PRODUCTION OF DAMPED ELECTRIC WAVES

"Wissenschafliche Arbeit". Erzeugung gedämpfter elektrischer Schwingungen

Ausgeführt als Diplomarbeit an der Technischen
Hochschule "Fridericiana" zu Karlsruhe unter
Aufsicht des Herrn Professor Hausrath.

W. Herbert Murphy.

Zirkel. 26 Karlsruhe i. Baden.

A Thesis.

Wm H. Murphy. B.Sc.

The production of damped electric waves, using as a source of energy a low potential alternating current; the grouping of same to form impulses of the same order as those of audible notes:

Description.

Different methods of producing damped waves.

The aims of all systems using damped waves are, maximum transmission distance and freedom from interference by atmospheric or other disturbances.

1) The first condition, that is a long-distance transmission, depends on the energy radiated and will be discussed in brief.

Practice has established the fact that a close tuning is only possible when the energy radiated from the aerial is radiated slowly, that is when the damping in the secondary circuit is small and as the damping equals $\pi \cdot 2 R_{II} \sqrt{\frac{C_{II}}{L_{II}}}$ where R_{II} is the resistance C_{II} the capacity in farads and L_{II} the inductance in henries of the aerial circuit, it is seen that C_{II} must be as small as possible. A system such as the one being referred to can be indicated as in Fig. 1 or its equivalent Fig. 2. Circuit O. being the charging circuit

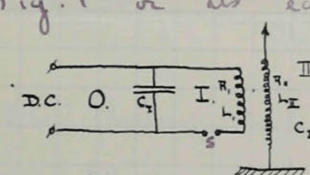

Fig. 1.

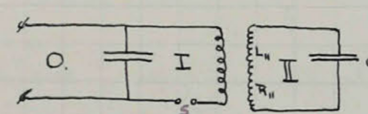

Fig. 2.

which includes only the leads from the direct current source and the condenser C_I, circuit I is the resonant circuit in which the capacity C_I the inductance L_I the sparkgap S and the resultant resistance R_I, the circuit II is a second resonant circuit which however does not contain a spark gap; in general $L_I C_I = L_{II} R_{II}$ but that this is not necessary will be seen later. It is clear that there is a connection between the energy radiated and the distance transmitted, in fact it is not difficult to see that the greater the energy the greater the distance at which a wave can be detected; vice versa therefore; to increase the transmission distance we must increase the energy radiated.

Now the energy radiated depends partly on the form of the antenna, or better, on the radiating qualities of same; the aerial being given, the energy depends on the current in circuit II and also on the damping of same, naturally also on the number of impulses pro unit of time, that is, the number of sparks pro unit of time in circuit I.

As most radiating systems of large radiating quality have a small capacity and as a high potential would be required to give a sufficient current by low impulse frequency, we can appreciate that a limit will very soon be reached over which the potentials cannot rise owing to insulation difficulties which do not include only the ordinary difficulties of breakdown but also cause a detrimental increase of the aerials damping! Such a system is the "Braun-Slaby-Arco" system in which a common spark gap is placed in the primary circuit, the secondary being closely coupled to same. The connections are shown in Fig. 1. On account of the close coupling we have, in accordance with theory and practice, two waves in the aerial, one slightly above, the other slightly below the true wavelength of the aerial, the divergence being greater the closer the coupling; only one of these waves is of use so that the energy radiated by the other is necessarily lost. Regarding the sparkgap, it is known that the passage of a spark heats the metal and thus ionizes the air in the gap, in this condition a much lower potential is required to pass over, it is as it were a greatly reduced resistance; this being the case the energy oscillating in II can by virtue of the close coupling produce a large enough potential in I to break over the gap, that this backaction is a loss is obvious.

A loose coupling will overcome this effect but at the same time our stray losses will increase so that no gain will be registered.

At best our energy in II is $a\frac{C_2V^2}{2}$ where V is the mean potential which, as has been said before, cannot be indefinitely high, a is the number of impulses received per second. This at once gives us a guide along which lines to proceed in order to increase the energy.
The number of discharges in an ordinary spark gap are from 20 to 30 per second, the periods of rest being about 500 times the periods of discharge. If now we could produce from 500 to 2000 discharges per second we would have a tone, if more than this number, groups could be formed, the frequency of which should lie within the audible range. It should be noted that our energy being now distributed it is only necessary to work with lower potentials and still to obtain more energy than previously.

2) The second condition, that is freedom from interference is met so long as we have a musical note, primarily because the receiver can be tuned very accurately to a clear note and secondly because interference will be distinguished if at all noticeable as a crackling noise if atmospheric or as hisses or notes of other heights if originating from other stations.

The spark frequency.

We have noted the effect of the ionization of the spark gap; could we use a gap with quick disionizing qualities it is obvious that once the energy was stored in the secondary the potential there induced in I from II would not be sufficient to break over the gap, another point would be that the closer the coupling the quicker the energy from I would be transferred to II and thirdly the quicker I resumes its state of rest the sooner can the cap C_I be charged that is the greater the spark frequency.

To obtain a disionizing sparkgap it is only necessary to increase the cooling of same which is done by either placing the gap in hydrogen, in which case one plate is concave the other convex so that the sparks will occur at different points; or else to use a series gap in which the gaps are about 0,2 mm apart. The latter has the advantage that a higher potential can be used.

Wiens system.

We are now able to extinguish our spark gap at the instance the total energy is in II and thus to obtain a quickly damped oscillation in I, as would have been the case with the Braun circuit using a loose coupling only that here no energy or at least much less energy is lost a stray loss between I & II. Figure. 3 and 4 show roughly was is meant; in both cases the aerial or secondary circuit is open. Fig 3 is with the use of an ordinary gap Fig 4. with use of a series gap. T_0 is the time of charging C_I

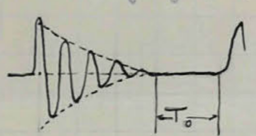

Fig. 3

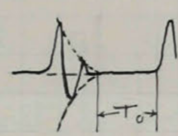

Fig. 4.
15 - 20% coupling

If we consider the secondary closed and closely coupled then in the case of the Braun circuit I & II will swing as in Fig 5, in the case of the Wien circuit I & II will swing according to Fig. 6 which is also similar to the Braun case with loose coupling only ~~that~~ the amplitudes are of course larger. It should be noted that in the Wien system I can be charging in the time T_0 so that the next wave in II joins the last of the previous groups. It might here be mentioned that T_0 being small enough & the damping in II small enough, the groups can be made to overlap, we would thus have an undamped train of waves.

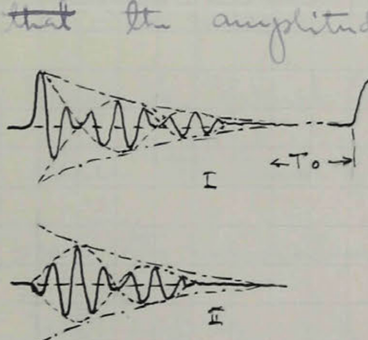

Fig. 5

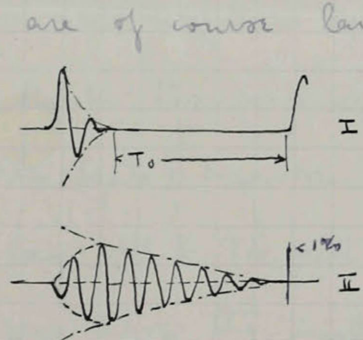

Fig 6.

Regarding Fig. 5 it will be noted that the energy is radiated in beats instead of continously, that part swinging in I is therefore a loss.
In the Wien circuit we noted that the capacity C_I could be charged while I was swinging and this should of course be aimed at as it will be the most efficient utilization of the time.

Ideal impulses.

Regarding what has been shown in the last chapter we can say that the better the quick extinction action of the gap the closer can the coupling be made, as the secondary will swing by itself after the first half beat. Now the time of the half beat depends on the coupling, (with a coupling one, that is with direct and not induction coupling, the time would be that of one fourth period) therefore from the above we can say; the better the gap, the shorter the time of the half beat. If now we have brought our conditions so far that we have only one half swing in I then we have what is called an ideal impulse; regarding same we at once note that there will be no need for tuning provided the period of the secondary is not greatly at variance with the actual periodic time of the primary; certainly changes can be made in the period of the secondary great enough to bring the secondary out of tune with a receiving system.

To produce this ideal impulse one cannot, as would at first be imagined, proceed to tighten the coupling, (although this would of course reduce the time of the beats) because even with this quick extinction gap the ionization lag will be too great referred to the length of the beat and we would again have the inefficient oscillating between the primary and secondary althoug of course at a much quicker rate; so it is that a coupling greater than 20-30% can not be used, where the coupling means mutual inductance divided by the square root of L_I times L_{II}

There are two obvious solutions by which one half period or better one impulse can be obtained; one would be to increase the extinction action or disionizing action of the gap, the second to discharge the condenser aperiodically.

The first solution was found by Boas who constructed a series gap of wolfram buttons which are as suitable but cheaper than platinum, with such a gap it is possible to stop the oscillations at the end of the first half-period thus causing the spark to act directly as an interrupter in the primary circuit, the energy being transferred inductively to II which need of course not be tuned to I. Other advantages are that the coupling can be greater than 30%, that the stray-losses are therefore reduced & the efficiency increased, to this is added the fact that only one discharge takes place across the gap so that no further losses occur here and the gap remains cool.

The second solution was discovered by Rein who made the discharge aperiodic and used the quick extinction gap in a hydrogen atmosphere. The impulse is quite as sharp in the previous method due to the fact that the spark which might as well be spoken of as an arc, in this condition, increases rapidly in resistance as the current decreases so that this increase of resistance is superimposed on the actual aperiodic phenomenon and thus decreases the time by which the current is again say 1% of the maximum value.

To bring this more clearly* it will be best to follow the occurances as they take place in such a circuit, Before the gap can jump over, our condenser must have been charged, the instant the critical potential has been reached the condenser discharges so that a current i_2 from the condenser and the constant current i will flow through the gap; the gap being

*Dr. Glatzel Helios Nr. 11. XIX 1913.

heated by the discharge, ions are produced and tend to reduce the resistance of the gap. Our current which naturally rises of its own accord will in this case rise the more quickly as the resistance decreases; the fact that the emission of electrons is about proportional to the square of the current accounts for the fact that the potential across the gap will be less than it was before. In the meantime the current has reached its maximum value, (which will be about the value calculated using the mean value of the resistance for the time in question) which will be the higher and have been reached the sooner, the lower the resistance has dropped; the same is true for the current decrease, the greater the disionizing the steeper the fall of current so we see the importance of using a wolfram or hydrogen gap. Most of our energy has now been transferred to the secondary especially if our circuit was aperiodic, if not quite but nearly aperiodic the effect will be the same with the following continuation.

Some of the energy not having been held this energy will have stored itself in the capacity again; on discharging, the current i_2 will flow in the opposite direction to which it did before in fact it will flow against the current i from the direct current source, if now i_2 is slightly larger than i we see that the current i_1 is reduced to zero and then made negative and the arc will necessarily go out, if now i_2 and i are nearly equal $i_2 - i$ will be negligible. The current in the arc is shown in Fig. 7. a. the current in the swinging circuit in Fig 7. b the charging current being red.

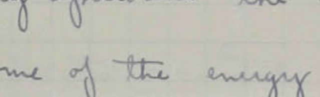

Fig 7 a

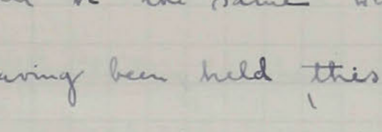

Fig 7 b

The dotted line. shows the discharge if the resistance were const.

T_0 the time of charging is smaller the smaller the capacity and the greater the potential E. The smaller T_0 the smaller can T_1 be made, but T_0 should be so long that our secondary can swing out therefore C_I will be made large.

It will be sufficient to mention the fact that if i can continue flowing that is if the potential has not been reduced sufficiently to extinguish the arc, we will have a pulsating effect which is not wanted, if on the other hand the potential of reversal is great enough the arc can be formed again so that we have a continuous swinging which would be of use in case undamped waves were wanted but which in this case are also not desired.

The charge of the primary circuit Capacity.

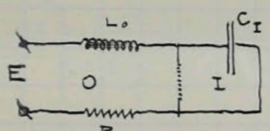

Fig 8

If E is the D.C. source L_0 a choke coil R_0 a resistance and C_I the capacity then the inductance L_I which is very small compared with L_0 can be neglected.

The potential on the capacity $e_c = \frac{1}{C}\int i\,dt$ i being the current in the circuit R_0 consumes $R_0 i$, L_0 consumes or rather stores $L_0\, di/dt$ and C_I stores $\frac{1}{C}\int i\,dt$ the total E is therefore equal to $R_0 i + L_0\, di/dt + 1/C_I \int i\,dt$ on the other hand

$e_c = E - R_0 i - L_0\, di/dt$ (1) differentiating we have $\frac{1}{C_I} i = 0 - R_0\frac{di}{dt} - L\frac{d^2 i}{dt^2}$

set $i = A\varepsilon^{-\alpha t}$ then $di/dt = -\alpha A\varepsilon^{-\alpha t}$ and $d^2i/dt^2 = \alpha^2 A\varepsilon^{-\alpha t}$

therefore $L_0\frac{d^2 i}{dt^2} + R_0\frac{di}{dt} + \frac{1}{C_I} i = 0 = \left(\alpha^2 L_0 - \alpha R_0 + \frac{1}{C_I}\right)A\varepsilon^{-\alpha t}$ $\therefore \alpha^2 L_0 - \alpha R_0 + \frac{1}{C_I} = 0$

and $\alpha = \frac{R \pm \sqrt{R^2 - 4L/C}}{2L}$ $\alpha_1 = \frac{R - \sqrt{R^2 - 4L/C}}{2L} = \frac{RC - \sqrt{R^2C^2 - 4LC}}{2LC}$

$\alpha_2 = \frac{R + \sqrt{}}{2L} = \frac{RC + \sqrt{R^2C^2 - 4LC}}{2LC}$ the general solution for i is therefore

$i = A_1\varepsilon^{-\alpha_1 t} + A_2\varepsilon^{-\alpha_2 t}$ (2) substitute i in equation (1) and we have

$e_c = E - R_0 A_1\varepsilon^{-\alpha_1 t} - R_0 A_2\varepsilon^{-\alpha_2 t} + L_0\alpha_1 A_1\varepsilon^{-\alpha_1 t} + L\alpha_2 A_2\varepsilon^{-\alpha_2 t}$

rearranging we have $e_c = E - \frac{R_0 + \sqrt{R^2 - 4L/C}}{2}A_1\varepsilon^{-\frac{R_0 - \sqrt{R^2-4L/C}}{2L}t} + \frac{R_0 - \sqrt{}}{2}A_2\varepsilon^{-\frac{R+\sqrt{}}{2L}t}$

at the time $t = 0$ $i = 0$ $e_c = 0$ $i = i_0 = A_1 + A_2$ & $e_0 = E - \frac{R+\sqrt{}}{2}A_1 + \frac{R-\sqrt{}}{2}A_2$ $\therefore A_1 = -\frac{e_0 + E + \frac{R-\sqrt{}}{2}i_0}{\sqrt{R^2+4L/C}}$ and $A_2 = \frac{e_0 - E + \frac{R+\sqrt{}}{2}i_0}{\sqrt{R^2+4L/C}}$

Substitute again as $e_0 = 0 = i_0$

and $A_1 = \frac{E\cdot C}{\sqrt{R^2C^2+4LC}} = -A_2$ $i = \frac{EC}{\sqrt{R^2C^2+4LC}}\left\{\varepsilon^{-\alpha_1 t} - \varepsilon^{-\alpha_2 t}\right\}$ (3)

and $e_c = E\left\{1 - \frac{C}{2\sqrt{R^2C^2+4LC}}\left[\left(R + \frac{\sqrt{}}{C}\right)\varepsilon^{-\alpha_1 t} - \left(R - \frac{\sqrt{}}{C}\right)\varepsilon^{-\alpha_2 t}\right]\right\}$ (4) Note $EC = Q$

Steinmetz. Trans. El. Phenom.

ε_c being given we can therefore calculate the time of charging.

If we consider the energy equation we note that the energy at any instant is $E\,i$ watts, neglecting L we say that i^2R. is lost as heat and $\frac{q}{C_x}\,i$ is stored in the capacity. $E\,i = i^2R_0 + \frac{q}{C_x}\,i$

for the complete charge the energy is $A = \int_0^\infty E\,i\,dt = \int_0^\infty i^2R\,dt + \int_0^\infty \frac{q}{C}\,i\,dt$

substituting $i = \frac{E}{R}\varepsilon^{-\frac{1}{RC}t}$ and $i\,dt = dq$ we have $A = \frac{E^2}{R}\int_0^\infty \varepsilon^{-\frac{t}{RC}}\,dt =$

$$\frac{E^2}{R}\int_0^\infty \varepsilon^{-\frac{2t}{RC}}\,dt + \frac{1}{C}\int_0^Q q\,dq = \frac{E^2}{R}\left[RC\right] = \frac{E^2}{R}\left[\frac{RC}{2}\right] + \frac{Q^2}{2C}$$

but $E = Q/C$ ∴ $Q^2/2C = E^2C/2$ ∴ $\underline{E^2C = \frac{E^2C}{2} + \frac{E^2C}{2}}$ from this we see that however we may charge C_x only 50% of the energy expended is available, that is that the efficiency is 50%.

In the case last concerned $R^2 > \frac{4L}{C}$ or $R^2C^2 > 4LC$ that is we dealt with an aperiodic charge, if however $R^2C^2 < 4LC$ our discharge is oscillatory and we will consider the equations. Steinmetz.

$\sqrt{R^2 - \frac{4L}{C}} = \alpha$ is imaginary $= j\xi$ ∴ $\xi = \sqrt{4L/C - R^2} = \frac{\sqrt{4LC - R^2C^2}}{C}$

$a_1 = \frac{R+j\xi}{2L}$ $\quad a_2 = \frac{R-j\xi}{2L}$ $\quad$ ∴ $i = A_1\varepsilon^{-\frac{R+j\xi}{2L}t} + A_2\varepsilon^{-\frac{R-j\xi}{2L}t}$

$= \varepsilon^{-\frac{R}{2L}t}\left\{A_1\varepsilon^{\frac{j\xi}{2L}t} + A_2\varepsilon^{-\frac{j\xi}{2L}t}\right\}$ $\qquad e_c = E - \varepsilon^{-\frac{R}{2L}t}\left\{\frac{R+j\xi}{2}A_1\varepsilon^{+\frac{j\xi}{2L}t} + \frac{R-j\xi}{2}A_2\varepsilon^{-\frac{j\xi}{2L}t}\right\}$

$\left[\varepsilon^{j\xi} = \cos\xi + j\sin\xi\ ,\ \varepsilon^{-j\xi} = \cos\xi - j\sin\xi\right]$ ∴ $i = \varepsilon^{-\frac{R}{2L}t}\left\{(A_1+A_2)\cos\frac{\xi}{2L}t + j(A_1-A_2)\sin\frac{\xi}{2L}t\right\}$

$B_1 = A_1 + A_2$ $\quad B_2 = j(A_1 - A_2)$ $\quad$ then $i = \varepsilon^{-\frac{R}{2L}t}\left\{B_1\cos\frac{\xi}{2L}t + B_2\sin\frac{\xi}{2L}t\right\}$.

$e_c = E - \varepsilon^{-R/2L\,t}\left\{\frac{RB_1+\xi B_2}{2}\cos\frac{\xi}{2L}t + \frac{RB_2-\xi B_1}{2}\sin\frac{\xi}{2L}t\right\}$

for $t=0$ $\quad i=i_0$ $\quad e_c=e_0$ $\quad$ ∴ $i_0 = B_1$ & $e_0 = E - \frac{RB_1+\xi B_2}{2}$ $\quad$ ∴ $B_1 = i_0$ $\quad B_2 = \frac{2(E-e_0) - Ri_0}{\xi}$

i_0 being 0 & e_0 being 0 we have for charge

$i = \frac{2E}{\xi}\varepsilon^{-R/2L\,t}\sin\frac{\xi}{2L}t$ and $e_c = E\left\{1 - \varepsilon^{-R/2L\,t}\left(\cos\frac{\xi}{2L}t + \frac{R}{\xi}\sin\frac{\xi}{2L}t\right)\right\}$

It has been shown before that the efficiency is 50% when we charge the capacity to its full amount, we are however interested to investigate the η at the point of highest voltage.

In case R^2C^2 is negligible compared to $4LC$ then $e_C = E - E' \cos 2\pi nt$ or $= E\left\{1 - \varepsilon^{-\frac{R}{2L}t} \cos \frac{t}{LC}\right\}$

and $i = E\sqrt{\frac{C}{L}}\, \varepsilon^{-\frac{R}{2L}t} \sin \frac{1}{\sqrt{LC}} t = I' \sin 2\pi nt$

We have shown that $e_C = E - E\varepsilon^{-\frac{R}{2L}t} \cos \frac{\sqrt{4LC - R^2C^2}}{2LC} t + \frac{RC}{\sqrt{4LC - R^2C^2}} \sin \frac{\sqrt{4LC - R^2C^2}}{2LC} t$

and have said that $e_C = E - E' \cos 2\pi nt = E - E' \cos \frac{\sqrt{4LC - R^2C^2}}{2LC} t$

from this we find that $E' = E\varepsilon^{-\frac{R}{2L}t} + \frac{E\varepsilon^{-\frac{R}{2L}t} RC}{\sqrt{4LC - R^2C^2}} \tan \frac{\sqrt{4LC - R^2C^2}}{2LC}$

if now to simplify matters R^2C^2 is neglible and $\frac{R}{2L} \doteq 0$ we can write

$E' = E + E\frac{RC}{2\sqrt{LC}} \tan \frac{1}{\sqrt{LC}}$ if therefore our gap is so set as to allow the same to break down at a potential nearly equal E' we will have a higher efficiency than 50%. The energy stored at the point of maximum potential is $\frac{E'^2C}{2} = \frac{E^2C}{2}\left(1 + \frac{R}{\sqrt{LC}} \tan \frac{1}{\sqrt{LC}} + \frac{R^2}{4L} \tan^2 \frac{1}{\sqrt{LC}}\right) < \frac{4E^2C}{2}$ & $> \frac{E^2C}{2}$

We can therefore reach an efficiency, by using an oscillatory charge, of nearly 100%, practically about 75%.

Discharge of the Condenser.

If our condenser has been charged to a point at which the spark gap breaks down we are at once concerned with the oscillatory circuit the period of the charging circuit being so low in comparison that the total energy can be practically said to swing in I. Considering the aperiodic case we have E_c the potential, C_I the capacity L_I the inductance and R_I the resistance of the inductance + the resistance of the circuit + the mean resistance of the gap. e_c the instantaneous potential at the condenser is $= \frac{E_cC}{2\sqrt{R^2C^2 - 4LC}}\left\{\left(R + \frac{\sqrt{\ }}{C}\right)\varepsilon^{-\frac{RC - \sqrt{\ }}{2LC}t} - \left(R - \frac{\sqrt{\ }}{C}\right)\varepsilon^{-\frac{RC + \sqrt{\ }}{2LC}t}\right\}$ and $i = \frac{E_cC}{\sqrt{\ }}\left\{\varepsilon^{-\frac{RC - \sqrt{\ }}{2LC}t} - \varepsilon^{-\frac{RC + \sqrt{\ }}{2LC}t}\right\}$ as before.

assuming that the current curve returns to zero not at infinity but at a time about thrice the time of reaching its maximum owing to the disionizing of the gap, it would be important to know the length of time required to reach the maximum. If we set α_1 for $\frac{-RC - \sqrt{R^2C^2 - 4LC}}{2LC}$ & α_2 for the other root then $i_c = \frac{E_cC\,\alpha_1\alpha_2}{\alpha_2 - \alpha_1}\left(\varepsilon^{+\alpha_1 t} - \varepsilon^{\alpha_2 t}\right)$

differentiating this we have $\frac{di}{dt} = \frac{\alpha_1\alpha_2 E_c C \alpha_2 \epsilon^{\alpha_2 t} - \alpha_1 \alpha_2 E_c C \alpha_1 \epsilon^{\alpha_1 t}}{\alpha_2 - \alpha_1} = 0$

$\therefore \alpha_1 \epsilon^{\alpha_1 t} = \alpha_2 \epsilon^{\alpha_2 t}$ $\quad \frac{\alpha_2}{\alpha_1} = \epsilon^{t(\alpha_1 - \alpha_2)}$ $\quad \log_\epsilon \frac{\alpha_2}{\alpha_1} = t(\alpha_1 - \alpha_2)$

$t = \frac{\log_\epsilon \alpha_2 - \log_\epsilon \alpha_1}{\alpha_1 - \alpha_2}$ the time the current is 0 & the potential also 0 will therefore be xt where x it has been assumed will be about 3. Certainly x will depend on the dissionizing ability of the gap, so that no fixed value can be calculated. Calling the time of charging the capacity T_0 and the time of discharging T_1 we can say that the time of one half period in II will have to be less than $T_0 + T_1$ which it of course will be.

The maximum effect will be when one half period of the wave in II is equal to the time T_1

Similarly if our discharge is oscillatory $i = -\frac{2E_cC}{\sqrt{4LC - R^2C^2}} \epsilon^{-\frac{R}{2L}t} \sin \frac{\sqrt{4LC - R^2C^2}}{2LC} t$

set $\delta = \frac{R}{2L}$ and $\frac{\sqrt{4LC - R^2C^2}}{2LC} = \omega$

then $\frac{di}{dt} = + \frac{2E_cC}{\sqrt{4LC - R^2C^2}} \delta \epsilon^{-\delta t} \{-\delta \sin \omega t + \omega \cos \omega t\} = 0$

$\omega \cos \omega t = \delta \sin \omega t$ $\quad \frac{\omega}{\delta} = \tan \omega t$ that is $\frac{\sqrt{4LC - R^2C^2}}{2LC} \cdot \frac{2L}{R} = \tan \frac{\sqrt{4LC - R^2C^2}}{2LC} t$

$= \frac{\sqrt{4LC - R^2C^2}}{CR}$ in case R^2C^2 is negligible we can say

$\frac{2}{R}\sqrt{\frac{L}{C}} = \tan \frac{1}{\sqrt{LC}} t$

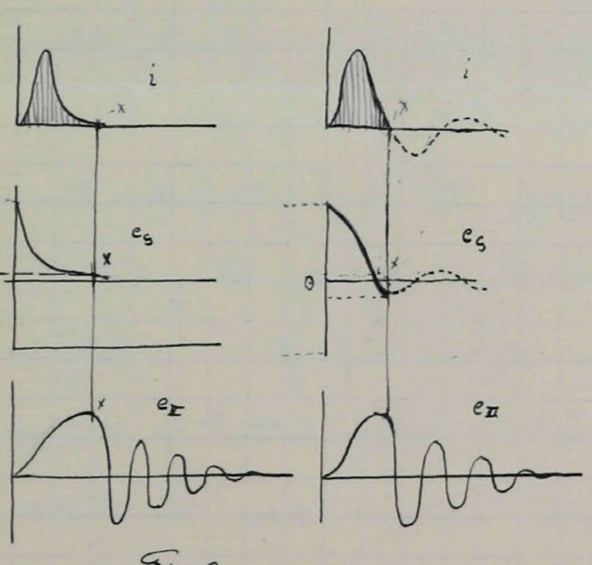

Fig. 9

Fig. 9 will show the two modes of discharge. The figures on the left represent the aperiodic discharge, those on the right the periodic. The upper row shows the current in the gap, the middle row the potential and the lower row the potential induced in the secondary by the current i flowing in the coil L_I.

x is the point at which the gap extinguishes.

Note that in the aperiodic case the current and potential are both nearly zero at close, while in other case potential is a maximum but below critical height.

We have said that the damping of I must be large so that the second halfperiod will lie far below the instantaneous critical value of the spark gaps, or else that an aperiodic discharge is necessary; in the former case ϑ_1, the logarithmic decrement of the damping is $\delta T = \frac{R_I T}{2 L_I} = \frac{R_I}{2 L_I n} = \pi R \sqrt{\frac{C_I^F}{L_I^H}} = \frac{1}{150} \frac{C_I^{cm} R_1^{\omega}}{\lambda^m}$ where λ is the wavelength in meters. ϑ_1 increases as the energy drawn by II increases, that is R^{ω} increases as R does not depend only on circuit I but also on circuit II, from this we see that we must work with the largest permissible coupling; an increase of C will naturally increase ϑ but the current amplitude would also increase and thus impair the extinguishing action of the gaps.

The production of a tone.

We have said before that to have a tone it will be necessary either to have one discharge per wave or else to have a large number in groups. If our circuit I is so calculated as to give 1000 sparks per second we will have a certain tone which tone can be improved by regulating the sparking by means of a toothed wheel in I, obviously our number of sparks per second being fixed the tone cannot be increased we can however obtain 1/2, 1/3 1/4 etc. the number of sparks or impulses by rotating our wheel more slowly. To obtain impulses more equivalent to sound impulses it has been found that a large number of impulses in groups were most satisfactory; as the efficiency of this method is of course greater owing to the greater number of discharges per second it is of course the method adopted. If for example we have 20000 discharges per second and we have a toothed wheel rotating in I in such a manner that 1000 contacts are made a second then we would have 20 swings from contact to contact, if now the time of contact was one fourth the time from contact to contact we would have 5 swings per group as shown in Fig 10 which shows circuit II.

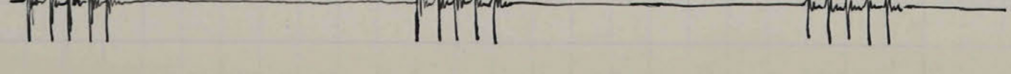

Fig 10

Another and better means whereby a tone can be produced is by placing a second circuit parallel to the gap, this circuit can be so designed as to give the same action as a Duddel musical arc, thus causing a discharge to jump the gap or part of the same and consequently to allow the main condenser to discharge regularly and at a lower potential than it would otherwise have done. Fig. 11 shows the circuit in question.

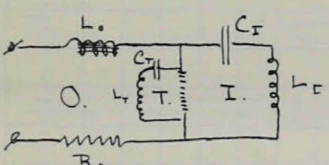

Fig 11.

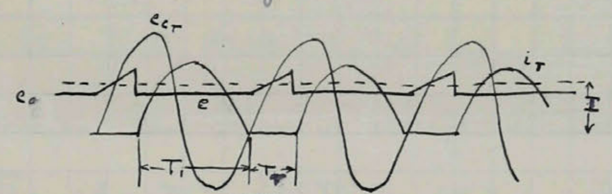

Fig 12.

<u>The period of the tone circuit.</u>

Assume i_0 constant and that potential at the gap is constant during the short time of discharge. T_1 lies between the values $\pi\sqrt{L_T C_T}$ and $2\pi\sqrt{L_T C_T}$ according to whether $i_0/I_T = 0$ or 1. T_T depends on the time required for C_T to charge. If L_0 or R_0 are sufficiently large, the charging curve is straight, T_T decreases with increasing i_0, with decreasing capacity C_T and decreasing spark potential e_s at gap.

$n_T = \frac{1}{2\pi\sqrt{L_T C_T}}$ The smaller the capacity and the gap potential, the more nearly does the equation for n_T hold, because T_T and the time of charge are identical. As the periods T_T can not be kept constant owing to variations in the condition of the gaps, it is clear that T_T must be made as short as possible, so that a small change in T_T will have less effect on the tone, this can be done when I_T the max. current in the tone circuit is about equal to I of the direct current line. In circuit I. we are desirous of having a large energy production, therefore C_I must be as large as possible L_I as small as possible, L_I being limited by the fact that enough turns must be left in order to couple II. to I. C_I^{cm}/L_I^{cm} can be said to be about 50. The stronger the damping and the greater T_a with respect to T_1, the nearer do we come to the ideal impulse excitation. On the other hand in T we only wish to obtain good sine waves here the periods of rest T_{T_0} are to be as short as possible. The energy is only to be so great as to make the guiding action sure and accurate. L_T should therefore be large C_T small $C_T^{cm} \div L_T^{cm} = 0,0025$ I_T should be about equal to I of D.C. line. It is necessary to mention the fact that C_I is being charged at the same time as C_T that therefore the time of charge is reduced somewhat say about ,76 %. The advantages of this system are the possibility of acoustic tuning and the large range of tone variation.

If our circuits are now correctly dimensioned and we wish to change the tone it is obviously only necessary to vary C_T or L_T if on the other hand our tone is to be constant and the wave length altered we will only vary C_{II} or L_{II}. Regarding the tone circuit T we see that we have a pulsating current as the tone circuit current whose maximum value is about equal to I_{dc} is added to the direct current. For any values of the period, the instant the potential in C_T has risen high enough to cause the gap to break down, the electricity stored in C_I up to that instant will be discharged in one impulse and falls off so quickly that no appreciable energy can be delivered by the tone or D.C. circuits; as soon as the discharge is completed C_I charges again as the gap is now non conducting. Charges and discharges now follow each other until the pulsating current has reached zero, from this point on the caps C_T and C_I load again and the cycle repeats itself. If the loading of C_T takes place quickly enough, we can see that a larger groups can be built up than when using a toothed wheel, a better tone is thus produced and the transmission facilitated.

If now we change the capacity C_T or L_T considerably in the desire to obtain a different tone, we are at once confronted by the fact that the current amplitude of both circuits will have changed. We are interested in circuit T and note that if a change has taken place the maximum value of the current i_T which is I_T will not be about equal to I_{DC} but will either be considerably larger or smaller. If smaller we have swings of type one in which the current never reaches zero and the arc consequently does not extinguish itself, this is of course not desired, if on the other hand the current maximum is so much larger than I_{dc} that a negative current can flow then our light will again not extinguish itself. We see therefore that although this system allows tone variations the range of variation is limited.

Another difficulty is that owing to the fact that the potential is about 5000 volts, the potential maximum will be nearly 10000 volts, that our capacity will therefore have to be insulated and built for a still higher potential, but as the energy to be delivered is low and our capacity will only be of the range of 10 microfarad we see that its expense will be relatively great.

A better way of acting on the circuit and the one adopted by us is similar to the arrangement described by Glatzel in Helios XIX 1913 Fig. 13

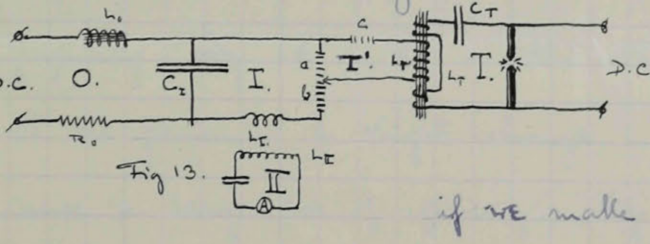

Fig 13.

If we consider C_I charged and at its highest potential nearly 2E and if we make the gaps a + b or c + b so great that no discharge can take place then we have the conditions from which to start. Obviously it will be necessary that a and c be equal, for if not then a + b or c + b will be the smaller and the discharge take place along the smaller, the presence of $L_{T'}$ will however allow c to be somewhat smaller than a. If now we produce electric swings in our Duddell circuit T and transform the potential up by means of an induction coil or transformer to a value sufficient to break down the gaps a + c then as far as I. is concerned a and c are shortcircuited, if now the potential of C_I is high enough to cover this distance b we will have a discharge. The maximum potential being just sufficient to break over b we will have only one impulse per charge of C_I naturally however C_I can charge and discharge a number of times while a and c are shortcircuited and this is the condition desired, we will then get groups of waves as in Fig. 10. Before our potential in T' has again reached a height sufficient to break over a + c we must note that our capacity C_I will have been charged but that in this case the potential will be E_c and not nearly double that value it will therefore on consideration be necessary to so dimension the gap that E_c will be sufficient to break it down, this means that at the next charge our potential will never reach the value 1,7 E_c or whatever it may be, the energy stored will be less but the time of reaching E_c being less than the time of reaching the maximum we will have a greater number of impulses per unit of time. Circuit II will necessarily have to be so dimensioned that the oscillations fall off to an inappreciable value before the next impulse occurs in order to have a most efficient radiation at any desired frequency Fig. 14. If on the other hand the waves overlap and fit together at one frequency a slight change in the spark- or the secondary- frequency will cause a large loss of efficiency. Fig 15 b. If on the other hand we are to work

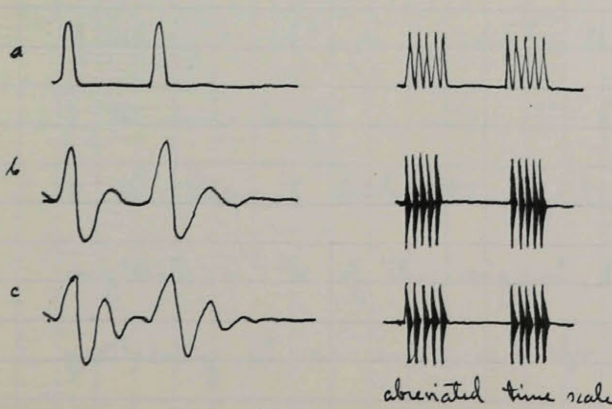

Fig. 14.

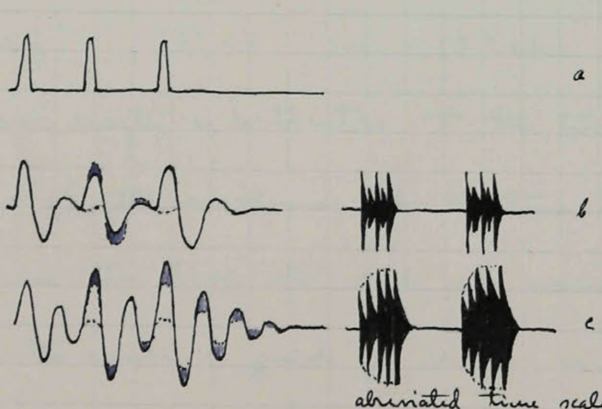

Fig 15.

with a constant wave length then a cumulative effect as in 15 c will be of value.

In 15 b the red areas are losses in 15 c they are gains.

Another advantage of the system is that the capacity in the tonecircuit will only have to be built for a low voltage and consequently be cheaper than in the previous case, our regulating is all done at a low voltage so that there is freedom from danger and most important of all C_T and L_T can be varied as much as desired without affecting the time of charge of C_I except inasmuch as the time of short-circuit of gaps a and c is altered. We have an independence between C_I and C_T which is therefore valuable because it allows us to increase our tone range considerably. It will have been noted that the circuit c $L_{T'}$ b L_I C_2 is a circuit which has resonant qualities, b should therefore be too large for our tone potential so that the action of this circuit be negligible.

The tests and experiments.

The original purpose of our investigation having been the guiding of the high frequency waves by means of a telephone and this part of the research not having thus far been fulfilled, owing partly to the pulsating source of our direct current; it has been thought better not to include these experiment in the following in spite of the fact that a considerable time was spent in their behalf.

Formulae used and apparatus.

1 farad = $9 \cdot 10^{11}$ cm   1 μf (microfarad) = $9 \cdot 10^5$ cm   1 cm = $1{,}11 \cdot 10^{-6}$ μf

1 henry = 10^9 cm   1 mh (millihenry) = 10^6 cm   1 cm = 10^{-6} mh

λ the wave length in meters λ^{cm} the wave length in centimeters T the time of one period τ the time at which the amplitude is $1/\varepsilon$ the maximum, A the time at which the amplitude is 1% of the original, that is the time after which we assume the oscillation practically at an end. $n = \frac{1}{T}$ is the number of periods per second, m is the number of periods in the time A.

ϑ is the logarithmic decrement of the damping δ the damping factor.

$\lambda^{cm} = 2\pi\sqrt{L^{cm} C^{cm}} = 2\pi\sqrt{L^{H} \cdot C^{F} \cdot 9 \cdot 10^{20}}$ $T = 2\pi\sqrt{L^{H} C^{F}} = 2\pi\sqrt{L^{cm}\, C}$ electromag units

$\lambda^{cm} = 3 \cdot 10^{10}\, T$ $T = 1/n$ $\delta = \frac{R}{2L^{H}}$ $\frac{1}{\delta} = \tau = \frac{2L^{H}}{R}$

$\vartheta = \delta T = \pi R \sqrt{\frac{C^{F}}{L^{H}}} = \frac{1}{150}\frac{C^{cm} R}{\lambda^{m}} = \frac{1}{0{,}591}\frac{\lambda^{m} R}{L^{cm}}$ $\frac{1}{\vartheta} = \frac{\tau}{T} = n$ of swing to $\frac{1}{\varepsilon}$ th value of maximum.

$\tau = \frac{1}{\delta} = \frac{2L^{H}}{R}$ $\frac{\tau}{T}$ is $\therefore \frac{1}{\vartheta}$ and gives the number of swings as τ is the time of the swings and T is the time of one swing.

Time of swings to 1/100 of original value. A is original amplitude and $A/100$ the last amplitude in our series. $\frac{A}{A/100} = \frac{100}{1} \cdot \frac{e^{-\delta t}}{e^{-\delta(t+mT)}} = e^{\delta m T}$

$\therefore \log_e 100 = \delta m T = 4{,}605$ m is therefore equal $\frac{4{,}605}{\delta T} = \frac{4{,}605}{\vartheta}$

the time for one swing is T for m swing Tm but m is $\frac{4{,}605}{\delta T}$ therefore the time $A = \frac{4{,}605}{\delta}$ $\underline{m = \frac{4{,}605}{\vartheta}}$ $\underline{A = \frac{4{,}605}{\delta}}$

Our aim being primarily the production of ideal impulses we used the Wien circuit with a special Wolfram series gap. As source for our energy we used a 4000 Volt direct current generator of 8 KW capacity, no success was to be recorded as the gaps were continually being burnt together, indicating that the energy was too great. Even under the best conditions of operation the gaps were in a few moments too hot to handle; another inconvenience was that the gap extinguished so soon as the secondary circuit was put into operation due to losses in the gap.

A more convenient apparatus and one having been loaned to us for this very purpose by the manufacturer, was next erected and brought into operation. The apparatus which was originally intended for X ray use consists of a transformer a synchronous motor and a large micanite disc on which are mounted two copper segments of 90 degrees arc each. The synchronous motor which is fed by the same single phase current as the transformer has this commutating disc mounted on its axis; two brushes 180° apart connected to the high potential terminals of the transformer are so placed that they can make contact with the rotating copper segments; less than 90° behind these brushes, that is with regard to the direction of rotation of the plate, there are two other brushes which in turn are connected with the high-tension terminals of the apparatus. The regulation was such that one, two, three, or four coils could be used in the primary of the transformer, besides this resistances in series with the coils could also be varied or cut out thus giving a considerable range of voltage and current.

To obtain an estimate of the current the machine could supply the following test was made (Fig 16) A micrometer spark gap was put across the circuit in order to be able to judge the potential. The three capacities were placed in the circuit in order to absorb the pulsations in the circuit,

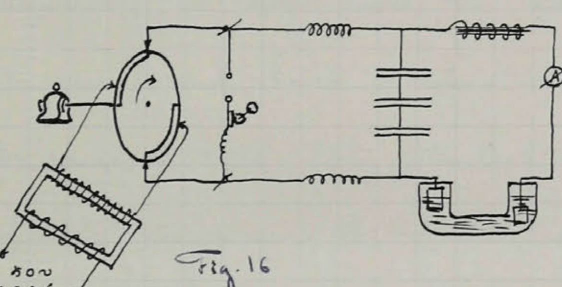

Fig. 16

their capacity was found to be ,01 μf or 9000 cm; an induction coil was placed in the line and used as a choke coil, while a water rheostat was used as a resistance. Previous measurements showed that the resistance was 102000 ohms so that on reading ,035 amperes on the hotwire instrument, the voltage could be calculated as 3000 Volts which was in accord with values measured at the spark gap. Using a smaller resistance we were able to measure ,1 ampere a current far in excess of that delivered by a Wimhurst machine for instance. To obtain an idea of the wave shape of the potential it occurred to us that a glimmlight oscillograph could be used. This consisted of a vacuum tube in which two rectangular metal plates were used as electrodes, in combination with this apparatus a rotating mirror was necessary which latter was made in the workshop. The glimmtube has the peculiarity that a glow or cathode light forms on the cathode the length of which glow is nearly proportional to the potential on the tube. If therefore this light be regarded in a rotating mirror an accurate idea can be formed of the shape of the waves in general.

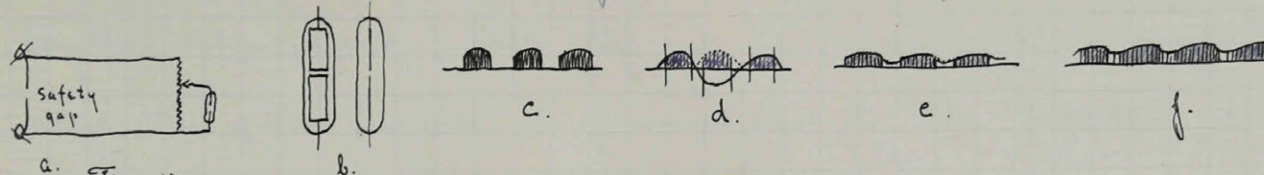

Fig. 17.

With no resistance in the circuit the picture seen in the rotating mirror was as shown in 17c, that this is correct can be seen by comparing same with d which shows the effect of rectifying the current.
On placing a choke coil of 200 henries in the circuit the picture was seen to be broader than before c. In connection with this point it is necessary to say that on testing the glimmlight on an alternating current it was found that a glow did not occur under 500 volts, it can therefore be judged that the potential actually varied according to the upper line of the curves. A capacity of .04 μf across the terminals served still further to smoothen out the impulses, at best we still had a pulsating circuit however. A threephase converter has been designed and is being constructed in the workshops but has unfortunately not been completed in time to bring results of the tests into this thesis.

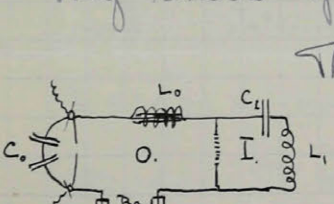

Fig 18

The production of damped oscillations; the charging circuit C_0 acts chiefly to smoothen out the impulses of our supply it also acts of course to increase the period of swing of circuit O. as compared to the period of I. which is what is desired as in that case the total energy collected in C_I will swing in circuit I. C_0 was at first taken equal to ,01 μf L_0 equal to 100 henries and 3400 ohms resistance and R_0 = 100,000 ohms. The sparks across the series gaps were rare and weak, by reducing L_0 and R_0 however the strength of the sparks increased as also did their number.

Leaving off C_0 caused the sparks to be very weak but of a great multitude, which was due to pulsating character of the supply.

Next C_0 was made $5 \cdot 10^{-6}$ f. $L = 100$ h and $R = 6340$ ohms $n = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ for this value $n = 7$, with the eye 8,6 sparks could be counted per second, the greater number is of course due to the fact that the capacity was not quite charged before the gap broke down, increasing the gap actually reduced the number of sparks to about 7 per second.

The primary circuit.

Experimenting on the primary circuit we started again by leaving off C_0, 30 gaps of a Wolfram series gap were adjusted to a distance each of ,2 mm, L_I consisting of 14 spiral turns was ,0815 mh $= 8 \cdot 10^{-5}$ h $= 81500$ cm $C_1 = 5000$ cm $=$,0056 μf. The number of sparks counted per second was about 6 at the lowest potential which agrees with the calculated value, the potential was next increased untill we obtained about 8,6 sparks per second, λ was measured by a wavemeter and found to be 1285 meters. To judge the damping, readings were taken on the wavemeter corresponding to the maximum deflection α of ammeter in the the wavemeter circuit and the two readings at which $\alpha/2$ was read. Calling these values λ_0 λ_1 and λ_2 we found that $\lambda_0 = 1285$ m $\lambda_1 = 1405$ m and $\lambda_2 = 1160$ m ϑ_1 the damping decrement of I plus ϑ_2 the decrement of the wavemeter equals $\pi \frac{\lambda_1 - \lambda_2}{\lambda_0}$ in this case $\pi \frac{.245}{1285}$ $=$,648 $\vartheta_2 \doteq$,1 leaving $\vartheta_1 \doteq$,55 the equivalent resistance of I. is $R_I = \frac{\lambda^m \cdot 150 \cdot \vartheta}{C^{cm}} = 21,2$ ohms, this includes the mean resistance of the gap and the resistance of the total circuit I. $\delta = \frac{R}{2L^H} = 1,30 \cdot 10^5$ $T = \frac{\lambda^{cm}}{3 \cdot 10^{10}} = 4,28 \cdot 10^{-6}$ seconds. $A = 4,605 \cdot 7,7 \cdot 10^{-6} = 35,6 \cdot 10^{-6}$ seconds which is the time by which the current is negligible. $m = \frac{4,605}{\vartheta} = 8,4$ swings.

Adding a spark gap of nonextinguishing qualities to our series gap changed the values of λ_0 λ_1 & λ_2 to 1275 m 1165 m and 1395 m this would make $\vartheta_1 = ,47$ $m = \frac{4,605}{,47} = 9,8$ $A = Tm = 42,10^{-6}$ seconds.

ϑ being smaller shows that the presence of one defective gap out of 31 gaps, that is 3,2 % of total, will cause a drop in the damping of 14,5 % and will increase the time of swing to 1% by 17%, this serves to show that great care must be taken to see that the gaps are all operating correctly, which can be seen after some practice and which can at any rate be detected by seeing if any of the gaps have become heated. Once adjusted and cleaned it was found that the gaps could be used continuously without any local heating occurring.

Next the number of gaps in series was reduced.

Using 8 gaps, all other conditions being as before, we found $\lambda_0 = 1270$ λ_1 & λ_2 = 1164 and 1400 $\vartheta_1 = ,48$ instead of ,55

Taking off 7 turns from the original 14 turns in L_1 L_1 became ,04 mh C_1 being ,0056 µf. $\lambda_0 \therefore = 2\pi\sqrt{203750000} = 895$ m, the actual reading of the wavemeter was 880 m which can be accounted for by the fact that the accuracy of readings are not very great and as the damping is flat the maximum on the wavemeter could not be very accurately determined. λ_1 & λ_2 were 965 ~~and~~ 780 so that $\vartheta_1 = ,56$

The next test was with reference to the distance between the gaps. The 30 gaps were accordingly brought to ,1 mm from each other. The number of discharges naturally increased so that only a buzzing tone was heard. $\lambda_0 = 1284$ $\vartheta_1 = ,815$ $A = 24,2 \cdot 10^{-6}$ seconds, that is nearly one half as great as before, this shows very clearly the effect of bringing the gaps closely together; it is due to the decreased potential, the decreased heating and consequently to the reduced production of ions!

It being of interest to note the effect of C_o readings were taken with C_o and without same. a) without C_o $\lambda_o = 1284$ $\lambda_1 \lambda_2 = 1500$ and 1115 $\vartheta_1 = ,82$ b) with C_o $\lambda_o = 1300$ $\lambda_1 ; \lambda_2$ 1550 and 1040 $\vartheta_1 = 1,11$ $A_a = 24,3 \cdot 10^{-6}$ $A_b = 17,8 \cdot 10^{-6}$, the capacity has therefore an actual value inasmuch as the pulsations are smoothed out and the gap can therefore extinguish itself more easily. In case a one ammeter in the wavemeter which reads in watts, gave a reading of ,06 watts while in case b) the reading was ,16 watts this increase therefore substantiates the assertion that a greater amount of energy will flow in I when C_o is in the circuit. On examining the glimmtube, which was coupled to L_1, in the rotating mirror the two cases were as shown in Fig. 19.

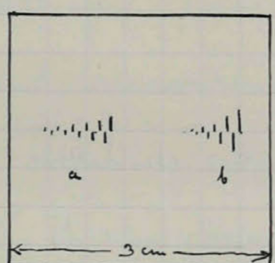

Fig 19.

Our mirror rotated in a steel cylinder into which a window 3 × 3 cm had been cut; by careful measurements it had been found that the glimmtube was visible in the mirror while the latter made 1/34 revolution, if now or mirror rotates at 330 rps the mirror is seen once every revolution and for a time $= \frac{1}{2 \cdot 330} = ,0015$ seconds for 1/2 revolution, the time for 1/34 rev is consequently $\frac{1003}{34} = ,000088$ seconds any distance measured in the field will therefore be easily expressed as a fraction of a second as 3 cm = ,000088 seconds and 1 cm = ,0000294 seconds that is $2,94 \cdot 10^{-5}$ seconds. In case b the length of visible oscillation was 6 mm $= 1,78 \cdot 10^{-5}$ in case a 8,2 mm $= 2,4 \cdot 10^{-5}$ seconds where A as given above is seen to agree accurately.

Increasing the inductance L_o which was done by using a larger choke coil, the energy reached a still higher value. $\lambda_o = 990$ $\vartheta_1 = ,7$ $m = 6,5$.

The secondary circuit.

Our primary circuit having a wave length of 2520 m a galvanically coupled secondary circuit was added. Fig. 20. $L_{II}C_{II}$ being $= L_I C_I$ the two circuits were tuned. It was noted that the spark became very arc like, showing that a considerable amount of energy was being drawn.

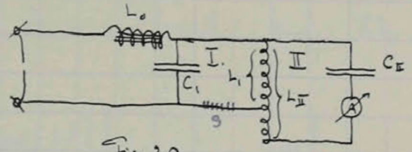

Fig 20

That this was actually the case was shown by the hotwire ammeter A which indicated a current of three amperes.

To study the effect of the coupling we were forced to use shorter waves owing to the apparatus at hand, this of course had the undesirable effect of causing the beats to be further apart. Our resonance curve for I, II being still open, was very flat, the maximum being about 1590 m. On coupling, and measuring the wave length of II it was found to be 1730 and the resonance curve very sharp., a current of 1 ampere being indicated by Ⓐ, it was obvious that we had a short Wien impulse or else an ideal impulse. The inductance L_I was next varied so that the wave length of I. would also be 1730, in this tuned condition the current in II has reached a value of 2,2 amperes. Our circuit had now been changed to an inductively coupled circuit being otherwise the same as in Fig. 20

The secondary being open, the glimmlight was coupled to the primary and observed in the rotating mirror. With weak energy and a low potential 6 to 7 sparks could be distinguished on increasing the potential 8 sparks could be discerned, the maximum was also greater.

$C_I = 10\,000$ cm $= 111 \cdot 10^{-10}$ f $\quad L_I = ,076$ mh $= 7,6 \cdot 10^4$ cm $\quad \vartheta = ,57 \quad R_I = 14,4\ \omega$

$\frac{4,605}{\vartheta} = \underline{m = 8}$, closing II we had for II 5 Amperes. $\lambda = 1740 \quad \vartheta_1 = ,10 \quad \underline{m = 46}$

L_{II} consisted of 22 turns that is about ,1025 mh = 102,500 cm

C_{II} was 7380 cm $\lambda^{cm} = 2\pi\sqrt{L_{II}C_{II}} = 1730$ m which is correct. $T = 5{,}8\cdot10^{-6}$

$t = 267\cdot10^{-6}$ sec. Fig 21. shows the primary when the secondary was open, when it was closed, and the secondary. Without regarding the center picture we can tell from the one on the right, which represents the swings in II, that at least three

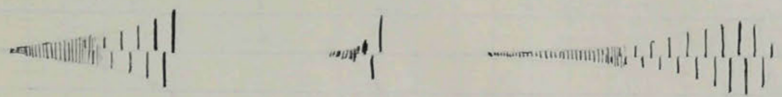

Fig. 21

impulses have been added, in other words that we actually have a Wien impulse and not the ideal impulse. To shorten the beat it was necessary to tighten the coupling or else by increasing the natural damping of I, by reducing L_I, or increasing C_I as $\vartheta = \pi R\sqrt{\frac{C}{L}}$.

Making $C_I = 17500$ cm and $L_I = 10320$ cm λ became 840 m.

changing II to correspond $\lambda_0 = 850$ $\lambda_1 \lambda_2 = 875, 812$. $\vartheta_1 + \vartheta_2 = ,234$

C_{II} was now 3600 cm and L_{II} 50200 cm = ,05 mh. this is by a comparatively weak coupling; by increasing same the current increased and $\vartheta_1 + \vartheta_2 = ,146$ that is nearly one half the former value, showing that there is an effect produced by the coupling which is of course due to the shortening of the beats. ϑ_1 by loose coupling was ,164 $\underline{m = 29}$ by tight coupling $\vartheta_1 = ,076$ and $\underline{m = 66}$

So far we had evidently produced Wiens impulses but not ideal ones, we therefore proceeded by increasing C_I making this capacity $4{,}10^4$ cm = ,05 μf

L_I was 5300 cm = ,005 mh II open.

$\lambda_0 = 970$ $\lambda_1 \lambda_2 = 1270$ 744 $\vartheta_2 = ,67$ $\vartheta_1 = 1{,}57$ $T = \frac{\lambda^{cm}}{3\cdot10^{10}} = 3{,}23\cdot10^{-6}$

$m = \frac{4{,}605}{\vartheta} = 2{,}94$ swings $\delta = \vartheta/T = ,485\cdot10^{6}$ $R = 2\delta L^{H} = 4{,}85$ ohms, it is evident that if we have practically only 2,94 oscillations with the secondary open we will have still less with the secondary closed in fact on closing II only one impulse was seen by strong excitation. Fig. 22. shows the glimmlight in I and II for a. strong excitation b. medium and c. weak excitation.

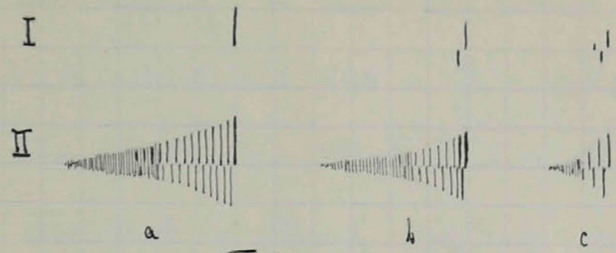

Fig. 22

That the number of discharges in a unit of time was reduced by the lower excitation is also evident owing to the lower potential and consequently the longer time required to charge C_I.

$C_{II} = 3600$ cm $L_{II} = 6{,}5 \cdot 10^4$ cm $= 6{,}5 \cdot 10^{-2}$ mh $\lambda_0 = 970$ $\vartheta_2 = ,068$ $\vartheta_1 = ,026$

<u>$m = 178$</u> for strong excitation. $\delta = 8{,}05 \cdot 10^3$ $R = 2\delta L = 1{,}05$ ohms.

at increased excitation $\lambda_0 = 973$ $\vartheta_1 + \vartheta_2 = \frac{\pi\, 49}{973} = ,158$. To show how ϑ_2 has been determined this case can be an example. The maximum reading of the ammeter in the wavemeter circuit is called α_0 and the wave length is the wave length of the circuit measured, in this case $\lambda_0 = 973$. a resistance which has been carefully determined is next placed in the wavemeter circuit and the reading α_1 obtained. Now R_m and C_m are known so that the decrement due to the resistance can be found this is called $\Delta\vartheta_2$ and is $\frac{1}{150} \frac{C_m^{cm} R^{\omega}}{\lambda^m}$ see page 18. in this case $\Delta\vartheta_2 = \frac{1}{150} \frac{288}{973} 20{,}5 = ,0405$

$$\vartheta_2 = \frac{\Delta\vartheta_2}{\left(\frac{\alpha_0}{\alpha_1} \cdot \frac{\vartheta_1 + \vartheta_2}{\vartheta_1 + \vartheta_2 + \Delta\vartheta_2}\right) - 1}$$

$\therefore \vartheta_2 = ,123$ and $\vartheta_1 = ,035$ <u>$m \therefore = 132$</u> for medium excitation.

To check this result the readings were repeated and tabulated

Amperes to transformer	Amperes in II	$\vartheta_1 + \vartheta_2$	ϑ_2	ϑ_1	<u>m</u>
,7	1,4	,1032	,0772	,026	177
,5	1,15	,126	,0785	,0275	167
,1	0,8	,126	,091	,035	131

In the above the wavemeter was not moved so that all conditions should be constant.

Conditions being as in case one where our current was 1,4 Amperes we reduced the coupling so that the current in II was only ,75 Amperes $\lambda_0 = 973$ as before λ_1, λ_2 954 and 996 $\vartheta_1 = ,051$ as compared with ,026 $m < 88$

We see therefore that ϑ_1 is small when the energy delivered is large and also that a strong coupling reduces ϑ_1

As the oscillations in II are so much more rapid than in I, changes made in O. will have no special effect on II except inasmuch as the charging period of C_I would be slightly altered. To see whether this was the case L_0 was changed from 100 h to 20 henries $R_0 = 140\ \Omega$ $R_I = 20\ \Omega$ $C_1 = 5 \cdot 10^{-6}$ f. $\frac{R^2}{4L^2} = 32$ which is negligible compared to $\frac{1}{LC} = 10^4$, $n = \frac{1}{2\pi}\sqrt{\frac{1}{LC}} = 15,9$ periods pro second that is the time is nearly onehalf of the previous, $\delta = \frac{R}{2L} = 17,9$ $\vartheta = \frac{\delta}{n} = 1,13$ $m = 4,06$ in the original ϑ was 3,68 $m = 1,25$ the time of interest is the time one half swing $= T/2 = ,\underline{031}$ seconds. this being shorter than before more sparks could be formed in a given time therefore the energy would be greater.

Impression of tone.

Our last step is the guiding of the discharges so as to cause them to appear at constant intervals and thus to give the impression of clear tones. Circuit I only is of interest here as any interruptions in II although giving a tone will at the same time reduce the energy transmitted as I will be operation while II is open. Any variations or interruptions in I only serve to regulate the pulsations, certainly no energy can be lost in the gap during these intervals as would be the case when the interruptions were made in the secondary.

Two methods were tried out, one mechanical and one electrical.

a) Mechanical method.

The idea is very simple and consists in rotating a toothed brass wheel in I, the wheel forming part of the circuit the teeth acting as interrupters. The wheel was mounted on a steel spindle on which was also mounted a helium tube Fig. 23.

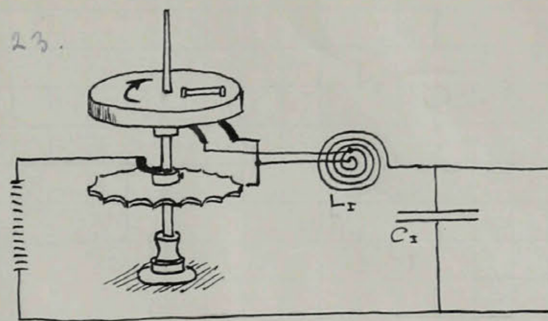

Fig 23.

By observing the rapidly rotating tube which was connected across one turn of L_I it was easy to determine whether a spark occured at each tooth or not. Now the time of charge of C_I is about $T/4$ which was seen to be ,035 seconds while the time of discharge was $5,8 \cdot 10^{-6}$ seconds. a total of about ,015 seconds as the time of discharge is practically negligible in this connection. Now to obtain a tone of 500 fregueney that is $\frac{1}{500}$ second per period = ,002 seconds it is obvious that our time of charging is too great. Reducing same by a further reduction of L and C brought us to a range where a number of charges and discharges could take place per tooth.

b) The electrical method.

This method has been mentioned before; here as in the previous case the time of charging C_I must be so low as possible. Both systems can be said to have worked well, especially the latter which gave a good tone in a telephone receiver circuit influenced by circuit II.