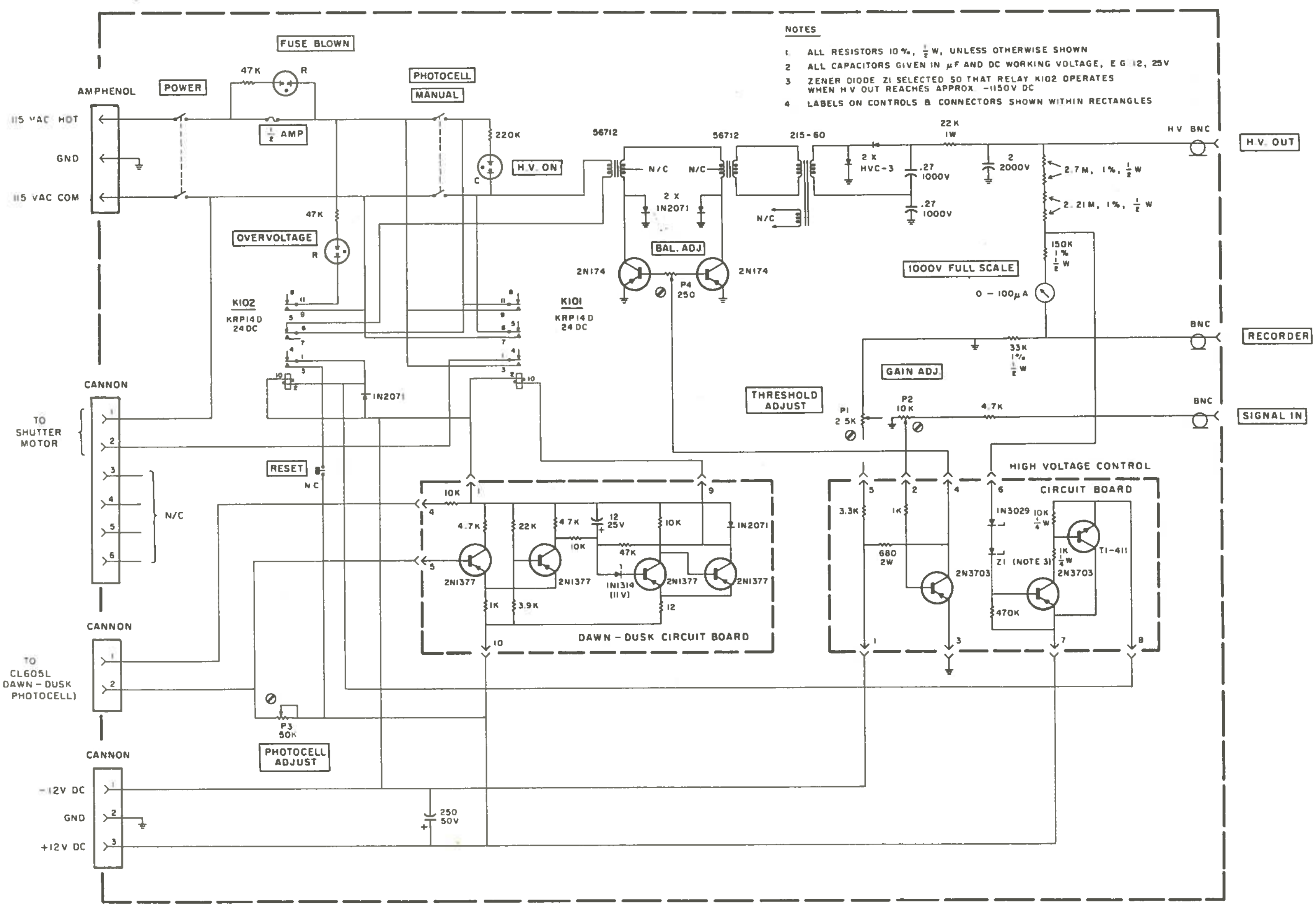

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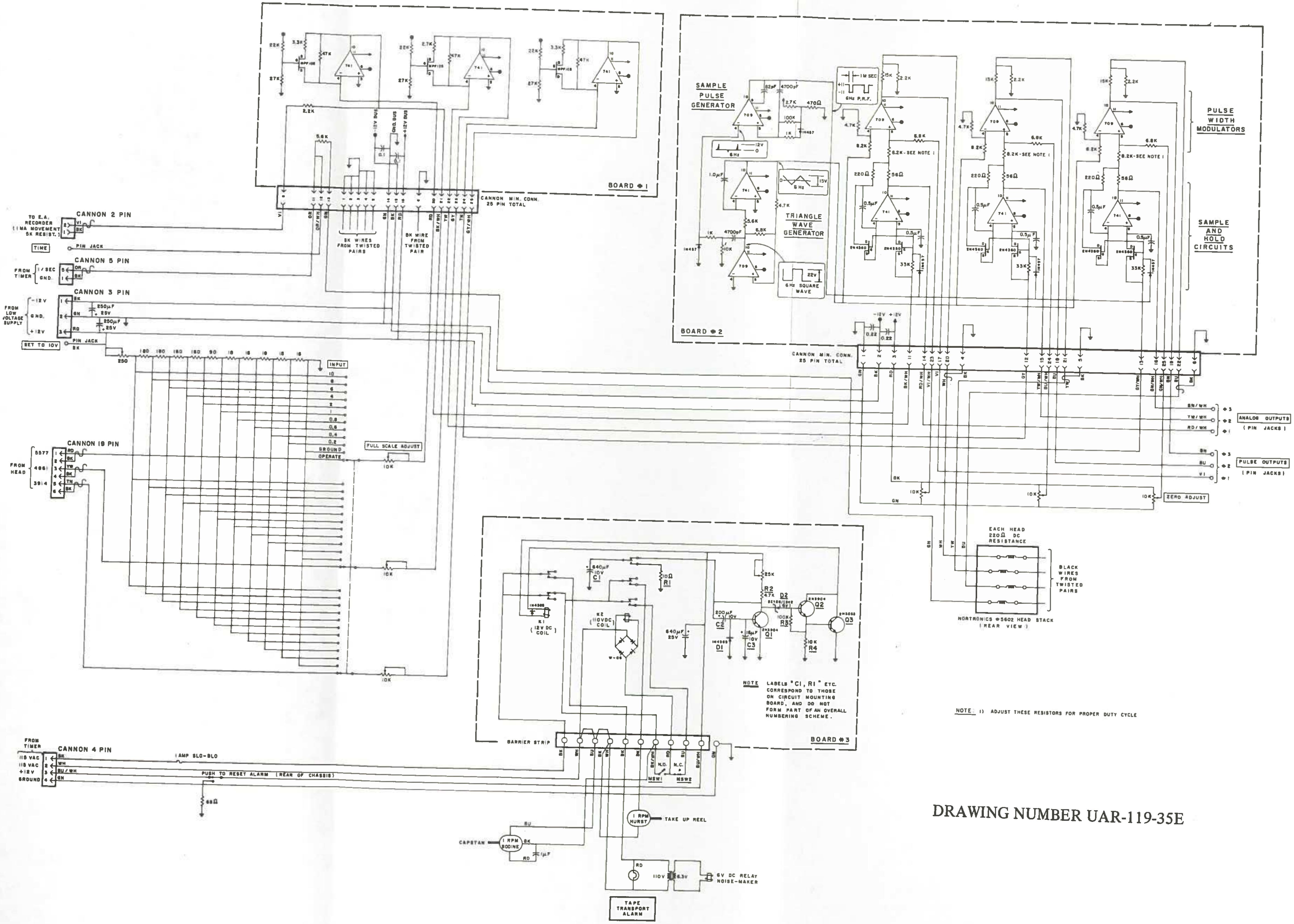

DRAWING NUMBER UAR-119-35E

Plate I Detector module, showing lens and filter assembly removed from module case

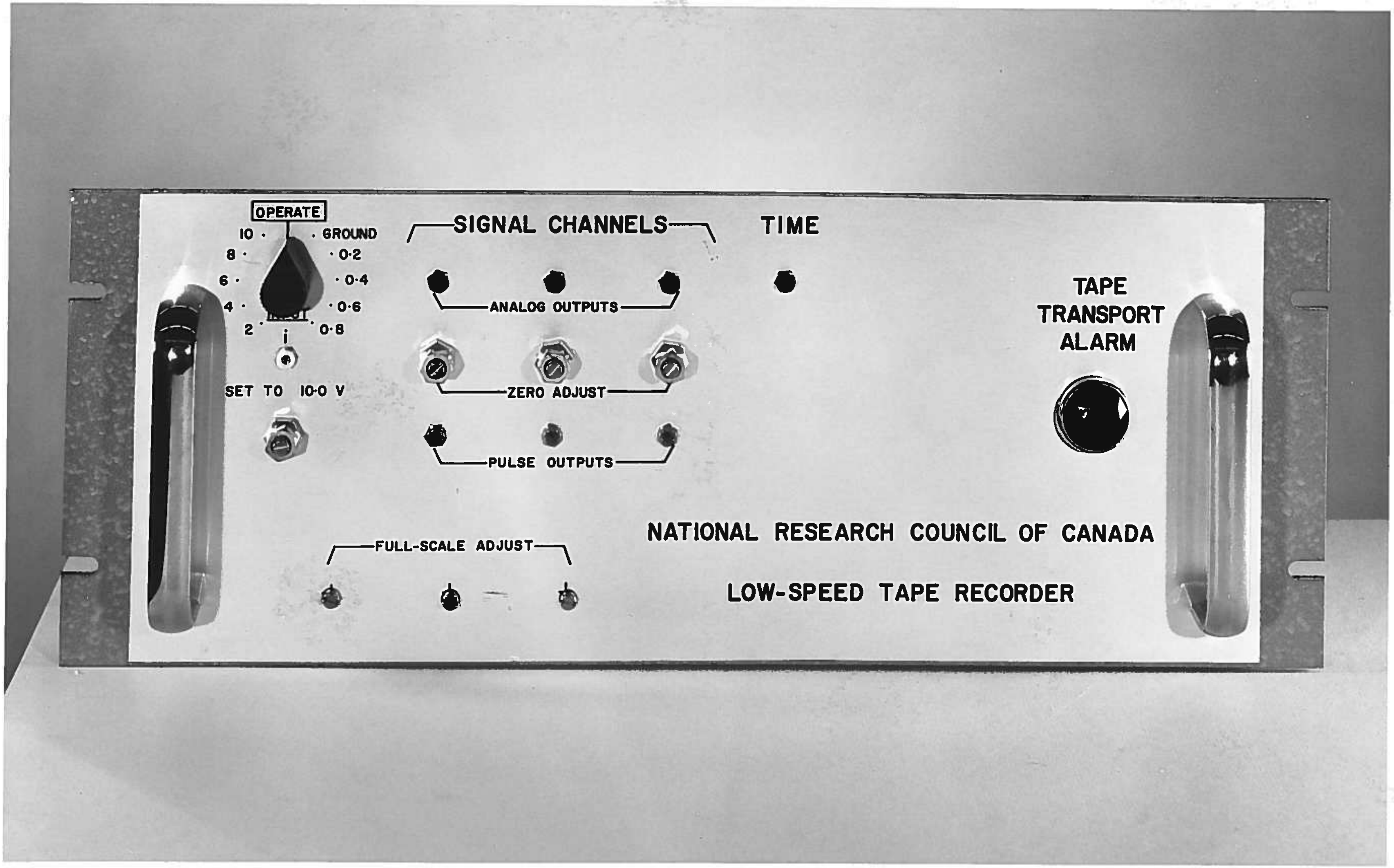

Plate II Front panel of low-speed tape recorder

Plate III Rear view of low-speed tape recorder, showing pressure roller arm relief stop in position for shipping or storage. Note twist in tape between tape tension arm guide and final tape guide

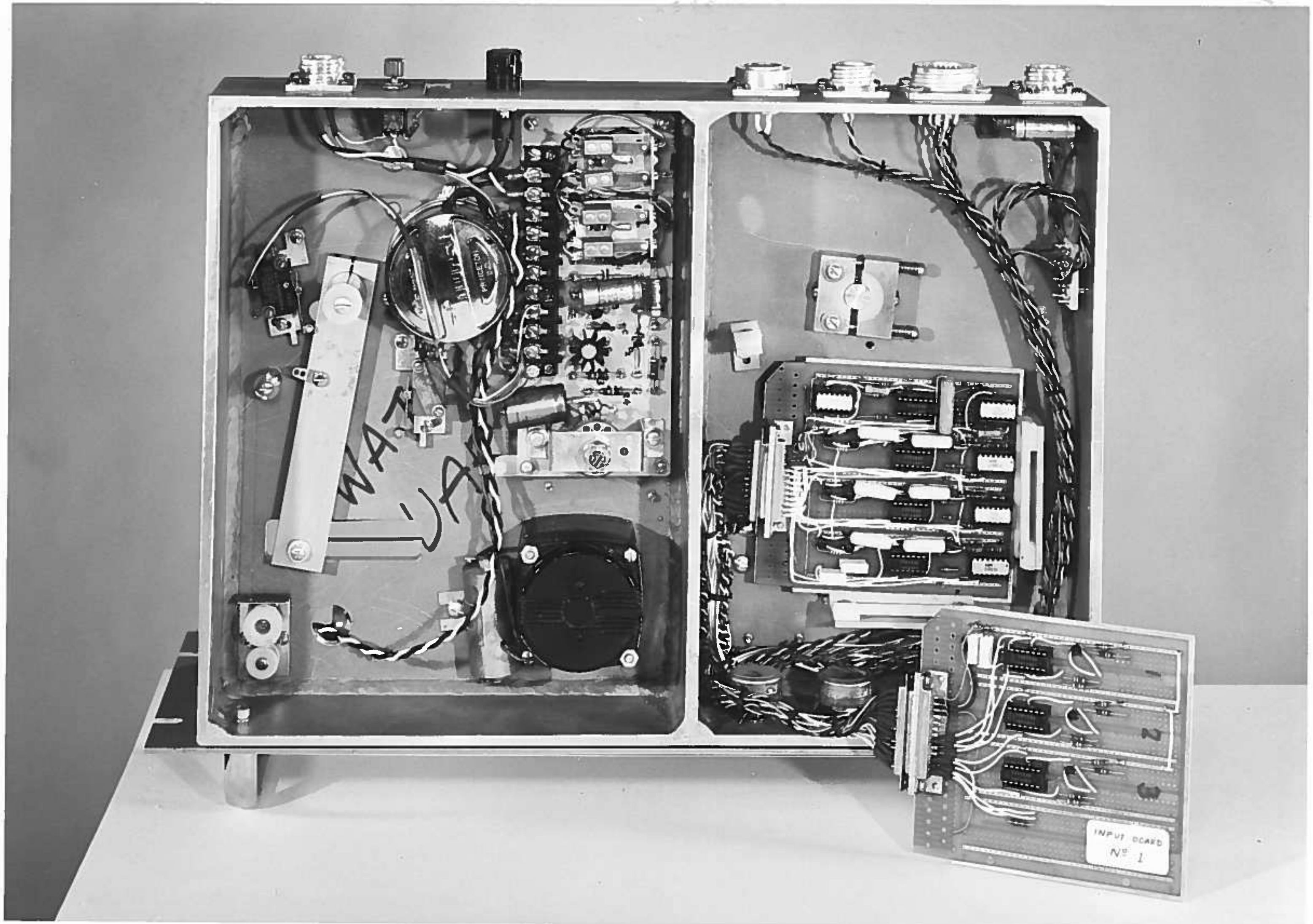

Plate IV Bottom view of low-speed tape recorder, with circuit board No. 1 removed for testing or servicing. Note the feed reel brake above circuit board No. 2, the tape transport alarm time constant adjustment potentiometer above the Bodine motor, and the Nega'tor spring motor at the lower left