The GENERAL RADIO EXPERIMENTER

VOL. VIII. No. 6 NOVEMBER, 1933

ELECTRICAL COMMUNICATIONS TECHNIQUE AND ITS APPLICATIONS IN ALLIED FIELDS

CATHODE-RAY OSCILLOGRAPHS AND THEIR APPLICATIONS

FOR many types of experimental work, the cathode-ray oscillograph is particularly adaptable. The new designs eliminating the use of gas as a focussing medium increase the maximum frequency range far beyond that which can be obtained with any other oscillograph.

The electron beam can be deflected either magnetically or electrically. The former has the disadvantage that the magnetic coils required have a relatively low impedance and may well be a serious load on low-power circuits. The electrostatic deflecting plates have a very high capacitive reactance,* and, consequently, do not disturb the circuits to which they may be connected. For this reason all General Radio cathode-ray oscillograph tubes have electrostatic deflection

---

*The electrode capacitance of the TYPE 528-A Cathode-Ray Oscillograph Tube is less than 2 $\mu\mu$f. That of the tube used in the TYPE 635-A Electron Oscillograph is less than 50 $\mu\mu$f.

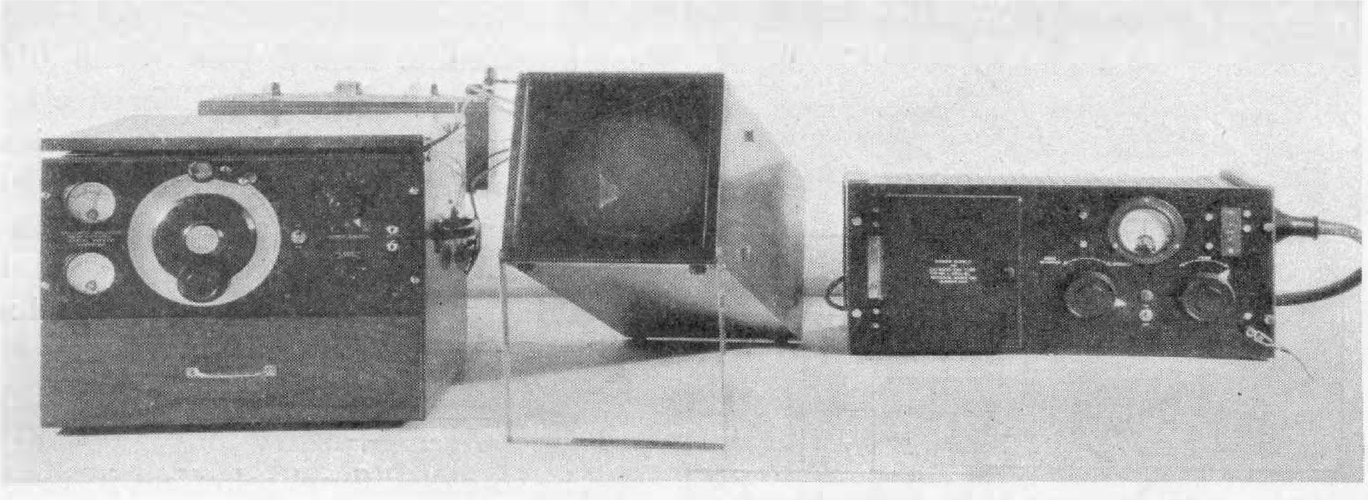


FIGURE 1. Measuring percentage modulation of a TYPE 484-A Modulated Oscillator with a TYPE 528 Cathode-Ray Oscillograph by the method shown in FIGURE 2. An amplifier was used between the audio oscillator and the horizontal deflecting plates, the TYPE 219 Decade Condenser (behind the oscillator) being used to correct the phase shift in the amplifier. Illustration from an unretouched photograph

plates for both horizontal and vertical deflections.

In addition, the ruggedness of cathode-ray oscillographs recommends them for general work. They cannot be permanently harmed by heavy overloads.

The upper frequency limit of electromechanical oscillographs such as the string or mirror types is limited by the inertia of the moving element. The limit is usually around 10 kilocycles. The cathode-ray beam, on the other hand, is practically inertialess and the theoretical upper limit of frequency in a hard tube is determined by the point at which the period of the high frequency approaches the time required for the electron to pass through the deflecting plates. This limit for a well-designed tube is about 200,000 kilocycles. The hard cathode-ray tube, therefore, is particularly adapted for the observation of high-frequency phenomena. It will, of course, operate quite as well as any electromechanical oscillograph at low frequencies and, because of such adaptability, is becoming more and more the general handy-man about the laboratory. It is far beyond the range of this brief story to discuss all or even a majority of these uses. There are, however, certain functions that a cathode-ray oscillograph performs with particular effectiveness. We can discuss a few of these.

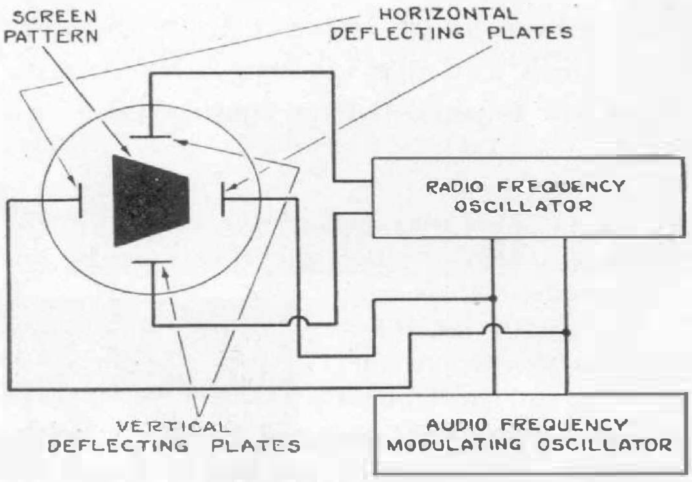


FIGURE 2. Method of measuring percentage modulation with a cathode-ray oscillograph

In Figure 2 is sketched a means for measuring the percentage of modulation of a radio-frequency oscillator. The modulated radio-frequency voltage under observation is impressed across the two vertical deflecting plates of a cathode-ray oscillograph. Across the horizontal plates is impressed a voltage of the modulating-oscillator frequency. For the sake of simplicity, the schematic is drawn with the same audio-frequency source modulating the radio-frequency oscillator and deflecting the beam horizontally. The amplitude of oscillation of the radio-frequency oscillator varies at the same rate that the spot is swept back and forth across the screen by the audio-frequency source. Therefore, there results a trapezoidal pattern on the screen which has a maximum amplitude proportional to the peak of the radio-frequency wave and a minimum proportional to its lowest amplitude. The degree of modulation is measured by the difference between the greater and the lesser vertical deflection. The actual degree of modulation can then be determined by comparing the two amplitudes with a pair of dividers. The percentage modulation is expressed by

$$\frac{MAX - MIN}{MAX + MIN} 100.$$

The so-called flywheel effect in modulated radio-frequency oscillators, or the tendency of the radio-frequency amplitude to overshoot the amplitude

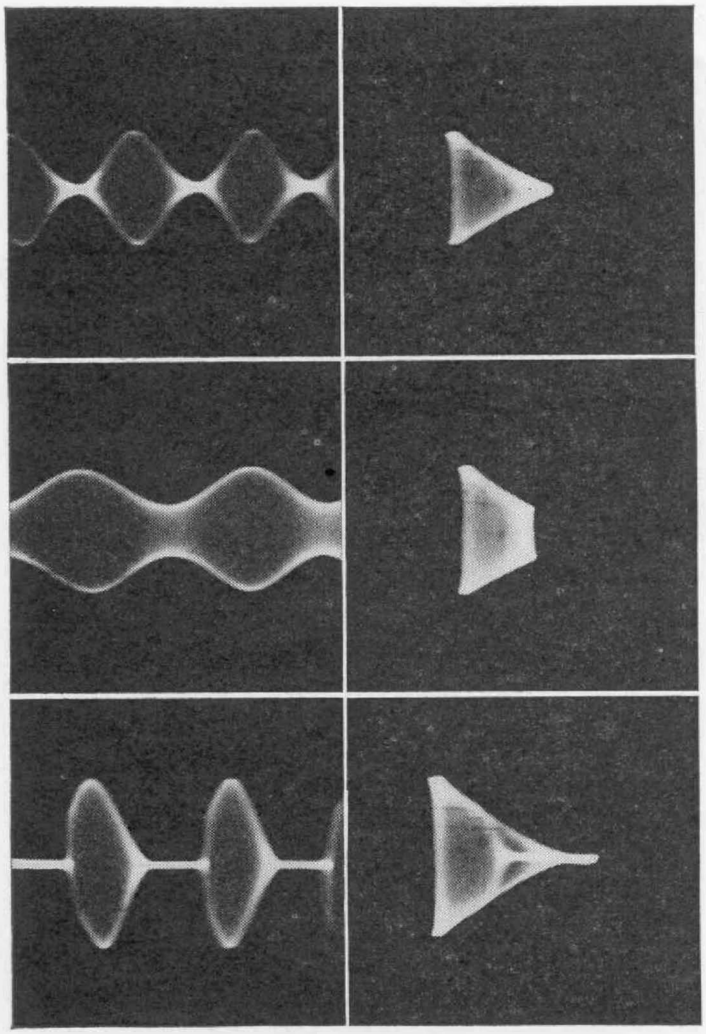


FIGURE 3. Oscillograms showing, respectively, 100%, 43%, and severe over-modulation, on a TYPE 484-A Modulated Oscillator. The figures at the right were obtained by the method outlined in FIGURE 2; those at the left by applying to the vertical deflecting plates the modulated carrier and to the horizontal plates a voltage from a TYPE 506-A Bedell Sweep Circuit controlled by the audio modulating voltage

of the modulation, shows up in these patterns as narrow loops on the sloping sides of the pattern. A perfectly modulated oscillator will show an almost perfect trapezoidal pattern.

The cathode-ray oscillograph makes an excellent peak voltmeter or ammeter. The deflection of the beam is linear with applied voltage, but the sensitivity depends upon the anode potential that is used. High anode potentials result in electrons having a high velocity and low sensitivity (but a bright spot). Low anode potentials mean greater sensitivity. With the TYPE 528-A Cathode-Ray Tube with 3000 volts on the anode, about 100 volts on either pair of plates will give a deflection of one inch. Anode voltage of 1000 gives a sensitivity of 33 volts per inch deflection. The voltage sensitivity can be calibrated by direct current; and the direct-current calibration will hold with good accuracy up to high radio frequencies. In order to investigate the amplitudes attained in transient phenomena, it is only necessary to observe the path of motion of the spot and to note its maximum amplitude.

The type of screen used on the TYPE 528-A and to a lesser degree on the TYPE 635-A General Radio Oscillographs has an appreciable persistence of fluorescence; that is to say, after the transient trace has passed, the screen will continue to glow for a very short length of time, but sufficient to allow the eye to note its general shape and amplitude. To study the behavior of the mercury-vapor type of rectifier tube wherein the initial current surge at each reversal of current in a cycle is very high and abrupt, the current into the filter is passed first through a small

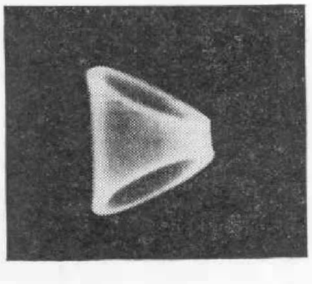


FIGURE 4. This type of pattern, instead of the trapezoid, results when the variations in carrier amplitude are not in phase with the audio-frequency voltage applied to the horizontal plates. Shunting the amplifier output with an adjustable condenser restores the trapezoid

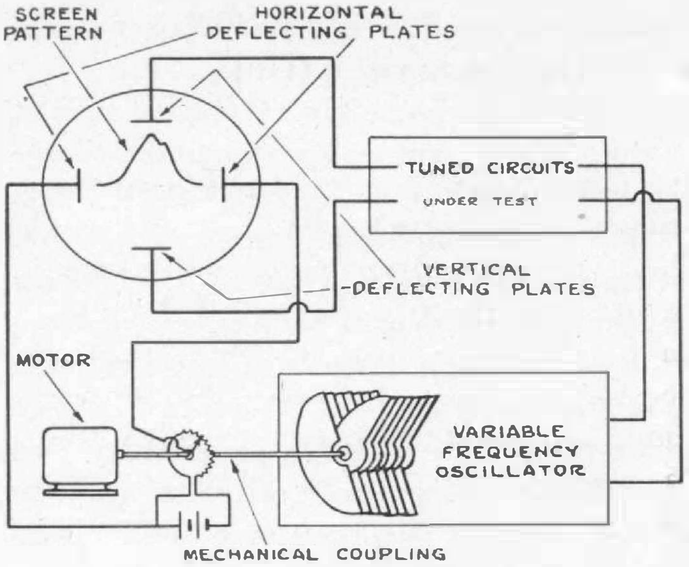


FIGURE 5. Diagram showing how a cathode-ray oscillograph can be used for tracing resonance curves

resistor across which the vertical deflecting plates are attached. The primary voltage at the input of the step-up transformer is impressed across the horizontal plates. The resultant pattern is not a true indication of the actual shape of the current wave, but excellent ideas of its amplitude and the effect of various types of filter inputs can be obtained.

In the example shown in Figure 5 the tuned circuits of the receiver are slightly out of line, which accounts for the double hump in the output resonance curve. By the observation of the pattern during the adjustment of the alignment condensers, the set can be brought into adjustment with considerable speed. The tuning condenser of the oscillator and the potentiometer, which determines the horizontal deflection of the pattern, is kept continuously in rotation by a small motor. The rate of rotation is adjusted so that the trace repeats itself eight or ten times a second, thus providing a continuous indication of the resonance curve of the high frequency amplifier.

Frequency comparisons are a particularly useful application of cathode-ray tubes. In comparing two frequencies by the zero beat method, listening to them with a pair of phones, the observer may be handicapped by two difficulties.

1. The two oscillators, unless well isolated, may have a tendency to lock into step over a fairly wide frequency range if working into a common detector.

2. Beats lower than about twenty cycles per second cannot be heard. Two equal frequencies impressed respectively on the vertical and horizontal plates will result in a stationary elliptical pattern. The mutual conductance between these pairs of plates is practically nil, thus the locking-in tendency is very slight. Any motion of the pattern at all is immediately apparent so that the comparison at zero frequency difference is readily accomplished.

The deflecting plates of the General Radio TYPE 635-P1 Electron Oscillograph Tube have a capacity reactance comparable to the usual grid admittance of a triode radio receiving tube. The TYPE 528-A Cathode-Ray Oscillograph Tube has only about one-tenth this capacitance. Transformers and other input devices for these tubes can be of the same design as those intended for ordinary vacuum tubes, but of course must be capable of operating with a secondary peak voltage between 50 and 200 volts. Practically all standard radio- or audio-frequency transformers are suitable.

In discussing applications for these versatile tubes, the tendency is to carry on indefinitely and only a few possibilities have been mentioned in the foregoing. —A. E. THIESSEN

DIRECT CAPACITANCE AND ITS MEASUREMENT

THE ordinary two-terminal condenser — whether air, mica, or other dielectric — is composed of at least three separate capacitances connected in a closed loop or delta. Besides the main capacitance connected between the two terminals and called the direct capacitance, each terminal has a "stray" capacitance to surrounding objects such as a shield or the ground, as shown in Figure 1. The condenser thus becomes a three-terminal system.

Usually the direct capacitance is much larger than the stray capacitances so that the total capacitance that would be measured between the two terminals differs from the direct capacitance by a few per cent at most. Figure 1, on the other hand, shows four instances in which the stray capacitances cannot be ignored.

In the shielded cable, the stray capacitances are of the same order of magnitude as the direct capacitance.

In a shielded transformer the shielding is placed to reduce direct capacitance between primary and secondary to a very small amount. There the stray capacitances are a hundred times the direct capacitance.

The two binding posts,* for example, have a direct capacitance between them of only 0.3 $\mu\mu$f, yet the capacitance obtained by an ordinary measurement is 2.0 $\mu\mu$f because each terminal has a capacitance of 3.4 $\mu\mu$f to the metal panel.

If, however, one terminal were "grounded" to the metal panel, thus short circuiting one stray capacitance, the total capacitance measured between terminals would be $0.3 + 3.4 = 3.7$ $\mu\mu$f. This illustrates the fact that the exact capacitance of any condenser depends on the manner in which its terminals are connected to each other and to nearby objects, either directly or via external circuits. It shows the importance of being able to measure direct and stray capacitance.

One method of measuring direct capacitance is shown in Figure 2. The three measurements indicated there are made with one of the three capac-

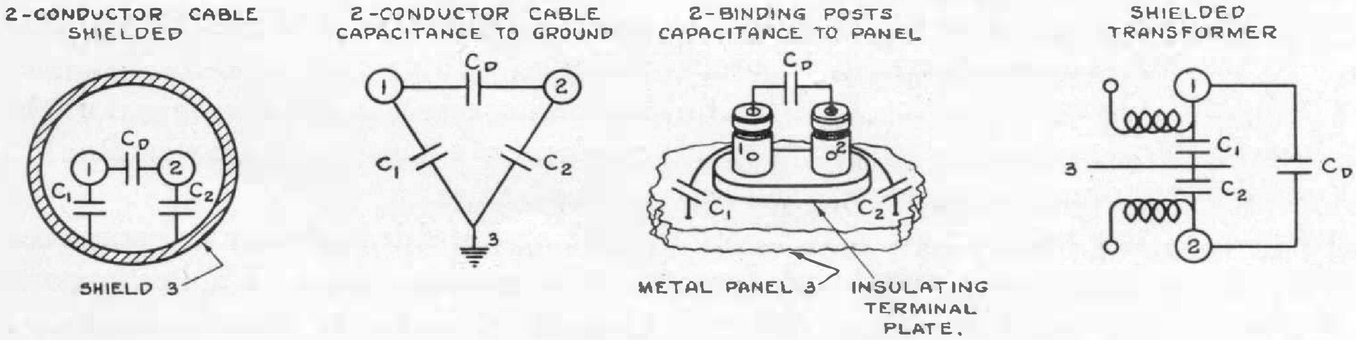
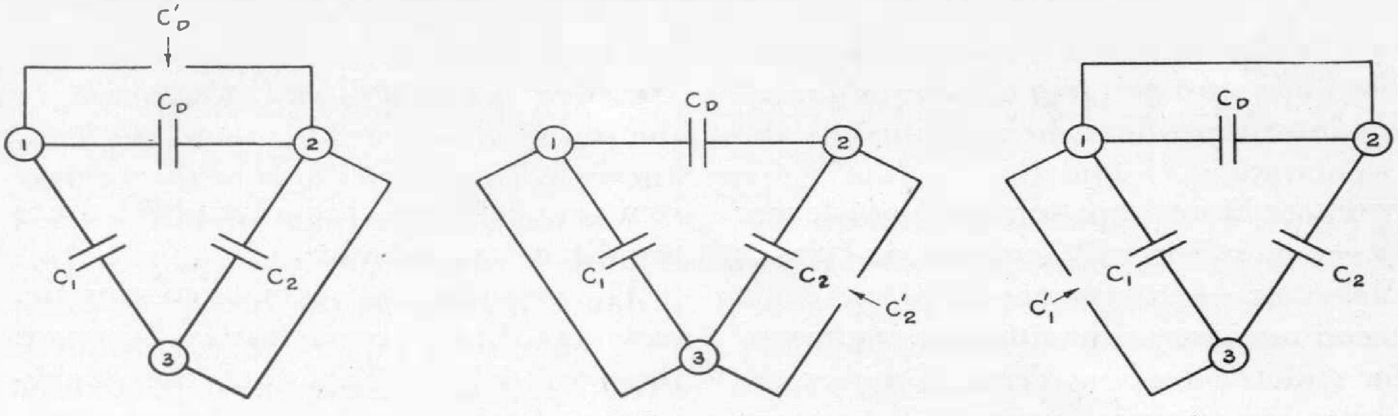


FIGURE 1. Four instances in which it is essential to know the direct and stray capacitances of a condenser

---

*General Radio TYPE 138-VD. The two terminal plates are TYPE 274-Y.



$C'_D = C_1 + C_D$ $C'_2 = C_2 + C_D$ $C'_1 = C_1 + C_2$

FIGURE 2. Direct capacitance can be calculated from the results of the three measurements indicated above. Note that, when any one of the capacitances is short circuited, no change in the equation results if the capacitance across the other capacitance is measured, e.g., across C_2 instead of C_1 in the right-hand drawing

itances short circuited each time. The capacitances are given by

$$C_D = \frac{C_D' - C_1' + C_2'}{2},$$

$$C_1 = \frac{C_D' - C_2' + C_1'}{2},$$

$$\text{and } C_2 = \frac{C_1' - C_D' + C_2'}{2}.$$

The dissipation factor ($R\omega C$) of the direct capacitance is given by

$$D_D = \frac{D_D' C_D' + D_2' C_2' - D_1' C_1'}{2C_D}.$$

A second and somewhat more convenient method, because it eliminates calculation, involves the measurement of direct capacitance by connecting the third terminal to some point on the bridge such that the stray capacitances are no longer included in the measurement as shown in Figures 3, 4, and 5.

Figure 3 is an equal-arm bridge of which the General Radio TYPE 216 Capacity Bridge is an example. When the third terminal is connected to the junction of the ratio arms, the direct capacitance is correctly measured, but its power factor is less than the true value by $B\omega C_2$, where B is in ohms, ω in radians per second, and C in farads. The capacitance C_1 disappears across the detector.

The third terminal may also be connected to the junction of one ratio arm and standard condenser N as in Figure 4. The direct capacitance is then in (fractional) error by the term $\frac{C_1}{C_N}$ because the capacitance C_1 is placed in parallel with the arm N. Its power factor will also be in error, if the power factor of the C_1 is large. The other capacitance C_2 merely shunts the generator. This connection is often used in unequal-arm bridges where B is much greater than A, so that C_N is greater than C_P and, as a result, the fractional error term $\frac{C_1}{C_N}$ becomes negligible.

Direct capacitance is measured on the General Radio TYPE 650-A Impedance Bridge in the above manner by connecting the third terminal of the condenser to any ground terminal G of the bridge.

When the third terminal is connected to the junction of a Wagner ground (Figure 5), both the direct capacitance and its power factor are measured correctly. The balancing procedure is, however, somewhat tedious because the main and Wagner ground balances are interdependent, being joined by the capacitances C_1 and C_2.

There is an important difference between a shielded three-terminal capacitance, in which the shield is the third terminal, and an unshielded condenser for which the third terminal is ground, although both may be represented schematically by Figure 1. When the shield forms the third terminal, it may generally be placed where wanted without reference to the point at which the bridge is grounded. When ground is the third terminal, only that type of connection may be used which a particular bridge allows.

When the junction of the capacitance arms *N* and *P* is grounded, as will occur on the TYPE 216 Capacity Bridge, one ground capacitance (C_1 of Figure 3) is short circuited, so that only the three capacitance method of Figure 2 may be used. The condenser is measured when directly connected and when transposed, giving C_D' and C_2'. For the third measurement (C_1'), the *1* and *2* terminals of the condenser are short circuited and connected to the junction of the *B* arm and the "unknown capacitance" arm of the bridge.

When either the junction of the arms *A* and *N*, as in the TYPE 650-A Impedance Bridge, or the junction of the two ratio arms *A* and *B* is grounded, the direct capacitance of the condenser is measured, as in Figures 3 and 4. Its power factor is in error, as previously discussed.

When a Wagner ground is used, the direct capacitance and its power factor are correctly measured.

The shield of a three-terminal capacitance frequently has a considerable capacitance to ground, making it, in effect, a four-terminal capacitance. For this case care must be taken that this shield-to-ground capacitance is either short circuited or placed where it does not affect the measurements.

For all of these measurements, substitution methods may be used. The formulae applying in each instance will be unchanged.

—ROBERT F. FIELD

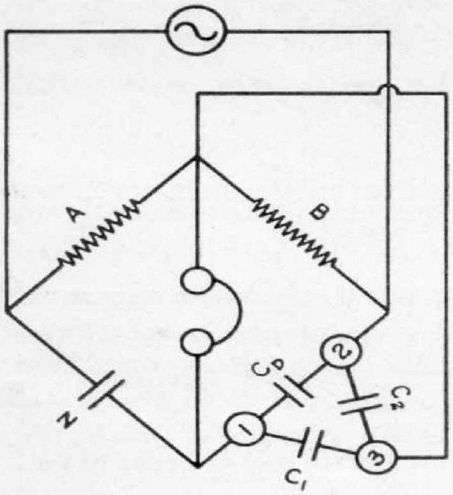


FIGURE 3. Direct capacitance measurement on an equal-arm bridge such as TYPE 216 Capacity Bridge

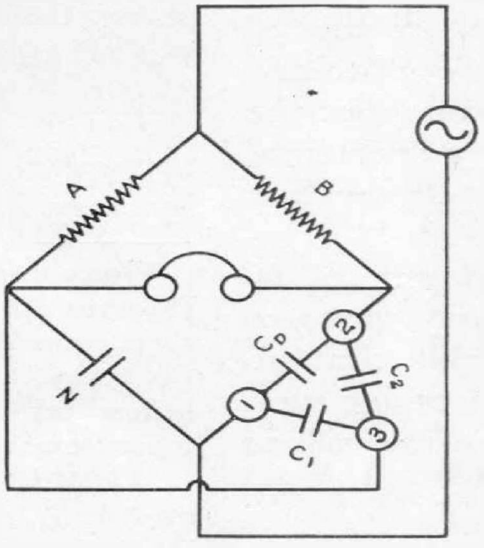


FIGURE 4. Direct capacitance measurement on a TYPE 650-A Impedance Bridge. Oscillator and detector can be interchanged

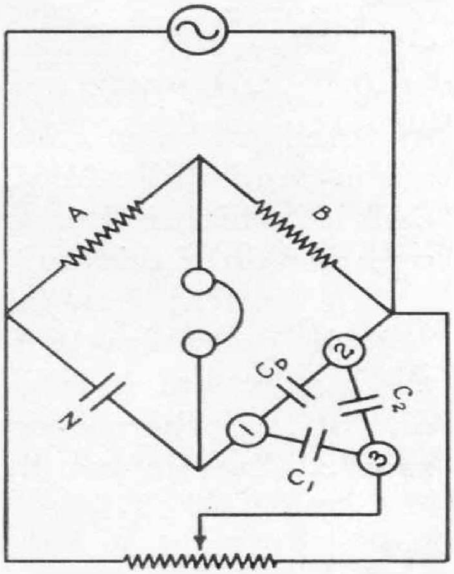


FIGURE 5. Direct capacitance measurement on a bridge using a Wagner ground connection

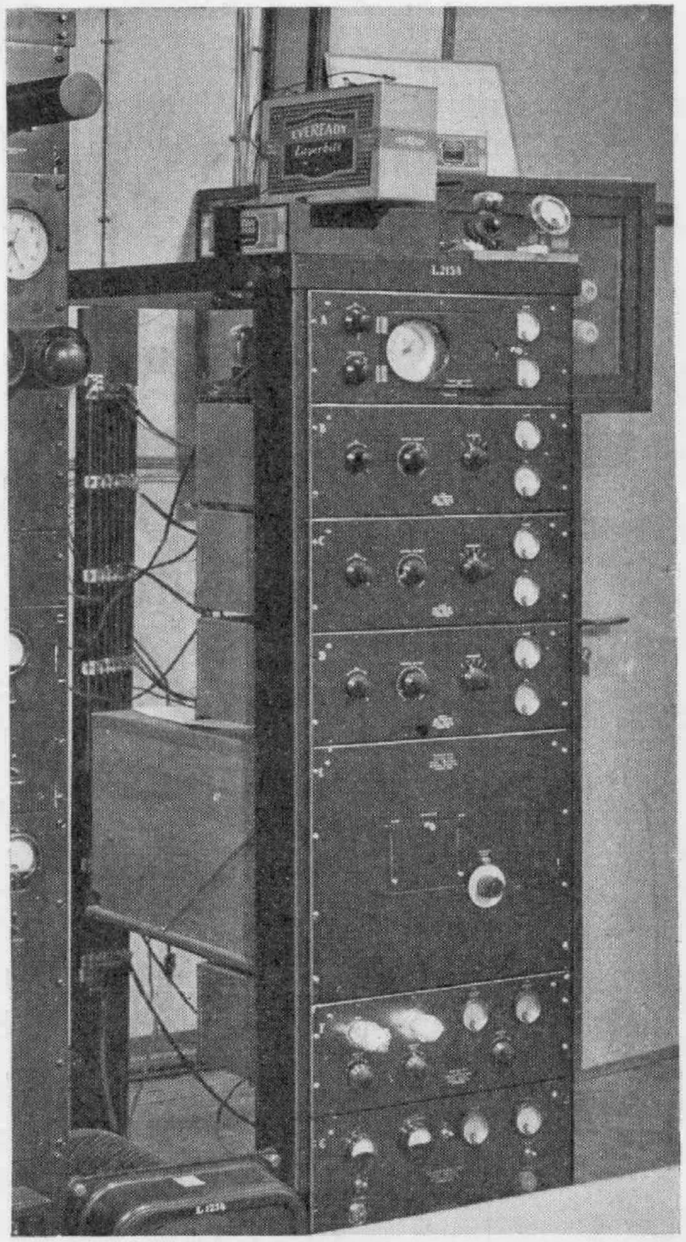
ON SERVICE IN TROPICAL JAVA

THE Colonial Department of the Dutch Government, which maintains radio telephone and telegraph service between the Hague and the Netherlands East Indies, is maintaining a General Radio primary standard of frequency at its station in Bandoeng, Java. Mr. H. Van der Veen, the engineer in charge, has just reported on its performance.

". . . You will be interested to know that the Standard-Frequency Equipment which our service bought from your company some years ago has been in constant use ever since its installation and that it has given very satisfactory results. All our high-frequency routine checking, as well as other work, is done by means of the controlled frequencies from your standard equipment. I am enclosing a photograph of the installation at Bandoeng."

This installation is a Class C-21-H Standard-Frequency Assembly, consisting of a 50-kc quartz crystal oscillator and a clock for measuring the crystal frequency in terms of time signals. From it are obtained hundreds of harmonics throughout the audio- and radio-frequency spectrum, each of which is known to better than one part in a million.*

The unit at Bandoeng is one of 26 now in operation in various parts of the world, but it is probable that no one of the others operates under such severe climatic conditions. Java has a tropical forest climate characterized by very high humidity.



---

*For a description of the apparatus consult Bulletin 10, a 70-page manual on frequency measurements published by the General Radio Company. Copies are free to engineers and others professionally concerned with radio measurements.