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2. Illustrations should invariably be in black ink on white paper or tracing cloth. Blueprints are inacceptable.

3. Corrected galley proofs should be returned within 12 hours to the office of publication. Additions or major corrections cannot be made in an article at this time.

4. A brief summary of the paper, embodying the major conclusions, is desirable.

5. The Club reserves the right of decision on the publication of any paper which may be read before the Club.

* For 1932 the Chairman of the Papers Committee is Mr. F. X. Rettenmeyer, 463 West Street. New York City.

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PROCEEDINGS
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Vol. 9 MAY-JUNE, 1932 No. 5-6

Notes on the design of radio receivers†

By LINCOLN WALSH

THE design of radio receivers is today a problem of obtaining satisfactory performance within limits set by considerations of cost and size. Satisfactory performance is largely a question of the resistance of the tuned circuits, both radio and intermediate frequency. Sensitivity and selectivity are improved as circuit resistances are decreased. Fidelity is seriously impaired as the resistance is decreased, beyond certain limits, unless band-pass circuits are employed.

The resistance of tuned circuits is commonly expressed in several ways:

The series resistance in ohms, R.

The power factor, pf; or its reciprocal, Q.

The band width at half amplitude, B, expressed in kilocycles at a given carrier frequency.

These expressions are related as follows:

$$\frac{R}{2\pi f L} = pf = \frac{1}{Q} \qquad (1)$$

$$\frac{1}{pf} = Q = \frac{2\pi f L}{R} \qquad (2)$$

$$B = \frac{\sqrt{3}\,R}{2\pi L} = \sqrt{3} \times f \times pf = \frac{\sqrt{3} \times f}{Q} \qquad (3)$$

The expression for B is derived as follows:

The series impedance

$$z = R + j\,2\pi f L + \frac{1}{j\,2\pi f C} \qquad (4)$$

at resonance

$$j\,2\pi f L + \frac{1}{j\,2\pi f C} = O \qquad (5)$$

and

$$z = R \qquad (6)$$

when the amplitude has been reduced to half by shifting the frequency of the applied voltage Δf

$$z = 2R = R + j\,2\pi\,(f \pm \Delta f)\,L + \frac{1}{j\,2\,(f \pm \Delta f)\,C} \qquad (7)$$

An approximation that has negligible error in all practical cases gives

$$z = 2R = R \pm 2j\,2\pi \Delta f L \qquad (8)$$

$$4R^2 = R^2 + 16\pi^2 (\Delta f)^2 L^2 \qquad (9)$$

$$\frac{3R^2}{16} = \pi^2 (\Delta f)^2 L^2 \qquad (10)$$

$$\Delta f = \frac{\sqrt{3}\,R}{4\pi L} \qquad (11)$$

As Δf is the frequency change in one direction to reduce to half amplitude, the band width B is twice Δf.

$$B = 2\Delta f = \frac{\sqrt{3}\,R}{2\pi L} \qquad (12)$$

or

$$B = \sqrt{3}\,f\,\frac{R}{2\pi f L} = \sqrt{3} \times f \times pf = \frac{\sqrt{3} \times f}{Q} \qquad (13)$$

The parallel tuned impedance of a tuned circuit, expressed in ohms, is

$$Rt = \frac{(2\pi f)^2 L^2}{R} = \frac{2\pi f L}{pf} \qquad (14)$$

$$= \frac{1}{(2\pi f)^2 C^2 R} = \frac{1}{2\pi f C\,pf} \qquad (15)$$

expressed as a conductance in mhos

$$g = \frac{1}{Rt} = \frac{R}{(2\pi f)^2 L^2} = \frac{pf}{2\pi f L} \qquad (16)$$

$$= (2\pi f)^2 C^2 R = 2\pi f\,c\,pf$$

Factors in Circuit Resistance

The resistance of a tuned circuit consists of the copper resistance of the coil, and the dielectric loss, made up of the losses in the condenser, in the coil form, in the tube and in the leads. In general, losses are also reflected into the tuned circuit from the primary circuit from which it receives its energy.

The resistance of a coil at radio frequency is many times its resistance to direct current. In a coil designed to cover the broadcast range, the power factor due to copper resistance only, at 1,500 kc. will be close to 0.8 per cent over a wide range of coil dimensions and size of wire. At 600 kc. the power factor due to copper resistance will vary from 2 per cent for some of the smaller coils now in use, to about 0.4 per cent for the larger coils employed in the earlier receivers.

In coils using solid copper wire, the diameter of the wire may be varied from about one-third the distance between turns, up to the point where the wires are almost touching without greatly affecting the power factor. Using larger wire reduces the power factor slightly at low frequencies, and increases it slightly at high frequencies.

The effect of shields is to decrease the inductance of the coil and to decrease the resistance to a slightly less degree, so that the power factor is only slightly increased. The reduction of resistance seems to be due to a reduction of skin effect. When the coil is not shielded the current crowds to the inner surface of the wire. In the shield

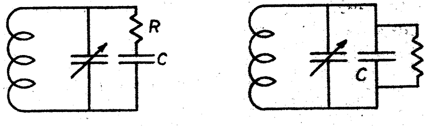

Fig. 1.

$R = \frac{pf}{2\pi f c}$ $g = 2\pi C pf$

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†*Delivered before the Radio Club of America, May 11, 1932.*

he current crowds to both inner and outer surfaces, and the consequent reduction in resistance more than compensates for the energy loss due to currents flowing in the shield, the net reult being a drop in the coil resistance almost as great as the drop in inductance.

Coil Diameter

To obtain the coil of lowest power factor in an aluminum shield of given diameter, the coil diameter should be about 0.6 times the shield diameter; in a copper shield about 0.65. Cost considerations will dictate a coil slightly smaller than these sizes, as the power factor does not increase rapidly with decrease of diameter, but the material and labor costs drop in proportion to diameter.

If the coil diameter is 0.707 times the shield diameter the loss is slightly increased, but the coil has the unique property of having its inductance substantially independent of small variations in the diameter of the coil form. This is due to the reluctance of the magnetic path being equal inside and outside the winding, so that any change in diameter increases the reluctance of the inner path by the same amount that it decreases the reluctance of the outer path, or vice versa. The inductance then depends on the diameter of the shield, the length of winding and the number of turns.

The dielectric loss, when expressed as a conductance across the circuit varies in proportion to frequency. It may be represented by a condenser of fixed capacity and constant power-factor comprising part of the tuning capacity of the circuit, as shown in Fig. 1.

In a circuit having fixed inductance, and tuned by a variable capacity, the dielectric loss when expressed as a series resistance or as band width varies as the third power of frequency. Expressed as power factor it varies as the second power of frequency.

Among the main contributors to dielectric loss are the insulators and compensators of variable condensers, and the insulation of the leads connecting the grid, coil high terminal and variable condenser stator. Care should be taken in the placing and insulation of these leads, or their loss may exceed all the other losses of the circuit.

The power factor due to dielectric loss may vary from values too small to measure to about 1.5 per cent, at 1,400 kc.

The r-f. system of the average broadcast receiver has a power factor due to all causes of about 1.4 per cent at 600 kc. and 1.7 per cent at 1,400 kc., corresponding to band widths for individual stages of 15 kc. and 42 kc. The intermediate frequency stages of superheterodynes have band widths of 6-10 kc., corresponding in a 175 kc. amplifier, to a power factor of 2-3 per cent.

The loss reflected from the primary consists of the reflected plate impedance of the tube, and the loss due to current circulating in the primary coil itself. The loss due to circulating current is determined by measuring the power factor of the secondary with the primary removed, and then measuring the power factor with the primary in position and connected to its normal circuit, with the preceding tube plate connected to the primary, but the cathode cold or the tube biased beyond cutoff. The difference of these two power factors gives the loss in the primary.

The power factor due to reflected plate impedance is a measure of efficiency of coupling between the plate of the amplifier and the tuned circuit. For maximum transfer of energy into the secondary circuit, the impedance of the primary should equal the plate impedance of the tube. The primary impedance is

$$z_1 = R_p \times \frac{pf}{pf_o} - 1 \qquad (17)$$

where R_p is the plate impedance of the tube.

pf is the power factor of the circuit in normal operation with the tube operating at R_p normal.

pf_o is the power factor of the circuit normal except that R_p is substantially infinite (cathode cold, or tube biased almost to cutoff).

The expression for primary impedance is derived as follows:

Neglecting $L_{1L}\ \tau^2$, the total resistance across the tuned circuit is Z_2

$$\frac{1}{Z_2} = \frac{1}{Z_{2-o}} + \frac{1}{R_p\tau^2} \qquad (18)$$

$$\frac{pf}{2\pi f L} = \frac{pf_o}{2\pi f L} + \frac{1}{R_p\tau^2} \qquad (19)$$

$$\frac{pf - pf_o}{2\pi f L} = \frac{1}{R_p\tau^2} \qquad (20)$$

$$\frac{pf - pf_o}{pf_o} = \frac{2\pi f L}{R_p\ \tau^2\ pf_o} \qquad (21)$$

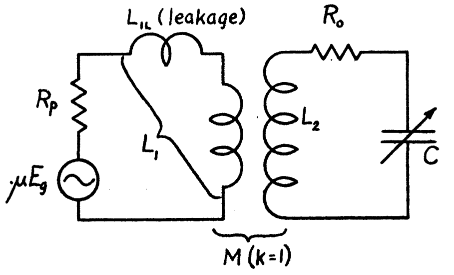

Fig. 2. Actual circuit.
Effective turns ratio or voltage turns ratio $\tau = \frac{L_2}{M}$

$\frac{2\pi f L}{pf_o}$ is the secondary tuned impedance and $\frac{2\pi f L}{pf_o\ \tau^2}$ is the primary tuned impedance. Then the preceding equation reduces to

$$\frac{pf}{pf_o} - 1 = \frac{z_1}{R_p} \qquad (22)$$

This method must be modified when the primary leakage inductance is not negligible relative to R_p.

The method as described in general is correct for all circuits except those employing a primary circuit tuned to a frequency below the low end of the frequency range.

The relation between primary impedance, voltage ratio, gain, and power factor is shown in Fig. 4.

It will be seen that if the primary impedance is made somewhat below optimum, the power factor, and therefore the selectivity are considerably improved, with a very slight reduction of gain.

Computation of Gain

Knowing the inductance L, power factor pf_o, and voltage ratio or effective turns ratio τ of a tuned amplifier stage, the gain can be computed as follows:

Tuned secondary impedance

$$z_2 = \frac{2\pi f L}{pf_o} \qquad (23)$$

Tuned primary impedance

$$z_1 = \frac{2\pi f L}{pf_o \times \tau^2} \qquad (24)$$

The voltage developed across the primary is

$$\mu E_g \times \frac{z_1}{z_1 + R_p} \qquad (25)$$

The voltage developed across the secondary

$$E_s = \tau\ \mu\ E_g \frac{z_1}{z_1 + R_p} \qquad (26)$$

Amplification

$$\frac{E_s}{E_g} = \tau\ \mu \frac{\frac{2\pi f L}{pf_o\ \tau^2}}{\frac{2\pi f L}{pf_o\ \tau^2} + R_p} \qquad (27)$$

The optimum effective turn ratio or voltage ratio is

$$\tau = \sqrt{\frac{z_2}{R_p}} = \sqrt{\frac{2\pi f L}{pf_o \times R_p}} \qquad (28)$$

The optimum gain is

$$\frac{\tau_{opt} \times \mu}{2} = \frac{\mu}{2} \sqrt{\frac{2\pi f L}{pf_o \times R_p}} \qquad (29)$$

The above expressions are primarily for use with 3-element tubes in which the plate impedance is low. When the plate impedance is greater than the tuned secondary impedance, it is in general not possible to secure optimum coupling and gain.

When the plate impedance is very much greater than the primary impedance (27) reduces to

$$\frac{E_s}{E_g} = \frac{\mu}{R_p} \frac{2\pi f L}{pf_o\, \tau} = g_m \frac{2\pi f L}{pf_o\, \tau} \qquad (30)$$

When the plate is directly coupled to the tuned circuit this further reduces to

$$\frac{E_s}{E_g} = g_m \frac{2\pi f L}{pf_o} \qquad (31)$$

Most superheterodynes employ in their intermediate-frequency stages a pair of coupled circuits, the first of which is directly coupled to the plate of the amplifier tube, with the coupling between them critical or over. The tuned primary impedance is half the impedance of one circuit alone. The tuned impedance of such a circuit is generally a considerable fraction of the impedance of the screen grid amplifier tube.

The primary impedance is then

$$\frac{2\pi f L}{2\ pf} \qquad (32)$$

The voltage amplification is (33)

$$\frac{E_s}{E_g} = \mu \frac{\dfrac{2\pi f L}{2\ pf_o}}{\dfrac{2\pi f L}{2\ pf} + R_p}$$

the voltage being substantially the same across both primary and secondary.

Methods of Measuring Resistance

The more common methods of measuring resistance at high frequencies may be grouped under the following headings:

High frequency bridge.
Resistance variation.
Capacity variation.
Frequency variation.

The ordinary a-c. bridge has been used to measure the series resistance of tuned circuits. It has been used also to measure the primary impedance of tuned transformers at resonance, when this value was of the order of 1,000 to 10,000 ohms. This method has been found fairly accurate, but it is so difficult to operate a bridge of this character that is very rarely used.

The resistance variation method is perhaps the most widely used method of measuring resistance. A voltage is induced in the tuned circuit, and a vacuum tube voltmeter connected across the circuit or an ammeter connected in series with the coil and condenser, and the circuit tuned to the applied voltage. The reading of the meter is noted. Resistance is introduced in series with the inductance and capacity, and its value adjusted until the meter reading indicates half current or voltage. When the meter reading is proportional to voltage squared, the reading should be adjusted to quarter the original deflection. The value of resistance introduced is then equal to the resistance of the circuit.

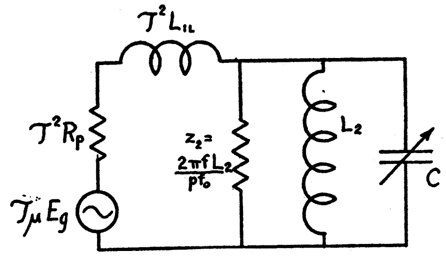

Fig. 3. Equivalent circuit.

Precaution must be taken that the induced voltage does not change when the resistance is introduced.

This method is open to the serious objection that the results are accurate only when the resistance is in series with all the tuning capacity. In the average broadcast circuit at 1,400 kc. more than half of the capacity of the circuit is distributed, or reflected from the primary, and less than half is in the condenser, and the results obtained are correspondingly in error.

In the capacity variation method, a small calibrated variable condenser is connected in parallel with the tuning condenser; the circuit is tuned to resonance with an applied voltage as indicated on a vacuum tube voltmeter. The meter reading is noted and the auxiliary condenser setting increased until the voltmeter reading has dropped to quarter scale, indicating one-half voltage. This is repeated, decreasing the condenser setting.

Call the difference of the two settings $2 \Delta C$. Then

$$\frac{2\pi f}{\sqrt{3}} \Delta C = \frac{pf}{2\pi f L} = \frac{R}{(2\pi f L)^2} \qquad (34)$$

or

$$\frac{\Delta C}{\sqrt{3} C} = pf = \frac{R}{2\pi f L} = \frac{1}{Q}$$

This method is quite satisfactory and accurate. It does call for the inductance or capacity being known. The auxiliary condenser may add sufficient dielectric loss to the circuit to seriously affect the results at high frequencies.

When the voltmeter reading is dropped to half instead of quarter on a square law meter, the same expression results, but the $\sqrt{3}$ (1.732) drop out of the expression.

Then

$$2\pi f \Delta C = \frac{pf}{2\pi f L} = \frac{R}{(2\pi f L)^2} = \qquad (35)$$

$$\frac{1}{Q\, 2\pi f L} = pf\, 2\pi f C = \frac{2\pi f C}{Q}$$

$$\frac{\Delta C}{C} = pf = \frac{1}{Q} \qquad (36)$$

Frequency Variation Method

In the frequency variation metho the circuit is tuned to resonance wit a voltage from the signal generator, a indicated by a vacuum tube voltmeter The frequency of the generator is increased until the voltmeter falls to hal it original value, and the frequenc noted. The frequency is then decrease until the voltmeter falls to the same hal value. The difference of frequency fo the high and low settings represent the band width at half amplitude. Fro this figure the power factor may b directly determined

$$pf = \frac{B}{f \times \sqrt{3}} = \frac{B}{f \times 1.732} \qquad (37)$$

The main requirement of the frequency variation method is that th signal generator shall be accuratel calibrated for small changes in frequency. It is desirable to have the scal divisions in fifths of a kilocycle in th broadcast range to permit band widt measurements to tenths of a kilocycle This does not mean that the frequenc calibration of the generator must b within one-fifth kilocycle, but that fo small variations of frequency, the vernier shall read to fifths.

In practice, measurements have bee found to be reproducible to plus o minus 1 per cent. The accuracy of calibration of the vernier is well within per cent.

The vacuum tube voltmeter used i this work is of the conventional plat rectification type, uses any type o tube, and imposes zero load on the tune circuit. The type of tube used is th type with which the circuit is intende to operate, so that the measurement are taken with the circuit normal i every respect. When a screen grid tub having four or more elements is use the control-grid is the input element o the voltmeter, the plate and screen ar connected together and act as the plat The suppressor grid is connected t plate or to cathode.

In measuring the antenna circuit o a complete receiver the signal generator is connected through the dumm antenna to the antenna lead of the receiver, and the grid lead of the firs tube is connected to the grid of th voltmeter tube. The band width meas urement is then made without making any changes in the receiver. For measurement of interstage circuits, the generator is connected to the grid of the amplifier tube, the grid lead to the succeeding tube connected to the voltmeter tube, and the band width measured.

It is not necessary to feed the energy into the circuit through the amplifier tube or the primary circuit. The energy may be fed through a coupling coil connected to the generator and very loosely coupled to the coil under test. The generator frequency may be changed slightly by connecting the coupling coil across its terminals, but this does not introduce any appreciable error into the band width measurement.

The frequency variation method has the advantage that no change is necessary in the circuit to be measured; it is not necessary to open the circuit to insert a resistance, or to add a calibrated vernier condenser in parallel with the circuit. The inductance does not have to be known to determine power factor or band width. Over the resistance variation method it has the advantage that the results do not depend on a resistance standard, which may not be accurate at the frequency of the test. These points become increasingly important at the higher frequencies. The method does call for a special form of signal generator having a calibrated frequency vernier.

Band Pass Circuits

The frequency variation method cannot be applied directly to measure the resistance of tuned circuits in band-pass coupled circuit systems. In this case it is necessary to uncouple the coils before measuring them. Energy may be fed to the first coil of the coupled system through its primary, and to the other coil or coils by loosely coupling them to a coupling coil connected to the generator.

A useful method of measuring band-pass circuits is to measure the band width of the pair of coils at quarter amplitude. If the coils are very loosely coupled this band width will be the same as the average of the band widths of each of the two coils at half amplitude. As the coupling is increased, the band width at quarter amplitude increases in proportion to the increase in coefficient of coupling. The gain of the circuit also increases, reaching within 5 per cent of the maximum attainable when the band width has increased about 50 per cent over the minimum band width.

Measurement of Resistance Units at High Frequency

The frequency or capacity variation method can be used to measure the value of any resistance unit at any frequency by noting the change in power factor when the resistor is connected in series or parallel with a tuned circuit. The choice of series or parallel connection and the value of inductance and capacity should, if possible, be such that the power factor of the circuit with the resistance connected is not over 5 per cent. The error due to the approximation in expression (8) used to determine the simple expression for power factor, multiplies the result by 1.004 at 5 per cent power factor, and increases as the second power of power factor.

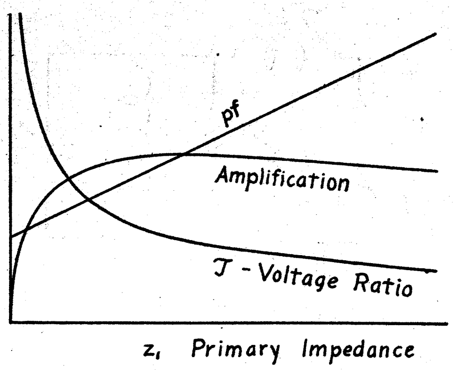

Fig. 4.

When the resistance R is in series

$$R = 2\pi \text{ f L} \times (\text{change in power factor}) \qquad (38)$$

When in parallel

$$R = \frac{2\pi \text{f L}}{(\text{change in power factor})} \qquad (39)$$

The Decibel as a Method of Rating Receivers for Sensitivity

We have found the use of the decibel as a measure of the sensitivity of receivers, of the gain of amplifier stages, and of the sensitivity of detectors, to be a distinct advantage. The system which has been under consideration by the I. R. E. Technical Committee on Radio Receivers expresses voltages in decibels below 1 volt. Sensitivity is then the signal input expressed as decibels below 1 volt, modulated 30 per cent, required to give normal output of 50 milliwatts. The decibel rating has the advantage that the rating of a receiver increases with its sensitivity, and that the number representing the rating does not vary over a great range for variations in sensitivity which perhaps are barely noticeable to the user. The difference in usefulness between a 5 microvolt set and a 1 microvolt set is not such as to justify a difference of 5:1 in their rating. On the decibel rating these sets are rated respectively 106 and 120, which ratings represent better the usefulness of the receivers to the user who is looking for sensitivity.

The fact that the rating increases with sensitivity eliminates the confusion which the microvolt rating caused all except engineers.

Much work is being done on field strength measurement in decibels so that these measurements can be more easily correlated with receiver sensitivity in decibels than with sensitivity in microvolts.

In laboratory work the decibel system is a great convenience. By having the output of the generator and the scale of the vacuum tube voltmeter calibrated in decibels, all need for computations to determine the gain of a stage or the sensitivity of a receiver is eliminated. When the tube of the vacuum tube voltmeter is changed the only change in calibration is to use a calibration figure which is added to the scale reading in decibels. All tubes can be made to follow the decibel scale, which is made square law, by adjusting the grid voltage. Most tubes should be adjusted to a plate current with no a-c. voltage applied, of approximately .5 ma. The exact value should be determined by trial, applying voltages differing by 5 or 6 db. and noting whether the meter reading changes by exactly that amount. This simple calibration eliminates the need of making a new scale or a new calibration curve when the voltmeter tube is changed.

The sensitivity of a projected receiver can be computed very quickly as follows:

Detector sensitivity (defined same as receiver sensitivity)	2 db.
I-F. amplifier gain..........	44
Translator gain	30
R-F. amplifier gain..........	30
Antenna stage gain..........	14
Receiver sensitivity	120 db.

In a well designed receiver, the sensitivity will be found to agree very closely with the computed sensitivity.

The decibel as originally defined is a measure of power gain or loss.

$$\text{Gain or loss in db.} = 20 \log_{10} \frac{E_2}{E_1} \qquad (40)$$

when E_1 and E_2 are measured across equal impedances. As used in radio receiver work, the decibel is a measure of voltage gain or loss, and the impedances are neglected. This is because vacuum tubes in general are voltage rather than power operated devices, and their input resistance very high. This neglect of impedance should be borne in mind when comparisons are made with decibel measurements where impedance is taken into account.

REFERENCE

L. A. Hazeltine, "Discussion on The Shielded Neutrodyne Receiver," Proc. I.R.E., Vol. 14, No. 3, June 1926.

Book Review

RADIO-FREQUENCY MEASUREMENTS, by Hugh A. Brown. Published by McGraw-Hill Book Co., Inc., New York City, 1931. *Price,* $4.00. (386 *pp. Illustrated. Cloth.*)

This recent volume compiled by a professor of electrical engineering of the University of Illinois is a combination laboratory manual and textbook. It is prepared particularly for the engineer and advanced student and is "intended to present both the well-known methods of making certain measurements and some of the important advances recently made in the solution of radio-frequency measurement problems."

The selection of the group of measurements included is worthy of mention. It is rather difficult for a technical writer to prepare a suitable text on this subject without going beyond the normal range of topics and to maintain his work within reasonable proportions. Hence we appreciate the care and thoroughness Professor Brown has employed in the compilation of this volume. Within the recent years a book of this type that would be suitable as a ready-reference for popular measurements of radio-frequency practices has been generally demanded and thus we feel that this particular work fulfills its purpose admirably.

The general composition of the text consists of nearly seventy-five measuring circuits and individual manipulations employed in solving problems of radio-frequency standards. There also appears some measurements that are of audio-frequency or continuous-current nature. The treatment of this subject is unique among works of this type. The first part considers the elucidation of the underlying theory of the material, which is followed by a compendious discussion of the procedure of measurement and finally there is given a general argument of merits and limitations of the method involved.

The measurements appearing are of a varied group and are accompanied by circuit schematics and illustrated with cuts of some of the laboratory setups. Free use is made of engineering mathematics which is to be found throughout the text and employed as a means of exact expression of certain technical idiosyncrasies. Among those considered are measurements of the elements comprising a simple tuned circuit, frequency and wave form, antenna, thermionic-tube, coefficients, electromotive force, current, power, and transmitters, receiver, and piezo electricity. It is also replete with an appendix wherein there appears (among several other subjects) an interesting discussion relative to circuit drivers and piezo-electric quartz crystals.

Not only is this book an ideal laboratory guide for the senior student; for to the advanced reader it will also prove of especial value because of the recent collection of standard information contained herein and interestingly perpetuated in this succinct manner as to render it a service.—*Reviewed by Louis F. B. Carini.*

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Multicoupler Antenna System: This system comprises a well designed antenna with one or more downleads to which as many as thirty radio receivers may be connected by means of specially designed coupling devices, known as multicouplers. The reception of each radio set is excellent, whether one or thirty sets are connected to the common antenna. It may readily be installed either in a finished building or one in course of construction.

Electronic Multimeters: After a year's development and research in our laboratory, we have perfected for the Rawson Electrical Instrument Company, several types of electronic milli-voltmeters and micro-ammeters of unusual design in a manner never before attempted.

Tone Compensating Circuits for the Improvement of Audio-Amplifiers: Special circuit arrangements were developed for adapting tone control to radio receivers or electrical phonograph pickups. Deficiencies in phonograph records or loud speakers can be overcome by means of these special circuits.

Radiotherm Machine for Hospital Use: Apparatus of unique design was developed for the French Hospital, New York City, for the application of radio frequency oscillations to produce fever in the human body.

Photoelectric Amplifiers: A portable unit for measuring ultra-violet light was developed, as well as many ultra-sensitive circuit arrangements for visible light cells.

Triple Twin Circuit Improvements: After many months of special research and development work for the Revelation Patents Holding Company, a number of basic and important circuit arrangements were developed for the commercial application of this tube.