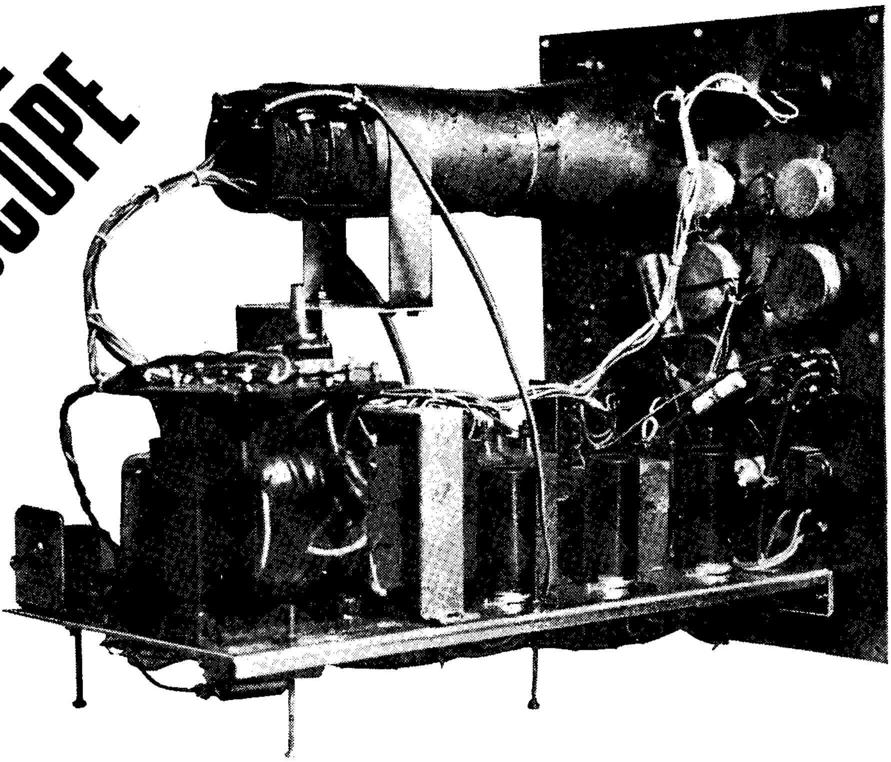
INEXPENSIVE OSCILLOSCOPE



By
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PART ONE

SPECIFICATION

Display tube
Electrostatically focused and deflected, 3in diameter screen, medium persistence green phosphor. Type 3BP1, 3EP1, or 3GP1.

Y amplifier
Input impedance 1MΩ, 30pF.
Maximum sensitivity approximately 200mV/cm.
Six-range attenuator with following steps:
(1) X1 0dB; (2) X3 10dB; (3) X10 20dB; (4) X30 30dB; (5) X100 40dB; (6) X300 50dB.
Response $\pm$3dB from 5c/s to 175kc/s, with a useful display gain up to 1Mc/s.

Time base and X amplifier
Time base switch provides the following ranges: (1) 100ms/cm to 10ms/cm; (2) 10ms/cm to 1ms/cm; (3) 1ms/cm to 10μs/cm; (4) 100μs/cm to 10μs/cm. The fine control gives adequate overlap between ranges.
The fifth position gives facilities for external signal input to the X amplifier while muting time base and sync signals.
With the time base on, the X amplifier gain gives a trace expansion of at least six times. With the switch in the external position the X amplifier has a maximum sensitivity of about 800mV/cm, and a response of 10c/s to 75kc/s $\pm$3dB, and a useful display gain up to 200kc/s.

Sync
Synchronising is continuously variable for all types of Y input signal. Switching allows an external sync signal to be applied if required.

Calibration
An internal calibration unit gives a square wave output at 50c/s with a mark/space ratio of 1 : 1, an amplitude of 1 volt peak to peak, and a rise time better than 5μs.

Power consumption
The total power consumption rom the mains is less than 50 watts.

Dimensions
The approximate overall dimensions are height 12in, width 9in, and depth 15in.

The following article describes an extremely useful and comprehensive oscilloscope which the writer has used extensively during the past few months and which has proved indispensable in practice and reliable in operation. This instrument should prove of particular interest to both the serious experimental amateur and the spare time radio or television serviceman. Those interested in audio equipment work would also find it very useful.

The oscilloscope was designed with a number of factors in mind. First, the circuit had to use all standard easy-to-get components and valves, while the cost had to be kept to a minimum. Second, the circuit had to be kept as simple as possible for ease of construction and be simple to set up, while maintaining the majority of useful features met with in much more expensive commercial instruments. Finally, it had to have reliability over a long period together with ease

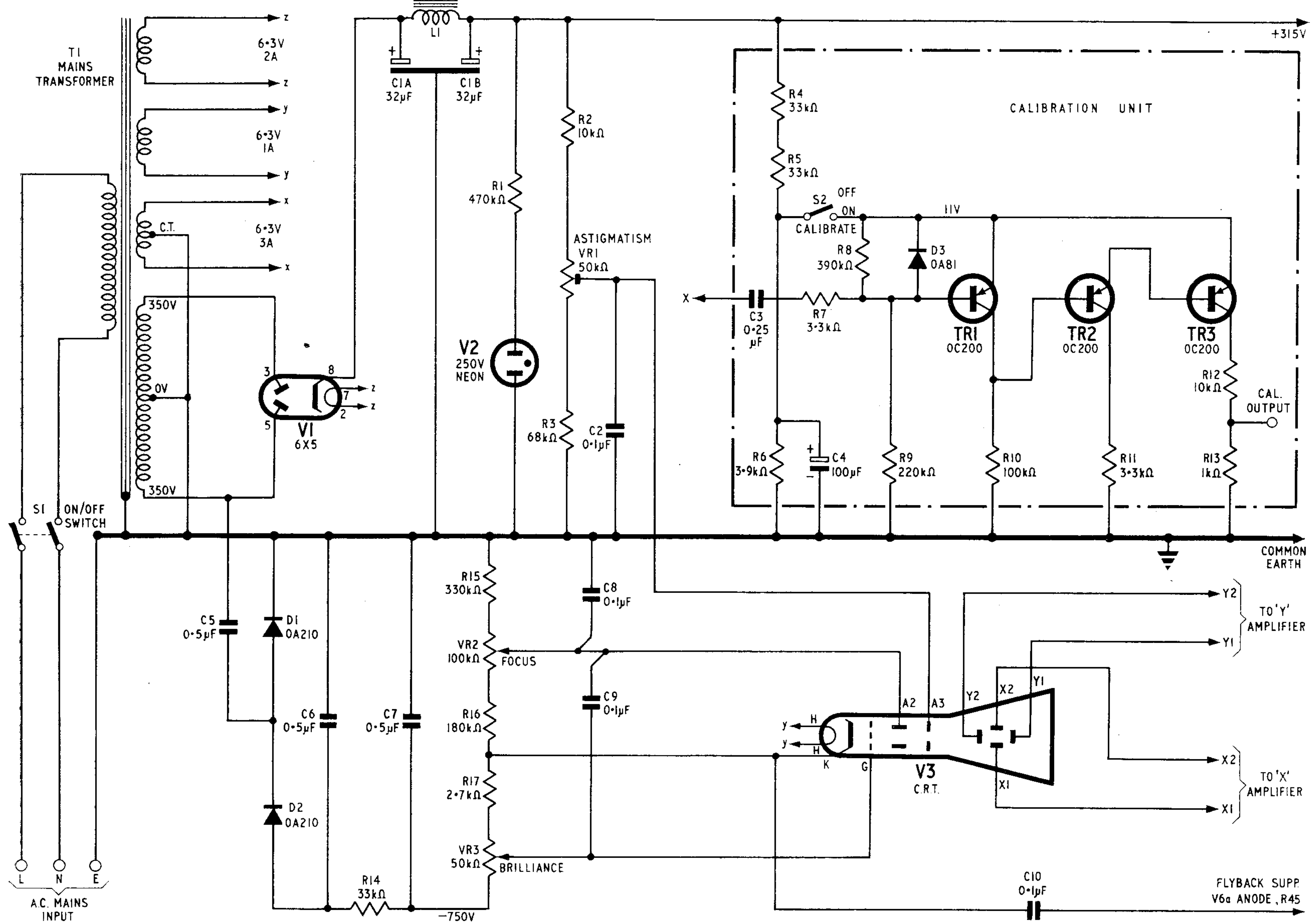
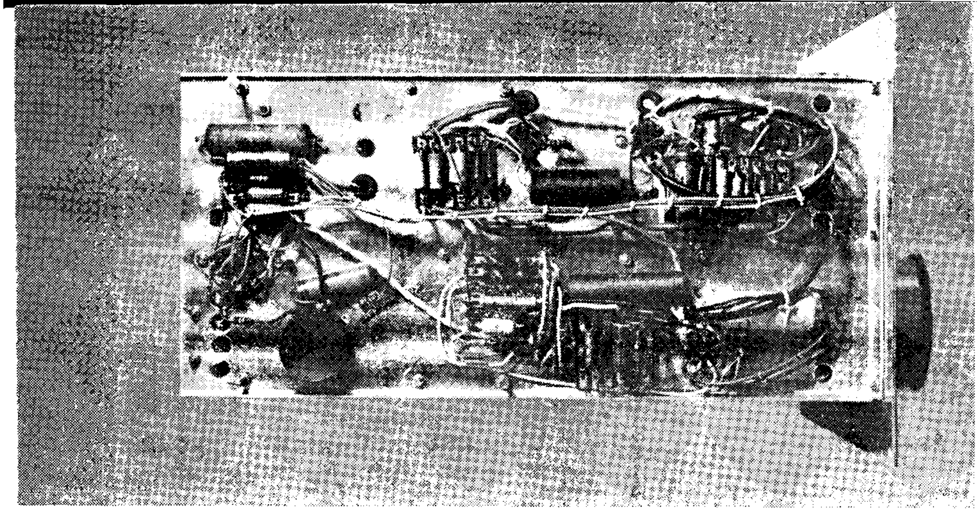


Fig. 1. The power supply section, the cathode ray tube and the calibration unit



Underside view of the completed instrument

and simplicity of servicing which meant that the number of different types of valves employed had to be kept to a minimum.

The circuit finally evolved after a considerable amount of work is shown in Figs. 1, 2, and 3 and is considered the best compromise between the various conflicting features mentioned above.

The instrument is built around a 3in tube with green trace and relatively short persistance such as the type 3BP1, 3EP1, or 3GP1. These are American surplus tubes and can be obtained at very reasonable prices although, as with all surplus equipment, the supply position does fluctuate from time to time and place to place. Any of these three tubes may be used quite satisfactorily in this instrument, the minor differences in characteristics being automatically taken care of during the setting up and calibration of the completed oscilloscope.

Only two types of valves are used in the 10 valve circuit: these are the cheap and easily replaceable double triodes ECC81 and ECC82.

A conventional h.t. and e.h.t. arrangement is used. The only high tolerance components used are in the Y attenuator and a few resistors in the Y amplifier.

PRINCIPAL FEATURES

The main design features include a six range Y attenuator in 10dB steps to 50dB, cathode follower input in both X and Y amplifier first stages, linear X and Y gain controls, and push-pull d.c. coupled outputs to the c.r.t. deflection plates. Both X and Y shift controls are d.c. coupled giving a positive shift action in both planes. A four range time base circuit with a fine control gives ample overlap between ranges.

Facilities are also available for external X input, the time base and sync circuits being muted in this position. The sync circuit also has switching facilities for external or internal use while the sync control locks the time base to the signal being displayed. The Y amplifier was designed to give the best compromise between gain and bandwidth in the number of stages available. The maximum sensitivity of 200mV/cm with a flat response to nearly 200kc/s and a useful display gain to over 1Mc/s should cover the majority of practical applications.

An internal transistor square wave calibration circuit is included, this being extremely useful for checking and setting up the Y amplifier. It also provides a useful time calibration check on the time base.

Finally, a pre-set astigmatism control is used to give optimum focus over the screen width.

Features which are not included and which are found in some of the more expensive commercial oscilloscopes are: stabilised h.t. and e.h.t. supplies, d.c. coupled Y amplifier with differential input, and extensive triggering facilities. While these features are obviously advantageous and increase the scope and usefulness of an instrument, it was not considered worthwhile to include them in the relatively simple and practical oscilloscope envisaged. Not only would their incorporation have increased the size and circuit complexity of the instrument, but the extra number of stages and power supplies to perform these functions would have made the oscilloscope prohibitively expensive for the amateur constructor and the advantages derived would be outweighed by the extra expense involved.

One other point which may be mentioned (though in the opinion of the writer it is a debatable one) is the inclusion of switching or plug facilities for direct external connection to the c.r.t. deflection plates. In practice the number of occasions when this feature is required are extremely rare. The stray capacitance due to the plugs or switching and the extra wiring involved all mean extra loading on the X and Y amplifier output stages with a resultant deterioration at the h.f. end of the amplifier response curves. For this reason this feature was not incorporated in the design though it could be included at negligible cost if required, but with consequent fall off in amplifier h.f. gain.

Before going on to the constructional details, a brief description of the various circuit functions will be of interest and will also help to clarify the working of the instrument and the uses to which it may be put.

POWER SUPPLIES

Fig. 1 shows the power supply section, the cathode ray tube, and the calibration unit.

The mains transformer T1 feeds the full-wave rectifier V1, and the pulsating d.c. output is smoothed by L1 and C1. The h.t. is at a potential of 315 volts.

Three heater windings are provided on T1: y–y for the c.r.t., x–x for the valves V4–V8 inclusive and z–z for the rectifier V1. The valve heater winding x–x is centre tapped—this is essential in order to reduce hum in the amplifiers to a minimum.

The e.h.t. is derived from a half wave voltage doubling circuit comprising C5, D1, and D2. The final output after smoothing by C6, R14, and C7, is in the region of minus 750 volts with respect to earth.

As A3 is fed from the astig. control VR1 connected in a divider network across the h.t. supply, this means that approximately 1kV is applied across the c.r.t. The e.h.t. divider chain R15–VR3 provides the necessary voltage levels for the tube electrodes, VR2 being the focus control and VR3 the brilliance control.

Adequate decoupling is provided against spurious signal pick-up by means of C2, C8, and C9. Flyback suppression is applied to the tube cathode via C10 which provides d.c. isolation between the two circuits. A large positive-going pulse (about 60 volts peak) is applied via this capacitor from the time base circuit during the flyback period, and drives the cathode positive with respect to the grid so cutting the tube off during this period.

Another divider chain across the h.t. line, R4–R6, provides a suitable low voltage supply for the transistor calibration circuit, the large capacitor C4 providing extra smoothing. A small neon tube V2 shows when the h.t. is switched on. The warming-up period is less than a minute.

The low voltage supply for the transistor calibration unit is taken via S2 to the common positive supply line for this circuit. This supply is about 11 volts.

COMPONENTS . . .

Resistors

R1	470kΩ	R32	1MΩ 5% H.S.
R2	10kΩ	R33	10kΩ 5% 3W
R3	68kΩ	R34	220Ω
R4	33kΩ 1W	R35	1MΩ
R5	33kΩ 1W	R36	1MΩ
R6	3·9kΩ	R37	10kΩ
R7	3·3kΩ	R38	10kΩ 5% 3W
R8	390kΩ	R39	10kΩ 5% 3W
R9	220kΩ	R40	1·8kΩ 5%
R10	100kΩ	R41	10kΩ
R11	3·3kΩ	R42	1MΩ
R12	10kΩ	R43	120kΩ
R13	1kΩ	R44	1MΩ
R14	33kΩ 1W	R45	33kΩ
R15	330kΩ 1W	R46	1kΩ
R16	180kΩ 1W	R47	1MΩ
R17	2·7kΩ	R48	4·7kΩ
R18	1MΩ 5% H.S.	R49	220kΩ
R19	5·6kΩ 5% H.S.	R50	2·2MΩ
R20	6·8kΩ 5% H.S.	R51	2·2kΩ
R21	1MΩ 5% H.S.	R52	47kΩ 1W
R22	10kΩ 5% H.S.	R53	33kΩ 1W
R23	1MΩ 5% H.S.	R54	4·7kΩ
R24	39kΩ 5% H.S.	R55	1MΩ
R25	120kΩ 5% H.S.	R56	10kΩ
R26	1MΩ 5% H.S.	R57	33kΩ 1W
R27	10MΩ 5% H.S.	R58	33kΩ 1W
R28	100kΩ 5% H.S.	R59	2·7kΩ
R29	680 kΩ 5% H.S.	R60	10kΩ
R30	1MΩ 5% H.S.	R61	1MΩ
R31	390kΩ 5% H.S.	R62	120kΩ

All 10% ½W unless otherwise indicated

Potentiometers

VR1	50kΩ wire wound, linear
VR2	100kΩ carbon or wire wound, linear
VR3	50kΩ carbon or wire wound, linear
VR4	25kΩ wire wound, linear
VR5	25kΩ wire wound, linear
VR6	1MΩ carbon, linear
VR7	2MΩ carbon, linear
VR8	25kΩ wire wound, linear
VR9	25kΩ wire wound, linear

Capacitors

C1a	32μF } dual elect.	C14	2μF paper 350V
C1b	32μF } 450V	C15	220pF silver mica 250V
C2	0·1μF paper 350V	C16	0·1μF paper 150V
C3	0·25μF paper 150V	C17	0·02μF paper 350V
C4	100μF elect. 25V	C18	15pF silver mica 350V
C5	0·5μF paper 750V	C19	15pF silver mica 350V
C6	0·5μF paper 1,000V	C20	2,000pF paper 350V
C7	0·5μF paper 1,000V	C21	1,000pF paper 250V
C8	0·1μF paper 500V	C22	0·01μF paper 250V
C9	0·1μF paper 500V	C23	0·1μF paper 250V
C10	0·1μF paper 1,000V	C24	1μF paper 250V
C11	0·25μF paper 750V	C25	0·05μF paper 500V
C12	16μF elect. 350V	C26	16μF elect. 350V
C13	0·025μF paper 150V	C27	0·5μF paper 350V

Switches

S1	D.P.S.T. toggle
S2	S.P.S.T. toggle
S3	2 pole, 6 way rotary
S4	S.P.D.T. toggle
S5	2 pole 5 way rotary

Valves

V1	6X5
V2	miniature neon lamp, 250V
V3	3BP1, 3EP1, or 3GP1
V4	ECC81
V5	ECC82
V6	ECC81
V7	ECC82
V8	ECC82

Semiconductors

D1	OA210
D2	OA210
D3	OA81
TR1	OC200
TR2	OC200
TR3	OC200

Inductors and Transformers

L1 Smoothing choke, 20H 50mA

T1 Mains transformer. Primary 230–250V. Secondaries: 350-0-350V 60mA; 6·3V 3A, centre tapped; 6·3V 2A; 6·3V 1A. (Radiospares "Heavy Duty" type with extra heater winding wound on)

Miscellaneous

Five B9A valve holders and screening cans. One I.O. valve holder. Seven OZ sockets and plugs. One coaxial socket. Grommets, tag boards and tag strips. Mu-metal shield and base for c.r.t.

CALIBRATION UNIT

The input sine wave signal to the calibration circuit is taken from one end of the heater supply "x" through the isolating capacitor C3 and limiting resistor R7 to the base of the first transistor TR1. Here the signal is clipped by the base-emitter diode action of this transistor and the diode D3. To achieve symmetrical clipping TR1 is suitably biased by R9 which in effect controls the mark/space ratio to a certain extent. The output developed across the load resistor R10 is a symmetrical semi-square wave.

The transistors TR2 and TR3 form a cascade amplifier (sometimes called an alpha plus pair) having an extremely high gain. The output developed across R12–R13 is a symmetrical square wave having a fast rise time (5μsec) as this part of the amplifier is driven between its fully bottomed and fully cut-off conditions.

The reason for the tapped load is that the signal amplitude available is the full supply voltage (11 volts) which is rather high for practical applications. Only that part of the signal across R13 is actually used, this being the ratio of the divider resistors to the supply voltage, in this case one-eleventh of 11 volts. This means that a calibration signal of 1 volt peak to peak is available at the output terminal.

Y AMPLIFIER AND ATTENUATOR

The circuit of the Y amplifier and the input attenuator is given in Fig. 2. Input is coupled via the isolating capacitor C11 to the attenuator switch S3. In position 1 the input is fed directly to the grid of the first stage, V4. In the other five positions tapped potentiometers are brought into circuit, the values of the resistors being so arranged to give increasing values of attenuation up to a maximum of about 50dB or X300 sensitivity. This means, for example, that in the sixth position the maximum sensitivity will be approximately 300 $\times$ 200mV/cm, or 60 volts/cm.

The first stage of the amplifier V4a is a cathode follower which gives a high input impedance with a low output impedance so ensuring good isolation between the input circuit and output. The cathode load is a potentiometer VR4 which constitutes a linear Y gain control, maximum sensitivity occuring when the slider is at the cathode end of the potentiometer.

Output from the slider of VR4 is coupled to the input of the second amplifier stage V4b through C12. This half of the double triode operates as a conventional amplifier with a relatively low anode load to increase the h.f. response.

It must be noted that the decoupling capacitor C13 across the bias resistor R34 is quite critical, having a noticeable effect on the amplifier response; too low a value gives rounding of the corners on a square wave signal while too high a value gives overshoot.

The output of this stage is coupled via C14 to the input of the cathode coupled push-pull output stage V5a,b. Here again relatively low values of anode load are used to maintain the overall h.f. response. A certain amount of negative feedback is also obtained through the common bias resistor R40.

The Y shift control VR5 applies a variable d.c. voltage to the valve grids. Altering this control changes the bias level on the grids in opposite directions, i.e. as one grid is made more negative the other is made correspondingly positive. Both stages can therefore be swung over their full characteristic by means of this control, the anode voltages changing in accordance with the change in grid voltage.

The grid of V5b is effectively decoupled against stray pick-up and ripple by means of C16, while the small capacitor C15 provides h.f. compensation. The outputs to the Y deflection plates of the c.r.t. are directly coupled from the anodes of V5.

The large value coupling capacitors C12 and C14 were necessary to give a good l.f. response; though the long time constants involved give a slight delay in signal response (most noticeable when the Y gain is altered with a sudden jerk) this action is unavoidable if a good l.f. response is to be maintained. This is one of the problems which would be obviated if a d.c. coupled amplifier were used.

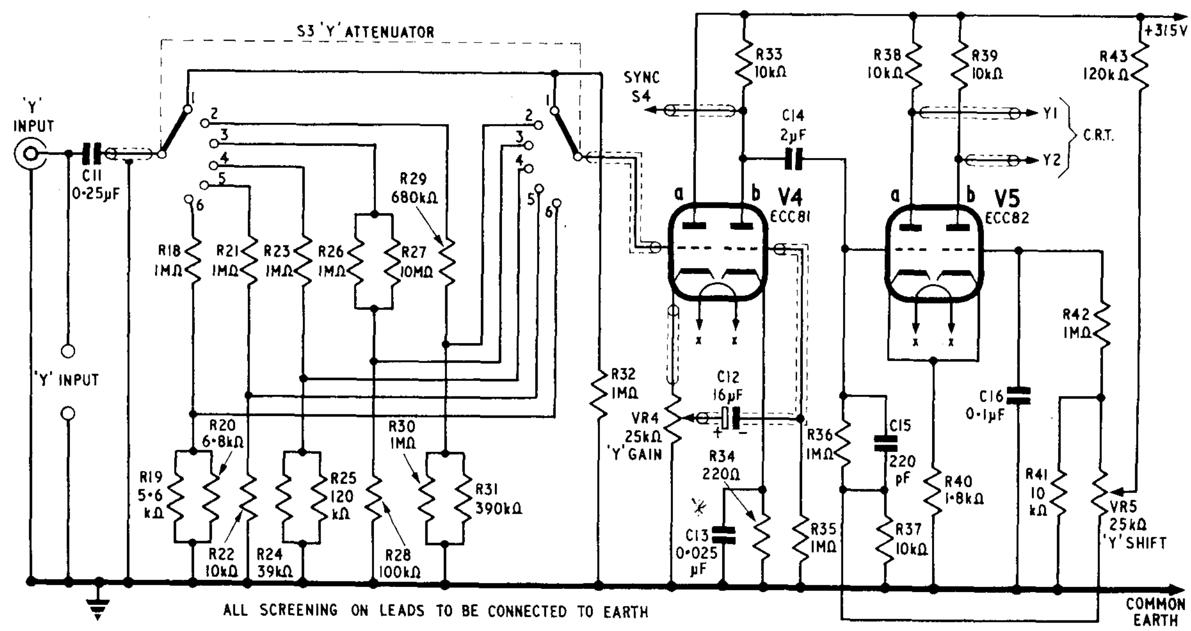


Fig. 2. The circuit of the Y amplifier and the input attenuator

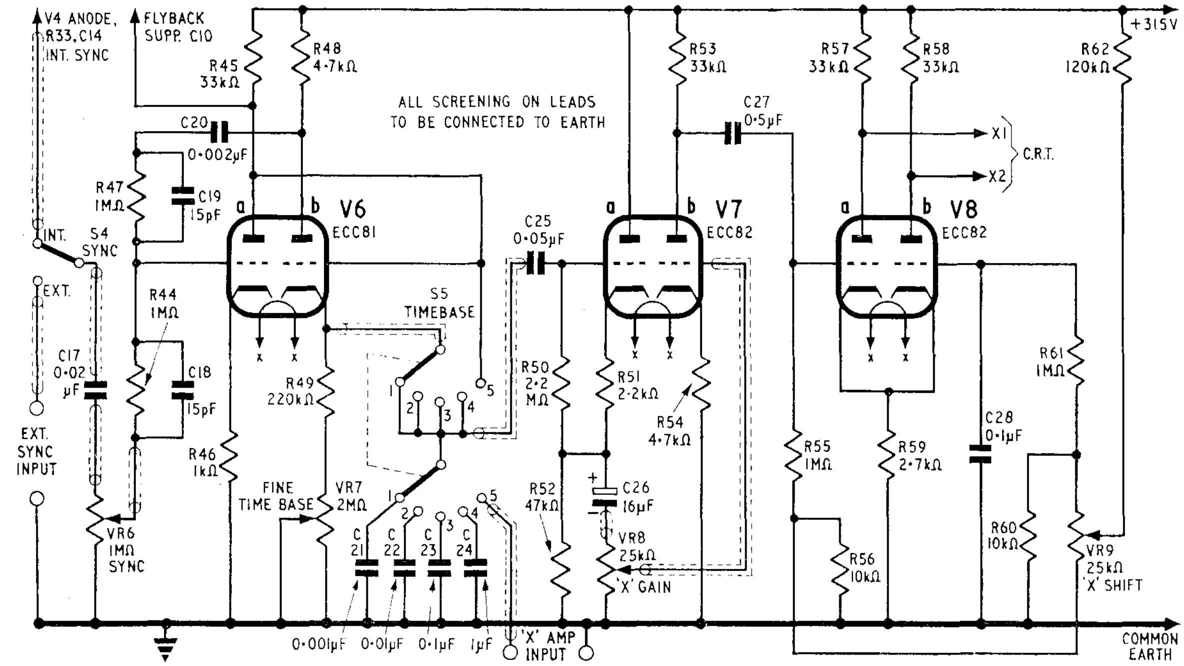


Fig. 3. Time base generator and X amplifier circuit

TIME BASE AND X AMPLIFIER

Fig. 3 gives the circuit of the time base generator and the X amplifier.

The synchronising and time base generator functions are carried out by V6a,b which is simply a rather unorthodox form of multivibrator or flip-flop circuit. The saw-tooth waveform is dependent upon the charge and discharge of the capacitors C21–C24 through the multivibrator action. The waveform at the anode of V6a takes the form of a series of short time duration sharp positive-going pulses which correspond to the flyback period, thus the capacitor is rapidly charged during this period as V6a will be cut off and V6b will be conducting as its grid is d.c. coupled to the anode of V6a.

Having charged the capacitor the circuit reverts to its original position through the coupling C20, R47. The whole of this action is very rapid. The circuit must now wait until the charged capacitor has discharged via R49, VR7, this being the scan period whose time is principally determined by the time constant C21–C24 selected by S5 the coarse control and VR7 the fine control. When the capacitor is discharged the complete sequence is repeated, the action being repetitive. The output therefore obtained at the cathode of V6b is an extremely linear saw-tooth waveform, the linearity being improved by the bias resistor R46 which allows the slightly non-linear portion of the discharge curve to fall in the cut-off portion of the valve characteristic.

A secondary advantage of the circuit is that the sharp positive-going pulse at V6a anode can be conveniently applied to the c.r.t. cathode and so ensure effective flyback suppression. By applying an external signal to the grid of V6a the multivibrator action and thus the time base can be locked or synchronised to this signal. This synchronising signal is derived from the Y amplifier or externally, depending upon the position of S4. It is fed through the isolating capacitor C17 to the sync control VR6. This control allows the amplitude of the incoming signal to be set until the signal and time base are effectively locked.

The saw-tooth signal obtained at the cathode of V6b is taken through the switch S5 to the cathode follower V7a. The last position on S5 allows an external signal to be fed into V7a, while at the same time V6b is short circuited, this stopping the time base generator and muting the sync signal. In this manner the time base/sync circuit is prevented from interfering with the external signal being applied to the X amplifier due to stray coupling across the switch and associated wiring.

The cathode follower V7a serves the same function as the cathode follower in the Y amplifier, the output signal being developed across the load R51, with R52 providing the necessary bias. The signal is coupled via C26 to the X gain control VR8. With S5 set to one of the time base ranges, VR8 serves as an X expansion control allowing an effective screen diameter of at least six times to be obtained. This feature allows small parts of a composite signal to be displayed on a much larger scale. With an external X signal applied VR8 serves as a straightforward gain control.

The output from this control is applied to the grid of V7b which is a conventional amplifier. A large value bias resistor R54 is used in order to maintain maximum linearity. The output of this stage is coupled via C27 to the cathode coupled push-pull output amplifier V8a,b. This is a similar circuit to that incorporated in the Y amplifier.

It will be found in practice that a slight non-linearity may occur on the very slow sweep speeds, this is partly due to the time base and partly due to the fall off in l.f. response in the X amplifier. This effect can be obviated by increasing the X gain until the small non-linear part of the trace "disappears" off the edge of the tube face.

Next month: Details of the construction will be given