

**LESSON
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INTRODUCTION TO THE CATHODE-RAY OSCILLOSCOPE



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INTRODUCTION TO THE CATHODE-RAY OSCILLOSCOPE

Complete service on a modern radio receiver has come to include more than merely re-establishing the proper resistance and condenser values and aligning the various tuned circuits for maximum response at one or two settings of the dial, as at 600 and 1400 kilocycles, for example. Present day receiver design requires that due consideration be given the fact that a radio set really receives, amplifies, and reproduces a band of frequencies rather than a single frequency, as it has been ordinarily understood. For example, although a set is tuned to 720 kilocycles, it amplifies and reproduces a band of frequencies extending from $2\frac{1}{2}$ to 5 or more kilocycles on either side of the 720-kc. resonant frequency.

To obtain optimum performance from such a receiver, it is necessary to know how it responds to the various frequencies included in this extended range, and such information can be obtained only from an examination of the general sensitivity and response curves of the set. The importance of these response curves is also emphasized by the fact that many broadcast stations are sending out improved quality programs of the high fidelity type with wider side bands, and the receiver must be capable of translating these outer bands into the corresponding higher audible frequencies. In addition, the close coupling employed in some of the newer i-f transformers actually requires a check of the response curve of each i-f stage to note whether or not all trimmer condensers have been adjusted correctly.

This means that for efficient servicing and aligning, a quicker way must be had for obtaining these curves than the old method of measuring the response of the receiver with an output meter for a number of frequencies above and below the

resonant frequency, and then plotting a curve manually from the data obtained.

It was to meet this requirement that the cathode-ray oscilloscope was developed, for with the aid of a suitable signal generator correctly connected to the radio receiver, there is instantly delineated on the screen of the oscilloscope a trace of the signal wave as it passes through the particular stage of the receiver to which the oscilloscope is connected. The necessary corrective adjustments can then be made, and at every instant the shape of the signal wave is visible so that proper alignment can readily be established.

The calibrated signal generator must be capable of furnishing a steady signal at any frequency within the range over which modern radio receivers tune. Also, the signal generator must be equipped to modulate either the amplitude of the signal at an audio frequency (400 cycles at 30% modulation is common practice), or the frequency of the signal over a range of 15 or more kilocycles on either side of the main frequency to which the generator is tuned. This latter process is often referred to as wobulating the signal frequency. In addition suitable sweep voltages must be provided for spreading out the signal wave across the screen of the tube. In some makes of oscilloscopes part of this modulating equipment is self-contained, while in others it is part of the signal generator. Separate wobulators are also available so that the standard test oscillator can be used in connection with an oscilloscope.

The applications of the oscilloscope, however, are not limited merely to observing response curves of radio receivers. The oscilloscope is very flexible, and the better it is understood the more uses for it are found. For example, it can be used as an A.C. peak voltmeter or ammeter, as a D.C. voltmeter, for making phase and frequency determinations, locating distortion in audio amplifiers, making hum observations, modulation analysis, determining audio transformer characteristics, etc.

THE CATHODE-RAY TUBE

The cathode-ray tube, which is the essence of an oscilloscope, is like an indicating voltmeter of infinite resistance, that uses in place of a pointer a ray of electrons. These electrons are caused to strike a fluorescent screen and produce a spot of light. The signal voltages to be analyzed are impressed on a pair of deflecting plates that cause this electron ray to swing up and down; and since the ray has no weight or inertia, its response is practically instantaneous. Also, it requires negligible power for its movement and it puts no load on the circuit that is being tested. By means of a suitable sweep voltage the ray is at the same time deflected horizontally, with the result that the spot of light delineates on the screen a pattern or trace of the signal voltage wave.

The cathode-ray tube operates on the same basic electron principles as that of the regular amplifier tubes in a radio receiver. An indirectly heated cathode emits a mass of electrons, and around this cathode is a cylindrical grid that has an opening at the end through which a beam of electrons can escape. This grid is at a negative potential with respect to the cathode, and by varying this potential the number of electrons that pass through can be controlled. Since the number of electrons reaching the screen determines the brightness of the spot, this grid potential control is termed the "Intensity Control" on the oscilloscope.

The electrons next pass through an accelerating cylinder that is at a positive potential with respect to the cathode and is called Anode No. 1. The potential of this Anode No. 1 also is variable, and since this Anode has the additional effect of concentrating or focusing the electrons into a sharp point or line, this control is called the "Focusing Control". The electrons are then further accelerated through another cylinder, Anode No. 2, which is at a still higher fixed positive potential.

After emerging from Anode No. 2 the ray of electrons on its way to the

screen passes between two sets of deflecting plates. One pair of these plates is mounted in a vertical position; and when a potential is put on these plates, they deflect the beam to the left or right in a horizontal plane. They are consequently labeled the Horizontal Deflecting or merely "Horizontal" plates on the oscilloscope. The other pair of plates are mounted in a horizontal position, and when electrically excited deflect the electron beam up or down in a vertical plane. They are consequently called the Vertical Deflecting or merely the "Vertical plates. It is onto these deflecting plates that the signal voltages to be checked are impressed. The resulting dual-deflecting influence exerted on the electron ray by both sets of plates, causes it to trace the shape of the signal voltage under observation.

The complete oscilloscope consists then of a cathode-ray tube and the necessary auxiliary equipment. This includes first a built-in power supply for providing the required operating potentials. There are also two resistance-coupled amplifiers, one for amplifying the signals for the vertical deflecting plates and the other for the horizontal plates. Each amplifier is also equipped with a suitable gain control so that full-screen deflections can be obtained both vertically and horizontally for different signal intensities.

For spreading out the images horizontally across the screen a suitable saw-tooth oscillator of the relaxation type is provided. In the earlier oscilloscopes neon lamps were used in this oscillator, but all later instruments employ the recently developed No. 885 gas-discharge triode. This oscillator has two controls, one a range selector and the other a vernier for fine control. And lastly, the synchronizing control for setting the images in a fixed position on the screen. This control has an auxiliary 2-position switch so that either external or internal synchronizing can be cut in.

The heart of an oscilloscope is the cathode-ray tube. The other component parts are merely accessories to provide the necessary operating conditions for this tube. These accessories include a power pack, a pair of resistance coupled amplifiers (one for the vertical and the other for the horizontal deflecting plates), a sweep frequency generator, and a system of switches and controls for arranging the proper connections and regulating the size of the image.

The power pack generally consists of two sections, one for supplying the required potentials to the cathode-ray tube and the other for operating the amplifiers and sweep frequency generator. These two sections are connected in series with the common junction point grounded to the metal housing. In other words, contrary to customary practice, instead of grounding the negative side of the high voltage system the positive side is grounded.

A typical hook-up arrangement as is used with cathode-ray tubes in oscilloscopes is illustrated in the accompanying diagram. The cathode is internally tied to one side of the heater, and as shown is also connected to a point on the voltage divider which is above minimum negative potential by an amount equal to the drop across R-3. R-3 is a potentiometer with the slider connected to the grid of the tube. Any point on this potentiometer is below cathode potential, and by shifting the slider up or down the grid can be made less or more negative than the cathode. Since this negative potential on the grid determines the number of electrons that can ultimately reach the screen on the tube, it regulates the brightness of the spot or image. It is therefore called the Intensity Control. This control usually also has the On-Off power switch attached to it.

R-2, which comprises the next section of the voltage divider, is also a potentiometer, but has its slider connected to Anode No. 1. Any point on R-2

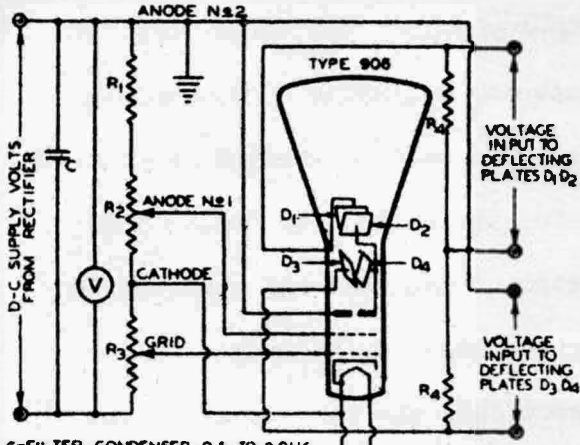
is above cathode potential, and by moving the slider up or down the potential on Anode No. 1 is made more or less positive than the cathode. The potential on Anode No. 1 determines the sharpness and outline of the image, and accordingly R-2 is called the Focusing Control. R-1 is merely a fixed bleeder resistor for dropping the voltage to the proper value needed at R-2.

Anode No. 2 is at maximum positive potential and is connected directly to the output of the power supply system. This point is also grounded, as was mentioned previously. Examination of the deflecting plates further shows that one of the vertical and one of the horizontal plates are tied together and in turn connected to anode No. 2. The advantage of this arrangement is that a common ground connection can be brought out. To impress a signal on the vertical deflecting plates, it is therefore only necessary to connect the high side of the signal supply to the free vertical plate (brought out to a separate tip jack) and the low side to ground. Similarly, to impress a signal on the horizontal deflecting plates, connection is made to the free horizontal plate and to ground. Essentially there are only two controls to the tube, the Intensity and the Focusing Control. However, there are two additional controls generally associated with the tube that assist in locating the image on the screen. One of these is the Vertical Positioning and the other the Horizontal Positioning Control. Each of these also consists of a potentiometer connected across a portion of the voltage divider. The slider of one is connected to the free vertical plate and the slider of the other to the free horizontal plate. By adjusting these potentiometers the potential of the free plates can be made positive or negative with respect to the grounded plates and the image accordingly shifted vertically or horizontally.

OPERATING CONTROLS ON AN OSCILLOSCOPE

Although at first sight an oscilloscope appears to have a perplexingly large

TYPICAL OSCILLOGRAPH CIRCUIT

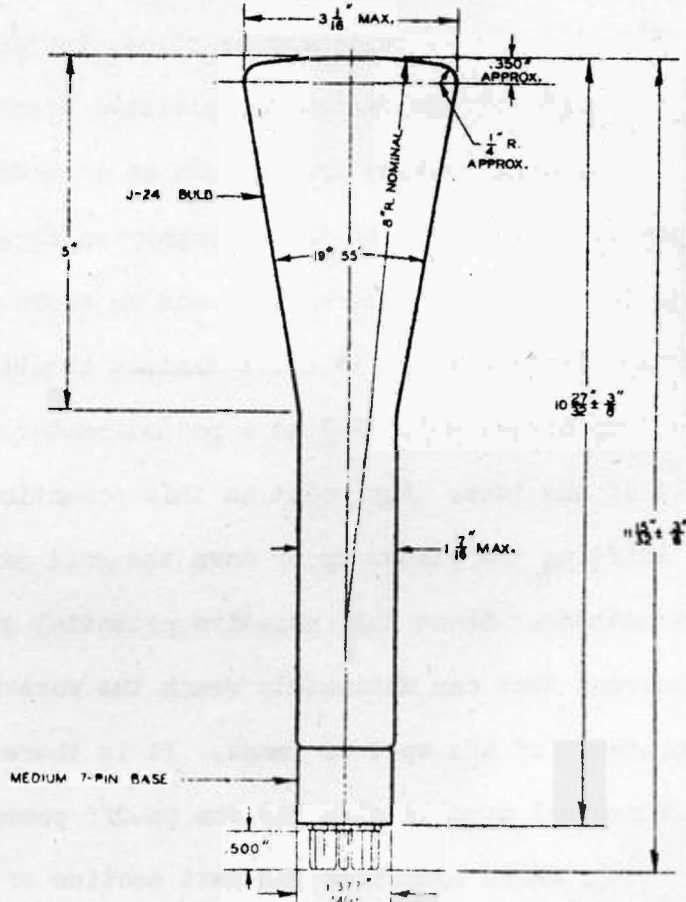


C=FILTER CONDENSER-0.5 TO 2.0UF
 R1+R2+R3=BLEEDER POTENTIOMETER HEATER SUPPLY
 R1=0.5MEG OHM R2=0.2 MEG OHM R3=0.02 MEG OHM
 R4=1 TO 10 MEG OHMS
 V= VOLTMETER

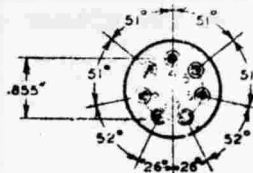
NOTE 1: TYPE 906 HAS NO BULB TERMINALS. ALL LEADS ENTER THROUGH BASE
 NOTE 2: PLATES D2 AND D4 ARE CONNECTED WITHIN THE TUBE TO ANODE N#2



OUTLINE DRAWING



PIN N#1-HEATER
 PIN N#2-GRID
 PIN N#3-DEFLECTING PLATE D3
 PIN N#4-ANODE N#1



PIN N#5- DEFLECTING PLATE D1
 PIN N#6-ANODE N#2, DEFLECTING PLATES D2 & D4
 PIN N#7-HEATER & CATHODE

number of controls, confusion can easily be dispelled if it is recalled to what portion of the oscilloscope each particular control belongs and what adjustments are made with it. The following controls are generally found on an oscilloscope panel. On various makes of instruments these controls may be arranged or labeled differently, and on some several may be combined into one composite control, but an examination of the panel will always reveal the majority of those described below to be used.

INTENSITY

This control generally also incorporates the "on-off" switch for the entire instrument, and regulates the brightness and intensity of the spot or line. It should be turned only high enough to produce a small noticeable spot. When the oscilloscope is idle for a time, the intensity should be turned down to conserve the activity of the screen. Never leave the beam or line in one spot too long, as this may burn the screen material.

FOCUS

This control regulates the size and sharpness of the spot or line, and should always be set for minimum readable brilliance.

HORIZONTAL SHIFT

This control moves the position of the spot or line horizontally to the right or left so that the pattern can be set where it is desired.

VERTICAL SHIFT

This control moves the spot or line up or down in a vertical plane when such shifting is necessary.

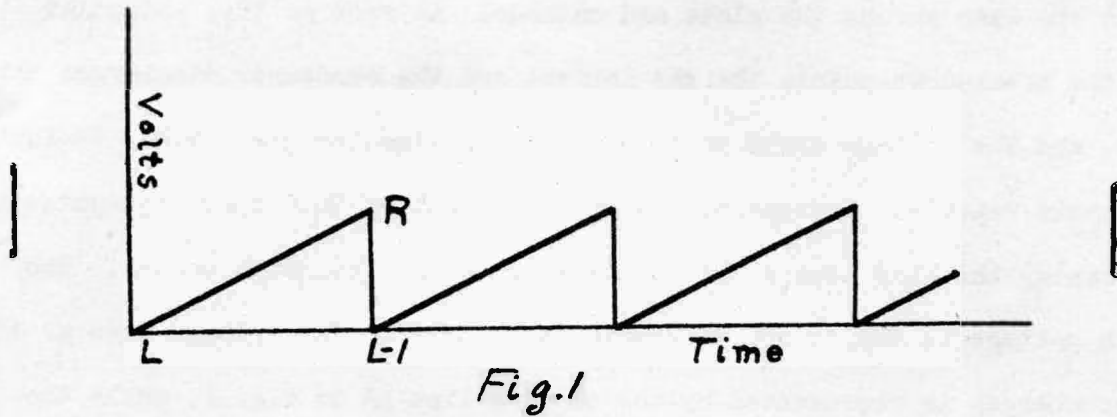
HORIZONTAL GAIN

This control cuts in an amplifier to intensify the signal fed to the horizontal plates. It is a gain control on the amplifier and regulates the length of the horizontal line or pattern.

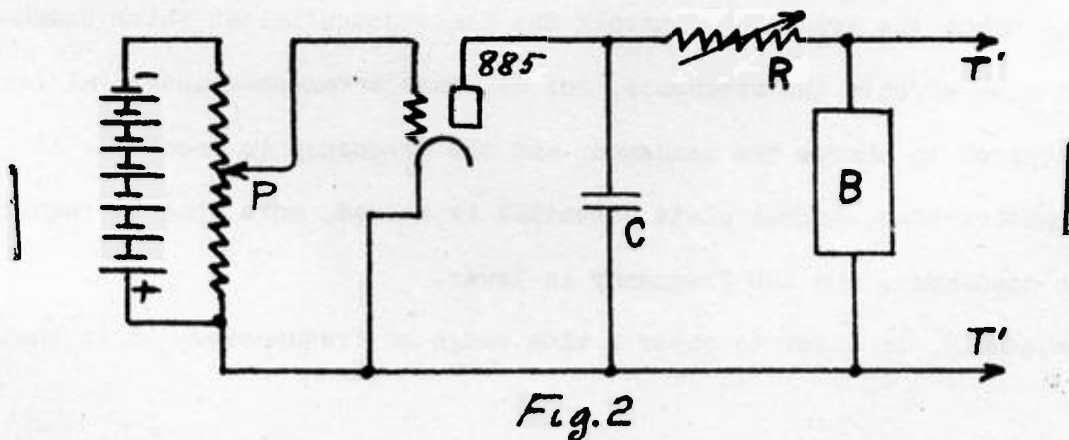
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it deflects the beam from left to right (L to R), and in dropping to zero it brings the beam back to the starting position L. Since this return sweep is virtually instantaneous, the screen does not fluoresce, and the return is not visible.



Such saw-tooth voltage is commonly generated with a special oscillator system of the relaxation type that employs a type 885 gas triode. This tube is filled with an inert gas that is normally non-conductive; but if the plate potential increases beyond a certain value, the gas ionizes and becomes conductive and permits a free passage of current from cathode to plate. As soon as the plate potential drops sufficiently, the gas again de-ionizes and current flow ceases. By means of a negative bias on the grid the potential at which break-down occurs, can be regulated. Therefore, the tube is called a grid-controlled gaseous-discharge triode.



The basic circuit of such a saw-tooth oscillator is shown in Fig. 2. A condenser C is connected from plate to cathode, and in series with the plate-supply B is a variable resistor R. Negative bias on the grid is obtained from the potentiometer P. As current flows into condenser C, a potential builds up across it and also across the plate and cathode. As soon as this potential reaches the break-down point, the gas ionizes and the condenser discharges through the tube, and the voltage drops to zero. At this time the gas quickly de-ionizes and the cycle repeats. Increasing the grid bias raises the break-down potential, and decreasing the bias lowers the potential at which discharge occurs. The saw-tooth voltage is tapped off at terminals T and T'. The voltage rise as the condenser charges is represented by the sloping line LR in Fig. 1, while the quick drop to zero on discharge is represented by the vertical line RL'.

HOW SAW-TOOTH FREQUENCY IS CONTROLLED

The period of time required for the voltage to rise from zero to maximum depends upon the size of the condenser and the value of the resistor. The larger the condenser the more current must flow into it to raise its potential to a given value, and the greater the time required to sweep the beam across the screen. In other words, the larger the condenser the lower the frequency, and the smaller the condenser the higher the frequency of the oscillator. Also, for a given condenser the charging period can be lengthened (the oscillator frequency lowered) by increasing the series resistor. Decreasing the resistor raises the frequency. Since the grid bias controls the plate potential at which break-down occurs, it also affects the frequency, for at lower break-down potential less time is required to charge the condenser and the frequency is greater. At greater negative bias, higher plate potential is needed, more time is required to charge the Condenser, and the frequency is lower.

Consequently, in order to cover a wide range of frequencies, it is customary

practice to employ a number of fixed condensers so that any one of them can be cut into the circuit by means of a suitable selector switch. With each condenser a limited band of frequencies can then be covered as determined by the value of the series resistor R. Two controls are thus used on an oscilloscope for regulating the saw-tooth oscillator; one a coarse selector for choosing the band within which the operating frequency lies, and the other a vernier for adjusting the oscillator to the exact frequency desired. Frequencies up to 20,000 and 30,000 cycles per second are developed in this manner in different makes of oscilloscopes.

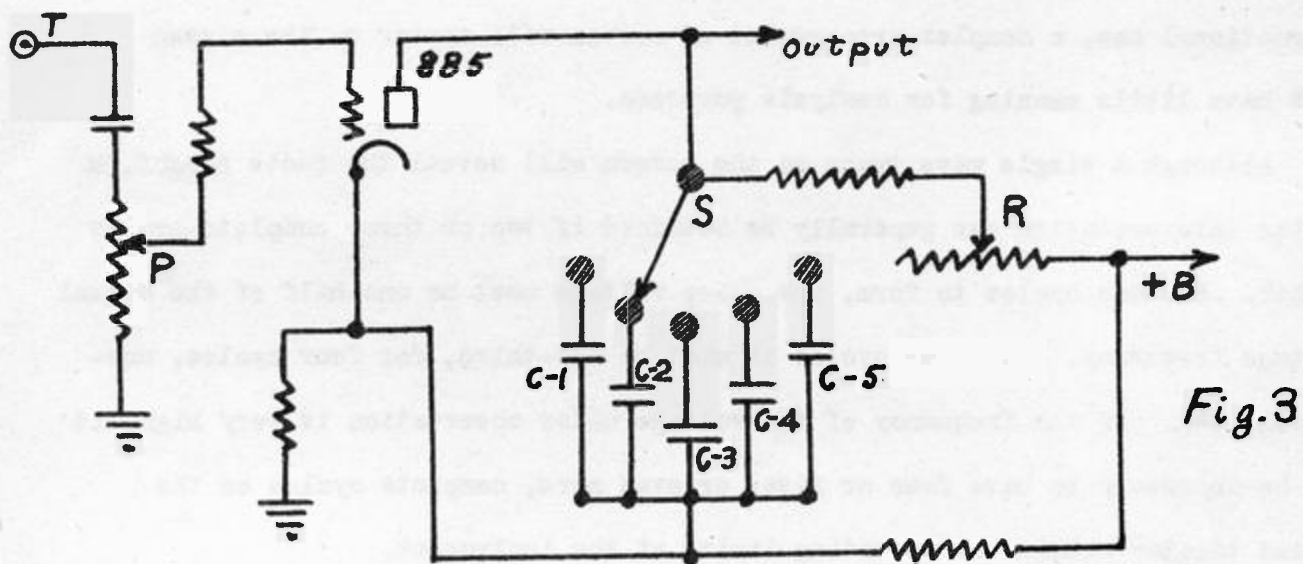


Fig. 3

A typical saw-tooth sweep oscillator system as employed in a number of commercial oscilloscopes is shown in Fig. 3. Switch S selects the frequency band by cutting the required condenser into the circuit, while resistor R is the vernier control for making the fine frequency adjustment. Potentiometer P controls the grid potential on the gas triode and determines the plate potential at which ionization and discharge occurs. Since potentiometer P also serves to "tie in" the sweep oscillator with the other operating potentials, it is generally

labeled the Synchronizing Control. Its use is explained further in another section.

SIMPLE WAVE FORM REQUIRES INTEGRAL FREQUENCY RATIO

The nature of the image appearing on the screen of the cathode ray tube depends upon the relation existing between the frequency of the voltage applied to the vertical plates and that of the horizontal sweep voltage. To obtain a simple pattern of the voltage wave under test, the horizontal sweep frequency must be equal to or be a sub-multiple of the test voltage frequency, that is, the ratio of the test voltage frequency to the sweep voltage frequency must be a small whole number, as 1 to 1, 2 to 1, 3 to 1, 4 to 1, etc. If the ratio is a fractional one, a complex arrangement of curves will appear on the screen that have little meaning for analysis purposes.

Although a single wave trace on the screen will reveal the facts sought, a better interpretation can generally be obtained if two or three complete cycles appear. For two cycles to form, the sweep voltage must be one-half of the signal voltage frequency, for three cycles it must be one-third, for four cycles, one-fourth, etc. If the frequency of the voltage under observation is very high, it may be necessary to have four or five, or even more, complete cycles on the screen to stay within the operating limits of the instrument.

When an oscilloscope is put into operation and the sweep frequency is being adjusted, a maze of curved lines will first be observed moving across the screen. The greater the ratio between the test voltage frequency and the sweep frequency, the greater will be the number of such lines as long as the ratio is of a fractional value. As the sweep frequency is changed, and the ratio approaches an integral value, the number of lines rapidly diminishes until finally a single trace appears. As was previously explained, coarse adjustments are first made with the selector switch which cuts in different frequency bands, and finer

adjustments are then made with the vernier control.

THE SYNCHRONIZING CONTROL - ITS PURPOSE AND USE

After the sweep frequency oscillator on an oscilloscope is adjusted so that one or several wave forms of the signal voltage under test appear stationary on the screen, there is still a tendency for the image to shift slowly to the right or left due to drifting of the oscillator frequency or of the signal voltage. This is overcome by impressing a small portion of the signal voltage onto the grid circuit of the sweep frequency oscillator, for since this grid tends to control the breakdown potential between the plate and cathode, these signal impulses lock the two frequencies in step and fix the image on the screen.

This tying-in process is called synchronizing the two frequencies, and the control by means of which this is accomplished is termed the Synchronizing Control. The synchronizing action will maintain whether the synchronizing frequency is the same as the sweep frequency or whether one is a multiple or sub-multiple of the other - as long as the ratio of the two frequencies is a small integral number.

INTERNAL AND EXTERNAL SYNCHRONIZING

The synchronizing impulses that are fed to the grid of the sweep frequency oscillator can be taken either from the signal voltage that is impressed on the vertical deflecting plates of the cathode ray tube or from some external voltage source, depending upon the nature of the test that is being made. In the first case it is called internal synchronizing and in the second external synchronizing.

The synchronizing control consists of a high resistance potentiometer the slider of which is connected to the grid of the sweep frequency oscillator. One end of the potentiometer is grounded and the other is connected through a fixed condenser to the center terminal of a double-throw switch mounted on the panel of the oscilloscope. In one position this switch is labeled "Ext. Syn." and in the other "Int. Syn." In the external position it connects to a special tip jack

on the panel labeled "Ext.Syn." In the internal position it connects through a suitable filter resistor to the plate circuit of the vertical amplifier, which is the amplifier that supplies the signal voltage under test to the free vertical deflecting plate.

PROPER MANIPULATION OF THE SYNCHRONIZING CONTROL

The purpose of the synchronizing control, it was explained, is to lock in step the vertical deflecting frequency and the horizontal sweep frequency after the latter has been set to produce a stationary image of the desired number of wave forms on the screen. The proper adjustment of the synchronizing control has much to do with the shape or appearance of the wave forms.

Generally a single wave on the screen is not enough to permit correctly judging the form of the wave, for a number of distorting factors may be too prominent. Two or three waves will tell a better story. Then the horizontal sweep amplitude must be adjusted so that the waves will not be crowded together, but will be well spread out across the screen. This amplitude adjustment is made by manipulating the horizontal amplifier gain. After these settings are made, the synchronizing control is cut in. This control should be advanced only far enough to set the image stationary. If it is turned too far, it will not only cause distortion of the wave forms, but it will also influence the sweep frequency by impressing too high a potential on the grid of the sweep oscillator. A little practice will readily make it a simple matter to quickly obtain optimum adjustments.

Examination Questions on following page.