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ACCURACY CONSIDERATIONS IN THE USE OF TUNED-CIRCUIT WAVEMETERS

By Charles E. Worthen*

PROBABLY the most common type of frequency standard is the tuned-circuit wavemeter. The accuracy of measurements made with such an instrument depends not only upon the accuracy rating of the wavemeter itself, but upon a number of other factors as well, all of which should be considered in determining the ultimate accuracy.

The precision of setting of a wavemeter is as a rule somewhat greater than its rated accuracy. As a specific example, consider a low-frequency wavemeter of the General Radio precision type with a 2500-division scale, settings of which can be duplicated to within one tenth of a division. The condenser used in this instrument has a minimum capacitance of about 50 $\mu\mu f$ and a maximum of 1500 $\mu\mu f$.

If we arbitrarily fix the lowest useable scale reading as 100 divisions, it would appear that this wavemeter could be set to one part in 1000 at the low capacitance end and one part in 25,000 at the high capacitance end. Since the capacitance of the condenser varies uniformly with scale setting, and frequency varies as the square root of capacitance, we could set to one part in 2000 or 0.05 per cent. in frequency at one end and to one part in 50,000 or 0.002 per cent. at the other end.

Actually, the sharpness of the tuned circuit and the characteristics of the thermogalvanometer resonance indicator determine the ultimate precision of setting. At the high capacitance end of the scale, the top of the resonance curve covers about 5 divisions and at the lower end about 0.5 division. Converting these values to frequency, the width of the peak is from 0.1 to 0.2 per cent. By setting to the center of the peak a precision of about 0.05 per cent. can be realized. By using the incremental capacitance method † to obtain the resonance indication, the pre-

* Engineering Department, General Radio Company.

† James K. Clapp, "Improving the Precision of Setting in a Tuned-Circuit Wavemeter," *General Radio Experimenter,* IV, September, 1929. This issue is now out of print. The method referred to involves the use of a small condenser which may be shunted across the main tuning condenser by means of a push button. The wavemeter is adjusted until the resonance indicator gives the same deflection when the incremental capacitance is in or out of circuit. In other words, the operation of the push button spans the resonance peak. This method of setting is used on the General Radio Type 624 Precision Wavemeter. — Editor.

cision of setting can be increased to one part in 20,000 or 0.005 per cent.*

The rated accuracy of the wavemeter is not as high as these figures would indicate. This is due to possible errors in calibration and to aging of the tuned circuit. Although extreme care is used in calibration, some errors are bound to occur in setting the driving oscillator to the frequency standard and still others in setting the wavemeter to the driver. A third source of error is the plotting of the calibration curves. If all these errors are cumulative (which is quite possible) the accuracy to within which the wavemeter can be guaranteed is materially reduced.

After the wavemeter is calibrated, the constants of the tuned circuit are subject to some drift due to aging effects in the materials of which it is constructed. Over a period of one year this may amount to as much as 0.1 per cent. The effect of temperature on the tuned circuit is of considerable magnitude, and in a high-precision wavemeter (guaranteed to 0.1 per cent.) special construction or a temperature correction must be used

If a metallic body is placed in the field of a wavemeter inductor, its effective inductance may be materially changed, and the calibration is no longer correct for the conditions under which it is used. Similarly, the capacitance of near-by objects will affect the frequency of an oscillator. When a wavemeter is placed near an oscillator, both effects occur: the wavemeter changes the oscillator frequency and the presence of the oscillator affects the wavemeter. Whether or not these changes are large enough to appreciably affect the accuracy of the measurement depends on the conditions under which the measurement is made and may best be determined by experiment.

Even when the capacity effects just mentioned are negligible, another error may occur, due to "transformer action." The coils of the oscillator and wavemeter act as the primary and secondary windings of a transformer, and the impedance of the wavemeter is reflected into the oscillating circuit. The magnitude of the reaction depends on the L/C ratios of the two circuits and the value of coupling between them. When the wavemeter is set to resonance, the impedance reflected into the oscillating circuit is purely resistive, and the change in oscillator frequency thus produced is negligible. If the wavemeter is not in resonance, the reflected impedance has a reactive component, and the frequency of the oscillator is materially changed.

As the capacitance of the wavemeter condenser is varied through resonance, the frequency changes as shown in the accompanying diagram, where the zero axis represents the frequency of the oscillator before the wavemeter is coupled to it.† The point at which this curve crosses the axis is the setting at which the wavemeter is in resonance and this setting should be used in entering the calibration chart.

The frequency change shown in the diagram can be detected by listening in a heterodyne detector as the wavemeter condenser is varied. If the heterodyne is set to zero beat with the wavemeter far from resonance, then as the wavemeter is tuned, the beat note will rise and then fall to zero twice. The direction of the beat-frequency change cannot, of course, be detected.

With a given wavemeter and oscillator and a given degree of coupling between them, the magnitude of the change is entirely independent of the

* The precision is inversely proportional to the figure given, that is, the lower the percentage figure, the higher the precision.

† This discussion assumes that the oscillator is uncontrolled, that is, that its frequency is determined by the reactance of its tuned circuit.

oscillator power. The higher the power of the oscillator, however, the smaller the degree of coupling necessary to produce a given deflection on the thermogalvanometer.

When the wavemeter is coupled to a controlled oscillator or to the output of a power amplifier, these effects are usually negligible. The capacitance effect of the presence of the oscillator or power amplifier upon the wavemeter is, however, still present.

When using reaction methods of resonance indication, the point of maximum reaction is where the greatest frequency shift occurs, so care should be taken to make the reaction as small as possible or else the setting should be made by listening to the beat note as outlined above.

In making frequency measurements with a wavemeter, if no care is taken to eliminate or minimize the various effects which have been discussed, the best accuracy which can be realized is about 0.5 per cent. but if due attention is given to them, the rated accuracy of the wavemeter can be reached. Even then the "rated accuracy" may be of a materially lower order than the percentage precision with which one is able to read the scale.

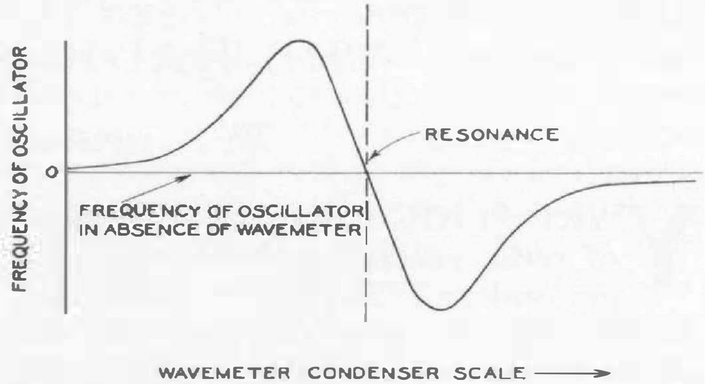

Figure 1. Reaction of a wavemeter upon the frequency of an oscillator to which it is coupled

Figure 2. A General Radio wavemeter of the precision type referred to in this article. The condenser is driven by the micrometer control handle at the right, one complete turn of which revolves the condenser through 1/25 of a semicircle. The micrometer shaft carries an accurate 100-division scale, so that any desired setting of the condenser can be duplicated to within at least one part in 2500. Besides, tenths of divisions can be estimated

SIMPLIFIED SENSITIVITY MEASUREMENTS FOR THE RADIO SERVICE MAN

By CHARLES T. BURKE*

YARDSTICKS for the evaluation of radio receivers have come into general use. In the research laboratory where new designs are developed very elaborate systems of measurement have been set up, covering every feature of receiver performance.† Simplified tests are also in use on the production lines, where the performance of every set may be checked against the specifications determined by the development laboratory. There has been, however, no general means available for a performance check in the field. To a limited extent the methods used in the development laboratory have been applied to field checks by some of the larger organizations, but these methods are not generally suited to service testing.

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† *I. R. E. Yearbook*, 1929, pp. 106–128. See also Charles T. Burke, "The Standard-Signal Method of Measuring Receiver Characteristics," *General Radio Experimenter*, IV, March, 1930.

It is recognized that a sensitivity measurement serves as an excellent indication of the receiver performance. Any serious fault in the receiver will be accompanied by a loss of sensitivity as compared with standard performance. The usual method of measuring sensitivity is illustrated in Figure 1. A modulated source of radio frequency is connected to the receiver through a dummy antenna. The power output of the receiver is measured in a standard output circuit. The magnitude of signal voltage required to give equal output power under standardized measuring conditions is of course a measure of the sensitivity of the receiver.

A number of simplifications may be made in the procedure outlined above to make it more suitable for service testing. A test-signal generator for service testing should be easily portable and all unessential adjustments should be eliminated. It is also desirable that

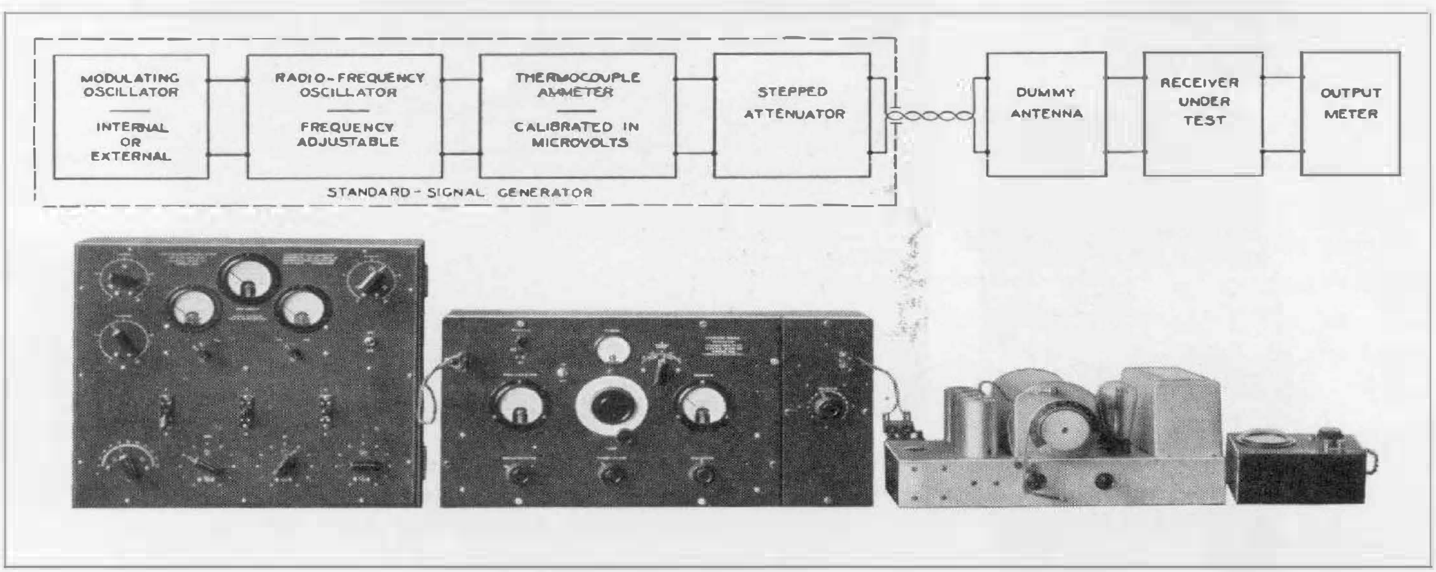

FIGURE 1. Component parts required for the standard-signal method of measuring sensitivity as recommended by the Institute of Radio Engineers. Above: an outline chart. Below (left to right): TYPE 377-B Low-Frequency Oscillator for supplying external modulation; TYPE 403-C Standard-Signal Generator; TYPE 418 Dummy Antenna; receiver under test; and TYPE 486 Output Meter

the instrument be alternating-current operated in order to avoid the necessity of carrying batteries for it.

Thorough shielding is a further requirement for any instrument with which comparative sensitivity measurements are to be made; otherwise differences in shielding of the receivers will introduce wide variations. The shielding must, of course, also include complete isolation from the alternating-current line if the receiver under test is also alternating-current operated. An adequate test-signal generator should provide a modulated radio-frequency voltage continuously adjustable in frequency and constant in amplitude over the broadcast range. It should also provide means for changing its output by definitely known amounts. This last requirement involves the design of an attenuator or voltage divider which will be accurate at high frequencies and also requires careful shielding of the instrument.

The uses of such a test-signal generator are numerous. It can be used on the demonstration floor to compare the sensitivity of different receivers, always extremely difficult to do under store conditions by other means. It is in the field of receiver servicing, however, that the test-signal generator has its greatest usefulness. Being easily portable, it can be taken to the job and with its assistance, the service man can immediately determine whether or not a real difficulty exists in the receiver. He can also isolate receiver troubles from troubles due to local conditions or to antenna and ground installation. If the trouble is in the receiver, the test-signal generator provides an immediate check on the efficacy of the means taken to remedy the defect, since the restoration of the receiver to normal sensitivity can be interpreted as a successful cure. This use of the generator permits the making of all kinds of minor adjustments of the receiver on the owner's premises and eliminates unnecessary transportation of the receiver to the shop. The test-signal generator is also used in the customary neutralizing and aligning adjustments where a source of modulated radio-frequency voltage is required.

The General Radio Company has been working for a considerable period on the development of a test-signal generator which will fulfill the requirements outlined above. The result of

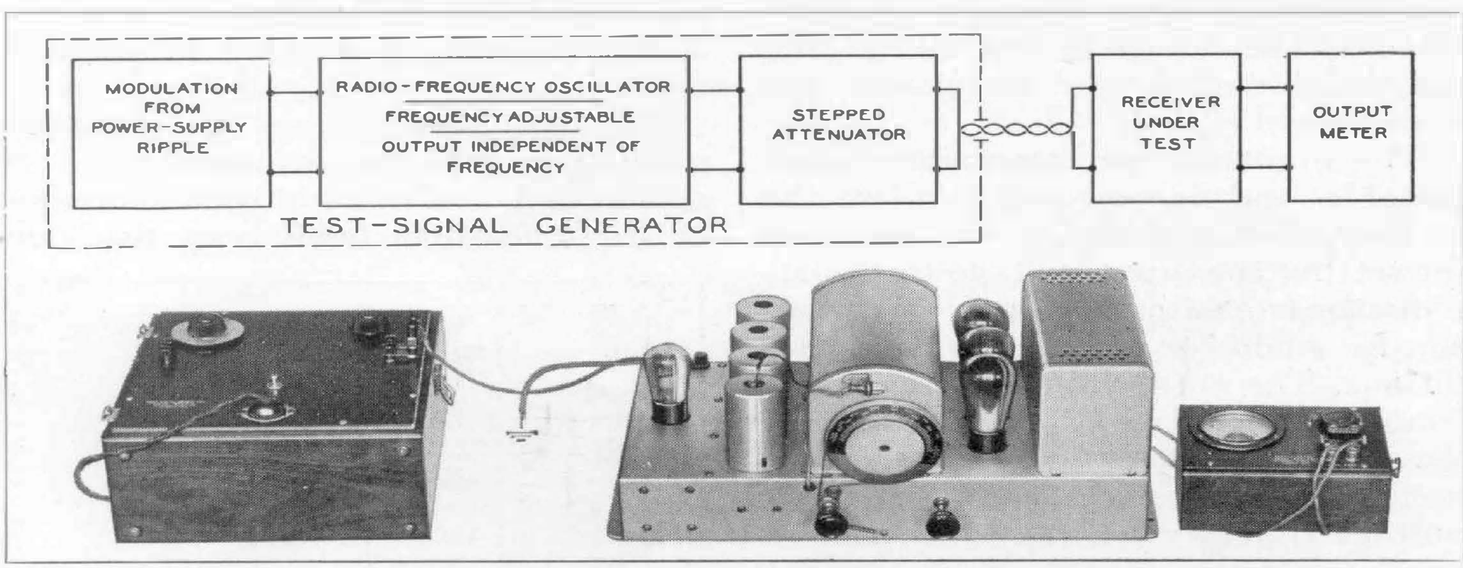

FIGURE 2. Component parts required for the simplified sensitivity measurement described in this article. Above: an outline chart. Below (left to right): TYPE 404 Test-Signal Generator; receiver under test; and TYPE 486 Output Meter. Note the similarity between this and the arrangement shown on the opposite page

this development is the TYPE 404 Test-Signal Generator. It consists of a constant-output vacuum-tube oscillator modulated by the rectifier ripple, and an attenuator, together with a power-supply transformer and rectifier.

The attenuator is carefully designed, and well shielded. The value of the instrument in making comparison depends entirely on the accuracy of the attenuator, and this portion of the circuit has, therefore, received particular attention. The attenuator has voltage ratios of 1, 2, 5, 10, 20, 50 and 100; a range that will include all modern types of receivers. An additional set of terminals provides an output of about 0.1 volt for making neutralizing and aligning adjustments. The error in attenuator ratios is less than 5 per cent. for adjacent ratios, and the cumulative error in the entire attenuator does not exceed 20 per cent. This means that the instrument will *compare* the sensitivity of two similar receivers with an accuracy of 5 to 20 per cent.

The absolute value of the output voltage may vary, due to aging of tubes or to changes in line voltage. The change in output due to line voltage variations is approximately proportional to the change in line voltage and may be corrected for, if the line voltage is measured.

The input to the attenuator is adjustable and is correctly set at the factory. Where facilities are available for setting the input voltage to the attenuator from time to time, correction can be made for changes in tube conditions. The total voltage attenuation from the point of adjustment to the lowest output point is 1:100,000. The oscillator is so designed that the output voltage is nearly constant over the entire frequency range. The voltage variation is less than plus or minus 5 per cent.

The test-signal generator is entirely alternating-current operated. This feature requires considerable care in the design of the instrument, in order to keep radio-frequency currents out of the line. Since the radio receiver is usually operated on the same line as the signal generator, any leakage into the line would be picked up in the receiver. A careful study of this problem has resulted in filtering in the line input to the generator, such that the receiver and the signal generator can be operated from the same socket without interference.

It should be emphasized that the test-signal generator does not give an absolute reading of sensitivity in microvolts. So many factors affect such readings that even a laboratory instrument may be 10 per cent. in error in absolute value. The TYPE 404 Test-Signal Generator has a series of relative output figures, and is primarily designed for comparative work, either against a standard, or as a straight comparison between two sets. The comparison does not have to be made at the same input level to the receiver, however, since the ratio between the output at various steps is indicated. The range of the instrument is of the order of 10-1000 microvolts, with an additional 100,000-microvolt terminal. The leakage is equivalent to about 2 microvolts.

In using the test-signal generator for making sensitivity measurements, it should be borne in mind that a number of simplifications have been made in

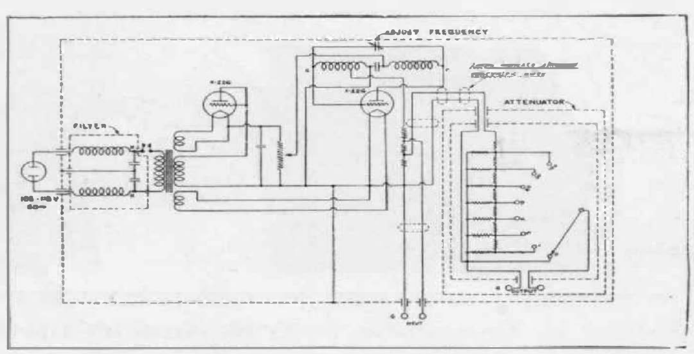

FIGURE 3. Wiring diagram for the TYPE 404 Test-Signal Generator

this instrument to make it best adapted to the requirements of receiver servicing. These simplifications in the test method are such that the measurements obtained with the test-signal generator cannot be compared with those obtained by other methods of measurements, such as the standard sensitivity test outlined by the Institute of Radio Engineers and generally used in development laboratories. The modulation in the test-signal generator is obtained from the rectifier ripple and is not adjustable either in frequency or in percentage. Readings taken with the test-signal generator are, however, comparable among themselves. If receivers of the same type are being compared, the generator can be connected directly to the antenna-ground posts of the receiver. If the receivers of widely differing types of input circuit are being compared, it is desirable to use a blocking condenser of about 100 $\mu\mu$f capacitance between the generator and the receiver under test. The sensitivity of a receiver is measured in terms of the radio-frequency voltage input required to give a certain output power. Of two receivers delivering the same power to the speaker circuit the more sensitive is, of course, that which requires the smaller input voltage. The general practice is to substitute for the speaker a suitable resistance load and a means for measuring either the current through or the voltage across it. A convenient value of output power is selected (50 milliwatts is often used because it is the Institute of Radio Engineers' standard) and the input from the signal generator adjusted to give this value of output for all the receivers measured.

MISCELLANY

By THE EDITOR

WE are publishing Mr. Worthen's precautions for the use of a tuned-circuit wavemeter in the hope that it will dispel one of the common misapprehensions that are held by many users of precision wavemeters. This question has become serious since the announcement of the new TYPE 423 Vacuum-Tube Oscillator which enables the user to convert his General Radio TYPE 224, 224-A, or 224-L Precision Wavemeter into a heterodyne wavemeter. The greatly increased precision of setting which one can obtain by listening to the beat note has led many people to assume that they were making much more accurate measurements.

The point is that the frequency stability of a heterodyne wavemeter is no better than the stability of the tuning circuit with which it is associated. A heterodyne wavemeter may enable one to minimize the error in setting a given unknown oscillator to a desired frequency, but the reliability of that heterodyne wavemeter as a standard of frequency is no greater than the reliability of its tuned circuit.

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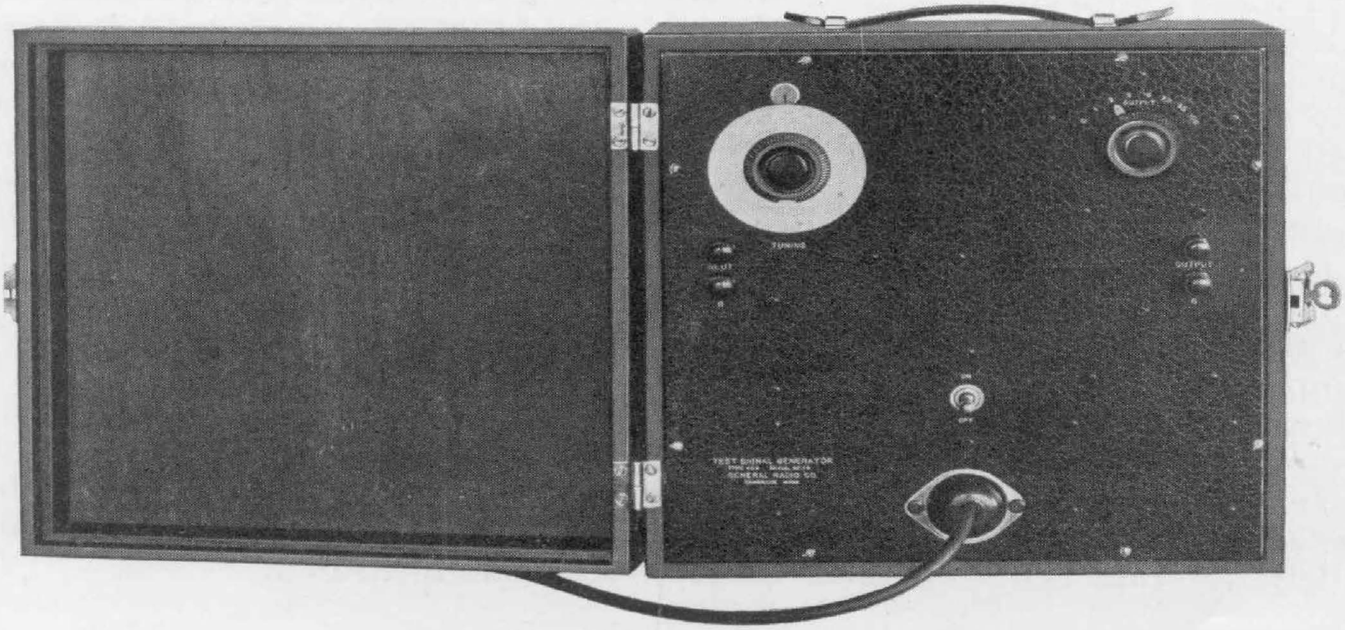
A Service-Testing Oscillator of Radically New Design



Type 404 Test-Signal Generator

SERVICE engineers from progressive radio manufacturers have repeatedly asked for a simplified method by means of which the individual serviceman could make sensitivity measurements. The TYPE 404 Test-Signal Generator is the answer.

The new instrument is the ideal oscillator for the serviceman. It delivers a modulated voltage of known magnitude at any point in the broadcast band, and with its help defects can be localized which without it would require time-wasting cut-and-try methods. It replaces the unreliable listening test with an actual, readily duplicated measurement.

In addition, it performs all of the usual functions of the simple oscillator in making neutralizing and aligning adjustments.

The engineers who designed the test-signal generator studied the serviceman's requirements from every angle to make sure that no neglected detail would mar its perfect performance. Each individual instrument is given a thorough check in the laboratory to make sure that it is as good as the original design.

See this issue of the *Experimenter* for a discussion of test-signal generators in general and the TYPE 404 in particular. It will be cataloged in a new bulletin for the serviceman which will be mailed to all serviceman readers of the *Experimenter* on September 15.

Price, $95.00

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