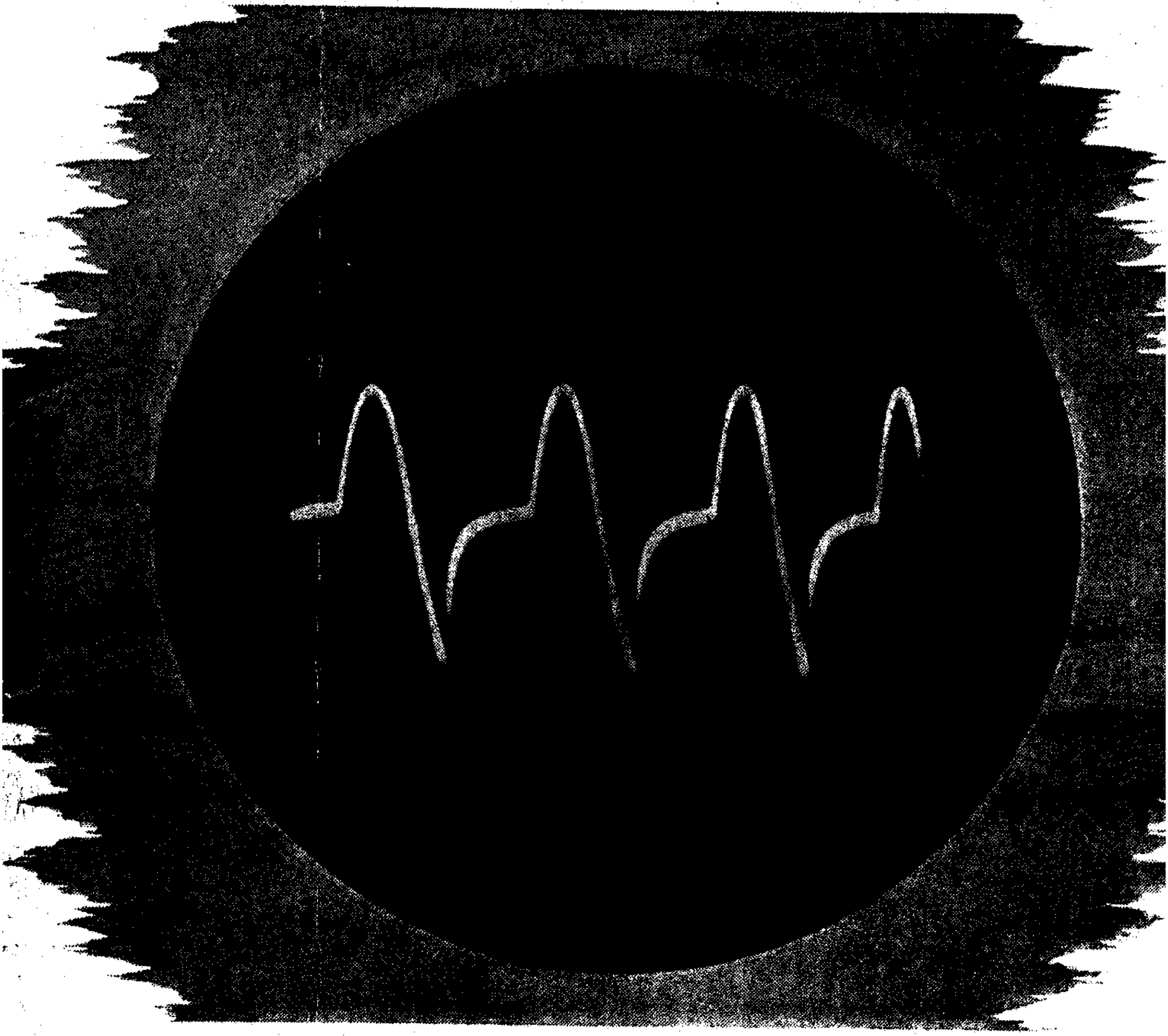
The CATHODE RAY OSCILLOSCOPE

Its uses as an aid to Radio Service

By W. E. MILLER, M.A. (Cantab.), M.Brit.I.R.E.



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FOREWORD

This book is based on a series of articles written for "The Wireless & Electrical Trader," and has been published to satisfy the large demand for reprints of the articles in handbook form.

Acknowledgments are due to A. C. Cossor, Ltd., and The Mullard Wireless Service Co., Ltd., for the loan of instruments enabling the photographs of traces to be obtained in "The Trader" Laboratory; and to E. A. W. Spreadbury, A.M.Brit.I.R.E., of "The Trader" Technical Staff, for suggestions as to the subject matter covered, and for considerable help in the experimental and photographic work.

W. E. M.

Second Edition

Since the first edition was published, there has been an increasing demand for the book by those who are coming into contact with oscilloscopes and the cathode ray tube generally in connection with their work in the Services, and also by trainees and students of technical colleges.

Owing to the fact that the principles of commercial oscilloscopes have not changed since the publication of the first edition, it has not been felt necessary to revise the subject matter in the new edition.

W. E. M.

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The Cathode Ray Oscilloscope

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THEORY OF THE TUBE

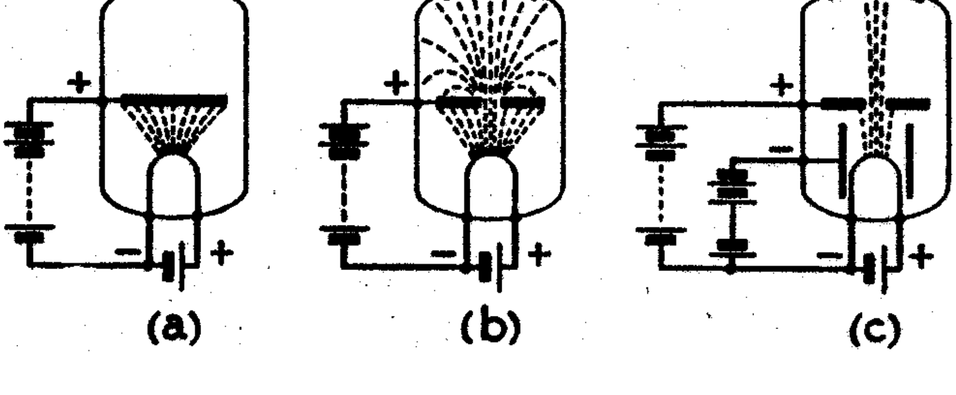
IN view of the fact that many prospective users of cathode ray oscilloscopes are still unfamiliar with the construction and operation of the cathode ray tube itself, it is proposed to deal with this subject at the outset.

There is no doubt that a full understanding of the design of tubes and their associated circuits is of utmost importance to the user of an oscilloscope, enabling him to realise fully the capabilities and limitations of the instrument.

In considering the design and operation of the cathode ray tube, we can regard it as a development of the ordinary thermionic diode. In Fig. 1 (*a*) we have an evacuated container with a heated filament or cathode emitting a stream of electrons. The electron is, of course, a minute negative charge of electricity. Normally, a heated filament only emits a few electrons, which pass back to it in the absence of anything tending to remove them. If we insert another electrode, and maintain it at a positive potential with respect to the cathode (filament), then the negative electrons, obeying the ordinary laws of attraction and repulsion, are attracted to the positive anode, and flow round the external circuit to the cathode, forming the anode current. The number of electrons reaching the anode depends, up to a point, on the positive potential to which the anode is raised, and in addition, the higher the potential, the greater the acceleration of the electrons, and the greater their speed on reaching the anode. So far we have the ordinary diode valve.

Now consider Fig. 1 (*b*), where we have the same diode, except that the anode is pierced with a small hole in its centre. Again we have the electrons reaching the anode, but this time some of them will pass through the hole in the anode. Of these, the slower ones will only just pass through, and will be attracted back to the anode. Those with the greatest speed, withstanding the attraction of the anode, will travel in a straight beam to the wall of the evacuated bulb. Between these two extremes will be electrons of intermediate speeds which will be bent from the straight beam to a greater or lesser extent, partly by the attraction of the anode, and partly by mutual repulsion. Their paths are indicated roughly by the dotted lines, and it will be seen that the

Fig. 1—Three stages in the development of a simple cathode ray tube.



effect is something like that of a fountain.

It was soon discovered that the electrons arriving at the inner surface of the glass bulb had the very useful property of causing certain materials to become fluorescent when they impinged on them. This fluorescence makes itself visible as a luminosity of a colour depending on the materials with which the inside of the bulb is coated. In the embryo cathode ray tube shown in Fig. 1 (*b*), the whole of the end of the bulb, if suitably coated, would be illuminated to a greater or lesser extent, being bright at the centre, and fading off outwards.

The next step was to find some method of "focusing" the electron beam, so that all the light would be concentrated in a single spot on the screen. The first method employed was to introduce a small quantity of inert gas (such as argon) into the evacuated bulb, which, on "bombardment" by the fast-moving electrons, became ionised. The result of ionisation of the gas is to knock some of the negative electrons out of the neutral gas molecule, leaving it as a positive ion. These ions, being relatively heavy, do not move quickly away from the electron beam, but instead they remain in it for some time, and have the effect of attracting to the centre of the beam the slower moving electrons which would normally be

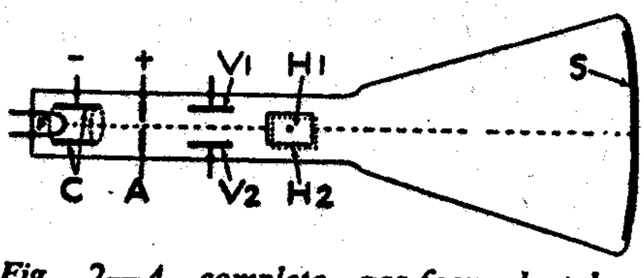


Fig. 2—A complete gas-focused tube, showing all the electrodes. The action of the vertical and horizontal deflecting plates is explained in the text.

dissipated outwards, and would therefore either fail to pass through the anode aperture, or, having passed through, would return to the anode, or reach the screen some distance from the central spot.

The beam thus becomes concentrated, and the spot on the screen is made smaller and brighter. "Focusing" under these circumstances is assisted by varying the filament current, so that the number of electrons emitted is no greater than the positive ions can handle.

This method of focusing suffers from many defects, so further means of getting over the difficulty were sought. It was found by Wehnelt that if the filament were surrounded by a negatively charged cylinder, the effect of this, in repelling the outer electrons in the beam, was to concentrate them down a central core. This caused a much greater number to pass through the anode aperture, after which the positive ions took charge of the situation and kept the beam concentrated. This is shown in Fig. 1 (*c*).

The negative potential of the Wehnelt cylinder must be considerably less than the positive potential of the anode, otherwise no electrons will reach the anode and pass through it. Actually, it is of the order of one-tenth or one-fifteenth in the "soft" type of tube under consideration. Focusing of the beam may be effected partly by varying the cylinder potential and partly by altering the filament current. These variations also affect the intensity of the spot by altering the number of electrons which reach the anode.

Fig. 1 (*c*) really shows the simplest type of "soft" cathode ray tube, in diagrammatic form. In practice, the glass envelope is tubular, expanding at the end, and flattened to form a more or less plane screen.

We must now consider how the light spot on the cathode ray tube screen can be used for oscilloscopic work. In an oscilloscope we are really causing variations in voltages or currents to be indicated on a screen in the form of a line of light which is generated in the same way as we "plot" a graph. In most cases two axes at right angles are employed. In plotting voltage variations the horizontal axis represents the time, and the vertical the voltage. The position of any point on the line is defined by its horizontal and vertical distances from the origin. The same applies to the cathode ray tube. The spot is really a "point" on the line, and its movement generates the line. Obviously, then, for oscilloscopic work one must be able to move the spot about over the screen.

Fortunately, this is a relatively simple matter in a cathode ray tube. We have seen that the beam is really a stream of electrons, and the movement of these, and hence of the beam, can be influenced by a magnetic or electrostatic field. In practice for most purposes it is more convenient to use the electrostatic field, and two parallel flat electrodes are built into the tube between the pierced anode and the screen, and are so positioned that normally the beam passes between them in a plane parallel to them and equidistant from them.

In Fig. 2, F is the filament of the tube, C the Wehnelt cylinder (" shield "), A the pierced anode, and S the screen. V1 and V2 are the two deflecting plates mentioned above, seen edgewise.

Now suppose a DC potential is applied between V1 and V2, so that V1 is positive with respect to V2. Since the beam is composed of negatively charged electrons, these will be attracted towards V1, and repelled away from V2. The result is that the beam as a whole will be deflected upwards in passing between V1 and V2, to an extent depending on the applied voltages. It should be noted that the deflected beam, after leaving the plates V1, V2, continues in a straight path until it impinges on the screen. Obviously, it will now reach the screen at some point above the centre. Now suppose that the voltages on the plates V1, V2 are reversed, so that V2 is positive with respect to V1. Obviously, the beam will now be moved downwards, but to the same extent as before.

If now an alternating potential is applied between V1 and V2, the spot will move up and down in time with the fluctuations in the input, and will thus trace out a line, of length proportional to the applied voltage. At very low frequencies it will be possible to follow the movement of the spot, but at frequencies of 35 C/S or more the effect will be that of a straight line of light, free from noticeable flicker. This, however, will tell us very little about the characteristics of the applied voltage. In order to study them we must trace them in two dimensions on the screen.

For this purpose, a second set of plates is mounted in the tube, with planes exactly perpendicular to those of the first set. These plates are indicated at H1 and H2 in Fig. 2, the lower plate being dotted and slightly displaced.

This set of plates will, if energised by a varying voltage, move the spot of light horizontally along the screen. By energising both sets of plates, either by the same or by different voltages, the spot of light is caused to follow a path which is the result of a combination of the two paths it would have travelled if the sets of plates had been energised separately.

So far we have only considered the " gas focused " or soft tube, which, although suitable for most oscilloscopic work, has the disadvantage that, when examining extremely high frequency phenomena, there is a tendency for the heavy focusing ions not to follow the rapid movement of the beam, so that the focus deteriorates. The extent to which this occurs depends on the gas pressure and other factors, some tubes being much better than others.

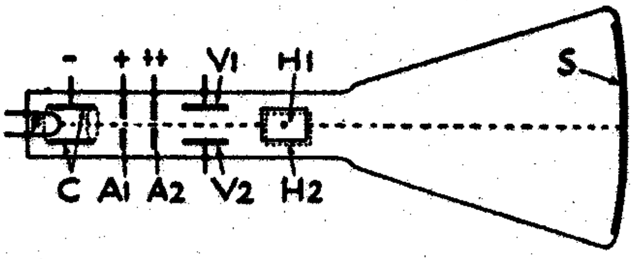


Fig. 3—A hard type of tube in which focusing does not depend on gas content, but on the relative voltages applied to the two anodes.

Consequently, the " hard," or completely evacuated, tube is used in many oscilloscopes. As its name implies, the tube is pumped free from gas, and therefore the advantages of ionisation in assisting the focusing are lost. Focusing in the hard tube is accomplished by the use of two or more pierced anodes, which are supplied with variable positive potentials. Fig. 3 shows a simple hard tube with two anodes.

If we consider, for the purpose of analogy, that the electron beam is comparable with a beam of light, then the pierced anodes A1 and A2 can be regarded as lenses. These " electron lenses " have an effect on the electron beam somewhat similar to that of an ordinary glass lens on a beam of light. They tend to bring the beam to a focus at a definite point, and since this point must be on the screen, it is necessary to adjust the potentials applied to the anodes.

The hard tube is, of course, fitted with the negative " shield " (C), and this controls the brightness of the spot. Naturally, the two pairs of deflector plates are retained in the hard tube.

The internal construction of cathode ray tubes may differ in certain respects from the elementary types considered above. For instance, the filament in modern tubes is replaced by a heater/cathode assembly, soft tubes often have a special form of deflector plate construction to avoid distortion; while hard tubes may have more than two anodes.

TUBE SUPPLIES

HAVING considered briefly the internal construction of a cathode ray tube suitable for oscilloscopic work, it is clear that, whether the tube be of the "soft" gas-focused type, or of the "hard" electron-lens focused type, it will need a heater supply; a positive anode supply (more than one in the case of a hard tube), and a negative shield bias.

In the case of the soft tube, the shield bias is made variable and controls the focus, and also the brightness, of the spot or trace. In the case of hard tubes, the variable shield bias controls the brightness, while the positive supply to one of the anodes is also made variable, and controls the focus.

The various power supplies are usually obtained from a simple form of power unit included in the oscilloscope casing. Practically all commercial oscilloscopes are for AC operation, although there is no reason why AC/DC or even battery-operated types should not be successfully made.

In AC models matters are so arranged that all necessary voltages are taken from a single power supply, and Fig. 4 shows one of the simple forms which such a supply for a hard tube may take. The HT rectifier is a half-wave type, and two smoothing condensers and a smoothing resistance (R1) are shown. In practice, R1 and the second condenser may sometimes be omitted without introducing a ripple on the trace.

Across the HT output is connected a potentiometer consisting of R2, R3 and R4 joined in series. R2 and R3 are each separate potentiometers with adjustable sliders, whereas R4 is a fixed resistor.

On the right is the neck end of the cathode-ray tube in schematic form. The heater is run from a separate low voltage secondary on the mains transformer (not shown). R2 is the negative end of the network. The cathode is connected to the junction of R2 and R3, and the shield of the tube goes to the slider of R2. Consequently, the shield is always negative relative to the cathode, depending on the distance of the slider of R2 from the junction of R2, R3.

Hence R2 varies the negative bias on the shield and acts as the brightness control in the case of a hard tube.

The slider of R3 goes to the first anode of the tube, and is always at a positive potential relative to the cathode, depending on its distance from the cathode end of R3.

The maximum HT voltage (at the top end of R4) is applied to the second anode of the tube, and is usually not variable. Since R3 is variable, this control enables the voltage on the first anode relative to that on the second anode to be adjusted and so provides for focusing.

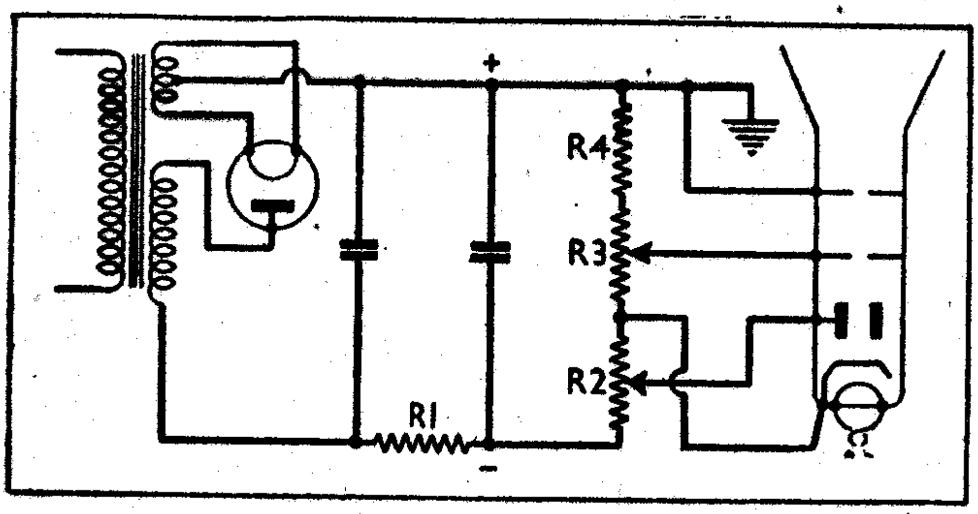


Fig. 4—A simple form of power supply for a hard cathode ray tube. Its features are fully described in the text.

In actual practice, since the amount by which the first anode voltage normally has to be varied is quite small, R3 is often replaced by a fixed resistor in series with a low value potentiometer so that the latter provides a fine degree of control.

With a gas-focused tube, R2 usually becomes the focusing control, and there is only one (fixed) anode voltage supply. Actually the focusing control also affects the brightness, and there is usually an optimum setting at which the best focus, coupled with adequate intensity, is secured.

The actual values of the various applied voltages depend largely on the type of tube used. In general, the larger the tube, the greater will be the anode voltages required. Thus, with a miniature tube (about 1 in. or 1½ in. screen), the first anode voltage may be 50 to 100 V, and the second anode something between 250 and 500 V. On the other hand, a 4-in. tube may require a first anode voltage up to 500 V and a second anode voltage up to 1,200 V or more.

The negative shield voltage may be of the order of 20 to 40 V. It is important that this bias should not be reduced excessively, otherwise the tube may be damaged, just as an ordinary valve may be seriously affected if it is run with a low grid bias. On most commercial oscilloscopes a stop on the control R2, or a fixed limiting resistance, is provided to prevent the tube being seriously over-run.

In any case, however, it is always best to run the tube at the maximum bias consistent with a reasonably bright trace.

There is another point in connection with Fig. 4 which is worth noting, and that is that the positive of the HT supply is earthed. This is not always the case but it is a practice which is largely employed, since it renders the tube far more immune from the influence of external stray fields, which might deflect the spot, if not off the screen, at any rate away from its centre.

As a result of earthing the positive of the HT supply, the electrodes which, in an ordinary valve, would be regarded as safe to handle, actually become the dangerous ones. Obviously, with the HT positive earthed, the second anode is safe, because it is at earth potential. The cathode, however, may then be anything up to 1,000 V or so *negative* to earth, and therefore dangerous to handle, while the shield (corresponding to the grid in an ordinary valve) is even more negative with respect to earth.

Not only must the manufacturers of the oscilloscope take precautions with regard to insulation, etc., of the negative end of the circuit, but the user must remember which parts are "live" if he ever has to carry out investigations inside the casing of the oscilloscope.

Where the negative end of the high voltage supply is earthed, the second anode becomes the most dangerous electrode (relative to earth).

It is now necessary to consider the method of positioning the cathode ray spot on the end of the tube. If the tube were accurately made as far as the alignment of the electrodes was concerned, and if none of the deflecting plates were able to acquire static charges, and if there were no external electrostatic or electromagnetic fields, then the spot should be exactly central on the end of the tube.

In practice, tubes may not be absolutely perfect in their alignment, or other factors may result in the spot being off centre to a certain extent. Although not essential, it is desirable that for most observations the cathode ray spot should be approximately central on the end of the tube.

For other observations (for example, the response curve of the IF stages of a receiver, used for alignment) it may be advantageous to have the spot centred from left to right, but nearer the bottom than the top of the tube.

In order to have the spot position under the control of the operator, provision is usually made for this by variable controls on the oscilloscope. These "shift" controls, as they are called, are generally marked "horizontal" and "vertical," and may be operated either by knobs on the control panel, or, since they are of a subsidiary nature, may be in some less conspicuous position, and operated by screwdriver slots in the spindles of pre-set controls.

Wherever they are placed, their effect is to apply a certain amount of voltage bias to one of each pair of plates relative to the other. In many oscilloscopes, one of each pair of plates will be connected permanently to the second anode of the tube (which, as we saw earlier, is usually at earth potential). Reference should now be made to the diagram (Fig. 5), which

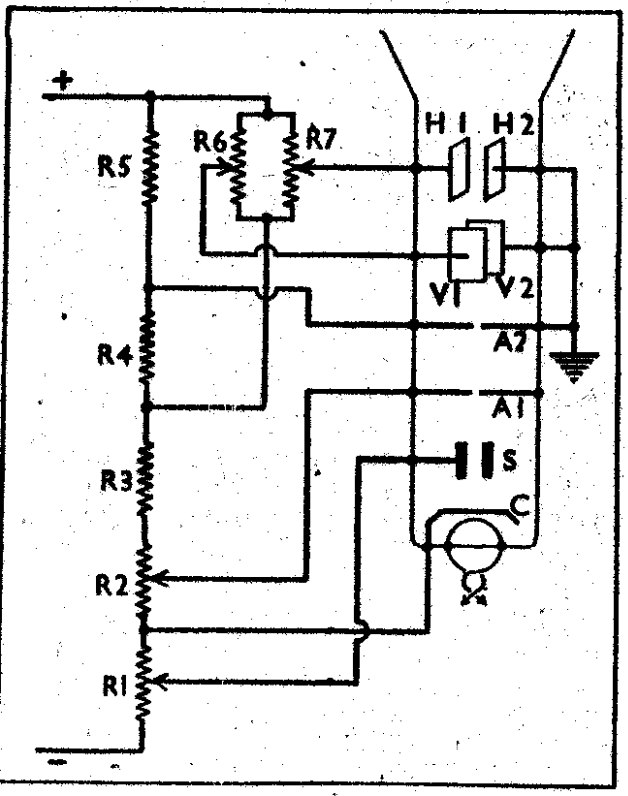


Fig. 5—Diagram showing one method of introducing shift controls in an oscilloscope.

shows one of the horizontal* plates (H2), and one of the vertical plates (V2) connected externally to the second anode (A2) and earth.

The positive and negative HT lines are on the left of the diagram (the mains transformer, rectifier and smoothing arrangements being omitted for the sake of simplicity). Across the HT supply is the potentiometer network R1, R2, R3, R4, R5, which is an elaboration of the network R2, R3, R4 shown in Fig. 4.

R1 is the brightness control, applying a negative bias to the shield S, relative to the cathode C, which is connected to the junction of R1 and R2. R2 is the focus control, varying the positive voltage of the first anode A1, relative to cathode.

The second anode A2 is connected to the junction of R4 and R5, being higher in voltage than A1 by the drop along part of R2, and R3, R4. R5 is between the second anode and the positive HT line, so that the voltage on the second anode is less than the maximum HT voltage by the amount of the drop along R5. R4 and R5 are generally equal in value, so that the voltage at the top of R5 is positive to the second anode by a certain amount, while the voltage at the bottom of R4 is negative to the second anode by the same amount.

Across these two points are two potentiometers, R6, R7, wired in parallel. The slider of R6 goes to the plate V1, while the slider of R7 goes to H1.

Obviously, with the slider of R6 halfway along its resistance element, the voltage of V1 will be (approximately) the same as that at the junction of R4, R5 (since these are equal in value), and therefore V1 will be at A2 and V2 (earth) potential.

By varying the position of the slider, V1 will be given a positive or negative potential relative to A2 (and V2), depending on whether the slider is above or below the centre of R6. Consequently, since the vertical position of the spot depends on the potential of V1 relative to V2, the effect of operating the knob of R6 is to shift the spot up or down, as required.

The same remarks apply to the control R7, except that in this case the spot may be shifted horizontally across the screen as required. Sometimes one of the controls is omitted for the sake of economy, while another scheme is to provide a single shift control which can be applied to either the horizontal or vertical plates as required.

Again, where no shift controls are provided, it is possible to alter the position of the spot by applying an external biasing voltage.

In some oscilloscopes, provision is made for obtaining direct access to all the plates, in which case H2 and V2 are disconnected from each other and earth by suitable switching, while the shift arrangements are also put out of action.

Some oscilloscopes employ slightly different methods of shifting the spot, the difference being usually in the manner of obtaining the necessary bias. It is common practice to tap this off the time-base HT supply, instead of the tube supply, but in principle the method is the same.

* Throughout this book, the deflecting plates will be described by the effects they produce. Thus the plates producing a horizontal deflection will be described as horizontal plates, though actually they are those mounted vertically in the tube.

VOLTAGE MEASUREMENT

BEFORE going on to the subjects of time-bases and amplifiers, it will be instructive to see what can be done with the equipment as it stands. When this has been thoroughly absorbed, it will be time enough to advance to more complicated matters.

It was seen on an earlier page that the application of a DC voltage to one deflector plate of a pair, relative to the other, caused a movement of the spot. This immediately suggests that the tube can be used as a voltmeter by measuring the displacement of the spot.

If AC is applied, of course, the spot is drawn out to a line proportional in length to the amplitude of the applied signal, that is, to twice the *peak* voltage. Note that an oscilloscope used in this way becomes a peak voltmeter, and allowance must be made for this in calculating RMS* values.

Before an oscilloscope can be used for voltage measurement, it must be calibrated. Most manufacturers of these instruments quote the deflection sensitivity to be expected.

A typical commercial oscilloscope may have a sensitivity of the order of 10 V RMS per centimetre.

Owing to the fact that slight changes in the tube sensitivity may occur as time goes on, due to the ageing of the HT rectifier valve and similar causes, it is advisable where actual voltage readings, rather than comparisons, are required to check up the calibration occasionally. In some oscilloscopes an extra winding on the mains transformer is provided, with a terminal suitably marked for connection to the input to the vertical plates, the voltage of this winding being specified. For more accurate work an AC voltmeter can be used to check the voltage of this winding while it is being used for calibration. Alternatively, a measured AC voltage can be applied from an external source.

Naturally, an oscilloscope is rarely used for DC voltage measurements, as ordinary DC voltmeters are usually available, but for AC it is quite useful, for the following reasons: First, its scale is linear, and voltage is easily read off by means of the ruled millimetre scale usually fitted in front of the tube. If, when calibrating, it is found that a voltage of 20 produces a line 10 mm. long, then a 25 mm. line is obviously produced by a 50 V input. Second, the instrument is virtually independent of frequency, and RF voltages can be measured as easily as supply and audio frequencies. Third, the input impedance (using direct connections to the deflector plates, and cutting out any input potentiometers) is extremely high, so that errors due to loading the circuit being measured are unlikely.

Against these facts there is the disadvantage that the range is limited by the sensitivity and size of the tube. Thus, with direct connections to the plates, a 3-in. tube and a sensitivity of 10 V per cm., it will not be possible to measure voltages below, say, 5 V very accurately, while the size of the tube limits the maximum voltage to about 75 V. If higher voltages are to be measured, they must be applied through a potentiometer arrangement, the oscilloscope being connected across a section of the potentiometer.

For measurement of lower AC voltages, recourse must be had to an amplifier. Most oscilloscopes incorporate a suitable voltage amplifier, and sometimes this can be adjusted to different sensitivities.

A good modern oscilloscope with a 2-stage amplifier may have a sensitivity as high as 10 mV per cm., or even greater.

In using the amplifier of an oscilloscope for AC voltage measurement, it must be borne in mind that the amplifier may limit the range of frequencies which can be measured with accuracy, while it may have an input arrangement which places a load on the circuit being measured. In some cases a switch is provided for disconnecting the variable input potentiometer of the amplifier, permitting the voltage being measured to be applied direct to the grid of the amplifier valve, in which case the trouble does not arise.

* The RMS, or "root-mean-square" voltage of AC is less than the peak voltage, and is the value which, multiplied by the RMS current, gives the same power as would be given by a DC voltage and current of the same value. The RMS voltage is thus the "effective" voltage, to be used in any calculations involving power, and measured by most AC meters, whereas peak voltage represents the maximum instantaneous voltage to which an alternating current can rise. It is the peak voltage which is actually registered on an oscilloscope, but this is readily converted to the RMS value by dividing by the square root of 2 (or multiplying by 0.707).

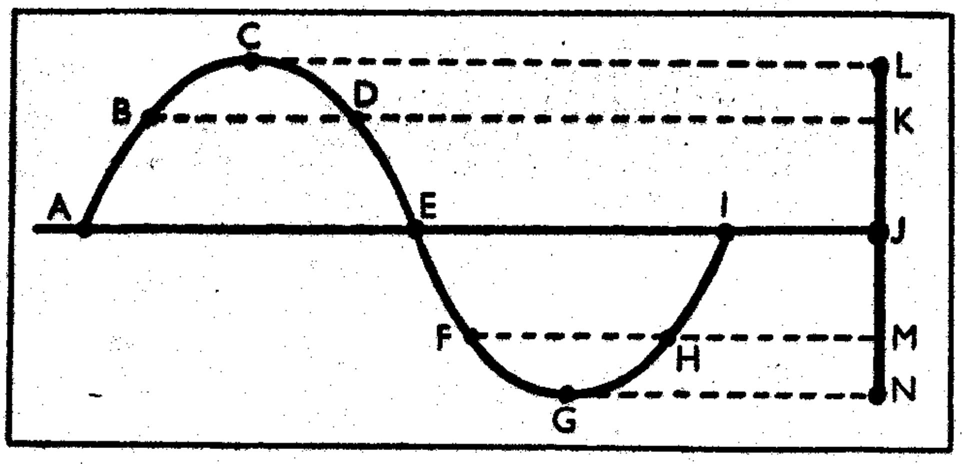


Fig. 6—Generation of a straight line traced by an AC input.

Care must be taken when measuring AC voltages, as has been indicated earlier, not to get confused between peak and RMS values, and between the voltage and the amplitude (peak to peak voltage), which is double the voltage. A reference to Fig. 6 will make this clear. *A* to *I* represents one complete cycle of AC. On applying this to the vertical plates of the tube the line *LKJMN* is produced. *J* represents the initial position of the spot on the tube, corresponding to the point *A*, of zero voltage, on the incoming wave of AC. As the wave progresses, the voltage rises, and the spot begins to move vertically upwards. Point *B* on the wave corresponds to point *K* on the oscilloscope screen, the peak *C* corresponds to the top of the line (*L*), then the voltage falls to point *D* (*K* again on the screen), then to *E* (*J* on the screen). The voltage then reverses, and the *JMN* portion of the line is drawn out (corresponding to *EFG*). Finally, the spot returns via *N* and *M* to *J*, corresponding to *GHI* on the wave.

A complete cycle has thus been traced, and this is repeated 50 times per second in the case of a 50 C/S supply, giving the impression on the screen of a steady line of length *LN*. It will be noted that *LN* is equal in length to the vertical distance between *C* and *G*, that is, it is proportional to the peak to peak voltage, or amplitude, of the incoming wave. Obviously, the true peak voltage is proportional to the height of *C* above the horizontal *AEI*, that is, to the length *LJ*, which is half *LN*.

If DC is used for calibration of the tube, and the tube is then used for AC voltages, the result must be divided by two to get the peak voltage.

If AC is used for calibration, the applied voltage having been checked on an ordinary AC voltmeter reading RMS voltages, then the readings obtained will be true RMS voltages, and will need no correction.

The relation between RMS and peak voltages for a pure sine wave, such as is theoretically given by good AC supplies, is that the RMS voltage is approximately 0·707 times the peak voltage.

Consequently, to convert peak voltages to RMS voltages the peak value is multiplied by 0·707; to convert RMS voltages to peak voltages, the RMS value is multiplied by 1·414.

Before leaving the subject of voltage measurements, it is as well to point out that the deflection sensitivity for both sets of plates of an oscilloscope is not necessarily the same—in fact, it is nearly always different, and in most cases the vertical plates have the greatest sensitivity.

This point is unimportant when using only one set of plates for voltage measurements, but it becomes a problem when examining the results of applying voltages to both sets of plates.

PHASE DIAGRAMS

IT will at this stage be instructive to see what effects are obtained by using both sets of plates for the delineation of AC inputs.

Consider now the two sine waveforms shown on the left of Fig. 7. One has a horizontal axis, and the other a vertical axis, and represent the input to the horizontal and vertical deflector plates respectively. It will be noted that the two figures represent voltages *in phase*, that is, at any given time the instantaneous voltage of each is the same, and is changing at the same rate and in the same sense.

Visual Phase Relationships

Successive points 1, 2, 3, etc., on the vertical curve correspond with points 14, 15, 16, etc., on the horizontal curve. To find the resulting figure produced on the oscilloscope screen, this is plotted out by drawing a vertical line through point 1, and a horizontal line through point 14, and producing them until they meet (at A). Next the same thing is done for points 2 and 15, giving point B, and so on. In this way the figure A B C D C B A E F G F E A is drawn out, which is, as will be seen, a straight line inclined at 45 degrees to the horizontal.

Now consider the two waveforms on the right of Fig. 7. In this case the vertical input lags behind the horizontal input by a quarter wavelength or 90 degrees (or the horizontal input leads the vertical input by the same amount). Adopting the same method we find that this is the circle A B C D E F G H I J K L A.

Adopting similar graphical methods, it will be found that for intermediate values of phase difference, inclined ellipses are produced. Fig. 8 shows the figures for various phase differences.

Fig. 9 is a reproduction of photographs of zero and 90 degree phase diagrams. The left-hand picture shows the inclined line produced by two in-phase voltages, and the horizontal and vertical lines were produced by separately applying the individual voltages to their respective plates. The right-hand picture shows the circle produced by a 90-degree phase difference, the horizontal and vertical lines again being produced by the separate voltages.

Fig. 10 shows the circuits used to obtain Fig. 9. The in-phase diagram was produced by applying the voltages across the two resistances R1, R2 to the two sets of deflector plates. To obtain the 90-degree phase shift, a condenser C was used, in series with a resistance R. The voltage across C was applied to one set of plates, and the voltage across R (produced by the flow of current through C) was applied to the other set of plates.

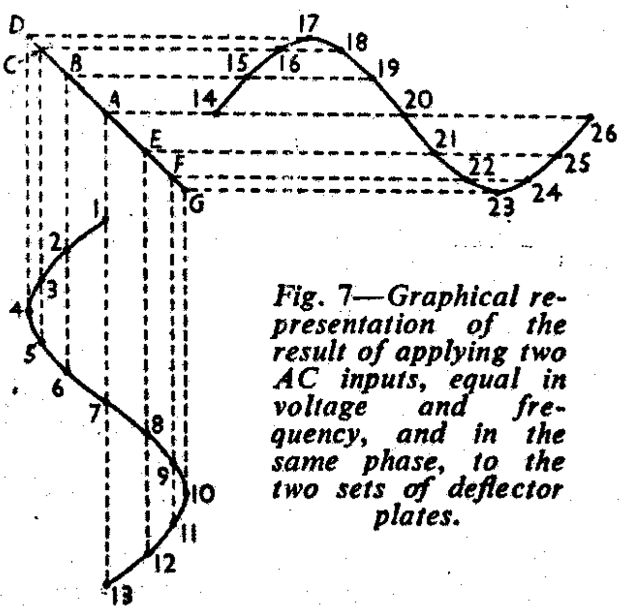
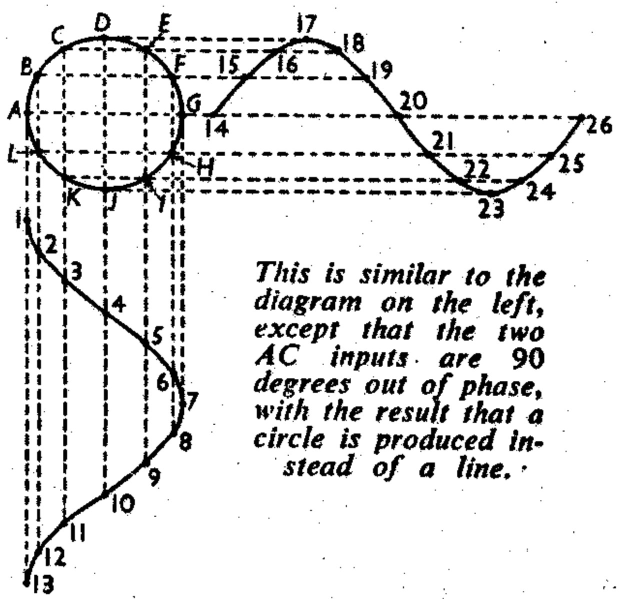


Fig. 7—Graphical representation of the result of applying two AC inputs, equal in voltage and frequency, and in the same phase, to the two sets of deflector plates.



This is similar to the diagram on the left, except that the two AC inputs are 90 degrees out of phase, with the result that a circle is produced instead of a line.

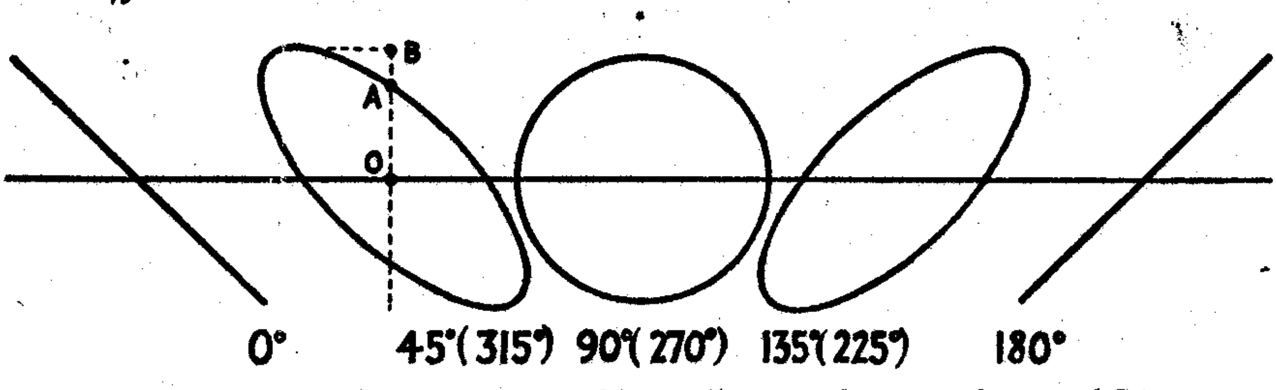


Fig. 8—Figures obtained for various phase differences between the two AC inputs.

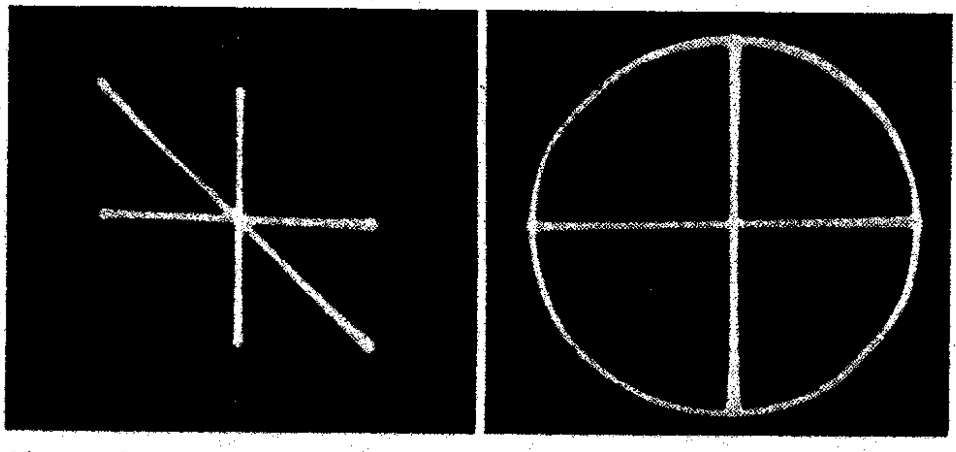
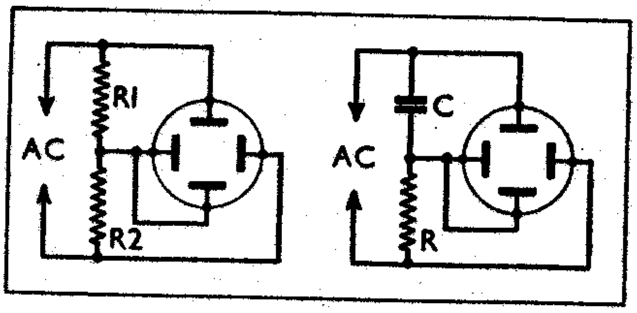


Fig. 9 — (left) shows actual photographs of the figures produced according to Fig. 10.

Fig. 10—(below) gives the circuits used for producing Fig. 9.



Since the current through a condenser leads the voltage across it by 90 degrees, the voltage across R leads the voltage across C by 90 degrees also. In this experiment, the reactance of condenser C must be equal to the value of resistance R, otherwise the voltage across C will not equal the voltage across R, and the circle will not be obtained. Using a 0·1μF condenser, with a 50 C/S AC input, the reactance is about 32,000 O, so that R should have this value. In practice, a 50,000 O variable resistance can be used for R, and adjusted to produce a true circle.

In studying phase diagrams, it must be remembered that so long as the two voltages are equal (and the two sets of deflector plates have equal sensitivities), the inclination of the line (0 or 180 deg.)or the major axes of the ellipses, will always be at 45 degrees to the horizontal.

If the voltages are not equal, the inclination will be different, and the tangent of the angle of inclination to the horizontal will give the ratio of the vertical voltage to the horizontal voltage. This forms a method of comparing two voltages, even when these are out of phase.

The degree of eccentricity of the ellipse (which is independent of its inclination) gives a measure of the phase difference between the two voltages. Referring the left-hand ellipse of Fig. 8, if ϕ is the phase angle, sin ϕ is equal to OA divided by OB.

The oscilloscope in this way can be used to check up phase shifts in different parts of a radio or television receiver, or an amplifier, but a certain amount of care must be used to avoid misleading results. For instance, if it is necessary to use the amplifier in the oscilloscope, one must first check up to see that this itself does not introduce a phase shift.

FREQUENCY COMPARISON

ANOTHER interesting application of the cathode ray oscilloscope is its use for comparison of frequencies.

Using the simplest of oscilloscopes, there is no difficulty in comparing two frequencies with extreme accuracy, providing that their ratio does not exceed about 10 to 1. Thus, using a standard frequency of, say, 1,000 C/S, frequencies of from 100 to 10,000 C/S can be accurately compared with it.

Those who have studied elementary physics will remember the well-known Lissajou figures or patterns which are produced under certain circumstances by the combination of two frequencies having certain ratios to each other.

The cathode ray oscilloscope can be used quite easily to produce Lissajou figures on its screen, by feeding AC inputs of two different frequencies to the horizontal and vertical sets of deflector plates.

In the previous section, the effect of feeding in two voltages of the same frequency was seen, and the result was a line, ellipse or circle, depending on the phase relationships between the two inputs. This, is of course, a special case of the Lissajou patterns, and whenever a line ellipse or circle is produced, the two inputs have the same frequency.

Suppose now that the horizontal deflector plates are fed with a 50 C/S input, while a 100 C/S input is supplied to the vertical plates, using the circuit shown to the left of Fig. 11. The resulting figure is that shown on the left of Fig. 12, and takes a " figure-of-eight " form which is characteristic of a 2 to 1 ratio. Actually, the shape changes as the phase alters, but the form can always be recognised.

If the 100 C/S input had been applied to the horizontal plates, and the 50 C/S to the vertical plates, the figure would have been the same in shape, but rotated through 90 degrees.

For the production of the figures, the author used the time-controlled 50 C/S AC mains on the horizontal plates, and the output from a beat-frequency oscillator, suitably amplified, for the vertical plates.

It will be found instructive to wire up the circuit indicated in its simplest form on the left of Fig. 11, and slowly run the variable frequency oscillator through a range of frequencies from, say, 25 to 500 C/S, assuming that a 50 C/S input is applied to the horizontal plates.

It will be found that one gets a definite stabilised pattern at various points, while in between these points it is jumbled. The stabilised patterns are at the simple ratios between the two frequencies, such as 1 to 1, 5 to 4, 4 to 3, 3 to 2, 2 to 1, and so on.

The next point to consider is how, having obtained a pattern, one can recognise the ratio it represents. Fortunately, for fairly simple ratios, this is very easy. One merely counts the loops in the pattern along its top or bottom edge, and then along one side, and the ratio of the two is the ratio of the frequencies.

At the left of Fig. 12, it will be seen that there are two loops counting horizontally, and one counting vertically, and hence the ratio is 2 to 1.

The figure on the right of Fig. 12 is more complex. Here we have seven peaks horizontally and two vertically, so the ratio is 7 to 2. As the horizontal frequency was 50 C/S exactly, the vertical frequency must therefore have been 175 C/S, and had we been calibrating our variable frequency oscillator, this pattern would have provided the exact calibration point for 175 C/S.

By examining patterns of various kinds one can soon obtain calibration points over a wide range, but it is fairly obvious that as the ratio between the two frequencies increases, the figures get more complex and this is the only reason why 10 to 1 is suggested as the limit of the ratios observable. Of course, if the horizontal frequency is changed to another value, one can extend the calibration range to any extent which is desired.

It should be emphasised that the figures represent ratios only ; frequencies of 50 and 100 C/S produce the " figure of 8 " pattern, and so would 500 and 1,000 C/S 20,000 and 40,000 C/S and so on.

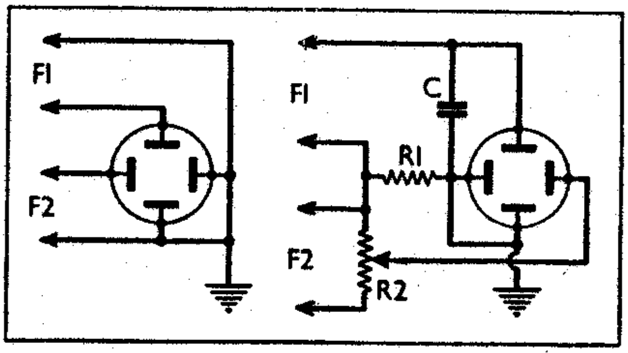


Fig. 11 — (above) Circuits used for the patterns on the right.

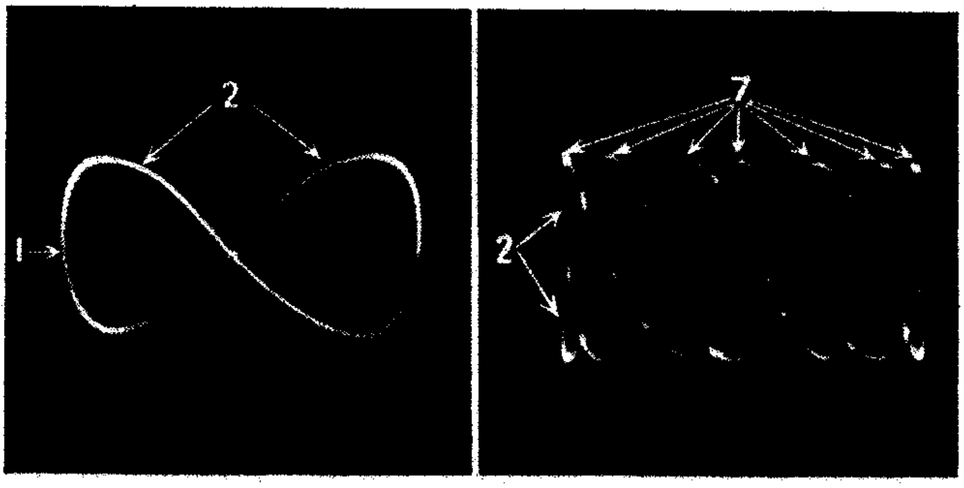


Fig. 12 — (right) Photographs of 2 to 1 and 7 to 2 patterns.

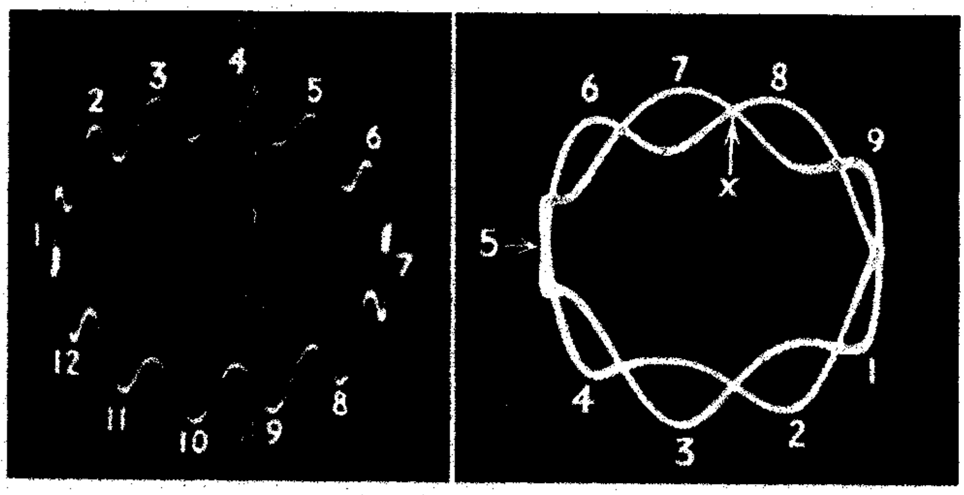


Fig. 13 — *Circular oscillograms of* 12 *to* 1 *and* 9 *to* 2 *ratios.*

Fig. 13 shows a different type of pattern that can be produced by the circuit shown at the right of Fig. 11. The condenser C and the resistance R1 are adjusted so as to produce an out-of-phase oscillogram of the frequency F1, which is the lower in value of the two. An open ellipse or a circle will be suitable. In series with the low frequency is injected the higher frequency F2, controlled in voltage by the potentiometer R2.

This has the effect of "modulating" the lower frequency by the higher one, and producing patterns such as are shown in Fig. 13. On the left we have a ratio of 12 to 1 (greater than the suggested maximum of 10 to 1), which is interpreted by counting the loops on the outside of the pattern. These are indicated by numbers, and care must be taken at the "3 o'clock" and "9 o'clock" points not to count too many. There are twelve significant loops, and the fact that the pattern does not cross over anywhere shows that the ratio is 12 to 1.

The pattern on the right of Fig. 13 shows nine loops, indicated by numbers, but here it will be noticed that the pattern is of a double nature, and there is a row of intersection points, such as at X. This indicates that the ratio is 9 to 2. If there were two rows of intersections (triple pattern) the ratio would have been something to 3, and so on.

With a little experience, one can become skilled at interpreting patterns of both types, and apart from calibration work, the method is often useful where a quick check on frequency against a standard is desirable.

When interpreting flat patterns as in Fig. 12, take care that the "front" and "back" of the pattern do not happen to coincide, otherwise the wrong ratio will be obtained. It is best to cause the pattern to move slightly to make certain that this masking effect is not taking place.

TIME-BASES

SO far we have only considered the simplest applications of the oscilloscope, and before going on to more advanced uses it is necessary to deal with a feature which is built into practically every commercial instrument, that is, the sweep or time-base circuit.

In most of the advanced applications of the instrument it is necessary to examine a voltage or current waveform, which may be simple or complex. The waveform is, of course, produced by a varying voltage or current plotted against time.

In order to delineate such a waveform on the screen of the oscilloscope in a comprehensible manner, we must apply the varying voltage to one pair of deflector plates (usually the vertical ones), and at the same time sweep the spot horizontally at a steady rate, that is, so that its horizontal displacement is directly proportional to time.

The horizontal "base" used is called a time-base or "sweep"; it is possible to have different kinds of time-base, but the one which is the simplest, and almost exclusively used in ordinary oscilloscopes, is the linear type mentioned above, and it is to this type that we shall confine our discussion entirely.

In its most elementary form, a linear

time-base circuit would merely sweep the spot from, say, left to right across the screen at a constant rate. Such a sweep is generally known as a "single stroke" sweep, and though it is sometimes used for examining transient phenomena, and, in fact, some commercial oscilloscopes have means whereby it can be produced, for ordinary use it is not of great help, since we generally need to see the applied waveform spread out on the screen for as long as is necessary to examine it.

Consequently, some means must be adopted to provide a continuous sweep, and in order to secure this, the spot must be swept across the screen and must then return and be swept across again, this being repeated as long as necessary.

Ideally, the time taken for the spot to return from the end of its travel to its starting point each time (often called the "fly-back" time) should be zero, but in practice this is not possible, and the fly-back occupies a certain small period of time. As this is usually only one-thirtieth to one-hundredth of the time occupied by the sweep proper, its effect is for most purposes negligible.

Fig. 14 shows a graphical representation of the voltage which is applied to the horizontal deflector plates to produce a linear time-base. Starting from the point O the voltage increases regularly with time, as represented by the sloping straight line OA, and so moves the spot across the screen. At A the spot has reached the end of its travel, and the voltage drops suddenly (but not instantaneously) to zero. AB therefore represents the fly-back. If it were instantaneous, it would be represented by the vertical line AX; as it is, XB is the fly-back time, and is only a small fraction of the time occupied by the sweep (OX).

Arriving back at the starting point again (point B, zero voltage), the gradually increasing voltage is again applied (BC), the voltage again collapses (CD), and the cycle repeats (DE, EF). This goes on continuously, and the result is a line drawn horizontally on the screen, a definite number of times per second, depending on the sweep frequency.

The sweep voltage waveform is often called a saw-tooth wave, in view of its resemblance to the teeth of a saw, as will be seen from Fig. 14. It is important that the portions OA, BC, DE, etc., of the wave should be absolutely straight, otherwise the sweep will not be truly linear, and will result in a certain amount of distortion of all waveforms for whose examination it is used.

It is obvious, in considering the means whereby a saw-tooth waveform can be produced, that there are at least four points to bear in mind: the total voltage required (at the peaks A, C, E, etc.); the reduction of fly-back time; the linearity of the growth of voltage; and the frequency of the sweep.

As far as the first is concerned, this depends on the type of tube used, and in any case is often made variable so that the width of the trace can be set to a suitable value; obviously the width of the trace will be proportional to the applied sweep voltage.

The reduction of fly-back time and the linearity of the sweep are matters for careful design of the sweep circuits; the frequency of the sweep must be made variable over a suitable range, so that waves of various frequencies can be readily examined.

On considering the matter, it will be evident that the trace produced on the screen with an input of a certain frequency on the vertical plates will depend on the

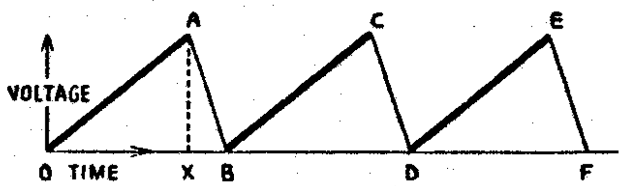


Fig. 14—Waveform of a linear time-base.

frequency of the time-base applied to the horizontal plates. Taking the simplest possible case, let us examine a pure sine wave of 1,000 C/S on a linear time-base with a frequency also of 1,000 C/S. The spot will travel horizontally to its full extent in one thousandth of a second, but in this time the applied alternating voltage has just completed a full cycle, so that the trace produced will be as shown at A in Fig. 15.

Now suppose we reduce the frequency of the time-base to 500 C/S. While the spot is moving to its full extent horizontally the voltage on the vertical plates will have completed two whole cycles, and this will be shown on the trace as at B in Fig. 15. If the frequency of the time-base is still further reduced, say to 100 C/S, we shall get ten complete cycles on the trace, as at C in Fig. 15.

For the comfortable examination of the waveform, it is obvious that C is not very satisfactory—it is far too cramped. Consequently, the necessity for having the time-base adjustable to something comparable with the frequency to be examined is easily appreciated.

Out of interest, the trace produced by having the time-base running at *twice* the frequency of the wave to be examined, is shown at D in Fig. 15. Here only the first half of the cycle is completed on the first stroke of the time-base, the second (negative) half being traced out (below the base line) on the second stroke of the time-base, and so on.

The figures A to D in Fig. 15 were drawn neglecting the effect of the finite time occupied by the fly-back. The trace actually obtained in the case of the single cycle (A) is shown at E, and it will be noted that the trace is not quite completed before the fly-back occurs. The distance between the end of the trace where the fly-back starts (X) and the point where the ideal trace should finish (Y) gives an idea of the time occupied by the fly-back and serves as a test for estimating whether the time-base is well designed in this respect. The distance XY should be quite small.

At this point a brief consideration of the methods of producing the saw-tooth waveform is desirable.

In essence, a saw-tooth waveform is produced by allowing a condenser to charge from a DC supply in such a way that the voltage across it rises at a steady rate, and it is this voltage that is applied to the horizontal plates of the CR tube to produce the linear sweep.

When the voltage has risen to a value sufficient to sweep the spot across the screen the condenser has to be suddenly discharged, and then allowed to charge again in the same way, the whole process being repeated at speeds from 10 to 200,000 or more times per second, according to the required frequency.

It might be thought that by allowing a condenser to charge through an ordinary resistance the result would be a steady increase in voltage across the condenser but this is not so, for the curve produced in this way is exponential, the charging rate being fast at first, and then gradually decreasing. Fig. 16 shows such a curve, and it will be noticed that the curve, taken as a whole (O to B), is far from linear. Taking a small part of the initial portion (O to A), this will be seen to approximate more closely to the ideal straight line, but if we arrange for the condenser to be discharged each time its voltage reaches A, the difficulty is that the sweep voltage, represented by AX, is then only a small fraction of the total (BY) that is possible with the particular condenser and applied DC voltage, and is probably not enough to sweep the spot right across the tube screen.

This state of affairs can be improved by increasing the applied DC voltage, but there are, of course, limits to which one can go in this direction. However, it is a method often used, and with care the resultant trace can be made reasonably linear.

A much better method is to use, in place of the fixed charging resistance, a constant current charging device, which, between wide extremes of applied voltage, will only permit a certain current to flow in the circuit, thus preventing the initial rush of current into the uncharged condenser.

Several devices are available for this purpose, one being a diode valve, operating under conditions in which it is "saturated."

If the valve is operated in this way, and connected with its anode circuit in series with the condenser in the time-base, it is obvious that, after the diode reaches saturation, the current flowing into the condenser will be the anode current of the

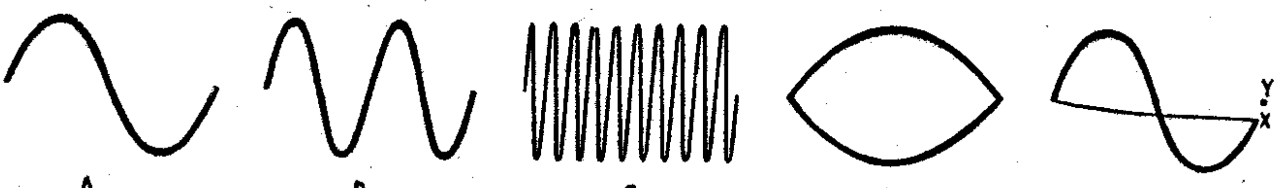


Fig. 15—Traces of a sine wave with the time-base set at various frequencies.

diode, and will be constant. Consequently, the rise in voltage across the condenser will be linear.

One of the disadvantages of the diode is that saturation does not occur until a certain anode voltage is reached, which is generally rather higher than is convenient. To obviate this, and another minor difficulty, use is made of the characteristics of a screened RF pentode.

With this type of valve, for a given grid bias, the anode current is practically constant for various values of anode voltage above a certain minimum value. Thus a screened RF pentode, in series with the condenser in the time-base, will result in an almost truly linear sweep. Further, by varying the control grid or screen voltage of the valve, one can control the value of the charging current, and so vary the frequency of charging. This, however, will not provide sufficient variation in the frequency of the time-base for oscilloscopic requirements, so that in addition there must be provision for switching in charging condensers of various values to provide different ranges of frequency, the variable bias or screen voltage of the charging valve acting as the fine adjustment.

Having seen how the linear charging of the condenser is accomplished, the question of the discharge of the condenser at the end of each sweep must be considered.

One method would be to connect across the charging condenser a neon tube. Normally, this tube is non-conducting, but as soon as the voltage across the condenser reaches the "striking" voltage of the neon, the lamp glows, due to the ionising of the neon, and the condenser discharges rapidly through it. As it does so, its voltage falls suddenly to the "extinction" voltage of the neon, when the tube ceases to glow, becomes non-conducting again, and the condenser begins to charge again, the cycle of operations then being repeated.

Obviously, the maximum change of voltage on the condenser will be the difference between the striking and extinction voltages of the neon, which is only about 30 V, and is too small for supplying the necessary sweep without amplification.

In order to obtain a larger available output, the neon tube is replaced by a gas-discharge triode. This valve is similar to an ordinary AC triode, but is filled with mercury vapour, helium, argon or some other inert gas. The time-base charging condenser is connected from anode to cathode of this valve, and the applied DC voltage is fed via a resistance or a constant current device. Normally, the gas-discharge valve has a very high impedance, and has no appreciable effect on the condenser, but when the voltage of the latter has risen to a certain critical voltage (which will also be the

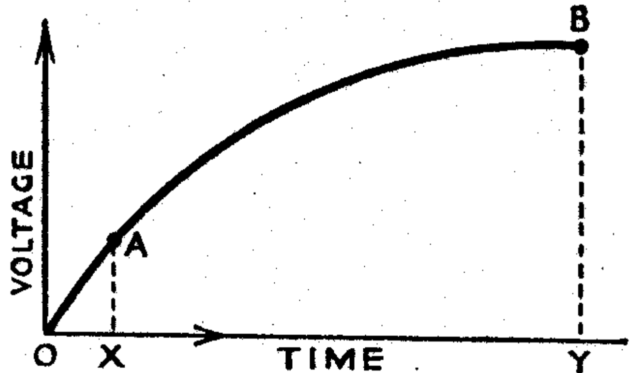


Fig. 16—*Curve of a condenser charging through a fixed resistance.*

voltage applied to the anode of the valve) the gas in the valve suddenly ionises, the impedance of the valve drops to a negligible value, and immediately discharges the condenser. The ionisation of the gas then ceases, and the cycle repeats.

The point about the gas-discharge valve is that the critical anode voltage at which ionisation occurs can be very high—up to 1,000 V or so, and is controllable by the value of the negative bias applied to the grid. The "control ratio" of the valve (analogous to the amplification factor of an ordinary triode) may be from 15 to 40, according to the type, and this figure, multiplied by the grid bias, gives the anode voltage at which the valve will fire.

By varying the grid bias the firing voltage of the valve can be varied, and as this also varies the change in voltage across the condenser during each cycle, it obviously forms a good method of varying the width of the sweep.

In place of the gas-discharge valve, an arrangement of hard valves is sometimes used, and this method of producing the saw-tooth wave permits a very reliable time-base to be made which will operate successfully up to very high frequencies.

It is not possible to consider these

circuits in detail, but they all operate by causing one valve to control another which discharges the condenser periodically, and similar variable controls are employed to those in the gas-discharge type of time-base.

It is often necessary to hold a picture stationary on the screen, and even if the frequency of the time-base is adjusted critically to the frequency of the incoming signal, or some sub-multiple of it, there is nearly always a certain amount of drift.

Positive locking is achieved by feeding part of the incoming signal to the grid of the discharge valve, when it acts in such a way as to trigger the valve at the correct instant, and so synchronises the time-base with the signal. Naturally. before this can happen, the time-base must be set to the frequency necessary.

Provision is often made for varying the strength of the synchronising signal, for if it is not great enough the picture will not hold, while if it is too great, the curve produced will be distorted.

Some oscilloscopes also contain provision for synchronising the time-base with the 50 C/S mains, or with some external source.

As has been explained earlier, in most observations of waveform we are interested in what is happening relative to time, and therefore we use a time-base applied to the horizontal deflector plates of the oscilloscope, and apply the voltage to be examined to the vertical plates. in this way we get a curve showing voltage against time.

Obviously, a " time " base is not the only one which can be used on the horizontal plates. For instance, we may wish to see how the voltage at some part of a circuit varies with frequency. One example of this is the response curve of the IF stages of a receiver, where we are interested in the voltage variation over a band of about 30 KC/S. Another is the response curve of an AF amplifier, where the voltage variation over a range of, say, 20 to 10,000 C/S is of interest.

If we were to apply the voltage across the secondary of an IF transformer to the vertical plates, with the linear time-base set to a suitable frequency, we should merely see the waveform of the IF voltage at that part of the circuit ; such a curve would tell us nothing about the frequency response of the circuit

Suppose now that we replace the linear time-base by a suitable frequency base, in which the voltage applied to the horizontal plates is proportional to frequency, then the curve produced will show the voltage across the IF secondary for various frequencies within the IF range, and will therefore be a graphical representation of the IF response.

For the production of such a curve, a special type of signal generator, which is " frequency-modulated," is usually needed, though some modern oscilloscopes incorporate their own frequency modulator.

A good deal more will be said on this subject when we come to the use of the oscilloscope for receiver alignment ; at present the main thing to remember is that bases other than the linear time-base can be, and are, used for various applications of the oscilloscope.

For the second application mentioned above, a rather similar method is used, except that the frequency base varies from, say, zero to 10,000 C/S.

Again, in some cases we use a voltage base, as, for instance, in the tracing out of the dynamic characteristics of a valve. An AC voltage is applied to the grid of the valve and also to the horizontal plates, while the resulting AC voltage developed across a load resistance in the anode circuit is applied to the vertical plates. In this way the familiar grid voltage/anode current curve is produced, since the anode current will be proportional to the voltage developed across the load resistance, and therefore to the vertical deflection.

With these remarks we will leave the subject of time and other bases for the present, except to recapitulate that any modern oscilloscope should have a linear time-base built in, and that for the widest applications this base should extend in frequency up to, say, one-tenth of the highest frequency input one is likely to wish to examine. The frequency should be smoothly variable over the whole range, and there should be provision for synchronisation with the waveform to be examined. An adjustment for the width of the base is an advantage.

It should be possible to switch the time-base off, and obtain access to the horizontal plates for investigations not requiring the time-base, and also to permit the use of an external base when necessary.

AMPLIFIERS

WE now come to the subject of the amplifiers used in oscilloscopes, which was mentioned on page 7 in connection with voltage measurement. It is unusual to-day to find an oscilloscope which does not include at least a single-stage amplifier for feeding the vertical plates.

The need for an amplifier, at least for the input to the vertical plates, can be readily understood. It was seen on page 7 that the sensitivity of the tube in the oscilloscope might be of the order of 10 V RMS per centimetre, so that for a deflection of 5 cm, which would give a fair sized trace on a 4-in. tube, an input of 50 V RMS would be required.

Now if we are examining voltages in a radio receiver it is unlikely that anything of the order of 50 V will be encountered except towards the output end of the set. In the early part of the AF section the voltage may be of the order of 1 V or less ; in the RF stages it may very well be as low as a few millivolts.

Consequently, to secure a reasonably sized trace, a voltage amplifier must be employed, at any rate, to feed the vertical plates. As far as the horizontal plates are concerned, the time-base, if used, is designed to give the requisite length of sweep, but if the instrument is being used without the time-base (for phase diagrams or frequency comparison, for instance), an amplifier may be needed here as well.

It is unusual to find a commercial oscilloscope with twin amplifiers, but some, by means of switching or external connections, permit the single amplifier to be applied to the vertical or the horizontal plates at will.

Considering the amplifier as usually fitted, for use in conjunction with the vertical plates, there are several features which are desirable if the instrument is to be of the maximum benefit.

In the first place, there is the actual amplification or gain. It is not uncommon to find a gain of 2,000 in a 2-stage amplifier using pentodes, and this is sufficient to give a reasonable picture with an input as low as 10 mV. RF waveforms in the early stages of a receiver can therefore be examined comfortably.

On the other hand, if only a single triode is used in the amplifier, the gain may be only 20 or so, which, although adequate for AF work, limits the usefulness of the instrument as far as the small RF voltages in a receiver are concerned.

Next, there is the frequency response of the amplifier. Ideally, this should be linear up to the highest frequency which is likely to be examined, but in practice most amplifiers suffer a fall in gain at very low and very high frequencies.

Television has brought the necessity for wide linear frequency response, and for certain video frequency work the amplifier should be linear up to at least 2 MC/S, and should preferably have a good response much higher than this.

For normal use, however, such a wide frequency range is not essential, and a fairly level characteristic up to 100 KC/S is sufficient. It is often found that with a 2-stage amplifier one can obtain either high sensitivity with a restricted frequency range, or lower sensitivity with an extended frequency range. This is made possible by suitable switching, and is a useful feature.

Next, the input impedance of the amplifier for certain work should be high, to prevent any appreciable loading effect on the circuit to which the instrument is connected. An input impedance of 1 or 2 MO is satisfactory ; in cases where a low impedance potentiometer is used for regulating the amplifier gain there should be provision for cutting this out of circuit when it is necessary to have a high input impedance.

The input capacity of the amplifier should be as low as possible to avoid spurious effects on the incoming waveform, and to avoid any appreciable phase shift which would give misleading pictures. For the same reason the amplifier throughout should be designed to produce negligible phase shift between the input and output circuits. Phase shift is most likely to be encountered at the lower and upper ends of the amplifier's frequency range, and over the majority of the range it is not usually present.

Finally, the amplifier must be free from amplitude distortion, at least up to the point where a picture of maximum height is obtained on the tube.

This list of requirements may seem rather exacting, but obviously there is little use in having an amplifier in an oscilloscope if it is going to introduce errors in the pictures being examined.

If the user is aware of any limitations in the amplifier which might affect his results, and bears them in mind, not much harm will be done ; the purpose of these notes was to bring home to the user that one cannot always expect the amplifier to operate reliably under exacting conditions for which it may never have been designed.

TRACING HUM

A POINT has now been reached where we can consider the use of the oscilloscope in connection with fault finding in a radio receiver. At the outset we shall deal with fairly simple applications of the instrument, and we suggest that anyone learning to use an oscilloscope should experiment on the chassis of some standard receiver for himself.

If he experiments on the lines suggested, he will soon get familiar with the uses of the instrument, and will be able to apply it to a wide variety of investigations. To read the descriptions only is not enough ; it is essential that practical experience is acquired by carrying out the experiments described.

To commence, we will examine the power supply circuit of an AC receiver of conventional type, using a full-wave rectifier valve, reservoir and smoothing condensers, and a smoothing choke (or speaker field). Fig. 17 shows a diagram of the smoothing circuit, C1 being the reservoir condenser, L the smoothing choke, and C2 the smoothing condenser.

The oscilloscope is used with its amplifier and gain control in action. If there is switching for two or more different gains, use the lowest gain position, and start with the gain control at minimum.

The amplifier is used for two reasons. In the first place, there is a DC voltage

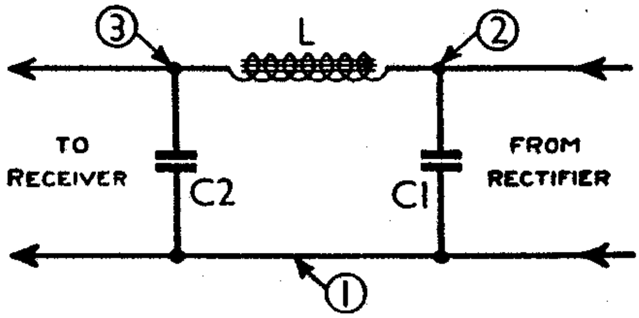


Fig. 17—Portion of a power supply circuit under investigation.

across the circuit, and if applied direct to the plates it would deflect the spot off the screen, unless a reverse bias were applied. Secondly, although in the circuit being examined the DC voltage is high, in the majority of cases the superimposed AC ripple is low. By using the amplifier the DC is eliminated, and only the AC component appears on the screen, and can be amplified to the required degree.

Care must be taken to see that the DC input voltage is not so high as to damage the input control of the oscilloscope amplifier, and where no series condenser is used internally, it is advisable to have a 2 or 4 μF type in series with the test prod to the amplifier input.

Set the linear time-base to a low frequency which will lock with the input. In a full-wave rectifier circuit on 50 C/S mains the ripple frequency will be 100 C/S. If the time-base is set to 25 C/S four complete cycles will be produced on the screen. Actually, in the full-wave illustrations (Fig. 18) the time-base was running at 16·67 C/S, resulting in six cycles in the trace.

The oscilloscope should be set for synchronisation between the input and the time-base, and since the input frequency does not vary, positive locking is possible.

To examine the circuit, the earth, or " earthy " side of the oscilloscope input is connected to the negative line of the circuit (point 1 in Fig. 17), and the amplifier input is connected to points 2 or 3. Fig. 18 shows the type of trace which may be expected under the conditions described below.

Trace A.—Obtained with amplifier input on point 2. C1 extremely low capacity, or open circuited. L and C2 normal.

Trace B.—Amplifier input on point 2. C1 low in capacity (about 1 or 2 μF instead of 8 or 16 μF). L and C2 normal. Amplification same as for trace A.

Trace C.—Amplifier input on point 2. C1, L and C2 all normal. Amplification same as for A and B.

Trace D.—Amplifier input on point 3. C2 open circuited, L and C1 normal. Amplification about 15 or 20 times A, B and C. Without this extra amplification, trace would be almost a straight line.

Trace E.—Amplifier input on point 3. L, C1, C2 all normal. Amplification same as trace D.

Trace F.—Amplifier input on point 3. C1 open circuited, L and C2 normal. Amplification same as D and E.

Trace G.—Amplifier input on point 3. C1, C2 normal, L short circuited. Amplification same as A, B and C.

For purposes of comparison, a few half-wave rectifier traces are given in Fig. 19. With the same time-base setting, there will only be half the number of complete cycles in the trace, since the ripple frequency is 50 C/S on 50 C/S mains. The time-base was set at 12·5 C/S for the traces of Fig. 19, giving four cycles per trace.

Trace H.—Amplifier input on point 2.

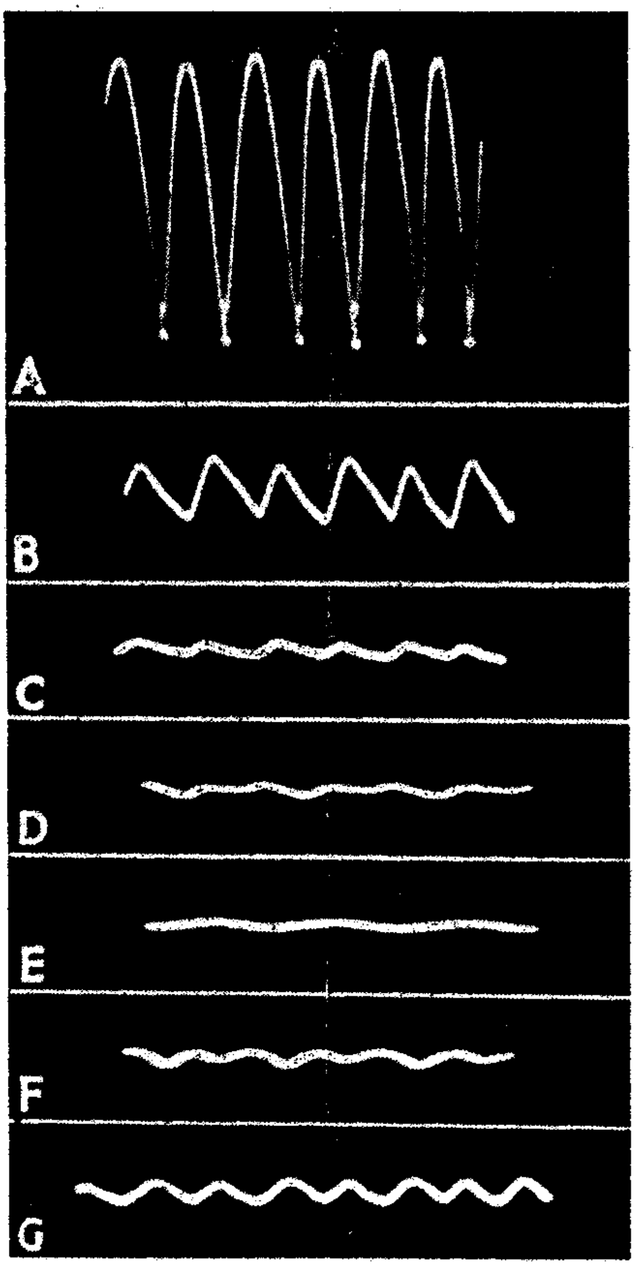


Fig. 18—*Full-wave rectifier circuit traces.*

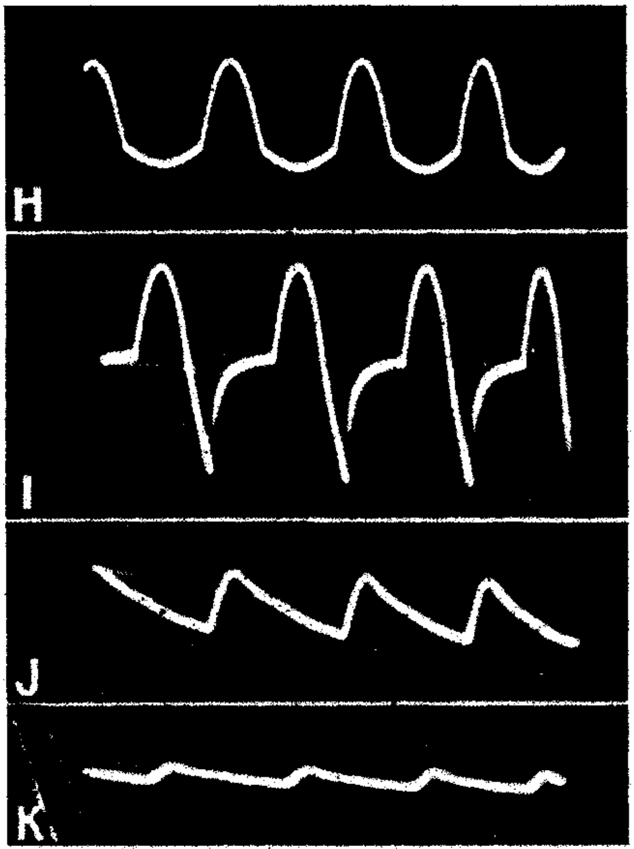


Fig. 19—*Half-wave rectifier circuit traces.*

C1 open circuited and L disconnected (rectifier isolated). Note gaps between peaks, typical of half-wave operation.

Trace I.—Amplifier input on point 2. C1 open circuited, L and C2 normal. Compare full-wave trace A.

Trace J.—Amplifier input on point 2. C1 low in capacity (about one-eighth normal), L and C2 normal. Amplification same as for trace I. Compare full-wave trace B.

Trace K.—Amplifier input on point 2. C1, L and C2 all normal. Amplification same as for traces I and J. Compare full-wave trace C.

The half-wave versions of traces D to G were found to be so similar as not to warrant illustration.

In interpreting these traces, the engineer should be concerned not so much with their shape, as with their height. It is impossible, owing to many variable factors, to give precise information on this point, and the best plan is to experiment with one or two receivers, and try the effect of reducing condenser capacities, etc., noting the heights of the traces obtained with a certain amplifier gain, and the amount of hum heard in the loudspeaker.

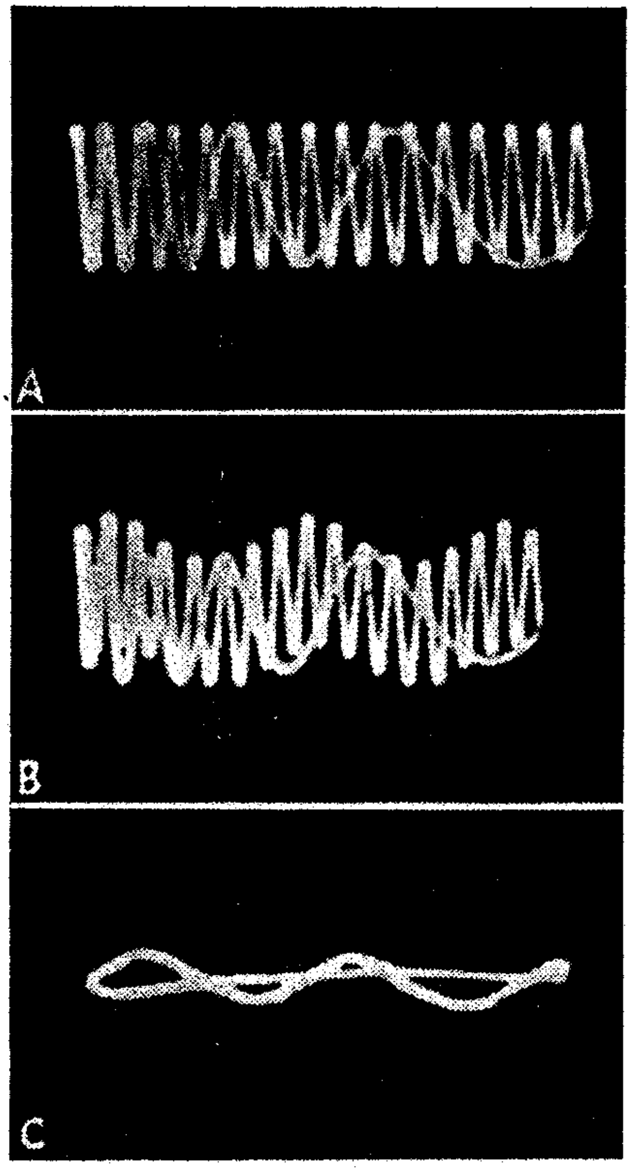


Fig. 20—A, *AF modulation alone* ; B, *AF modulation with hum* ; C, *hum alone.*

In this way it is possible to judge how much ripple is normal and permissible, and when it is necessary to improve the smoothing.

The experiments described are by nature of exercises in the use of the oscilloscope — their practical help in service work is not so great as most of the investigations which will be described later.

The effects of various types of fault in the HT power supply circuit of a mains receiver have now been considered. Any fault of this kind will, of course, cause a ripple to enter the receiver, and if its effect is large enough, it will be detectable in various parts of the set with an oscilloscope. Thus a fault which results in a definite hum heard at the loudspeaker will be seen if the oscilloscope is connected across the speaker speech coil.

Several photographs with the oscilloscope connected in this way are shown in Fig. 20. An RF signal from a signal generator, modulated at 400 C/S, and injected into the aerial/earth circuit will, of course, produce a 400 C/S note at the loudspeaker.

On the oscilloscope screen, this appears as a sine wave, as shown at A in Fig. 20, where the time base of the oscilloscope has been set to 25 C/S, resulting in sixteen complete waves in the trace. (The return trace which is superimposed can be neglected.)

If the trace is not a good sine wave, this may be due to one of three causes. Distortion may be occurring in the receiver, due to overload or to a fault of some kind ; alternatively, the modulation of the signal generator may be distorted ; thirdly, and much less likely, there may be distortion or overload in the oscilloscope amplifier.

At this point it may be suggested that at the outset the signal generator should be checked up on the oscilloscope. It will be essential later on, when examining the effects of distortion in the receiver, to know that the input is a pure sine wave, or at any rate, to know what degree of distortion is present. Few signal generators designed for ordinary alignment and testing work give an absolutely pure modulation note, neither is this necessary. Even for oscilloscope work, absolute purity of the waveform is not essential, though it is very desirable.

To check up the waveform, one can take the AF output of the signal generator direct to the oscilloscope amplifier input terminals, and set the time-base to give two or three complete traces on the screen. By inspection the purity of the waveform can then readily be judged, and any slight distortion noted for future reference. Another test can be made by feeding a modulated RF input to the oscilloscope, keeping the time-base set as before.

There should now be a patch of light on the screen, roughly rectangular in shape, but with the characteristic 400 C/S modulation causing a wavy top and bottom edge. This figure is generally referred to as an " envelope." The patch of light is really caused by the large number of RF wave traces packed together so closely that the eye cannot resolve them individually. They will only be visible by increasing the speed of the time-base.

Having obtained the modulated RF envelope, the wavy edges should have the same characteristics as the simple 400 C/S trace previously examined. If the latter was a pure sine wave, and the modulation on the RF envelope is not, there is obviously a fault in the signal generator.

Returning to our investigation of hum, the trace shown at A in Fig. 20 is what should be obtained when there is no hum present. It is just possible that the top and bottom edges of the trace will be slightly wavy, due to a small superimposed hum. The effect on the screen will be that the AF trace will "wriggle" slightly, since it is unlikely that the AF input and the superimposed ripple will both be accurately synchronised at the same time. A slight movement of the AF trace can be neglected, but anything serious means that it is being modulated by an appreciable ripple.

The trace at B in Fig. 20 shows the effect of a bad ripple on the AF trace. It will be observed that the AF trace is heavily modulated by a 50 C/S hum. If a line were drawn passing through each peak of the AF trace, a 50 C/S sine wave would be produced. This is clearly indicated in trace C, which shows the effect of switching off the signal generator, leaving the hum only.

It should be pointed out that in the case of trace B, it is unlikely that a steady picture will be obtained. The reason is that although the signal generator output is supposed to be modulated at 400 C/S, in practice the frequency may be quite considerably off this value, and unless it happens to be some exact multiple of the frequency of the hum it will not be possible to synchronise both the AF and its superimposed hum. To photograph trace B it was necessary to employ a beat frequency oscillator as the source of modulation, and this had to be adjusted accurately so that with the time-base set to 25 C/S, both the modulation and the hum could be synchronised to obtain a steady picture.

If the hum is produced in the HT supply circuit of the receiver, and rectification is of the full-wave type, the ripple on the AF output will have a frequency of 100 C/S. Hum produced by faults in the receiver heater supply, for example, a heater/cathode leak, will have a frequency of 50 C/S (assuming 50 C/S supply mains). By noting how many complete AF waves occur in one complete cycle of hum, one can say whether the hum is 50 C/S or 100 C/S. With a 400 C/S modulation, 50 C/S hum results in eight complete waves in one hum cycle, while 100 C/S hum results in only four complete waves in one hum cycle. In the traces shown, 50 C/S hum is present.

This method of differentiation is a help in diagnosing the source of the trouble. In order to locate it more definitely, one works backwards from the output end of the receiver, connecting the oscilloscope to anode and grid circuits, and noting the point at which the hum disappears. Naturally, as this is done, it will probably be necessary to increase the gain of the oscilloscope amplifier progressively to obtain a trace of reasonable height.

In order to get some idea of the effect of a certain amount of hum on the AF trace, it is a good plan to introduce some artificially into the set, noting the effect in the loudspeaker, and also on the oscilloscope screen.

One way of doing this conveniently is to place a leak across the cathode and heater of one of the AF valves in the set. If this artificial leak is made variable (by using a 250,000 O variable resistance, for instance) it is possible to watch the effect of a gradual increase in hum, at the same time noting its effect in the loudspeaker. In this way it will probably be found that the oscilloscope shows the hum long before it becomes intolerable in the loudspeaker.

By experimenting for an hour or two on these lines much useful information will be gained, together with further experience on the handling of the oscilloscope.

In all these experiments the receiver chassis and the oscilloscope should be earthed, and the oscilloscope leads should be screened to avoid, as far as possible, the introduction of spurious hum in the picture.

DISTORTION TRACING

THE cathode ray oscilloscope is an ideal instrument for the checking and location of distortion in a receiver or amplifier, and some experiments should now be made in this direction, using one or two different receiver chassis, a signal generator, and the oscilloscope.

Dealing first with distortion in the AF stages, for the method now to be described one needs an undistorted AF input. For this, the AF modulation from an ordinary signal generator is often useless, and before proceeding further it will be necessary to examine the waveform of the generator it is proposed to use. To do this, the AF output is applied, via the vertical amplifier of the oscilloscope to the vertical plates, and the linear time-base is set to give three or four traces on the screen. The result should be something like the lower trace A, Fig. 21, which is comparatively free from distortion.

If the signal generator gives a badly distorted trace, and it is impossible to secure a better one, or a proper beat frequency AF oscillator, it may be possible to use the 50 C/S AC mains, stepped down to a low voltage via a transformer and variable potentiometer. Even in this case, however, it will be necessary to make a preliminary examination of the waveform to make sure that the stepping-down process has not introduced distortion. The maximum input voltage required will normally be quite low. It will hardly ever exceed 10 V, and will usually be less than 1 V. It should be smoothly adjustable down to 0·1 V or so.

In checking for AF distortion, one starts at the output end of the receiver and works towards the demodulator (detector) stage. A good starting point is to connect the oscilloscope across the loudspeaker speech coil. The voltage here is low, so that the vertical amplifier of the oscilloscope will have to be brought into use.

Some of the AF traces which may be obtained are shown in Fig. 21. These were obtained with a signal generator having a good AF waveform and a double beam oscilloscope. The advantage of the latter is that the distortion may be checked at two points simultaneously, and on gradually increasing the AF input one can see at which of the two points distortion begins to be noticeable.

The following notes refer to the lettered traces in Fig. 21.

Traces A.—The AF input (400 C/S) was fed into the pick-up sockets of a standard AC superhet employing a power pentode output valve. The lower curve shows the input waveform and the upper one the waveform at the loudspeaker speech coil. Note that the lower curve is undistorted, but the upper one shows a certain amount of distortion, which, however, was not audibly noticeable.

Traces B.—These traces were taken under the same conditions, but the AF input was increased (note the greater height of the lower curve compared with the lower curve A). The upper curve is now badly distorted, due to overload of the grid circuit of the output valve.

Traces C.—Here one of the oscilloscope input circuits was transferred from the pick-up sockets to the grid circuit of the output valve, leaving the other oscilloscope input across the loudspeaker speech coil. The input was nearly as large as in traces B. It will be seen that, in addition to the serious distortion at the loudspeaker, there is also a certain amount of distortion in the input to the grid circuit of the output valve (lower trace). Consequently, this is taking place between the input and the grid of the output valve, probably in the triode first AF valve.

Traces D.—The receiver in this case was an AC superhet with a power triode output valve, and the oscilloscope inputs were across the triode grid circuit and the loudspeaker speech coil. The AF input was raised until the input to the grid circuit of the output valve was as high as possible without distortion (lower trace). Under these conditions the valve is overloaded (upper trace).

Traces E.—These were taken under the same conditions, except that the input was increased, showing distortion in the penultimate stage (lower trace), and very serious overload and rectification in the output stage (upper trace).

Naturally, the examples illustrated have been exaggerated to some extent to show the effects more clearly. In practice, the degree of distortion will probably be less than that shown in most examples, but will nevertheless be quite visible on the screen.

Indication of Distortion with a Pure Input

Unfortunately, the illustrations do not show the differences between second and third harmonic distortion. For this a base line is desirable, which will enable one to judge the relative heights of the positive and negative peaks. Second harmonic distortion makes the positive peaks sharp and of greater amplitude than the negative peaks, which become rounded. The trace is thus symmetrical relative to the base line.

With third harmonic distortion the positive and negative traces are symmetrical, but their skirts are kinked at low distortion percentages, while their peaks have a kind of pip when the degree of distortion is greater.

In many cases both even and odd harmonics may be present, which will give a combination of the two effects.

When investigating AF distortion effects, it is a good plan to provide the oscilloscope input leads with test prods so that they can be quickly applied to various parts of the circuit. Obviously, one works backwards towards the detector stage until the distortion is no longer apparent. It is then occurring between this point and the previous one checked.

If everything is normal as far back as the output from the detector stage, then the detector itself, or earlier stages, must be suspected.

Although the tracing of AF distortion only has so far been covered, it is fairly obvious that with suitable modifications to the input and to the oscilloscope connections one can similarly check distortion in other sections of a receiver.

For instance, IF distortion is often present in a set, but any attempt to trace it aurally or by means of ordinary measuring instruments is almost certain to be a failure. With an oscilloscope, however, the problem is considerably simplified.

If we feed into the control grid circuit of the last IF valve a signal at the intermediate frequency, and connect the oscilloscope across the secondary of the last IF transformer, with its linear time-base set to a low frequency (say 50 C/S), we shall obtain a rectangular patch of light on the screen, which is really the "envelope" of a large number of narrow sine waves, packed so close that they cannot be individually seen.

Suppose now that the IF signal is modulated at, say, 400 C/S, the AF

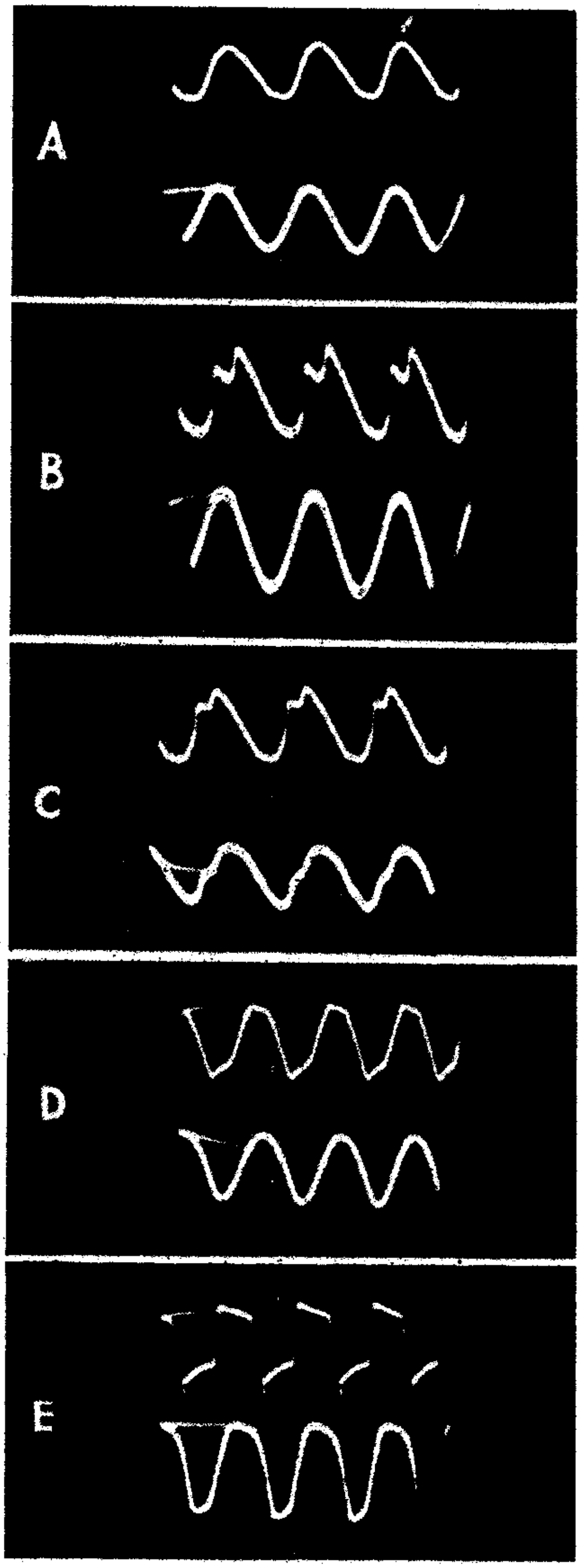


Fig. 21—A series of AF traces, the significance of which is fully explained on page 22 opposite.

modulation being of good sine waveform. The result on the screen should then appear something like A in Fig. 22.

It will be seen that instead of a rectangle, one obtains an "envelope" with the 400 C/S wave impressed on the top and bottom edge. In A, this is comparatively undistorted, which indicates that no fault lies in the IF stage under examination. To obtain a steady picture, the time-base must be set to some frequency which is a submultiple of the AF modulation frequency.

Distortion will readily be noticed if it is present. For instance, slight valve overload will show up as a flattening of the peaks of the modulated wave. Serious overload may produce a result something like that shown in B in Fig. 22. This, incidentally, was produced by removing the AVC bias of a standard receiver, and increasing the input until the stage was thoroughly overloaded. Partial rectification is occurring.

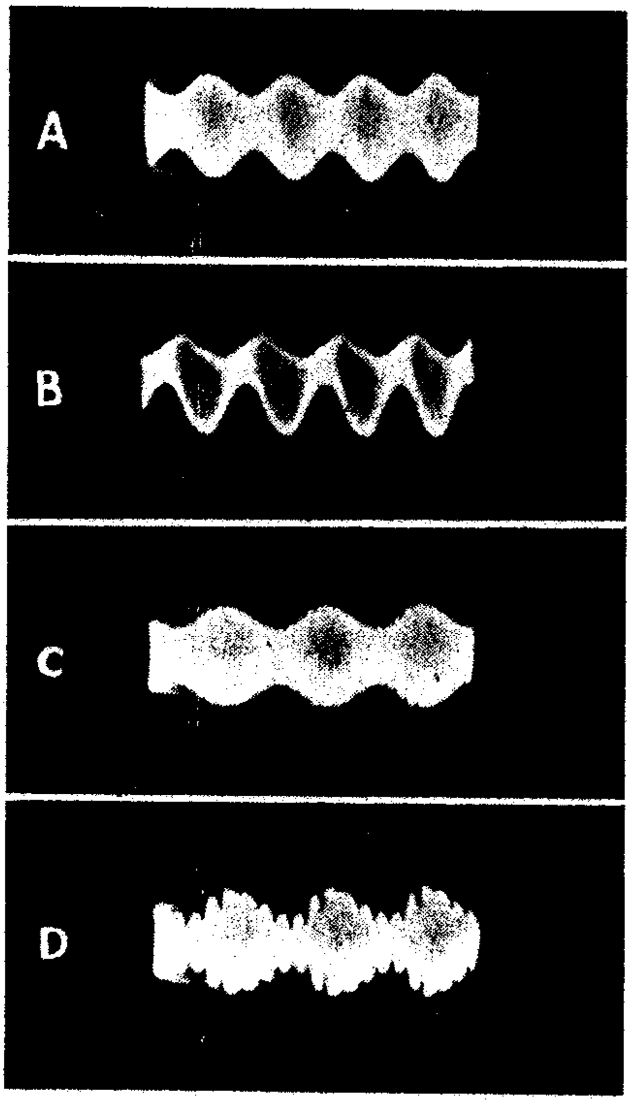


Fig. 22—Four IF traces, modulated with AF, showing various effects which are fully explained in the accompanying text.

In a similar way RF distortion may be checked, but there is an important point to remember here, and that is, that the amplifier in the oscilloscope may not be suitable for use at radio frequencies, so that insufficient amplification may be available to produce an "envelope" of adequate height.

This, of course, does not apply to many modern oscilloscopes, which, as has been stated earlier, may have reasonable degrees of amplification up to 1 or 2 MC/S; it is, however, necessary to bear the point in mind. As far as intermediate frequencies are concerned, the amplifiers of most commercial oscilloscopes should be able to deal with them adequately.

IF or RF distortion can be localised by similar methods to those used in the AF section of the receiver, though as one works back to the input of the set, owing to the small voltages encountered, the degree of amplification in the oscilloscope may need to be quite considerable.

Care should be taken to prevent pick-up on the oscilloscope leads, keeping them as short as possible, and using screened low-capacity cable with the screen earthed.

It is important that the connection of the oscilloscope should not have a disturbing effect on the working of the receiver, otherwise one is likely to get effects which cannot readily be diagnosed. This is where an oscilloscope with an amplifier having a high input impedance and low input capacity is important. If the oscilloscope has provision for alternative input impedances, the highest one should always be employed wherever possible.

The input capacity of the amplifier and the connecting leads, when connected across a tuned circuit such as the secondary of an IF transformer, will, of course, affect the tuning of this circuit, and it is a good plan to correct for this by reducing the capacity of the associated trimmer sufficiently to bring the circuit into resonance again. This can readily be done by tuning for maximum height of the trace on the screen after everything is connected up and working.

Distortion Checking with a Distorted Input Waveform

With the same set up as has just been described for RF and IF distortion tracing, one can readily check up the AVC action of a receiver. A small modulated RF signal is fed into the aerial and earth terminals, accurately tuned, and picked up on the oscilloscope either just prior to the second detector (demodulator) stage, or just following it. The " envelope " or single trace is observed on the screen, and should be undistorted.

The input is then gradually increased, when the height of the picture should likewise increase, until the AVC delay voltage is exceeded, when the AVC should take charge, and thereafter any further increase in input (even up to the full output of the signal generator) should not result in any considerable increase in the height of the trace, or in any observable distortion of the modulation peaks.

Demodulator distortion can also be easily checked by examining first the input to this stage in the form of a modulated RF envelope, which should be undistorted, and then, without altering the signal input arrangement, transferring the oscilloscope across the demodulator diode load. At this point there should be a trace of the modulation only, similar to that obtained in the AF experiments. The trace should be free from distortion —if not, the demodulator comes under suspicion. If, despite accurate focusing, the trace is thick some RF is present in the demodulator output.

Where a triode or other type of valve is used instead of a diode, the oscilloscope should be connected from its anode to chassis, with a suitable condenser in series (say, 0·1 μF), if this is not already included in the oscilloscope amplifier input circuit itself.

Instability in the RF or IF stages of a receiver can be traced by observing the modulated envelope as mentioned earlier. The trace C in Fig. 22 shows the effect of instability which caused oscillation at a frequency above audibility. It will be seen that the AF modulation curve is jagged, caused by the super-imposed oscillation.

Actually, the photograph is not as clear as the original image, and to make it clearer matters were arranged so that the oscillation was lower pitched, resulting in trace D, where the superimposed frequency shows up much more clearly, and, incidentally, is accompanied by distortion of the AF portion of the trace.

Partial instability is indicated by the superimposed oscillation being present over only a certain part of the trace, which is shown to some extent in illustration C.

In dealing with AF distortion checking on page 22, it was pointed out that it was essential to use an undistorted input signal when judging amplifier distortion by an examination of the input and output waveforms. The AF signal obtained from the average commercial service signal generator is rarely sufficiently free from distortion to make it suitable for this purpose, and not everyone can have access to a proper beat frequency or other type of AF oscillator giving a pure output waveform.

In this case, one can adopt a method which does not involve a pure input, nor does it necessitate the use of the timebase of the oscilloscope. By referring back to page 9, it will be seen that if we apply two sine waves of the same frequency, one to the horizontal and one to the vertical deflector plates of the oscilloscope, and if the two waves are in phase or 180 degrees out of phase, we shall get a sloping straight line on the screen. The slope will depend on the relative amplitudes of the two waves.

A point which was not mentioned on page 9 (because it did not arise at the time) is that even if the two waves are not pure sine waves, we shall still get a straight line, providing both waves are distorted equally and in the same manner. This obviously opens up a method of using a distorted input to an amplifier and yet being able to show up any additional distortion introduced by the amplifier.

Suppose for instance that we feed the AF output of a service signal generator (which probably has a distorted waveform) into the input of the amplifying stages under test, at the same time applying this input to the horizontal plates of the oscilloscope, while the output of the amplifying stages is at the same time applied to the vertical plates. Then if the amplifier introduces no distortion of its own, the result should be a straight line.

There is a difficulty to be overcome, however. The input to the amplifier will be of the order of a volt or so, and will not provide sufficient deflection of the

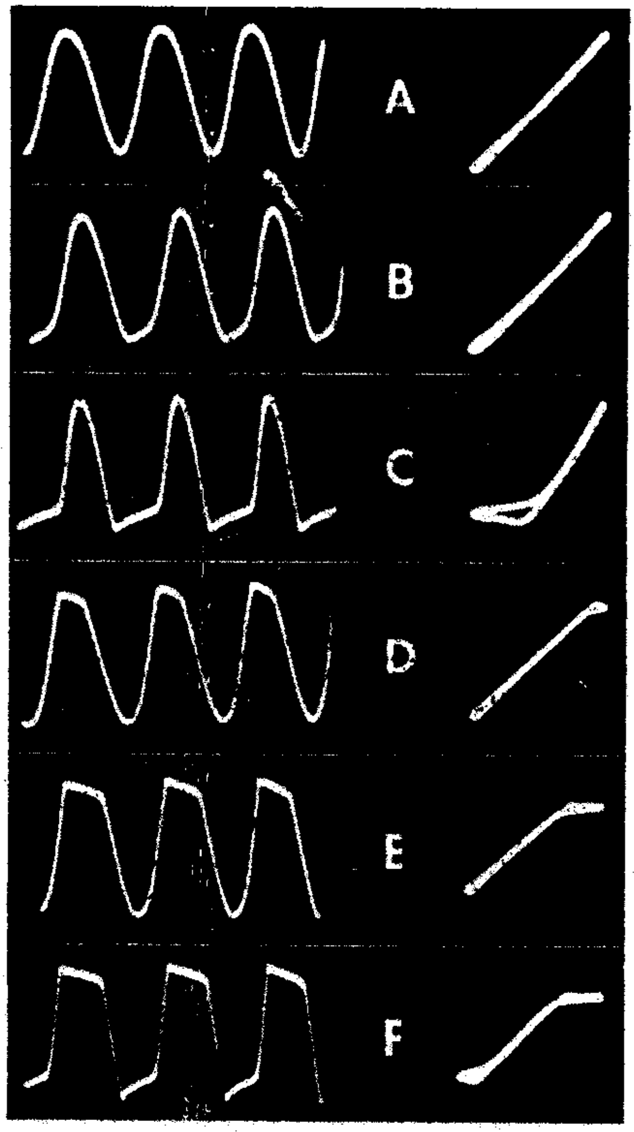


Fig. 23—*AF distortion traces obtained as explained in the text.*

spot in the horizontal direction, whereas the output, if taken from some high (AF) voltage point will be adequate for producing ample vertical deflection. The result will be that an almost vertical line is produced, whereas for showing up distortion by this test, the line should be at about 45 degrees to the horizontal.

It is clear that in some way the input voltage must be raised before it is applied to the horizontal plates to a value approximately that of the output voltage.

The best way of doing this is to use an AF amplifier following the signal generator, so that the voltage available is adequate for the required deflection. Across the high AF voltage output circuit of this amplifier we connect a potentiometer so arranged that we can tap off the necessary small input voltage for the amplifying stages under test. The ratio of the potentiometer should be approximately equal to the gain of the amplifying stages under test.

Then if the total voltage across the potentiometer is applied to the horizontal plates of the oscilloscope, and the output voltage of the amplifying stages under test is applied to the vertical plates, we should get our straight line inclined at about 45 degrees on the screen.

In this way we avoid the necessity for the oscilloscope time-base and for any oscilloscope amplifier ; in fact, a cathode ray tube, with its power supplies, is all that is necessary. The amplifier following the service signal generator need not be absolutely distortionless, as any distortion produced will only add slightly to the distortion of the signal generator output, which is assumed to be present, and which will not affect the results.

A number of photographs were taken to illustrate the effects of distortion of various kinds. The results are given in Fig. 23. Against each line is the corresponding output waveform, produced as explained on pages 22 and 23. To make the effects clear, a pure sine wave input was used, but the inclined lines would be the same even if a moderately distorted input were used.

The following notes on the traces shown explain their features.

Trace A.—This shows an almost undistorted output, the wave being practically of sine form, and the line nearly straight.

Trace B.—Here the stages under test are overloading slightly, due to excessive negative bias on the output valve. The valve is " bottom bending," and the lower end of the line is slightly curved and thickened.

Trace C.—With a larger input and excessive negative bias, serious bottom bending is occurring. The " line " resembles the lower part of a valve characteristic. The loop is caused by a certain amount of phase shift.

Trace D.—Here the peaks of the wave are distorted, and the top of the line bends round, due to insufficient grid bias on the output valve.

Trace E.—The same fault is shown here, but in an exaggerated form. The top of the line is horizontal for an appreciable length.

Trace F.—This was produced by insufficient grid bias, coupled with a reduced HT supply to the valve (reducing the permissible anode swing). The output valve is top and bottom bending, and the result is that the " line " resembles a valve characteristic.

The straight line is only produced when the two voltages applied to the oscilloscope are in phase (or 180 degrees out of phase). For intermediate degrees of phase shift an ellipse or circle will be produced. This forms a ready means of checking whether phase shift occurs in the amplifying stages under test. It is not very important in ordinary radio work, but in television phase shift may cause trouble.

The left-hand trace of Fig. 24, shows the type of figure produced, in place of a line, when there is no distortion, but a small phase shift between the input and output of the amplifier The right-hand trace is that produced when phase shift and appreciable top bend distortion are present.

Actually most amplifying stages produce various phase shifts at different frequencies ; at low frequencies a lead is usually introduced, while at high frequencies a lag is produced. If a variable AF oscillator is available, a frequency can usually be found at which the lead balances the lag, and the overall phase shift is zero. This fact was used to produce the lines in Fig. 23.

RECEIVER ALIGNMENT

ONE of the chief uses of the cathode ray oscilloscope in radio service work is for receiver alignment, and it is true to say that to-day oscilloscopes are sold mainly on account of this, despite the fact that they can be employed for a variety of other service purposes.

Many engineers at present using oscilloscopes for alignment are working by rule of thumb methods—they know what connections to make, and what knobs to turn, but precious little else about what they are doing, with the result that when a snag occurs they are at a loss to diagnose its cause.

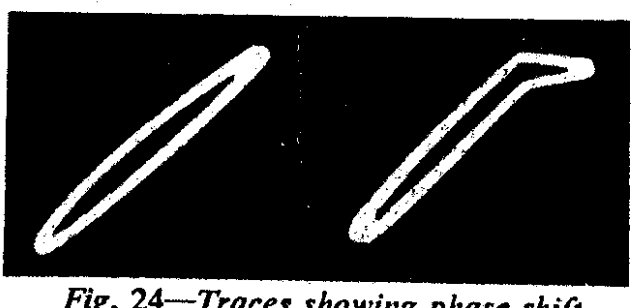


Fig. 24—Traces showing phase shift.

In the belief that rather more explanatory details than are given in the average instruction book accompanying an oscilloscope are needed, it is proposed to deal with receiver alignment in some detail.

The main reason for using an oscilloscope for receiver alignment is that by this means, the actual response curve of the stages being aligned can readily be shown on the screen, and the effects of any adjustments made to the receiver are shown up instantaneously by a change in the dimensions and shape of the trace on the screen.

By no other method can one instantaneously see the effect of alignment adjustments on the response curve of the set, and since many modern receivers depend on their IF response curve largely for their quality of reproduction, and, incidentally, were aligned originally at the factory by an oscilloscopic method, it is obvious that a similar method should be used for re-alignment.

In considering how the response curve of, say, an IF stage can be shown on the screen of the oscilloscope, consider what happens when the correct intermediate frequency is injected from a signal generator into the IF stage, and the output taken to the vertical deflector plates of the oscilloscope.

If the time-base is switched off, a vertical line is produced on the screen, its height being proportional to the voltage output of the IF stage. If we alter the trimmers or other adjustments of the stage, the line will increase or decrease in height, and at the correct adjustments, from the voltage point of view, the line will reach its maximum height.

This is precisely what occurs when aligning with a signal generator and output meter—in fact, under the conditions mentioned, the oscilloscope is giving us no more information than would an output meter or AC voltmeter connected at the output end of the receiver—it is merely indicating the voltage output.

In the case of a visual method of alignment, we are interested not only (or mainly) in the maximum voltage output, but also in the response curve produced by the alignment process.

To throw the response curve of the stage under test on the screen calls for apparatus different from or at any rate, supplementary to the ordinary type of signal generator.

If we produce our vertical line, as explained earlier, and then switch on the time-base of the oscilloscope, we merely convert the line into a rectangular patch or, if the time-base runs fast enough, into the waveform of the *input signal* ; if we modulate the IF input with AF, we get the AF modulation peaks shown up on the IF envelope, as explained on page 20. None of these pictures tells us anything more about the response of the stage under test, however, because the input is at a fixed frequency. What is needed is some method of " drawing " the response curve on the screen.

This curve, as normally drawn, is a graph showing voltage output, plotted vertically, against input *frequency*, plotted horizontally. Now it is easy to show the voltage output on the tube screen, as has already been mentioned ; the difficulty is in the production of the variable frequency, and its method of application to the horizontal plates.

In place of the ordinary " time "-base in which the horizontal deflection voltage is directly proportional to time, we need a frequency-base, where the horizontal deflection voltage is proportional to the frequency of the input signal.

The response (or resonance) curve of an IF amplifier may be from, say, 6 to 20 KC/S wide in a radio receiver, so that a graph covering a frequency range of, say, 30 KC/S will be suitable.

Obviously, this variation will have to be relative to the fixed IF of the stage under test. Suppose this IF is 470 KC/S, then if we vary the input of the signal generator from 455 to 485 KC/S we shall cover the 30 KC/S band width, and our response curve will be well within it.

To provide an input of a suitable nature to the stage under test, the frequency of the voltage applied, while remaining at an average value equal to the true IF of the stage, must vary rapidly, say, 15 KC/S above and below this frequency, in order to swing over the full band-width of the stage.

Special signal generators having this type of output are available, and are known as frequency-modulated oscillators, or wobbulators. Sometimes an attachment permits an ordinary signal generator to be frequency-modulated. The use of a frequency-modulated oscillator is essential for visual alignment.

In addition to providing a wobbulating input to the stage under test, some means must be adopted for using the linear time-base of the oscilloscope in conjunction with the wobbulator.

For ordinary waveform observation, the time-base is adjusted to some ratio of the frequency of the input, in order to secure several complete cycles on the screen. For visual alignment, however, the frequency of the time-base bears no relation at all to the mean frequency of the signal.

Since the movement of the cathode ray spot horizontally across the screen is proportional to time when the linear time-base is in use, then if the frequency variation of the wobbulator is also proportional to time, and the wobbulator is synchronised as to its repetition frequency with the time base, then the horizontal movement of the spot will now be proportional to frequency.

This is what is required along the horizontal axis, and if the voltage output of the wobbulator is fed to the stage under test, and the output of this taken to the vertical plates of the oscilloscope, we shall trace out the response curve.

To sum up, a frequency-modulated oscillator provides a signal which is continuously varying in frequency at some pre-determined rate slightly above and below the mean frequency, the latter being adjustable to the requirements of the stage being aligned. At the same time, means are provided for linking up the frequency-modulated oscillator with the linear time-base of the oscilloscope so that horizontal distances on the tube screen are proportional to frequency.

The first method of producing frequency modulation was a mechanical one. A small variable condenser, with a rotor capable of continuous rotation, was connected across the normal tuning condenser of the oscillator, and driven at a constant speed by a fractional HP electric motor. By this means the effect of a continuous variation of the tuning capacity was produced, with a consequent variation in the output frequency of the oscilloscope.

In order to secure the same variation of frequency at all frequencies covered by the oscillator, which is essential for serious work, the method described is not satisfactory, because the percentage change in capacity produced by the rotary condenser varies with the setting of the main tuning condenser.

To get over this trouble, a beat-frequency type of oscillator is used. This, of course, involves the mixing of two frequencies, one fixed, and the other capable of variation, to produce a variable output frequency. If the rotating condenser is placed in parallel with the tuning condenser of the fixed frequency oscillator, the latter's frequency will vary about the mean fixed frequency.

On combining its output with that of another oscillator capable of being tuned, we shall obtain a beat frequency, frequency modulated, and, furthermore, the modulation band width over the whole range of the variable oscillator will be constant. In other words, with 30 KC/S modulation, if we tune the variable oscillator to give a mean output of 1,000 KC/S, the actual output will be a band from 985 to 1,015 KC/S; if the mean output is set at 100 KC/S, the actual output will be a band from 85 to 115 KC/S.

Modern frequency-modulated oscillators do not operate by the mechanical method described; instead, a valve circuit is used to effect the frequency modulation.

It should be mentioned at the outset that these nearly all operate on the beat-frequency principle in order to secure constant band width of the modulation over the whole range.

For frequency modulation using a valve, use is often made of the Miller effect, whereby a variation in the anode load or the internal resistance of the valve is reflected as a variation of the input capacity of the valve; if the valve is connected with its grid circuit across the oscillator tuned circuit, this variation in capacity will vary the frequency and provide frequency modulation.

In order to vary the internal resistance of the modulator (Miller) valve, grid bias is supplied to it from the linear time-base of the oscilloscope, whose voltage is DC, continuously varying from zero to a maximum, and then repeating. By adjusting the time-base to a certain speed, it is clear that the speed of the frequency modulation can be adjusted. The speed usually chosen is about 25 C/S.

Other means are sometimes used to employ the oscilloscope time-base in such a way that it varies the impedance of the modulator valve, which in turn affects the tuning of one of the oscillator valves, and so provides frequency modulation of the signal.

From the service engineer's point of view, he is not primarily concerned in how the frequency-modulated signal is produced, and we shall next consider how he must employ it for alignment.

Broadly speaking, the method of alignment using a frequency-modulated oscillator and a cathode ray oscilloscope follows closely the method employed when an ordinary signal generator and output meter are used, at any rate as far as the alignment frequencies, the order of alignment, and the various adjustments are concerned.

In other words, once a service engineer has grasped the principles of visual alignment, then he will be able to deal with any receiver for which ordinary alignment instructions are available. No special instructions are normally necessary for visual alignment.

The first important point to consider is the method of connecting up the equipment to the receiver being aligned. If the receiver is of the superhet type, the IF adjustments will be carried out first.

The connection of the frequency-modulated oscillator will be the same as for a normal amplitude-modulated type. The instrument is usually fitted with a screened output cable, and the screen of this will be connected to chassis (AC or battery receivers) or true earth (AC/DC receivers). The "live" lead, for IF alignment, is connected, via a fixed condenser of 0·01 μF to 0·1 μF, to the point where the signal input is required.

Providing that the receiver is not badly out of alignment, the signal will be fed into the mixer control grid of the frequency changer valve. This is usually the top cap connection of the valve. The existing top cap connector should be left in place.

The oscillator section of the receiver should be put out of action by short-circuiting the oscillator section of the gang condenser, or the oscillator grid coil, or by connecting a 0·1 μF condenser from oscillator grid to chassis.

In addition, it is customary to put the AVC circuits of the receiver out of

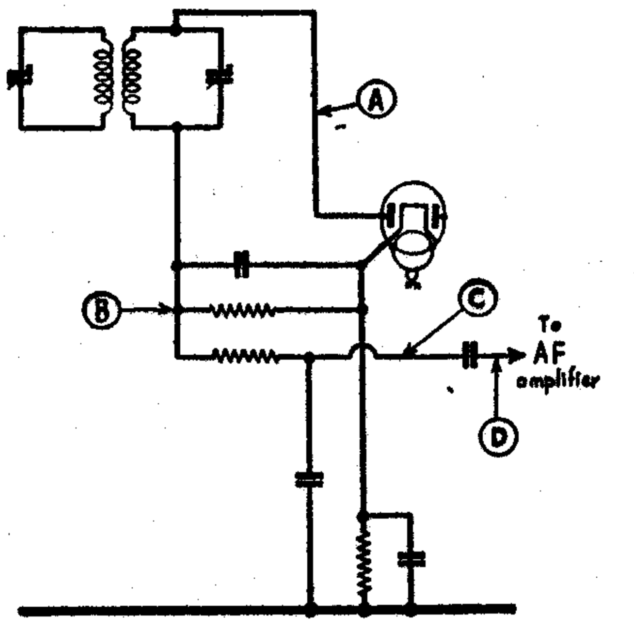


Fig. 25—*Points for connection of the oscilloscope to a superhet.*

action by connecting to chassis the end of the AVC line which goes to the RF and IF grid returns. It is possible to avoid cutting out the AVC, if it is of the delayed type, by working with a signal input less than the value of the delay voltage. On the whole, however, it is probably best to render the AVC entirely inoperative ; one must still work with a fairly low input, however, to prevent overloading the receiver and possibly producing distorted response curves.

Where variable selectivity is used the set should be adjusted for maximum selectivity. AFC circuits, if employed, should be switched out of action.

As far as the connection of the oscilloscope is concerned, we have the choice of working with the unrectified IF output of the stages under alignment or the rectified AF output. In the former case we obtain a double " envelope " of the waveform, while in the latter a single line curve is produced.

It will usually be found that the output available just prior to the detector of the receiver (where the oscilloscope must be connected to obtain the IF envelope) is insufficient to give a trace of adequate height without amplification ; as the vertical amplifiers of some oscilloscopes will not respond well to the higher intermediate frequencies, the production of a response curve of suitable size is likely to be difficult. This, of course, does not apply to some of the better oscilloscopes, but it must be borne in mind.

Another disadvantage of the " envelope " response curve is that it is normally much fainter than the single line curve, and is not therefore so suitable for observation under normal lighting conditions.

The AF (rectified) curve avoids these disadvantages by providing a bright trace, which can readily be amplified by the vertical amplifier of the oscilloscope.

Fig. 25 shows a skeleton circuit diagram of the final IF stage, second detector, and AF feed of a typical superhet. The lettered arrows show points to which the oscilloscope vertical amplifier input terminal can be connected to obtain various types of curve. The oscilloscope itself must have its earth terminal connected to a good earth, and the receiver and signal generator must also be earthed.

If the IF envelope type of curve is required, connection may be made to point A, via a very small condenser. Actually, two insulated wires twisted together for a turn or two, giving a capacity of the order of one $\mu\mu$F, will serve, or the insulated lead can be twisted round the appropriate connection wire in the chassis. The lead should be as short as possible, but unscreened, to avoid a capacity load on the circuit.

At point B, the high potential end of the signal diode load, the AF signal, with a small residual IF, is present. If the oscilloscope is connected here, via a very small coupling condenser, the AF is blocked, but the residual IF passes to the oscilloscope, and will produce the envelope type of curve. It will be small, however, and will need more amplification by the oscilloscope amplifier.

Connection to point B, via a large coupling condenser (about 0·5 μF) will result in the AF trace being produced, but the residual IF will also be present, and will manifest itself as a thickening of the trace, particularly at the peak and skirt. This can be avoided by the use of an external IF filter unit, or by using the receiver's own IF filter, connecting the oscilloscope (via a large coupling condenser) to point C. Here the comparatively fine AF trace only should be obtained, and, incidentally, this point is, in the author's experience, one of the best places for connection for general alignment work.

Curves Obtained With Various Oscilloscope Connections

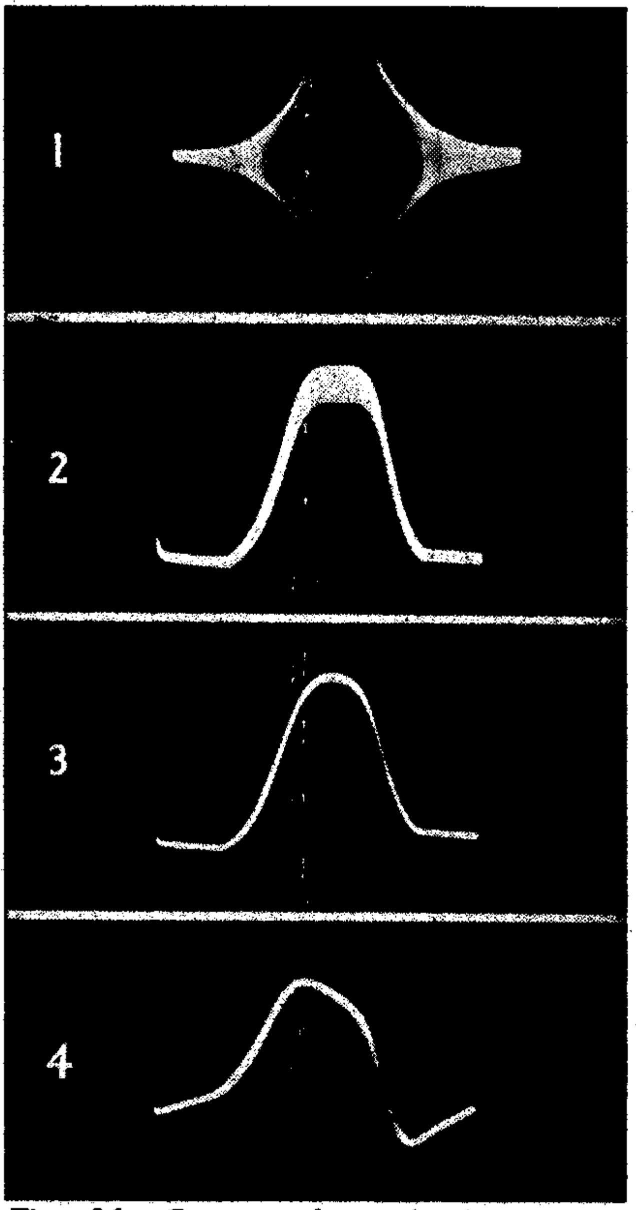


Fig. 26—Curves obtained from points shown in Fig. 25.

The final point, D, on the far side of the AF coupling condenser, often introduces phase distortion in the picture, due to the comparatively low value of the condenser, and the trace obtained is not satisfactory.

Illustrations of curves obtained at the various points mentioned are given in Fig. 26.

Curve 1 is the IF envelope obtained at A, using a small coupling to the oscilloscope amplifier input. Notice that the curve is symmetrical about the horizontal base line. The outline of the " filled-in " figure shows the response of the IF stages. If the oscilloscope is connected to point B, via a small coupling, a figure similar to 1 in Fig. 26 is produced provided extra amplification is used.

Using a large coupling condenser at point B, however, results in curve 2 of Fig. 26, which is an AF trace, containing residual IF. This is shown by the thickening of the peak of the curve. By using a large coupling condenser connected to point C, curve 3 of Fig. 26 is produced. This is the AF curve, free from IF, and is the best one to use for observations of the response of the stages being aligned. Curve 4 of Fig. 26 shows the result of connecting the oscilloscope to point D. The curve should be similar to curve 3, but the effect of the AF coupling condenser has been to introduce phase shift, distorting the trace produced. The effect may not be quite the same in other circumstances, but in any case, point C in Fig. 25 is usually better than point D.

Where the receiver to be aligned is of the TRF type, the connection of the oscilloscope will naturally be slightly different, though the same principles are employed. Fig. 27 shows a skeleton triode detector circuit of a TRF receiver.

If the oscilloscope amplifier is connected to the anode of the valve (point A) via a very small coupling condenser, we shall obtain the RF envelope of the response of the preceding stages, because both RF and AF are present at the anode, and the small coupling condenser blocks the passage of AF. An oscillogram like trace 1 of Fig. 26 will thus be obtained.

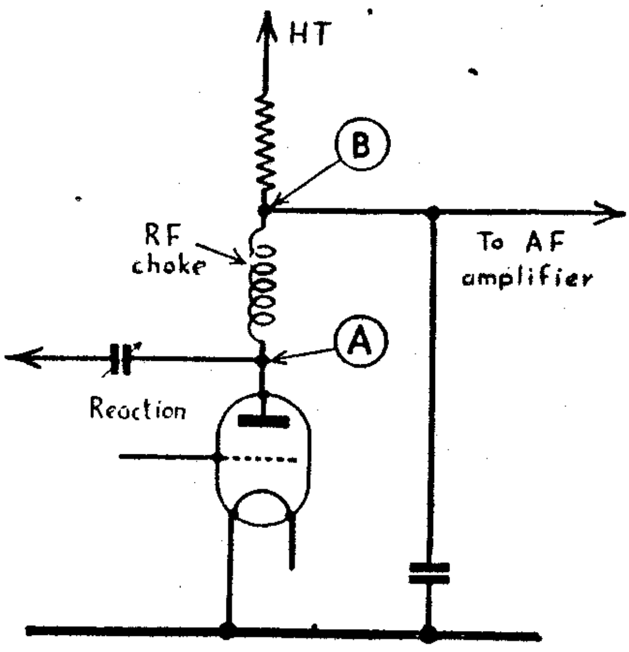


Fig. 27—Points for connection of the oscilloscope to a TRF receiver.

Using a large coupling condenser at point A will result in an AF trace containing RF (like curve 2 in Fig. 26). At point B (Fig. 27) the result obtained, using a large coupling condenser, will be a single line AF trace, as at 3 in Fig. 26 At this point the residual RF has been removed by the anode choke (and by-pass condenser, if used). Naturally, any distortion introduced by the detector stage will modify the response curve, but with modern receivers, unless there is a fault in the detector circuit, any distortion so introduced is likely to be negligible.

The circuit of Fig. 27 shows the detector with a resistive anode load, as for RC coupling to the succeeding AF stage. In cases where the detector is transformer coupled to the succeeding valve, the primary of the AF transformer in the anode circuit forms a reactive load, which will cause distortion of the response curve. In such cases it is necessary temporarily to disconnect the primary of the AF transformer, and replace it with a resistor having a value equal to the load of the transformer primary. A value of the order of 50,000 O is often suitable. If the detector is followed by a parallel-fed transformer, it will only be necessary to disconnect the top of the primary of the transformer.

Similar connection arrangements apply in the case of tetrode or pentode detector valves, where used.

It will be noticed that in the examples of AF traces shown in Fig. 26 the peaks are all above the horizontal base line. In practice, the peaks of the curves may come above or below the base line, depending on the type of detector used in the receiver, and on the number of stages of amplification used in the vertical amplifier of the oscilloscope. Each extra stage inverts the image.

From the practical point of view there is no point in trying to arrange for the image to be above the base line in all cases, for it is just as simple to align with either type of curve.

Where a curve having its peak above the base line is obtained, one will naturally operate the vertical shift control of the oscilloscope so that the base line is somewhat below the centre of the tube, in order that an image of reasonable size can be obtained without having its peak too close to the top of the tube. If the peak is below the base line, the vertical shift control will be operated to bring the base line above the centre of the tube.

Returning to the connections of the frequency-modulated oscillator, it was pointed out that these are precisely the same as if an ordinary amplitude-modulated type were in use. The connections for IF alignment have been given ; for RF and oscillator alignment the output leads from the generator are transferred to the aerial and earth sockets of the receiver, the usual dummy aerial being used in series with the aerial connection.

The oscilloscope connections remain the same for all the alignment operations. Naturally, after the IF alignment (which is always carried out first), the oscillator section of the receiver, which has been put out of action during IF alignment, must be rendered normal again. The AVC circuits (and AFC if present) should remain out of action.

Throughout alignment, the rule should be to work with the least possible signal input, obtaining a response curve of suitable size by increasing the gain of the oscilloscope vertical amplifier. In fact, it is a good plan to keep the amplifier gain control at maximum, and reduce the input to a suitable value.

The necessary switching for the frequency-modulated oscillator, and the inter-connections between it and the oscilloscope will depend on the make of equipment in use.

If the frequency-modulated oscillator is of the self-contained type, there will probably need to be only one connection between it and the oscilloscope, to pick up the time-base voltage from the latter to control the frequency-modulation.

Where a separate frequency-modulator unit is used, in conjunction with an ordinary signal generator, these two will also have to be inter-connected, and particular care must be taken to ensure that the output obtained is of the correct frequency ; usually the signal generator will have to be set at such a frequency that, beating with the fixed frequency of the frequency-modulator unit, it produces as a resultant the desired signal frequency. A careful study of the manufacturers' instructions on this and other points is essential if satisfactory results are to be obtained from the instruments.

ALIGNMENT OPERATIONS

COMING now to the actual alignment operations, and assuming that the receiver is a superhet, the frequency-modulated oscillator is connected up to the set as already described for IF alignment, while the oscilloscope is connected to give the AF (rectified) single line trace.

This assumes that the receiver is not seriously out of adjustment ; if it is, the best plan is to work first of all with an amplitude-modulated input of the correct intermediate frequency and peak the IF stages with this, before proceeding to the final adjustments on the actual response curve. In fact, until some experience in visual alignment has been obtained, it will probably be best to carry out initial adjustments with an amplitude-modulated signal in all cases.

Some frequency-modulated oscillators have a switch which converts them to the amplitude-modulated type when desired, in which case all one has to do is to switch over to this, leaving all the connections undisturbed. Where a separate frequency-modulator unit is employed, the output from the signal generator must be removed from the unit, and taken to the receiver in place of the output from the modulator unit.

When the oscilloscope is connected to obtain the rectified trace (as has been recommended) the output from the signal generator must be modulated with AF (usually 400 C/S), and the result on the oscilloscope screen will be the 400 C/S modulation only. If the time-base is set at 25 C/S, which is often the frequency used for frequency-modulation, the trace will contain sixteen complete sine waves, and will resemble trace A of Fig. 20 (page 20).

We are not interested in the shape of the wave at the moment, but merely in the height of the image. Once the image has been obtained (and if the receiver is much out of alignment a large input from the signal generator may have to be used) the trimmers or iron cores of the IF transformers must be adjusted for maximum height of the image. It is usual to work from the secondary of the last IF transformer towards the input of the set, finishing with the primary of the first IF transformer. During the whole of this process the input from the signal generator must be progressively reduced as the circuits come into line.

When no further increase in height for a given input can be obtained, it can be assumed that the IF stages are peaked at the correct frequency. At this stage one can change over to a frequency-modulated input, by appropriate switching or connections, with the assurance that the response curve will be visible on the screen (providing that, in the case of a separate modulator unit, the signal generator is adjusted to a frequency of the correct value to give as a beat frequency the desired IF).

The reason for starting with an amplitude-modulated signal is that, even if the circuits are badly out of line, providing one injects a large signal, some response is bound to be visible ; under the same conditions with a frequency-modulated input, if the IF stages of the receiver happened to be off tune by an amount greater than the extent of the frequency sweep (say, 30 KC/S), as is quite possible, no response curve at all would be seen on the screen, and no indication would be provided as to the amount or direction in which the set was off tune.

The result is that one would have to search for the image while swinging the oscillator tuning control, and then, while aligning, gradually bring the tuning control to the correct IF setting. This tedious process is avoided by first peaking the stages with an amplitude-modulated signal.

After switching over to frequency modulation, and making sure that the input is of the correct frequency and is sufficient to provide a trace of reasonable height, it will probably be found that a curve something like trace C of Fig. 28 is visible on the screen.

It may be found that the curve is not central on the base line, which means that the frequency-modulated oscillator setting is not quite the same as the IF to which the set is aligned. Unless the displacement of the curve to one end of the base line is considerable, it is permissible to centre it by a slight readjustment of the input frequency, as the error will not be sufficient to be appreciable.

If the displacement of the image is considerable, however, it will be necessary, after the setting of the oscillator has been checked, to re-align the IF stages so that

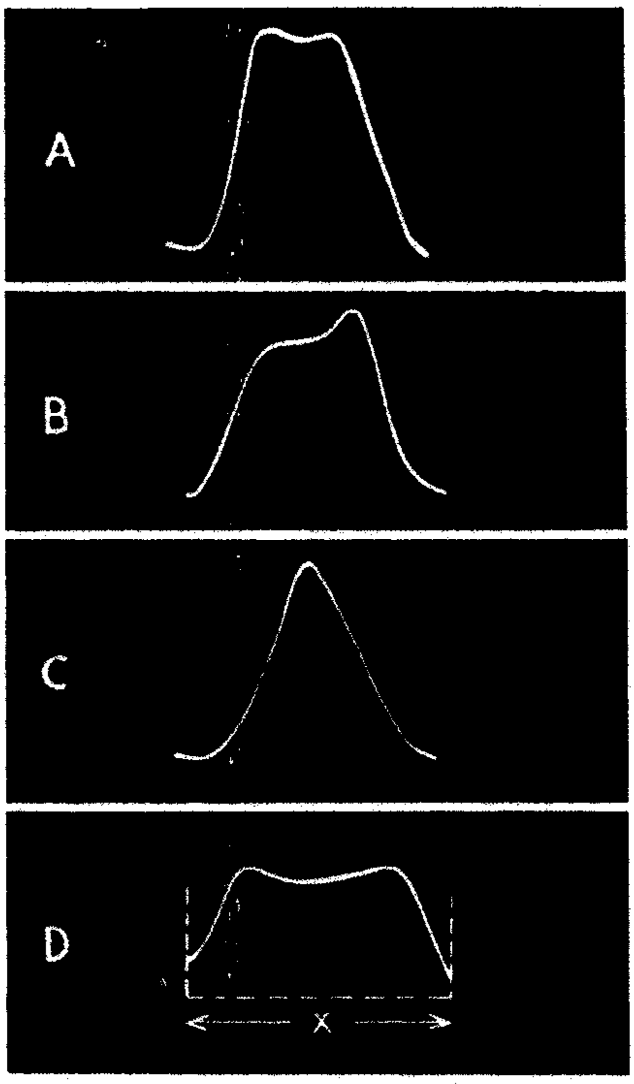


Fig. 28—Response curves showing various features which are described in the text.

the peak is centralised on the base line. This should not be necessary, however, if the stages have previously been accurately peaked with an amplitude-modulated signal, as already described.

Assuming that the curve has been centred on the base line, and that it resembles C in Fig. 28, this curve indicates a single peaked response which normally cannot be considered satisfactory in a receiver designed to give good quality reproduction. There is an exception to this, namely, a variable selectivity receiver where, at the position of maximum selectivity, a curve as shown may be normal. In this case, before proceeding further, the selectivity control should be adjusted to see whether the peaked curve opens out and, if so, a position should be chosen which is somewhere about mid-way between maximum and minimum.

The correct type of curve to aim at is shown at A in Fig. 28. It should be symmetrical, steep-sided, and with a fairly level top (though a dip in the centre cannot usually be avoided entirely). At any rate, the dip should not be so deep as to give the impression of two similar but separated peaks.

The width of the trace, in the case of a normal receiver, should be about 9 KC/S at a height equal to about one-tenth of the total height of the curve. At this level the signal voltage has fallen to one-tenth of its maximum. In practice, one often measures the band width at a level rather higher than this, say, at about one-quarter the maximum height.

BAND-WIDTH CHECKING

THE measurement of band-width to a reasonable degree of accuracy may be made quite simply if one knows the frequency sweep of the oscillator (usually given by the makers). Suppose this is 30 KC/S ; now measure the total length of the base line produced on the screen, using a suitable scale. For simplicity let this be 60 millimetres. Then, obviously, every 2 mm represents 1 KC/S on the screen. By measuring the width of the response curve in millimetres, this can then readily be converted into KC/S band-width.

If the frequency sweep of the oscillator is unknown, the band-width of the response curve can be obtained in a different way. For this purpose a transparent scale with a vertical index line on it is desirable. In Fig. 29 suppose AB is the vertical line. The tuning control of the frequency-modulated oscillator is adjusted slightly so that the response curve is moved to the right until the left-hand side of the curve cuts the vertical line at the point C, which is at the level at which the band-width is to be measured. The full line curve indicates the position of the response curve. The reading of the oscillator scale is noted. Suppose it indicates 470 KC/S.

Now adjust the oscillator control so that the response curve is moved to the left, so that point D, at the same height as C, now cuts the vertical line of the scale. The dotted line curve indicates the new position of the trace, point D coinciding with C. Note the new reading of the oscillator scale, and suppose it is 461 KC/S. Then the band-width at the level CD is 470-461, or 9 KC/S.

Naturally, owing to the small difference between the two readings of the oscillator scale, this method is not one of great accuracy, but it is good enough for the present purpose. One type of frequency-modulator unit has a special control calibrated directly in KC/S for band-width measurements, and readings to a high degree of accuracy can be obtained with it.

Some receivers incorporating a variable selectivity control will give a peaked curve like C in Fig. 28, about 6 KC/S wide, at the maximum selectivity position, while at the minimum selectivity position the curve may be 15 KC/S wide. The curve D in Fig. 28 shows a very wide band response—it is actually rather more than 30 KC/S wide, the distance X being 30 KC/S. The curve also exhibits some lack of symmetry, and is really an example of faulty alignment.

Curve B in Fig. 28 is another example of faulty alignment, the curve being peaked on one side. It is recommended that the service engineer should experiment with several receivers in order to acquire skill in the production of correctly shaped response curves. It will probably be found that, starting with curve C (Fig. 28), adjustment of one of the IF trimmers will produce something like curve B (or its reverse). The next step is to reduce the height of the peak on the right of B by means of one of the other trimmers, aiming always at producing a curve similar to A. The technique is not one that can readily be described, but half an hour's experimental work on an actual receiver will soon indicate the types of adjustments required.

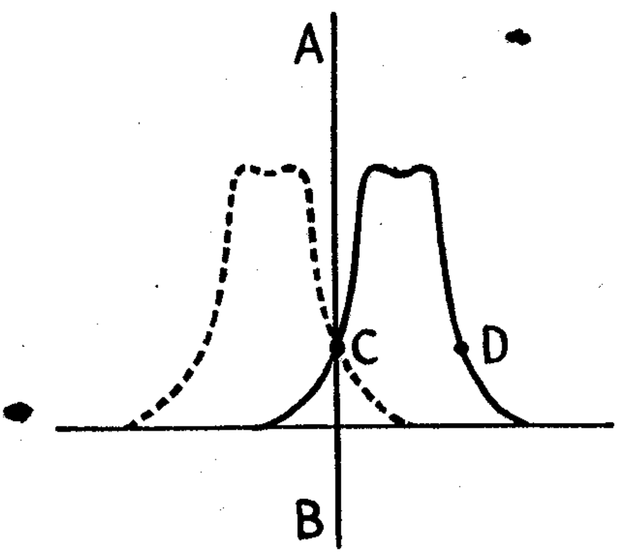


Fig. 29—Diagram illustrating one method of band-width measurement.

It should be remembered that a proper band-pass curve will never be as high as the single peaked curve, so that a set aligned by peaking, using a non-visual method, will never have a band-pass response. Some receivers have IF stages which are not capable of producing a band-pass response, and if this type of receiver is encountered, the best plan is to peak the transformers and then endeavour, by slight adjustments to the trimmers, to widen the curve at the top to some extent.

During the alignment process, the curve must be kept central on the base line. It is often found that a good curve is produced, but that it is off centre. This means that the set is now aligned to an IF

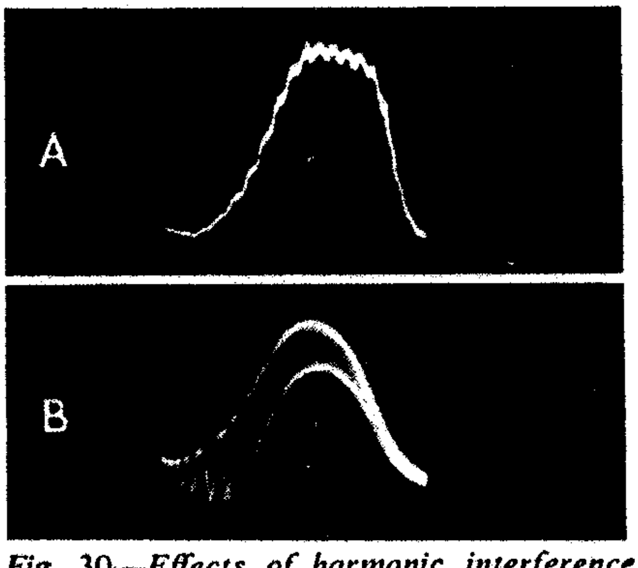


Fig. 30—Effects of harmonic interference and break-through on the response curve.

slightly different from the correct one, and the misalignment must be corrected. Usually, in a set with two IF transformers (four adjustments) it will be best to concentrate on the first three, as the secondary of the second transformer (if it has already been peaked) will probably need very little, if any, adjustment.

The reason for putting the receiver oscillator circuit out of operation before IF alignment is shown in Fig. 30. Interference between harmonics of the receiver oscillator and the IF signal can produce effects as at A and B. At A the superimposed frequency is fairly low, but at B it is higher, and the result is a partial envelope which thickens up the response curve. It is possible to "dodge" these effects by adjustment of the receiver tuning control, but the best plan is to put the oscillator circuit out of action, as already described. A somewhat similar effect is sometimes produced by direct pick-up from a transmitting station.

Having aligned the IF stages of the receiver satisfactorily, attention must be turned to the RF and oscillator stages. The output from the frequency-modulated oscillator is transferred to the aerial and earth sockets of the receiver (via a suitable dummy aerial), and the receiver oscillator circuit is put into action again. From this point the alignment follows closely the instructions given by the manufacturers of the particular receiver.

Taking one waveband only (similar adjustments will apply to each band, except for the actual frequencies used), the frequency-modulated oscillator is adjusted to give the correct signal for the high frequency end of the band (usually about 1,400 KC/S on MW and 300 KC/S on LW), and the receiver is tuned to the corresponding wavelength on its scale. The response curve should then be visible on the screen. The MW oscillator trimmer should then be adjusted to centralise the curve on the base line. If the curve is not visible at all, the oscillator trimmer should be slowly adjusted each way in turn until it appears, and is finally centred.

The MW trimmers for the aerial and RF circuits (if any) must now be adjusted for maximum image height. The response curve should, of course, be the same as that obtained during IF alignment. If band-pass RF or aerial circuits are used, however, their adjustments may affect the shape, as well as the height, of the overall response curve. In this case they must be carefully adjusted to retain the symmetry and general shape of the curve, at the same time increasing its height as much as possible.

Having performed the alignment at the higher frequency end of the scale, the tracker for the band must be adjusted, if a variable one is provided. In this case, a frequency-modulated signal of the correct mean frequency (usually about 600 KC/S for MW, and 167 KC/S for LW) must be injected, and tuned in until the response curve is central, by means of the receiver tuning control. The tracker is then adjusted for maximum image height.

The image will shift sideways as the tracker is adjusted. If its height increases at the same time, continue adjusting in the same direction ; if it decreases, adjust in the opposite direction. If the image moves off the screen before it reaches its maximum height, it can be brought back into the field by a slight re-adjustment of the receiver tuning control.

When maximum height of the image has been secured, the tracker may be regarded as correctly adjusted. It is then desirable

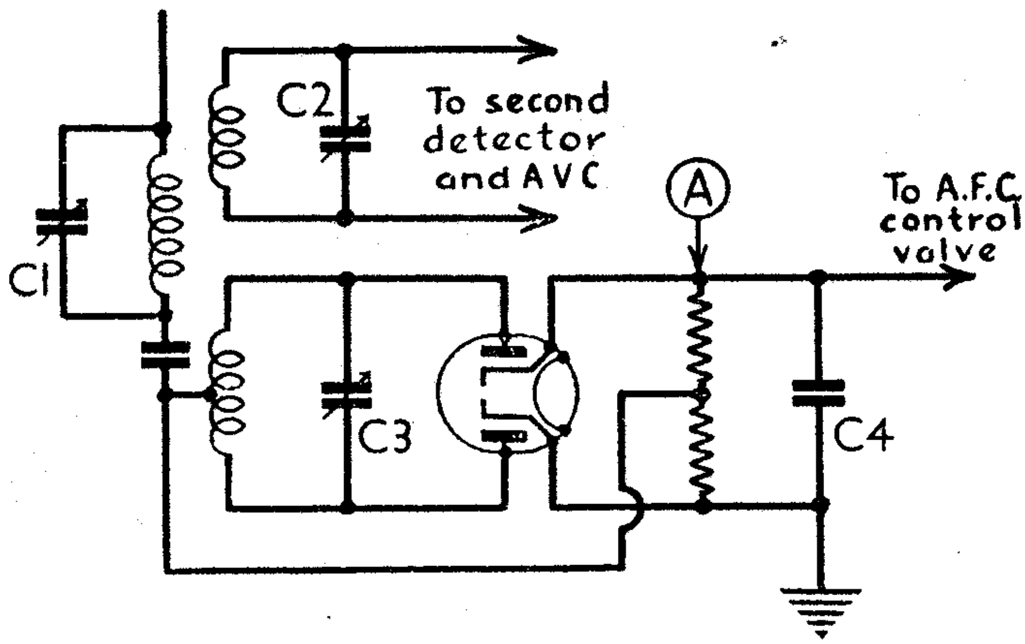


Fig. 31—Skeleton diagram of a typical AFC discriminator circuit, showing connection point for the oscilloscope.

to return to the higher frequency end of the scale again and make any slight re-adjustments which may be necessary.

This procedure is repeated for each of the wavebands of the receiver, and the alignment is then complete, except where adjustable IF or second channel filters are provided. These can be adjusted by the ordinary non-visual methods, since they do not affect the response of the receiver, but since the visual equipment is connected up, it may just as well be used. The signal fed in should be amplitude-modulated, and the manufacturers' instructions for the filter adjustments should be followed, the object being to trim for *minimum* height of curve in each case.

Certain modern superhet receivers (mainly of the automatic tuning type) incorporate automatic frequency control circuits, for which visual alignment is particularly suitable. The AFC circuits should be dealt with after the usual IF alignment.

First of all, align the normal IF stages very carefully by the visual method, making sure that the input frequency is absolutely correct, and that the response curve on the screen is exactly central on the horizontal base line. During this process the AFC circuit should be put out of action, by operating its switch (if one is provided), switching the set to " normal " or connecting point A in Fig. 31 to chassis. Incidentally, Fig. 31 is a skeleton diagram of a typical AFC discriminator circuit of the phase-shift type, using a centre-tapped discriminator secondary on the final IF transformer, feeding a double-diode valve with separate cathodes, the AFC control voltage being developed across load resistances connected from cathode to cathode, the voltage then being fed to some suitable control valve circuit.

During the normal IF alignment, trimmers C1 and C2 will be adjusted. To observe the AFC voltage curve, transfer the oscilloscope input lead (with a 0·5 μF condenser in series) to point A in Fig. 31, at the same time putting the AFC circuit in action again by switching, or by removing the short-circuit from A to chassis. It will be advisable temporarily to disconnect condenser C4 in Fig. 31 to avoid distortion of the discriminator curve, or at any rate, to substitute a component of lower capacity here.

The setting of the frequency-modulated oscillator must on no account be altered, but must remain the same as for the IF alignment. The resultant curve should be like B in Fig. 22, where it will be seen that the sloping line joining the two peaks cuts the base line exactly at its centre, and the curve is almost symmetrical. Usually it will be found almost impossible to obtain an absolutely symmetrical curve.

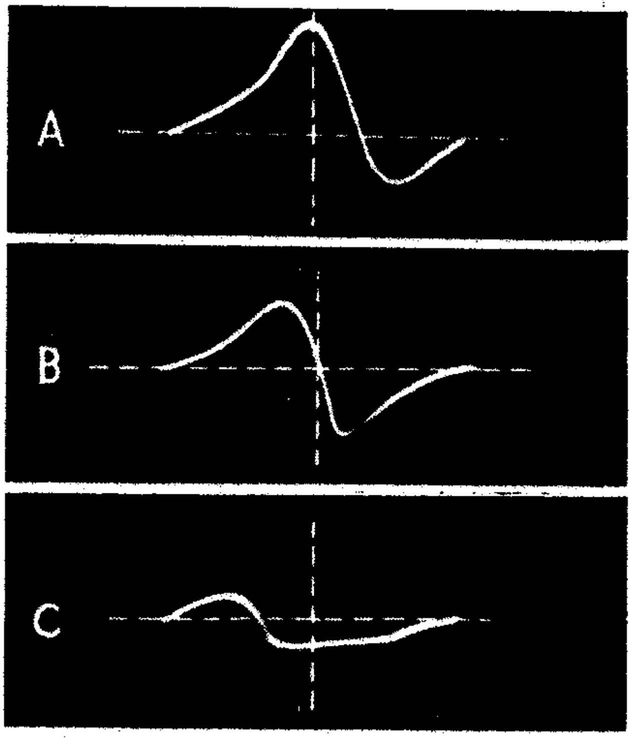


Fig. 32—Three AFC discriminator curves.

Curves A and C of Fig. 32 show the results of incorrect adjustments of trimmer C3 across the discriminator secondary. In A the sloping line cuts the base line to the right of its centre ; in C it cuts it to the left, while the discriminator response curve is also much reduced in amplitude. C3 should be adjusted to secure a trace resembling B as much as possible.

The distance between the two peaks of B gives a measure of the extent of the AFC control in KC/S. This is usually fixed by the manufacturers of the set, and adjustments to it are rarely possible.

There is another type of AFC circuit, using two separate discriminator secondaries, each with its own trimmer. In this case, separate adjustments to each peak may be made, but the final result should be the same as before.

Leaving the alignment of superhet receivers, the simpler TRF types may be briefly considered. The method of connection of the oscilloscope to the detector valve was dealt with on page 31, and indicated in Fig. 27. The oscillator is, of course, connected to the aerial and earth sockets of the receiver via a suitable dummy aerial.

If the set is badly out of alignment, it will be as well first of all to peak the set, at the correct aligning frequencies, using an amplitude-modulated input. When this has been done, the input should be changed to frequency modulation, and the response curve centred and observed on the screen.

Assuming that the receiver incorporates band-pass circuits in the RF or aerial stages, the associated trimmers should be slightly adjusted to produce the best band-pass curve possible. If there are no band-pass arrangements, one can still make slight trimmer adjustments in an endeavour to obtain a response of reasonable band-width, providing the sensitivity (height of the response curve) is not seriously reduced thereby.

Receivers incorporating a reaction control should be aligned with a moderate degree of reaction in use, and not at a point just short of oscillation.

MISCELLANEOUS TESTS

IT should be clear from what has already been written that an oscilloscope having a vertical amplifier which will deal with radio frequencies up to, say, 1 MC/S (even if its curve is not linear up to this point) will be of much greater use for general test work than one which will only deal with inputs up to, say, 100 KC/S or less.

The point is that in an ordinary receiver the RF and IF voltages encountered are not of a sufficiently high value to give a reasonable deflection on the tube when applied directly to the plates. Amplification is necessary, and the vertical amplifier must be capable of dealing with frequencies up to about 500 KC/S for IF tests, and up to about 1 MC/S (300 m) for RF tests.

One useful application of the oscilloscope, providing that its amplifier is good enough, is its use as a detector of RF voltages in a circuit where they should not be. For instance, RF and IF filter circuits can be tested to see whether they are functioning correctly by feeding an RF signal to the aerial and earth terminals of a receiver, tuning it in, and then applying the oscilloscope input, via a small coupling condenser (about 1 or 2 $\mu\mu$F), to various parts of the circuit.

The presence of RF voltages will be indicated by a band of light (if the time-base frequency is low) or by the actual RF waveform (if the time-base frequency is high enough) on the screen, the height of the image being proportional to the RF voltage present.

Thus at the input side of an RF filter a large response is present, but at the output side the response should be slight. How slight depends on the circuit, of course, but a little experimental work with one or two receivers will soon indicate the order of the voltage to be expected.

In this way, by-pass and decoupling condensers can be checked *in situ* in the set, for if the oscilloscope is connected across such a component, the alternating voltage across it should be negligible, since its impedance should be very small. An open-circuited decoupling condenser in a receiver can soon be located in this way by the fact that there will be a voltage across it which is higher than normal. The actual voltage to be expected must be ascertained by experiments on components known to be satisfactory.

An oscilloscope can also be usefully employed in the AF section of a receiver incorporating push-pull circuits of various types. The two halves of push-pull circuits can readily be checked for balanced operation by throwing their AF voltages on the screen. Here a double-beam oscilloscope is useful, enabling each half of the circuit to be observed simultaneously.

Such tests are particularly suitable in the case of RC coupled push-pull amplifiers incorporating phase splitting or phase reversing valves, where a faulty valve or component may introduce lack of balance in the output stage, resulting in overload and distortion.

Another use for the oscilloscope is in the examination of the waveform given by vibratory rectifiers, as used in car radio sets and other equipment designed to obtain HT supplies from an LT source. In this connection it should be pointed out that it is best to check the vibrator when it is connected up to its associated circuits, so that the various buffer condensers, chokes, etc., are in circuit with it, and preferably when it is on load. A test on the vibrator alone will give very little useful information.

The oscilloscope should be connected with its input connected across one half of the primary of the transformer following the vibrator, the "earthy" side going to the centre tap of the winding, and the high potential side to one end of the winding.

The vertical amplifier of the oscilloscope should be in use, and the linear time-base should be adjusted, when the vibrator is running, to give two or three complete cycles on the screen.

There are two types of vibrator in use, the simple two-contact type, which needs a valve rectifier, and the four-contact self-rectifying type. These are sometimes designated "non-synchronous" and "synchronous" types respectively.

With the oscilloscope connected as described, the two types of vibrator give similar, but not identical, curves. The curves of Fig. 33 were secured with a non-synchronous type, and it will usually be found that the synchronous type gives a curve which differs in having small "pips" at each corner of the trace, but otherwise the general shape is the same.

Trace A of Fig. 33 shows the result obtained from a vibrator, under full load, which was working satisfactorily. The curve is not the ideal one, for there should be no indentation at the left-hand corner of each peak, but it was the best obtainable from the unit which was being examined. Actually, the flat top of the trace should occupy about 80 per cent. of the half cycle, while the sloping line should extend down two-thirds of the height of the trace.

Note that the short vertical lines are hardly visible, since the voltage change here is exceedingly rapid, and the "writing speed" of the oscilloscope spot is likewise very fast, leaving only a very faint trace.

The operation of the vibrator with various input voltages may be studied. A 6 V vibrator should run steadily at all voltages between 5 and 7·5 V, and a 12 V type, at voltages from 10 to 15 V. Any unsteadiness will result in flickering of the trace on the screen. Failure to run correctly at low or high voltages may mean dirty contacts, or incorrect contact adjustment.

The effect of faulty or wrong value buffer condensers is to modify the trace given by the vibrator. The buffers in the primary circuit (if any) and in the secondary will affect the curve. Trace B of Fig. 33 shows the effect of a very low capacity buffer (about one tenth of the optimum value). Note how the curve is broken up and jagged compared with trace A.

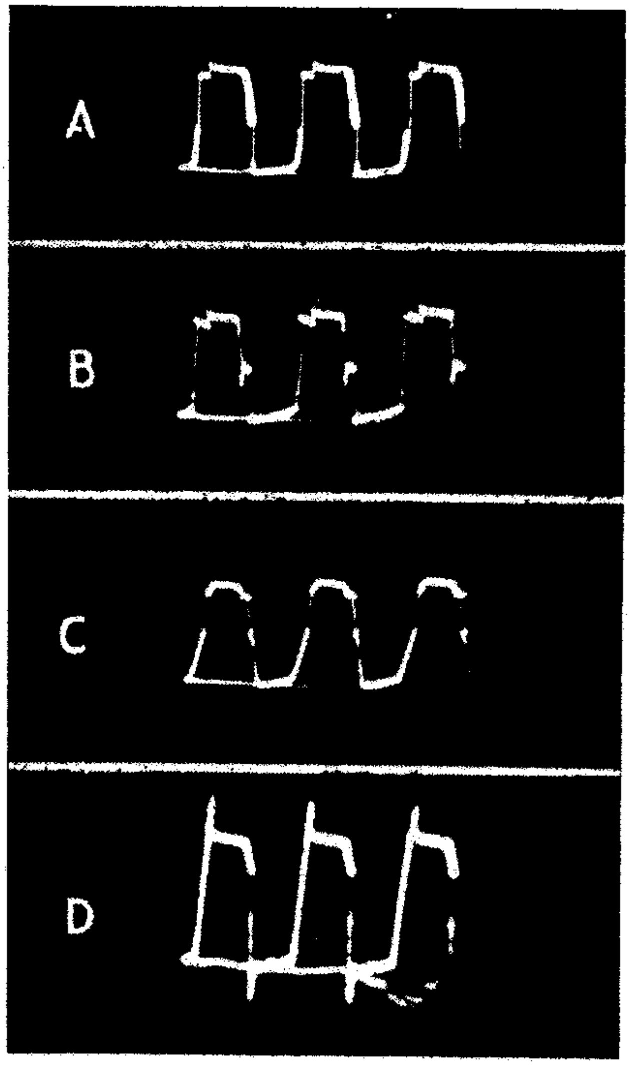


Fig. 33—Examples of traces obtained under various conditions from a vibrator unit.

Too high a value of buffer condenser also affects the operation of the vibrator. Trace C of Fig. 33 shows the effect of a buffer having a capacity ten times the normal value. Note how the corners of the peaks are cut off, and the horizontal portion of the curve reduced in length.

The effect of running the vibrator without a load on its output circuit is shown in trace D. Note that this is higher than the other three traces, and has spikes at the left-hand corners of the peaks.

Another effect (not illustrated) is caused by contact chatter. This results in a number of minor peaks superimposed on the horizontal portion of the main curve, and is often an indication that the contacts are dirty, or in need of adjustment.

Sometimes the vibrating reed of the unit is not central between the two opposing contacts, or moves further in one direction than the other. This may give rise to what is known as " single-footing," which produces a severe dip in the response curve of alternate half-cycles.

It is suggested that those intending to use the oscilloscope for vibrator testing should experiment with a unit which is known to be good, and try the effect of changing buffer condensers and otherwise altering the performance.

Although it is not an application of the oscilloscope which is likely to be needed by service engineers, the tracing of AF amplifier curves may at least be mentioned. It will be remembered that for IF response curves a frequency-modulator has to be used to produce the horizontal deflection of the spot, this generally having a range of about 30 KC/S altogether.

Suppose we use an AF modulator, having a range, say, 20 to 10,000 C/S. If this is linked up with the horizontal time-base of the oscilloscope so that the horizontal deflection is proportional to frequency, and if it is also applied to the input of the AF equipment being tested, and the output is applied to the vertical amplifier, then the result on the screen will be the AF voltage response curve.

This is sometimes used for production testing of AF equipment, but the frequency-modulator necessary is a specialised piece of equipment, and is not commercially obtainable.

The oscilloscope is sometimes used for delineating dynamic valve characteristics. For this a voltage base on the horizontal plates is necessary. For instance, suppose it is required to trace out the grid voltage/anode current curve of a valve. An AC voltage at 50 C/S is applied to the grid circuit of the valve, and also to the horizontal plates of the oscilloscope, while the AC voltage across a resistance in the anode circuit of the valve is taken to the vertical plates. The time-base of the oscilloscope is not used, but unless a horizontal amplifier is incorporated, it will be necessary to increase the voltage applied to the horizontal plates externally, in order to get sufficient deflection. One way of doing this is to feed about 50 V AC to a variable potentiometer, apply the whole 50 V to the horizontal plates, and take the slider of the potentiometer to the grid of the valve. The slider can then be adjusted to give a suitable voltage input to the valve, according to its type.

The resistance in the valve anode circuit may be 1,000 O or less, and the voltage across it can be amplified by the vertical amplifier of the oscilloscope.

Naturally, the voltages applied to the oscilloscope must be chosen to give a trace which is suitable for examination. The " straight " portion of the characteristic should slope at about 45 degrees, upwards to the right, and the oscilloscope connections must be reversed, if necessary, to produce the conventional type of figure. It should actually look something like the right-hand trace F of Fig. 23 on page 28.

It is necessary to provide the usual DC negative grid bias for the valve, which may be obtained from a battery in series with the AC input to the grid circuit. To obtain the proper dynamic characteristic, the correct load resistance for the valve must be included in series with the HT supply to the anode, and in order to study the effect of different load resistances, the resistance across which the vertical voltage is developed for the oscilloscope should be separate from the load resistance.

In this way the grid volts/anode current curve of a valve may be studied, and with slight re-arrangements other standard characteristics may be shown on the screen ; it is unlikely, however, that the oscilloscope will ever replace the conventional valve tester for ordinary radio service work. The method was merely included as another example of the versatility of the oscilloscope.

TELEVISION WORK

IT is a foregone conclusion that eventually the cathode ray oscilloscope will be largely used in connection with television receiver testing, as it lends itself ideally to the solution of many of the problems encountered in this work.

Some of the oscilloscopes on the market have been designed with television requirements in view. For instance, the vertical amplifier must have a very wide frequency range to deal with video frequency signals. It must be linear at least up to 2 MC/S, and preferably up to 3 MC/S or even higher. The time-base should have a frequency range up to 15,000 C/S or more; the input impedance of the oscilloscope should be high, and phase distortion in the amplifier must not occur.

Unfortunately, at the present time, there is very little in the way of auxiliary television testing equipment available commercially. For instance, for alignment of the vision receiver a frequency-modulated SW oscillator with a sweep of about 5 MC/S is desirable; for synchronising filter adjustments a special generator is necessary. The latter, by the way, can be obtained from one or two sources to special order, but it is naturally expensive.

For the present, therefore, we have to fall back on the actual television transmissions themselves, which, in districts of good signal strength, enable a good many tests to be made.

The effect of non-linear television time-bases is usually visible on the television screen, the picture being expanded or compressed at one side. The oscilloscope, however, is more sensitive to this type of fault. For instance, trace A of Fig. 34 is the waveform of the line time-base of a typical receiver, and it will be seen that the inclined strokes are slightly curved, showing non-linearity. Despite this, the picture on the screen did not appear to be suffering from this fault. It is clear that the oscilloscope forms a critical test for time-base linearity.

Trace A was obtained from a magnetic scanning circuit, and is the waveform across a 20 O resistance in series with the line deflecting coils. It therefore represents the saw-tooth *current* flowing in these coils. The voltage across the coils should not be used as a test.

Incidentally, care must be taken with magnetic scanning systems, as very high peak voltages, possibly ten times the steady anode voltage of the time-base output valve, are liable to be encountered in the line section of the time-base.

Electrostatic time-bases can be similarly checked, and here the saw-tooth *voltage* applied to the deflector plates must be examined. Usually this voltage is high, and must be applied to the oscilloscope via a suitable potentiometer, otherwise the spot will be swept off the screen.

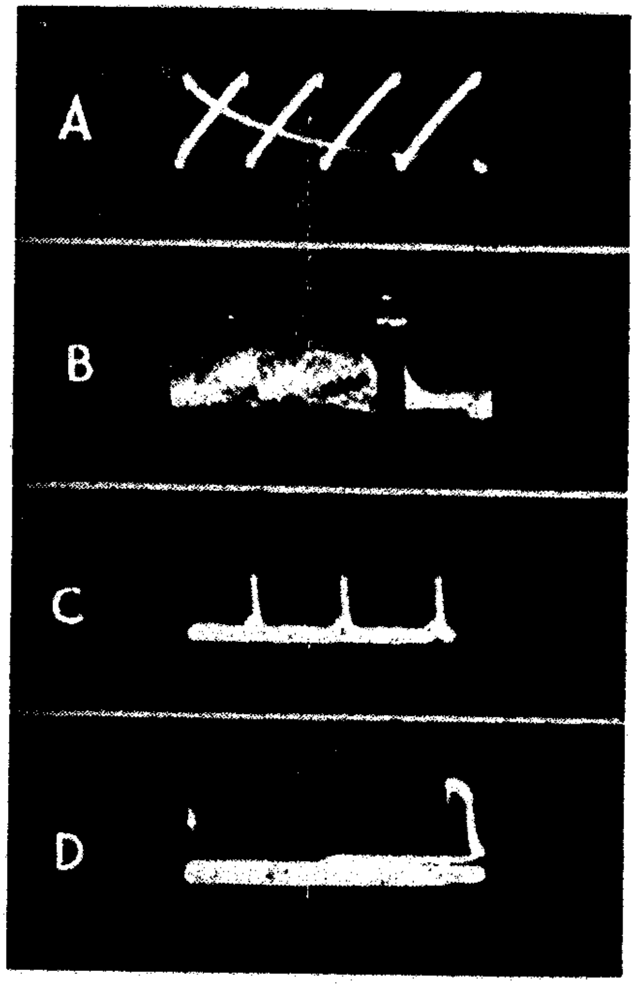


Fig. 34—Television receiver traces.

Alternatively, the voltages at the grid of each of the push-pull output valves may be examined. The voltages should be equal in each case, but 180 degrees out of phase.

For the line time-base, which runs at 10,125 C/S, the oscilloscope time-base should run at 2,531 C/S to give four complete traces; for the frame time-base, running at 50 C/S, the oscilloscope time-base set at 25 C/S will give two complete traces.

The synchronising pulses fed to the time-base may readily be examined with an oscilloscope, and the functioning of the synchronising filter or separator circuits thereby checked. For instance, trace B of Fig. 34 shows the type of signal obtained at the anode of the video frequency output valve, just prior to the synchronising separator and filters. One complete line signal is shown, the oscilloscope time-base running at 10,125 C/S. Note the flame-like picture content (this, of course, changes formation if a moving scene is being televised) and the line synchronising pulse.

The Cathode Ray Oscilloscope

At a point between the synchronising separator and the filters one should obtain the line and frame pulses, with no picture content. By running the time-base at 50 C/S, the trace will show one frame pulse, and a large number of line pulses (over 200) which will probably not be individually defined. If there is picture content, a relatively bright band will appear at the top or bottom of the trace, and will indicate inadequate action of the separator valve.

With the oscilloscope connected on the time-base side of the line synchronising filter the result should be the line pulses only. Trace C of Fig. 34 shows three line pulses, the oscilloscope time-base running at 3,375 C/S. Note the thick base line, which shows a small percentage of picture signal still remaining, but not enough to cause trouble.

On the time-base side of the frame synchronising filter, with the time-base running at 50 C/S, one obtains a single frame pulse. This is shown in trace D of Fig. 34. Any line pulse content remaining will show as a vertically striated band of light along the base line. It was just visible on the oscilloscope, but does not show up in the photograph. Any line content of the level shown at D is negligible; if, however, it were half the height of the frame pulse, it would be necessary to examine the synchronising filter for faults.

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