contact of the disc d 1. In this position it is clear that there is a 1 to 1 ratio between the disc d-2 and the wheel w with a resulting kv-a. hour registra-

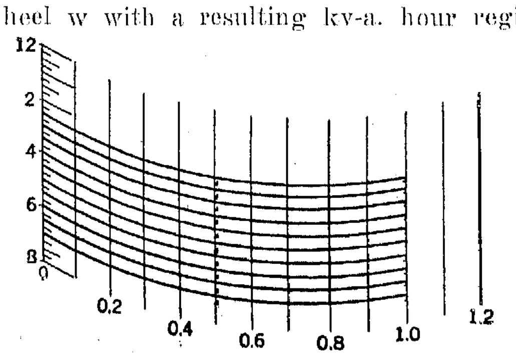


FIG. 12. 50 Per Cent Power Factor Record

tion equivalent to kw. hours. As the power factor becomes less than 100% the reactive meter starts to rotate and referring to Fig. 2 again the rotation

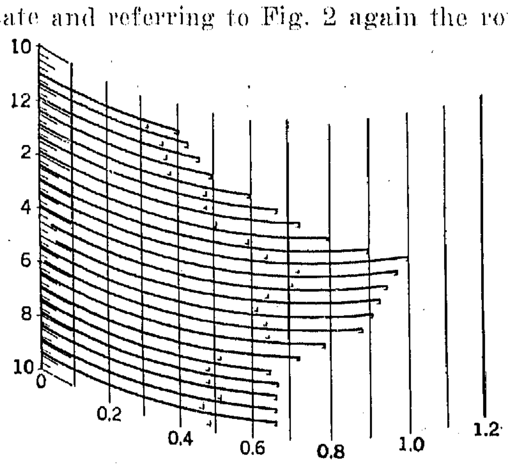


FIG. 13. Constant Power Factor and Variable Load

of a/c is the cosine of the angle which measures the departure of the axis xy from the unity power factor position. In Fig. 4 the mechanism has reached the zero power factor position and the axis xy passes through the contact of the disc d-2, the watthour meter being at rest. In this position we have a 1 to 1 ratio between the reactive meter disc and the wheel w making reactive watthours equivalent to kv.a. hours. With a leading power factor the reactive element reverses and Fig. 5 shows how

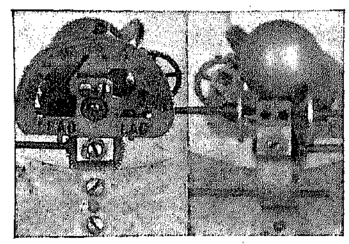

FIG. 14. Front and Rear Views of Ball Mechanism

with a 70.7% leading power factor, the axis of rotation is vertical but the wheel w still gives a correct integration of the vector sum of the motions which go to make up kv-a. hours. This could be carried through the whole circle diagram of leading and lagging power factor and reverse power, but with reverse power the wheel w would have to be driven from the lower part of the ball and this would cause mechanical interference.

There might be some question of whether there would be any slipping in a friction drive of this sort, but measurements show that the power required to operate the pen, and kv-a. counter mechanism is only one-eighth of the power required to slip the wheel w on the ball. By checking the rotation of the wattmeter discs against the record on the chart, it is found that the proper registration is transmitted, which proves that the ball functions correctly.

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# THE STANDARD WAVEMETERS OF THE BUREAU OF STANDARDS*

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The standards of radio frequency of the Bureau of Standards are wavemeters consisting of standard variable air condensers with a number of interchangeable inductors. A description of these wavemeters is given in this paper[1]. In Figs. 1 and 2 are shown two of the types that the Bureau has used. The simpler one shown in Fig. 1 is the type of standard wavemeter that was in use at the Bureau until about four years ago. This wavemeter consisted of a variable air condenser of special design, a fixed inductor, and two copper wires joining the condenser and inductor in series. A hot-wire milliammeter with a single loop of wire connected to its terminals, as shown in Fig. 1, served to indicate resonance. A number of calibrated condensers and several inductors furnished several wavemeters covering a wide range. These condensers and inductors are described in Circular 74 of the Bureau of Standards. After tests were completed with a wavemeter of this type, the condenser, inductor and connectors were put away in a case until needed again. There was always the chance of changing the calibration of the condenser by carrying it from

1 The establishment of the frequency calibration of these standards and the associated questions of their absolute accuracy are outside the scope of the present paper. That subject is covered in "Reducing the Guesswork in Tuning," by J. H. Dellinger, Radio Broadcast, July, 1922, and in a Bureau of Standards Scientific Paper now in preparation.

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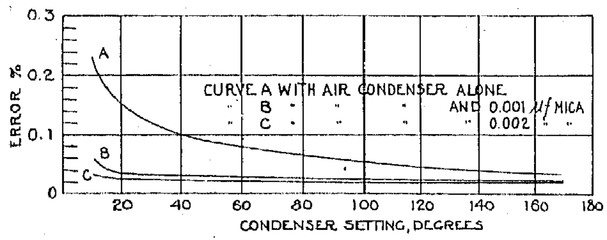
one place to another, and the chance that errors were introduced by using different connecting wires, or that they were bent somewhat, introducing slight errors.

### Improved Mounting

Much of the difficulty mentioned above was overcome by permanently mounting a standard variable air condenser and connecting leads for the coil terminals upon a table equipped with rubber-tired wheels. With careful treatment of the table, the sources of error in handling the condenser and connecting wires were eliminated. The resonance indicator for this wavemeter was a combination of a single turn of wire and a Weston "thermogalvanometer" Model 425, the latter consisting of a thermo-element and a direct-current indicating instrument. The turn of wire was mounted with its plane parallel to the turns on the wavemeter inductor, but was not fixed in position. It could be moved along a line perpendicular to the axis of the wavemeter coil. The indicating instrument and turn of wire were connected to the grounded terminal of the wavemeter. This wavemeter covered a range from 30 to 4600 kilocycles per second (10,000 to 65




meters) using a condenser of about 0.001 microfarad capacity and six fixed inductors.

### Improved Type of Primary Standard

A wavemeter of this type was built having several improvements in its construction, chief among these being the addition of four mica condensers which could be connected in parallel with the variable air condenser to extend the range of the wavemeter, and the addition of a micrometer adjustment for the movable plates of the variable air condenser. This wavemeter has been described in detail in a paper by Mr. R. T. Cox[2]. This wavemeter is one of the primary standards of the Radio Laboratory, covering a range from 3.48 to 4900 kilocycles per second (86,000 to 61 meters) using six inductors and various combinations of condensers. The resonance indicator used for the majority of the work with this wavemeter is a crystal detector, two turns of wire and a sensitive wall galvanometer.

### Second Improved Type of Primary Standard

A second primary standard wavemeter has been built similar to the one mentioned above. It is shown in Fig. 2 and embodies the main features of construction of the other primary standard wavemeter, having a Bureau of Standards type variable air condenser of 0.001 microfarad capacity and four mica condensers of 0.001, 0.002, 0.004, 0.008 microfarad capacity arranged to be connected in parallel with the variable condenser. The mica condensers which are shielded are mounted on a metal support, so that short links may be used in connecting any condenser into the wavemeter circuit.

The connections to the inductor are made of 3 mm. brass rod forming a rectangle 25 by 29 cm. Four rods support the connections to the inductor. The two on the insulated side of the condenser are of Pyrex glass, while those on the grounded side of the condenser are of different materials. The support nearer the condenser is of brass and connection to the ground is made through its lower extremity. The support nearer the inductor is of laminated phenolic insulating material. The box in Fig. 2 encloses one of the inductors similar to that in Fig. 1, which are interchangeable.

The inductors used in this wavemeter are of the type described in Bureau of Standards Circular 74, p. 320. *The three smallest inductors have been enclosed in boxes to prevent the accidental displacement of any of the turns and the resulting change in the calibration of the wavemeter. A fourth inductor was not boxed in since it had a great many turns and the slight displacement of one or two turns would not affect the calibration noticeably. A fifth inductor has three layers, the layers being spaced about one centimeter apart.

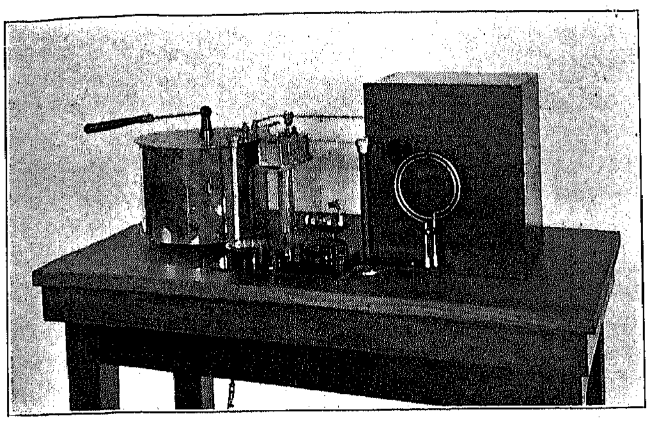
The resonance indicator used in the standard wavemeter consists of two turns of wire mounted in a fixed position beside the inductor which may be connected to either a model 425 Weston thermogalvanometer or to a crystal rectifier and direct-current milliammeter. The latter combination is much more sensitive than the former and permits much looser coupling between the radio-frequency generating set and wavemeter. The instrument shown in the photograph has a full-scale range of 2 milliamperes, but when in use the current is usually kept between 0.4 and 0.8 milliampere. This permits of extremely loose coupling between the generator and the wavemeter. The resonance indicator circuit is not grounded or connected to the wavemeter circuit in any way. A greater deflection may be obtained by grounding the resonance indicator circuit at certain ranges of frequency, but this is noticed particularly with the crystal rectifier and milliammeter which is more sensitive than the other instrument. The increase in deflection is caused by the apparent increase in coupling with the generator resulting from connecting to the ground connection. The increase in deflection is noticed particularly with the smaller inductors,

2 See Journal of the Optical Society of America and Review of Scientific Instruments, Volume VI, No. 2, March, 1922, p. 162, "Standard Radio Wavemeter, Bureau of Standards Type R70B."

*The description of a similar set of seventeen inductors is given in Bureau of Standards Letter Circular 103, "Description of a Series of Single-Layer Inductance Coils Suitable for Radio-Frequency Standards."

where there is likely to be a change in the calibration because of the proximity of the two turns of wire at ground potential to the wavemeter inductor.

This method of resonance indication permits of looser coupling than may be obtained with the indicator directly in the wavemeter circuit, except perhaps for the very high frequencies. When a



crystal detector and a sensitive wall galvanometer are used, the wavemeter may be from ten to twenty feet from the generator, but such a combination is not portable although very accurate results may be obtained in this way. When an indicating device of 4 or 5 ohms resistance is placed in the wavemeter circuit, the equivalent resistance of the circuit is considerably increased and closer coupling is necessary.

Another feature of this wavemeter of some interest is the fact that the table is made with two tops separated by pads of sponge rubber about 1½ inches thick. The upper table top to which the wavemeter circuit is attached is thus prevented from striking the main table top by pieces of sponge rubber between the apron and the main table top. With four-inch rubber-tired wheels the air condenser is kept quite free from jarring and vibrations when moving it about the laboratory. It is quite important that this precaution be taken if the calibration of the wavemeter is to be reliable.

The standard wavemeters are used with a ground wire attached to the shielded side of the air condenser. This reduces the error in noting the resonance point which is likely to be caused by capacity effects between the wavemeter circuit and the body of the operator. When making measurements of frequency the wavemeter is coupled to the radio-frequency generating set as loosely as possible and gives suitable resonance indication. The distance between generating set and wavemeter will vary from a few inches at high frequencies to several feet on lower radio frequencies. The operator always stands on the grounded side of the wavemeter when making measurements and well away from the inductor.

**Data on Coils and Condensers**

The following tables give detailed information on the primary standard wavemeter just described.

**Capacity of Condensers in Microfarads**

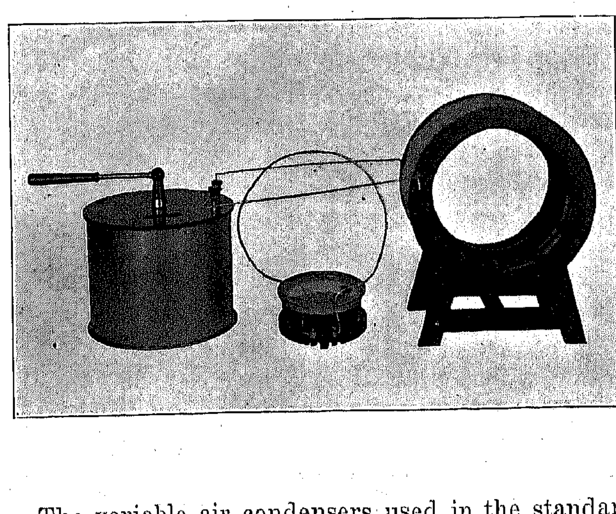
| Variable Air | | Fixed Mica | | | |
|---|---|---|---|---|---|
| 10° | 175° | I | II | III | IV |
| 0.00012 | 0.0012 | 0.001 | 0.002 | 0.004 | 0.008 |

**Ranges of Various Coils and Condensers**

| Coil and Condenser | Frequency, Kilocycles per Sec. | | Wave Length, Meters (Approx.) | |
|---|---|---|---|---|
| Combination | 10° | 175° | 10° | 175° |
| E | 4610 | 1500 | 65 | 200 |
| F | 1650 | 615 | 180 | 490 |
| G | 700 | 233 | 425 | 1285 |
| G & I | 241 | 172 | 1240 | 1740 |
| G & II | 174 | 142 | 1720 | 2110 |
| H | 280 | 93 | 1070 | 3220 |
| H & I | 95 | 68 | 3120 | 4380 |
| H & II | 70 | 57 | 4300 | 5280 |
| L | 73 | 29.5 | 4100 | 10160 |
| L & I | 30.3 | 22.0 | 9900 | 13600 |
| L & II | 22.3 | 18.3 | 13400 | 16400 |

**Constants of Inductors of Primary Standard Wavemeter**

| | Inductor | | | | |
|---|---|---|---|---|---|
| | F | F | G | H | L |
| Diameter, cm........ | 12.5 | 12.5 | 22.8 | 27.9 | 38.0 |
| Length, cm........... | 6.6 | 7.1 | 9.4 | 15.4 | 18.2 |
| Number turns...... | 8 | 22 | 39 | 96 | 320 |
| Spacing, cm......... | 0.8 | 0.3 | 0.2 | 0.2 | 0.1 |
| Size wire (high frequency cable)..... | 48x38 | 48x38 | 48x38 | 48x38 | 32x38 |
| Distributed capacity, $\mu\mu$f ............... | 8 | 11 | 11 | 14 | 90 |
| Pure inductance, $\mu$ henries......... | 9.2 | 56 | 382 | 2439 | 22880 |
| Equivalent resistance, ohms for frequency corresponding to 10° setting of air condenser ........... | 2.4 | 2.2 | 6.2 | 11.3 | —— |
| to 175° setting of air condenser ........ | 0.4 | 0.7 | 2.0 | 5.1 | —— |
| d. c. resistance ohms. | 0.27 | 0.44 | 1.54 | 5.1 | 21.0 |



The variable air condensers used in the standard wavemeters of the Bureau of Standards employ semi-circular plates. The capacity of such a condenser varies in direct proportion with the setting of the dial or, in other words, the capacity calibration curve is a straight line if the extremes of the scale are omitted. Considering the 0.001$\mu$f condensers used in the standard wavemeters the capacity ratio from 10° to 175° is about 1 to 10. By means of the vernier the condenser setting may be read accurately to 0.1° or a capacity variation of about 0.64$\mu\mu$f.

### Precision of Setting

The following values have been computed on the basis that a change in the resonance point of 0.1 degree on the condenser scale can be detected. This is well within actual practice in many cases but may be somewhat better than can be depended upon when mica condensers are added in parallel with the variable air condenser.

**Calculated Percentage Error for Reading Condenser Scale 0.1° from True Resonance Point**

| Condenser setting, Degrees | Air condenser alone | Air with 0.001 $\mu$f mica | Air with 0.002 $\mu$f mica |
|---|---|---|---|
| 10 | 0.24 | 0.06 | 0.03 |
| 20 | 0.15 | 0.03 | 0.02 |
| 30 | 0.12 | | |
| 50 | 0.09 | | |
| 90 | 0.06 | | |
| 130 | 0.04 | | |
| 170 | 0.03 | 0.02 | 0.02 |

Fig. 3 shows the percentage errors in graphical form. From curve A it would appear that with the variable air condenser alone if used below 40° on the scale, errors above 0.1% are likely to be introduced. It should be borne in mind, however, that the tuning and resulting resonance point indication is very sharp in this region so that the error from this source is not likely to be as great as is indicated by the curve. However, if the condenser calibration is changed slightly in the course of use and this part of the scale is used, larger errors may be expected than if the upper part of the scale is used, or a smaller inductor with a fixed condenser. From about 40° to the upper limit of the scale the precision increases from a possible error of 0.1% to about 0.03%.

Curve B is for the case of adding a 0.001$\mu$f mica condenser in parallel. The error decreases from about 0.03% to 0.01%. If further condensers are added the error is decreased very much theoretically and practically it becomes difficult to determine the resonance point on account of the broad tuning.

Measurements may readily be made with a 0.001 $\mu$f fixed condenser in parallel with the various inductors, and somewhat less easily with a 0.002 $\mu$f condenser in parallel.

From the above it seems desirable to make use of the variable air condenser alone only above 40° on the scale. An examination of the possibilities of fulfilling this requirement, except perhaps on the highest frequencies at present, shows the following:

Coil E with 0.001 $\mu$f overlaps coil F alone at 40°.
Coil F with 0.002 $\mu$f overlaps coil G alone at 40°.
Coil G with 0.001 $\mu$f overlaps coil H alone at 40°.
Coil H with 0.003 $\mu$f overlaps three-layer coil readily.

The data on the above coils apply particularly to the primary standard wavemeter which is given the laboratory designation A, but are also applicable to primary standard B except that in it there is another coil after coil H, and the three-layer coil is omitted. The largest coil of 125 millihenries inductance would not have this overlap unless much more capacity were added to the previous combination. Another three-layer coil would furnish a desirable addition to the primary standards and would overlap with a 0.001 $\mu$f condenser well up on the large coil. The larger mica condensers of 0.004 $\mu$f and 0.008 $\mu$f may be used to extend the range of the wavemeter.

The statement was made above that from about 40° to the upper limit of the condenser scale the possible error ranges from 0.1% to 0.03% and if we take 0.1% as the largest permissible error, then the variable air condenser should not be used below 40° on the scale. In the case of the 0.001 $\mu$f condensers used in the standard wavemeters, the capacity at 40° is in the neighborhood of 300 $\mu\mu$f. The capacity ratio from 40° to 175° then is approximately 1 to 4. If no fixed capacity is to be used with the variable air condenser, there seems to be no advantage in a condenser of 1 to 10 ratio or rather in having a low capacity value for the lower settings. It is a decided disadvantage and should be avoided on account of the magnitude of the possible errors in its use. However, if fixed condensers are to be used paralleling the variable condenser, the 1 to 10 ratio is advisable since it gives much better overlaps than would otherwise be the case.

### Summary

The primary standard of radio frequency of the Bureau of Standards consists of two standard wavemeters which cover the frequencies in general use, viz., from about 18 to 4600 kilocycles per second (16,650 to 65 meters). These wavemeters are quite similar in general construction, each consisting of a variable air condenser, four fixed condensers, a number of interchangeable inductors, and a resonance indicating device, all mounted in a fixed position upon a specially constructed movable table.

The variable air condenser is about 0.001 $\mu$f maximum capacity and is a Bureau of Standards type of condenser, having its movable plates connected to a metal shield which is connected to ground when in use. Four shielded mica condensers are also provided having capacities of 0.001, 0.002, 0.004, and 0.008 $\mu$f.

Five inductors are provided for primary standard wavemeter A. Four of the five inductors are of the single-layer spaced winding type, employing skeleton frames of laminated phenolic insulating material wound with high-frequency cable and forming coils of polygonal cross-section. The inductors are provided with terminals so that they are interchangeable. The three smallest coils are boxed in to prevent changes in the inductor constants from the displacement of a portion of the winding by handling.

(Continued on page 134)

sonal Department of the Goodyear Tire and Rubber Company, Akron, Ohio.

**Howard C. Whiston,** M.E. '18, is still with the Carnegie Steel Co., Steubenville, Ohio. His address is 326 Reserve Avenue.

**Norman E. Elsas,** M.E. '18, has a position with the Fulton Bag and Cotton Mills at Atlanta, Ga. He lives at 64 Fairview Road.

**Paul L. Garver,** M.E. '18, is with the Transportation Division of the Westinghouse Electric and Manufacturing Co., 30th and Walnut Streets, Philadelphia, Pa.

**Ford H. McBerty,** M.E. '19, is employed by the De Laval Separator Co., at Poughkeepsie, N. Y.

**James R. Carson,** M.E. '20, is associated with Dwight P. Robinson and Company of 125 E. 46th St., New York City.

**Andrew M. White,** M.E. '21, has left the Hudson Motor Car Company in Detroit and is now in Baltimore, Md. His address is The Homewood Apartments.

**R. McConnell Matson,** E.E. '21, is residing at 143 Furman Street, Schenectady, N. Y., where he is employed by the General Electric Company.

**Walter R. Prosch,** M.E. '22, has a position with the Pratt and Whitney Co. in Philadelphia as a sales engineer. He is living at 213 South 45th St.

**Carl V. Linn,** M.E. '22, has recently become engaged to Miss Evelyn Huber of Bayshore, Long Island.

**William F. Mahon,** M.E. '22, is learning the coal business with the Delmar Coal Co., at Fairmount, West Va., where his address is 506 Fourth Street.

**Hiram K. Ormsby,** M.E. '22, has a position as sales engineer with the Armstrong Cork and Insulation Company in West Virginia. He can be reached at 1015 Broadway, Cincinnati, Ohio.

**Irving G. McChesney,** M.E. '23, is employed by the Rochester Gas and Electric Corporation as a test engineer. He writes that he would be glad to hear from "any of the old bunch interested in power plant work."

**Walter B. Hough,** M.E. '23, is associated with the Forest Products Engineering Company and is temporarily located at South Ashburnham, Mass. His address is Box 120.

**Gerald De W. Mallory,** M.E. '23, is employed by the Goodyear Tire and Rubber Company at Akron, Ohio.

**Graham D. Horne,** E.E. '23, is in the testing department of the General Electric Company, at Schenectady, N. Y.

**Alfred H. Marsh, Jr.,** M.E. '23, has left Washington, D. C., and is now in Pittsburgh. His address is 5469 Bartlett St.

## THE STANDARD WAVEMETERS OF THE BUREAU OF STANDARDS

(Continued from page 126)

The resonance indicator consists of two turns of heavy wire fixed in position near the wavemeter inductor and two indicating instruments. A thermogalvanometer is used for coarse adjustments and a crystal detector and d. c. milliammeter for finer adjustment. The latter instrument permits of much more accurate indication of the resonance point than the former.

The condenser scale may be read correctly to 0.1° throughout its range. The precision of setting the wavemeter to a given frequency is dependent on the sharpness of the resonance point as denoted by the resonance indicating instrument, which in turn will vary with the amount of capacity in the wavemeter circuit. For capacity values such as are in general use at this time the precision varies from 0.2% for low condenser settings to about 0.02% with fixed condensers of about 0.002 microfared capacity. In the majority of work with the wavemeter these values will vary between 0.1% and 0.03%. A more sensitive resonance indicator is essential for work at higher precision. The precision of measurement may be increased by using more sensitive resonance indicators.

## A NOTE ON CRITICAL FREQUENCIES OF A SERIES ELECTRIC CIRCUIT

(Continued from page 127)

the capacity reactance. The maximum storage of energy in the capacitance occurs at a frequency considerably lower, as shown by eq. (12). For free oscillations the energy storage in the inductance and capacitance is the same, except for the damping effect of the resistance, as the total energy in the circuit is stored, first in one and then in the other. It is, therefore, logical to expect the natural frequency of the circuit to fall somewhere between these two frequencies, which it does.

Even though the amplitude of the current decreases as the frequency is increased above the point for which $\omega L = 1/\omega C$, the decrease in current at first is smaller than the corresponding increase in $\omega L$ so that the maximum voltage across the inductance is not reached until the frequency has been increased considerably (in this case 52%) above that which gives maximum current in the circuit.

For oscillograph records of transient and permanent conditions in similar circuits, the reader is referred to the book on "Electric Transients" by Magnusson, Kalin, and Tolmie. A mathematical treatment may be found in books such as "Transient Electric Phenomena and Oscillations" by Steinmetz; "Electric Oscillations and Waves" by G. W. Pierce; "Alternating Currents" by Alexander Russell and "Calculation of Alternating Current Problems" by Louis Cohen.