XXII. *A Note on the Relation of the Audibility Factor of a Shunted Telephone to the Antenna Current as used in the Reception of Wireless Signals.* *By* BALTH. VAN DER POL, Jun., *Doct. Sc.* (*Utrecht*) *.

IN the measurements of the strength of wireless telegraph signals, it is usual on board ship to employ a shunted telephone receiver and to measure the signal strength by the value of the shunt required to reduce the signal strength to a point at which dots and dashes may be just differentiated.

Such measurements have been made by Dr. L. W. Austin † and by Mr. J. L. Hogan, Jun.‡, to find experimentally the law according to which the received antenna currents vary with the wave-length and distance from the sending station.

The above results have been criticized by Prof. A. E. H. Love, F.R.S. §, who has raised doubts how far Hogan's audibility factor $(R+S)/S$, where R is the resistance of the telephone and S that of the shunt, is proportional to the square or to the simple value of the antenna current I.

Love has suggested that certain results of Austin and Hogan indicate that $(R+S)/S$ is proportional to I^2 for large values and to I for small values, in which case the theoretical results of Love ‖ and Macdonald ¶ would be in close agreement with the corrected experimental data of Hogan.

As long as the phenomena occurring at the contact of the two substances of a crystal detector are neither qualitatively nor quantitatively known, we cannot calculate the relation that exists between the antenna current and the value of the shunt S required to reduce the signal strength to just audibility.

Direct measurements of the antenna current at great distance from the sending station cannot be made, for no ammeter exists with which it is possible to measure high frequency alternating currents of the order of 5 micro-amp. The only way, up to the present, to find the value of the receiving antenna current at great distances is to determine the shunt S. Of course an experimental way must then be found to compare the values of the required shunts S with the actual antenna currents.

* Communicated by Prof. J. A. Fleming, F.R.S.

† 'Bulletin of the Bureau of Standards' (Washington), vol. vii. No. 3 (1911), p. 315, and 'Journal of the Washington Academy of Sciences,' Dec. 4, 1914.

‡ 'Electrician,' vol. lxxi. p. 720 (1913).

§ Phil. Trans. Roy. Soc. Lond. vol. ccxv. A, p. 105 (1915).

‖ Love, see paper cited.

¶ H. M. Macdonald, Proc. Roy. Soc. (ser. A), vol. xc. (1914) p. 50.

From the two papers of Austin * it is not quite clear how this calibration was made, and Hogan † assumes that his "audibility factor"

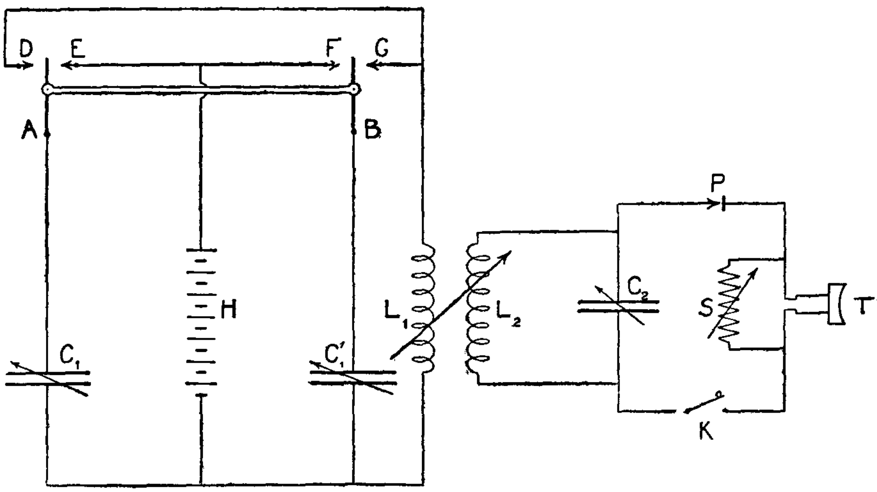
$$A_f = \frac{R+S}{S},$$

where R is the resistance of the telephone, is proportional to the *square* of the antenna current †.

It was suggested to me by Dr. W. H. Eccles that this point could be experimentally examined in the laboratory. Dr. J. A. Fleming, F.R.S., thereupon kindly placed at my disposal the means for doing this in the research department of the Pender Electrical Laboratory of University College, London. The following is a short account of the experiments so far conducted.

To generate high frequency oscillations of a steady character a double Fleming and Clinton commutator ‡,

Fig. 1.



mounted on the same shaft, was used. This commutator, though originally designed for measuring small capacities, but now connected in the circuits as shown in fig. 1, was

* See papers cited.

† See papers cited, and also Love, Phil. Trans. Roy. Soc. Lond. vol. ccxv. A, p. 128 (1915).

‡ J. A. Fleming, 'Principles of Electric Wave Telegraphy and Telephony,' 3rd ed., p. 205.

found to produce very steady oscillations, of which the amplitude, wave-length, damping, and number of trains per second could be varied at will within considerable ranges.

In fig. 1 H is a high tension battery of secondary cells, C_1 and C_1' are two variable air-condensers of approximately equal capacity. The working of the two commutators is such that A is connected to D at the same time that B is connected to F. At this moment the condenser C_1' becomes charged to the voltage of H and any charge on C_1 is discharged through the self-inductance L_1, so that in the circuit C_1L_1 high frequency oscillations are set up. At the moment when the commutator has revolved through an angle of 90°, C_1 becomes charged and C_1' discharges through the same inductance L_1, for at this moment A is connected to E and B to G. The capacity of C_1' was varied, so that with its leads and L_1 it was in tune with C_1, its leads, and L_1. The leads C_1A, C_1'B, HE, and L_1G were made up of 20 strands, each 30 metres long. The commutator, which was driven by an electromotor at a speed of approximately 3500 R.P.M. (467 discharges per second), was not in the same room where L_1 with the receiver circuit No. 2 was placed, to avoid the noise of the commutator interfering with the small sounds to be heard in the receiving telephone. The inductance L_1 consists of a flat vertical coil of one layer of 15 turns with an inside diameter of 8·5 cm. and an outside diameter of 21 cm. Coil L_2, whose distance from L_1 can be varied by known amounts up to 100 cm., has the same dimensions as L_1, but consists of *two* layers. L_2 forms, with the variable air-condenser C_2, a high frequency circuit from which the signals, produced by tapping the key K, can be heard in the telephones T which, in series with a Perikon detector [Chalcopyrite $Cu\,FeS_2$ – Zincite ZO], are connected across the terminals of C_2. A headgear of two Sullivan telephones [resistance $R=1240\ \Omega$ in series] was used. These telephones were shunted by a variable resistance S as shown in fig. 1.

The E.M.F. induced in L_2 is proportional to MI, where M is the mutual inductance between the parallel coils L_1 and L_2 and I the current amplitude in circuit No. 1, when only the couplings coefficient $k=M/\sqrt{L_1L_2}$ is small enough not to allow for any appreciable reaction from circuit No. 2 on circuit No. 1. Varying therefore the mutual inductance at a constant primary current has the same effect on circuit No. 2 as varying the primary current I at a constant coupling.

By moving L_1 to and fro the distance between L_1 and L_2

can be determined for which, with a certain shunt S, the sound of the signals, made by tapping the key K, can just be differentiated. The value of the mutual inductance M was then found by the use of a curve calculated from the formula of Maxwell-Rosa *.

$$M = 2\pi^2 n_1 n_2 \sqrt{aA}\, k^{3/2}\{1 + 3/8\, k^2 + 15/64\, k^4 \ldots.\},$$

where n_1, n_2 are the number of turns of L_1 and L_2,
a, A are the *mean* radii of the coils L_1 and L_2,
and

$$k = \frac{(a+A)^2}{\{\sqrt{(a+A)^2+d^2}+d\}^2},$$

where d is the distance between the flat coils.

In the experiments coupling coefficients were used only between the limits

$$k = \cdot 003 \text{ and } \cdot 0002.$$

The wave-length used was about 1125 metres.

The results of these measurements are recorded in the following table :—

$\log \frac{R+S}{S}$.	log M.	$\log \frac{R+S}{S}$.	log M.
·0816	1·419	·7104	1·875
·0962	1·446	·8573	1·902
·1173	1·471	·9671	1·980
·1502	1·520	1·1271	2·060
·2095	1·583	1·2175	2·102
·2617	1·628	1·3359	2·164
·3502	1·680	1·4116	2·197
·4065	1·704	1·5051	2·251
·4427	1·738	1·6266	2·313
·4869	1·762	1·7993	2·394
·5416	1·804	1·9227	2·473
·6128	1·813	2·0969	2·515

A curve (see fig. 2) was then plotted for which the ordinates indicate the *logarithms* of the mutual inductance for a constant current [which is proportional to the antenna current for a constant coupling], and where the abscissae give the logarithm of the audibility factor (R + S)/S.

For values of log (R+S)/S from *·6* to *2·2* (audibility

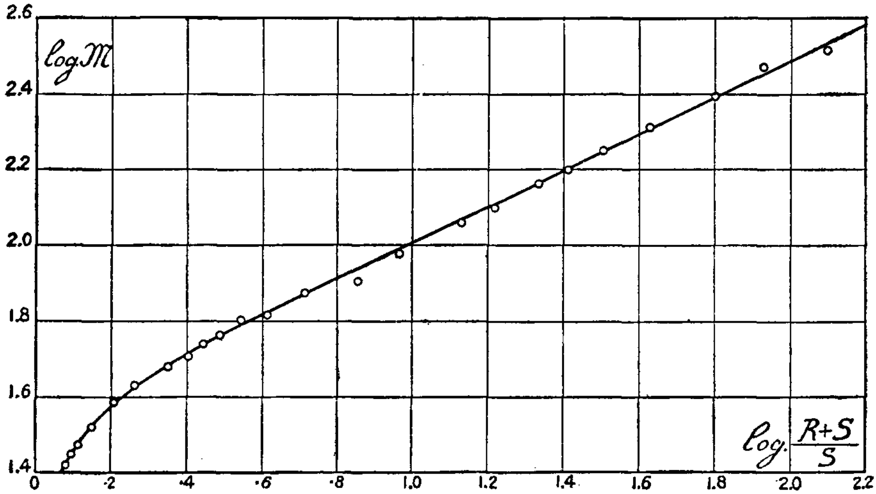
* See Bulletin of the Bureau of Standards, vol. viii.

factors from 160 to 4) our experiments indicate the relation

$$\frac{R+S}{S} \sim I^2,$$

for between these limits the curve is a straight line with an inclination angle $= \tan^{-1} \cdot 5$.

Fig. 2.



For values of log $(R+S)/S$ from ·08 to ·6, *i. e.* for values of $(R+S)/S$ from 4 to 1·2, the audibility factor is proportional to a power of I ranging in this interval from 2 to ·7.

Summary.

The assumption that the audibility factor of a shunted telephone is in general proportional to the square of the antenna current, as stated by Hogan, seems to be invalid. For large values of the current we found a proportionality between the audibility factor and the square of the current, and for weaker signals the audibility factor was found to be proportional to a power of the current varying between 2 and ·7, in agreement with Love's expectations.

The author hopes to pursue these investigations further and to give an account of the results arrived at.

In conclusion, I should like to express my thanks to Prof. J. A. Fleming for the facilities afforded to me for conducting the experiments here described in his laboratory.

Pender Electrical Laboratory,
University College, London.