

## On the Measurement of Wave Length for High Frequency Electrical Oscillations

This content has been downloaded from IOPscience. Please scroll down to see the full text.

1907 Proc. Phys. Soc. London 21 902

(<http://iopscience.iop.org/1478-7814/21/1/362>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 134.121.47.100

This content was downloaded on 02/10/2015 at 03:48

Please note that [terms and conditions apply](#).

LXII. *On the Measurement of Wave Length for High Frequency Electrical Oscillations.* By ALBERT CAMPBELL, B.A.\*

(From the National Physical Laboratory.)

[Plate XXXIII.]

§ 1. *Introduction.*

IN all work with high frequency electrical oscillations, such as for example in wave telegraphy, it is of the utmost importance to be able to determine with accuracy the wave-length actually employed, and for this purpose several types of wavemeter are now in common use. In order to ensure accuracy in such measurements, it was suggested some time ago by the Post Office Authorities that arrangements should be made for the calibration of wavemeters at the National Physical Laboratory. As the results of our first series of investigations in the matter appeared to be of general interest, we publish them here by the kind permission of Major O'Meara, C.M.G., Engineer-in-Chief to the Post Office. Our experiments comprised the construction and testing of a standard wavemeter, and the verification of an ordinary commercial wavemeter sent to us by the Post Office. I shall designate this instrument (A) and our standard wavemeter (B) respectively. While it is unnecessary here to go into the history of the subject, I should like to give one or two references to earlier work by other observers which gave us much assistance, namely the experiments of Pierce † and those of Gehrecke‡.

While our work was in progress an important paper by Diesselhorst § appeared, and the results there published were in ample confirmation of those we were obtaining, as also were the earlier results of Pierce.

\* Read June 25, 1909.

† Phys. Review, vol. xxiv. p. 152, 1907.

‡ *Elektrotech. Zeitschr.* (26), p. 697, 1905

§ *Jahrbuch der drahtlosen Telegr. u. Teleph.* vol. i. (1908).

### § 2. *Description of Wavemeter (A).*

Wavemeter (A) is of the Dönitz type and consists of a variable air condenser, with a range from about 100 to 1070 mmfd. (micromicrofarads), a thermo-junction and galvanometer, and a series of coils (A 1, A 2, . . . . to A 10) of self inductances ranging from 0.76 to 2313 microhenries. The combination is capable of measuring oscillation frequencies over a range extending from about 20,000,000 down to 100,000  $\sim$  per sec., or wave-lengths from  $\lambda = 15$  metres up to  $\lambda = 3000$  metres. It must be kept in mind, however, that the accuracy obtainable depends on the part of the condenser scale at which the reading is taken. For example, at a reading of 20 the frequency can barely be read to 0.5 per cent.

As the coils (A 1, A 2, . . . . .) of (A) are of solid (not stranded) wire of diameters from 0.32 up to 3.2 mm., the values of their self inductances at the high frequencies are, for most of the coils, considerably lower than those obtained at ordinary frequencies of 0 to 1000  $\sim$  per sec.

With a view to checking the results of the direct experiments by calculation from the measured inductance and capacity of a wavemeter in which the inductances would be much less affected by frequency, and thus to obtain a standard instrument for future use, we constructed a wavemeter (B) in which the coils are all of highly stranded wire.

### § 3. *Description of Standard Wavemeter (B).*

The general arrangement of (B) was similar to that of (A). The variable condenser (from 100 to 900 mmfd.) was of special design, with amberite washers to give very high insulation. It was kindly presented to the Laboratory by Dr. Alexander Muirhead, F.R.S. We added to it a direct reading scale, which can be read to 1 in 2000 at the upper end and to 1 in 200 at the lower. The scale was constructed by a very careful series of tests by Maxwell's Commutator Method and was found to be very uniform.

For the inductances, three coils (Q b, Q 1, and Q 2) were used. They were all wound on ebonite tubes with stranded wire (7/36<sup>a</sup>), *i. e.* containing seven insulated strands, each of

diameter 0.19 mm. In each coil the terminals were brought to a considerable distance (18.5 cm.) from the centre of the coil by fixed leads run parallel to one another 1 cm. apart. In this way too close proximity between the coil and the condenser plates was avoided. A Duddell thermo-ammeter of 1.5 ohms resistance was used to complete the circuit of the coil and the condenser, and by observing its maximum deflexion the point of resonance was obtained. The sensitivity of course varies with the coil used and with the nature of the oscillatory circuit ; it was found to be sufficient for the purpose in the experiments described below. Fig. 1 (Pl. XXXIII.) shows a photograph of the wavemeter and of one of the coils separately.

#### § 4. *Measurement of the Self Inductances of the Coils.*

The self inductances of all the coils were measured at ordinary frequencies (0 to 1000  $\sim$  per sec.) by a method specially designed for the accurate measurement of such low values (A. Campbell, Phil. Mag. Jan. 1908). The comparisons were made against a standard variable mutual inductance with ranges of 0 to 200 and 0 to 2000 microhenries, the lower range being readable to 0.01 microhenry. The absolute value of this was measured in terms of the new Laboratory Standard of mutual inductance, whose value has been calculated to a very high degree of accuracy (see Proc. Roy. Soc. A. vol. 79, 1907). The subdivision of the scale of the variable mutual inductance was effected by the help of Maxwell's method of comparing two mutual inductances, Its accuracy was verified by an independent method as follows. A mutual inductance coil was constructed with the primary and secondary circuits both of well stranded wire (10 and 20 strands respectively), and, with all the strands in each circuit in series, the value was adjusted to be equal to the 10 microhenry reading on the scale. Then, by taking  $p$  strands of the primary and  $q$  strands of the secondary, the value would be  $\frac{pq}{200} \times 10$ , and thus inductances of  $\frac{1}{200}$ ,  $\frac{2}{200}$ ,  $\frac{3}{200}$ , ... of the full scale reading were obtained. On testing these against the actual scale, the subdivision was found to be perfectly satisfactory.

The details of winding and values of the self inductances of the coils of Wavemeter (B) are given in Table I. In actual working these values had to be increased by the

TABLE I.

Coil.	Coil Diameter. cm.	Axial Length. cm.	Turns.	Self Inductance. Microhenries.
QB.....	13.5	3.6	40	360.3
Q1 .....	7.4	3.9	48	170.7
Q2 .....	7.6	1.7	23	57.8 <sub>2</sub>

addition of the measured self inductance of the rest of the circuit, consisting of the leads, ammeter, and condenser; the total addition was about 0.5 microhenry, of which 0.1 microhenry was due to the condenser.

#### § 5. Tests of Standard Wavemeter (B) by Photographing Sparks.

In order to obtain an absolute calibration of the standard wavemeter, the frequencies of the oscillations with which it was tested were determined by including a spark gap in the main oscillation circuit to which the wavemeter was loosely coupled and photographing the spark trains by help of a rotating mirror.

The apparatus was arranged as follows:—

The source of current was a small alternator whose frequency could be varied from 50 to 200 ~ per second; this was connected through a small high voltage transformer to a spark gap with cadmium electrodes shunted by a glass plate condenser and a bare wire inductance in oil. A large variable air condenser consisting of six aluminium disks, each 100 cms. in diameter, could be put in parallel with the glass plate condenser, and, by suitable variation of the capacity and inductance in circuit, oscillations of frequencies from 300,000 to 1,200,000 ~ per sec. could be obtained. A

special camera (fig. 2) was constructed and mounted for rigidity on a long slab of sandstone. At one end of the camera was the rotating mirror, which was concave and of 200 cms. radius of curvature. It turned on a vertical axis and was driven by a small motor, the speed being kept constant by an arrangement described below. The other end of the camera had two branches which carried respectively the spark electrodes and a pair of guides allowing the plate carrier to be smoothly raised or lowered while the rotating mirror threw the images of the spark trains as streaks upon the plate. The distance from the mirror to the plate was 200 cms. The speed of rotation of the mirror was kept constant (usually at about 60 revs. per second) as follows. On the axis was mounted a commutator and this was connected with a condenser, a bridge, battery, and galvanometer, for Maxwell's Commutator method of measuring capacity. By applying a slight variable brake to the rotating axis, the galvanometer light-spot could be kept at zero. When this was the case the speed was steady, and could be measured with a counter or deduced from the value of the condenser and the resistance in the bridge. From measurements of a number of the spark train photographs on each plate, the average displacement from spark to spark was found; and the frequency was calculated from this displacement, the distance from the mirror to the plate, and the speed of rotation of the mirror.

While each photograph was being taken the reading of the standard wavemeter was also observed, care being taken to keep the coupling to the spark circuit very loose.

The value ( $n$ ) of the frequency obtained from the spark photographs was in each case compared with the values ( $n_1$ ) calculated from the measured values  $K$  and  $L$  of the capacity and inductance in the wavemeter circuit. Since the wave-meter coils have a certain amount of distributed capacity, it was necessary to take account of this. The required correction was made by Glazebrook and Lodge's formula (Cambridge Phil. Trans. p. 171, vol. xviii. 1899),

$$p^2 L K \div 1 - \frac{N-2}{N^2} \cdot \frac{k}{K},$$

where  $p=2\pi n$ ,  $N$ =number of turns in coil,  $k$ =capacity from turn to turn, and the capacities and inductances are in absolute measure. The value of  $k$  was found by testing the capacities of coils with bifilar windings of wire similar to that in the coils used. The correction is small, being in no case more than 1 part in 1000. The results are given in Table II.

TABLE II.

Plates Nos.	$n$ By Sparks ~ per sec.	$n_1$ From K & L of Standard Wavemeter. ~ per sec.
61 & 62	290,300	290,500
47	516,800	516,800
57 & 58	818,300	821,200
55	1,042,000	1,039,000

We may remark that the small differences between  $n$  and  $n_1$  are quite within the limits of probable experimental error. On the same plate the value of  $n$  deduced from the various spark trains sometimes showed an extreme variation of 1.2 per cent. from the mean; in the best experiments the variation was about 0.5 per cent. from the mean. In general the mean of 5 to 10 spark trains was used and the average variation from the mean was from 0.2 to 0.6 per cent. in the value of  $n$ .

#### § 6. *Comparison of Wavemeter (A) with Standard (B).*

The condenser of (A) was tested throughout its range by Maxwell's Commutator Method and gave the results shown in Table III. which shows the scale readings to be very nearly proportional to the capacity. At the higher readings the accuracy of measurement of  $K$  is here of the order of 2 or 3 parts in 1000.

TABLE III.

Reading. Degrees.	K mmfd.	K/Reading.
20	126	6.1
40	245	6.0 <sub>6</sub>
60	367	6.1 <sub>2</sub>
80	486	6.0 <sub>3</sub>
100	607	6.0 <sub>7</sub>
120	724	6.0 <sub>8</sub>
140	851	6.0 <sub>3</sub>
160	966	6.0 <sub>4</sub>
180	1075	5.9 <sub>3</sub>

The coils (A4, A5, ..... to A9) were tested for self inductance ( $L_0$ ) at ordinary frequencies. In Table IV. are given the values found (including the working circuit in each case). Approximate dimensions of the winding are also

TABLE IV.

Coil.	2a Coil Diameter. cm.	l Axial Length. cm.	d Wire Diameter. cm.	N. Turns.	Self inductance, microhenries.	
					$L_0$ .	$L_\infty$ .
A4 .....	5.2	10.7	0.32	32	21.6 <sub>2</sub>	19.5 <sub>3</sub>
A5 .....	8.0	11.3	0.32	33	44.9 <sub>8</sub>	42.0
A6 .....	5.1	5.6	0.09 <sub>1</sub>	55	100.5	97.5
A7 .....	5.1	9.6	0.09 <sub>1</sub>	95	195.0	189.8
A8 .....	7.6	5.3	0.05 <sub>6</sub>	90	531.8	524
A9 .....	7.6	8.9	0.05 <sub>6</sub>	150	1039	1025

given. In the last column are given the values of  $L_\infty$  (*i. e.* the value of the self inductance for infinite frequency, assuming that the current in that case is practically confined to the skin of the wire). These values have been calculated

by the approximate formula (due to Heaviside):\*

$$L_0 - L_\infty = \frac{26N^2ad}{1000l} \text{ in microhenries,}$$

where  $N$  = number of turns,

$a$  = radius of coil,

$l$  = axial length of coil,

$d$  = diameter of wire,

all the dimensions being in centimetres.

The application of the formula to such short coils is not quite appropriate, however, as it has been deduced on the assumption that the solenoid is long.

The two wavemeters were then loosely coupled to the same oscillation circuit and simultaneous readings taken at various frequencies. From the calibration of (B) already established and the results in Table III. the effective values of the self inductances of the coils of (A) were deduced; they are given in Table V.

TABLE V.

Coil.	Comparison Frequency ~ per sec.	Effective L (deduced). Microhenries.	L. (Mean).
A4 .....	1,125,000 1,338,000	20.1 19.8	19.9
A5 .....	837,400 975,500	42.6 42.5	42.5 <sub>5</sub>
A6 .....	665,100	99.1	99.1
A7 .....	366,700 394,800 466,800 473,400 665,100	190.5 190.5 191.1 192.0 191.8	191.2
A8 .....	284,500 290,300 322,800	530 530 532.5	53 <sub>1</sub>
A9 .....	290,300	104 <sub>3</sub>	104 <sub>3</sub>

\* Collected Papers, vol. i., p. 356.

From Table VI. it will be seen that the observed effective values of  $L$  (to be used in working the instrument) lie between  $L_0$  and  $L_\infty$  in all cases but the last. The discrepancy here may be due to an error of 0.5 per cent. in determining  $n$  which might occur in consequence of the reduced sensitivity when using a coil of such high resistance as A 9.

The column headed  $L_n$  gives the values of  $L$  calculated from  $L_\infty$  for the actual values of  $n$  by means of Cohen's formula\*. It will be noticed that this brings the observed and the calculated values of the inductances (at the high frequencies) considerably closer.

TABLE VI.

Coil.	Effective $L$ .	$L_n$ .	$L_0$ .	$L_\infty$ .
A4 .....	19.9	19.6	21.6 <sub>2</sub>	19.5 <sub>3</sub>
A5 .....	42.5 <sub>3</sub>	42.1	44.9 <sub>3</sub>	42.0
A6 .....	99.1	98.1	100.5	97.5
A7 .....	191.2	190.8	195.0	189.8
A8 .....	531	526	531.8	524
A9 .....	104 <sub>3</sub>	1029	1039	1025

### § 7. Conclusion.

Thus it appears that within the limits of wave-length used, the wavemeter with coils of well stranded wire gave results in close agreement with theory, while in the case of the instrument with coils of solid wire the agreement was as close as could be expected, as the correcting formulas are only strictly applicable to long solenoids.

In conclusion I would express my best thanks for kind assistance to Major O'Meara and his staff; to Prof. R. Ll. Jones, Messrs. H. C. Booth and T. L. Eckersley, who skilfully aided in the experiments; and to Dr. Glazebrook for valued help and advice throughout the work.

\* Bulletin, Bureau of Standards, vol. iv., no. 1, p. 177 (1907).

## DISCUSSION.

Mr. W. DUDELL said the paper was a valuable one because accurate experiments on self-induction and capacity at high frequencies were required. With reference to the photographs he asked if the Author had used his method to photograph arcs and, if so, with what results. It would be interesting to know how low it is possible to get the apparent resistance of a coil with high frequency currents by stranding the wire.

Dr. ERSKINE-MURRAY, referring to Mr. Duddell's remarks, said that in actual practice the resistance could not be reduced more than about 10 per cent. by stranding.

Mr. TAYLOR congratulated the Author, and pointed out that the wavemeters described could only be used at the transmitting station. Wavemeters were required which could be used at receiving stations. Referring to the question of stranding he pointed out that it was possible to overdo the stranding and obtain less satisfactory results than could be obtained by stranding with a fewer number of wires.

Mr. G. B. DYKE called attention to experiments similar to those described which were being carried out by Dr. Fleming at University College. With reference to the spark photographs he was surprised that an accuracy of 1 in 1000 could be obtained.

The AUTHOR in reply stated that as the whole distributed capacity of the inductance coils had very little effect on the frequency of resonance, the dielectric hysteresis of the ebonite would be negligible except as regards damping. Sparks appeared to give sharper and more accurately measurable photographs than vacuum tube discharges or arcs, except mercury arcs, which gave the clearest and best pictures.

---

LXIII. *An Electromagnetic Method of Studying the Theory of and Solving Algebraical Equations of any Degree.* By ALEXANDER RUSSELL, M.A., D.Sc., and J. N. ALTY, A.I.E.E., *Faraday House, London* \*.

## CONTENTS.

1. Introduction.
2. The Electromagnetic Method.
3. Quadratic Equations.
4. The Equation to Curves passing through the Neutral Points.
5. Cubic Equations.
6. Finding the Roots of an Equation.
7. Description of Apparatus.

1. *Introduction.*

THE electrical device recently invented by Mr. Arthur Wright enables us to find approximate values of the real

\* Read June 25, 1909.



FIG. 1.

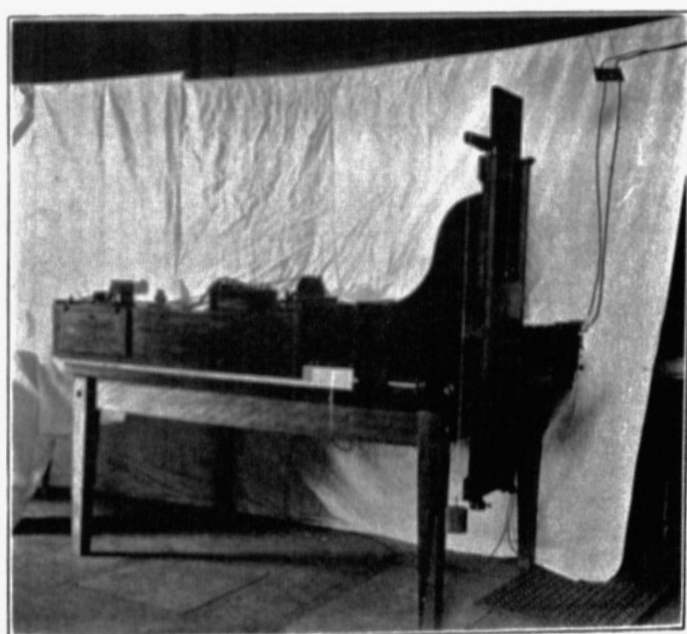


FIG. 2.