AERIAL TESTING.

By J. K. Catterson-Smith.

SYNOPSIS.

An extension of a method of testing due to W. H. Eccles is described. Graphical representation of aerial tuning characteristics is used to show the linear relation between tuning inductance and the reciprocal of the tuning capacity.

The use of a high frequency bridge method of determining the tuning characteristics and aerial resistance is described.

METHOD.

Among the more important tests on aerials are those for determining the tuning characteristics which depend upon the static inductance L_o and the electrostatic capacity C_o of the elevated and earth system.

It has been pointed out by W. H. Eccles (*Handbook of Wireless Telegraphy and Telephony*, 2nd edition, 1918, 121) that these quantities may be measured with accuracy by finding the tuning inductance L_T necessary to raise the wavelength of the aerial to 1·84 times that at its natural fundamental frequency.

The relation between the added inductance and the aerial constants is :—

$$L_T = L_o \frac{\cot\theta}{\theta}, \quad \text{where } \theta = \frac{\pi}{2} \cdot \frac{\lambda_{nat}}{\lambda} \qquad (1)$$

Thus Eccles' method is to test at the wavelength making $\cot\theta/\theta = 1 \cdot 0$, which occurs when $\theta = 0 \cdot 855$ radian, consequently the required test wavelength is :—

$$\lambda = \frac{\pi}{2} \cdot \frac{\lambda_{nat}}{0 \cdot 855} = 1 \cdot 84\, \lambda_{nat.}$$

In the same way, as Eccles points out, the electrostatic capacity C_o may be measured by finding the series tuning capacity C_T necessary to lower the wavelength of the aerial to 0·774 times that at its natural fundamental frequency.

The relations in this case are :—

$$C_T = C_o \frac{\tan\theta}{\theta} \qquad (2)$$

and the test is carried out at the wavelength making $\tan\theta/\theta = 1{\cdot}0$, which occurs when $\theta = 2{\cdot}03$ radians.

These methods are useful, and it is worth while considering their extension with a view to increasing the reliability of the observations on a given aerial. It will be recognised that the above method of obtaining C_o is open to the objection that the measurement must be conducted at a frequency about 30 per cent. above the natural fundamental frequency of the unloaded aerial, and this increases the chance of error.

The form of test found most satisfactory is a combination of the above two tests at a number of wavelengths. The quantities L_T and C_T found necessary for a given wavelength are plotted to a vertical scale of L with $\frac{1}{C}$ as abscissa.

A series of converging graphs is obtained and they intersect at a point which gives the effective values of the aerial inductance and capacity at the fundamental wavelength.

The theory of stationary waves on wires, which fortunately appears to apply accurately to most aerials, shows that in the case of an aerial connected at its base to both tuning inductance and series capacity the oscillatory conditions are governed by the relation :—

$$\frac{L_T}{L_o}.\theta - \frac{C_o}{C_T}.\frac{1}{\theta} = \cot\theta \qquad (3)*$$

Thus the relation between L_T and $\frac{1}{C_T}$ is linear and this is confirmed by experiments.

The slope of the graph connecting L_T with $\frac{1}{C_T}$ is :—

$$\alpha = \tan^{-1}\frac{C_o L_o}{\theta^2} \text{ or } \left(\frac{\lambda}{2\pi u}\right)^2.$$

These graphs, of slope $\tan\alpha$, may be analysed and used for the determination of L_o and C_o, etc., as shown in Fig. 1 and in the examples quoted below.

* A graphical presentation of Equation (3), which has been found helpful, is given in Fig. 11, Appendix.

RELATION BETWEEN STATIC AND EFFECTIVE QUANTITIES.

The effective values of aerial inductance and capacity, at fundamental wavelength, L_e and C_e are given by the point of intersection of the tuning graphs.

The relation of L_e and C_e to L_o and C_o is as follows :—

(*a*) If an aerial of effective capacity C_e is loaded with $L_T = L_e$ the resulting wavelength will be $\sqrt{2}.\lambda_{\text{nat.}}$ Consequently $\theta = \frac{\pi}{2\sqrt{2}}$ and $\cot\theta = \frac{1}{2}$ or $L_e = \frac{\sqrt{2}}{\pi}.L_o$.

(*b*) If an aerial of effective inductance L_e has connected in series with it a condenser of capacity $C_T = C_e$ the resulting (shorter) wavelength will be $\frac{1}{\sqrt{2}}.\lambda_{\text{nat.}}$ Consequently $\theta = \frac{\pi}{\sqrt{2}}$ and $\tan\theta = 2$ or $C_e = \frac{2\sqrt{2}}{\pi}.C_o$.

Thus if the static quantities are known, the tuning graphs may be plotted for any values of L_T or C_T.

The tuning characteristic graphs, if plotted from tests, give either L_o and C_o from the intercepts or L_e and C_e from their point of intersection O′, see FIG. 1.

TEST ON AERIAL NO. 1.

Observations made on a small aerial and counterpoise, at the Indian Institute of Science, are given in Figs. 2 and 3 from which the data in Tables I and II are taken. The average value of L_o obtained

TABLE I.

Wavelength observed metres	L_T μH	$\frac{\lambda_{\text{nat}}}{\lambda_1}$	θ radians $\frac{\pi}{2}\frac{\lambda_{\text{nat}}}{\lambda_1}$	$\frac{\cot\theta}{\theta}$	$L_o = L_T \div \frac{\cot\theta}{\theta}$ μH
2,000	1350	0·202	0·317	9·65	140
1,500	710	0·27	0 424	5·23	136
1,000	300	0·405	0·636	2 12	141
745	140	0·543	0·855	1 00	140
600	68	0·675	1·06	0·527	129
405	0	1·0	1·57	Average $L_o = 137$.	

over a range of 405 to 2000 metres wavelength is 137 microhenries and this compares well with the value of L_e given by the intersection of the graphs at 62 microhenries from which $L_o = \frac{\pi}{\sqrt{2}} \times 62 = 138$ microhenries.

In Table II the average value of C_o for wavelengths below the natural fundamental is found to be 0·00082 microfarads and this again

TABLE II.

Wavelength observed metres	C_T mfds.	$\frac{\lambda \text{ nat}}{\lambda_1}$	θ radians $\frac{\pi}{2} \frac{\lambda \text{ nat}}{\lambda_1}$	$\frac{\tan\theta}{\theta}$	$C_o = C_T \div \frac{\tan\theta}{\theta}$ mfds.
314	0·00083	1·29	2·02	1·00	0·00083
257	0·00027	1·58	2·46	0·333	0·00081
				Average C_o = 0·00082.	

compares well with the value of C_e which Fig. 2 shows to be 0·00074 microfarads and from which $C_o = \frac{\pi}{2\sqrt{2}} \times 0{\cdot}00074 = 0{\cdot}000825$ microfarads.

These tests show that various influences result in a departure from the linear relationships at the lower wavelengths. This may be due to the higher frequencies extending beyond the range for which the testing apparatus was intended.

The straight line graphs, Figs. 2 and 3, afford a striking confirmation of the validity of the stationary wave theory applied to ordinary aerial systems and show that for a loaded aerial the wavelength (metres) is given by :—

$$\lambda = 59{\cdot}6 \sqrt{L.C} \qquad (4)$$

where $L = L_T + L_e$ in microhenries,
and $1/C = 1/C_T + 1/C_e$ in milli-microfarads.

It may be remarked that the graphical determination of L_o and C_o or L_e and C_e avoids the possibility of such errors as may arise in single determinations of these constants.

Measuring Apparatus Employed.

The tuning characteristics may be plotted from observations made by means of various arrangements of testing apparatus. It is, however, advisable to adopt one which at the same time will give the aerial resistance.

In the experiments described a bridge-method of the type shown in Fig. 4 was used, and it will be seen that a known resistance was balanced, with ratio arms, against that of the tuned aerial system; the bridge-circuits being supplied with current the frequency of which was observed by means of a standard wavemeter.

A preliminary experiment was carried out with this bridge on a circuit made up to represent, approximately, an aerial with tuning reactances. The circuit under test consisted of a fixed mica condenser of 0·00104 microfarads capacity and a stranded-conductor inductance coil of 126 microhenries with tuning inductance and capacity in series.

Tests were carried out at 1000, 710 and 400 metres wavelength with the results plotted in Fig. 5. It will be seen that there is close agreement between the point of intersection O′ and the values of the concentrated inductance and capacity connected as indicated in Fig. 5.

The actual connections for the high frequency bridge used are shown in Fig. 6 and a few details of the apparatus are given below.

When used for testing aerials the following arrangement is used:—

(i) *30-Watt High Frequency Valve Generator.*—This is an ordinary tuned anode oscillator having two Marconi-Osram type T-15 valves. Tapping points in the anode inductance coils and adjustable condensers give approximately 250 to 20,000-metres wavelength range. The high frequency generator is coupled to the bridge and circuits under test as shown and the usual load dealt with by the set is of the order of ten ohms non-inductive resistance across the coupling. The valves require 200-volts anode and 6-volts filament accumulator batteries.

(ii) *High Frequency Bridge.*—This consists of screened bridge and ratio arms, and an indicating galvanometer. The latter is a sensitive unipivot pointer instrument connected across the bridge by a delicate vacuum thermo-junction.

The aerial and earth or counterpoise are connected to the bridge as shown, and in series are such adjusting reactances as are necessary, i.e., L_T and C_T are standard laboratory tuning inductances and capacities.

(iii) *Wavemeter.*—A loosely coupled standard or sub-standard wavemeter is arranged so that the heterodyne beat-note in the headphones enables the experimenter to check the frequency of the test very accurately. This is necessary because the slightest change in frequency throws the bridge galvanometer off zero. The beat-note eliminates all such difficulties in carrying out the tests. At times the presence of harmonics in the generator wave-form may cause uncertainty as to the exact wavelength; with a little care, however, there is no chance of mistakes. The standard inductances and capacities in the circuits afford a check on the wavelength.

A bridge-test should be commenced with a 50 or 250 milliampere vacuum heater thermo-couple and loose coupling to the generator. After preliminary adjustment for resonance of the bridge and aerial circuits the vacuum junction is exchanged for a more sensitive one of 10 m.a. capacity which generally suffices for the test. The possibility of using other forms of detector in place of the thermo-couple across the bridge has not been examined. There seems little doubt that for some purposes thermionic valve amplifier detector circuits might prove advantageous.

The sensitiveness of this bridge with a 10-milliampere vacuum thermo-couple and pointer galvanometer is shown by Fig. 7 in which the deflection of the thermo-galvanometer is plotted vertically. The wavelength of the testing set was altered step by step from 364 metres to 417·5 metres when connected to an aerial having a natural fundamental wavelength of 405 metres. It will be seen that one metre change in applied wavelength produced the readable deflection of 0·5 division which may be regarded as satisfactory for aerial testing.

The apparatus described was manufactured and supplied by Messrs. H. W. Sullivan, Ltd., London, with the standard wavemeter calibrated by the National Physical Laboratory, and considering the extremely high frequencies used, surprisingly consistent measurements may be achieved.

Aerial Resistance.

The value of a bridge-method of testing is emphasised when, as is almost always the case, the aerial efficiency is required to be known. As an example of this the measurements on a small aerial have been plotted in Fig. 8.

The system tested consisted of an inverted 'L' aerial having twin wires supported between two tubular steel masts of 90 feet height and 200 feet span. The system being connected to either a waterpipe earth or an insulated, untuned, counterpoise about five feet above the ground level, the aerial was carefully tuned when making observations of the resistance at various wavelengths.

The two aerial circuit resistance graphs are seen to differ greatly as the fundamental wavelength, 405 metres is approached, but at higher wavelengths the difference disappears.

The separation of the total aerial resistance into its components, viz., radiation resistance, conductor resistance and resistance equivalent to dielectric losses when working above the fundamental natural wavelength, is usually based upon the approximate expression :—

$$R_{\text{total}} = A.\,\lambda^{-2} + C + D.\lambda \text{ ohms} \qquad (5)$$

A closer approximation may be that given by T. L. Eckersley (*J. Inst. Elec. Eng.*, 1922, **60**, 585) whose expression for total resistance includes additional terms for conductor skin effects, corona and leakage loss.

In the case of the aerial and counterpoise tested, Fig. 8, lower graph, the total resistance above about 1000 metres wavelength is given by a straight line from which it appears that in this case dielectric losses predominate.

As a matter of interest the resistance of a 0·0020 mfd. condenser having mica and moulded insulation was measured by means of the high frequency bridge over a range of from 1,000 to 9,000 metres wavelength. The observations are plotted in Fig. 9 from which it is seen the resistance of this condenser is practically proportional to the wavelength.

It is to be hoped that a more satisfactory method of separating the losses in the neighbourhood of the fundamental wavelength may be evolved. When working at lower wavelengths the radiation resistance has been calculated by S. Ballantine (*Proc. Inst. Radio Eng.*, 1924, **12**, 823) to attain a limiting maximum value at about 56 per cent. of the fundamental wavelength. Below this it varies with the distribution of stationary current waves.

Some measurements on ordinary aerials working under these conditions are to be undertaken.

Department of Electrical Technology,
Indian Institute of Science,
Bangalore,

[Accepted, 27-1-26.]

APPENDIX.

The theory of stationary waves on open type aerials provided with tuning arrangements at the current loop (base of aerial) shows that the wavelength is given by :—

$$\lambda = \frac{2\pi.u. \sqrt{L_o.C_o}}{\theta} \qquad (6)$$

where L_o is the static inductance in henries,
C_o is the electrostatic capacity in farads,
and $u = 3 \times 10^8$ metres per second.

It is convenient to express Equation (6) in terms of the natural fundamental wavelength of the unloaded aerial, thus :—

When $L_T = 0$ the ratio $\cot\theta/\theta = 0$, which occurs at $\theta = \frac{\pi}{2}$ hence the unloaded aerial wavelength is :—

$$\lambda_{nat} = 2\pi u \sqrt{L_o.C_o} \div \frac{\pi}{2}.$$

Further when L_T is added at the base of the aerial the wavelength is given by equation (6) or the ratio $\frac{\lambda_{nat}}{\lambda} = \frac{2}{\pi}\theta$ (7)

The significance of Equation (1), page 21, as regards the fundamental and harmonic free oscillations is more readily appreciated if presented graphically as in Fig. 10. The straight line OA, having an inclination $\frac{L_T}{L_o} = \frac{\cot\theta}{\theta}$, intersects the cyclic values of $\cot\theta$ at λ_1, λ_1', λ_1'', etc., at θ_1, θ', θ'', etc., which give (Equation 7) the fundamental and harmonic wavelengths of the loaded aerial. Similar graphs have been given by P. K. Turner (*Exp. Wireless and W. Eng.*, 1924, **1**, 723).

The graphical presentation of Equation (3), page 22, for inductive and capacity tuning is shown in Fig. 11. Equilibrium wavelengths in such cases occur when one of the straight lines for $\frac{L_T}{L_o}\theta$ intersects a graph for $\left[\cot\theta + \frac{1}{\theta}.\frac{C_o}{C_T}\right]$.

Printed and published by George Kenneth at the Diocesan Press, Post Box 455, Madras—1926 C13197

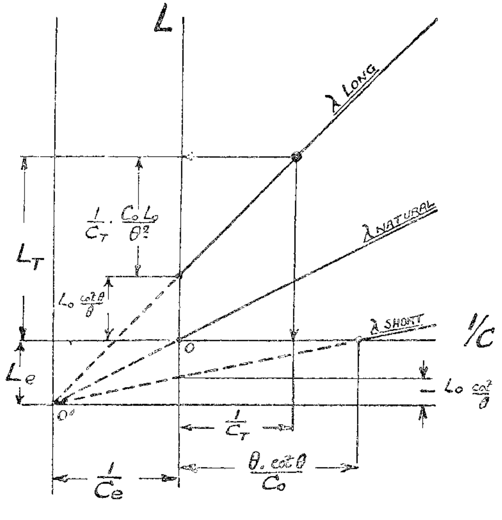


Fig. 1. *Analysis of Characteristics.*

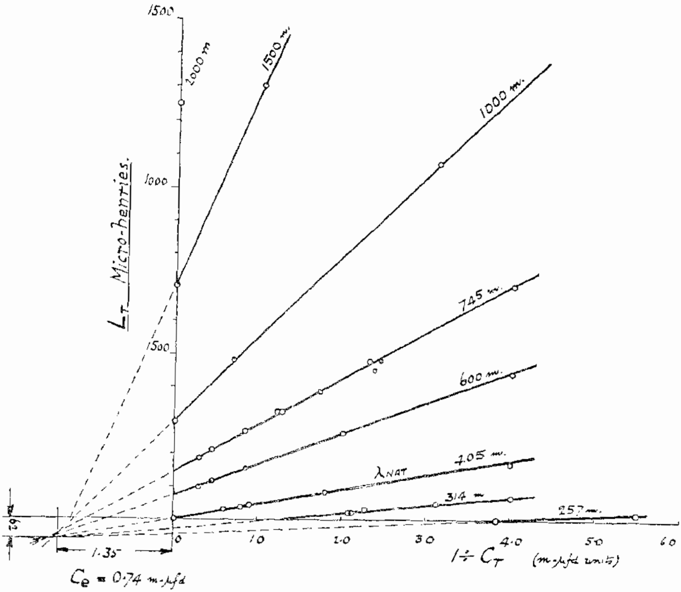


Fig. 2. *Tuning Characteristics of Small Aerial with Counterpoise.*

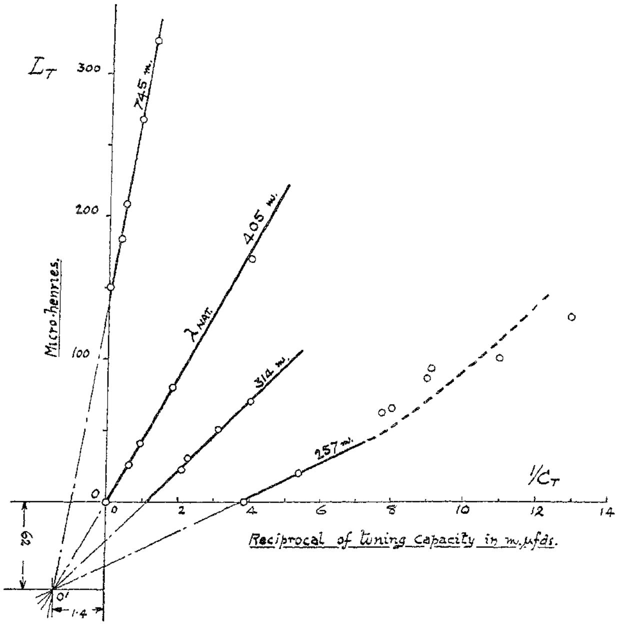


Fig. 3. *Tuning Characteristics below Fundamental Wavelength.*

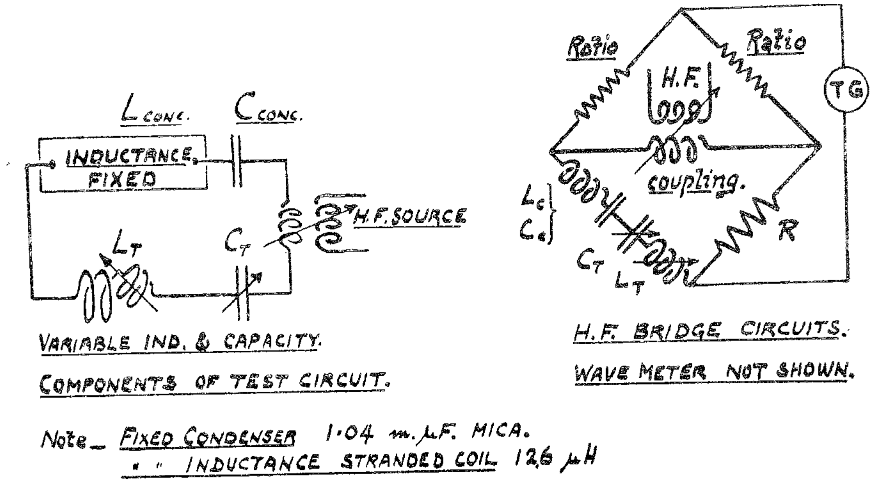


Fig. 4. *Aerial Equivalent Circuit.*

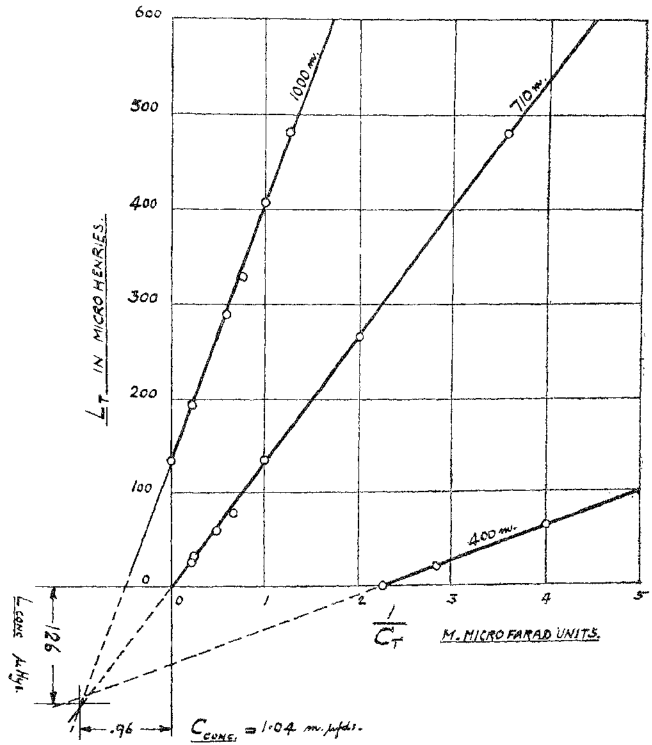


Fig. 5. *Experiment with Concentrated Circuit Constants.*

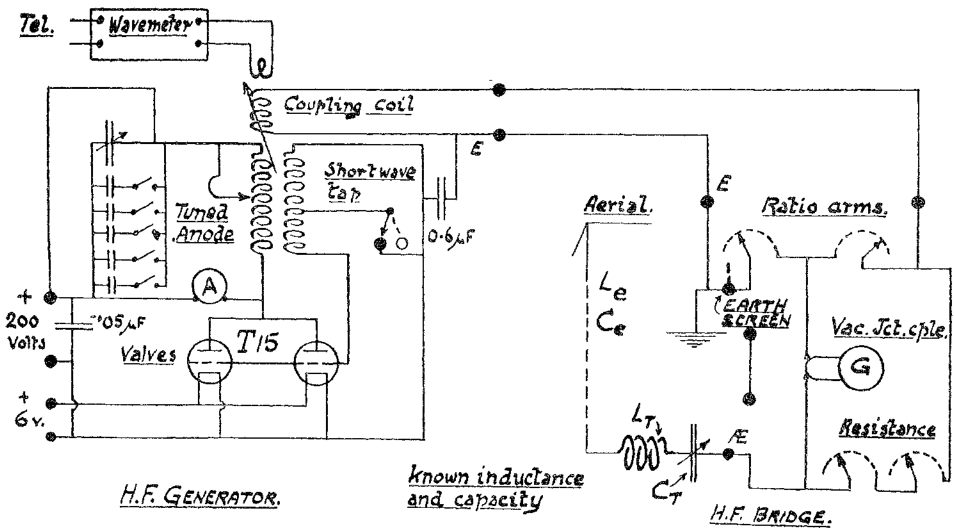
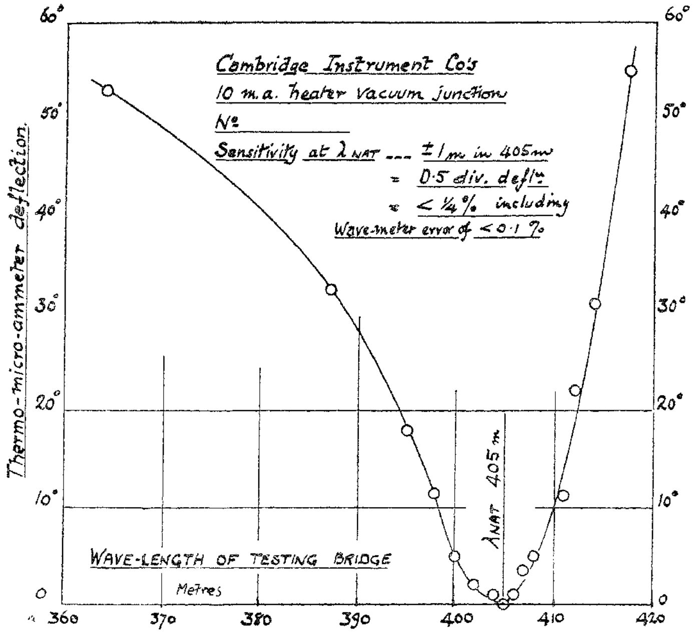


Fig. 6. *30-Watt H.F. Generator and Aerial Testing Bridge with Wavemeter.*



Cambridge Instrument Co's
10 m.a. heater vacuum junction
No.
Sensitivity at λ NAT --- ±1m in 405m
= 0.5 div. defln.
= < ¼% including
Wave-meter error of < 0.1 %
Thermo-micro-ammeter deflection.
WAVE-LENGTH OF TESTING BRIDGE
Metres
λ NAT 405 m
0
10°
20°
30°
40°
50°
60°
360
370
380
390
400
410
420

Fig. 7.

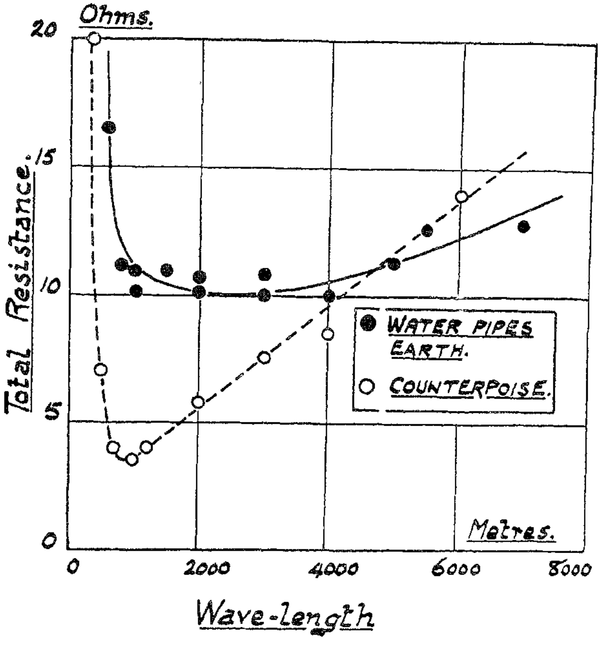


Fig. 8. *Aerial Resistance, Inverted L. Two 90 ft. Steel Masts 200 ft. apart. Indian Institute of Science, Bangalore.*

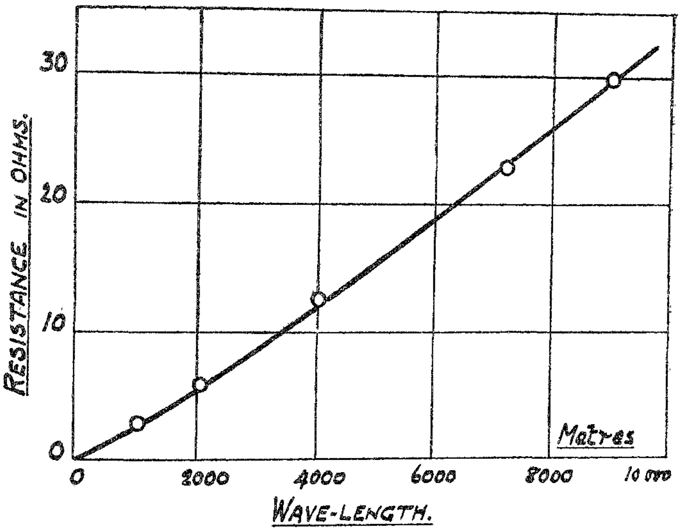


Fig. 9. *Variation of Dielectric Resistance with wavelength.*
0·002 μ fd. mica and moulded plate condenser.

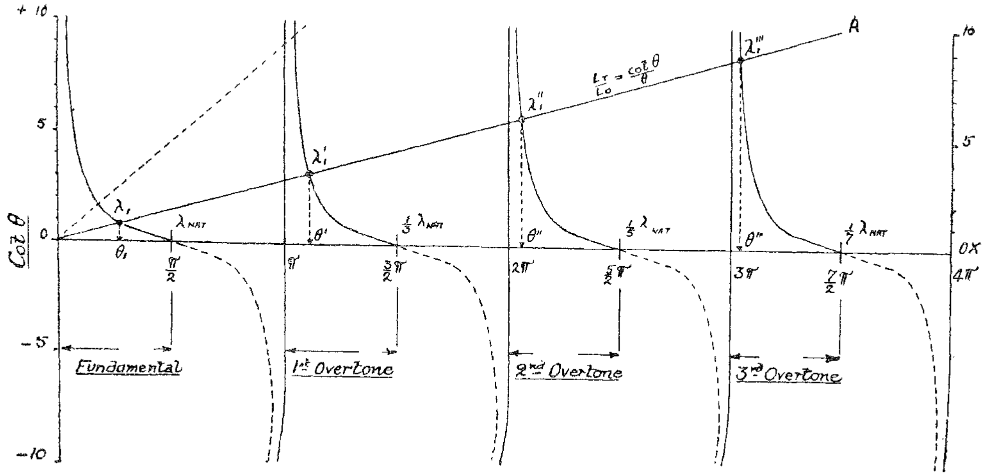


Fig. 10. *Wavelengths of Harmonics of Loaded Aerial.*

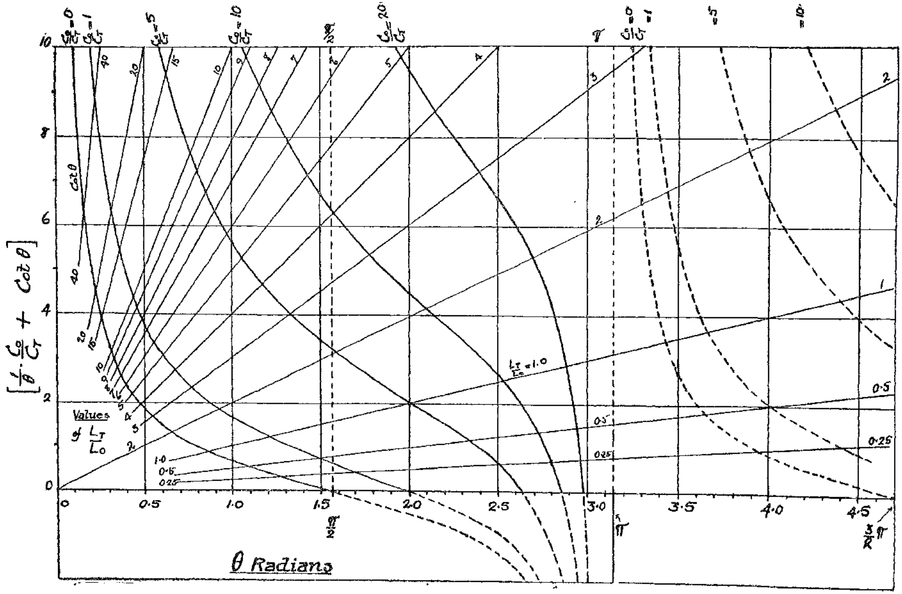


Fig. 11. *Graphs for* $\frac{L_T}{L_o}\cdot\theta - \frac{C_o}{C_T}\cdot\frac{1}{\theta} = \cot\theta$