Results of Experiments. Third Day.

Result of third day's experiments.

1. The magnetic detector is inferior to both the electrolytic and Shoemaker coherers, but there is not sufficient evidence to show which of the latter is the better.

2. Observations showed that the Marconi tuner does not allow of sufficiently delicate adjustment and was not superior to the smaller tuner. The Service tuner will therefore be submitted for approval as soon as the design and specification are finished.

3. The requisite amount of coupling still remains undetermined, but the limits between which the best coupling lies have been very greatly reduced.

4. Both the electrolytic and Shoemaker's coherers were quite strong when heard, but the atmospherics overpowered them.

In all probability another 50 miles would have been obtained but for this disturbance.

5. Although the tuned shunts will overcome a considerable amount of atmospherics, as soon as sparks can be drawn off the aerial they become nearly useless. The additional capacity of 1,600 jars in the latest design may help to overcome this.

Shoemaker coherer.

6. This was the first time Shoemaker's coherer was tried, and it was not thoroughly understood. It is simpler even than the electrolytic. It consists of a "simple cell," the negative plate being a platinum point and the excitant dilute $H_2 SO_4$. This is short-circuited by a telephone, consequently it promptly polarises, a bubble of hydrogen forming on the platinum point. This bubble is dispersed by a high-frequency wave. The resistance of the telephones used was too high, and consequently the bubble took two or three seconds to form; while it is forming, there is a boiling noise which interferes with signals. By reducing the resistance of the telephones, this will probably be overcome.

ELECTROLYTIC COHERERS.

Electrolytic coherers.

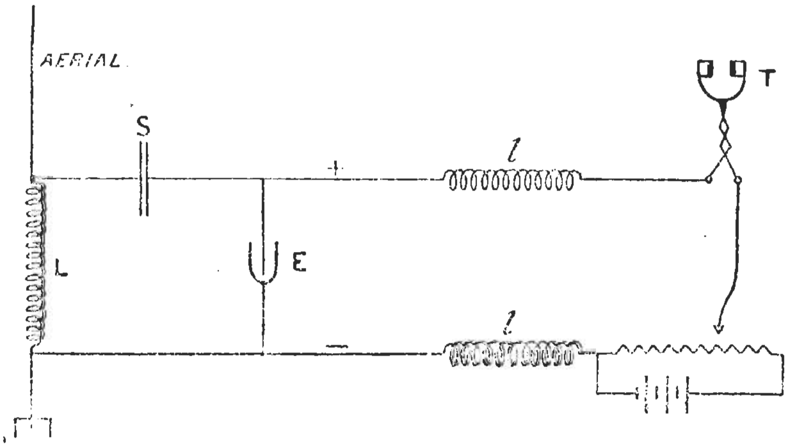
Three different types of electrolytic coherers have been tried in the "Vernon"; the Schlömilch coherer, as used with the Telefunken system, together with a complete set of receiving gear; the Shoemaker coherer and receiving gear of the International Telegraph Construction Company, New York; and an experimental coherer constructed by Mr. W. H. Sullivan. This type of detector when used with a telephone is very sensitive and has given excellent results.

General Principles.

Principles of electrolytic coherer.

The coherer (*see* Fig. 14) consists of two electrodes, one in the form of a fine point, in a dilute acid or alkaline solution. This cell is connected in series with a telephone and source of e.m.f.; the cell at once polarises, the back e.m.f. generated stopping the flow of current.

FIG. 13.

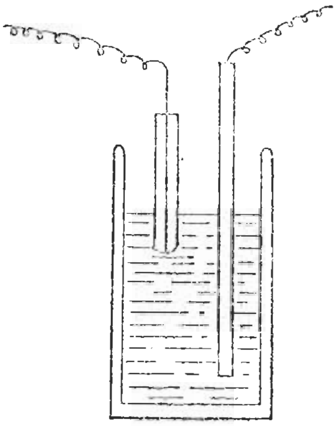


Manufacture of the fine point.

The fine point is made from Wollaston wire. A piece of fine platinum wire is inserted as a core to a cylinder of silver which is then drawn down to a fine wire. This is dipped into acid, the silver dissolved from the end, leaving a very fine platinum point. The Wollaston wire is placed inside a glass tube, the platinum point projecting through the glass, ending flush with it, exposing a small disc about $\frac{1}{1000000}$ of an inch diameter to the electrolyte.

In the Telefunken and the Sullivan electrolytic the fine platinum point or tip is made the anode, a platinum cup acting as the cathode, dilute sulphuric acid being the electrolyte used with Sullivan's coherer. A variable e.m.f. is applied by a potentiometer (*see* Fig. 13).

FIG. 14.



Circuit.

The circuit from the potentiometer is completed through the telephone T and the choking coils *l*, *l*, to the electrolytic E.

The aerial is earthed through the tuner L. The capacity S is about 90 jars, and prevents the potentiometer being short-circuited through the induction L, the choking coils *l*, *l*, preventing the wireless currents wasting in the telephone leads, &c.

When the circuit is completed through the potentiometer there is a temporary flow of current through the telephone and coherer. Immediately, however, the coherer polarises, and the current drops to almost nothing. This is heard as a " click " in the telephone. The polarisation is due to a very thin layer of oxygen forming on the small exposed platinum disc and setting up an opposing e.m.f. This layer of oxygen is most probably slowly dissolved by the electrolyte, as a very small current is always flowing, and is necessary to keep the cell polarised. If a condenser of high insulation resistance is placed in series with the telephone the coherer does not remain polarised, and will not work.

As the potential from the potentiometer is increased a critical point is reached, when the current from the coherer begins to grow rapidly, a small percentage increase in the potential producing a large percentage increase in the current. A hissing noise starts in the telephone, which rapidly increases in strength, becoming very violent. When the potentiometer is just below the critical voltage a very faint sound can just be heard, appearing to be due to bubbles slowly forming. With increasing potential this grows in strength and rapidity, eventually turning into the hissing sound, which must be due to a series of bubbles very rapidly forming and bursting.

The following table gives the current taken by the Telefunken electrolytic with different applied P.D'.s :—

Potential Difference.	Current.	Change in Current.
Volts.	Micro-Ampères.	
3·0	4·2	—
3·1	7·0	+ 2·8
3·2	13·2	6·2
3·3	30·3	17·1
3·4	57·0	26·7
3·5	105·0	48·0
3·6	169·0	64·0
3·7	220·0	51·0

The critical voltage being between 3·2 and 3·3 volts, the current rapidly increasing with higher voltages. With 3·3 volts a very faint sound in the telephone is just perceptible. This turns into a loud hiss when 3·6 volts is applied.

The high-frequency alternating P.D. from the aerial acting through the condenser S, Fig. 13, is superimposed on the direct P.D., and causes the current through the coherer to increase. Thus, if the applied P.D. is 3·2 volts, and the P.D. from the aerial ± 0·1 volt, the resulting P.D. would oscillate between 3·1 and 3·3 volts, the mean current being $\frac{1}{2}$ (7·0 + 30·3) = 11·6 micro-ampères, instead of 13·2, which was flowing before the aerial P.D. acted. This is on the assumption that the change in the polarising effects can change as rapidly as the oscillations in P.D. from the aerial, which is not so; for if the P.D. is suddenly decreased from 3·3 to 3·2 volts, the current drops, apparently instantaneously, to about 15 micro-ampères, fairly rapidly to about 14, and then much more slowly to 13·2, its steady value. It is more probable that the current would remain at 30·3 micro-ampères all the time the oscillations from the aerial lasted, and then very rapidly decrease to about 15 micro-ampères.

As the aerial oscillations do not last for more than $\frac{1}{30000}$ of a second for each spark, possibly the increase in current through the coherer would only act for a very short time, and probably not long enough to affect the telephone on account of its great inductance. The inductance L, however (*see* Fig. 13), is infinitely smaller, and the current through the coherer would probably flow through it and the condenser S, discharging the latter, which would charge again more slowly through the telephone.

If S is 75 jars, and the current through the electrolytic only lasts long enough to discharge it from 3·20 to 3·18 volts, or 17 micro-ampères for $\frac{1}{10000}$ seconds, the result would be very fair signals; as 75 jars, charged to 0·02 volts, give a fairly loud "click" when discharged through a telephone.

There is a complete circuit through the capacity S and the induction made up of L, the telephone, and the choking coils. This is an oscillatory circuit with a definite frequency of oscillation, and oscillations are started in it by the sudden discharge of the capacity S.

If S is small, the frequency of these oscillations will be great, and if S is great it will be small, so that the capacity of S regulates the frequency of the oscillations in, and therefore the pitch of the note given out by, the telephone.

With the telephones supplied for use with the magnetic detector, resistance about 160 ohms, S between 50 and 100 jars gives best results. With a special high-resistance telephone of 2,000 ohms, S about 0·5 to 1·0 jars gives best results, the signals with the two telephones being of about equal strength. There is a personal element, however, in the choice of the best condenser, its capacity varying with different people, but not widely.

The coherer works best when the potentiometer is adjusted so that the faint bubbling sound in the telephone can just not be heard.

The Shoemaker coherer is similar in action to the other two. The battery power is, however, provided by the coherer, which is also a cell. One plate consists of a very small platinum tip, as in the other coherers; the other of a rod of pure zinc, the electrolyte being a 30 per cent. solution of sulphuric acid.

The coherer is connected up as in Fig. 13, but the telephone is connected directly on to the choking coils *l*, *l*, the potentiometer not being required. The coherer, acting as a cell, begins to run down through the telephone, but at once polarises, hydrogen instead of oxygen now forming on the platinum tip, the current being the other way, and the platinum always the cathode.

The polarised cell being short-circuited through the telephones, the condenser S is not charged.

When, however, the high frequency P.D. acts on the cell, it breaks down the thin film of hydrogen, depolarises the cell, which instantly charges the condenser S, and this discharges through the telephone.

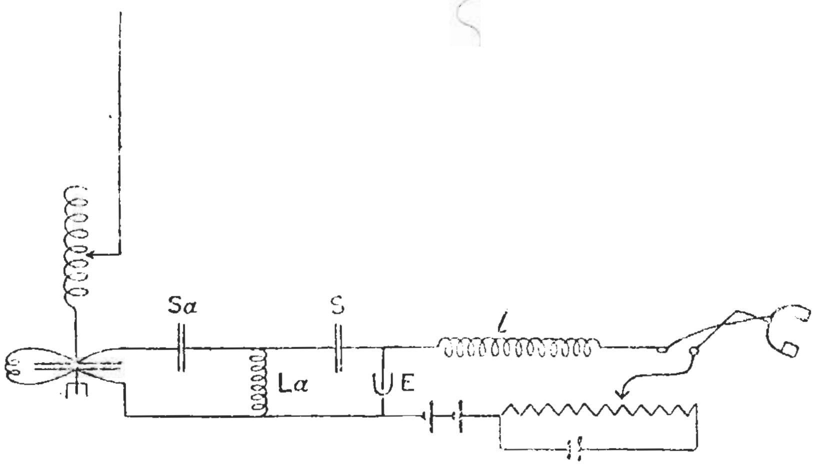
When the coherer is connected up to the telephone, a hissing sound starts, decreasing rapidly in strength, dying away completely in about one second. A violent atmospheric restarts this sound, which drowns signals for about a second afterwards. This is rather a disadvantage. It is very possibly due to the fact that platinum absorbs hydrogen, and that sufficient hydrogen has to be formed to saturate the platinum wire near the tip in addition to that required for polarisation; that with ordinary signals the platinum remains saturated, but with a violent discharge the hydrogen is dispelled, and the platinum has to be resaturated.

For comparative tests between the magnetic detector and electrolytic coherer, *see* "C" Tune, pp. 31 to 36.

Electrolytic and tuned shunts.

Tuned shunts and the electrolytic work well together, the tuning being sharp. The coherer will work if placed in parallel with either the acceptor capacity or inductance, both methods have been tried and appear to work equally well; when connected across the capacity, however, if the red plug is pulled out, disconnecting the shunt, the coherer will not work well, the telephone oscillating circuit is disturbed and there is a bubbling sound, due possibly to statical charges in the aerial discharging through the coherer. When connected across the acceptor inductance, as in Fig. 15, the shunt can be disconnected whenever required, simple resonance resulting.

FIG. 15.



In Fig. 15 S_a and L_a are the acceptor capacity and inductance respectively. S is a condenser about 90 jars, as in Fig. 13. As the lower part of the electrolytic E is connected to earth only one choking coil *l* is necessary. When using this arrangement for "B" tune, the best value for L_a is between 5 and 25 mic., and between 60 and 100 mic for Poldhu. This circuit was used during the two distance tests with "C" tune. During the latter set of experiments it was noticed that putting in a shunt of 25 jars made signals a little stronger than with simple resonance; no satisfactory explanation of this effect has yet been given. When using the circuit given in Fig. 13 it has sometimes been found better to shunt the inductance L, with a capacity in parallel, making it a rejector. As a general rule, simple resonance, as in that figure, gives better results.

Experiments have shown that the Telefunken electrolytic has a small capacity about 0·1 jars, and an insulation resistance while working of about 100,000 ohms. As it takes very little power and only a small P.D., it causes very little damping in the high-frequency circuit to which it is connected.

Electrolytic and recorded signals.

Experiments have been made with a view to recording signals with this coherer, they have not proved successful. "B" tune signals from Culver are very strong on a telephone; when a very sensitive Service relay is connected in place of the telephone these signals are recorded very indifferently, the relay alternately running away and refusing to work.

It is considered that a call up could be arranged which would work with a long dash possibly, making use of cumulative effects; and experiments are at present in hand.

The electrolytic coherer is very sensitive, works equally well with long and short waves, including "A" tune. Sharp tuning is easily obtained, and the coherer is especially suitable for a long train of waves.

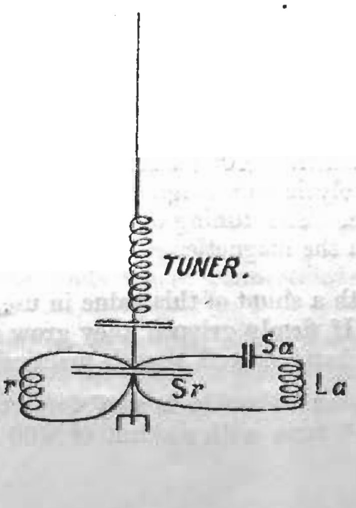
TUNED SHUNTS.

Tuned shunts.

During the year tuned shunts have been thoroughly tested by "Vernon," and some preliminary sets have been sent to sea for trial.

The circuit shown in Fig. 16 has been adopted. *See* also A.R. 1904, pp. 40–45.

FIG. 16.



S_R is rejector capacity, L_R rejector induction, S_A acceptor capacity, L_A acceptor induction.

It is convenient for comparison of results to take the value of the rejector capacity S_R as the measure of the shunting.

Receiving Twin Waves.

Several careful experiments were made with "B" tune from Culver and Portland, receiving with tuned shunts and the magnetic detector.

A rejector capacity of about 33 jars was used, and a coil of from 4 to 20 mic. placed in parallel with the magnetic detector, to reduce the strength of signals.

"B" tune waves are independent of each other.

The results show that the two waves of "B" tune are received quite independently. That the rejector, acceptor, and tuner must be tuned to one and the same wave, which is then received. When giving strongest signals the resonance constants of the different parts of the circuit agree within a few per cent.

The tuning of the tuner was sharp, the acceptor very sharp and well defined, and the rejector not at all well defined.

Tuning.

Sharpness of tuning with tuned shunts.

Further experiments show that the tuning of the tuner becomes sharper as the rejector capacity is increased in size, becoming very critical when the latter is large.

It is especially important that all connections should be thoroughly good. Low resistance is of paramount importance with short waves, while high insulation is of greater moment with long waves. Resistance in the acceptor reduces the sharpness of tuning in the tuner.

Sharpness of tuning in the acceptor depends on the loss of energy or damping taking place there. As the acceptor contains the receiving device it must always absorb energy, either by hysteresis as with a magnetic detector, or high resistance as with a filings coherer.

If the magnetic detector is used as the acceptor induction the tuning of the acceptor is not sharp. If, however, the magnetic detector is shunted by a low resistance coil of induction 20 mics., the magnetic takes only part of the acceptor current. The damping in the acceptor is decreased, and tuning becomes more critical. When a coil of 5 mics., say, is used, the tuning of the acceptor is very critical. The energy required to work an electrolytic coherer is apparently less than that required by the magnetic detector, and when it is used the acceptor tuning is very sharp.

When the acceptor tuning is very critical, the rejector tuning is quite the reverse, but when the acceptor does not tune sharply the tuning of the rejector is critical and of great importance.

The tuning of the whole circuit increases in sharpness and importance as the rejector capacity is increased in size.

The following is an interesting comparison of tuning effects. Poldhu was received with a rejector shunt capacity of 1,600 jars, a magnetic detector and electrolytic coherer being tried. The acceptor induction used with the latter was 80 mic. (about the same as that of the magnetic), the coherer being arranged as a shunt across the acceptor capacity. The correct tuning was—

Rejector L - - 0·6 mic. (approx.)
Acceptor S - - 13 jars with magnetic.
" " - - 12 " " electrolytic.

Tuning more critical with electrolytic coherer.

Effects of resistance.

With the electrolytic.—If the acceptor S was altered to 11·7 or 12·2 jars signals got very faint and this alteration of 2 per cent. had almost as much effect as a 50 per cent. change in the rejector L to 0·3 mic. With the magnetic.—A small variation in the rejector L made a great change in signals. If it was shifted to 0·45 mic. the result was absolute silence. But the acceptor S could be altered from 13 to 12 or 14 jars and make very little difference to signals. When accurately tuned the signals on the electrolytic were much louder than on the magnetic—as loud, in fact, as on the magnetic with simple resonance; yet with the 1,600 jar shunt in, if the acceptor S was a little out of tune (equally so with electrolytic and magnetic), the signals on the electrolytic were weaker than on the magnetic. The tuning of the aerial tuner also was more critical with the electrolytic than with the magnetic.

Effect of Resistance.—With a shunt of this value in use, if the aerial is touched with a dry finger signals weaken. If firmly gripped they grow very faint, and if an earthed wire is gripped with the other hand as well, signals practically cease.

The resistance of the shunt induction is very important, especially with shorter waves. When receiving "B" tune with a shunt of 100 jars, extra pressure on the switch contact, possibly decreasing the resistance by about 0·01 ohms, makes a noticeable difference in the strength of signals.

Thus when tuned shunts are used it is of vital importance that all contacts and connections are good and that insulation resistance is high.

Results obtained with tuned shunts.

Results.—When the jamming wave length is widely different from the wave length to be received, the selective power of a tuned shunt is very good, especially if the received wave is strong.

Thus with a shunt capacity of 1,000 jars Poldhu's signals can be easily read on a fourfold aerial on the mainmast of "Vernon III.," while "A" tune 3 mm. or "B" tune 1 mm. spark is being sent from a fourfold aerial on the foremast, the space between the aerials being clear of masts and stays and the distance only about 220 feet.

If the two waves were not very different, or if the wave to be received is not strong, the selective power is much decreased.

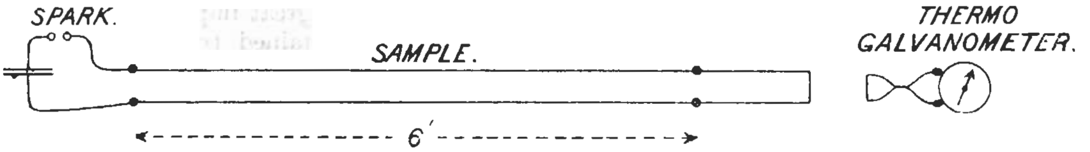
EFFECTS OF RESISTANCE ON HIGH-FREQUENCY CIRCUITS.

Damping by resistance.

In order to make use of loose coupling, sharp and selective tuning, also of longer wave lengths, it is of great importance that all loss of energy in both sending and receiving circuits is reduced to a minimum. A few of the principal experiments made on damping during the last year are given below.

An oscillating circuit was arranged, consisting of Poldhu condensers arranged to give a capacity of 60 jars with low resistance connections, the current being taken through two parallel lengths of wire 6 feet long, which could be exchanged for other samples of wire without disturbing the rest of the circuit. A low resistance thermal junction was fixed so that it was influenced by the circuit as in Fig 17, acting as an ammeter. A rapid spark of about 5 mm. was used with the following results:—

FIG. 17.



Sample Wire.	R*.	Galvanometer.
13 gauge copper - - - - -	·0143	18·5
$\frac{7}{18}$ bare aerial, new - - - - -	·0073	21·7
,, ,, , old - - - - -	,,	22·2
0·30-inch diameter, copper - - - -	·0013	29·7

R* is the resistance of the sample for a direct current in ohms.

The thermal junction was calibrated with a low-frequency current giving—

Mean square of current = galvanometer reading × a constant.

As the current in the main circuit, containing the sample, is proportional to that through the thermal junction, the square root of the mean square of the current, or R.M.S. current, in the main circuit is proportional to $\sqrt{29{\cdot}7}$ and $\sqrt{18{\cdot}5}$ with the stout wire and the 13 gauge wire respectively, *i.e.*, the current decreases from 5·45 to 4·30 when the resistance R of the sample is increased by 0·0130 ohms.

Conclusions.—A considerable loss may occur in a fairly persistent oscillating circuit due to a resistance as small as a one-hundredth part of an ohm.

The values with the old and new bare aerial being practically equal, show that old bare aerial covered with oxide and deposits from smoke is quite as good for wireless purposes as new, provided the ends where connections are made are thoroughly clean and bright.

Several further experiments have been made confirming these results. When an extempore "C" tune was rigged up with 120 jars, all primary leads were of stout wire, connections carrying more than a quarter of the primary current were of No. 1 gauge, (0·30-inch diameter) and even then with only half power these wires became quite warm. Copper tubing ¾-inch diameter is proposed for connections, the high-frequency current never sinking into the wire beyond a thin skin about one-hundredth part of an inch thick.

Referring to the above experiment, theoretically the galvanometer reading × the resistance in main circuit is constant.

The supply of energy to the circuit is constant. As the energy lost in radiation, &c. varies as $(\text{current})^2$, radiation may be assumed not to exist provided a resistance causing an equal loss is assumed to take its place. Loss of energy from circuit = mean C^2R = mean square of current × resistance = galvanometer reading × resistance × constant.

This loss of energy = the constant supply.

∴ Galvanometer reading × resistance is constant, the resistance including that of the spark-gap and connections and a resistance to allow for hysteresis loss in the condensers and the loss due to radiation.

Taking a formula given by Lord Rayleigh, the resistance of 13 gauge is increased about 6 times and that of 1 gauge 16 times by skin effect, making the resistance of the two samples ·086 and ·021 ohms respectively for high-frequency currents, with resonance constant 250, as used for experiment. If "r" is resistance of connections, radiation, &c., we get—

$$18{\cdot}5\,(r + {\cdot}086) = 29{\cdot}7\,(r + {\cdot}021).$$
$$\therefore\ r = {\cdot}087 \text{ ohms.}$$

Possibly about a half or a quarter of this was due to connections. This leaves the resistance of the spark-gap and loss in condensers and through radiation equivalent to about ·06 ohms.

The total resistance of the circuit when the stout wire was used was $= r + {\cdot}021 = {\cdot}108$ ohms.

The power supplied to the circuit was about 450 watts, and this was wasted by the high-frequency current flowing through ·108 ohms ∴ R.M.S. value of current $= \sqrt{\dfrac{450}{{\cdot}108}} = 65$ ampères, nearly.

The absolute maximum value of the current being about 1,800 ampères, the calculated current a quarter period after the spark commences.

Thus the currents flowing in an oscillator primary are large, but rapidly wasted by resistance, &c.

The resistance of the spark-gap is very small, and it is of great importance that all the connections are of low resistance, especially if a long-sustained train of waves is required or if the capacity is large.

TESTING MICA CONDENSERS.

Testing mica condensers.

The following arrangement was used for testing the efficiency of sample mica condensers. A "sending" circuit, of 30 jars capacity built up with glass plates, and low-resistance connections with a small spark, was used to excite a low-resistance circuit, consisting of a low-resistance thermal junction, low-resistance connections, and the condenser under test, with a small air adjustable condenser in parallel for fine tuning adjustments.

The condensers were all about 10 jars. and were compared in pairs, readings being taken alternately. The most efficient condenser, No. 6, was then tried with and without a small additional resistance in series. The resistance was of fine wire 0·3-inch long, resistance for direct current being 0·63 ohms. The wire was 47 gauge, radius only 0·0025 cm., and much less than the thickness of the skin at the frequency used, so that the resistance would be practically unaltered by skin effect :—

Sample.	Galvanometer Reading.	R.	r.
		Ohms.	Ohms.
No. 6 - - - - - - -	28·5	·515	·050
" 6 with, 0·63 ω added - - - -	12·8	1·145	—
" 3 - - - - - - -	23·9	·615	·150
" 1 - - - - - - -	23·6	·620	·155
" 4 - - - - - - -	22·7	·645	·180
" 5 - - - - - - -	21·8	·675	·210

R is deduced on the supposition galvanometer reading × resistance in constant; and that the difference between the first two observations is due to the addition of 0·63 ohms.

The resistance of the thermal junction was 0·465 ohms for direct current, the wire being of 47 gauge was practically free from skin effects. Subtract this from R, r is roughly the resistance that would cause the same damping as that due to connections and loss in the condensers.

This experiment shows that these mica condensers, especially No. 6, are very efficient, and that resistance is of great importance also in receiving circuits.

Damping factor.

The damping factor for a given frequency is proportional to Sr. First condenser S = 10 jars, and ∴ damping = ·50 × constant. If a condenser of 1,000 jars is used, the resistance of the circuit, for the same damping, would have to be less than 0·0005 ohms. A variable induction of this resistance would barely be practical, but the resistance in a tuned shunt rejector should be as small as possible and contacts thoroughly good.

This experiment shows the great superiority of sample No. 6. This sample had been made up with much stouter connecting tabs than the others, and superiority may have been largely due to this fact. Condensers used in experimental tuned shunt rejector capacity were made up as sample No. 1. Condensers similar to sample No. 6 are now to be used.

The resistance of the thermal junction, being nearly 0·5 ohms, was much too large for this work. Thermal junctions of much lower resistance are about to be made up, and two of Duddell's "thermo-galvanometers" have been ordered for experimental work; they consist of extremely sensitive thermal junctions, and have been used to accurately measure the current in a receiving station 60 miles from a transmitting station with about the same power as the Service "B" tune. These instruments will be of the greatest use and make accurate measurements at the receiving end possible, which must lead to many most useful results, and will greatly simplify the experimental work.

TUNERS.

Tuners.

Experiments were made with different tuners to test their efficiency. Poldhu was received on a magnetic detector with a tuned shunt of 1,600 jars.

Tuner "A."—Marconi plug pattern of 7/20 gauge.
„ "B."—Of 20 gauge wound on beechwood and paper formers.
„ "C."—Ditto, wound on mahogany former.
„ "D."—Of 16 and 26 gauge wound on beech former.

Tuner.	Signals.	Resistance for Direct Current.
"A" - - -	Good - - - - -	0·3 ω.
"B" - -	Equal strength - - -	0·9 ω.
"C" - - -	Decidedly weaker - - -	0·9 ω.
"D" - -	Nearly equal to "A" - -	2·7 ω.

On account of the greater skin effect with "A," the resistance of the first three tuners was probably about the same for high-frequency currents, possibly about 1·5 ohms.

The difference between "B" and "C" must have been due to some loss in the wood or varnish used.

The resistance of "D" may have been about 3·5 ω for the high frequency. So that an increase of 2 ohm makes but a small decrease in strength of signals.

Further experiments were made confirming these results. The resistance of the tuner must be less, however, when its inductance is smaller.

TELEPHONE CONDENSER.

Telephone condensers.

When a condenser is used with the magnetic detector in parallel with the telephone, signals become clearer. It has been found that they become still clearer and sharper if the condenser is placed in series with the telephones. A capacity of between 50 and 100 jars is best when one pair of telephones is used, and between 100 and 200 jars when two pairs are used in parallel.

Two telephones on one M.D.

It was noted in H.M.S. "Royal Arthur" that one magnetic detector winding feeding two pairs of telephones in parallel is a much more sensitive arrangement than that using both windings of the magnetic, half the current from the aerial flowing through each primary, and one pair of telephones being connected to each secondary winding. This fact may have some connection with the critical current that is required by the magnetic detector suggested on page 32.