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17

THE DESIGN AND OPERATION OF A.N.A.R.E. COSMIC RAY RECORDER "C"

By

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PREFACE

The equipment described in this report was designed for continuous long term recording of cosmic ray intensity at the Australian National Antarctic Research Expedition's Station at Mawson, Antarctica. This equipment was put into operation in 1955. The records obtained will be used in studies of meteorological effects, directional asymmetries, periodic variations, solar flare and magnetic storm effects, world wide fluctuations and possible relationships with other geophysical and solar phenomena.

This work forms part of a joint A.N.A.R.E. - University of Tasmania project. The development and construction of the equipment was carried out in the Physics Department, University of Tasmania.

It is thought that this report will be of interest particularly to those participating in cosmic ray studies during the 1957-58 International Geophysical Year. The manuscript was originally prepared as a description of equipment and operator's handbook to accompany the equipment at Mawson. It is presented with only minor changes in order to avoid further delay in publication and because it is considered that it embodies valuable ideas which would not be apparent in a bare description of the equipment and which are the result of considerable experience in the management of scientific projects at remote stations.

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INTRODUCTION

The equipment described in this report consists of two independent Geiger counter telescopes of high counting rate, each mounted on a turntable so that the telescope axis may be set at any desired zenith angle and azimuth.

Each telescope is made up of three counter trays set one above the other, the sensitive area of each tray being one metre square and the separation of extreme trays 1.5 metre. (Provision is made for reduction of the telescopes to cubical geometry if required). Up to 30 cm. lead absorber may be inserted between the lower two trays.

Power supplies and electronic circuits recording three-fold coincidences are completely independent for each telescope. Scaling circuits are used to divide the coincidence rates down.

Records are obtained in two ways. The output of a scaling circuit is used to drive electromechanical registers, from which hourly count totals are obtained. The scale output pulses are also used to actuate a pen on a moving-chart recorder. This latter record enables a close examination of the form of sudden increases or other short term cosmic ray intensity fluctuations to be made.

Provision is made for changes in telescope azimuth setting according to any desired sequence to take place automatically at the end of each hour.

All automatic controls are actuated primarily by electrical contacts on a survey-type chronometer.

The entire equipment operates from the 240 volt 50 cycle mains supply at the station. Stabilisation for the recording circuits against a wide range of mains voltage and frequency changes is effected by a 500 watt electronic stabiliser.

It should be the aim of the operator to maintain the equipment in continuous and efficient operation (except during routine tests to be described in a later section). Loss of recording time should be kept to a minimum as losses will greatly impair the value of the records. It is of the greatest importance that detailed and accurate log books be kept, and a close liaison be maintained with meteorological and other scientific staff. All relevant meteorological and geophysical data should be collected regularly and examined in conjunction with the cosmic ray records.

MECHANICAL CONSTRUCTION AND ASSEMBLY

Each telescope is mounted on its own base and turntable, and mechanical construction details are the same for each. Discussion will be confined to one such unit.

As a base support and turntable, use has been made of a deck-mounting Bofors anti-aircraft gun base, made available by the R.A.N. It is supported on three $1\frac{1}{4}$ in. bolts set in concrete and adjustment of nuts on these bolts allows the axis of rotation of the turntable (and telescope mounted on it) to be set vertically with accuracy. The turntable rotates on a ball race 2 ft. in diameter.

Bolted directly to the top plate of the turntable is a yoke of 6 in. x 3 in. channel iron 4 ft. $6\frac{5}{8}$ in. wide and carrying, 3 ft. $3\frac{1}{4}$ in. above the turntable top, bearings for the $1\frac{1}{2}$ in. diameter stub axles attached to the telescope. The telescope may be swung within this yoke to any desired inclination to the vertical. Lateral stability of the yoke is increased by triangular end frames bolted to two more lengths of channel iron across the turntable top. This portion of the assembly may be seen clearly in Figures 1 to 6.

The axles are bolted to a rigid channel iron frame which is designed to carry up to $3\frac{1}{2}$ tons of lead absorber in the form of accurately cast blocks 20 cm. x 5 cm. x 5 cm. Four angle iron uprights bolted to the corners of this lead mount support the three counter trays, two above and one below the lead. The telescope assembly is designed to be inclined towards only one side of the yoke and may be held at any desired inclination by means of slotted bars, pivoted on either side of the lead mount and sliding over clamping bolts on the yoke. With lead thicknesses of under 20 cm. the centre of gravity of the telescope is below the centre of the axles and the two inclination setting bars are thus in tension.

The turntable is driven by a reversible $\frac{1}{4}$ H.P. motor (1425 RPM) operated via chronometer-controlled switches from the A.C. mains supply (not via the mains

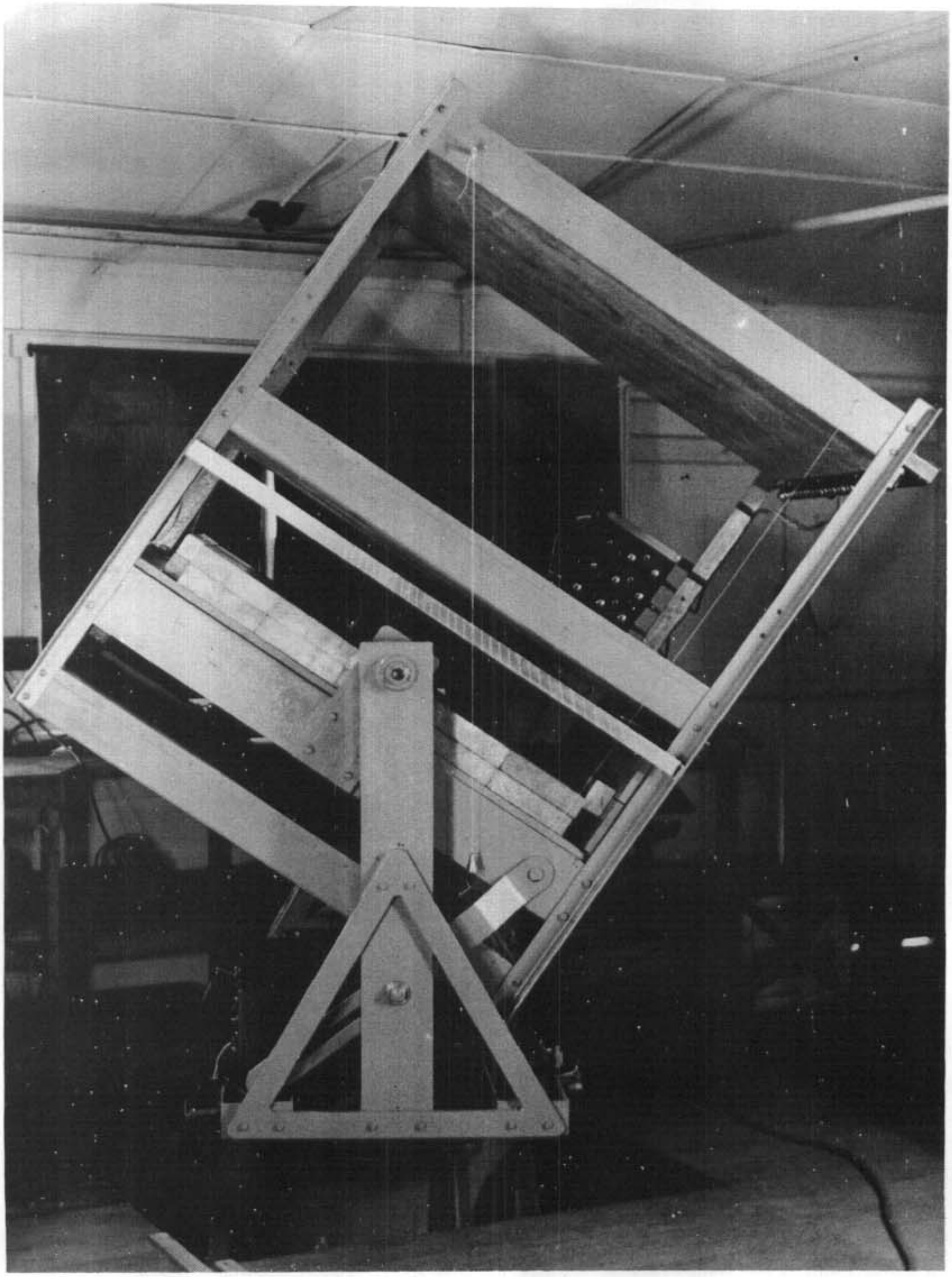

FIG. 1. ONE TELESCOPE FULLY ASSEMBLED.

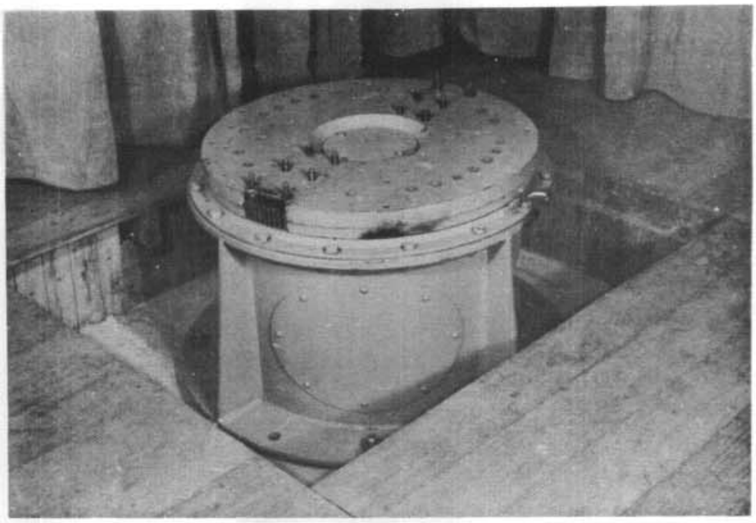

FIG. 2.

BASE AND TURNTABLE OF TELESCOPE.

FIG. 3.

YOKE IN POSITION.

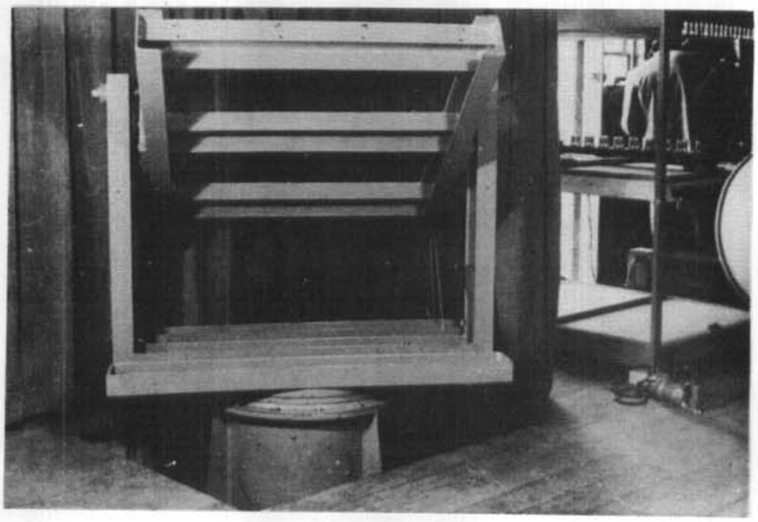

FIG. 4.

LEAD–MOUNTING PLATFORM IN POSITION.

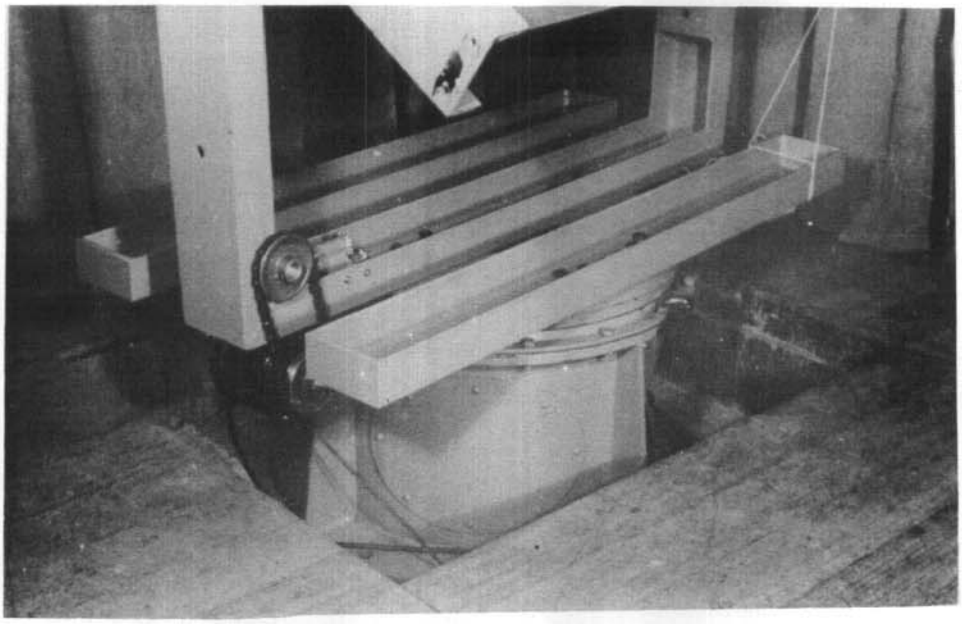

FIG. 5. (Above)

TURNTABLE DRIVE MOTOR IN POSITION.

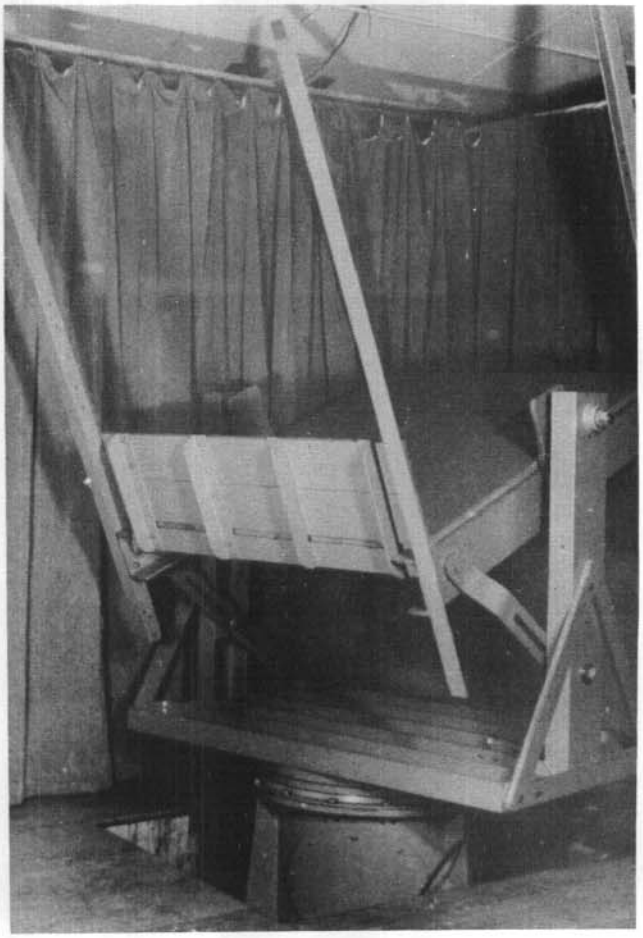

FIG. 6.

TELESCOPE READY FOR MOUNTING OF COUNTER TRAYS.

stabiliser). The motor is mounted underneath the projecting section on one end of the yoke and is coupled by a V-belt to the input shaft of a 100 to 1 single stage worm reduction gear box. The output of this is coupled by a further 12 to 1 (actually 175 to 15) reduction gear to a 2 ft. 6 in. diameter gear wheel fixed to the base support. This latter section of the drive mechanism is part of the original turntable drive on the gun base. The total gear reduction is thus approximately 1200 to 1 and there is ample time for any change in azimuth setting during the one minute interval allowed by the control unit. In order to avoid the use of slip-rings on all electrical leads to the turntable, suitable reversing controls on the motor are used in conjunction with the azimuth sequence control so that the turntable may never turn through the north position in either direction. Details of the control system are given in a later section.

It is of great importance when the telescope is being used for measurement and comparison of intensities at a fixed zenith angle and different azimuth settings that the axis of rotation of the telescope be well within one minute of arc of the vertical. Two spirit bubbles of sensitivity 20 seconds per division (0.1 in.) are mounted at right angles inside the yoke channel at the centre of the turntable. The base support screws must be adjusted so that when the turntable is turned to any position no movement of the bubbles greater than ½ division takes place. Once this condition is achieved the bubbles may be adjusted to read in the centre of the scale for convenience and frequent checks must be made to ensure that the correct conditions are maintained.

<u>Mechanical assembly procedure for complete equipment</u>. The base-supporting bolts form part of a rigid framework and this frame must be set in a concrete foundation in such a way that about 3 in. of each bolt protrudes <u>vertically</u> above the surface of the concrete.

Plans for the laboratory which is to house the equipment allow for two concrete blocks (one for each base) to be put in with their surfaces at floor level, and 12 feet apart, centre to centre. They are to be placed symmetrically in the 36 ft. x 15 ft. building. Provision is made for a ceiling height of 10 ft. 6 in. which will provide ample clearance for the telescopes whose maximum height above the concrete level is 9 ft. 6 in. It is essential for clearance reasons that the two base centres should be a minimum of 10 ft. apart.

When the concrete is properly set, assembly should be carried out in the following order: All mechanical components are numbered and appropriately marked, and throughout assembly, the marks on each component should correspond with those on its adjacent member. This is important in choice of parts which are duplicated (bracing triangles, angle uprights, trays, etc.) since, although nominally the same, small differences in bolt hole positions make assembly difficult if the marking code is not strictly followed.

1. Base-supporting nuts.

2. Base and turntable plus base-retaining nuts. (It should not be necessary at any time to separate the turntable from its base).

3. At this stage place the spirit bubble assembly on the turntable and carry out the levelling procedure. (See 12 below)

4. Before anything is mounted on the turntable bring all necessary electrical leads up through the central hole. The yoke, when in position partially covers this hole and leads cannot then be passed through the hole unless any attached plugs or sockets are removed. The leads required are listed at the end of 15 below.

5. Yoke with bracing triangles, motor and gearing attached. It is more convenient to assemble these latter on the yoke prior to mounting it on the turntable. Note that bolts holding one triangle to the yoke fit behind the gear box and it is thus necessary to bolt the triangle on first.

6. Bracing channels.

7. Telescope axles.

8. Lead mount and decking. The mount must be bolted in position so that the end which is to tilt downwards is facing in a direction

90^{o} clockwise from the end of the yoke which carries the motor.

9. Elevation - setting bars.

10. Lead. The blocks have been accurately cast to 20 cm. x 5 cm. x 5 cm. Each counter tray is sensitive over a one metre square, and the lead should be packed closely on the platform to cover an area of 105 cm. x 105 cm., allowing an overlap of $2\frac{1}{2}$ cm. on all sides of the telescope cross-section. The lateral boundaries of the sensitive area of a tray are equidistant from the side walls of the tray. The counter anode ends are aligned at a distance of 6 in. from the outside end of the tray (the end which inclines downwards when the telescope is tilted). This line corresponds with one 3 in. from the inside face of the lead-retaining wall. If the lead is spaced 2 in. from this wall (using 2 in. timber spacers) the required overlap will be obtained.

11. Angle-iron corner uprights.

12. Adjustment of base-levelling nuts. This should be done accurately. The turntable should be set so that one spirit bubble lies parallel with the line adjoining two of the three support nuts. One of this pair of nuts should then be adjusted until the difference in bubble position is less than $\frac{1}{2}$ division when the turntable is rotated through 180^{o}. The third nut may then be adjusted to achieve a similar condition in the direction at right angles to the first. Two bubbles set at right angles are provided for convenience and these may now be independently set to read in the centre of the scale. The axis of rotation of the turntable should now be accurately vertical and a thorough check should be made to see that the bubble readings do not change when the turntable is set in any position.

13. Trays. The corner uprights should not be fully tightened onto the lead mount until after the trays are in position. Tray circuits should be mounted and all counters

tested before the trays are placed in the telescope (see 15 below). Mounting of trays should never be attempted with less than 4 men, as each corner must always be supported to prevent slight sagging which may easily damage counters in the tray. A check should be made on the vertical alignment of the sensitive areas of the three trays.

14. Motor control switchgear. This is described later under "Control Equipment". Adjustments should be made so that in automatic rotation to a selected sequence of azimuth settings, the turntable comes to rest within 1 degree of the chosen positions. (One degree corresponds approximately to $\frac{1}{4}$ in. of turntable circumference). The choice of azimuth positions depends on the particular experiment to be carried out.

15. Mounting of recording circuits. As mentioned in 13 above, the tray circuits should be in position and all tray wiring completed before trays are mounted in the telescope. All counters should also have been tested. The coincidence circuit is mounted on two brackets bolted to one corner upright. The valves project inwards to allow ready access to the wiring by removing the chassis base cover. The scale chassis is screwed to the side of the middle tray. Pulse lines of coaxial cable connect the three tray circuit outputs to the coincidence circuit and the output of the latter to the scale circuit. A lead of twin shielded wire carries the scaled pulses down through the central hole in the turntable and across to the recording units on a nearby bench.

The two power packs and heater transformer stand on a sheet steel platform bridging one of the bracing channels on the turntable. Sockets carrying the power leads to the three tray chasses and coincidence chassis are wired similarly, but that which connects to the scale chassis is wired differently owing to the additional requirement for 240 Volt A.C. leads. It is suitably labelled and must under no circumstances be connected to one of the other chasses. One pair of wires carries HT plus and minus leads from the power pack to a small junction box mounted on the corner upright near the middle tray, and separate leads to the various chasses are taken from this junction box. Separate heater supply leads connect from each chassis directly to the transformer, and since one side of the heaters is earthed in each chassis, it is most important that all the heater earth leads are connected to the same transformer terminal. The live lead of each pair is clearly marked "blue" at the transformer end.

A distribution board on the turntable top carrying stabilised mains voltage(230V) supplies the two power packs, heater transformer and register driving circuit on the scale chassis.
The following leads are required from the turntable down through the base:-

(a) Mains lead direct from the output of the stabiliser on the bench to a four-socket distribution board on the turntable top.

(b) Power cable to motor (via motor control switchgear on the turntable). This lead comes directly from the control chassis on the bench to a 3 pin line-socket on the turntable. The motor current is not to be obtained from the stabiliser at any time as serious overloading of the latter will result.

(c) Twin lead from the control chassis on the bench to terminals on the motor switchgear on the turntable. This line is used to actuate the relay which resets the motor cut-out switch.

(d) Twin shielded lead from the output of the scale chassis to terminals on the bank of mechanical registers.

16. Bench units. These should be as close as possible to the two telescopes to avoid long connecting leads. They are the mains stabiliser, 50 Volt D.C. supply, mechanical

register bank, moving-chart pulse recorder, chronometer, and master control chassis.

Zenith angle indicator. This has been designed with a very open scale to allow accurate setting of the telescope inclination. The end limits to the sensitive area in the trays are clearly marked on the outside of the tray walls and stretched wires between pins at these marks on the two extreme trays should always pass directly over the corresponding centre tray limit marks. This ensures perfect tray alignment. The pin at the "cathode" end of the top tray also supports a plumb line used to indicate the telescope inclination on a graduated metal bar bolted between the side pair of tray-supporting uprights, at a level just below the centre tray. When the telescope is in a vertical position the plumb line should be parallel with the alignment indicating wire. Small positioning adjustments of the graduated bar are possible so that the scale zero may be accurately set opposite the plumb line when the telescope is vertical. The bar must then be set accurately horizontal. Calibration of the bar in units of one degree has been carried out assuming a perpendicular distance of 85 cm. from the axis of the plumb line pivot to the upper edge of the bar. The calibration will not be correct if this distance is not set at exactly 85 cm. Linear distances of 85 tan Z (Z = zenith angle) have been marked off from the zero point along the upper edge of the bar, providing a very open scale.

THE GEIGER COUNTERS AND TRAYS

The counter tubes are all manufactured to a standard design at the Physics Department of the University of Tasmania. Constructional details are shown in Figure 7.

The counters are of the external cathode type, the envelopes being made from soda glass tube manufactured by Australian Glass Manufacturers Sydney. The conductivity of this glass with the chosen wall thickness of one mm. allows very satisfactory functioning of the external cathode type of counter. Constructional problems are much simpler than those experienced with conventional internal cathode counters and experience has shown that uniformity of characteristics is readily achieved. The main disadvantage of the use of soda glass is that the Australian glass contains approximately 2 per cent of potassium of which 0.012 per cent is the radioactive isotope K^{40}. This leads to a relatively high back-ground counting rate (in the case of the

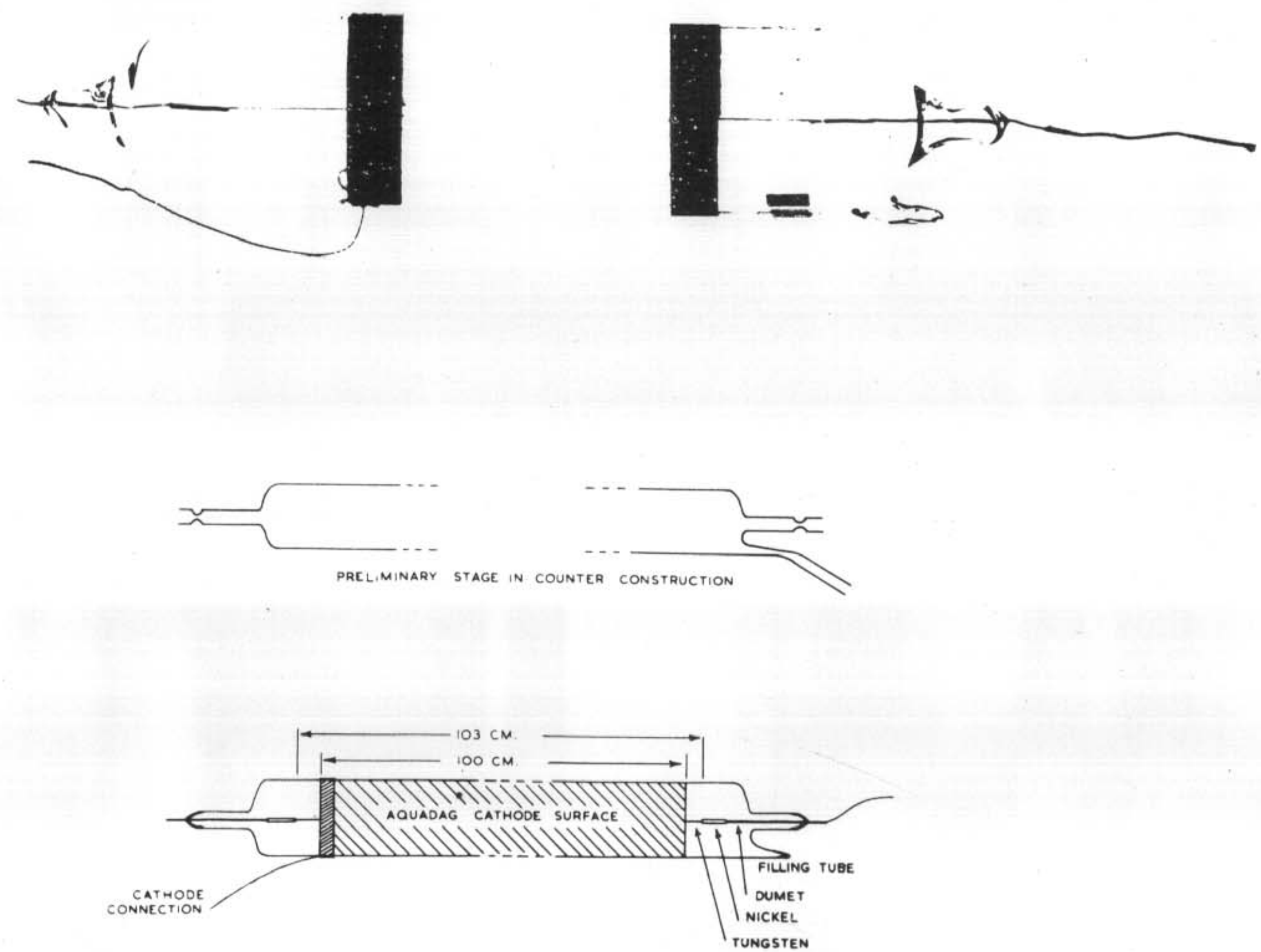

FIG. 7. CONSTRUCTIONAL DETAILS OF COUNTERS.

present counters about 40 per second) and thus shorter expected tube life, and the need for short resolving times in coincidence circuits to maintain a low accidental coincidence rate.

72 counters of this same construction were operated continuously for 14 months in a prototype telescope at Hobart without need for any replacement during this period and their performance was excellent. These counters were then subjected to a rejuvenation treatment involving the application of a 50 Volt potential difference for 4 seconds across the two ends of the anode wire (A.N.A.R.E. Report, Series C Vol. II). They are all still (after a further 6 months) operating satisfactorily.

A test on six counters showed that they are not affected by storage at -40°C for 12 hours.

Details of manufacture of counters. The glass envelopes are of internal diameter 40 mm. and wall thickness 1 mm. The tubing is cut and ends squared off at a length of 3 ft. 10 in. It is then rinsed with water, cleaned internally with a brush to remove dust, rinsed again and allowed to dry.

9 mm. tubing is joined onto the tube blank, and the filling tube is attached and drawn down to a small bore to facilitate later sealing off. These stages are shown in Figure 7 on previous page. Care is taken to fit the filling tube so that on sealing off it will project as little as possible beyond the diameter of the main tube. This ensures safe packing and easy mounting of counters in trays.

The completed envelope is then rinsed thoroughly with hot soapy water and then with tap water until all traces of soap have been removed. The whole inside surface should at this stage be uniformly "wetted". If not it is rinsed again with "Belloid" wetting agent and again with water. The tube is immediately immersed in a bath of fresh chromic acid, preferably warm, for a period of up to 4 hours. Acid is then rinsed thoroughly from the envelopes with tap water, using a fairly strong jet from rubber tubing fitted over the counter end. Following this the envelope is then left to drain and dry in a vertical position.

Preparation is then made for sealing in the anode wire. "Dumet" wire, after slight stretching to ensure straightness is cut into two pieces 3 in. and 7 in. in length. Half an inch of nickel strip is then spot welded to one end of each piece. Tungsten anode wire of 0.070 mm. diameter is spot welded to the nickel after cleaning with alcohol to remove any adhering die lubricants. The length of tungsten wire between the two nickel pieces should be between 102 cm. and 103 cm. A small soda glass bead approximately ¾ in. long is then fused to the dumet wire so that the extreme ends of the beads will finish just inside the 9 mm. end tubes of the counter envelope.

A large retort stand is used to clamp the envelope vertically and the anode wire is let down through the counter, the end with the short piece of dumet being at the top and held in a pin vise. (The 7" piece of dumet has enough weight to prevent the wire springing up into the middle of the counter). The blowing tube is connected to the filling tube and the other end of the counter is closed with a small rubber stopper. The first seal is made by heating the extreme end of the 9 mm. tube with a soft gas-air flame from a hand torch, allowing the glass to collapse evenly onto the glass bead. The seal is annealed in a sooty gas flame and allowed to cool.

The free end of the wire is then secured with a small clip, the tube reversed in the clamp, and the free end of the wire transferred to the pin vise, tightened, and centred. The final seal is then made in a similar manner to the first.

The counter is then ready for addition of the external cathode. The outer surface is cleaned with ether, and cellulose tape is used at each end to mask off exactly 1 metre. The limits of this one metre should be approximately equidistant from the two counter envelope ends and from the ends of the 0.070 mm. anode wire. The cathode surface of aquadag is then brushed on up to the durex tape limits and allowed to dry. The tape is then removed and the cathode connection wire of soft woven copper braid is splayed at one end and bound against one end of the aquadag under a strip of aluminium foil held firmly in place with cellulose tape. This is further bound with several turns of strong fine twine. The whole cathode surface is then given a coat of clear protective lacquer.

The filling of the counters is done in batches, each tube being connected to the pumping manifold at the filling tube. Prior to the attachment of the counters, the reservoir flask is filled with the appropriate gas mixture of anaesthetic ether and commercial argon. This is done by first evacuating the flask, flushing with ether vapour and then re-evacuating. Then ether vapour is let in to a pressure of 7.7 cm. mercury. Argon is then introduced into the flask (over heated calcium metal to remove any traces of oxygen and nitrogen) until the total pressure is 70 cm.

The counters are then joined to the manifold, and evacuated using a backing pump and two stage oil diffusion pump. They are tested thoroughly for leaks and the anode wires heated to bright red for several minutes using a 24 Volt battery across the two ends. The counters are flushed with filling mixture, re-evacuated and then filled to a pressure of approximately 9 cm. mercury. The exact pressure is adjusted to give a counter starting voltage of 1080 Volt. The filling tubes are then sealed off at the constriction by careful heating and the counters subjected to the test procedure outlined below.

Tests and counter characteristics. Immediately after filling, a counter-rate voltage curve is plotted for each counter and the pulses at each voltage examined using an oscillograph. Notes are made on the performance of each counter.

Batches of 10 to 20 counters are then connected in parallel on a test bench and set in operation, at approximately 1120 Volt, using a 2 megohm series resistor. They are left in this condition for 50 to 100 hours and then again submitted to final individual testing. It is found that some counters although not having very good characteristics immediately after filling, "settle down" during the initial few hours of operation, and are then quite acceptable. Any counters still unsatisfactory are refilled and tested again. This frequently results in producing a satisfactory counter. The overall acceptance proportion is approximately 90 - 95 per cent.

The characteristics of accepted counters are as follows:-

Threshold voltage	1100 - 1120 Volt
Plateau length	200 Volt minimum
Plateau slope	0.06 per cent per Volt maximum (average 0.03% per Volt)

Mean counting rate 35 to 45 counts per second, though this varies slightly with different batches of glass.

The efficiency of several sample counters has been measured at approximately 99 per cent. Inefficiency is largely due to "dead time" following each count, and is very slightly greater at higher voltages than near the start of the plateau due to the increased dead time per pulse.

<u>Tray assembly</u>. Each tray of outside dimensions 50½ in. x 43½ in. x 4.3/16 in. is made with side and end walls of 3¾ in. x ¾ in. oregon timber. The floor is cut from 3/16 in. pressed - wood sheet and screwed to the wooden frame. The outer top edges of the walls are recessed for the fitting of 1 in. x 1 in. x 1/16 in. aluminium angle strips which project inwards over the top surface of the walls leaving a gap for the lid to slide under. Either end piece of aluminium angle may be taken off for removal of the lid. The lid is of 3/16 in. pressed-wood strengthened against sagging by a light angle iron cross bar screwed to its upper surface. Brass bars drilled and tapped to take the tray mounting bolts are fixed into the wooden frame at each corner.

Each tray and lid is fully lined with finely woven brass-bronze wire mesh. This lining forms an efficient electrical screen for the counters.

24 counters lying parallel with the ends of the cathode surfaces in line provide a sensitive area nominally one metre square. However, since over-lapping counters are not used, the effective sensitive area is reduced by the possibility of particles traversing the glass counter walls without passing through a sensitive volume. In practice the outside limits of the sensitive area are kept fixed at one metre square to facilitate the alignment of trays in a telescope.

The counters rest on two sponge rubber strips raised off the tray floor by wood and perspex strips. They are held firmly in place by further strips built up from sponge rubber, perspex and square section steel tubing which may be tightened down onto the counters.

In positioning the counters before they are clamped, the limits of the aquadag cathode surfaces should be accurately aligned at the "anode end" 6 in. from the outside of the tray end wall. This alignment should coincide exactly with the marks on the outside of the tray walls, since it is these latter which are used as reference marks when aligning trays in a telescope. The lateral limits to the sensitive area in the tray are set one metre apart by wood blocks faced with perspex.

The high voltage counter supply line enters the tray through a socket in one end wall and cathode connections are made to a common line mounted on insulating stand-offs. This line is decoupled from the supply line by a resistance-capacity filter (100K and 0.1 microfarad) mounted inside the tray. Since the aquadag cathodes are at a high negative voltage with respect to the earthed tray screening, particular care should be taken in keeping the tray free of dust and the insulating rests and clamping bars in good condition.

In practice the lid will normally be removed from the "anode end" of the tray. Care should be taken at all times to prevent damage to the edges of the lid and to the light aluminium angle strips under which it slides, otherwise difficulty will be experienced in replacing the lid and the efficiency of the screening may be impaired by poor contact between lid and tray-wall screening gauzes.

ELECTRONIC RECORDING CIRCUITS

Figures 8 to 11 show the general system used for recording the number of cosmic ray particles which pass through all three trays of a telescope.

Very briefly, voltage pulses resulting from the passage of an ionising particle through a tray of counters are fed, after suitable shaping and amplification to the grid of one valve of a coincidence trio. Pulses from the other two trays are fed

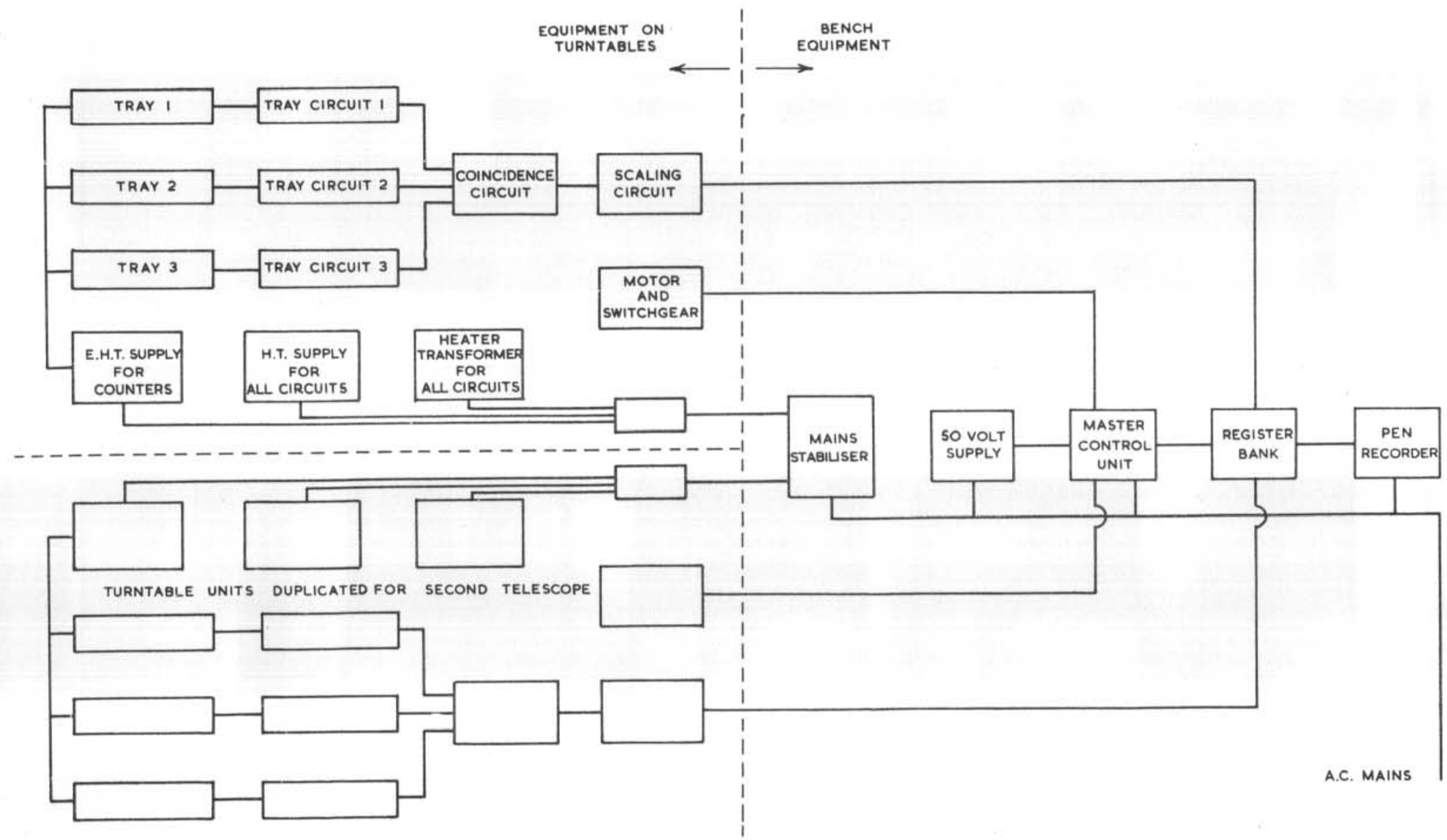

FIG. 8. BLOCK DIAGRAM OF CONTROL AND RECORDING CIRCUITS.

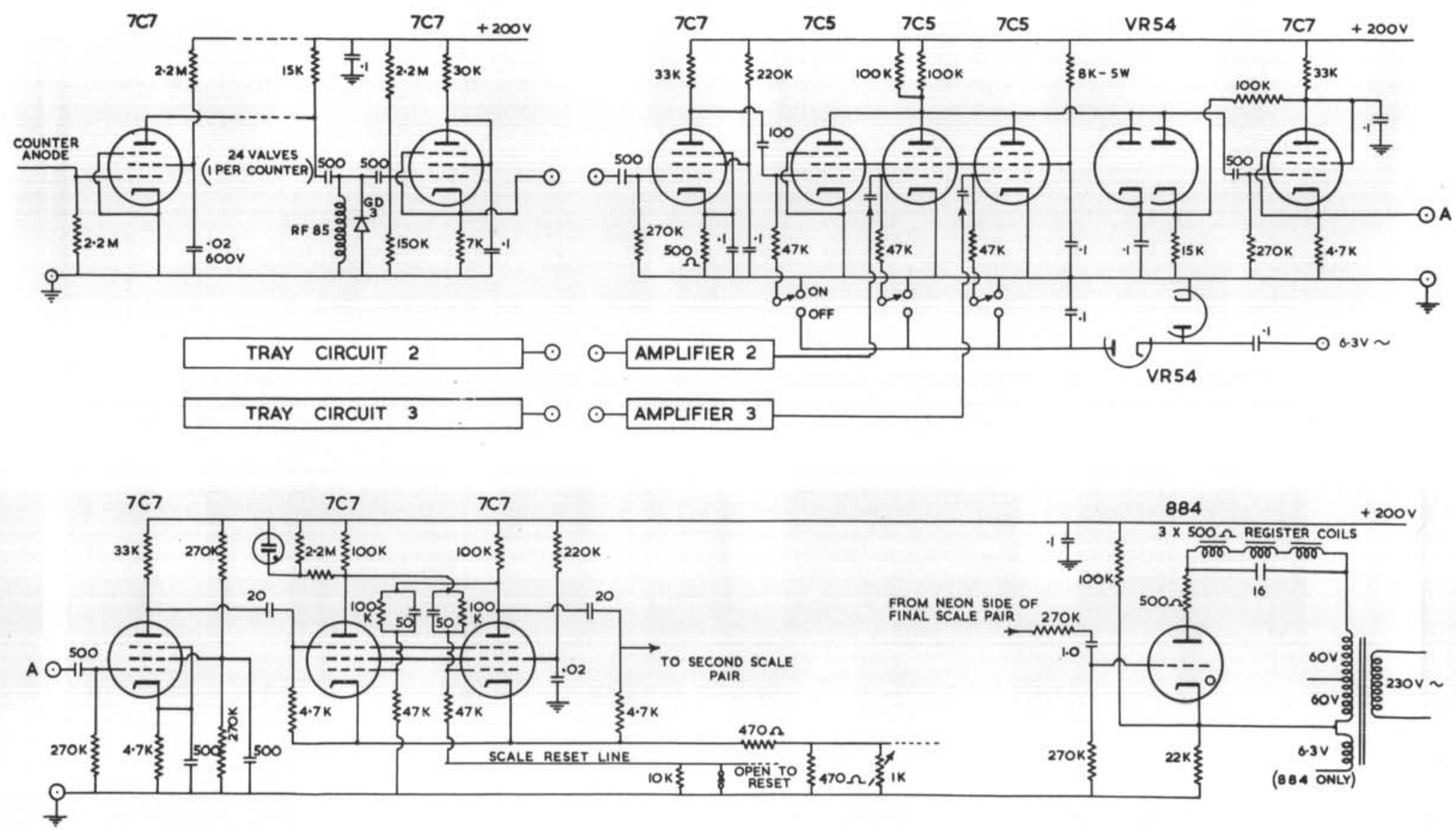

FIG. 9. RECORDING CIRCUITS.

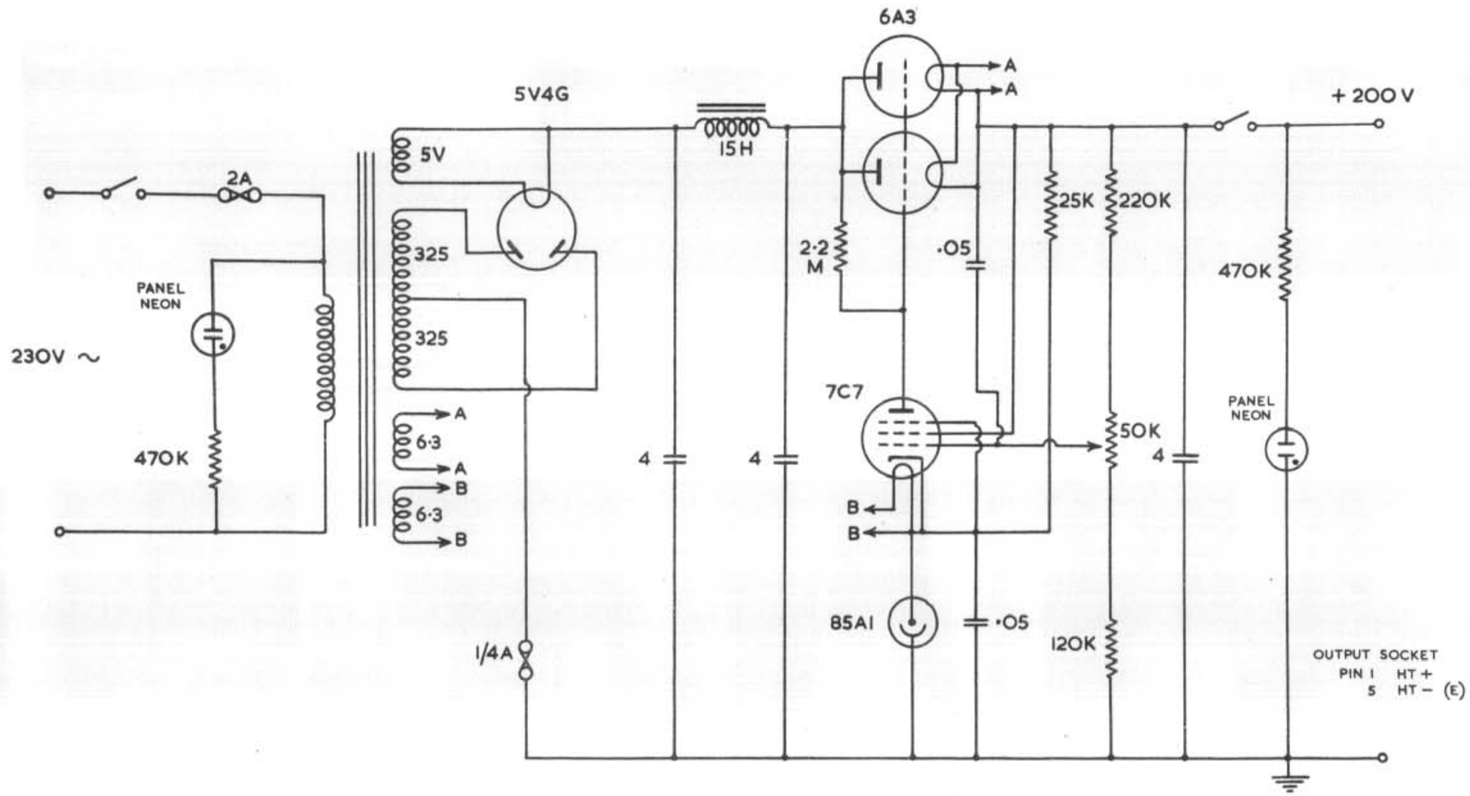

FIG. 10. H.T. (200 VOLT) POWER SUPPLY.

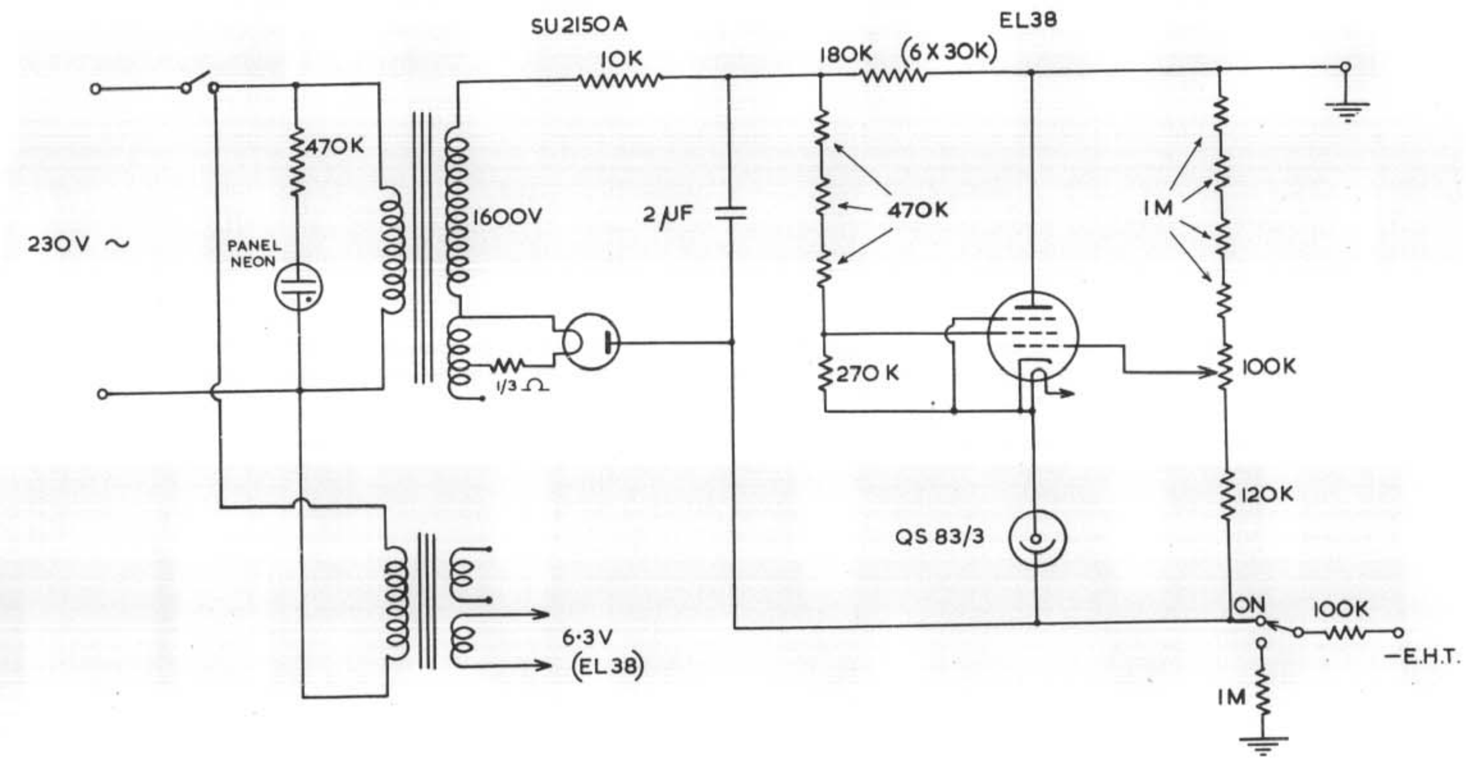

FIG. 11. E.H.T. POWER SUPPLY FOR COUNTERS.

similarly to the grids of the other valves of the trio. The discriminator valve following the coincidence trio gives a pulse at its output only when pulses from each of the three trays arrive "simultaneously" (within the coincidence resolving time) at the grids of the three coincidence valves. The discriminator output is fed to a scaling circuit which divides the number of coincidence pulses down to a convenient rate, its output being used to actuate an electro-mechanical register.

Factors influencing the choice of resolving times and scaling factors are discussed in the section on "Counting Rate Data".

The recording circuits for a telescope are built into five separate chasses referred to in the description which follows as tray strips (3), coincidence chassis, and scale strip. The physical positioning of these units may be seen in Figure 1, while the circuit details appear in Figure 9.

Tray strip chassis. This is mounted directly to the end of a counter tray. It performs the functions of (1) combining the pulses from the individual counters, and (2) producing a narrow output pulse, the onset of which occurs with the onset of a counter pulse.

Figure 12 is a simplified diagram of the circuit. $V_1 \ldots V_{24}$ are normally conducting. Resistors $R_1 \ldots R_{24}$ are the anode loads for each counter, and it will be seen that the counters are neutral to each other. V_1, V_2, etc., being pentodes, have a high differential anode resistance 1.5 megohm, i.e., the i_a/v_a curve is practically horizontal. Hence an increase of voltage of the common anode line causes no increase of i_a in any other valve. The valves therefore are also neutral to each other.

Counter GM1 firing produces a negative-going pulse across R_1, this pulse cutting off V_1. The reduction of current through the tuned circuit causes a rise at the common anode line of $i_a \sqrt{L/C}$. The pulse will last $\pi \sqrt{LC}$ secs. and the pulse shape will be approximately one half cycle of a sine wave. (After the first positive-going half-cycle the diode conducts, abstracting energy at a high rate from the tuned circuit, and no further change appears). C is not present in the circuit as a component, being made up of the anode-cathode capacitance of the 24 valves, and is approximately

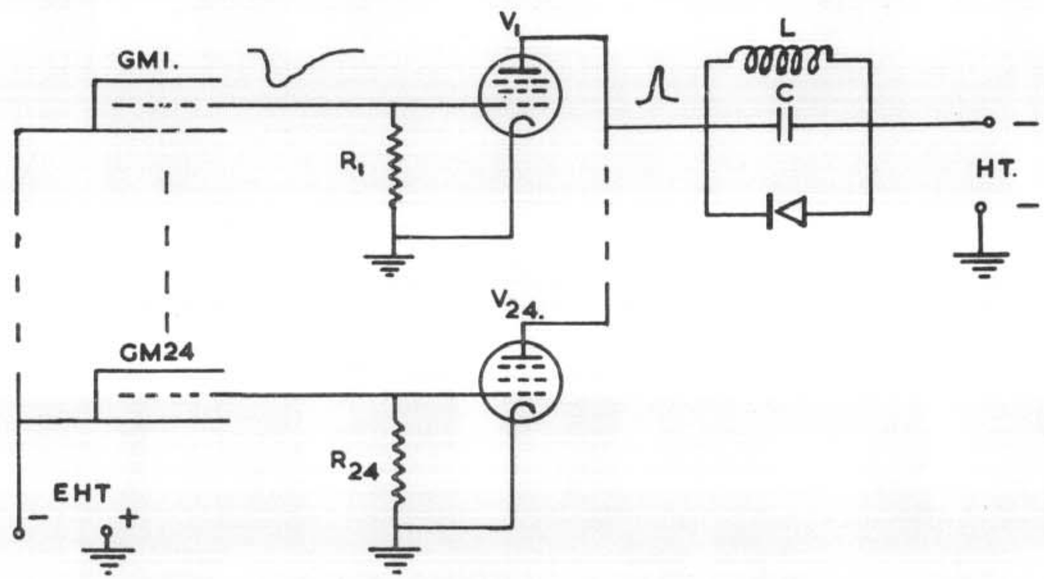

FIG. 12. SIMPLIFIED DIAGRAM OF TRAY STRIP CIRCUIT.

250 pf. L is 7mH. The standing i_a of V_1 is 0.45 ma. The pulse height expected is therefore $0.45 \times 10^{-3} \sqrt{(7 \times 10^{-3}/250 \times 10^{-12})}$ or 2.4 v approximately. The duration will be $\pi \sqrt{(7 \times 10^{-3} \times 250 \times 10^{-12})}$ or 4 μ sec . approximately.

The circuit gives figures both rather less than these due to the inclusion of the 15K plate feed resistor and 500 pf coupling condenser, not shown in the simplified sketch. Also V_1 does not cut off in zero time. The pulse is normally between 1 v and 1.5 v, depending on the magnitude of the counter pulse, and hence on the rate of change of the leading edge, and has a time duration of 3.2 μ sec .

$V_1 \ldots V_{24}$ should have equal anode currents. Each valve has a standing grid bias due to its grid current through the counter anode load. This voltage is usually about -0.5 v, but varies from valve to valve, and during the life of a valve. The anode currents, with a short grid-base valve as is the 7C7, would differ considerably if $V_1 \ldots V_{24}$ had equal screen voltages, as each valve would probably have a different standing grid bias. The screens are therefore fed individually through a high resistor (2 M or 2.2 M). Thus the valve with the highest negative bias due to the contact potential effect, collection of electrons by the grid, gas current effect, etc., also has the highest screen voltage, thus bringing its i_a very nearly to the level of the valve with the least negative bias.

The final point, that the onset of the pulse produced shall occur with the onset of the counter pulse is achieved because the 7C7 valves, at their low screen voltage, cut off at about -2v on the control grid. As there is a standing bias of about -0.5v, cut-off occurs in the first 1.5 v change of the counter pulses. These have a magnitude of between 15v and 50v, depending on the EHT, with a very high rate of change at the leading edge. Thus most of the pulse occurs below the cut-off level of the valve, and in fact the output pulse is finished long before the counter pulse has reached its peak negative value. The trailing edge of the counter pulse has a very small rate of change, and does not affect the tuned circuit.

A cathode-follower stage is inserted between the tuned circuit and the output terminal. This isolates the tuned circuit from the capacitance of the coaxial lead which will be joined to the output terminal, in addition to reducing the effect of such capacitance upon the shape of the pulse.

It is most important that the counters, and leads through to the grids of the 24 valves in the chassis be completely shielded against pick-up of high frequency signals from any nearby radio equipment or sparking relay contacts, etc. Checks on the efficiency of the shielding should be made from time to time.

Coincidence chassis. This contains three identical amplifier stages, one for each of the input lines from the three tray strip chasses. Each amplifier has a gain of about 25, and its output is coupled to the grid of one of the three coincidence valves. Some differentiation occurs in the coupling, and the pulse width at the coincidence grid is reduced to about 2.6 μ sec.

Only a small proportion of the pulses appearing at the coincidence grids arise from the passage of a single particle through all three trays. The function of the coincidence circuit and following discriminator is to provide an output pulse only when pulses arrive "simultaneously" at the three grids. The resolution time of the circuit depends on the pulse length at the grids. It is not advisable to have this less than about one μ sec. as short delays may occur in the counters themselves between the passage of a particle and the onset of the discharge. On the other hand long resolution times give an unnecessarily large accidental coincidence rate (see the section on "Counting Rate Data"). The figure of 2.6 μ sec. is regarded as satisfactory from both these points of view.

The pulse amplitude at the coincidence valve (7C5) grid should be sufficient to cut off the valve and should not be less than 13 v peak.

The anode circuit of the 7C5's is required therefore to show a considerable response when the three valves are cut off simultaneously, or nearly simultaneously, and a negligible response when one or two valves are cut off. This is equivalent to saying that the differential anode resistance r_a of each valve must be small compared with the common anode resistor R.

The shunt capacitance in the anode circuit is about 30 pf, due to the three valves, diode, input of the discriminator, and strays. R is given the value of 50K, so the anode time-constant of 1.5 μ sec. is shorter than the time the coincidence valves will usually be cut off. The anode voltage rise on coincidence thus has a steep leading edge, and the pulse is virtually rectangular, being limited to 15v.

The 7C5's are operated at zero bias, and a screen voltage sufficient to reduce the common anode voltage virtually to zero. Under these conditions the r_a of each valve is about 750 ohms. Hence with R = 50K, one valve being cut off raises the common anode potential by 0.5 v, and two by 2v. As a 2v rise will operate the scaling system, the cathode-follower output stage is biassed to beyond cut-off, and does not respond until the common anode line reaches 6v. The output pulse is therefore of 9v amplitude, though pulses of smaller amplitude will occasionally appear, due to partial accidental coincidences.

The limiter diode replaces the anode current in R when the common anodes have reached 15v, and no further rise appears. The diode protects the cathode-follower 7C7 from the 2 or 3 ma. grid current which would flow if the common anode rise were allowed to proceed, this current being greatly in excess of the valve rating.

Three switches are provided to allow "two-fold" or "one-fold" coincidence counting during equipment tests. They are located in the screen circuits of the valves of the coincidence trio. When a switch is off (toggle pointing away from the chassis pulse input sockets), the valve screen is lowered to earth potential and virtually all current through the common anode load resistor is carried by the remaining two valves. These two then produce the full coincidence output pulse if they are cut off simultaneously by pulses at their grids, and a pulse of only about 1.5v if only one of the pair is cut off. Two-fold coincidence operation is thus achieved. Similarly, if two channels are inactivated by the switches, the remaining valve passes on all pulses arriving at its grid with full coincidence output amplitude.

<u>Scale strip.</u> This consists of an amplifier-inverter first stage, followed by 8 scale pairs and a register-driving circuit.

Any integral power of 2 up to 2^8 is available as a scaling factor by connecting the 270K series grid resistor of the thyratron to the output of the appropriate scale pair. A short vertical lead indicates the correct anode. The scale pair valves after the take-off point are not removed from the chassis.

A low-gain (X4) amplifier precedes the scale-pairs, its chief function being to invert the positive pulse from the coincidence chassis.

The scale pairs each consist of two valves, these being so coupled together that conduction of one results in cut-off of the other.

At a common screen voltage of 30v or so, the anode of the conducting valve is about +30v with respect to E. The alternate grid is thus at +10v or so, and, as the common cathodes are at about +16v, the non-conducting valve has -6v bias, or about three times that necessary to reduce the anode current to zero.

The anode of the cut-off valve is not at +HT potential due to current in the shunt path and grid current of the conducting valve. These currents total about 0.9 ma., giving an anode voltage of approximately 110v.

The neon glows only if the anode to which it is connected is "low". Were this anode at 110v, some 73v would appear across the neon, or about 12v less than the striking voltage.

It is necessary for scale pairs to be "polarity sensitive". In this case, positive-going pulses at the common suppressor do not affect the scale pair, but a negative pulse reduces the anode current of the conducting valve. The resultant anode voltage rise permits the other to conduct, and temporarily both valves are conducting. It is a matter of chance which valve would finally remain conducting. A sense of direction is therefore required during the change-over period, and this is obtained by connecting small capacitors across the cross-feed resistors.

The effect of the capacitors is greatly to increase the coupling between the valves when the anodes are "moving". A much smaller rise is now necessary at the "low" anode to release the biassed-off valve, and the resultant fall at this anode drives the grid of the previously conducting valve far below cut-off. The change-over time is greatly reduced, and an "over-stable" position results immediately following a change-over. It follows that the scale pair cannot again be pulsed until the now cut-off valve grid has recovered to approximately its standing -6v bias, and this paralysis time is about 2.8 μ sec., with a standard-size input trigger pulse.

The paralysis times of the first scale pair will vary from 2.8 μ sec. to 10 μ sec., corresponding to 2v and 9v pulse heights at the input socket. Other scale pairs receive a standard height pulse from the previous one. The variation of paralysis times is not important in view of the low coincidence rate and the improbability of smaller pulses occurring.

The voltage excursion at a scale-pair anode is from 110v to 30v, and vice versa, and the fall takes place in about 2 μ sec. or 40v/μ sec. The differentiating circuit coupling the scale pairs is 20 pf, 4.7K. Approximately, therefore, a pulse of $CR\frac{dv}{dt}$, or 4v, is expected across the 4.7K resistor, and this pulse triggers the subsequent scale pair. The pulse is approximately rectangular, and of about 2.2 μ sec. duration.

When the scale pair anode rises from 30v to 110v, only a small positive pulse appears across the 4.7K as the rate of charge of the 20 pf capacitor is greatly reduced by the 100K anode resistor, except in the case of the input to the first scale pair. Here the previous anode resistor is 33K, and the amplifier valve does not cut off. A positive pulse then appears due to the positive-going trailing edge of the amplifier anode waveform. Positive pulses are of no importance as they do not affect the scale pairs, and are referred to here merely to explain the waveforms.

The sensitivity of the complete scaling strip can be adjusted by varying the standing bias on all scale pairs. The control is located near the thyratron, and varies the common cathode line from

19.5v (minimum sensitivity) to 12.5v (maximum sensitivity). Clockwise rotation increases the sensitivity. At maximum, pulses greater than 1v will be counted, and at minimum pulses greater than 2.5v. The control is set for a 2v pulse threshold, pulses being supplied from the pulse generator, and fed to the scale strip chassis input socket. The corresponding bias figure will be in the region of 16v.

A reset switch is also located near the 884. Moving the switch toggle towards the transformer sets the scale to zero, i.e. all neons extinguished. The switch may be left in the reset position for any length of time without harm. The reset is provided for convenience during testing, and is not used during normal operation.

The 884 operates three 500 ohm register coils in series. (A smaller number should not be connected). In the quiescent state the valve is biassed off by some 36v obtained from the +200v line. The 884 is pulsed when the scale-pair anode to which it is connected moves from the "low" to the "high" position, applying a 40v pulse to the grid. The coupling of CR, approximately 0.5 sec ., returns the grid exponentially to zero in about 2.5 sec .

The conduction time of the 884 depends, therefore, largely on the standing bias level, and at 36v is approximately 0.5 sec . Increase of bias (e.g. by shunting the 100K) will reduce this time, and adjustment, if ever required, should be made here rather than in the grid circuit.

The 884 operates as a half-wave rectifier when conducting, and produces about 75v across the three registers.

The valve will conduct permanently if its bias is removed, i.e. if the 200v HT is switched off. No harm is done, as the valve remains within its continuous-running rating, but from the point of view of valve life it is advisable, if the HT is likely to be off for a long period, to remove the valve from its socket, or disconnect the registers.

RECORDING EQUIPMENT

Two methods are used simultaneously to record the rate of output pulses from the scaling circuit. The first involves direct counting on electromechanical registers of the 4-digit P.M.G. message register type (S.T.C. type 5001-A). The second and subsidiary method employs a moving chart instrument in which pens record each tenth output pulse and make appropriate time scale marks on the chart. This second system is actuated primarily by electrical contacts fitted to a modified electromechanical register in series with those used in the main recording system.

The main system provides only hourly count totals, whereas the chart recorder allows inspection of shorter term fluctuations in counting rate and direct comparison of such fluctuations occurring in the two independent telescopes.

Main recording unit. In order to eliminate the need for taking hourly photographs of mechanical registers, as has been done in previous A.N.A.R.E. cosmic ray equipment, use has been made of a P.M.G. type uniselector switch actuated at hourly intervals to allow counting on a different register during each hour of a two-day period. This necessitates use of a bank of 48 registers for each telescope. As described in the section on "Timing Control Equipment", the pulse lines to the registers are opened during the one minute interval allowed for telescope rotation, and the uniselector switches a new register into the circuit at the end of this minute. The register circuits are electrically independent for the two telescopes, but simultaneous switching is accomplished on the one multi-bank selector.

The wiring of the register bank is shown in Figure 13 (see also Figure 14). As indicated the switch has 25 positions, only 24 of which are required for a one day cycle. A spare contact bank on the switch is used to allow jumping of one position. A pair of contacts, in series with the driving coil and opened when the coil is actuated, are shorted out when the contact bank wipers are in all positions except one. From this position, when the coil is next actuated, the wipers will jump one contact in each bank.

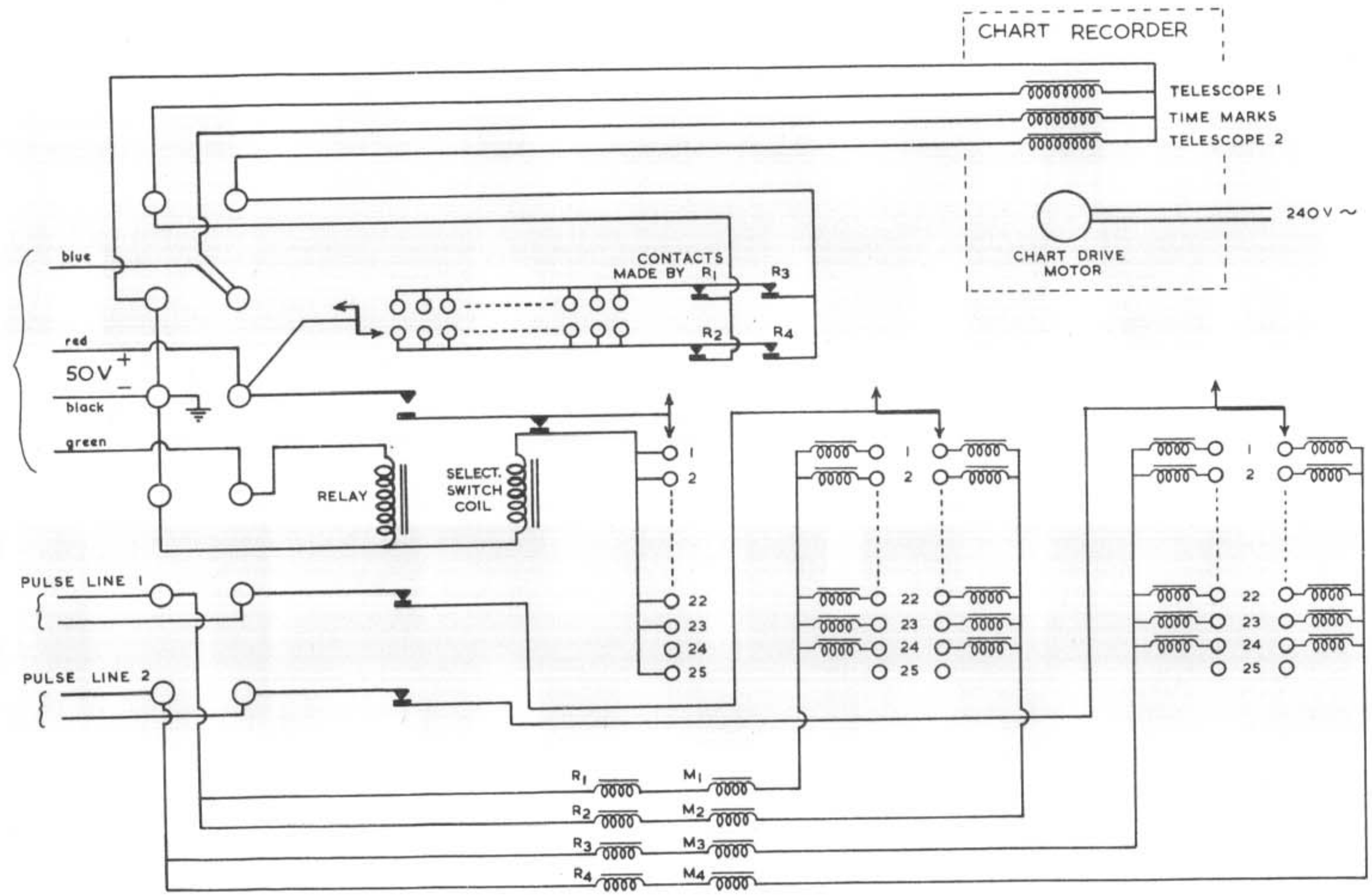

FIG. 13. WIRING DIAGRAM OF RECORDING UNITS.

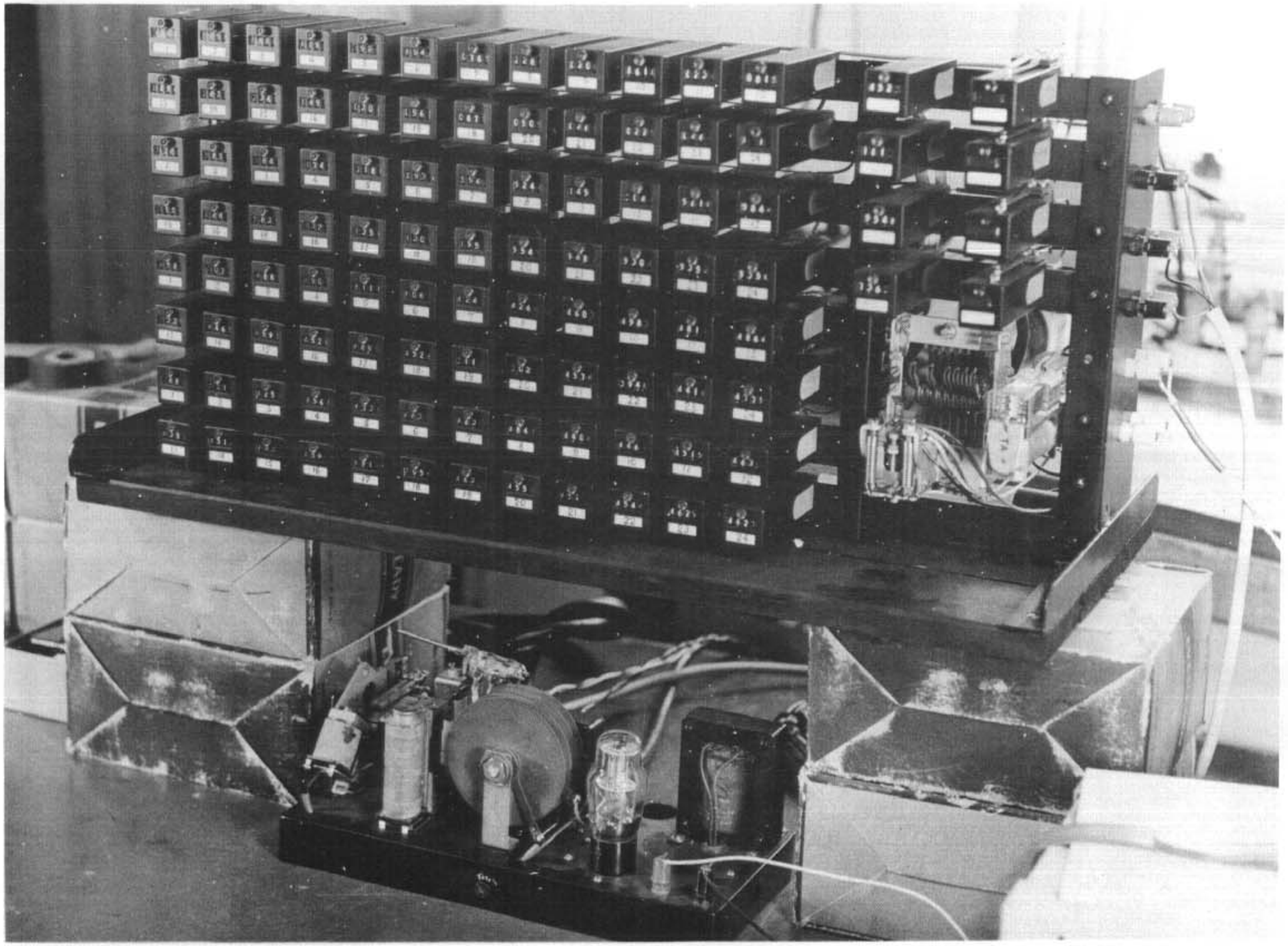

FIG. 14. REGISTER BANK.

A single master register and a register actuating the chart recorder pen are connected in series for the full 24 hours with whichever register is counting in each group of 24. Thus when the selector switch moves on to the second group of 24 it leaves a complete day's total standing in the previous master register. This total should always check with the sum of the 24 individual hourly totals. Any discrepancy is an immediate indication of a faulty register. Similarly, if preset correctly, the units figure on the modified register actuating the chart recorder pen should always check with that on the corresponding master register. (Only the units drum is present on these modified registers).

The selector switch should be set so that counting takes place on the first register of a bank of 24 during the first hour of the Greenwich day.

Chart recorder unit. In this instrument (Figures 13 and 15) a Venner Synchronous motor whose output shaft makes one revolution per hour drives a chart past three pens at a rate of 6 in. per hour. The chart is 6 in. wide and has a fine abrasive surface. The pens are of small diameter brass rod turned down to a point, and are held down vertically onto the chart by short lengths of spring wire. They leave a fine black line on the chart as it passes beneath them. The three pens are aligned perpendicularly to the direction of motion of the chart and are actuated by separate electromagnets in a small housing to the side of the chart. Each pen when actuated makes a short lateral mark. The two outer ones record the two independent telescope counting rates, a lateral mark being made for each tenth output pulse from the scaling circuit. The centre pen records accurate time marks at ten-minute intervals. Its electromagnet, operating from the 50 volt supply, is controlled directly from the master control chassis (see the section on "Timing and Control Equipment").

As shown in Figure 13, the electromagnets operating the two count rate pens are actuated from the 50 volt supply by electrical contacts made by a cam fitted to the units drum of an ordinary register. Each tenth register count is recorded and the contacts remain made for the interval between two counts.

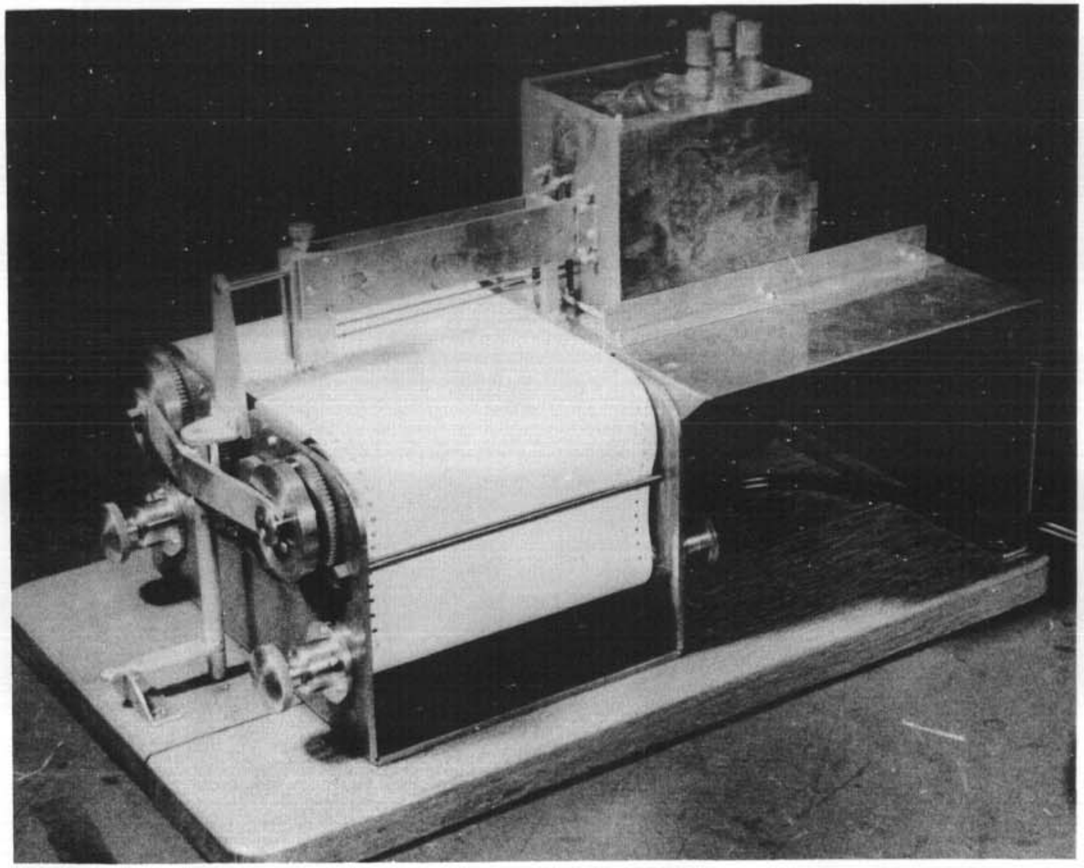

FIG. 15. CHART RECORDER.

The three pens are set close together and the chart width will accommodate up to ten record strips if at the end of the chart run, the electromagnet and pen assembly is moved laterally and clamped in a new position. The chart drive may be easily reversed to save interchanging feed and take-up spools and to avoid loss of recording time.

It is important that the correct Greenwich date and time should be marked clearly on the record chart at least once per day and the forward direction of pen motion relative to the chart suitably indicated.

TIMING AND CONTROL EQUIPMENT

Both telescopes are controlled from the same chronometer and primary switchgear. The only section of the control equipment duplicated is that which controls the sequence of azimuth settings of each telescope and is mounted on each turntable.

The chronometer used is a survey-type instrument manufactured by Thomas Mercer Ltd. It is fitted with electrical contacts which are made for 2 seconds at intervals of one minute. As described later making of the contacts allows a cam to move forward one step. This cam makes one complete revolution per hour and sets of contacts actuated by the cam are used to carry out the following operations:

1. For a period of one minute at the beginning of each Greenwich hour

    (a) Open the pulse lines to the registers.

    (b) Energise the coil of the register selector switch.

    (c) Close a switch in the mains lines to the motor switchgear on the turntables.

2. For a period of one minute at intervals of 10 minutes energise the coil controlling the time-marker pen on the chart recorder.

3. For a period of one minute, a few minutes before the end of each Greenwich hour, energise a coil which recloses the motor cut-out switch on each turntable, so that the motors will again be

started on the Greenwich hour (1(c) above).

The electrical circuits which perform these operations when actuated by the 60-position cam are shown in Figure 16. A simple 50 volt D.C. supply for operation of the relay coils is built into a separate chassis. This is shown on the same diagram, as is also the wiring of the two motor control units on the turntables. The relay which opens the pulse lines and energises the coil of the register selector switch is mounted on the register bank and is thus shown on the wiring diagram of that unit (Figure 13).

Cam-driving circuit. The chronometer contacts are necessarily very light and the makers recommend that a current of not more than 0.2 milliamp be carried by them when closed and that not more than 12 volt appear across them when open. To satisfy these conditions the contacts are connected in the grid circuit of an 884 thyratron which is normally non-conducting due to a d.c. standing grid bias of about -14.5 volt. Closing of the contacts reduces this bias to about -3 volt, and the 884 then functions as a half wave rectifier.

Current through the thyratron and from the 8 μf reservoir capacitor energises a 2000 ohm coil in the 884 anode circuit. 55 volt d.c. appears across the coil which closes a microswitch. 240 volt a.c. is thus applied to the primary of a transformer, 6.3 volt appearing across the secondary. This is rectified and fed to the solenoid actuating the 60-position cam.

Turntable switchgear for motor drive. Leads to the field winding of the $\frac{1}{4}$ H.P. 240v A.C. motor have been brought out separately and are connected to the mains line as shown in Figure 16 via a pair of two-way mercury switches. A single pole mercury switch is also included in the mains line. These mercury switches are mounted on a small frame attached at the circumference of the turntable (see Figure 17). Tripping posts may be mounted on the stationary bas in such a way that the single pole mercury switch is opened as the turntable reaches any chosen position when being driven round by the motor. The motor thus cuts out and the turntable comes to rest after a run-on of approximately $3\frac{1}{2}$ inches at the

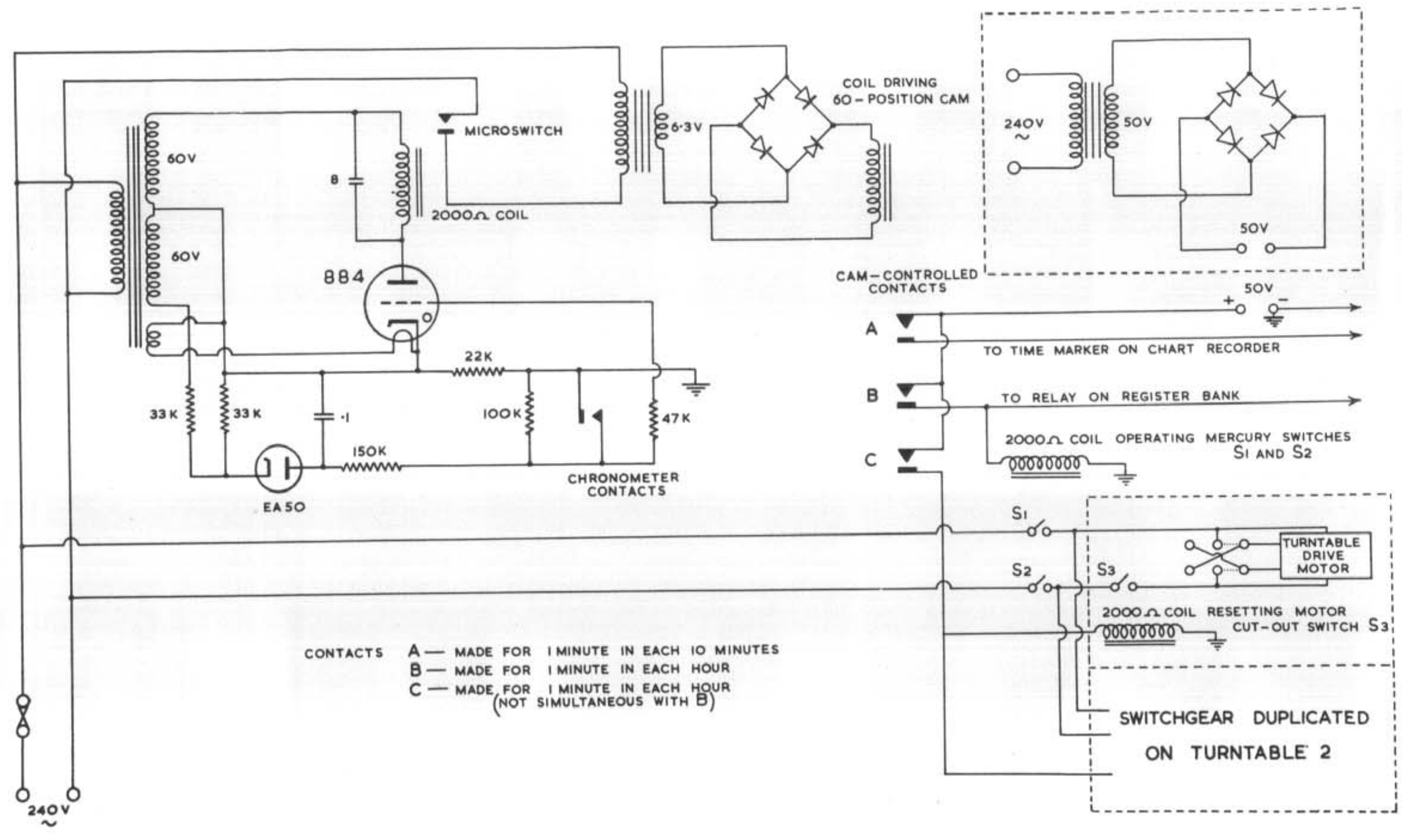

FIG. 16. WIRING DIAGRAM OF CONTROL EQUIPMENT.

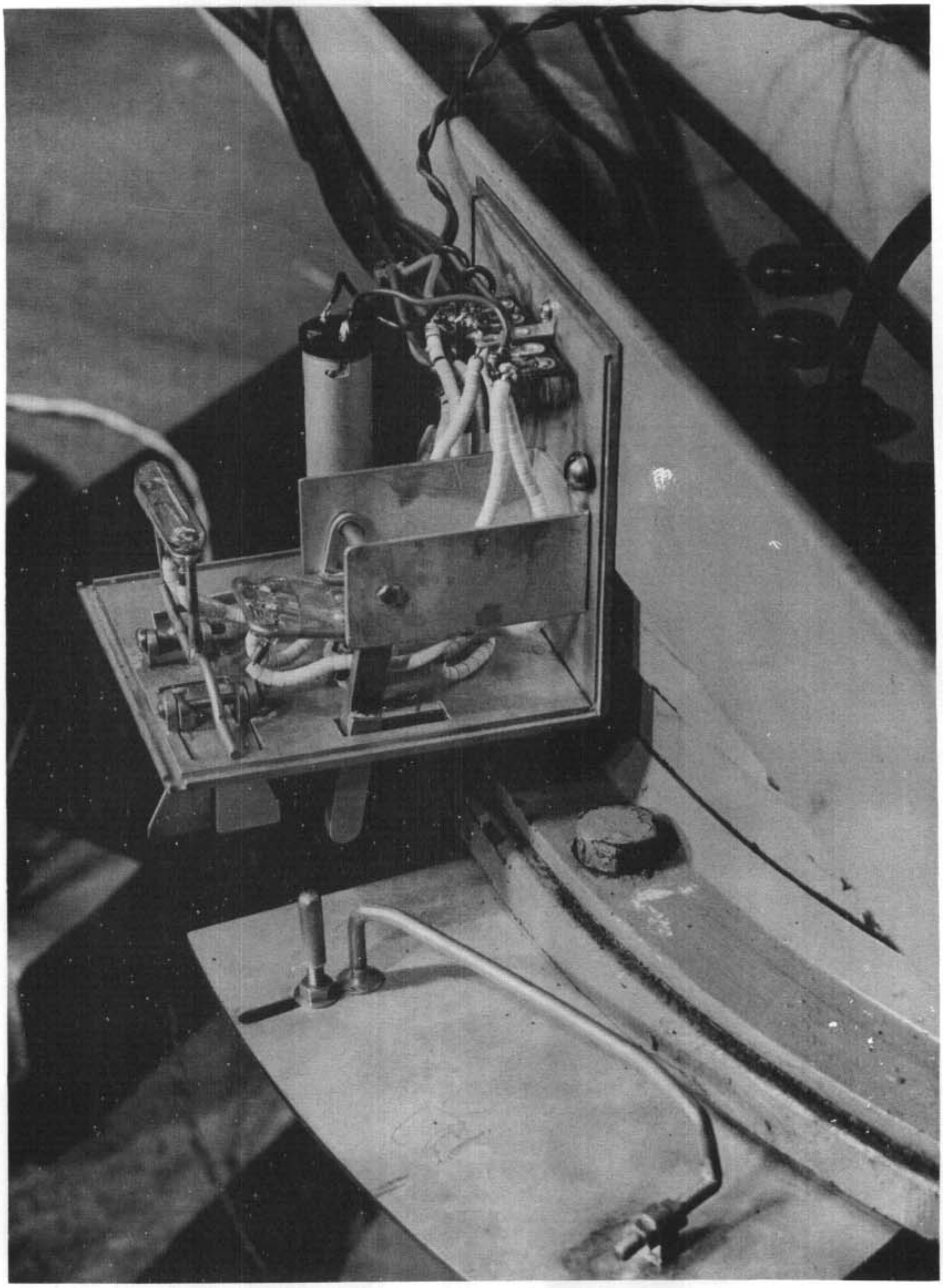

FIG. 17. DRIVE MOTOR CONTROL SWITCHES MOUNTED ON TURNTABLE.

circumference. It has been found that this run-on is of practically constant amount and no auxiliary homing devices are necessary to achieve the required accuracy of plus or minus 1° in azimuth setting of the telescope. The positions of the tripping posts may be readily adjusted so that the telescope comes to rest at any chosen azimuth.

In order to eliminate the necessity for sliprings on all electrical leads to the telescope which would arise if the turntable could rotate only in one direction, the pair of two-way mercury switches are used for reversing the motor at appropriate azimuth positions. The switches are changed over by a further tripping device on the base, set to operate during the run-on interval after the motor current has been broken. When the motor is energised again at the end of the next hour it will then drive the turntable in the reverse direction.

The tripping devices may be adjusted to produce automatically any desired sequence of telescope azimuth settings. An example is the sequence North - East - South - West - North - East - South - West - etc., the telescope remaining at each setting for one hour. To achieve this posts could be attached to the base to trip the motor cut-out switch at the appropriate positions, and reversing devices attached at North and West. The tripping posts for the motor cut-out switch may very simply be adjusted to trip when approached from only one or from either direction. Thus in the example quoted, the motor would not be cut out at the South and East positions when the turntable rotates from West back to North.

COUNTING RATE DATA

In this section a brief discussion is given of some of the more important factors which influence the counting rate of a telescope. Detailed treatments are not given, and the section is intended only as a guide to the equipment operator. It will be assumed that the number of single cosmic ray particles arriving per unit time is a Poisson variate.

Three fold coincidence counting - accidental coincidence rate. The counter trays are numbered 1, 2, 3 from the top.

Let N_1, N_2, N_3 be the background counting rates of the trays.

Let N_{12}, N_{23}, N_{13} be the total 2-fold coincidence rates between pairs of trays.

Let N_{12-3}, N_{23-1}, N_{13-2} be the rates of genuine two fold coincidences in which the single particle responsible does not also traverse the third tray.

Let τ be the resolving time of the circuit, (the interval before or after the arrival of simultaneous pulses from two trays within which an unrelated pulse from the third tray will be recorded as "coincident" with the other two. If the third pulse arrives outside this interval a "coincidence" is not recorded.)

Let A_{123} be the "accidental" coincidence rate due to the chance occurrence of three pulses at the three coincidence circuit inputs within the resolving time of the circuit and not arising from the passage of a single ionising particle through all three trays.

Then it can be shown that

$$A_{123} = 2N_{12-3}\, N_3\tau + 2N_{23-1}\, N_1\tau + 2N_{13-2}\, N_2\tau$$
$$+ \text{ terms of higher order in } \tau .$$

Terms of higher order in τ are negligible in comparison with those involving τ .

Now in a telescope in which the three trays are of equal sensitive area, and are equally spaced, and in which no mass of heavy absorber is placed between the trays

$$N_1 \simeq N_2 \simeq N_3$$

and $$N_{12-3} \simeq N_{23-1}$$

and $$N_{13-2} \simeq 0.$$

Thus

$$\underline{A_{123} \simeq 4\tau\, N_{12-3}\, N_1 .}$$

In the present case take $N_{12-3} = N_{12} - N_{123}$. Observed values of the relevant quantities for the present equipment, with the telescope pointing vertically, and with no absorber in the telescope are

$$N_{12} \quad - \quad 1900 \times 2^{7}/\text{hr.}$$

$$N_{123} \quad - \quad 800 \times 2^{7}/\text{hr.}$$

$$N_{1} \quad - \quad 54 \times 2^{16}/\text{hr.}$$

$$= \quad 2.5 \times 10^{-6} \text{ seconds.}$$

These figures give A_{123}, expressed as a percentage of N_{123} a value of approximately 1.32 percent.

This figure is not greatly altered by the presence of absorber in the telescope or by inclination of the telescope axis up to 50° from the vertical.

It may be pointed out that in the present equipment the contribution to the accidental coincidence rate arising from side showers of ionising particles is expected to be relatively small.

There is no direct method of measuring the actual, or the mean accidental coincidence rate in a three-fold telescope. Methods involving the artificial delay of pulses from one tray for a time exceeding , or the moving of one tray outside the telescope frame do not give a true indication of the mean accidental rate, and the calculation method outlined above gives perhaps the best estimate.

Count losses due to "dead time" of individual counters. In a single counter, following the initiation of one discharge due to the passage of an ionising particle, a certain time elapses before the counter will be capable of firing again. This period is the "internal dead time" of the counter, and particles traversing the counter within this time are not recorded. In the present equipment each counter anode wire is connected to the grid of a conducting valve and this valve is cut off by the negative-going counter pulse. The valve will not be capable of responding to a second pulse until after its grid returns above the cut-off point.

In the present case the time taken for this return is slightly longer than the internal dead time of the counter and thus determines an "effective dead time" for the counter. The effective dead time increases slightly with increasing voltage applied to the counter, since the pulses increase in amplitude and take longer to decay to the valve cut-off level. As the threshold voltage of the counters increases with ageing, it will be found necessary to increase the applied voltage gradually during the life of a counter, and this should be done if possible in such a way that the effective dead time per pulse remains substantially the same.

With a counter operating at 30 volt above threshold the measured effective dead time is approximately 350 μ sec. The observed mean background counting rate of a single counter is approximately 41/sec.

If N_0 = observed rate

N = true rate of incident particles

σ = effective dead time

then provided $N \ll \frac{1}{\sigma}$

$$N = \frac{N_0}{1 - N_0\sigma}$$

(The approximation is very good in the present case).

Using the figures quoted above, this expression leads to

$$N = 41.6/\text{sec.}$$

This represents a loss of 1.44 percent of the incident particles.

This loss occurs in all counters of a tray which is thus from this cause only 98.56 percent efficient.

In a three-tray telescope a single particle travelling within the telescope solid angle will not be counted by the coincidence circuit if it passes through a counter in any of the three trays during dead time . Thus the inefficiency of the telescope from this cause alone is considerable. This is one of the main disadvantages of the external cathode type of counter, in which soda glass is used. The background counting rate is high due to the presence of radioactive potassium in the glass and thus losses of genuine cosmic ray particles due to the relatively large proportion of dead time may be quite considerable.

The degree of inefficiency will change with the length of dead time per pulse and so affect the coincidence counting rate. For this reason, efforts should be made to keep such changes within small limits and notes made in the equipment log when checks are made to allow the effects of such changes to be evaluated if later found necessary.

Inefficiency due to non-overlapping of counters. Counters are not overlapped in the trays, and thus in each tray some particles may traverse the counter walls between the sensitive volumes of adjacent counters and not be registered. If for particles within the telescope solid angle the probability of striking sensitive volume in each tray is p, then the probability of striking sensitive volume in all three trays is p^3. It is difficult to estimate p accurately, particularly when the solid angle of the telescope is large, but an approximate estimate in the present case is 0.96, leading to a probability of only 0.88 of a particle being registered in all three trays. As long as the counter assembly remains unchanged in the trays this degree of inefficiency is not serious - it merely means that the counting rate will be lower than could be obtained if overlapping counters were used in each tray. However, glass tubing of a nominal diameter and wall thickness may vary slightly in both these dimensions. Hence replacement of a counter in a tray may alter the effective sensitive area of the tray slightly and so alter the "geometrical efficiency" of the telescope. Times at which any counter replacements take place should be noted in the equipment log.

Count losses due to finite circuit recovery times. It usually happens in pulse-handling circuits whose input pulses are randomly distributed in time that there are one or more sections of the circuit incapable of responding to the second of two pulses separated by less than a certain minimum time interval, and thus count losses can occur.

In the present case, apart from the losses due to the recovery time at the grid of the primary counter valve already discussed, there is virtually only one point where further losses can occur. This is at the output of the pulse shaping circuit.

If two counters in a tray fire within 8 μsec. of one another, the second of the pulses will not be passed on from the shaping circuit with sufficient amplitude to cut off the coincidence valve.

If we assume the input pulse rate to the shaper to be a Poisson variable of mean 980/sec., then the expected mean count loss at the output is calculated to be approximately 0.8 percent. Actually the true mean loss will be less than this because close pulses from each of the 24 individual counters are previously suppressed by the effective counter dead time.

Scaling circuit and registers. The scaling circuit has a resolution time of 2 μ sec. Pulses from the preceding circuits cannot arrive at the scale input with time separations of less than this resolution time and hence there is no count loss at this point.

Similarly with the scale factors normally used (to be discussed below) the probability of two scale output pulses being fed to the mechanical register within the resolution time of the latter is extremely small, and the resultant count loss is entirely negligible.

The choice of an appropriate scaling factor for a particular experiment is made such that (a) the register count rate is relatively low, to avoid excessive wear and (b) the expected statistical fluctuations in the scaled count rate are still sufficiently large for the fractional content of the scale at the end of each hour to be safely ignored. It is most important that small errors due to neglect of the scale content do not show any systematic variation. They should show no serial correlation and should have mean value 0, and any particular value of the error should be equally probable for all hours.

Let N_i = number of coincidences recorded per hour

$\bar{N}$ = mean value of N_i

C_i = number of scaled counts recorded per hour

$\bar{C}$ = mean value of C_i

F = scale factor

then considering N_i to be subject to statistical fluctuations only, the variances of N_i and C_i are given by

$$V(N_i) = \bar{N} \qquad V(C_i) = \bar{N}/_{F^2} = \bar{C}/_F$$

and the standard deviations by

$$S.D.(N_i) = \sqrt{\bar{N}} \quad S.D.(C_i) = \sqrt{\bar{N}/_F} = \sqrt{(\bar{C}/_F)}$$

If a scale factor is chosen such that S.D.(C_i) is at least 2 then very little is gained by recording fractional counts present in the scale at the beginning and end of each hour, provided that the errors committed in neglecting these fractional counts are entirely random.

In the present equipment, the register lines are open-circuited for one minute of each hour, during which the scale is allowed to run on without interruption. Thus at the commencement of a 59-minute recording period, the scale contains some fraction of a register count, all fractions being equally probable and having mean value $\frac{1}{2}$. Similarly at the end of the 59-minute period, the scale also contains some fraction of a count, all fractions again being equally probable, with mean value $\frac{1}{2}$. The two fractions are virtually independent chance variables and hence there is no possibility of systematic errors being introduced by ignoring them.

If n_1 and n_2 are the fractions of a scaled count present at the beginning and end of a 59-minute recording interval respectively, and N is the number of register counts recorded in that interval, then the true number of coincidences is

$$F(N + (n_2 - n_1))$$

n_2 and n_1 being independent variables with rectangular frequency distributions and mean values = 0.5.

This has mean value FN

$$V(n_2 - n_1) = V(n_2) + V(n_1)$$
$$= 1/12 + 1/12$$

$$S.D.(n_2 - n_1) = 0.41.$$

Thus by suitable choice of F to give S.D. (N) $>$ 1 the value of the records will not be greatly affected by neglecting the scale content and any small amplitude systematic variations in cosmic ray intensity will not be observed.

KEEPING OF RECORDS

Record forms. Two types of printed form are used (Figures 18 and 19). The first (Form 106) is used for listing the actual register readings and the telescope azimuth positions for each hour. Separate sheets are to be used for the two telescopes. Subtraction of register readings from their previous values gives the hourly count totals and these are to be entered in the appropriate columns and checked against the master register readings.

The hourly totals should be examined carefully for indications of faulty equipment operation and the two separate telescope rates compared.

All results rejected because of equipment faults or for other reasons, are to be marked out and reasons for rejection stated at the bottom of the form, as well as in the main log book. It is strongly recommended that assessment of the reliability of data be carried out by the operator himself after careful examination of data and reference to log books and equipment test schedules. However, all relevant information relating to rejection of data should be recorded, in case future re-examination is considered desirable.

The figures should be plotted in sequence on the graph-sheets supplied. A plot of hourly mean barometric pressure should be made on the same sheet. This, together with information from the meteorological staff concerning times of passage of fronts, or marked changes in air mass temperatures, should indicate

Form 106.

AUSTRALIAN NATIONAL ANTARCTIC RESEARCH EXPEDITION

COSMIC RAY RECORDS

Station ____________ Geometry ____________

Telescope No. ____________ Absorber ____________

Zenith Angle ____________ Scale Factor ____________

DATE / HOUR G.M.T.						
01						
02						
03						
04						
05						
06						
07						
08						
09						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
Total						
Master						
01						
02						
03						
04						
05						
06						
07						
08						
09						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
Total						
Master						

FIG. 18. A.N.A.R.E. FORM 106: ACTUAL SIZE 13 in. x 8½ in.

Form 107

AUSTRALIAN NATIONAL ANTARCTIC RESEARCH EXPEDITION

COSMIC RAY RECORDS

Station________ Telescope No.________ Geometry________ TABULATED :-

Year________ Zenith Angle________ Scale Factor________

Month________ Absorber________

HOUR G.M.T. / DATE	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
01																																
02																																
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C.D.O.—1344

FIG. 19. A.N.A.R.E. FORM 107: ACTUAL SIZE 13 in. x 8½ in.

whether significant intensity fluctuations have occurred which are not apparently connected with meteorological factors. Any marked variations of this type should be reported by radio.

The final accepted hourly count totals should be transferred to the second form (Form 107). One form should be used for each telescope azimuth setting, and records from the two telescopes kept separately. On a similar form, hourly mean station-level barometric pressures are to be entered. These are to be taken from the station barograph traces after checking these with the three-hourly mercury barometer readings. The figures entered should be (pressure - 940 millibar), to the nearest millibar.

If one telescope is operating vertically, daily means of hourly count rate (to one decimal place) and daily mean values of barometric pressure (to 0.1 mb.) are to be computed and entered on the forms. These should be computed only if 20 or more hours' count rate records are available. (For incomplete days, only those hours of pressure data should be used which correspond with hours of available cosmic ray data).

For purposes of investigation of daily periodic variations in cosmic ray intensity, the maximum possible number of complete days' records is required. There will be occasions when one or two hours' records are lost - e.g. during the regular routine equipment tests. In order that these days, if otherwise complete and satisfactory, may still be used for daily variation analyses, it is considered desirable to interpolate figures. Under no circumstances should more than two hours' figures be interpolated. Choice of figures should be made by examination of the sequential plot so that the chosen figure lies on a smooth average curve fitted to points on either side. Any such interpolated figures should be indicated on Form 106.

All Forms 107 are to be made out in duplicate and one copy should always be kept in another building at the station to minimise the chances of loss of data in case of fire. The duplicate set of records is to be handed over to the relief operator at the end of each year.

Log books. A log book is to be kept in duplicate in which complete details of equipment operation are entered together with all relevant information which may have a bearing on the records. Any faults which develop in the equipment must be fully described, together with all details of methods of correction. Information on any matter which may assist future operators should also be included. One copy of the log is to be left with the equipment and the other returned to the Expedition Office at the end of the operator's tour of duty.

A section of the log book should be devoted to a record of the number of hours operation of individual circuit chasses and power supplies, and to a record of the behaviour of individual counters.

A separate log book should be kept, also in duplicate, containing relevant data on meteorological conditions, times of occurrence of magnetic storms and other important geophysical phenomena. Meteorological data should include times of passage of fronts and information from radiosonde flights on the mean atmospheric day to day temperature changes.

Forms are provided for the recording of results of the regular routine tests described in "Test Procedures". These should be kept in duplicate, one set being left with the relief operator and the other returned.

The importance and value of keeping complete and lucid log books and records cannot be over-emphasised.

TEST EQUIPMENT

Pulse generator and C.R.O. The C.R.O. and pulse generator (Figure 20) are separate units apart from a common power supply.

The C.R.O. time-base has 11 fixed velocities, permitting time intervals to be measured within the range of 50 m . to 0.2 μ sec. A switch is provided to give continuous free-running or triggered operation. The time switch indicates the time required for the spot to move ½" horizontally across the face of the tube. Frequency and synchronizing controls are provided to enable the time-base to lock in with any waveform applied to the synchronizing terminal.

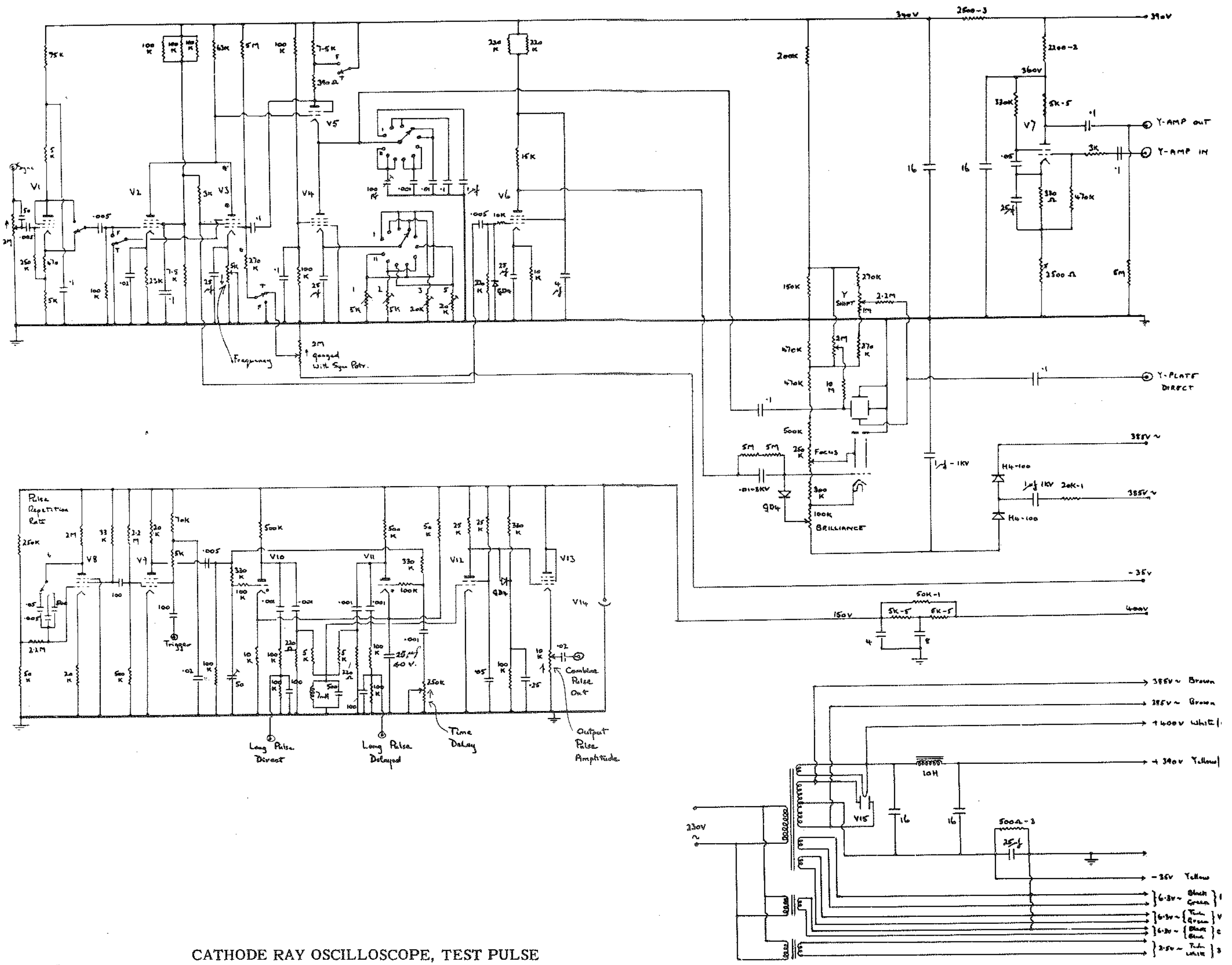


FIG. 20. CATHODE RAY OSCILLOSCOPE, TEST PULSE GENERATOR AND COMMON POWER SUPPLY.

The Y-plate amplifier response extends to above 1 mc/s at maximum gain. The calibration of the amplifier gain control refers to the peak-to-peak voltage at the amplifier input terminal required to give ½" vertical deflection at the face of the tube. The voltage required for the same deflection when connection is made to the Y-plate input terminal (amplifier output terminal disconnected) is 44v peak-to-peak. The picture on the tube is of the correct sign when the amplifier is in use.

The pulse generator produces facsimile 1-metre geiger counter pulses at repetition rates of 1, 20, and 400 pulses/second approximately. The facsimile counter pulse, termed the long pulse direct, is of 50v peak-to-peak, is negative-going, and has a fall time of 20 μ sec., and total duration of 350 μ sec. An identical pulse, termed the long pulse delayed, has the same repetition rate, but its onset may be delayed by the time delay control from 0 μ sec. to 50 μ sec. with respect to the start of the long pulse direct.

These two pulses are available at the appropriate terminals. In addition, each pulse is shaped by a ringing circuit to a width of 2 μ sec. The two shaped pulses are fed to a single line, are limited in amplitude and appear at the double short pulse terminal. This output is variable from 0 to 25v peak-to-peak. Due to the amplitude limitation, coinciding of the two pulses does not increase the output pulse amplitude.

The fourth terminal provides a trigger pulse for feeding to the synchronizing terminal of the C.R.O. section if it is required that the triggered stroke shall start slightly ahead of the long pulse direct. The trigger pulse is positive-going, is of 2v peak-to-peak and duration approximately 60 μ sec. It leads the long pulse direct by about 2.5 μ sec.

<u>Operation procedure C.R.O.</u> For observation of waveform of amplitudes between 1v and 50v peak-to-peak the amplifier will be required. Connect the waveform source to the amplifier input terminal, and connect the synchronizing amplifier output, and Y-plate input terminals together. The time-base switch may be either at trigger or free. If at free, adjust the time switch and frequency controls to give a suitable picture,

locking the trace with the synchronizing control. The synchronizing plus or minus switch is set as required. With symmetrical continuous waveforms, either position is suitable, but with unidirectional pulse waveforms, one position will be found more advantageous.

If trigger operation is required, switch to trigger, and turn the synchronizing control, which now becomes trigger sensitivity, anti-clockwise until the time-base ceases to run. A small clock-wise rotation will now look the trace. The synchronizing plus or minus control is important, as it determines the part of the waveform at which the time-base will start. The frequency control is not now used, and should be turned fully anti-clockwise, giving maximum length of sweep.

Waveforms of greater than 50v peak-to-peak should be applied to the Y-plate input terminal, which must be disconnected from the amplifier output terminal, but is left joined to the synchronizing terminal.

When the C.R.O. is used for observing waveforms in a circuit being fed from the pulse generator, the synchronizing terminal may be left connected as above, or joined to the trigger pulse terminal of the pulse generator, whichever is more convenient for observation.

<u>Operation procedure for pulse generator</u>. The long pulse terminals provide facsimile Geiger counter pulses and may be used instead of counters when pulse waveforms throughout the recording circuits are being examined. The output impedance is fairly high at these terminals, and the wave shape will suffer if connected across less than 1 megohm or so.

The resolution time between two trays of counters is measured by connecting the long pulse direct to one Geiger counter input in one tray, (the counter itself need not be disconnected, but the EHT should be switched off or turned below threshold) and the long pulse delayed to a similar point in the other tray. The least interval between the pulses which will not show two-fold coincidences <u>counted by the scaling system</u> is the resolution time of the system.

The short pulses are used to check the operation of coincidence and scaling systems at points where the original counter pulses have already been shaped.

The response time is measured by coinciding the two pulses, and then increasing the separation until the scaling system counts at double the rate. The response time is the least interval between the pulses which will double the count rate.

<u>Circuit description C.R.O.</u> The time-base is the conventional Puckle time-base, in which a capacitor C is discharged at a constant rate, and recharged to its original voltage at a much higher rate. The voltage across C is fed to the X plates of a C.R.O. tube, giving a linear scan, and a rapid flyback.

Referring to the simplified circuit, Figure 21, V4 is a pentode operating with fixed grid and screen voltages. Large variations of anode voltage have little effect on the anode current, and it will be regarded as a constant-current circuit element.

Consider C to be charged externally nearly to +HT potential and then connected across V_4. V_5 will thus be cut off, as its cathode will be nearly at +HT potential, and its grid at a much lower potential, due to conduction of V_3.

C will discharge at a constant rate through V_4, and V_5 cathode will eventually approach its grid potential. V_4 will now commence to draw current from the HT supply, and of course less from the capacitor, and a small voltage will appear across R_1. This voltage, applied to grid V_3, will cause a voltage rise at V_3 anode. V_5 will now conduct strongly, drawing almost all its current through C, and the voltage across R_1 becomes amply sufficient to cut off V_3. V_3 anode rises towards +HT potential, and C charges rapidly by cathode following action of V_5.

V_3 anode does not quite attain +HT potential, as some grid current flows in V_5. Eventually the anode-cathode voltage of V_5 is so small that the volts drop across R_1, is insufficient to cut off V_3, which reconducts, and cuts off V_5. C now discharges slowly through V_4, and another time-base sweep is in progress.

In the PG/CRO time-base, the discharge rates of C are set by a switch giving different values of constant-current level by biassing grid V_4. For any one switch position dv_0/dt is a constant, and hence a

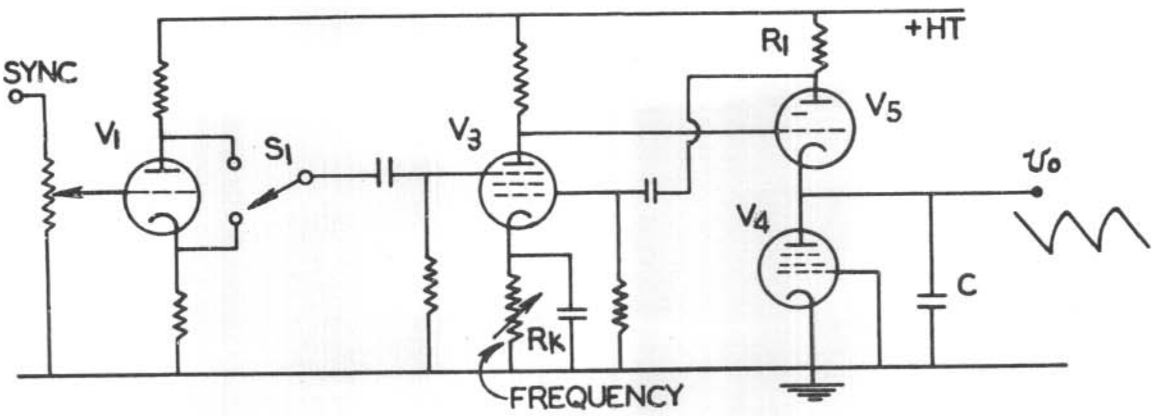


FIG. 21. SIMPLIFIED CIRCUIT OF CRO TIME BASE.

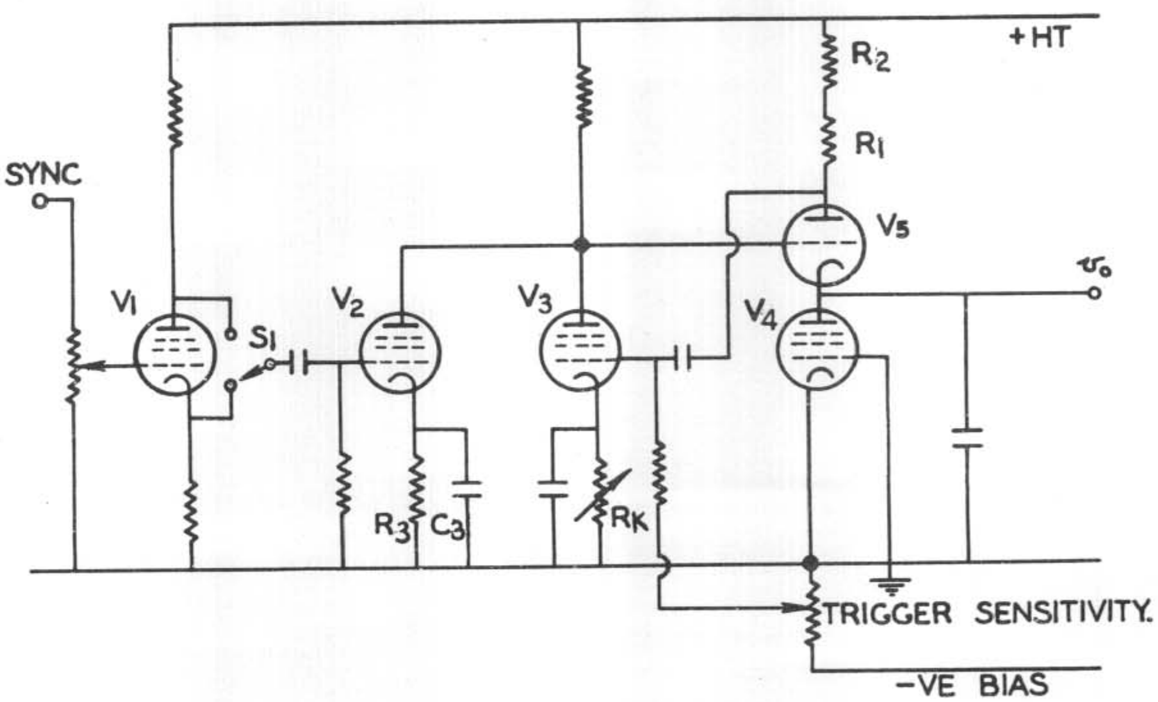


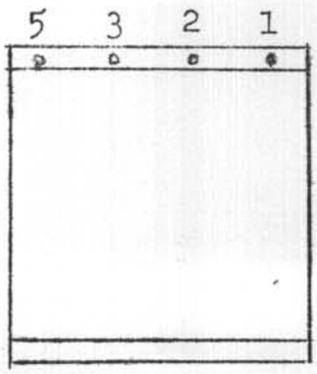
FIG. 22. SIMPLIFIED CIRCUIT OF CRO TIME BASE.

certain distance along the X axis on the screen is traversed in a certain time. In order to make the time-base run at any fraction or multiple of any frequency that may be applied to the Y-plates, the time-base frequency is made variable by altering the sweep amplitude. Halving the sweep amplitude of course doubles the sweep frequency. The frequency control is placed in the cathode of V_3, and sets the standing grid bias of V_3, and hence its anode potential. Increasing this potential by increasing R_K means that C will not have to discharge for so long before V_5 conducts, and initiates the fly-back, hence the sweep frequency is increased. dv_0/dt is of course unaffected.

As the time-base frequency range is from about 18 c/s to 180 Kc/s, or $10^4 : 1$, a constant-current level of 1 ma at 18 c/s would need to be 10 A at 180 Kc/s. Hence C is also switched by the time switch.

Switch positions are set out below:-

Switch Position	Pre-set R No.	C	Rate per ½" Unit at C.R.T.
1	1	1 µf	10 ms
2	3	.1 µf	3 ms
3	1	.1 µf	1 ms
4	3	.01 µf	300 µs
5	1	.01 µf	100 µs
6	5	.001µf	50 µs
7	2	.001µf	20 µs
8	1	.001µf	10 µs
9	5	100 µµf	5 µs
10	2	100 µµf	2 µs
11	1	100 µµf	1 µs



Physical position of pre-set R's, looking at rear of instrument.

Adjustment of the pre-set resistors, which set different constant-current levels of V_4, is given in the section on "Time-Base Adjustment".

For synchronizing purposes, a fraction of the signal voltage applied to the Y-plates is fed to the suppressor grid of V_3. Due to the shape of the Va/Vg_3 curves, the positive-going part of any wave has little effect, but the negative-going part causes a rise at V_3 anode, thus shortening the scan.

Adjustment of the frequency and synchronizing controls can make the time-base trip at the same negative-going point on successive waveforms, or group of waveforms, giving a stationary picture.

The sign of the synchronizing waveform may be inverted by S_1 (Figure 21) so that synchronizing will be possible when observing a series of positive-going pulses.

In the case of trigger operation, C is maintained fully charged, and commences to discharge through V_4 directly after the arrival of a voltage pulse at the synchronizing terminal. Another valve is added, the simplified circuit now appearing as in Figure 22.

On switching the trigger/free switch to trigger, V_3 grid is returned to an adjustable negative bias, which is set to a point sufficient to cut off the valve. V_5 grid therefore stands nearly at +HT potential (not quite, as a small grid current flows), and C is held charged to this same potential.

V_2, the added valve, is self-biassed to the point of cut-off, R_3 being of high value. The standing anode current of V_2 is so small that it may be neglected.

A positive-going pulse is necessary at the grid of V_2 to start the sweep. The pulses are applied at the synchronizing terminal, and if negative, are inverted by switching S_1 to V_1 anode instead of cathode.

The pulse causes V_2 to draw current, the current flowing via C_3. The common anode potential falls, cutting off V_5, and the sweep commences. V_2 and V_3 are neutral to one another, as each has a high differential anode resistance.

The current in V_5 anode resistance $(R_1 + R_2)$

ceases to exist, and hence V_3 grid receives a positive-going pulse, maintaining the common anode potential low whether the incoming pulse maintains or not.

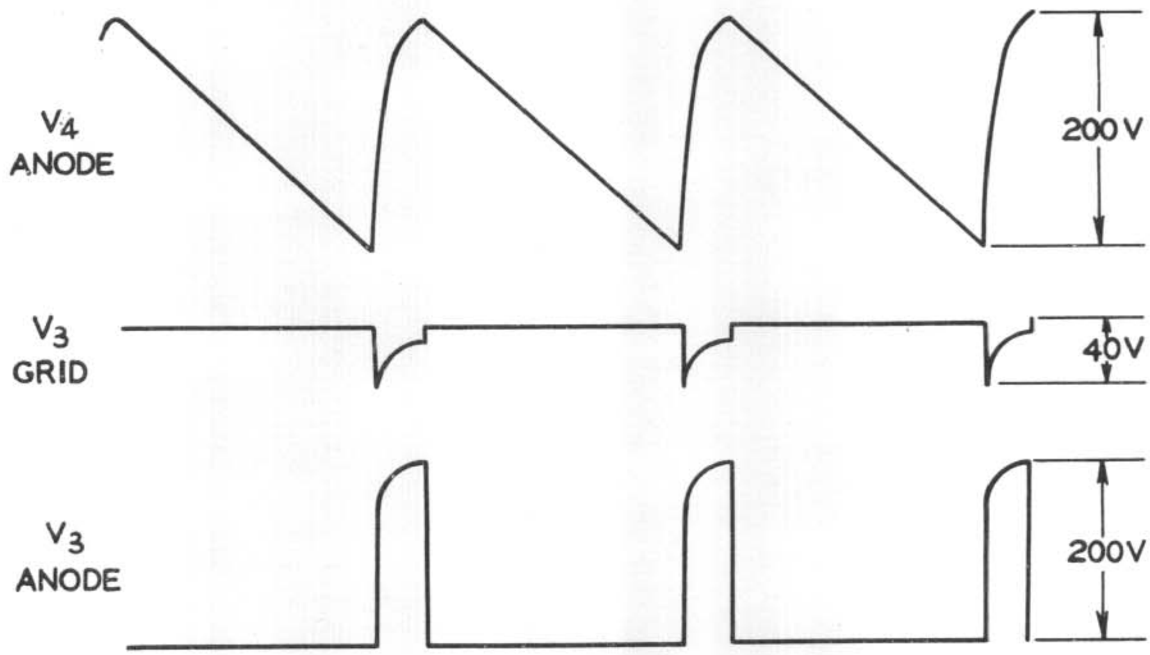
C continues to discharge through V_4, and eventually reaches a potential low enough to permit V_5 to reconduct. Current again flows in $(R_1 + R_2)$, cutting off V_3, whose anode potential rises. C now recharges at a high rate, and a very large negative pulse is fed to the grid of V_3. When C is recharged, this pulse disappears, but V_3 does not re-conduct due to the standing negative bias. V_2, in the absence of another triggering pulse, is always cut-off, and the circuit is back in its original quiescent condition.

It is necessary to increase R_1 by the addition of R_2 for the following reason. In the free-running condition R_1 may be quite small, as a pulse appears across it only during the flyback, when a heavy current is flowing through it due to C recharging. In the quiescent trigger condition the current through R_1 is less than the constant-current level of V_4, as some grid current flows in V_5. The pulse developed across R_1 when this current ceases would be insufficient to raise the grid of V_3 unless the trigger sensitivity control were advanced to a point where the time-base would free-run anyway. For satisfactory trigger operation it is necessary to increase R_1 by some 20 times, hence the addition of R_2.

The inclusion of R_2 greatly increases the re-charge time of C. This is not important, provided that the triggering pulse rate is not so great that the time-base will often be triggered again before C is fully recharged. If this occurs, the trace on the C.R.O. tube will jitter.

A circuit to suppress incoming pulses while C is recharging has not been included. If the ratio sweep duration/mean trigger pulse interval is very high as much information is obtainable from a free-running scan as from a triggered one. The synchronizing and the trigger sensitivity potentiometers are mechanically gauged, and are operated by the same spindle and knob.

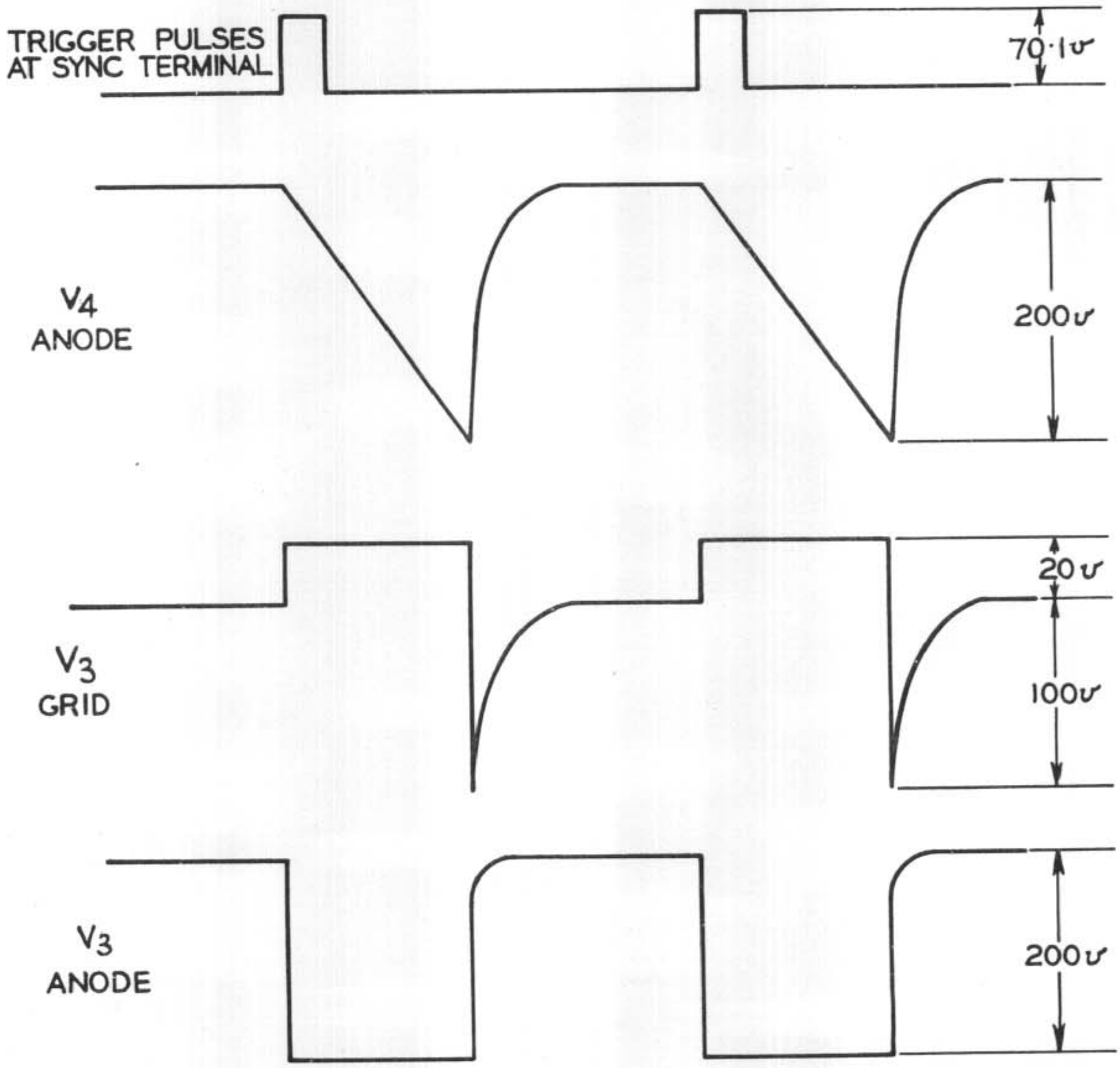
For beam suppression on flyback, V_6 (Figure 25) receives, under free-running time-base conditions, a positive-going pulse lasting the duration of the flyback, and is therefore biassed well back by a high value of R_4. A negative pulse therefore appears at the anode,



WAVEFORMS TAKEN ON EXTERNAL CRO

FREE RUNNING CONDITION.
FREQUENCY CONTROL AT MINIMUM.
TIME SWITCH IN POSITION 3.

FIG. 23.



WAVEFORMS TAKEN ON EXTERNAL CRO

FIG. 24. TRIGGERED OPERATION.

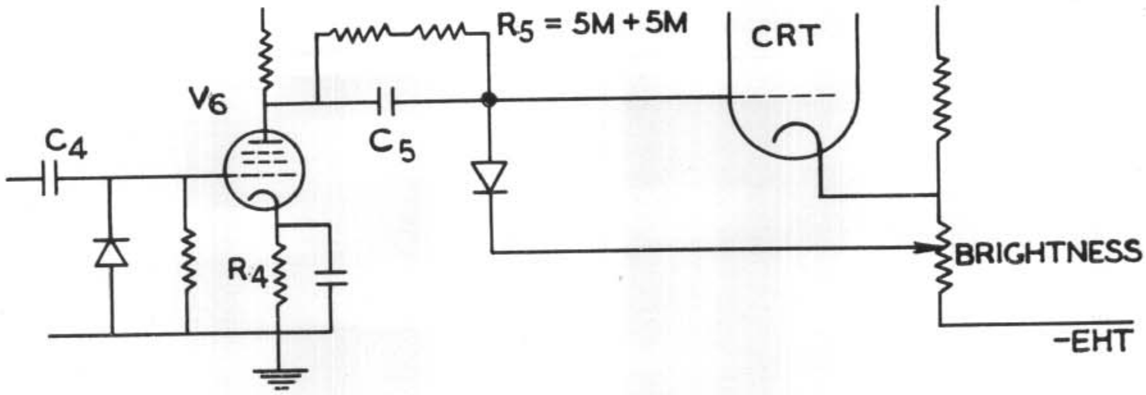


FIG. 25. BEAM SUPPRESSION OF FLYBACK.

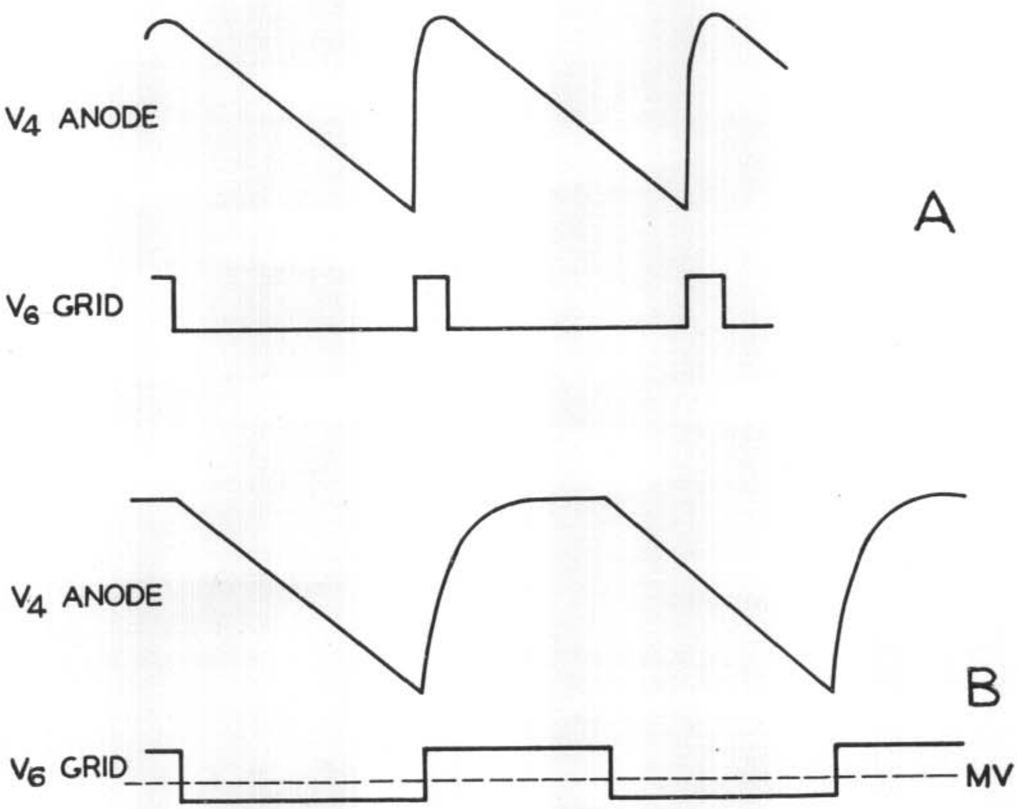


FIG. 26. WAVEFORMS. A. FREE RUNNING CONDITION.
B. TRIGGERED OPERATION.

which is fed to the cathode ray tube grid, suppressing the beam.

This state of affairs does not apply during trigger operation, unless the waveform at V_6 grid has its d.c. component restored. Considering some relative times, under free-running conditions the flyback time is about 1/10 of the sweep time. The waveform is as shown in Figure 26A, the mean value being practically the zero value, i.e. earth potential. Under trigger conditions V_3 is held cut off possibly for long periods, and V_6 grid has the waveform as in Figure 26B.

Here the mean value has moved up, due to the mean charge on C_4, and a smaller positive pulse affects V_6, as the part of the waveform below the mean value is below the valve cut-off point. A longer interval between sweeps would give scarcely any positive pulse at all. A diode is therefore placed between V_6 grid and earth which restores the charge on C_4 at each cycle, placing the mean value line on Figure 26B on the lower voltage edge of the waveform. The waveform amplitude is, of course, not affected.

A further diode is used between the CRT grid and cathode. Without this diode there would be severe hum modulation of the beam, due to the CRT cathode being affected by the hum ripple of the -EHT line, while the grid was held by C_5 to a steady point some 1100v above -EHT. A diode is therefore placed between the CRT grid and the slider of the brightness potentiometer, and arranged to be normally conducting by the current through R_5 (10M). The grid is therefore clamped to the brightness potentiometer potential, and, with the cathode, rocks up and down with the small EHT hum ripple, but the beam modulation is avoided. During the flyback, both diode and CRT beam are cut off. The resistance across which C_5 develops its negative voltage to cut off the beam and diode is the reverse resistance of the diode itself.

<u>EHT arrangement</u>. Figure 27 shows a voltage tripler, operating as follows: At the peak of the half-cycle from the transformer that makes D_1 cathode -ve, C_1 will be charged via D_1 and R to 2V volts. One half-cycle later the transformer end of R will be at -V volts with respect to earth, and C_2 will charge via R, C_1, D_2, and the lower half of the transformer to -3V volts.

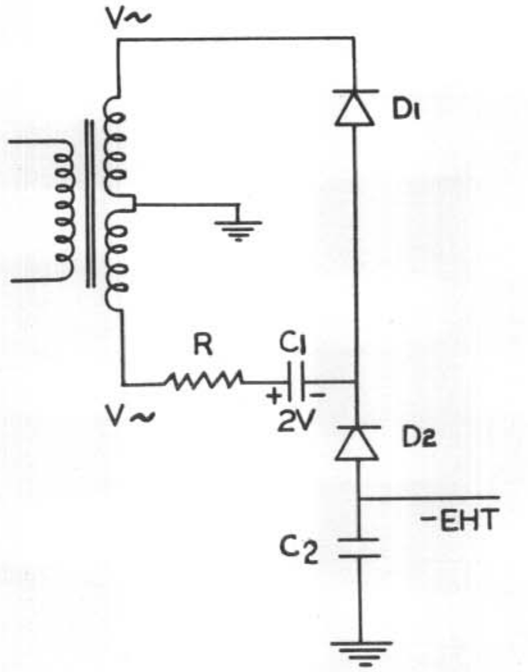


FIG. 27. E.H.T. ARRANGEMENT.

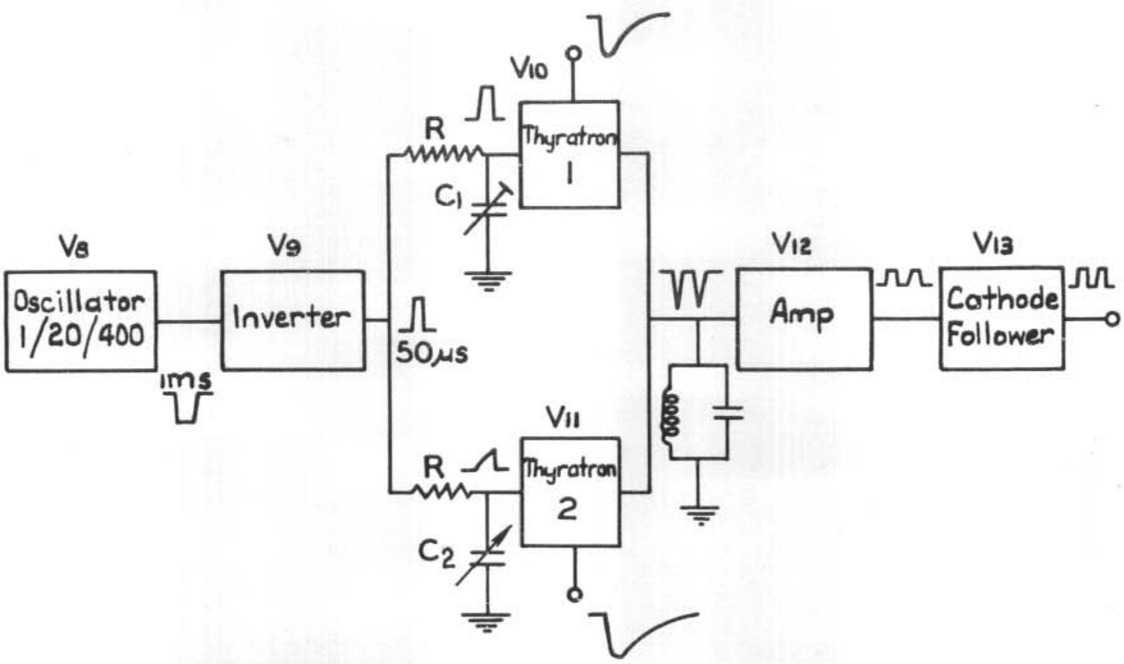


FIG. 28. SIMPLIFIED DIAGRAM OF PULSE GENERATOR.

The peak voltage across each half of the transformer (V) is about 450 volts hence C_2 would be charged to about 1350 volts. R is to limit the current through the rectifiers, and also serves to reduce the EHT to the required figure of 1100v. Its use, together with the large capacity of C_1 and C_2 (1 μf), makes further smoothing of the EHT supply unnecessary.

<u>Time-base adjustment</u>. The time-base constant-current levels are monitored by inserting a milliameter in the cathode of the constant-current valve.

The procedure is as follows:-

(1) Locate V_4, next to the focus control.

(2) Unsolder the orange lead to the time switch at the stand-off wire on Pin 5.

(3) Insert a 0 - 10 milliameter with the positive lead to Pin 5 and negative lead to the orange lead previously unsoldered.

(4) Adjust if necessary the potentiometers at the rear of the chassis, to give the following currents:-

Time Switch Position	Cathode Current (ma)
1	4.3
2	2.15
3	1.4
5	.86

The adjustments are made with the time-base free-running.
Keep to the same meter range throughout.

<u>Circuit description of pulse generator</u>. The oscillator produces square negative-going pulses of 1 msec. duration, at repetition frequencies of approximately 1, 20, or 400 per second (Figure 28).

The pulses are differentiated and fed to the inverter, from which a positive pulse of 50 μs. duration is obtained. The rate-of-change of the leading edge of these pulses is variable by a pre-set adjustment in the case of V_{10}, and continuously variable by C_2 in the case of V_{11}. The thyratrons are normally biassed off by a common potential. V_{11} may fire simultaneously with V_{10}, or later, depending on the setting of C_2. The maximum delay is 40 sec .

The anode pulses of the thyratrons are shaped to produce the facsimile counter pulses, available at the long pulse direct and long pulse delayed terminals. The pulses also are combined and differentiated by a tuned circuit, to a width of 2 μ sec ., and are fed to the amplifier V_{12}. The pulses at the amplifier anode are limited to a rectangular shape, and fed to the output amplitude control via a cathode-follower.

The oscillator is of the phantastron type, coupling between the screen and suppressor taking place across the cathode resistor.

Consider the circuit of Figure 29A, and the static characteristic of the circuit (not the valve alone) in Figure 29B. Point P corresponds to control-grid cut-off. At point Q the anode current is again zero due to V_K having become sufficiently large to bias off the suppressor. The region QS is unstable if the anode has coupling to the control grid, and an oscillator can be produced in this way.

The circuit then appears as in Figure 30A, with a set of specimen waveforms, Figure 30B.

At point 1, v_S is at maximum positive potential, and C is commencing to charge through R_K, the cathode-grid path, and R. i_a is zero, and v_a increases exponentially as C charges, whilst v_S moves in a negative direction, also exponentially.

The suppressor bias, v_K, follows v_S by cathode-following action of the triode cathode-grid-screen. Point 2 is eventually reached where i_a commences.

The action is now oscillatory, and i_a increases immediately to point x on the characteristic (Figure 30C). This point is unstable, and the working point jumps across to point 3. C now discharges through R_g, R_K, and the valve, these last two being shunted by R. The initial rate of discharge cannot be maintained, hence v_S moves in a positive direction, and v_a more rapidly in a negative direction, due to the gain of the valve. These movements can only take place as C loses charge, and the effect of

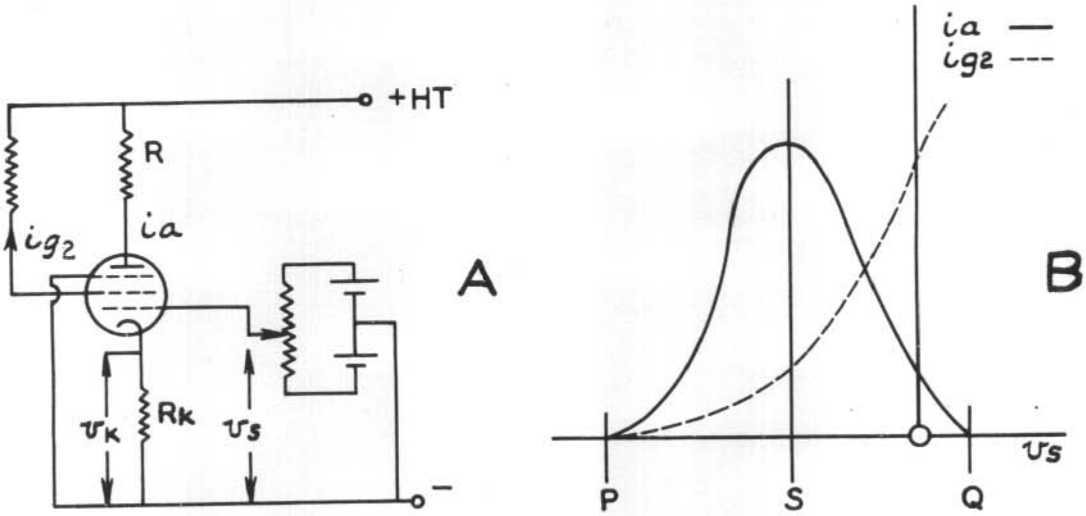


FIG. 29.

A. BASIC CIRCUIT OF OSCILLATOR.
B. STATIC CHARACTERISTIC OF CIRCUIT.

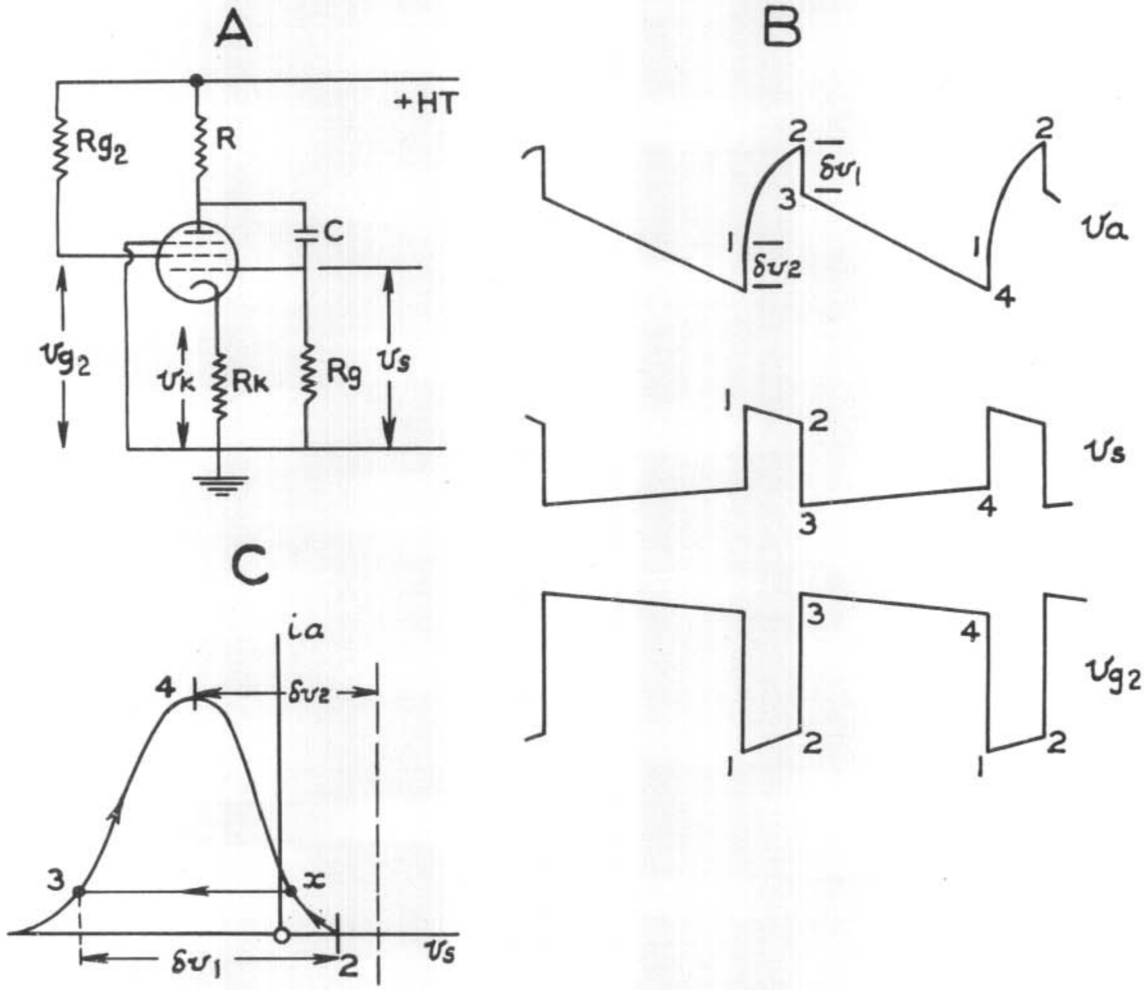


FIG. 30.

A. CIRCUIT OF OSCILLATOR.
B. SPECIMEN WAVEFORMS.
C. CHARACTERISTIC OF CIRCUIT.

COUNTER PULSE

COMMON ANODE LINE
(Tray Chassis)
300 ms/unit

(1) Counter pulses used.

(2) Facsimile counter pulses used.

RINGING CIRCUIT (Top)

2us/unit

(Counter or facsimile pulses)

CATHODE FOLLOWER OUTPUT

2us/unit

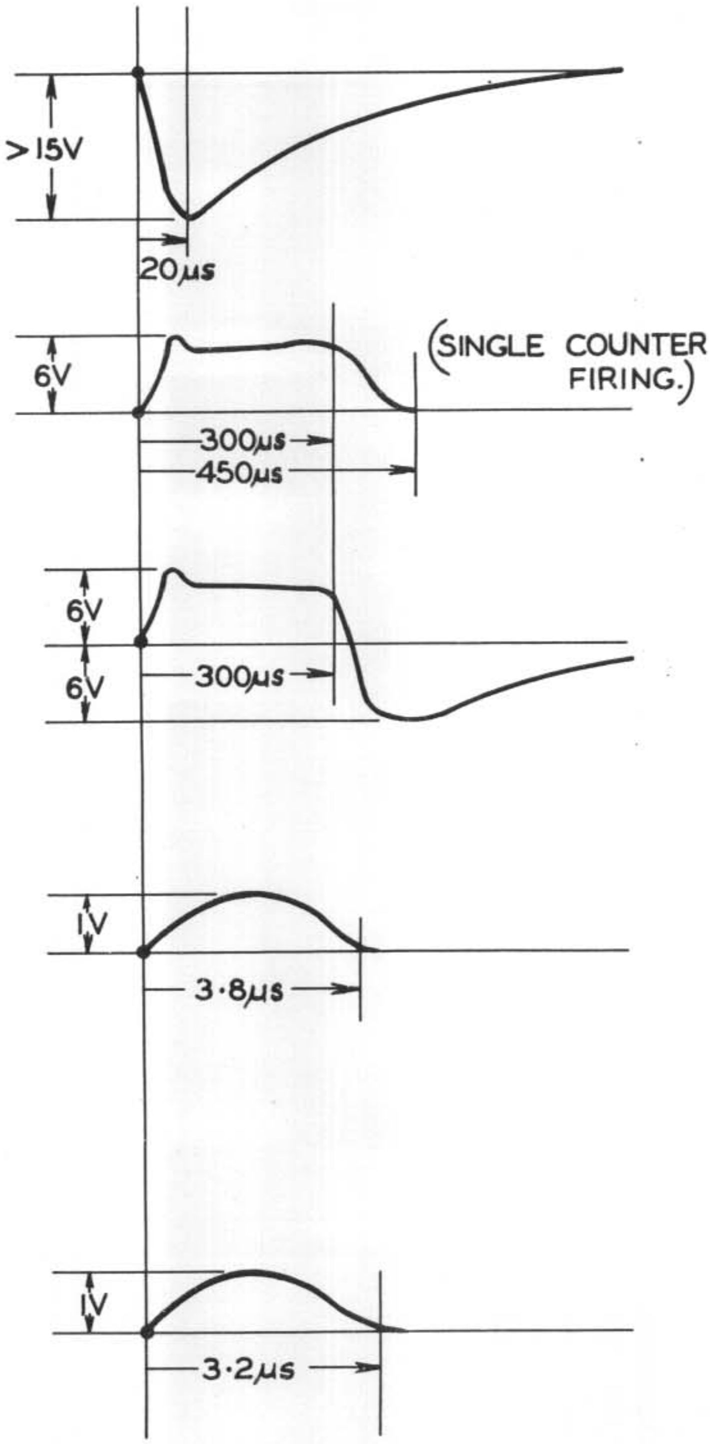


FIG. 31. RECORDING CIRCUIT WAVEFORMS TAKEN ON PG/CRO.

AMPLIFIER ANODE

(Coincidence Chassis)

CRO triggered from its amplifier input.

COINCIDENCE GRID

(1) Bias switch at ON.

(2) Bias switch at OFF.

COINCIDENCE ANODE

2us/unit

(1) One-fold.

(2) Two-fold.

(3) Three-fold.

DISCRIMINATOR CATHODE

2us/unit

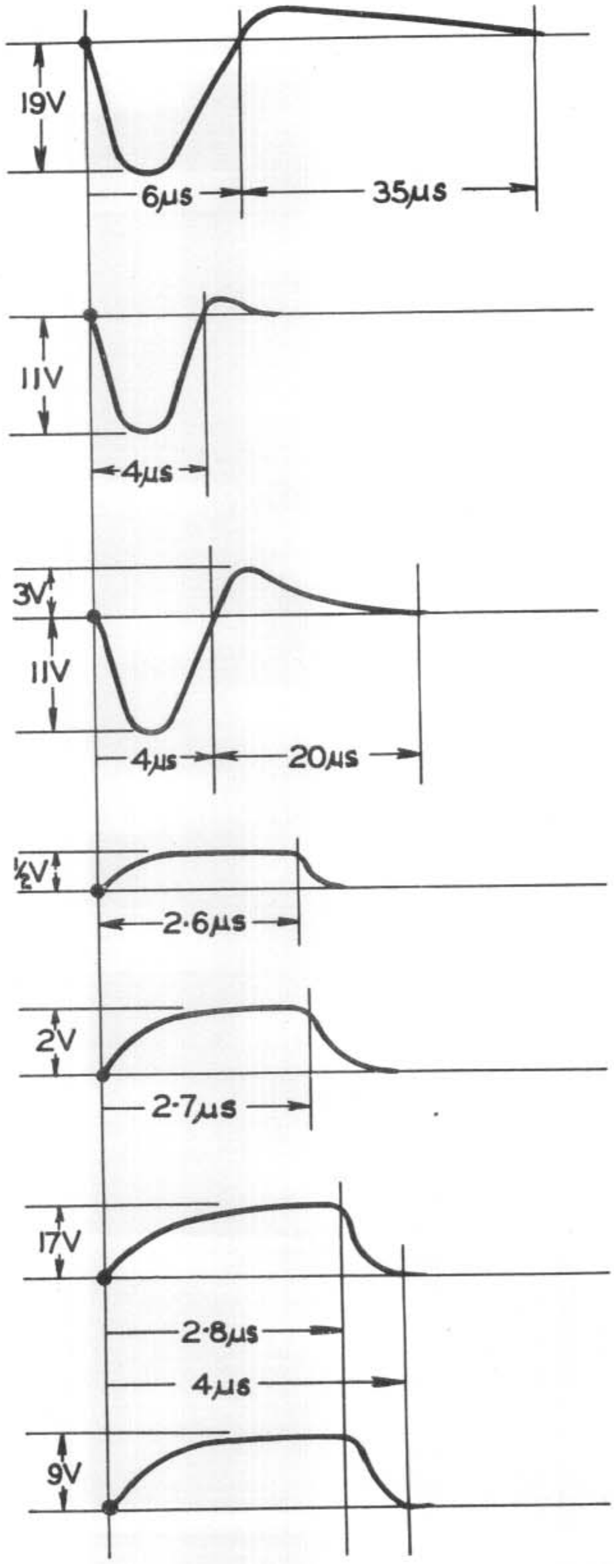


FIG. 31. (Continued)

ANODE OF SCALE INPUT AMPLIFIER

2us/unit

SUPPRESSOR OF FIRST SCALE PAIR

2us/unit

SUPPRESSOR OF FOLLOWING SCALE PAIRS

2us/unit

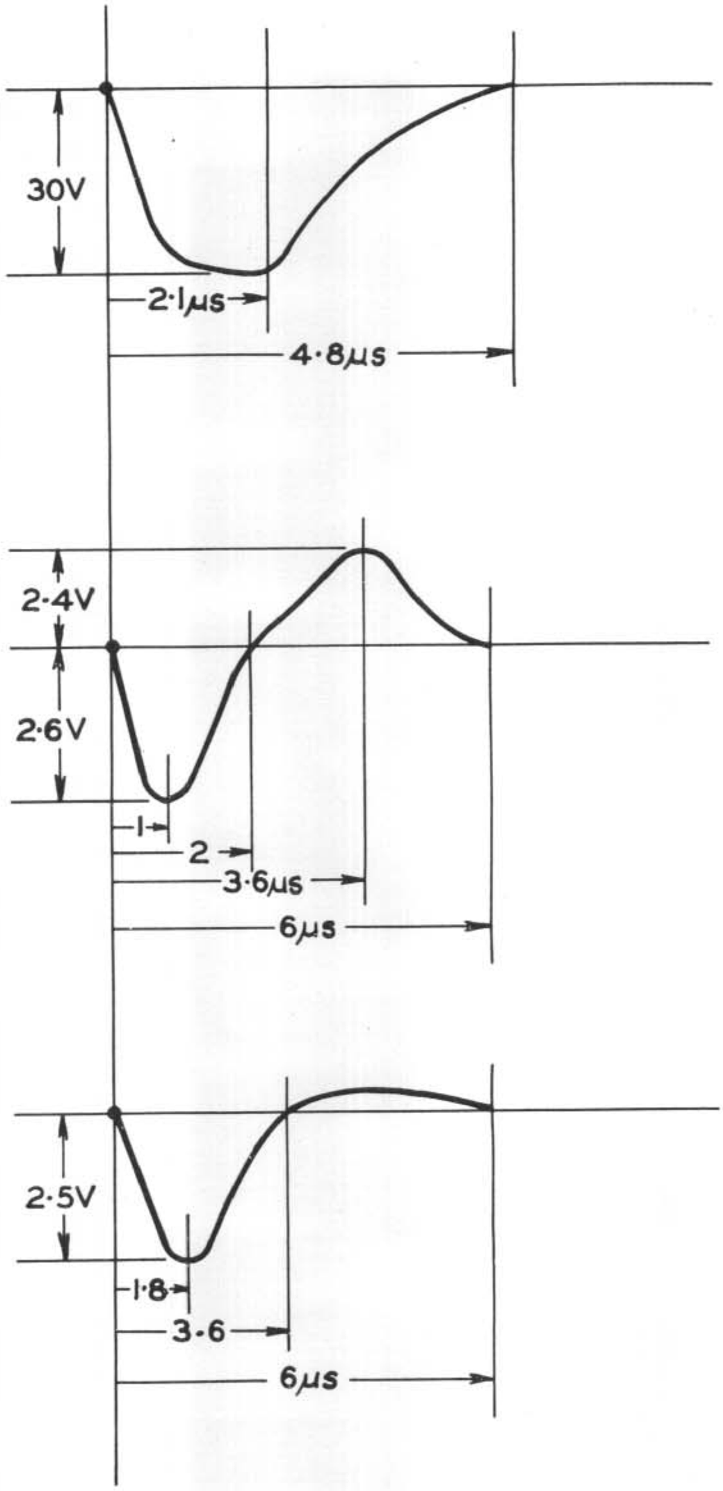


FIG. 31. (Continued)

the feedback, now negative, is greatly to increase the time-constant $C\,R_g$.

i_a increases until point 4 is reached, when oscillatory conditions again prevail, the working point transferring immediately to point 1. This point is a region of considerable grid-current, and C recharges as previously described.

The output is taken from the screen in the case of the pulse generator, and the negative-going edge (point 4 to point 1, v_{g2} waveform) cuts off the inverter stage, V_9.

The inverter is driven far below cut off, the grid rising after 50 μsec . due to the short time-constant coupling. The anode and screen waveform are thus rectangular, and positive-going.

The small screen waveform is fed to the trigger terminal for advance triggering of the C.R.O.

Thyratrons V_{10} and V_{11} are normally quiescent, the grids being returned to earth, and the common cathodes raised by 25v. The grids do not rise immediately with V_9 anode pulse, due to the integration of the couplings 330K - 50pf in the case of V_{10}, and 330K - 1000pf - 250K variable for V_{11}. The 50pf (max.) is semi-variable, and is adjusted so that V_{10} and V_{11} fire simultaneously when the 250K variable (the delay control) is at minimum delay, i.e. maximum resistance.

The chief energy source for V_{10} (or V_{11}) when firing, is the .001 capacitor with 220 Ohms in series. This capacitor discharges at a very high rate, not measurable on the C.R.O. The 884 anode resistor limits the anode current from the +150v line to a level which will not maintain ionisation, and conduction stops. The .001 capacitor now recharges, the 884 anode returning to +150v in about 2.5ms.

During this very brief period of conduction the 884 gas drop is about 20v, and the cathodes are permanently at +25v. Hence the anode fall is 105v. The waveform is differentiated, and a proportion fed to the long pulse terminal. The presence of the 100 pf capacitor makes this proportion rather less than half, and the long pulse is some 45v peak, and about 300 μs. duration.

The 100pf capacitor is added to reduce the rate-of-change of the pulse leading edge, thus more closely approximating that of a 1-metre counter.

105v also appears across the 220 ohm resistor at the instant of firing, i.e., a current of about 0.5 A from the .001. An additional 20 ma, flows through the 5K, charging the 500pf tuned circuit capacitor. These currents are of very brief duration, falling to zero in less than 1 μsec.

The tuned circuit capacitor discharges via the 7mH inductor, producing a negative-going half-sinusoidal pulse at the grid of V_{12}. The pulse amplitude is 6v, and duration 2 μsec. Each thyratron pulses the tuned circuit independently, the thyratrons being neutral to each other, 220 ohms being small compared with 5K. The pulse becomes 12v if both fire simultaneously.

The tuned circuit is slightly over-damped by the two 5K resistors, which appear in parallel from this point, but a smaller positive-going half-cycle would still appear. This is removed by V_{12} drawing grid current, thereby rapidly abstracting energy, and bringing the LC circuit to rest.

V_{12} operates at a screen voltage sufficiently high to reduce the anode voltage virtually to zero. This is done to remove any effect at the anode due to the slight positive grid excursion when damping the tuned circuit. V_{12} anode rise is limited, by conduction of a germanium diode, at 35v, the anode pulses being therefore generally rectangular, with slightly sloping leading and trailing edges, due to unavoidable circuit capacitance, and the need to conserve HT current.

V_{13}, the output cathode-follower, is conventional.

V_{14}, a VR150, is included to render the 150v line neutral to changes of power-pack voltage due to operation of the C.R.O. amplifier gain control, or time-base settings. The tube is fed, therefore, from the rectifier side of the smoothing choke.

TEST PROCEDURES

VOLTAGE AND CURRENT READINGS

Taken October, 1954, under quiescent conditions (EHT switched off) with meter of 20,000 ohm/volt D.C.

All voltages with respect to Earth.

	Reading	Meter Range
H.T. at junction box	200V	250V
Total HT current (measured in + line at junction box)	112.5ma	250ma
HT current to tray circuits (No.5)	14.9ma	50ma
(No.1)	16.2ma	"
(No.3)	14.7ma	"
H.T. current to coincidence chassis (B)	34.2ma	"
HT current to scale chassis (No.3)	32.4ma	"
Heater voltage at transformer	7.3V	10V AC
" " " tray circuits	6.5V	"
" " " coincidence chassis	6.7V	"
Heater voltage at scale chassis	6.6V	"

TRAY CIRCUITS

	Reading	Meter Range
Common anode potential	39V	50V
Screen voltages	16.5 - 22 V	"

COINCIDENCE CHASSIS (B)

	Reading	Meter Range
Amplifier anodes	130V	250V
" screens	85V	"
" cathodes	2V	10V
Coincidence trio anodes	$\simeq 0$	-
" " screens	55V	250V
VR54 limiter cathodes	15.5V	50V
Discriminator anode and screen	115V	250V
" cathode	11V	50V

SCALE CHASSIS (No.3)	Reading	Meter Range
Input tube anode	185V	250V
" " screen	85V	"
" " cathode	3.5V	10V
Scale pair anodes	28V, 110V	250V
" " screens	30 - 35V	50V
" " cathodes	16V	50V
Thyratron cathode	36V	50V
Voltage across 3 registers when thyratron is conducting	80V	250V

OVERALL COINCIDENCE RESOLVING TIME

Measured using facsimile counter pulse inputs at tray chasses — 2.5 µ sec.

RESPONSE TIME OF SINGLE CHANNEL

Measured by increasing separation of two facsimile counter pulse inputs in one tray chassis with coincidence circuit set to record "singles" until scale responds to second pulse of each pair — 8 µ sec.

SCALE INPUT SENSITIVITY Set at 2V

MINIMUM PULSE AMPLITUDE AT TRAY CHASSIS OUTPUT

Pulses just big enough for following circuits to respond — 0.2V

200 VOLT POWER SUPPLY

A resistor of 2500 ohm, 20 watt rating is connected between Pin 1, (HT^+) and Pin 5 of the output socket to form an artificial load. All voltages are taken with respect to chassis.

Item	Point	HT Switch On	HT Switch Off
5V4 Anode 1	Pin 4	320 v ~	323 v ~
" " 2	Pin 6	320 v ~	323 v ~
5V4 Cathode	1st 4 µf (blue lead)	400 v	480 v
6A3 Anodes	2nd 4 µf (white lead)	380 v	480 v
85A1 Anode	Pin 2	82.5 v	82.5 v
Output volts	3rd 4 µf (red lead)	200 v	<201 v
7C7 Grid	Pin 6	76 v	76 v

No measurable hum should appear on the 200 v line. The HT voltage may change slowly during the first 100 hours or so due to the 85A1 settling in. The ON - OFF stabilisation will not be affected. If an ON - OFF change of more than 5v occurs in the 200v line, change the 5V4 or the pair of 6A3's or both, as required.

The life of the 7C7 and 85A1 is likely to be better than 2000 hours, and will show by poor ON - OFF stabilisation with new 5V4 and 6A3's.

EHT POWER SUPPLY

The stabilisation against mains input voltage changes is such that no observable change in output volts occurs over the range 200 - 250 volt A.C. input.

Output volts range available	950 - 1440 volt
Volts across transformer secondary	1725 - 1740 RMS
Volts across 2 µf	1740 - 1900.

These measurements are made with a 2500 volt electrostatic meter and the ranges shown for the latter two refer to readings at minimum and maximum output volts settings.

TEST SCHEDULES

These are to be carried out regularly each fortnight. Results of all checks are to be entered on the forms provided. One copy of the results is to be brought back to Hobart with the log of work and one left with the new operator at the end of each tour of duty.

(a) Power supply check

Note and record (1) 200 v line voltage (2) EHT voltage (3) Heater voltage at transformer (4) HT current in + lead at junction box.

(b) Counter check

Remove covers from tray chasses. Check that counter pulses are present at each 7C7 grid. Adjust EHT if necessary to give a minimum of 15 v pulses and record new EHT.

(c) Tray strip valve check

Switch off EHT. Inject facsimile counter pulse from pulse generator to each 7C7 grid. Check that each valve produces the same pulse height (1 v) at the output socket.

(d) Resolving time check

Supply long pulse direct to grid of one valve in tray strip 1 and long pulse delayed to grid of one valve in tray strip 2. Switch off channel 3 at coincidence chassis and increase pulse separation until twofolds are no longer counted. Record the input pulse separation (resolving time). Repeat using channels 2, 3, with 1 switched off.

(e) Coincidence chassis check

Replace tray strip covers and switch on EHT. With the coincidence trio set to record threefolds remove each input plug in turn and check that removal of any one stops the scale from counting. Check waveforms at amplifier anodes and at coincidence grids. These should be very nearly identical in shape and amplitude. Check waveform at output socket (from discriminator). This should be $\simeq$ 9v.

(f) Scale strip check

Check input sensitivity using single short pulse from pulse generator. Record sensitivity and readjust if necessary to minimum input pulses of 2 v.
Inject single short pulses at 1 or 20/sec. and observe correct scaling.

DAILY ROUTINE

1. Wind chronometer.

2. Check chronometer against time signal from Station WWV.

3. Check contact cam on control chassis with minute hand of chronometer to ensure that cam operates correctly.

4. Check that counting is occurring on the correct registers.

5. Check correct orientation of telescope. Since no automatic record of azimuth sequence is kept, frequent checks are essential.

6. Read register bank up to date. Carry out subtractions immediately so that any faulty equipment operation may be seen, enabling correction of the fault to be carried out without further loss of recording time.

7. Examine chart recorder trace and reverse direction of chart drive if necessary.

8. Collect all relevant meteorological data.

9. Plot count rate and pressure figures.

CHASSIS PLUG AND VALVE BASE CONNECTIONS

Pin	Tray and Coincidence Chasses	Scale chassis	HT supply
1	HT +	HT +	HT +
2	HT - (E)	HT - (E)	-
3	)	230v AC	-
4	) heater	230v AC	-
5	) (E)	) heater	HT - (E)
6	)	) (E)	-
7	) heater	) heater	-
8	) (blue)	) (blue)	-

Pin	7C7	7C5	884	VR54	5V4G	6V6
1	H	H	Sh	Sh	-	-
2	A	A	H	H	H	H
3	G_2	G_2	A	$A(D_2)$	-	A
4	G_3	-	-	$K(D_2)$	A_1	G_2
5	I.S.	-	G	$A(D_1)$	-	G_1
6	G_1	G_1	-	-	A_2	-
7	K	K	H	H	-	H
8	H	H	K	$K(D_1)$	H.K.	K

Pin	85A1	QS83/3	6AC7	6SH7	3AP1	EL38
1	-	A	Sh	Sh	H	G_3
2	A	K	H	H	G_1	H
3	-	-	G_3	K	D_3(X)	-
4	-	K	G_1	G_1	A_1	G_2
5	-	A	K	K	D_1(Y)	G_1
6	-	-	G_2	G_2	$A_2 D_2 D_4$	-
7	-	K	H	H	H, K	H
8	K		A	A		K
						A(cap)

GD3, GD4 - red end cathode.

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