THE OSCILLOSCOPE
Design and Construction

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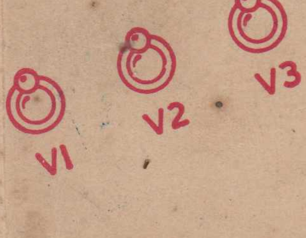

by J. A. HOPKINS

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The Oscilloscope :
Design and Construction

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by J. A. Hopkins

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I—*THE CATHODE RAY TUBE*

1. INTRODUCTION.

A HIGHLY sensitive portable and flexible instrument that imposes no load on the measured circuit, is unaffected by frequency variation over a very wide range, is usable equally on alternating or direct current equipment, and moreover gives a pictorial representation of the condition under investigation, naturally must become an inherent part of any modern test equipment. In consequence the Cathode Ray Oscilloscope has become a necessity for all who seek to explore cause and effect in an almost unending variety of fields. Wherever a graphical representation of a law or information of a multitude of types is required, the oscilloscope offers in many cases the only, and almost always the best means of satisfying the requirements.

An oscilloscope gives graphically an electrical effect as a function of time, so that whether or not the original subject is of an electrical nature, providing it can be made to reproduce an electrical equivalent, i.e. changes of potential, its characteristics can be viewed on the tube. Thus the application of the Oscilloscope ranges from all branches of electrical and general engineering, such as frequency comparison, wave form study on alternators, and muzzle velocity research, to the medical field for cardiac investigation.

Its applications to radio engineering, in which this book is mainly interested, are almost unlimited; study of waveforms, phase shift, modulation tests, alignment, response curves, hum tracing, fault finding to mention a few, so that the indication of some of its uses given in the final chapter, cannot by any means be accepted as exhaustive.

2. THE SCREEN.

The heart of the apparatus known as the oscilloscope is of course the cathode ray tube, all the associated circuits are attachments for the control of the operation of the tube. Thus a firm grasp of the construction and functions of the tube itself is essential for the understanding of the practical use of the equipment.

Basically the tube consists of a glass conical shaped bulb with an elongated neck containing the electrodes. The end face of the bulb is slightly domed and the inside of this dome is coated with a layer of material that has the property of fluorescing, which forms the screen on which the " pictures " are drawn. This screen consists of fine crystals with a diameter of ·1 mm. or less, spread over the glass and held in position by an adhesive. The " pencil " that draws the pictures is a beam of electrons that impinges on the screen causing it to fluoresce at the point of impact, i.e. it produces a spot of light. This spot is made to traverse the screen, and in order to give the appearance of a continuous line, material which continues to glow after the beam has moved on is used for the coating of the screen, the continuity of line effect being assisted by persistence of vision, the property whereby the retina of the eye retains a picture for a short period after the source has actually disappeared. For the best vision colours near green are generally most acceptable by the eye, and consequently it is common to use a deposit on the screen that gives a green fluorescence. About thirty different materials of various mixtures can be used for the coating, each having varying properties and colours. The colour of an unenergised screen has no relation to the colour of the spot, which depends on the fluorescing properties of the chemicals used in the manufacture of the screen. According to the materials used, the luminescence varies in an exponential manner, and the time constant actually used is dependant on the purpose for which the tube is to be employed. The property of continuing to fluoresce after the electron beam has been removed, is known as the "after-glow." Willemite coating, which gives a green picture, has a medium period of afterglow and has been in almost universal use from the early stages of development. Zinc sulphide is eminently suitable for television tubes, colour and afterglow are controllable according to the mixtures used, and a very brilliant picture can be obtained. If too long an afterglow is used there will be a tendency to blur the picture in normal circumstances, but under certain conditions a long afterglow is required, and some compounds have produced up to 10 seconds afterglow. An example of the need for a long afterglow is for photographing high speed transients. For photography a blue screen normally has the best effect on the film emulsion, cadmium or calcium tungstate are suitable deposits. A further example of the use of a long afterglow is when the spot traverses the screen very slowly, the long afterglow being necessary to give continuity of the picture. Such an occasion is in the use of an electrocardiograph for examining heart beats. The rate of movement of the spot is about one inch per second and for the doctor to be able to observe the complete trace a considerable afterglow is essential. A zinc sulphide and copper combine gives a suitable deposit for such use. At the other end of the scale zinc sulphide with a nickel "killer" has a negligible afterglow.

A word of warning before finally leaving the screen; concentration of a powerful beam on one spot can burn the screen. This is not necessarily indicated by actual discolouration, but the deposit over the area affected loses much of its power of fluorescence. That is there will be less brilliance over the affected area in comparison with the rest of the screen. Even a brilliant trace that continually moves over the same path can cause such damage. The remedy is simple; treat the screen carefully, do not use a trace at a higher brilliance than is necessary, and when not actually reading from the screen keep the brilliance down low and the beam defocussed.

3. BEAM PRODUCTION AND CONTROL.

So much then for the screen on which to view the picture; the next requirement is the production and control of a suitable beam which can traverse the screen to produce the required trace.

Two separate methods are in use, the soft tube which is filled with an inert gas such as argon, and the hard tube with a vacuum of about 10^{-7} cms. of mercury, each having its individual advantages and disadvantages. For a general purpose oscilloscope such as this book is mainly concerned with, the hard tube is the answer, and in consequence the main concentration is on this type of tube. Some brief detail of the soft tube is however necessary for general consideration.

In both types the actual electron emitting agent is a hot cathode either directly or indirectly heated, and it is in the actual control of the beam that the two types differ. The finer the beam, the finer and more accurate will be the image on the screen, and the first step towards this is to design the actual emitting surface of the cathode with as small an area as possible. One type of construction uses a small tungsten loop with a platinum wire welded to the bend, the tip of which is coated with the emitting compound. Another method is to mount the emitter in a cup shaped holder which is indirectly heated by a loop of tungsten. A mixture of barium and strontium oxides is used as the emitting compound.

Heating may be either from AC or DC. With the former method magnetic interference causing disturbances of emission may arise, and twisting the leads feeding the heater to give a non-inductive circuit will counteract this.

The direction of flow of the electrons is controlled by an anode or accelerator (see fig. 1) at a positive potential, placed

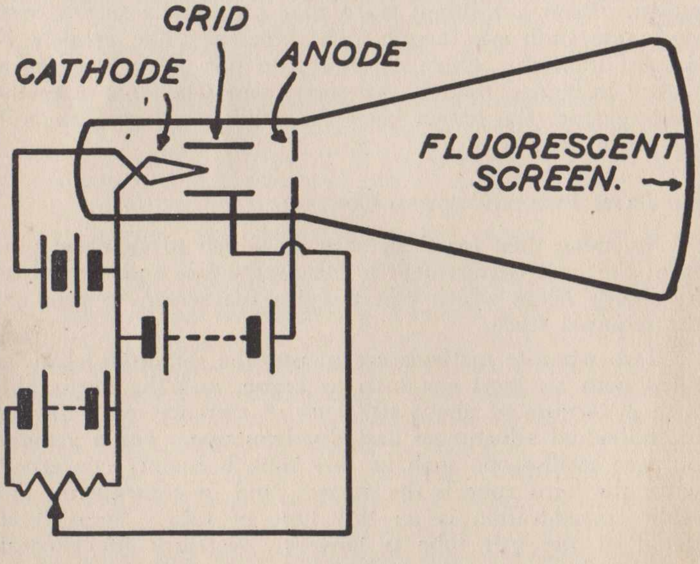


FIG.1. BASIC BEAM PRODUCING ELEMENTS.

a short distance from the cathode. A hole is drilled in the centre of the anode and some electrons pass through this hole to the screen. Those actually striking the anode plate produce heat, serve no useful purpose and consequently represent a reduction in efficiency. Thus the aim is to concentrate all the electrons to a narrow beam that will pass through the hole in the anode and on to the screen. This is effected by interposing a grid between the cathode and anode. This grid is known also as a shield or Wehnelt cylinder, although this latter nomenclature is fast dying out of use. The grid serves a double purpose: to concentrate the electrons into a beam that will pass through the anode, and to control the brilliance. It is at a negative potential relative to the cathode so that it tends to repel the electrons, exercising a constrictive action on them and controlling the number of electrons that leave the vicinty of the cathode. Thus the effect of the cylinder is to repel the electrons into a beam along its axis, whilst if it is made sufficiently negative it can cut off the supply of electrons completely.

4. SOFT TUBE FOCUSSING.

Thus far a beam has been produced that is made to impinge on a fluorescent screen, there is a control on the brilliance produced by the stream, and there is a coarse method of controlling the area of the beam. The next step is to introduce a method whereby the beam can be focussed so as to bring the focal point at the screen and thus obtain a sharply defined point of light. It is at this juncture that the esssential difference between the hard and soft tube appears.

In the soft type the gas at low pressure in the tube is easily ionised by bombardment of the electrons from the cathode, due to its dispersed state. The path of the beam therefore is accompanied by ions being formed as it progresses. Being heavy compared with the light, fast-moving electrons, the ions tend to stay in the path of the stream and form a central core. As the production of ions increases an attractive force is formed which pulls the electrons into the axis of the core. Thus the electrons are subjected to concentration by the attraction of the ionised core and the repelling force of the shield. The focussing action is therefore dependant on the rate of ion production, that is the number of electrons and gas molecules that collide, which is a function of the gas pressure and the number of electrons or beam current. If the accelerating voltage is low, then to compensate a stronger beam current would be required, and in consequence there is obviously a minimum accelerating voltage, normally about 300 volts, which will give sufficient ionisation to produce a sharp focus. On the other hand too high voltage reduces the ionisation efficiency and again the focussing falls off. Thus control of the focus may be effected by regulation of the filament current, that is regulation of the cathode electron emission, or variation of the accelerator potential, or the shield potential. Consequently as the grid potential increases and the brilliance decreases there is a falling off of definition, and in consequence a gas tube is not suitable where large fluctuations of brilliance are required, as for instance in television reproduction.

As will be seen later the beam can be made to move over the screen either by electrostatic or magnetic means, i.e. by deflector plates or magnetic deflecting coils. When deflector plates are used, one plate is made positive to the other and the electrons of the beam tend to move towards the positive plate while the ions have a tendency to move negative. The latter, however, having a much greater mass, move more slowly than the electrons and the area between the deflecting plates becomes filled with ions which have virtually been left behind. This produces a lagging effect which requires a definite potential to overcome it and gives the appearance of less sensitivity below this potential. This is known as "origin distortion." Fig. 2 gives an example of its effect.

In place of the pure sine wave as shown dotted, the "kinked" trace will be seen, the kink appearing where the voltage applied to the deflecting plates falls below the "threshold potential" required to overcome the ionic space charge. The effect can be prevented by applying a biassing voltage to the plate, so that any working voltage applied will always be above the threshold potential.

Soft tubes also have the drawback of being unable to focus at high frequencies. The formation of the ions must take an appreciable time, and if the work frequency applied to the deflector plates is too high then the beam will move too quickly for the ion core to be completely formed, i.e. there will be a loss of focus. In addition the heavy ionic core will not move fast enough and at times will be behind the electron beam, tending to disperse the electrons and again producing loss of focus. The actual limiting frequency depends on the focussing conditions as regards potentials, etc., but a general average is about 100 Kc/s.

This ionisation of the gas causes a further defect in that the ions are attracted by the source of the beam, which is at a negative potential, so that they drift towards the cathode and bombard it, damaging the coating and reducing the life of the tube.

To briefly summarise, the soft tube suffers from defects of :—

(a) Limited frequency response.
(b) Origin distortion.
(c) Limiting bias potentials.
(d) Short life—a few hundred hours.

On the other hand it offers the advantages of :—

(a) Low voltage operation—300 to 500 volts.
(b) The initial cost is low.
(c) Within limits as regards frequency etc., good senstivity, a brilliant spot, and good focus.

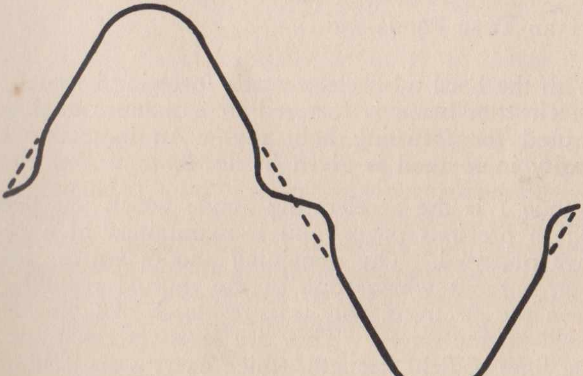


FIG 2. ORIGIN DISTORTION.

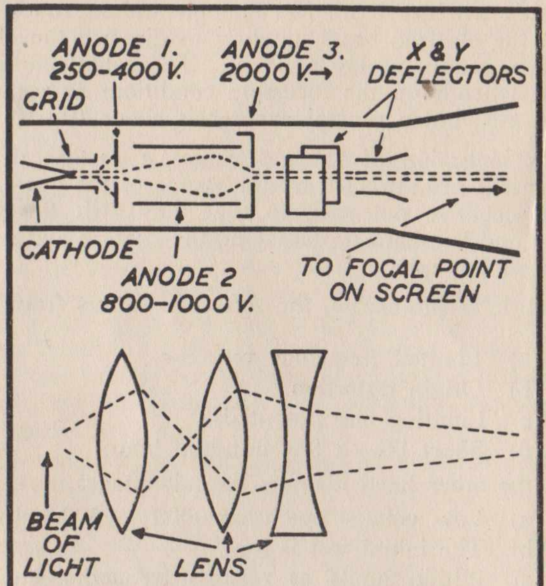


FIG. 3. FOCUSSING IN A HARD TUBE.

5. HARD TUBE FOCUSSING.

With the hard tube, electrostatic focussing is usual. That is the electron beam is focussed in a manner analogous to that used for focussing light rays. An indication of the similarity in method is given in fig. 3.

Anode 1 is the accelerating anode which has been discussed in previous pages, and is maintained at a constant positive potential. The remaining anodes are for focussing control, without which, due to the mutual repelling force between the electrons, only a large blotch of light would be obtained on the screen. They are in effect electronic lenses having lines of field strength, which exert a controlling force on the electron stream, by reason of the fact that electrons tend to move at right angles to the lines of force of any electrostatic field.

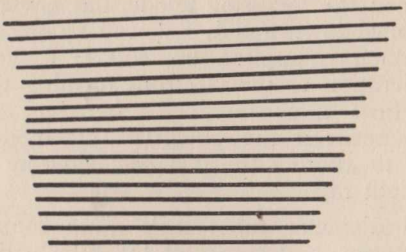
It will be noticed that the glass lenses are equivalent to points of abrupt change from high to low potential. Anode 2, often termed the focussing anode, has a variable positive potential applied to it, and is followed by the third or final anode to which is applied the full H.T. voltage, giving further acceleration to the electrons forming the beam and altering the lines of convergence. In effect any alteration of the ratio between the potentials of anodes 2 and 3 is equivalent to altering the distance between the focussing lenses for a light ray.

With small diameter tubes it is quite common to omit anode 1 as shown, and construct the tube with two anodes only, thus the variable potential will then be applied to anode 1.

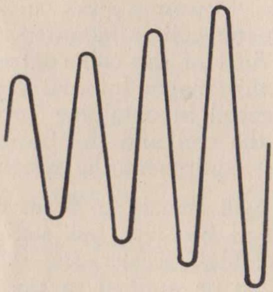
Electro-magnetic focussing gives an alternative system. An energised magnetic coil is mounted round the neck of the tube, and the field of the coil controls the path of the electrons. Whilst this makes internal construction simpler, difficulty is experienced in obtaining correct alignment between the axis of the coil and the beam, consequently for general purpose test equipment the system is rarely used.

The hard tube will remain in focus over a wide range of frequencies. It is however less sensitive than the gas tube as, due to the high accelerating voltages necessary, a higher potential must be applied to the deflector plates to swing the beam from its normal path. • Thus for example with a six inch tube it might be necessary to apply about 400 volts to the deflector plates in order to obtain a full swing across the screen. In a simple circuit one deflector plate is connected directly to the accelerator anode, and thus the other plate, to which the work signal is applied, fluctuates some hundreds of volts above or below the potential of the anode. That is there will be a fluctuating field through which the beam must pass, and which will defocus it at the ends of the line. This defect may be remedied by symmetrically coupling the deflector plates with respect to the anode. A phase reversing circuit is necessary to effect this and it will be further discussed when considering time base circuits.

Inter-action between the electrodes produces a further effect, that of " trapezium distortion." The fact that there is present an electrode to which is applied a high potential with respect to the anode, affects the beam sensitivity ac-



(a) Line Screen.



(b) Sine Wave.

FIG.4. TRAPEZIUM DISTORTION.

cording to its position in the tube. The effect is best indicated by a " line screen " as shown in Fig. 4, which also indicates its effect on a sine wave fed to the Y plates. This picture is obtained by applying a negative potential to an X and a Y plate. That applied to the X plate will force the beam across the tube to draw the line, and the potential applied to the Y plate is so synchronised that at the end of each X plate sweep the spot returns and moves down the tube to draw the next line. If there was no distorting effect a regular rectangular pattern of lines would result, but due to the increased sensitivity as the beam nears the plates to which the potential is applied, it tends to travel further so that a trapezoidal pattern is obtained. This effect can be minimised by applying the potentials symmetrically to the plates, as discussed previously. With gas tubes this effect though present is not so noticeable due to the lower potentials employed.

To briefly summarise on the hard tube, its advantages are:—

(a) A long life—several thousand hours.
(b) A good focus up to very high frequencies.
(c) Control of the brilliance does not affect the focus.
(d) The tube length can normally be shortened in comparison with a gas tube.

Its disadvantages are:—

(a) The necessity for high voltages.
(b) The sensitivity is reduced by the higher voltages.
(c) Falling off of focus at the edges of the screen.
(d) Trapezium distortion.

6. DEFLECTING METHODS.

To finally complete the tube, methods employed for controlling the movement of the beam over the tube must be considered. As has already been pointed out this can be done by deflecting plates, known as the X and Y plates, to which are applied the time base and work potentials, a negative potential repelling and a positive potential attracting the beam.

The X plates are mounted vertically and draw the beam across the tube, whilst the Y plates are mounted horizontally and draw the beam up and down the tube. That is the plates mounted vertically cause a horizontal deflection, and the horizontally mounted plates cause a vertical deflection. The work under test is normally applied to the Y plates and consequently these are sometimes referred to as the work plates, whilst the X plates are termed the timing plates.

As will be appreciated these plates set a limit to the amount of possible deflection of the beam, determined by the spacing of the electrodes and their distances from the screen. Should this limit be exceeded the beam will be broken up by contact with the plates, and the stream of electrons will pass both sides of the deflector, causing a shadow to be cast on to the screen. To extend the limit of travel, the deflectors are vee-ed out, instead of each pair being parallel, see fig. 5.

As an alternative the beam may be deflected by magnetic means by placing coils around the tube, one pair of coils being used to replace each pair of deflector plates. This method enables the maximum angle of deflection to be considerably greater than with electrostatic deflection, there being no physical hindrance to the path of the beam, and in consequence much shorter tubes can be used. The bulkiness of the coils and cores mounted around the tube are however somewhat a disadvantage.

Magnetic deflection has a further advantage in the absence of distortion produced by the presence of the deflector plates, but failure to carefully mount the coils will tend to produce an axial component of the magnetic field which would produce distortion and de-focussing.

7. DOUBLE BEAM TUBE.

It is often desirable to compare two separate work signals, and this can be effected by means of the double beam tube. In actual fact one beam only is emitted and this single beam is split into two components by the introduction of a third Y plate, which is placed midway between the normal Y plates. The signals are then fed one between this centre plate and the upper Y plate, and one between this centre plate and the lower Y plate. The deflection by the X plates is unaffected by this additional deflector on the Y axis, in consequence the time base potentials will control both parts of the split beam in the same manner, and draw in effect two traces across the tube. This allows the two images of the work signals to be viewed on the tube at

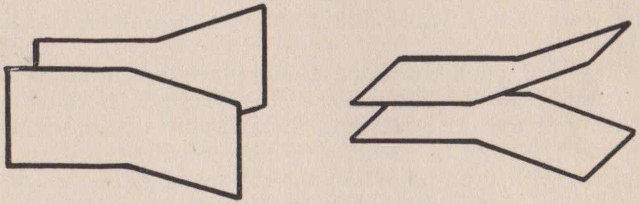


FIG. 5. X & Y PLATE FORMATION.

the same time on a common time base frequency. It must be appreciated that one of the traces will be inverted relative to the other, as a positive potential applied to the upper Y plate will draw the beam upwards, whilst a positive potential applied to the lower Y plate will have an inverse effect. Consequently what may appear to be a lagging current, due to this 180° phase displacement, will be in actual fact a leading current. With the total energy of the beam divided into two paths a less bright image will naturally result, whilst symmetrical feeding of the signals being impossible, prevention of trapezium distortion cannot be applied. Nevertheless it will be appreciated that a double beam arrangement offers possibilities of accurate comparison that is not otherwise possible.

II—*AUXILIARY EQUIPMENT*

1. THE TIME BASE.

Many of the uses to which the oscilloscope is put require the observations of electrical variations with respect to time. It is therefore necessary to arrange that the electron beam traverses the screen from one side to the other in a horizontal plane at a uniform and known rate. Further, at the end of each sweep a rapid return must be made to the initial position in order to repeat the sweep. A uniform sweep of this nature is known as a linear time base.

With such a time base potential applied to the X plates a horizontal line will be seen on the screen. If now the work potential is applied to the Y plates, the spot will trace out how this Y plate voltage varies in respect to time.

Let us consider the trace in fig. 6. After a certain period of time the potential applied to the X plates will grow and tend to move the spot horizontally over the distance o-a. At the same time the growing potential of the Y plates will tend to move the spot vertically over the distance o-b, so that the resulting travel of the spot will be approximately the diagonal of the rectangle o-c. Similarly during the following period the X plate will cause the spot to travel over a-d and the Y plate will cause the travel b-e giving the resultant position f. At a later period after the time o-g, whilst the time base potential continues to grow, the Y plate potential has passed its maximum in the positive direction and the distance of travel due to the Y plate has begun to decrease, giving the position i as the resultant.

Thus in total the spot sweeps out the wave form shown until the position j is reached when the spot flies back to its initial point o. On completion of the time base sweep if the potential aplied to the X plates drops immediately to zero, the spot will return at once to the point of origin, and application of a further gradually increasing potential

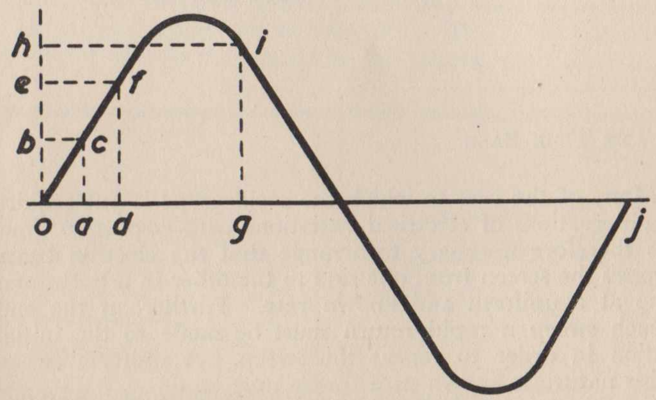


FIG.6. FORMATION OF TRACE.

to the X plates will once again draw the spot across the tube.

In consequence a potential is required for the X plates that varies with time in a manner as indicated by fig. 7, that is, a saw-tooth wave form.

Following the same lettering as used in fig. 6, during the period o-j, the potential applied to the X plates has increased from zero to j-k, and then at the instance j dropped again to zero, to repeat. The periods o-a, o-d, and o-g, are the periods considered in fig. 6.

It might be interjected here that there are of course other types of time bases for particular uses, such as an eliptical time base, an exponential time base, a single sweep time base, a circular time base, etc., but for general purpose testing the repeating linear time base has the most uni-

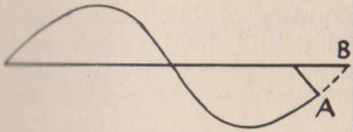


FIG.9. FLY BACK

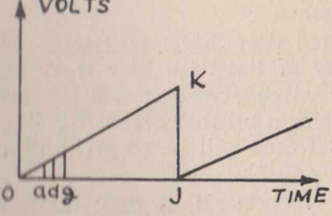


FIG.7. THEORETICAL TIME-BASE WAVEFORM.

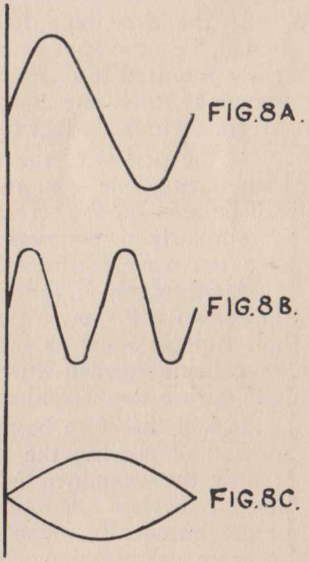


FIG.8A.

FIG.8B.

FIG.8C.

FIG.8 EFFECT OF TIME BASE SPEED

versal application, and in consequence is the one considered here.

If the time base is uncontrolled or free running, then unless the frequencies of the time base and the work potentials are the same or in harmonic relation to each other, each sweep of the variable applied to the Y plates will not always begin at the same instance, so that the beam will not trace the same path each time it sweeps across the tube. When there is only a small difference between the frequencies, the wave form shown on the tube will at each sweep commence at a point further along the cycle by a small amount, and result gives the appearance that the traced wave form is slowly travelling across the tube.

Consequently a necessary requirement of the time base is that some arrangement must be incorporated that will lock the time base to the applied work frequency, that is the time base potential must be triggered off at the required time. This is known as synchronisation.

If the time base has a frequency of 1,000 cycles per second, i.e., the spot scans the tube in 1/1000 seconds, and it was required to examine a sine wave potential of the same frequency, then one complete wave form will be seen on the screen, as indicated in fig. 8a.

If the period of the time base was reduced to 500 c.p.s. then during one scan two cycles of the examined potential will be seen on the screen, as indicated in fig. 8b.

Similarly if the period is further reduced to 100 c.p.s. then ten wave forms will be traced.

Alternatively if the time base frequency is doubled then the screen will show a positive half waveform and a negative half superimposed as indicated in fig. 8c; the positive half wave being formed during the first scan and the negative half during the second and so on.

It will therefore be appreciated that there must be some method of varying the frequency of the time base to bring it near the examined frequency as otherwise it will be impossible to view a complete waveform on the screen (fig. 8c), or the number of complete waveforms will be so great that accurate examination will be impossible.

The diagrams of fig. 8 are theoretical as they do not allow for the flyback, i.e. the return of the spot to the initial starting point after completion of the scan.

This obviously occupies a finite time, and in actual fact fig. 9 gives a more accurate indication than fig. 8a.

A is the point at which the flyback starts and the shorter the distance AB the better the design of the time base. Here then is a further requirement viz. a flyback time of very short duration.

Having given some consideration to the various requirements for the desired time base, details of how these requirements may be realized can now be examined.

The fundamental component of a linear time base circuit is a condenser. If a condenser is charged through a high resistance it gradually builds up its charge at a rate determined by the capacity and the resistance, in the manner indicated by fig. 10.

If this rising voltage is applied to the X plates the spot will traverse the tube and will return again if the condenser is discharged. The charging rate of a condenser C through a resistance R is given by the formula $Eo=E(1-\frac{t}{CR})$, and an alteration of R or C alters the time of the charge. The charge rate is not constant but falls sharply towards maximum, i.e., it builds up its charge in an exponential manner so that 63% of the applied voltage is obtained after a time CR, 83% after a time 2CR and 95% after a time 3CR.

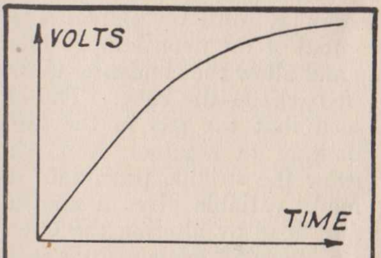


FIG.10 CHARGE OF A CONDENSER.

Such a voltage rise would produce a time base giving a picture that was unevenly spaced, that is the waveforms would appear crushed together at the ends of the trace. From fig. 10 it will be seen that for the first part of its charge the potential across the condenser plates increases virtually at a constant rate. Consequently if only the first portion of the charging period is used the resulting rise in potential will be linear. Obviously the desired maximum potential of the time base must be reached before the rate of charge of the condenser leaves the linear path. This can be effected by using a charging voltage source four or five times as great as the scan potential required. For example if 100 volts is required to move the spot from one side of the tube to the other, the time base H.T. will be 500 volts, and the circuit is arranged so that the condenser discharges when the potential across it reaches 100 volts.

This then has given the first part of the saw-tooth, and the next requirement is a discharge mechanism for the flyback period, which we have seen must be as short as possible.

Fig. 11 shows a simple circuit utilising the property of a neon lamp. The condenser C charges from the H.T. supply through the resistor R until the potential across it reaches the striking potential of the neon lamp. The neon will then start conducting and allow the condenser to discharge through it, causing the flyback on the tube. The characteristics of the neon are such that the gas in the lamp having been ionised, will continue to conduct even when the voltage across it falls below the striking potential. It will be noted that R being made variable gives a control over the frequency of the time base by altering the CR constant.

However, as a charging device it is not very satisfactory, the difference between the striking and cut off voltages is only about 40 volts, which for a tube of 1 mm. per volt sensitivity gives only 4 cms. travel of the beam. In addition as the frequency of the time base is increased, that is the total

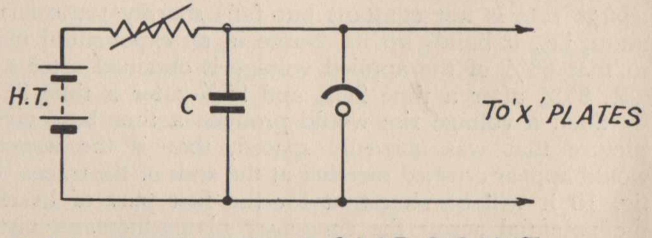


FIG. 11. SIMPLE TIME BASE CIRCUIT.

time of the charge and discharge becomes less, a limiting point will be reached when there will be insufficient time for the neon to de-ionise, the lamp will in consequence conduct continuously and the time base will stop; this will normally occur with a time base frequency of about 10 Kc/s. Although it is possible to extend the range of the time base by utilising a triode amplifier, the general limitations of the neon are such that it is rarely used, and it is normally replaced by a gas filled relay valve or a hard valve time base circuit.

2. SOFT VALVE TIME BASE.

The gas relay is a three electrode valve containing a small quantity of inert gas such as neon, helium or mercury vapour. Considering first a gas filled diode. At an anode potential of about 15 volts the electrons emitted from the cathode have sufficient velocity to ionise the gas molecules by impact. The anode potential at which this occurs is called therefore, the "ionisation potential." These heavy positive ions drift towards the cathode and produce a field sufficient to cancel the space charge so that the current through the valve can become the maximum emission current from the cathode, assisted by the secondary emission from the gas molecules. That is, the valve becomes a virtual short circuit and will pass a current limited mainly by the external circuit constants. A typical characteristic of such a valve is given in fig. 12a, the dotted line on the figure indicating the path

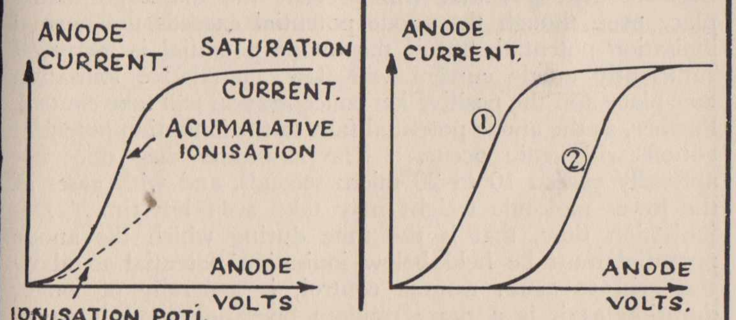


FIG.12A. GAS TRIODE CHARACTERISTICS. FIG.12B.

of the normal diode characteristic.

Consider now a third electrode—a grid, introduced into the valve. With small valves the grid may be of a conventional wire mesh triode structure. With large tubes, however, passing say 40 amps current, the grid structure will be in the form of a metal cylinder with holes and baffles to produce maximum shielding of the cathode. Fig. 12b gives an indication of the negative potential applied to the grid. The characteristic marked 1 is taken at zero grid potential, whilst characteristic 2 is with negative bias applied to the grid. It can be seen that before ionisation can take place the anode potential must be increased by an amount sufficient to overcome the bias. The amount by which the anode potential must be increased for each volt of bias applied to the grid, is known as the "control ratio." Thus if the control ratio of a valve is 20 then with a bias of –5 volts the anode volts must be increased by a further 100 volts to start ionisation. Normal valves have a control ratio of between 20 and 100 to 1.

Once ionisation has occurred a reduction of the anode voltage will not produce an anode current characteristic that will follow backwards over the path of the curve 2 of figure 12b, because the valve current is now controlled by the positive ion clouds, but it will return over a path that will follow more closely to that indicated by curve 1 of figure 12b. That is the current will not tend to reduce until the anode voltage falls below the ionisation potential.

In other words the valve is controllable so that sufficient negative grid potential will prevent the discharge taking place even though the anode potential exceeds the normal ionisation potential, but if the anode potential is increased sufficiently anode current will flow, cumulative ionisation take place and the positive ion concentration will take control. Further, as the anode potential falls to the ionisation potential cut-off will again occur. The ionisation time does not normally exceed 10 to 20 micro seconds, and with gases of the lower molecule weight may take even less time. De-ionisation time, that is the time during which the anode potential must be held below ionisation potential to allow the grid to again assume control, is generally of longer duration as it is a more random operation, and it varies from a few micro-seconds to 1,000 micro-seconds. When dealing with the higher frequencies, of course these times will be of importance.

General precautions to be adopted with relay valves, especially of the larger variety, is to insert current limiting resistors (R_1 of fig. 13) in the anode circuit, and the cathode should be hot before H.T. is applied.

Fig. 13 gives the basic details of a gas relay circuit.

When used for a time base circuit the grid bias is adjusted so that current flows at a predetermined potential. During the period when the valve is cut off, the condenser C charges up slowly from the source of H.T. through the resistor R, and the spot will be drawn across the tube until the potential across the condenser reaches the predetermined amount, when the relay fires and the condenser discharges until the valve is again nonconducting, as the anode voltage falls below the ionisation potential, and the process repeats itself.

With a ratio of 20 : 1 and 10 volts grid bias, the condenser will charge to 200 volts before the relay discharges it, that is the voltage applied to the X plates will vary from zero to 200 volts, which, with a sensitivity of 1 mm. per volt, would give 200 mms. travel.

In considering the values of the circuit components, the smaller the capacity of the charging condenser, with R constant, the quicker it will charge up and in consequence the frequency of the time base will increase. With most circuits a coarse control of frequency is provided by switching in various values of capacitance. There are of course many values of C and R which will give the required time constant.

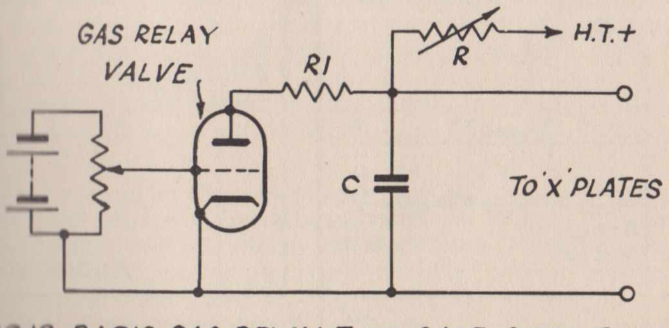


FIG. 13. BASIC GAS RELAY TIME BASE CIRCUIT.

The lower value of capacity is controlled by the fact that at high frequencies there is a tendency to oscillation, as the condenser may start to recharge during the de-ionisation period, the potential reached may be sufficient to reach ionisation value and a spurious oscillation will occur over and above the main cycle· On the other hand too high a value of condenser will mean a heavy current flowing through the valve and cause excessive bombardment of the cathode. An approximate formula for calculating the condenser size is given by $f = \frac{I}{CV}$, where f is the frequency, V is the firing volts, I is the charging current in micro-amps., and C is the capacity in microfarads. For general purposes the capacities will be of the order of ·0005, ·001, ·01, ·05 and ·5 microfarads.

3. SYNCHRONISATION.

Earlier it was seen that an essential requirement was interlocking or synchronisation between the sweep and the work voltage, that is inception of the time base sweep must be under the control of the impulses fed to the Y plates. This can be effected by feeding part of the Y plate voltage to the grid of the relay valve and thus causing a discharge to occur at the positive peak of the test voltage (that is a little before the condenser would reach its uncontrolled peak voltage), and cause the relay to fire.

Fig. 14 indicates the method of operation. "A" is the graph of the charge and discharge of the condenser, i.e. the time base potential, the dotted line showing the path it would

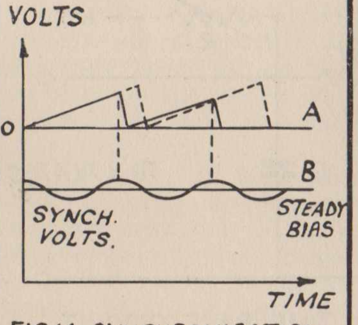


FIG. 14. SYNCHRONISATION

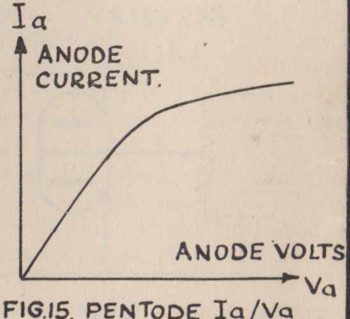


FIG. 15. PENTODE Ia/Va CHARACTERISTIC

follow were it uncontrolled. "B" is the graph of the synchronising voltage supplied from the work, which is superimposed on the steady bias voltage.

As the peak of the work voltage is reached the bias is lifted sufficiently to cause the relay to fire and discharge the condenser, and in consequence the time base is made to start always at the peak of this work voltage.

To ensure that the value of the synchronising voltage is not too high it is necessary to have some control, otherwise the condenser might at times discharge before the work potential reaches its peak, and a jumping effect will be seen on the screen.

4· CONSTANT CURRENT CONTROL.

It has been shown that in order to keep to the straight portion of the charging characteristic of a condenser, it is necessary to employ a high value of charging potential. If however some method be introduced that would control the charging current so that it was kept at a constant value, this necessity for high supply voltages can be avoided.

This could be arranged by inserting a saturated diode in place of the charging resistor. If the filament of the diode is run at a low temperature, a small potential applied to the anode would be sufficient to attract all the electrons emitted from the cathode, and no increase in the anode potential could, therefore, cause an increase in the anode current. The valve is said to be saturated, and provides the constant current device required. The charging current supplied by the diode to the condenser being at a constant rate, a linear time base will result, the speed of which will be dependant on the impedance of the diode. This impedance will in turn be dependant on the temperature of the diode filament, and for constant results a pure tungsten filament should be used.

This control of filament temperature as a means of controlling the charging impedance, is not a particularly suitable system, and use of a pentode valve provides a better method. When the grid and screen potentials of a pentode remain constant then the anode current is virtually unaffected by variations in the potential of the anode. This is illustrated by the Ia/Va characteristic of fig. 15, from which it can be seen that the current quickly builds up to a steady value and varies very little over a large swing of anode volts.

The charging rate of the condenser can therefore be controlled by varying the pentode grid potential, or alternatively the grid can be held constant at cathode potential and the charging rate controlled by the screen voltage. In either case the fact that the anode voltage is changing as the condenser charges does not, as has been seen, affect the rate of charge.

Figure 16 gives a pentode controlled time base circuit, employing a screen control (R_1) to vary the frequency of the time base.

The charging condensers are C_1, C_2, C_3 and C_4, a different value being switched in according to the time base frequency required. V_2 is the discharge relay valve, controlled by a variable bias obtained from a potentiometer with a value of 5-10,000 ohms. This variable resistor R_2 gives amplitude control of the time base by determining the potential at which the relay fires. The resistor is shunted by a condenser C_5 with a capacity of several microfarads.

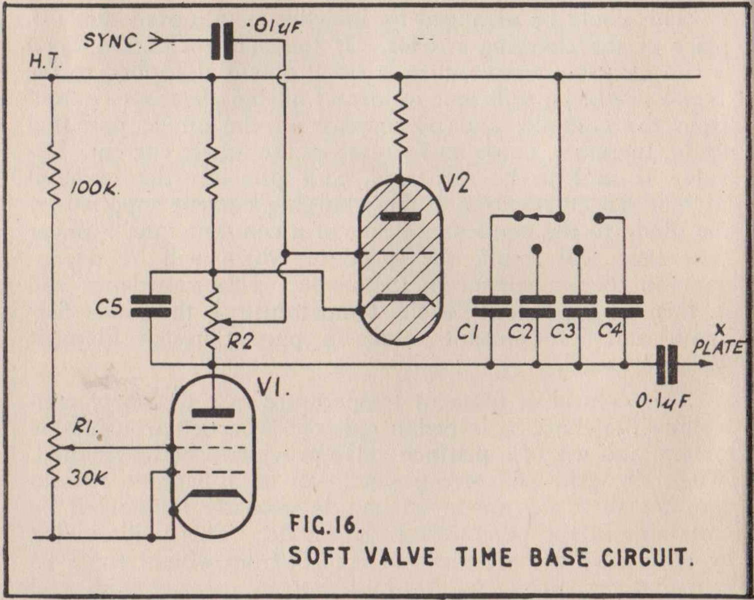


FIG. 16.
SOFT VALVE TIME BASE CIRCUIT.

This condenser maintains the bias on the relay, during the period that the time base condenser is charging, as without some capacitance there would be insufficient current through R_2 to maintain the bias. This method of applying the relay bias is not suitable where large variations of time base frequency are required, as the variations in charging current have a definite effect on the bias.

An alternative method of applying this bias is to connect the grid to a potentiometer circuit across the H.T. supply. This means that the grid is maintained at a steady negative potential relative to the anode of the relay valve. When the time base condenser is fully discharged the cathode of the valve is virtually at full H.T. potential, i.e. positive to the grid. As the time base condenser charges, the cathode will become less positive, that is the negative potential difference between the grid and the cathode will fall until it reaches the point at which the relay will fire. This method however, still leaves the relay bias affected by variations in the charging current.

This tendency to frequency variation, can sometimes be a disadvantage at high frequencies. A suitable method of overcoming this is to interpose an amplifier between the time base output and the X plates. By this means the striking potential and in consequence the bias of the relay can be kept as low as three or four volts, and distortion will occur only if the amplifier is overloaded.

In fig. 16 it will be seen that a condenser is inserted in the synchronising feed. This condenser should be of ·01 or ·02 microfarad capacity, and is supplied from the potential fed to the Y plates via a 2 megohm potentiometer. If the capacity of this condenser is too high in value there is a possibility of distortion due to grid current flowing in the relay valve when it fires, feeding back across the Y deflector plates and causing a vertical kick to the image at the point of firing, i.e. at the end of the scan. In fact with an inductive circuit connected to the Y plates for test, it is possible for this grid current pulse to produce a series of damped oscillations which can be seen on the screen. An alternative method of feeding the synchronising pulse to the relay valve is to use transformer coupling in place of the resistance capacity coupling previously discussed.

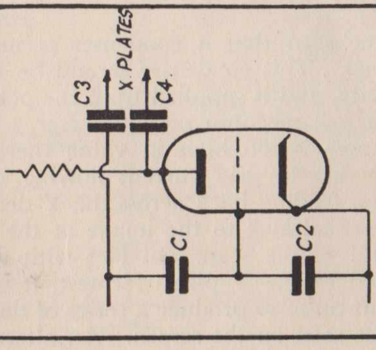


FIG. 17. SINGLE VALVE PUSH PULL CIRCUIT.

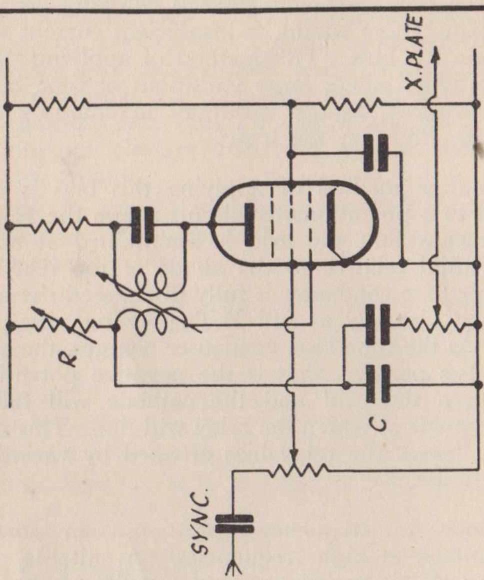


FIG. 18. HARD VALVE TIME BASE CIRCUIT.

5. PUSH-PULL TIME BASE.

When discussing de-focussing troubles in the tube, it was pointed out that the deflector plates had a tendency to cause loss of focus at the extremities of the time base. This can be overcome by so connecting the plates that they are electrically balanced with respect to the anode. This means that when any time base potential is applied to one X plate, an equal and opposite potential must be applied to the other. In other words a form of push-pull circuit is required to feed the time base potential to the X plates. Over and above the advantages of symmetrical deflection there is the additional advantage that with the amplification obtained from this push-pull circuit the relay striking voltage can be kept low. With a resistive load to give an undistorted output and using a triode circuit giving a straight characteristic over a large swing, up to 80% of the full H.T. supply can be used for deflecting. With a two valve circuit resistance capacity coupled, the time base condenser is coupled to the grid of the first valve the anode of which is connected via a condenser to one X plate, whilst the anode of the second valve is coupled to the other. The anodes of the two valves will be in phase opposition, and with a correctly balanced circuit, potentials of equal value but in opposite phase will be fed to the X plates.

An alternative circuit using one valve only is shown in fig. 17.

The condensers C_1 and C_2 are fed from the time base condenser, which also feeds via C_3 direct to one X plate. The valve acts as a phase inverter and feeds via its anode an equal voltage of opposite phase to the other X plate.

6. SHIFT CONTROL.

Two final controls for consideration at this point are the shift controls, one for each pair of deflector plates. It will be obvious that in a perfectly balanced tube the spot will normally appear, when there are no deflecting voltages applied, in the centre of the screen, and consequently one might assume that as the spot starts its scan from the centre point, that with the flyback it will return to the centre point, so that the time base line covers only half the screen. In practice, however, the condensers through which the deflecting potentials are supplied, isolate the plates from any DC potential. That is, in the fluctuating potentials supplied to the plates the DC component is lost, and a position is reached in which the applied potentials are symmetrical with respect to the tube and the scan covers the screen across its total width, provided, of course, that the potentials applied are sufficient to draw the spot over this length. Apart from this, however, some method of manual control of the positioning of the trace both horizontally and vertically is required. This can be obtained by applying a D.C. potential direct to the plates from a potentiometer across the H.T. supply. If magnetic deflection is used, adjustment can be made by moving the position of the coils or passing a current through the coils via a choke to isolate the work potential.

7. HARD VALVE TIME BASE.

It has been seen that for high frequency working there are drawbacks to the use of a gas relay valve. To overcome this the use of time bases utilising a hard valve as the discharge control has been developed, thus obviating the questions of ionising times, temperature changes, bias fluctuations etc. The usual method of operating a hard valve with its gradual variation in anode current, is not of course applicable to time base working, and quite obviously just to replace the relay by a hard valve will not meet the case. It is possible, however, to utilise a valve oscillator circuit to gvie a rapid charge and a slow discharge of a condenser, and thus obtain the required form of action for a time base circuit. This is the reverse of the previous method, when a slow charge and a rapid discharge of a condenser gave the time base and flyback potentials.

A normal inductively coupled oscillator circuit as shown in fig. 18, provides one method. Through the resistor R a positive bias is applied to the grid of the valve, which is also returned to earth through the time base condenser C. R is variable from 2 to 10 megohms and provides a fine frequency control. As a result of the oscillatory action of the circuit, the time base condenser C is rapidly charged until its potential is sufficient to cut off the valve, so that the oscillations cease. The condenser charge then leaks away slowly via R and this gradually decreasing potential is fed, via a ·1 mfd. condenser and a 500K variable resistor, to the

X plates. More usually it is fed to the X plates via an amplifier circuit, in order to obtain a sufficient potential to provide a complete time base sweep. When the charge on C has fallen sufficiently the valve again conducts, oscillations again begin, C rapidly charges to give the flyback, and the operation repeats.

An alternative method which forms the basis of the Puckle time base, is to utilise the principle of the multi-vibrator, the basic theory of which can be ascertained from fig. 19.

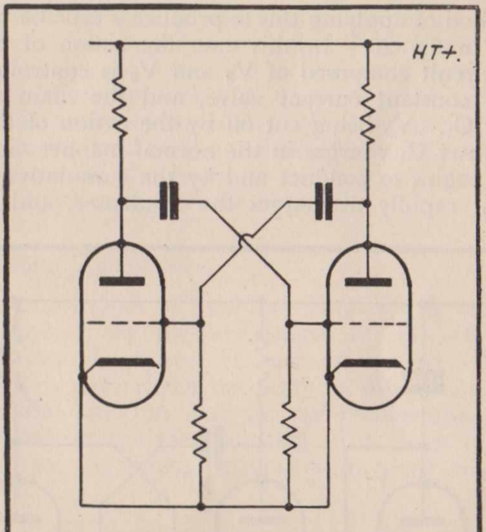


FIG. 19. MULTI-VIBRATOR.

The circuit is inherently unstable and generates continuous oscillations. Its method of operation is as follows. Due to instability in the circuit the grid of one valve, say V_1, will become more negative by a small amount and the anode potential of the valve will rise, due to the decrease in anode current. The anode voltage rise will be transmitted to the grid of V_2 via the coupling condenser, causing the grid of V_2 to become more positive and therefore lead to an increase in its anode current, causing a negative pulse at its anode which will in turn be fed to V_1 grid, giving a cumulative effect to the operation. The process is very rapid so that almost immediately V_2 becomes heavily conducting with its grid at moderate positive potential, whilst the grid of V_1 is driven so far negative that the valve cuts off. The system will then relax at a rate mainly determined by the time constant of the circuit. As the grid of V_1 approaches zero potential the valve begins to conduct and the feed-back starts in the opposite direction, V_1 becoming heavily conducting and V_2 cut off, and so on, generating a square top waveform.

A method of applying this to produce a time base potential is shown in fig. 20. In this case the action of the multivibrator circuit composed of V_2 and V_3 is controlled by V_1, the usual constant current valve, and the main time base condenser C_1. V_2 being cut off by the action of the circuit, the condenser C_1 charges in the normal manner via V_1 until V_2 again begins to conduct and by the cumulative action of the circuit rapidly discharges the condenser, and the cycle

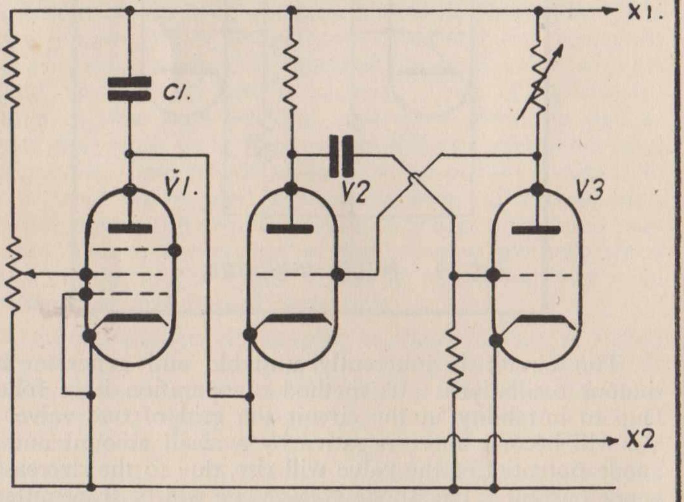


FIG.20. MULTIVIBRATOR TIME TIME BASE CIRCUIT.

repeats. Frequency control will be as usual via V_1, amplitude control by the anode resistor V_3, and the synchronisation pulse can be fed to the grid of V_3.

8. FLYBACK SUPPRESSION.

The flyback occurs during the steep portion of the saw-tooth waveform and in consequence travels at a much greater speed than the forward scan, and so is far less visible. Black out of this flyback is however a definite improvement, and can be carried out by applying a biasing potential to the grid of the tube at the appropriate time. During the discharge of the time base condenser, due to the heavy current flowing through the discharge valve, a negative pulse will be produced in the anode of this valve· If this pulse is fed via a condenser to the grid of the cathode ray tube a bias will be applied to cut off the beam at the time of the condenser discharge, i.e. when the flyback occurs.

9. DEFLECTION AMPLIFIERS.

With certain types of time bases it has been seen that in order to procure the required length of scan an amplifier circuit has been necessary. In general however the use of an amplifier is more often necessary in connection with the work potential, and no cathode ray oscilloscope would be complete without the incorporation of at least one amplifying stage for use when required with work potentials of a low level.

Obviously the essential of such an amplifying circuit will be non-distortion, as should the screen show a waveform distorted by the oscilloscope itself, accurate testing etc., will be impossible. Consequently a level response over a wide frequency range is necessary, simple resistance capacity coupled circuits are used, with a gain control from a potentiometer in the input. A great advantage of the C.R.O. is the fact that it imposes very little load on the circuit under test; in order that this advantage may be retained, obviously another requirement as regards the amplifier is that it also must impose very little drain on the work. Consequently the first stage of the amplifier must be of the high impedance type, and the capacity of the input terminals must be at a minimum. When used as a time base amplifier, it must be remembered that the amplifier must also handle the flyback pulse, so that in actual fact the amplifier must be capable of distortionless handling of the more stringent requirements of this higher speed pulse.

Fig. 21 gives an indication of the type of circuit used as a deflection amplifier. For the purposes of showing the method of switching, it has been drawn as a time base amplifier. It will be noticed that no decoupling condenser has been included in the cathode circuit. This is to provide negative feedback in order to assist in straightening the response characteristic. Too much feedback must not be employed, as otherwise at high frequencies distortion from oscillation might occur.

The choke included in the anode load is a measure for improvement of the high frequency response, which with a pure resistance capacity circuit would fall off, due to the apparent decrease of the effective impedance of the resistor

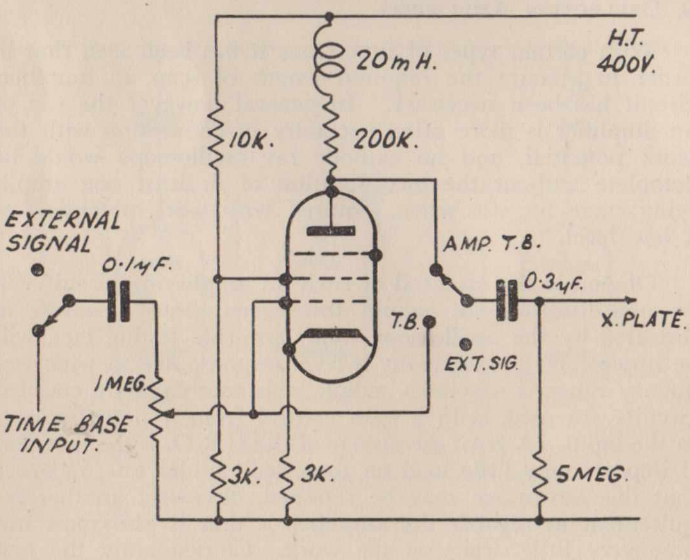


FIG. 21. DEFLECTOR AMPLIFIER.

at high frequencies arising from the shunting effects of the stray capacities. At the higher frequencies the impedance of the choke increases and assists in balancing out this apparent decrease of the resistance. In general so far as the construction of these amplifiers is concerned, they follow the rules normally applicable to audio frequency amplifiers, i.e. adequate screening particularly from other circuits and power supplies, whilst all grid circuit leads and volume controls should be adequately screened and earthed. This screening should also be extended to the choke in the anode circuits which should be enclosed in an earthed can with a diameter greater than twice the choke diameter.

10. POWER SUPPLIES.

Normally two separate power units are used in the C.R.O. One for supplying the necessary potentials to the electrodes of the tube itself, and one for the auxiliary circuits such as the time base and amplifiers. It is however possible to use the one power unit for both supplies especially where no amplifiers are incorporated, but for insulation purposes particularly, separate units are definitely desirable. For the tube alone only a few microamps are used, and one milliamp through the resistance chain of the power supply should be ample. Where, however, a combined power unit is used the time base relay will consume ten or more milliamps and with the restricted output from high votage rectifiers it will be advisable to incorporate a voltage doubling circuit.

Fig. 22 gives a circuit suitable for power supplies to the tube. Note particularly that the H.T. positive line is at chassis potential, in reverse to the normal procedure in radio circuits. This serves a double purpose in that the chassis will be at a safe potential with respect to the deflector plates, which are normally directly connected to the final anode which is at the most positive potential, whilst in addition it has been found that disturbance from external sources is reduced. It must therefore be appreciated that the cathode of the tube will be at maximum potential with respect to the chassis. The safest rule when dealing with the tube, is to touch nothing except of course for the controls, whilst the supply is switched on. Perfect insulation is essential with the high voltages used, and it is preferable to use a separate transformer for the heater supplies. Where earth

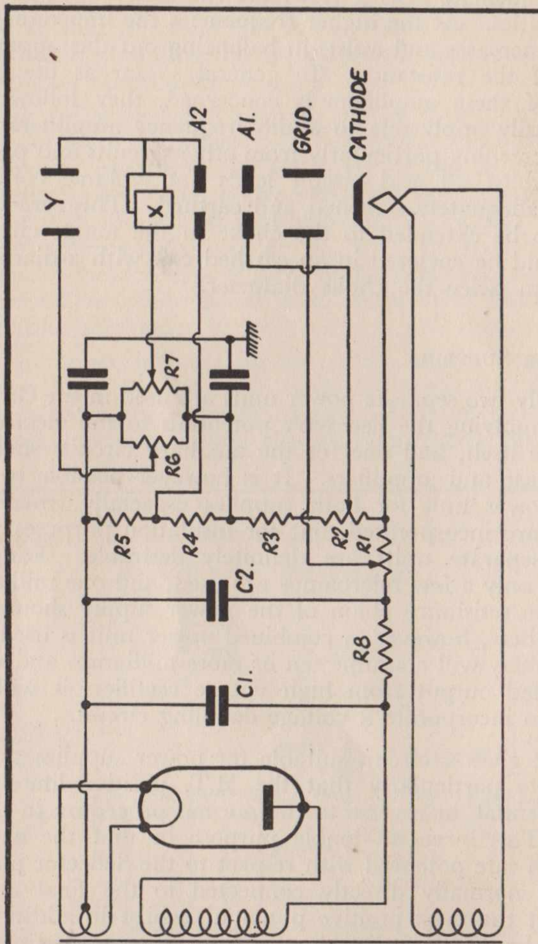


FIG.22. TUBE POWER SUPPLIES.

connections are indicated in connection with C.R.O's this normally refers only to connections to the chassis, a true physical earth connection is not generally necessary, and such a connection with one side of the mains earthed tends to impose an additional strain on the transformer.

A low current high voltage half wave rectifier is sufficient to provide the small current drain when required, and for the same reason resistance smoothing is completely adequate.

The resistors used in the potentiometer chain can be of low wattage as little power is dissipated, but for the variables in the chain, as they must be available externally for adjustments, they must have insulated arms, and if not mounted on an insulated panel be mounted through insulating bushes.

R_1 is the brightness control, variation of which will alter the bias on the grid which is at negative potential in the chain with respect to the cathode. With a soft cathode ray tube this becomes the focussing control.

R_2 is the focussing control, by altering the relative potentials of the anodes.

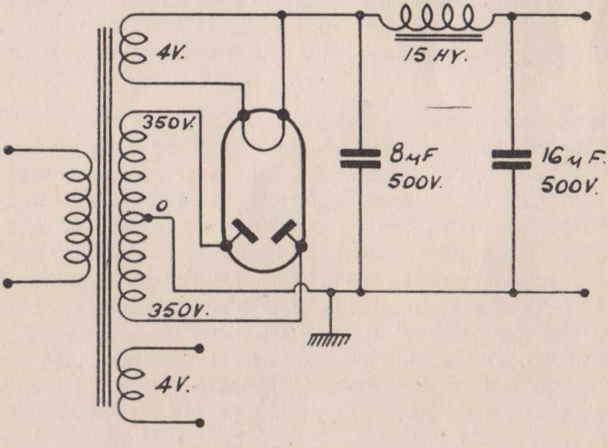


FIG.23. TIME BASE & AMPLIFIER POWER PACK.

R_6 is the horizontal shift control, and R_7 is the vertical shift control. To avoid accidental alteration of these controls and thus causing incorrect readings, these are sometimes preset by screwdriver control instead of knobs.

The reservoir and smoothing condensers C_1 and C_2 are 1 mfd. capacity and it will be realised that they are subjected to the peak voltage of the AC and in consequence should be rated at twice the DC voltage at least. C_3 and C_4 decoupling condensers are ·5 mfd. capacity 500v.wg.

In testing the output of these power packs, an electrostatic voltmeter gives the greatest accuracy, or a high grade moving coil meter, the drain from a low resistance meter in such a circuit would cause the reading to be completely inaccurate.

For the time base and amplifier power supplies, a standard type of power pack is used utilising a full wave rectifier and choke capacity smoothing, such as is shown in fig. 23. In this case of course the heater and H.T. winding can be conveniently incorporated in the one transformer, and the drain on the pack naturally depends on the types of time base and amplifier circuits used.

III—*BUILDING AN OSCILLOSCOPE*

1. The Chassis.

With a view to keeping costs down, not every possible refinement contained in the previous chapters has been included, and naturally the constructor in some cases may wish to incorporate alterations to the following circuits, according to his particular requirements, for instance a hard valve time base; but the oscilloscope constructed in accordance with the following notes and circuits gives very satisfactory results for general purpose usage.

The general layout and dimensions given in the various drawings assume that the tube will be adequately screened by a mumetal shield mounted close around it. The use of a shield is strongly recommended in all cases for use with a cathode ray tube, which is exceptionally sensitive to stray fields which can cause extremely misleading and very disappointing results. It should be possible to obtain such a shield at a very reasonable cost from the various surplus stores.

If it is not intended to use such a shield, then although the chassis gives some fair amount of shielding between the tube and the various circuits, it will be found that it is not sufficient and the power supplies must be constructed as a separate unit, with the connecting leads about a yard long, so that this power unit can be placed well away from the main chassis containing the tube. The smoothing units, however, should be retained in the main unit so as to be as close as possible to the circuits with which they are to be used. This question of the construction of the oscilloscope on a unit basis has much to recommend it and many constructors may decide to follow it and extend it to other parts of the general circuit.

The chassis is made of ⅛ inch sheet iron measuring 15¼ inches by 15¾ inches, bent to a U shape so as to give a depth of 4 inches and a length of 15¾ inches. Blocks ¾ inch square, and drilled and tapped 2 BA, are sweated into the four corners of each end to provide attachment points to which can be bolted the front and rear panels, see fig. 24a.

The top of the chassis is drilled with seven holes to take the valve holders and a condenser. Six of these holes are 1¼ inches diameter, and the other is 1½ inches diameter. The larger one is for the EF55 amplifier valve, and is situated at the third position from the front.

The front and rear panels are again of ⅛ inch sheet iron, and are screwed to the chassis by means of the blocks sweated to the corners of it. The actual centres of the four holes that must be drilled to take the fixing screws cannot be given as it will be necessary to line these up with the blocks. See figs. 24 and 24a.

In addition to these fixing holes the front panel must have in it a hole of 6⅜ inch diameter to give adequate clearance for the screen, and eight holes for the spindles of the controls. These holes are shown as ⅜ inch. diameter, but for the brightness and focus controls at least it is preferable for insulated bushes to be fitted to the panel, in which case, of course, the actual hole required will depend on the bush used. Where these bushes are used, the knob grub screws must be recessed and insulated, otherwise should the potentiometer breakdown the screw being live may cause a bad shock.

Finally there are two holes required for the calibrator and input sockets. These again depend on the actual type used. In the constructed model plug and socket types were used, but as a matter of taste the constructer might consider a screw type terminal to be more convenient. No external earthing connection has been provided for as a crocodile clip attached to the chassis has been found sufficient, but as in many cases it is necessary to connect the chassis of the oscilloscope and the apparatus under test, it might be considered preferable to include an earth terminal for use on such an occasion. Small diameter knobs with a good grip are used on the controls to give a good spacing between each for ease of manipulation.

The rear panel is drilled with two holes, 15/32 inches diameter, to provide for the on/off switch and the mains leads entry, two holes drilled 4BA clearance for the tube mounting, and a further four sets of holes to take the sockets for the link plugs. The sizes of these latter will de-

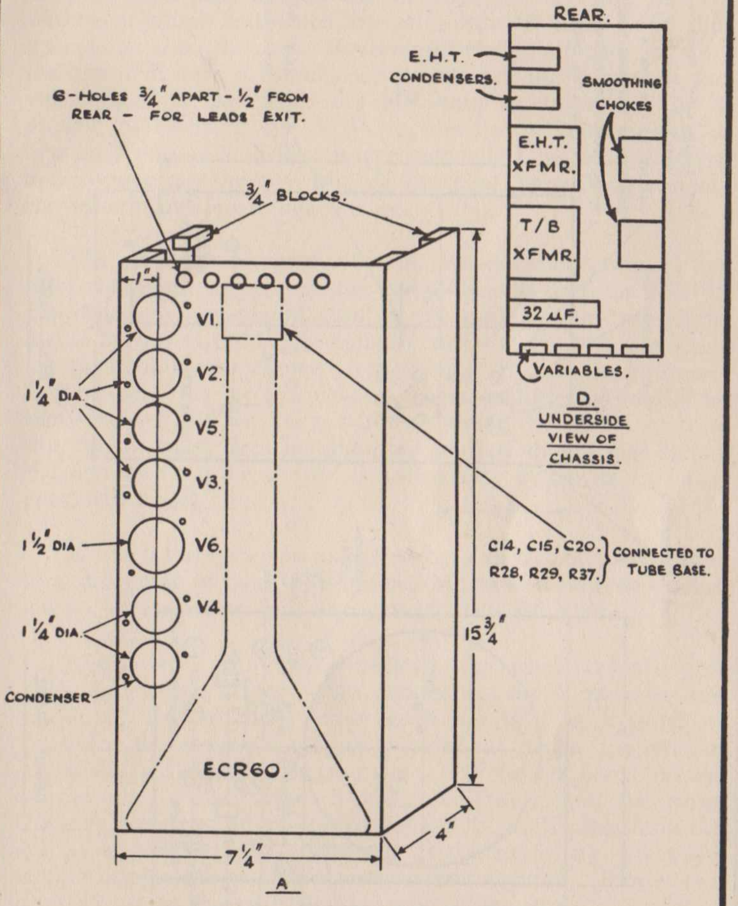


FIG. 24. CHASSIS CONSTRUCTION AND MOUNTING

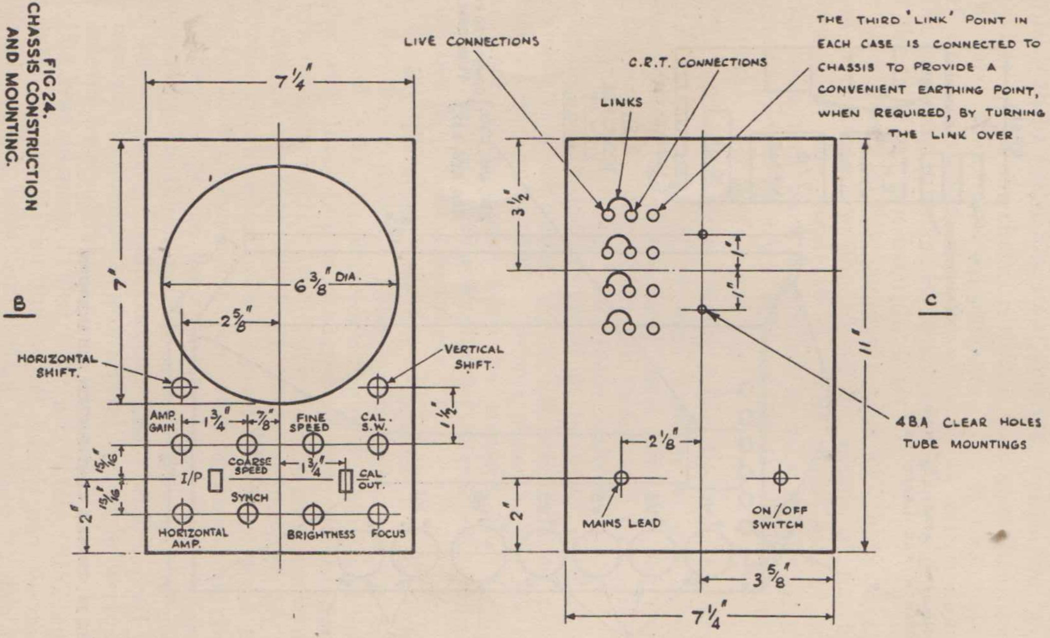


FIG 24.
CHASSIS CONSTRUCTION
AND MOUNTING.

FIG.24.a

FRONT PANEL.

REAR PANEL.

pend on exactly what type of linkage is adopted. These links should be clearly marked X1, X2, Y1, and SYNCH. If desired single plug sockets can be used and the link formed with two plugs connected by an insulated lead. If this system is used it must be remembered that one side of the link will have a direct connection with the anodes of the valves, and if the plugs are left hanging there will be a danger of shorting the H.T. to chassis. Consequently a two pin plug and socket is recommended, with a shorting link connecting the two pins of the plug, as making a neat, convenient and less dangerous job.

The exact fixing centres for the various mountings of the components on the chassis are not indicated as these will be controlled by the actual component used, but an indication of the layout of the larger components is given in figure 24D. Of particular importance is the fixing of the mains transformers and the two chokes. The transformers should be mounted with their fields running along the chassis, whilst the chokes must then be mounted so that their fields are at 90 degrees to those of the transformers; otherwise interference will result.

Mains interference is indicated by a distortion of the spot to a short line or oval, possibly two traces will be seen on the screen, or the beam will be modulated by 50 c.p.s.

Wiring etc., in general follows the usual construction rules, but in particular when connecting the Y plate to the anode of the amplifier valve keep the lead as isolated as possible, to reduce capacity which, at high frequencies especially will cause loss of gain. All heater leads should be twisted. The three ·1 mfd. condensers, and the three 2.2 meg. resistors, which are connected to the X plates and the Y1 plate, are actually connected at the tube base, the third anode being used as a convenient earthing point. Remember that so far as the cathode ray tube is concerned the chassis is at the point of high potential relative to the cathode i.e., reverse to normal. The dimensions as shown do not allow for any tube socket the leads having been soldered direct to the C.R.T. base. From the point of view of insulation and ease of replacement it might be desired to fit a holder for the tube, in which case the length of the chassis must be increased.

2. THE CATHODE RAY TUBE POWER SUPPLIES. (fig. 25.)

This is a normal type half wave pack supplying two kilovolts to the final anode, and two 4 volt supplies for the heaters of the C.R.T. and the rectifier. Where it is desired to wind the transformer the details are as follows.

The transformer is wound on a 1½ inch pile of Sankey number 4 laminations.

The primary for 230 volts supply is 1580 turns of 32 gauge enamelled copper wire.

The H.T. winding supplying 1,600 volts at 1 milliamp is 11.200 turns of 42 gauge enamelled copper wire.

The first heater winding for the C.R.T. supplies 4 volts at 1 amp., and comprises 28 turns of 22 gauge enamelled copper wire.

The second heater winding for the rectifier, supplies 4 volts at .65 amps and is 28 turns of 24 enamelled copper wire.

Paper interleaving should be used throughout, except for the heaters which should be insulated with oiled silk.

The two condensers should be capable of withstanding 3,000 volts peak working.

3. THE TIME BASE & AMPLIFIER POWER SUPPLIES. (fig. 26.)

This employs a full wave rectifier and supplies 400 volts H.T.

For those desiring to wind their own transformer the details are as follows.

The transformer is wound on a 1½ inch pile of Sankey number 4 laminations, and is based on seven turns per volt, less 7% for the primary to account for copper and iron losses.

The primary for 230 volts supply is 1580 turns of 30 gauge enamelled copper wire.

The H.T. winding supplies 325-0-325 volts at 50 milliamps, and is wound 2,280 plus 2,280 turns of 38 gauge enamelled copper wire.

Heater 1 (Rectifier) supplies 4 volts at 2.5 amps, and is wound 28 turns of 19 gauge enamelled copper wire.

Heater 2 (Relay) supplies 4 volts at 1.5 amps, and is wound 28 turns of 21 gauge enamelled copper wire.

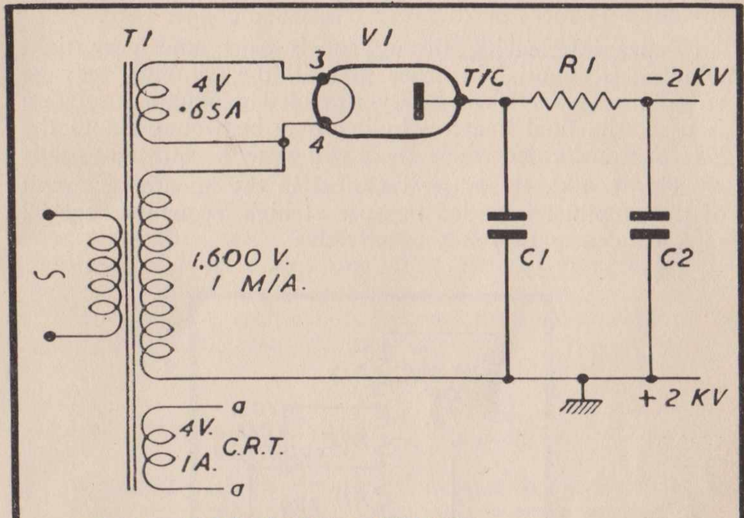


FIG. 25. C.R.T. POWER SUPPLIES.

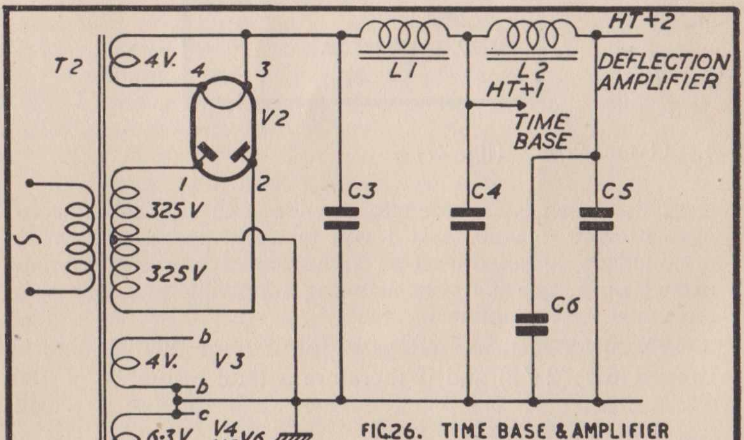


FIG. 26. TIME BASE & AMPLIFIER POWER SUPPLIES.

Heater 3 (Amplifiers) supplies 6.3 volts at 2.2 amps, and is wound 44 turns of 20 gauge enamelled copper wire.

Paper interleaving throughout is used, and very tight winding is essential in order that all the windings may go on to the core. If necessary provided adequate insulation is used, the final heater winding may be wound on to the E.H.T. transformer, where there will easily be sufficient room.

The ·1 mfd. condenser included in the smoothing circuit of the amplifier is added because at high frequencies the 32 mfd. condenser may not be effective.

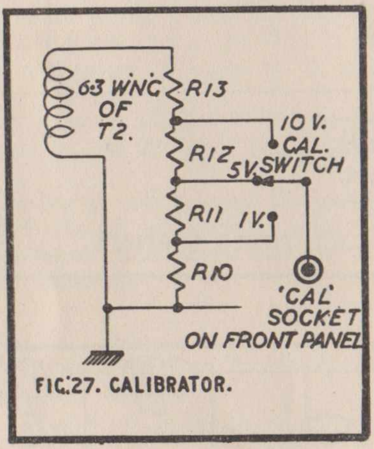


FIG. 27. CALIBRATOR.

4. CALIBRATOR. (fig. 27)

This circuit is included to provide A.C. calibrating voltages 10 volts, 5 volts, and 1 volt (peak to peak). They are obtained by a potentiometer arrangement of resistors, connected across the 6.3 volts winding supplying the deflection and time base amplifiers.

The peak to peak voltage supplied from this winding is 18 volts ($6.3 \times 2\sqrt{2}$) and if therefore a total resistance of 180 ohms is used for the potentiometer, each 10 ohm step will represent 1 volt peak to peak.

5. TUBE CONNECTIONS. (fig. 28)

This follows normal practice with the exception perhaps of the shift controls which, returned to earth via a 2·2 megohm resistor, are supplied from the deflection amplifier power pack.

A six inch three anode tube is used, with anodes one and three linked. The Y plate sensitivity of the tube is approximately double that of the X plates, complete vertical deflection requiring about 200 volts potential, and complete horizontal deflection requiring about 400 volts potential. The cathode is indirectly heated by a 4 volt heater.

The positive end of the resistor network is earthed in accordance with standard practice.

6. THE TIME BASE. (fig. 29)

A gas relay circuit is employed feeding into a double triode push-pull amplifier circuit, giving symmetrical deflection.

A 270 ohm resistor and a 10K resistor in the anode and grid circuits respectively, provide current limiting protection for the relay. The synchronising pulse, controllable by a 500K potentiometer, is fed to the grid of the relay, the bias which is controlled by a 50K potentiometer, in a resistor string across the H.T., this provides the amplitude control.

Constant current control is provided by the pentode EF37, grid 2 of which has a variable potential applied via a 25K potentiometer, which gives a fine speed control.

The coarse speed control is provided by a six way single pole switch, only five positions of which are used in the circuit shown, giving a choice of four time base condensers, and an " off " position for use when the spot only is required.

When it is desired to feed to the X plates direct, cutting out the time base, the circuit between the triode amplifiers and the C.R.T. can be broken by links on the rear panel (fig. 24a. C) one X plate being earthed if desired by twisting over one link, whilst the signal can be fed to the other X plate by a single plug inserted in the appropriate link socket. To avoid confusion in use it is desirable when wiring to follow a definite plan of connections for these links. Thus all C.R.T. connections should be taken to the right hand link socket (when viewed from the rear of the oscilloscope)

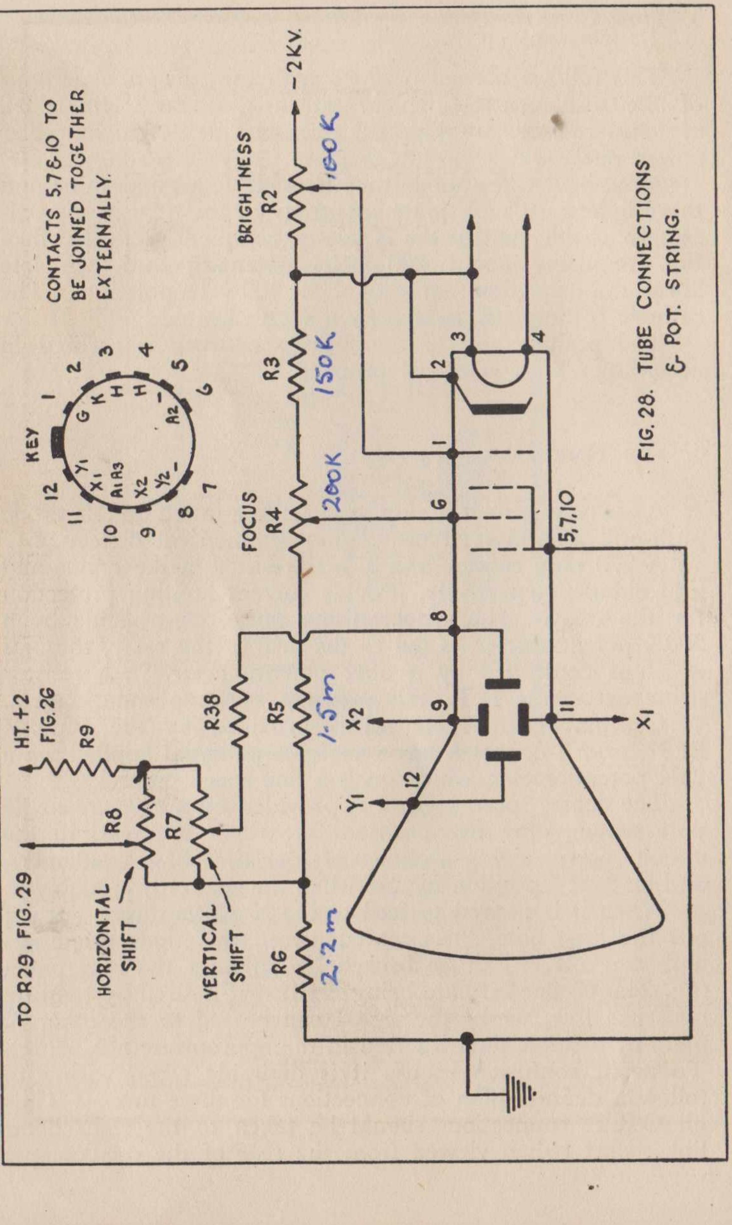
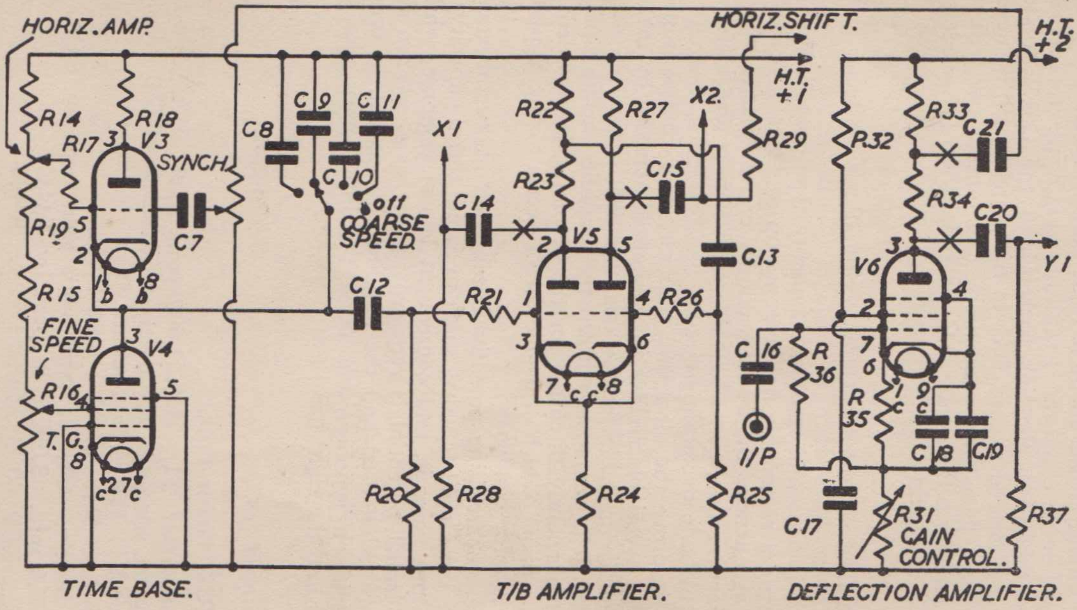


FIG. 28. TUBE CONNECTIONS & POT. STRING.



✱ Rear panel links.

FIG. 29. TIME BASE AND DEFLECTION AMPLIFIER.

so that without difficulty the user will know that incoming signals should be fed to these right hand sockets.

It will be seen that the ·1 mfd. blocking condensers remain in circuit between the link sockets and the C.R.T. plates, and if it is desired to feed D.C. to the plates it will be necessary to bye pass these condensers. In normal use without these condensers the steady D.C. potential from the anodes of the ECC34 would cause serious de-focussing.

7. THE DEFLECTION AMPLIFIER. (fig. 29).

This is a normal resistance capacity type pentode amplifier giving a reasonably flat response up to 4Mcs. As at the higher frequencies the 50 mfd. condenser would tend to lose its capacitive qualities, a ·1 mfd. condenser is also included in the cathode decoupling circuit.

To improve the all round response, gain control is provided by a variable resistor in the cathode circuit, by means of which controllable feedback is obtained.

When it is desired to cut out the amplifier, a link similar to that previously discussed for the X plates, is provided in the rear panel, which will give direct access to the Y plate, via a .1 mfd. condenser.

The synchronising potential is taken off above the anode load of the amplifier valve, so as to avoid added capacity in the output circuit, and consequent loss of response, whilst only a small potential is required in any case. When the links are being used and the amplifier bye-passed, in order to provide a synchronising pulse the input must also be tapped into the right hand synch. socket.

8. COMPONENTS.

(1) C.R.T. Power Pack.

Transformer T1. H.T. 1,600 volts at 1 m/A. Two 4 volt heater windings adequately insulated for 2,000 volts.

Valve V1 HVR2 by Mullard.

Resistors. R1. 270K ½ watt by Erie.

Condensers. C1. ·1 mfd. 3,000 volts peak by T.C.C.

C2. .5 mfd. 3,000 volts peak by T.C.C.

Tube. ECR 60 by Mullard, or VCR 97.

(2) Tube Potentiometer String.

Resistors.
R3. 150K $\frac{1}{2}$ watt by Erie.
R5. 1.5 meg. 1 watt by Erie.
R6. 2.2 meg. $\frac{1}{2}$ watt by Erie.
R9. 270K $\frac{1}{4}$ watt by Erie.
R7 & R8. 500K 2 watt variable by Morgan.
R2. 100K 2 watt variable by Morgan.
R4. 200K 2 watt variable by Morgan.
R38. 2.2 meg. by Erie.

(3) Time Base and Amplifier Power Pack.
Transformer T2. H.T. 325-0-325 volts at 50 m/A.
4 volt heater at 2.5 amps.
4 volt heater at 1.5 amps.
6.3 volt heater at 2.5 amps.
Valve V2. IW4/350 by Mullard.
Chokes. Two 10 henry 50 m/A.
Condensers.
C3. 4 mfd. 500 volt peak electrolytic by T.C.C.
C4. 16 mfd. 500 volt peak electrolytic by T.C.C.
C5. 32 mfd. 500 volt peak electrolytic by T.C.C.
C6. .1 mfd. 500 volt peak paper by T.C.C.

(4) Calibrator.
Resistors.
R10. 10 ohm $\frac{1}{4}$ watt by Erie.
R11. 40 ohm $\frac{1}{4}$ watt by Erie.
R12. 50 ohm $\frac{1}{4}$ watt by Erie.
R13. 80 ohm $\frac{1}{4}$ watt by Erie.
Switch. 3 way single pole.

(5) Time Base.
Valves.
T41 by Mazda V3 (Thyratron).
EF37 by Mullard V4.
ECC34 by Mullard V5.
Resistors.
R14 & R15. 22K $\frac{1}{2}$ watt by Erie.
R17. 10K $\frac{1}{4}$ watt by Erie.
R18. 270 ohm $\frac{1}{4}$ watt by Erie.
R20 & R25. 1 meg. $\frac{1}{4}$ watt by Erie.
R21 & R26. 47 ohm $\frac{1}{4}$ watt by Erie.
R22. 3.3K $\frac{1}{4}$ watt by Erie.
R23 & R27. 68K $\frac{1}{2}$ watt by Erie.
R24. 1K $\frac{1}{2}$ watt by Erie.
R28 & R29. 2.2 meg. $\frac{1}{4}$ watt by Erie.

R16. 25K variable 1 watt by Morgan (Fine speed control).
R19. 50K variable 2 watt by Morgan (Amplitude control).
R30. 500K variable 2 watt by Morgan (Synch. control).

Condensers.
C7. .01 mfd 350 volt working by T.C.C.
C8, C12, & C13. 2 mfd. 350 volt working by T.C.C.
C9. .02 mfd 350 volt working by T.C.C.
C10. .0015 mfd. 350 volt working by Dublier (M type).
C11. .00015 mfd. 350 volt working by Dublier (M type).
C14 & C15. .1 mfd. 350 volt working by T.C.C.

Switch. 6 way single pole. (Coarse speed control.)

(6) Amplifier.

Valve. EF 55 by Mullard V6.

Resistors.
R31. 2K variable by Reliance (T.W./1.)
R32. 33K 1 watt by Erie.
R33. 470 ohms 1 watt by Erie.
R34. 5K 6 watt by Erie.
R35. 150 ohm ¼ watt by Erie.
R36. 1 meg. ¼ watt by Erie.
R37. 2.2 meg. ¼ watt by Erie.

Condensers.
C16. .2mfd. 350 volt working by T.C.C.
C17, C18, C20 & C21. .1 mfd. 350 volt working by T.C.C.
C19. 50mfd. 12 volt working by T.C.C.

(7) Sundries.

Knobs. 10 Eddystone Cat. No. 593.

Valve Holders.
2 B4.
2 I.O.
1 M.O.
1 B9G.

Sockets.
Two—input and calibrator.
Four sets of plugs and sockets for links (rear panel).

Valve caps.
One standard small metal grid cap.
One insulated anode cap (red) Bulgin P92 type.

Mumetal screen for C.R.T.

IV—*THE OSCILLOSCOPE IN USE.*

1. Preliminary.

Having built the oscilloscope before actually putting it into use it is a wise precaution to provide a permanent kit of connecting leads for use with the instrument. This will prevent the usual hasty provision of makeshifts which will normally otherwise be resorted to. In the long run the provision of a proper kit will save considerable time and prevent the tendency to neglect or imperfectly perform some of the tests. Nothing of a complicated nature is necessary; screened leads with crocodile clips, prods, and plugs connected form the basis, and useful additions such as valve top cap adapters, a shorting clip with crocodile clips each end, etc., will suggest themselves according to the tests undertaken.

With the wide variety of uses possible, naturally only only a small number of applications can be described in this book, but they should be sufficient to indicate the general methods that should be followed. It is possible to roughly group the various applications under classifications such as the following.

(*a*) Utilising one pair of deflecting plates only, without any time base, for example use as a voltmeter.

(*b*) Comparison of a known and an unknown quantity, by using both pairs of deflecting plates, again without the time base, for example frequency comparison.

(*c*) A continuous graphical illustration of a function against time, that is using a repeating time base, for example waveform study.

(*d*) Illustration of a function against a base other than time, for example valve characteristics.

(*e*) Other uses not generally applicable to radio, for example cardiographs.

2. USING A SINGLE PAIR OF DEFLECTORS ONLY.

Used in this manner the Cathode Ray Oscilloscope becomes a voltmeter or ammeter, with that most desirable quality that it imposes no load on the circuit under test. When only one pair of plates are used the other pair must be connected together and earthed, to prevent the collection of stray charges. Apart from the fact that there is no loading effect on the measured equipment, among other advantages of using the C.R.O. (as against a normal type of moving coil meter), are that it is not affected by changes of frequency or temperature; it is almost impossible to overload it as any excessive voltage merely deflects the spot off the screen; and D.C. and A.C. voltages are both easily handled, although a special amplifier must be used for low values of D.C.

Calibration of the tube is the first step. For this purpose a transparent scale is mounted as close as possible to the screen. This should be removable so that for other tests there can be uninterrupted viewing. This scale can be made of a sheet of celluloid or perspex, and is accurately ruled into squares. As an alternative and simpler method, which meets with the majority of normal requirements, a strip of gummed transparent tape marked off in millimetres is stuck to the face of the tube in a vertical position, so that the deflection can be seen through the tape and read off on the scale. This scale can generally be left in position as it has little tendency to interfere with the reading of the images.

To set the scale, earth all the plates, focus the beam to the finest obtainable point, keep the brilliance low and then firmly fix the scale so that the zero point lies exactly over the spot. The scale should of course be marked off in both directions from a centre zero point.

After dismantling the previously applied earthing link, a known D.C. voltage from batteries, preferably checked from a reliable meter, is applied via the tube base connection (so as to by-pass the condenser otherwise in circuit) to the Y plates. This will move the spot to a new position on the screen, the distance moved over the scale corresponding to the applied voltage. The movement of the spot per volt applied is uniform over the screen, and the scale can therefore be easily calibrated. Thus, if on application of a hundred volts the spot moves a distance of 5cms, then each millimetre on the scale represents 2 volts.

If an A.C. calibrating voltage is used, e.g., from the calibrator in the equipment, then in place of the movement of the spot, a straight line will be drawn. It will be realised that when the positive half cycle is applied the spot will be drawn in one direction as the applied voltage grows to its positive peak, and as the voltage dies to zero and grows again to a peak in the negative direction, the spot will follow by returning to the zero point on the scale, and then moving to a peak position in the opposite direction, and so on, thus drawing a vertical trace on the screen for as long as the voltage is applied. That is with alternating potentials the line indicates peak to peak voltage, and not R.M.S. value, as read by the usual meter. In general it will be found preferable to calibrate the scale in R.M.S. values, alternatively the D.C. calibrated scale can be used showing peak to peak readings, so that only one calibration is necessary, and these peak to peak readings can then be converted to R.M.S. values by multiplying the value obtained from the scale by .353. Thus if an applied A.C. voltage causes a line on the screen indicating a peak to peak voltage of 100 R.M.S. value is 35.3 volts. Remember that the values quoted for the calibrating voltages supplied from the equipment are peak to peak.

These conversions are of course true only for a sine wave.

To differentiate between positive and negative half cycle a D.C. voltage of known potential can be superimposed and the movement of the trace noted. If the work under test has a D.C. component the picture will be displaced off centre and the use of a blocking condenser in the input lead will prevent this.

Such calibrations will of course apply only where the signals are fed direct to the deflector plates, and not through any amplifier stage. For accurate readings below say 5 volts, amplification will be necessary. For A.C. voltages the built in amplifier can be used, the gain being set at a convenient fixed value, and then a suitable A.C. calibrating voltage being applied to the plates. The scale must of course be re-calibrated for every setting of the gain control. Any distortion caused by a non-linear response of the amplifier will of course cause an incorrect reading, and the gain should be kept at a minimum to guard against this possibility. When an amplifier is used each stage will cause a reversal of phase, so that with a signal that has positive and negative peaks with different amplitudes, this point must be borne in mind when determining the potentials.

For D.C. voltages a special amplifier will be necessary as the coupling condenser normally incorporated will present an infinite impedence to the D.C. and for general purposes normal moving coil voltmeters are preferable.

For higher voltages some form of attenuation is necessary. This can be simply constructed by mounting ten one meg. ¼ watt resistors in series on a strip of bakelite. The input signal is then fed across the potentiometer and each mounting tag, to which the resistors are connected, will then form a step from which a suitable signal can be tapped off to feed to the Y plates, each step will represent one tenth of the total applied voltage.

For current measurements, the C.R.O. is actually used to measure the voltage across a known value of non-inductive resistance connected in series with the circuit under investigation. This voltage drop must be kept small to prevent any distortion due to interposing an excessive impedence.

Testing tone control circuits is one example of the use to which this voltage measurement property of the C.R.O. can be put. Varying frequencies over the range to be covered are fed into the circuit under test, at a constant voltage value. The output voltages are then measured on the oscilloscope, thus giving a comparison of the attenuation at the various frequencies.

3. COMPARISON TESTS.

In this case two A.C. potentials are fed to the oscilloscope, one to the X plates and one to the Y plates. Although there is a difference in the sensitivity of each pair of plates, due to the fact that one pair is mounted nearer to the final anode, for all other functions the X and Y plates may be taken as equal, and in consequence the C.R.O. can be used as a comparative measure, that is it can be used for ascertaining by how much and in what manner one quantity differs from another. Obviously any amplification necessary must be applied to both pair of plates to prevent the introduction of distortion from the test gear, and in general a potentiometer to ensure equal deflection is advisable.

(*a*) PHASE ANGLE.

If potentials of equal amplitude and frequency are applied to the X and Y plates, and if these potentials are also in phase they will each grow to a maximum at the same rate, and throughout the cycle they will each be exerting an equal force on the beam, one in a vertical direction and one in a horizontal direction. So that the resultant force will be the diagonal of the square formed by the horizontal and vertical amplitudes, and the spot will be made to move up and down along a straight line at 45 degrees to the horizontal. The applied signals need not be pure sine wave formation to produce this form.

If the signals are 180 degrees out of phase then once again they will pass through their maxima and minima together and produce again a straight line, but inclined in the opposite direction, as the maxima will in this case be of opposite potential, see fig. 31.

If the applied signals bear some intermediate relationship as regards their phase difference, an ellipse pattern will result, the production of which can be explained by fig. 30.

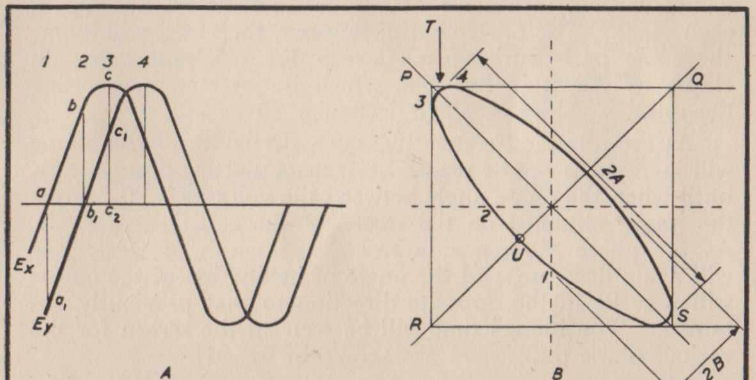


FIG. 30. FORMATION OF ELLIPTICAL IMAGE.

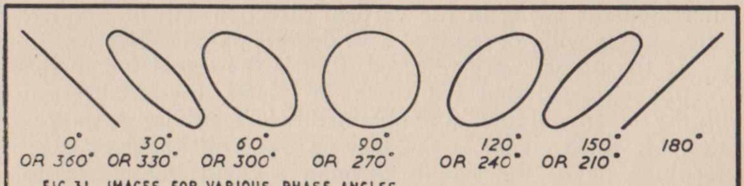


FIG. 31. IMAGES FOR VARIOUS PHASE ANGLES.

Voltage Ex is applied to the X plates and voltage Ey is applied to the Y plates, Ey lagging Ex in phase. At the period of time indicated by number 1 on the diagram, the potential applied to the X plates is zero, and in consequence the movement of the spot in the horizontal direction is nil, whilst the Y plates move the spot vertically to the position 1 shown in fig. 30B, due to the potential $a\text{-}a_1$.

At the period of time indicated by number 2, the Y plate potential is now nil and in consequence there is no vertical movement, the X plate potential however has now grown to the value $b\text{-}b_1$ causing a horizontal movement as shown in position 2 of fig. 30B.

Time 3 shows the horizontal movement at its maximum given by $c\text{-}c_2$, whilst the vertical movement, still growing, has reached the value given by $c_1\text{-}c_2$. Time 4 shows the vertical movement at its maximum, whilst the horizontal movement having passed through its maximum is now decreasing, and so on throughout the sweep of the waveforms the relative values varying in a constant manner in their relationship to each other. The movement of the spot, therefore, will follow the same path during each sweep the resultant being an ellipse as shown in fig. 30B, which is obtained by plotting the relative values obtained from fig. 30A.

As the phase difference increases, the width of the ellipse will increase as can be readily seen from plotting other curves, until when the phase angle between the voltages is 90 degrees the image obtained on the screen of the C.R.O. is a circle. As the phase difference increases, the width of the ellipse will again decrease, and the angle of inclination of the ellipse will now lie in the opposite direction to that previously obtained.. The images that will be seen on the screen for the various phase differences are shown in fig. 31.

Altering the amplitude of one signal only, has the effect of altering both the size and the shape of the image, as if the amplitude of the potential applied to the Y plate is increased the swing in the vertical direction will be greater, and a circle will not result at a 90 degrees phase difference.

If the phases were reversed, that is the signal fed to the X plates lagged that fed to the Y plates, the results seen on the screen will remain as obtained before, so that no indication of which signal is the lagging one will be given. By feeding one of the signals through a small inductance to produce an additional lag an indication can be obtained.

Thus if the ellipse becomes thinner then the signal fed through the inductance will be the leading one, and vice versa.

From fig. 30 it can be seen that with equal amplitudes the axes of the ellipse lie always on the diagonals of the square PQRS. Taking any image, if the length of the greater axis is called 2A and the length of the smaller 2B, then the phase angle can be found as follows.

The instantaneous values e_x and e_y of the voltages applied to the deflector plates are given by

(1) $e_x=E_x \sin \theta$

and (2) $e_y=E_y \sin (\theta+a)$.

Where E_x and E_y are the maximum voltages and a is the phase angle between them.

Eliminating sin θ from equations 1 and 2 gives

(3) $E_x^2e_y^2 + E_y^2e_x^2-2E_xE_ye_xe_y \cos a=E_x^2E_y^2 \sin^2 a$.

The maximum amplitudes of the signals actually applied are equal i.e., $E_x=E_y$, and at the points T and U of fig. 30 the amplitude of each signal is equal (although of opposite potential at point T).

i.e., for T we have $e_x=e_y=\frac{A}{\sqrt{2}}$ and for U, $e_x=e_y\frac{B}{\sqrt{2}}$

Substituting in equation (3) above gives

$$A=E\sqrt{2}\cos\frac{a}{2}$$

$$B=E\sqrt{2}\sin\frac{a}{2}$$

i.e. $\frac{B}{A}=\tan\frac{a}{2}$ or $a=2\tan-1\frac{B}{A}$

That is to find the phase angle between the two signals fed to the deflector or plates, measure the two axes find the angle the tangent of which is equal to their ratio, and double this angle is the required phase angle.

One aspect of this phase difference testing is the measurement of phase shift in ampliers. Signals of varying frequencies are fed direct to one pair of plates of the C.R.O. whilst a portion of the same signal is fed to the other pair of deflector plates via the amplifier under test. The amplitude of the inputs are controlled by a potentiometer and care must be taken to ensure that this does not itself introduce a phase shift. If a straight line is seen on the screen then there is no phase shift in the amplifier, a loop on the other hand will indicate a phase shift the extent of which can be calculated if required, as described previously. A variation in volume at any frequency, i.e., amplitude distortion, will be indicated by the straight line becoming deformed in some manner.

Another application is power factor calculation. The power factor of a supply voltage when applied to a certain load, can be ascertained by comparing voltage and current phase. A resistance across the load will provide a voltage for one pair of plates proportional to the applied voltage, whilst a non-inductive resistance in series with the supply current will provide a voltage for the other pair of deflector plates proportional to the current. This latter resistance must be small in value, so that the load conditions are not affected, and in consequence the amplifier of the C.R.O. will normally be used. From the ellipse obtained on the screen when these voltages are applied to the plates, the phase angle can be obtained and the power factor will be given by the cos. of this angle.

Coils and individual windings can also be tested for faulty operation by comparison with a standard identical unit which is known to be correct. In this case a diagonal line will indicate that the unit under test is sound, whilst an ellipse will indicate a fault.

Resonance is another case in which these properties can be used. When a circuit is supplied with a voltage at its natural frequency it resonates, and the current and voltage are in phase, if therefore it can be found at what frequency this in phase relationship applies, that frequency will be the resonant frequency of the circuit.

The circuit is fed with a voltage supplied from a signal generator, and the tube is connected with its X plates across the circuit, whilst the Y plates are connected across a non-inductive resistance through which flows the current supplied to the circuit. The frequency of the voltage supplied from the signal generator is varied, so that the resultant of the two potentials applied to the C.R.O. will be a series of ellipses and circles until the resonant frequency is reached, when the current and voltage will be in phase and a straight line image will be obtained.

(*b*) FREQUENCY COMPARISON—LISSAJOUS' FIGURES.

This is a continuation of the previous section which was concerned with the application of a particular Lissajous figure, obtained from signals at one frequency with a phase shift between them. When the signals applied to the oscilloscope are at a different frequency, then the phase shift between them is constantly varying, and the actual image seen on the screen is dependant on the ratio of the frequencies. If there is not a simple ratio between the frequencies, a muddled mixture of lines will be seen on the screen forming a useless picture. When, however, one frequency is a multiple of the other, a stationery pattern can be obtained from which it is possible to calculate the ratio between the two frequencies. These various patterns that can be so obtained are known as Lissajous' figures.

If, therefore, one of the frequencies used is of a known value e.g., the mains supply or from a signal generator, the value of an unknown frequency can be obtained from the particular figure on the screen. The actual method of calculation can be obtained from fig. 32, which gives examples of typical Lissajous' figures. Figures *a, b,* and *c,* are of the same ratio of frequencies, and serve to indicate the different images

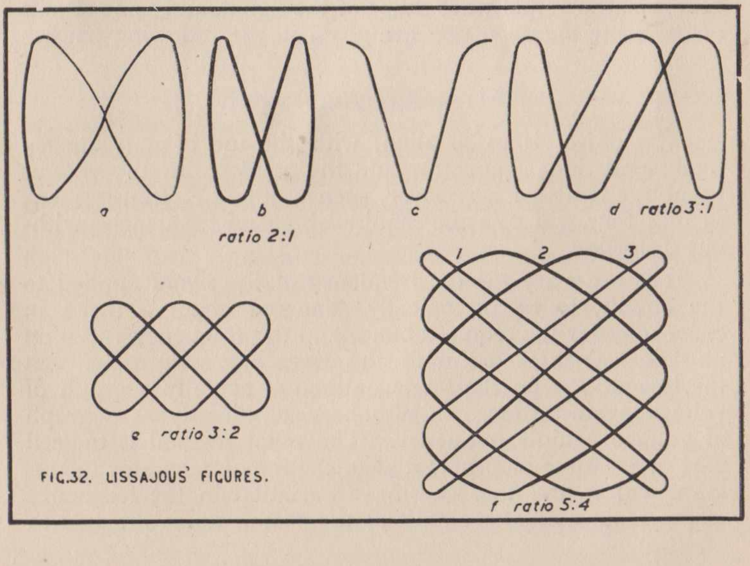


FIG.32. LISSAJOUS' FIGURES.

that can be obtained according to the actual phase angle between the signals.

There are two methods of calculating the ratio between the frequencies.

1. The ratio is the number of complete loops along the top of the image, to the number of loops along one side of the image.

2. The ratio of the number of loops along the edge, to the number of line intersections at the top of the pattern plus one. Thus in fig. 32F there are five loops along the edge and three intersections, and adding one to the latter figure gives a ratio of 5·4.

Beyond ratios of about ten to one the patterns tend to become unreadable, although use of an elliptical time base, obtained by interposing a phase splitting circuit of a condenser and resistor between the X and Y plates, will extend the range by spreading out the pattern into an elliptical form.

4. USING A REPEATING TIME BASE.

This section covers the tests for which, in general, the C.R.O. will mainly be used, and applies wherever it is desired to trace an image indicating variations of a potential with time, i.e., the actual wave shape of the signal, and some details of the more common uses are given in the following pages.

(*a*) ALIGNMENT ADJUSTMENTS.

The object is to so align, with the use of a frequency modulated signal generator and the oscilloscope, the various tunable circuits of a receiver, such as the I.F. transformers, so that they will pass the required band of frequencies without distortion.

It is necessary for the frequency of the signal applied to the circuit, to be periodically changing about a mean in order to cover the required band, and this frequency variation must be synchronised with the time base sweep, so that the image seen on the screen, although actually a graph of voltage against time, can also be read directly as a graph of voltage against frequency. The usual method is to feed part of the time base potential to the signal generator modulating valve, and thus causing a variation in the frequency of the main oscillator circuit at the same rate as the growth of the time base.

The type of curve to be obtained is a flat topped one such as is shown in fig. 33. A peaked response curve will indicate cut off of side band frequencies and consequent poor quality of reproduction. The ideal to be aimed at is a rectangle on a base of 20Kc/s., that is 10Kc/s. either side of the mean frequency to which the circuit is tuned. With experience it is possible to ascertain causes of error by the shape of the trace obtained. For instance one-sided humps are generally due to incorrect coupling, or regeneration, due to an open circuited decoupling condenser or lack of screening.

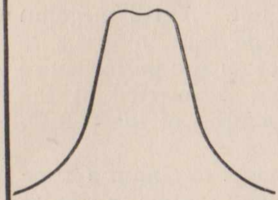


FIG.33. I.F. RESPONSE CURVE.

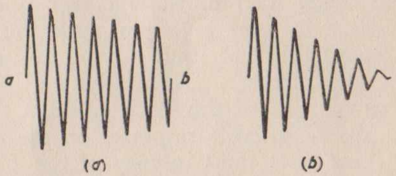


FIG.34. MODULATION TESTS.

(i) Tuning the I.F. Section.

The actual preliminary operations will of course depend on the exact nature of the circuit to be adjusted, but the following will give sufficient general indication to enable the main principles to be adapted to particular requirements.

Disconnect all A.V.C. lines from the A.V.C. portion of the double diode triode in the set. If necessary disconnect the diode load resistor from earth and transfer it to the cathode so that the A.V.C. delay voltage will be inoperative. Any A.V.C. filter circuit should be left connected in as its removal may upset the loading of the I.F. transformer. Earth the disconnected A.V.C. lines.

The next step is to stop the oscillator section of the set. This can be done by removing the valve where a separate oscillator valve is used. In other cases the oscillator section of the tuning condenser should be short circuited, a lead with crocodile clips fitted to each end is convenient for this. A straightforward short circuit is suitable for cases where the grid circuit is tuned, but when the anode circuit of the oscillator is tuned, in case there is H.T. on the condenser a .5mfd. condenser is used to short across the tuning condenser.

In order to provide the necessary locking between the time base and the variations of frequency, the X1 plate of the C.R.O., (via the rear link) should be connected to the appropriate point of the signal generator. This connecting lead should be screened with the screening earthed to both the signal generator and C.R.O. chassis. The output of the signal generator should now be fed to the grid of the frequency changer by a screened lead through a .01 mfd. condenser. The input of the C.R.O. should be connected to the diode load of the receiver under test. A 1-2 megohm resistor is used in series with the 'scope lead in order to prevent the lead itself having any effect on the performance of the receiver. Naturally the resistor is inserted at the receiver end of the lead. Adjust the controls of the C.R.O. to give a suitable response on the screen.

Next reset the trimmers of the I.F. stages to obtain a trace of maximum amplitude commensurate with symmetry similar to that of fig. 33.

(ii) TUNING THE R.F. SECTION.

Remove the shorting clips that were connected for I.F. tuning, from the oscillator section of the set, but leave the A.V.C. disconnected. Switch the set to the required wave band range, and feed the signal generator output to the aerial input terminal of the set. A dummy aerial will be needed for insertion between the radio and the signal generator, and normally this will be included as part of the standard equipment of the signal generator.

If the tuning frequencies stated by the makers of the set are known these of course should be used, otherwise assuming the dial calibrations of the set are accurate set the dial to 300 K/cs for long wave or 1,200 K/cs for the medium waves. If the calibration cannot be trusted then set the condenser with its vanes about ten degrees above minimum capacity. The signal generator should be set to a corresponding frequency, i.e. as stated by the makers, or 300 K/cs or 1,200 K/cs., whichever is being used.

Now adjust the oscillator trimmer (parallel condenser) of the set for maximum undistorted amplitude of the image, and then similarly set the trimmers of all the R.F. circuits.

Now set the tuning condenser to the padding frequency, if the maker's figures are unknown use 160 K/cs. for long wave or 600 K/cs. for medium wave, or adjust the condenser vanes so that they are about ten degrees short of full mesh, whichever system was followed in the first adjustment. Tune the signal generator to the appropriate frequency and adjust the output.

Then adjust the oscillator padder (series condenser) again for maximum undistorted image amplitude. If it is found difficult to find a definite setting slightly swing the tuning condenser either side.

The dial setting of the tuning condenser may be found to be slightly out after making final adjustments, and assuming this error is not due to any mechanical defects, this can normally be accomodated by dividing the inaccuracy over the scale. This will entail resetting the trimmers with the condenser calibration set to take up a little of this error, and then the padder is again reset, the condenser being swung a little as is found necessary, and finally any necessary small adjustments are made to the oscillator trimmer.

(*b*) TRACING CAUSES OF HUM.

Whilst the amount of hum that can be tolerated is a matter for judgement by the ear, tracing the cause and indicating the nature of the cure can only be effectively carried out by using a C.R.O.

It is preferable in practice to run through the simpler tests first as these will often be found sufficient to give the necessary indications, and then follow up with the more complicated tests, rather than thoroughly explore each stage step by step through the set.

If the calibrator output is fed to the synchronising link at the rear panel then the time base can be synchronised to the mains frequency. Connect the earth of the set to the chassis of the C.R.O. and connect a suitable test prod on a lead to the input socket of the C.R.O. The time base should be run at its slowest speed.

The actual number of waveforms that will be seen on the C.R.O. when testing will depend on the system of rectification used in the set under test. Full wave rectification giving twice the number of wave forms to that obtained when half wave rectification is used. The general practice with AC receivers is to use the full wave method, and the receiver hum will cause double the number of waveforms to that obtained from the mains, so that mains pickup and hum can be distinguished due to this difference of frequency. The first essential step, therefore, is to make sure that the difference between hum and normal mains pickup is known. If the input lead is held in the hand there will be sufficient induced voltage to cause a waveform of mains pickup to be seen on the screen, and the time base can be adjusted to produce a steady one or two waveforms at this frequency, hum voltages will then be represented by twice this number of waveforms.

Tests of the following nature can then be carried out. Connect a screened test prod to the set side of the smoothing circuit, e.g. the positive terminal of the smoothing condenser, and a sinusoidal waveform will be obtained indicating an AC ripple on the H.T. supply voltage. A certain amount of ripple will normally be always present, and if it is not excessive it need cause no worry. Should the waveforms so obtained be of alternative unequal amplitudes, indicating an unbalanced output from the rectifier or incorrectly positioned centre tap in the secondary of the transformer, then there is a possible source of hum.

Now apply the test prod to the anode of each valve as a continuation of this series of tests. A similar waveform to that previously obtained should be seen on the screen without any increase of amplitude, although it is feasible that there will be a tendency to decrease with the addition of the decoupling condensers in the circuit of the set. Similarly test the screen grids of each valve, and again the same waveform should be obtained with a tendency to decrease in amplitude due to the decoupling. There is a greater possibility of hum production at these points as the screen has normally a greater effect on the valve than the anode.

With a superhet check the oscillator section of the frequency changer. When the prod is placed on the grid the image obtained on the screen should be that of the oscillator frequency, which appears similar to the usual RF waveform with any hum present showing as a modulating frequency of the pattern. This point of the set is very critical and only a very small amount of such hum modulation can be tolerated.

Finally the grid of each valve in the circuit should be checked for hum, particular attention being paid to the grid of the AF amplifier valves. A.V.C. leads are a possible source of trouble at these points, and it may be found that additional screening will be necessary. The AF transformers must also be checked, and a further possible cause of hum trouble are unbalanced centre taps of heater windings.

Now connect the input lead of the oscilloscope to the output valve anode, and work back through each stage of the set in turn, check the effects of shorting the grid of the valves to earth (this will cut out the previous stage), and by this method the effect on the amplitude of hum due to each stage of the set can be traced.

Apart from hum, in general, fault finding tackled with the oscilloscope in conjunction with a signal generator, can be comparatively simple. The general principle is to connect the input of the C.R.O. to the output stage of the set, and feed a signal of the appropriate frequency to each stage of the set, working back from the output valve. The stage in which the fault occurs can then be quickly detected.

It is well to draw attention to the extremely simple method of finding whether or not the oscillator of a superhet is working satisfactorily mentioned in the hum tracing tests. That is connect the C.R.O. to the grid of the oscillator section of the frequency changer valve, when the RF waveform should be visible on the screen.

The rule for harmonics when these are being examined in an AC waveform, is that odd harmonics produce a symmetrical image, i.e. the waveform is similar both for the negative and positive portion of the trace, whereas even harmonics produce one portion of the trace in reverse to the other, that is as though one portion was being seen through a mirror.

5. USING A BASE OTHER THAN TIME.

In tests of this nature the X plates are not fed from the time base circuit of the C.R.O., but have potentials supplied from an outside source, which is being used as a base upon which the waveform it is desired to study can be drawn.

(a) FREQUENCY RESPONSE CURVES.

In this case the oscilloscope is used to show the manner in which a radio or amplifier responds over a band of frequencies, i.e. power output is plotted against a base of frequency. Once again a wobbulating signal generator is required, and it is connected as discussed previously for receiver alignment, that is so that the time base and frequency variations are tied. The signal generator is set so that the desired band of frequencies is covered, and is fed into the input of the set or the particular stage under investigation. The output of the apparatus is then fed to the input of the C.R.O., which will then show on the screen how the output varies as the various frequencies are fed to the amplifier or whatever is under test; that is the Y axis shows the extent of the output, and the X axis shows the frequencies at which this output occurs.

(*b*) MODULATION MEASUREMENT.

The cathode ray oscilloscope can be used in three ways to measure the depth of modulation of the carrier wave. One entails using the time base of the oscilloscope, the second falls more accurately under the heading of this section, i.e. a base other than time is used, whilst the third utilises more the principles of section 3. These are the methods which can be used for ascertaining modulation depths of transmitters and signal generators, etc.

With the first method the time base of the C.R.O. is used and the modulated signal to be measured is fed to the input of the oscilloscope. A modulated carrier wave will be seen on the screen, and the controls should be adjusted so that it is convenient to measure the maximum amplitude at the peaks and the minimum amplitude of the troughs. The actual unit of measurement used is immaterial as it is a ratio that is required. The compact area of the image seen on the screen will be the RF carrier and the outline of this area will be the modulating waveform. The percentage modulation can then be calculated from the following.

$$\frac{E\ \mathrm{max} - E\ \mathrm{min}}{E\ \mathrm{max} + E\ \mathrm{min}} \times 100 = \%\ \mathrm{mod.}$$

For the second method the modulating frequency only is fed to the X plates. This can be obtained if necessary from the modulated carrier by means of a detector stage. The modulated carrier is fed to the Y plates as before. A trapezoidal image as per fig. 34a will be obtained on the screen and the percentage modulation can be calculated as before that is :

$$\frac{a - b}{a + b} \times 100 = \% \text{ mod.}$$

With this method over modulation will be indicated by the image being pinched out at the end, as shown in fig. 34b.

For the third method a phase splitting circuit is necessary, a variable resistor and condenser will provide this. The signal is then fed to both the Y plates and the X plates, the supply to the X plates being via the phase splitter so that the horizontal and vertical deflections are 90 degrees out of phase. An unmodulated carrier will then give a circle as the image on the screen. Modulation will cause the circle to broaden out into a thick ring. The modulation percentage in this case is then given by the width of the pattern to the diameter of the inner circle, multiplied by 100.

(c) VALVE CHARACTERISTICS.

The characteristics of a valve are the graphs of two varying functions which affect the behaviour of the valve. Thus one characteristic may be the graph of how the anode current varies with changes of grid potential, the Ia/Eg curve, whilst another is the graph of variations of anode current with anode voltage, the Ia/Ea characteristic.

This can, of course, be plotted point by point with the aid of meters, but for speed and accuracy such methods do not compare with the use of the C.R.O. which gives a drawing of the curve on its screen, of a dynamic characteristic, i.e. one depicting the behaviour under actual working conditions. Another great advantage of using the C.R.O. for valve investigation, apart from speed and general convenience, is that the valve has extremes of voltages applied to it for only transient periods which do not last sufficiently long to normally cause trouble, whereas under other circumstances such extremes can cause damage to the valve.

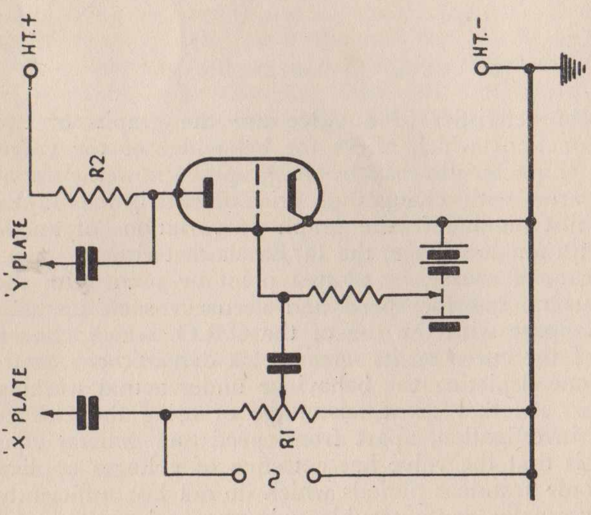


FIG. 35 CIRCUIT FOR
Ia/Eg CHARACTERISTIC.

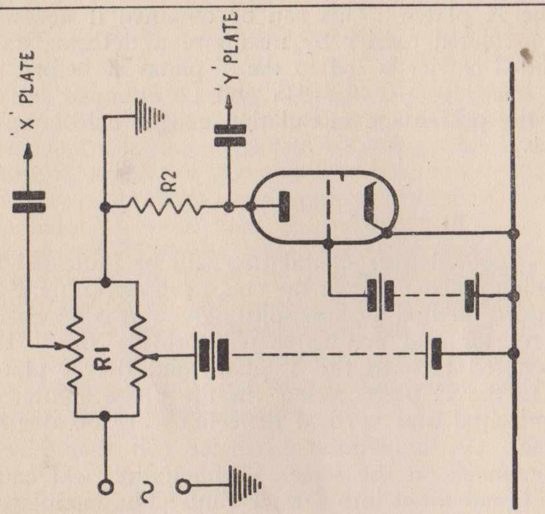


FIG. 36 CIRCUIT FOR
Ia/Ea CHARACTERISTIC

The valve is supplied with its usual H.T., L.T. and bias voltages either from a mains supply unit or batteries, the latter being preferable.

What is required is that the X plate sweep varies at the same rate as the bias varies on the valve for an Ia/Eg curve, and in consequence the source of supply for the fluctuating grid voltage is also connected across the X plates so that the desired synchronisation is automatically obtained. AC from a mains transformer is suitable for this fluctuating supply. As an alternative the time base potential of the C.R.O. can be used to provide the varying grid potential by inserting the potentiometer R_1 of fig. 35 in the link circuit on the rear panel, but the former system is the more simple.

The actual range of the grid variations is, of course, much smaller than the potential required for an adequate base sweep; and in consequence the potentiometer is included in the circuit to provide the necessary adjustment. The Y plates are connected across the resistor R_2 in the anode of the valve so that as the current through the valve varies, the potential drop across this resistor varies, and it is this fluctuating potential that is fed to the Y plates to cause the vertical displacement of the beam. The deflector plates will not, of course operate from a current fed to them, but require a potential to deflect the beam and hence this necessity for this anode resistor, but as the P.D. over the resistor is directly proportional to the current flowing through it, the curve on the screen can be read as a current curve. In addition the presence of a load in the anode circuit creates conditions approaching the more normal operation of the valve.

There is, of course, no conventional flyback operating on the X plates, the action being along the following lines. As the voltage applied to the grid grows in a positive manner, this voltage is applied to the X plates in amplified form, and tends to move the spot in a horizontal direction. At the same time, due to the decreasing bias, the current through the valve increases and the potential applied to the Y plates grows in a similar manner, so that the Y plates tend to move the spot in a vertical direction, and the resulting image on the screen follows the line of the conventional characteristic. As the AC cycle applied to the grid reaches its peak, and begins to decrease, the Y plate potentials will decrease at exactly the same rate as they previously increased, so that the spot travels back over the same path, creating only one image on the screen.

For another common family of valve characteristics, the grid bias is held steady and variations of anode current with anode voltage variations are plotted. The circuit for obtaining curves of this nature is shown in fig. 36.

Again in this case the X sweep is provided by the external alternating voltage, and the potential across the anode resistor R_2 is fed to the Y plates. The AC voltage across the potentiometer R_1 has the effect of alternatively aiding and opposing the steady anode voltage so that the actual potential applied to the valve anode is swept between two limits, causing a variation in the anode current which produces a curve on the screen against a base of varying anode voltage.

6. GENERAL USES.

The scope of the C.R.O. as applied to radio is of course far more extensive than the various indications given in this chapter, but they serve to show the methods of application so that the use of the oscilloscope can be adapted for the particular need in hand. In addition, of course, there are numerous applications outside the field of radio proper, and this field of use is being continually extended. Such examples are its application in Radar for the measurement of distances by echo reception. Pressure is another example; with carbon pile resistors the actual voltage variations due to different pressures can be shown on the screen of the C.R.O. after amplification. B.H. curves for iron can also be drawn on the C.R.O. screen, the X axis being the magnetising force, the potential being obtained from a resistor in series with the applied current to a primary winding round the iron, whilst the Y axis is the magnetic flux, obtained from the voltage arising from a secondary winding.

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