GENERATION AND RECEPTION

OF

ULTRA SHORT RADIO WAVES

" GENERATION AND RECEPTION OF ULTRA SHORT RADIO WAVES " .

by

W. H. Moore, B.Sc.

Thesis submitted to the Faculty of Graduate Studies and Research, McGill University, in partial fulfilment of requirements for the degree of Master of Science .

May, 1932 .

TABLE OF CONTENTS .

Table of Contents . (cont.)

Table of Contents . (conc.)

I . INTRODUCTORY .

(i). Historical Introduction .

The communication of intelligence between remote points on the earth's surface without the aid of connecting wires was developed from a fantastic dream in the minds of visionary theorists and optimistic experimentalists into a practicable working possibility in the closing five years of the nineteenth century . Credit for the final developments made at that time must go to Marconi, but his work was the culmination of a long series of investigations carried out by Clerk-Maxwell, Preece, Hertz, Branly, Lodge, Tesla, Popoff, Righi, and many others, all of whom were responsible for theoretical or experimental advances which brought one step closer the goal finally reached by Marconi .

The distance over which signalling was accomplished without wires was rapidly extended from a few hundred yards to hundreds of miles . The feat of spanning the Atlantic wirelessly was first achieved by Marconi on December 12th, 1901. The transmitters used at this time consisted of large spark coils directly connected to an aerial and ground, while receivers utilized coherers similarly placed directly between aerial and ground . Wavelengths of the damped electrical oscillations thus produced were of the order of one to two thousand metres .

Early in 1902 Marconi succeeded in receiving signals from Poldhu at distances up to 2099 miles while on board a liner en route to New York . It was noticed on this trip that signals could not be heard beyond 700 miles during daylight, greater distances being covered only at night . Marconi found that by increasing the length of the waves used the effect of daylight could be overcome . On this account further developments tended towards the use of greater and greater wavelengths to cover the ever increasing distances demanded .

During the following twenty years communication between points thousands of miles apart was carried out by means of wireless stations of increasing size and power, employing wavelengths up to as high as thirty thousand metres and powers as great as 500 kilowatts . Spark coils and high frequency alternators were superseded for transmission purposes by the thermionic vacuum tube, invented by Fleming and improved by de Forest . The early methods of reception - coherer, magnetic detector, electrolytic detector, crystal detector, and others - were rendered obsolete by the application of the vacuum tube to reception .

Signalling was done by means of codes consisting of various combinations of dots and dashes, as in landline telegraphy, but developments in wireless telegraphy were closely paralleled by the development of various systems of wireless telephony . The human voice was heard across the Atlantic Ocean for the first time in November, 1906, when tests being carried out by R. A. Fessenden between Brant Rock and Plymouth were overheard by wireless operators at Macrihanish, Scotland .

The longer wavelengths were used for signalling over long distances while for communication over short distances equipment was developed using wavelengths down to 200 metres . Wavelengths shorter than this were considered to be of but little value, and their use was confined mainly to laboratory demonstrations and amateur experimentation .

About the year 1922, however, it began to be generally realized that the very short wavelengths, below one hundred metres, had rather remarkable properties as regards transmission over long distances . Investigations carried out by Marconi and others demonstrated that these very short waves could be used successfully for communicating over distances up to the greatest found on earth . Furthermore the amount of power necessary was but a small fraction of that required for similar distances when using long waves . During the past decade, therefore, energy has been concentrated on the development of wireless systems using short waves down to as low as 10 metres in length .

When the long range possibilities of short wavelengths below one hundred metres began to be appreciated, interest was greatly stimulated in the development of directional types of radiating systems . Radio transmitters concentrating their energy in a narrow beam radiating in one definite direction rather than broadcast in all directions as heretofore, became a practical possibility . Before this time the wavelengths generally used had been so great as to prohibit the use of reflecting systems, due to the large size necessary, and so directive radiators had not received much attention . Stations intended for broadcast services do not, of course, employ reflectors, but for long distance point to point communication purposes the use of beam reflectors for both transmission and reception has become quite general in modern high power short wave stations Their use occasions a great saving in the amount of power required, since the energy otherwise broadcast uselessly in all directions is concentrated in a narrow beam pointing in the single direction in which it is wanted .

The behaviour of waves in that part of the general spectrum lying between the shortest wavelengths generally used for radio communication and the longer wavelengths in the heat band is not very well known even to-day . Indeed it is only within the last five years that the gap has been closed and this part of the spectrum investigated for the first time by the extension of radio waves downwards and heat waves upwards in wavelength . Oscillations produced by electromagnetic means were obtained on shorter and shorter wavelengths and those produced by thermal methods were obtained on longer wavelengths, until finally there was a small frequency band over which experimental investigators were able to produce oscillations by either electric or heat methods .

The main attraction for the use of radio waves of the order of a few centimetres in wavelength lies in the possibility of using reflecting beam radiating and receiving systems of very small dimensions . The range of communication possible when using waves of this order of magnitude was not known a few years ago, nor had the development of methods for their production and reception progressed very far . This was largely due to the fact that such work as had been done gave somewhat unpromising results, and indicated that these very short wavelengths were valueless for communication purposes over any except extremely short distances .

The dissertation contained in the following pages is concerned with an investigation into the problems involved in the generation and reception of these very short waves, a few centimetres to a few hundred centimetres in wavelength .

(ii). Reason for this Research .

The work described in this dissertation was commenced in 1926 at the instigation of Dr. L.V.King, of the Physics Department, McGill University, and investigations were carried out by the author for the National Research Council of Canada during the summers of 1926 and 1927 . These early experiments were, for the most part, performed in the laboratories of the Royal Canadian Corps of Signals in Ottawa, with the assistance of Major W. Arthur Steel, and, during the first part of the work, Lieut. K. G. McCullagh of the R.C.C.S.

The later experimental work on Barkhausen-Kurz oscillations, by means of which the highest frequencies were produced, was carried out by the author in the Electrical Engineering Department at McGill University during the academic sessions 1929-1930 and 1931-1932 .

The initial investigations were commenced with the following specific objective in mind . It was desired to obtain a high frequency oscillator from which could be radiated sufficient power to enable reliable transmission to within a distance of twelve miles or so . The radiation was to be confined to a narrow beam of a sufficiently short wavelength to enable the use of a directional radiating system which would be continuously rotatable . This last requirement necessitated the use of an extremely short wavelength in order that the reflecting system might be reduced to dimensions comparable with an ordinary large size searchlight, such as is used in lighthouses .

The intention was to use this short wave beam as an adjunct to the usual searchlights in marine navigation . A fixed signal was to be emitted by the beam transmitter, which would be continuously sweeping about in every direction by slowly rotating . At the same time a higher wave transmitter operating on the more usual frequencies was to be sending out automatic telephone signals from some such source as a phonograph, which would give the direction in which the beam was pointing at each instant . The two transmitters were to be properly synchronized so that when the beam was pointing in any direction the radiotelephone broadcast would tell what that direction was . Thus a ship obtaining its bearing from two or more of these stations could determine its position by resection, knowing the location of the transmitters . To obtain this service the ship would require but a simple short wave receiver to receive the directional signal, in addition to its ordinary radio equipment which would serve to receive the radiotelephone broadcast . Thus it would be possible for small craft to make use of this system of direction finding where it would not be economically feasible for them to carry the present type of complicated and expensive direction finding equipment .

In commencing the later work on Barkhausen-Kurz oscillations it was hoped to develop an oscillator which could produce several hundred watts output on a wavelength of fifty centimetres or less, and to investigate reception on these wavelengths at whatever distances were found to be attainable, using various types of beam transmitters and receivers . It was also hoped that further qualitative and quantitative information on the production of oscillations of very high frequencies might be obtained . The phenomena observed at frequencies of the order of one thousand megacycles are not at all well understood as yet, and the accumulation of data and the development of technique in methods of producing these frequencies appears to be well justified .

(iii). Definition of Ultra Short Waves .

The term short waves is a rather indefinite one, and has generally been considered to mean wavelengths of less than one hundred metres . It is a purely relative term, of course, and when we say ultra short waves, we use an even less definite term, of the second order of relativity, so to speak .

At the Hague Conference held in September, 1929, it was decided by international agreement to adopt officially the following nomenclature for the classification of wavelengths :

Long	3000 metres and upwards .
Medium	200 - 3000 metres .
Intermediate	50 - 200 metres .
Short	10 - 50 metres .
Ultra Short	10 metres and less .

The scope of the work covered herein is confined to the ultra short wave band, and deals mainly with the shorter wavelengths down to one metre and less .

(iv). Acknowledgments.

The author wishes to take this opportunity of expressing his appreciation to Lt.-Col.W.Arthur Steel* and Lieut. K.G.McCullagh, of the Department of National Defence, for their helpful cooperation in the earlier part of this investigation, and to Dr. F. S. Howes of the Department of Electrical Engineering, McGill University, for his kindly interest and assistance in this work .

He also wishes to thank the Northern Electric Company, Limited, for their generosity in constructing a number of specially designed vacuum tubes . In particular Mr.B.H.Steeves of that company was very kind in making valuable suggestions .

* Now in charge of radio research , National Research Council of Canada, Ottawa, Ont.

II. REVIEW OF PREVIOUS DEVELOPMENTS .

(i). Early Experiments .

The production of very short electromagnetic waves is not at all a recent development . In Hertz's original experiments in 1888 he employed one oscillator which operated on a wavelength of 60 centimetres . This particular oscillator consisted of two copper sheets each 40 centimetres square and 60 centimetres apart connected to two polished gilt balls two or three centimetres apart . Spark coil excitation was used to set the system in oscillation, and the wavelength determined by calculation from the mechanical dimensions of the circuit .

Lodge in 1890 obtained oscillations in a single metallic sphere five centimetres in diameter, but found it much easier to obtain oscillations with larger spheres . Sir J. J. Thomson has shown that the oscillations from pole to pole of a charge upon a conducting sphere causes radiation of wavelength equal to 1.4 times the diameter of the sphere . Thus in the case of Lodge's five centimetre sphere the wavelength was seven centimetres .

Nichols and Tear in 1923 published the results of some work in which a method of obtaining electrical oscillations was developed by which wavelengths down to 1.8 millimetres were produced . In this system the oscillator consisted of two tiny tungsten cylinders which formed the electrodes of an oil-immersed spark gap . In the particular oscillator with which the 1.8 millimetre waves were obtained these cylinders were 0.2 millimetre in length and 0.2 millimetre in diameter separated by a gap of 0.01 millimetre . The system was excited by applying a potential of 30,000 volts at frequencies of 500 to 1000 cycles to the oscillator, a water resistance, and a condenser, all in series . A radiometer type of receiver was used .

The longest heat waves so far measured had a wavelength of about 0.3 millimetre . Thus there remained a gap to be explored of from 0.3 to 1.8 millimetres to complete the spectrum between heat and electromagnetic waves .(1923).

Within the last few years experiments carried out by a number of investigators have resulted in the closing of this gap, and over a narrow overlapping band of wavelengths it is now possible to produce oscillations by either heat or electrical methods . This work has been done mainly by extending the lower limit of electric waves, as it is found that above about 0.3 millimetre in wavelength oscillations are more easily produced by electrical than by thermal methods . Glagolewa-Arkadiewa has obtained waves down to 0.082 millimetre in length by electrical means . She used as oscillators finely divided metallic particles suspended in a viscous oil . A coating of the resulting gummy mixture was applied to the surface of a wheel rotating between the sparking electrodes .

(ii). Types of Valve Oscillators .

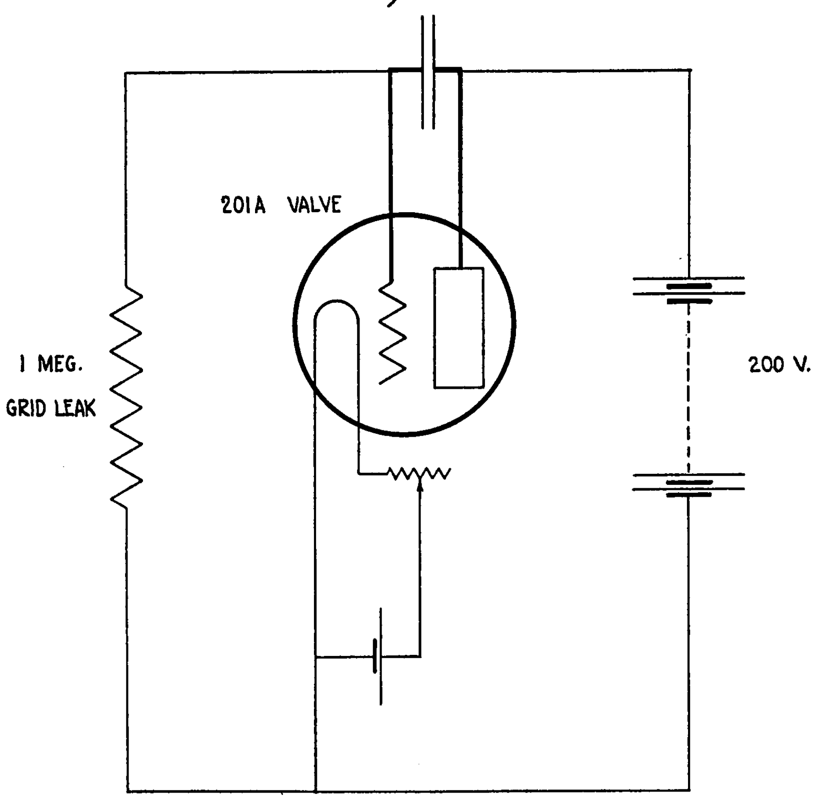
Turning now to electron tube oscillators we find that investigations have been carried out along a number of lines, with a view to producing electrical oscillations of shortest possible wavelength .

It has been found by a number of experimenters that stable oscillations may be obtained down to about two metres in wavelength using standard types of vacuum tubes and simply reducing the constants in conventional types of oscillating circuits . Below about two metres major difficulties begin to appear . High power tubes can no longer be used because the dimensions of the valve elements themselves are sufficiently great, even though the external oscillating circuit be reduced to the smallest possible mechanical dimensions, to maintain the natural period of the circuit at some value possibly in the neighbourhood of three or four metres . One is thus compelled to use low power valves, usually either five or seven and a half watt transmitting valves, or else receiving valves .

By removing the four prong base of a standard 201a type vacuum tube and connecting a small 0.001 microfarad fixed condenser between the grid and plate leads as close as possible to the glass envelope, a short wave oscillator is obtained which will give wavelengths down to below one and one half metres (Fig.1) . This circuit is really the familiar ultraudion circuit, the oscillating circuit being reduced to the capacity of the fixed condenser in series with the internal grid-plate capacity of the valve and the inductance of the two short straight wires, each possibly and inch long, making connections with the grid and plate .

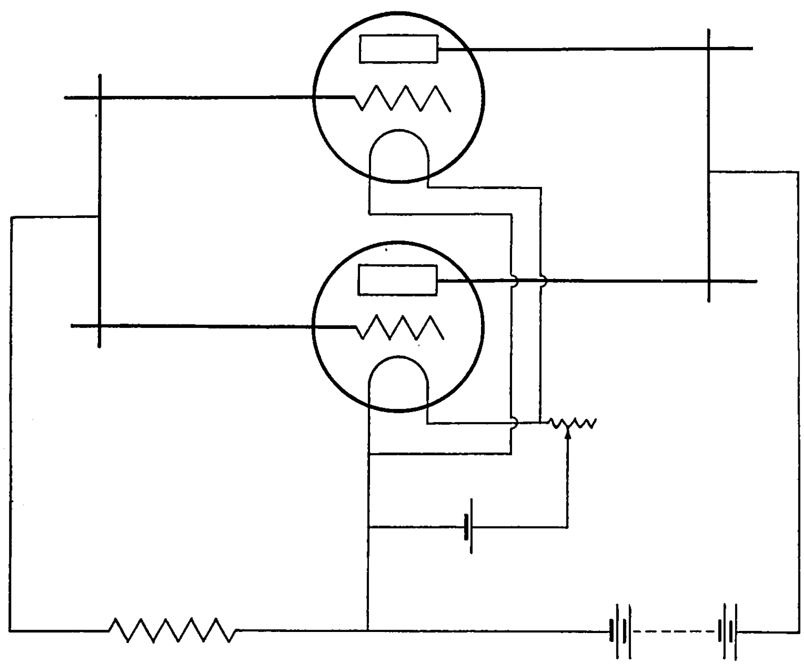
In an oscillator of this type the oscillations are not very stable and the wavelength is not variable since the

Fig. 1.



ULTRAUDION OSCILLATOR.

Fig. 2.



MESNY ULTRA SHORT WAVE CIRCUIT.

tuning of the circuit is fixed at a value determined largely by the internal interelectrode capacity of the valve . By extending the length of the grid and plate wires and moving the fixed condenser up and down these wires the wavèlength may be varied and adjusted , but this immediately increases its length to two metres or more .

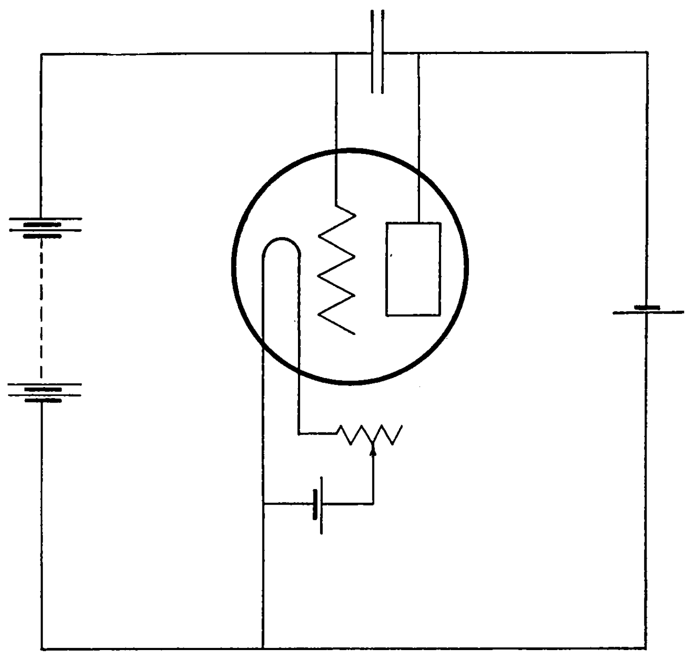
The push-pull circuit developed by Mesny has been widely used in experimental work, and produces somewhat more stable oscillations than the above circuit, as well as allowing greater control at shorter wavelengths . This circuit uses two vacuum tubes whose grids and plates are paralleled through inductances, the centre tap of each of which is connected to the filament (Fig. 2) . The grid and plate inductances usually take the form of parallel straight wires joined by a shorting bridge . With this circuit stable oscillations may be obtained down to below three quarters of a metre, and the wavelength can be varied by sliding the bridges along the grid and plate wires .

Positive potentials are applied to the plates in these oscillators, and either grid biassing batteries, grid leaks, or simply a straight wire connection to the filament is used . Oscillation takes place and is produced in the usual way as in circuits operating on the longer wavelengths, the wavelength being determined by the values of inductance and capacity in the external circuit, and also by the fixed grid-plate capacity of the particular tube in use .

In an article written by C. R. Englund[43] in the Proceedings of the Institute of Radio Engineers, a considerable amount of experimental work is described in which the conclusion is reached that with ordinary commercial vacuum tubes now on the market the lower limit attainable is a wavelength of about one and a half metres . This agrees with the investigations carried out by the author for the National Research Council of Canada . The types of circuits employed were mostly more or less conventional circuits with the inductances and capacities reduced to very small values .

A distinctly different type of high frequency oscillator was developed by Barkhausen and Kurz about the year 1920 . The usual plate and grid potentials were reversed in polarity, a high positive voltage being applied to the grid and a small negative or zero voltage being applied to the plate (Fig. 3) . It was found that this connection could be used to produce extremely high frequencies, wavelengths of the order of one half metre and less being obtained . The explanation was that the oscillations took place entirely within the tube, and consisted of pure electron field vibrations about the grid . The hot filament emitted clouds of electrons in the usual way, and these electrons were drawn at a high velocity towards the positively charged grid . A large proportion pass through the grid spaces, are repelled by the negative anode, again attracted through the grid, and repeat the process . Thus the frequency of oscillation is largely determined by the time required for the individual electrons to traverse the interelectrode spaces . This in turn depends on the applied field, so that the frequency is considerably affected by the

FIG. 3.



CIRCUIT FOR THE PRODUCTION OF BARKHAUSEN-KURZ AND GILL-MORRELL OSCILLATIONS.

potentials used . No external oscillating circuit is used and the constants of the external circuit do not affect the wavelength generated . The amount of energy radiated by an oscillator of this type is, as might be expected, a very small quantity and has not usually been considered to be of value except for measuring purposes .

In experimenting with the Barkhausen-Kurz type of oscillations two other investigators, Gill and Morrell[5] , found a third type of oscillation produced . Using a circuit of the Barkhausen variety, having positive grid potentials and negative plate potentials, oscillations were obtained having the properties of the usual type of circuit in which regeneration builds up oscillations in a resonant circuit . In the Gill-Morrell experiments the values of inductance and capacity in the external circuit control the frequency, whereas in Barkhausen-Kurz circuits they do not . Wavelengths obtained are considerably lower than those obtained with the first type of circuit in which positive plate potentials are used .

Another system which has been investigated for the production of very high frequency oscillations uses the magnetron vacuum tube . It is found that a two element vacuum tube may be made to generate oscillations under certain circumstances . If the anode consists of a circular cylinder with the cathode a long straight wire filament at its centre, the superimposition of an electromagnetic field of uniform strength with its direction parallel to that of the filament will, if the field is strong enough, prevent electrons from the filament from reaching the plate, and they will move in circular orbits whose diameter is less than that of the plate . It is found, however, that there is sometimes a small radio frequency current flowing to the plate which may be detected on hot wire meters . Japanese investigators have used this fact to obtain some promising developments in the production of very short wavelengths . Okabe[12] describes the production of a minimum wavelength of 5.6 centimetres, using a magnetron oscillator .

(iii). Frequency Determination .

When a circuit has been obtained which gives stable oscillations at high frequency, the problem still remains to find out exactly what this frequency is . In the case of the oscillators of Hertz, Lodge, Nichols and Tear, and other extremely high frequency oscillators of that type, the frequency was determined by calculation from the measured constants of the circuit . This can be done with whatever type of oscillator is used, but it is usually desirable to have some convenient method of accurately determining wavelengths by comparison with some calibrated variable standard . The usual method of loosely coupling a calibrated circuit, consisting of a known value of inductance and capacity to the oscillating circuit, can be satisfactorily used down to about two metres . The indication of resonance is obtained either from a thermocouple or hot wire instrument in the wavemeter circuit, or from the deflection of the plate current meter in the oscillator circuit as the two circuits come into resonance . However, the mechanical dimensions of the capacity and inductance of this type of wavemeter become very small when the wavelength is below about two metres , and it is difficult to calculate the values of inductance and capacity with accuracy .

Another method of measuring these short waves is to use the arrangement devised by Lecher . A pair of parallel wires is coupled to the oscillator and standing waves produced . A shorting bridge on these Lecher wires is slid backwards and forwards and indicates the position of the nodes or antinodes of the standing waves . The wavelength is thus determined by direct measurement of the distances between these points . The indications of nodal points may be obtained either by observing the deflection of the plate current meter in the oscillator or by using a thermocouple, neon tube, or other indicating device directly in the shorting bridge on the Lecher wires . Wavelengths down to a few centimetres in length may be readily measured with the Lecher wires type of wavemeter .

(iv). Power Obtainable .

In the oscillators of Hertz, Lodge, and Nichols and Tear, the amount of power radiated is extremely small . Very delicate receivers can give measurable indications of reception up to distances of only a few metres . With what we shall call the normal type of valve oscillating circuits, that is, those in which oscillations are built up at the natural period of the circuit by the regenerative action of an electron valve, the maximum power available is of the order of a fraction of a watt on these minimum wavelengths, since to produce waves as low as 100 centimetres the smallest type of receiving tubes must be used.

With Barkhausen - Kurz types of oscillators the amount of power obtained has, so far, been very small, since low power valves have been used in the experiments . The Gill - Morrell type of oscillations have been obtained with considerable intensity as compared with Barkhausen - Kurz oscillations, but the maximum amount of power involved is still a matter of but a few watts .

The magnetron oscillator was originally developed on a high power scale, tubes having been designed to operate at power frequencies with an output of many kilowatts . As the frequency is increased, the dimensions of the tube must be decreased, so that less power can be used . However, at a wavelength of 40 centimetres sufficient oscillating energy can still be produced (probably a few watts) to enable readable signals to be heard at a maximum distance of one kilometre . In this particular experiment, described by H. Yagi[46] , single Hertzian resonators were employed at both transmitter and receiver, with the addition of a parabolic reflector and collector at the transmitter and receiver respectively . A system of director chains and wave canals, described by Yagi, was also employed with a very marked improvement in results . These consist of a series of Hertzian resonators, that is, simply full or half wave vertical antennae, mounted along the axis of the parabola of the reflector . The receiver consisted of a crystal detector at the centre of the Hertzian resonator with a three stage amplifier for the modulation frequency . A Barkhausen type of receiver has also been employed with somewhat better results in detecting modulated waves in the neighbourhood of 1.5 metres .

(v). Reflectors and Beam Systems .

An extensive series of investigations carried out at Tohoku Imperial University, Sendai, Japan, has demonstrated the practicability of using parabolic reflectors and wave directors on wavelengths below five metres . The above experiment on forty centimetres by the same investigators shows that the types of reflectors and directors already developed can be employed to advantage, in conjunction with oscillators producing waves less than 100 centimetres in length .

III. THEORETICAL CONSIDERATIONS .

(i). Types of Oscillatory Circuits .

A general review will now be made of oscillatory circuits in use on the normal wavelengths at present used for communication purposes . An attempt will be made to determine on a theoretical basis which of these circuits should be most likely to prove adaptable to the production of wave-lengths of the order of one metre .

Undamped oscillations consist of an unlimited series of waves of constant and undiminishing amplitude, and, in the simplest case, of constant frequency . An electrical disturbance in any part of a valve circuit, for example making or breaking the filament circuit, may produce oscillations of electric charges, that is, of electrical energy, about the circuit. Unless certain conditions hold, however, this oscillating energy will rapidly be dissipated in the resistance of the circuit in the form of heat, and also of radiation ; that is, the oscillations will have a high decrement or attenuation . If by some means we find it possible to reduce this attenuation to zero, the oscillations will build up to some maximum value, determined by the losses in the circuit, and will persist with constant amplitude at this value . These are what are called continuous waves, or undamped oscillations . They are produced in vacuum tube circuits by adding sufficient energy to the oscillatory circuit to compensate for the losses in it . This is possible due to the "negative resistance" characteristic of the valve, which renders it possible by feeding back energy from another circuit to the oscillatory circuit, to reduce the effective resistance to zero, so that oscillations of constant amplitude persist indefinitely .

Returning this energy from the plate to the grid circuit, in the case of the ordinary three-electrode valve, is accomplished by coupling the two circuits together . There are two general methods of coupling possible, namely capacitative coupling and inductive coupling . These two types of reaction are illustrated in Figs. 4 (b) and (c), respectively .

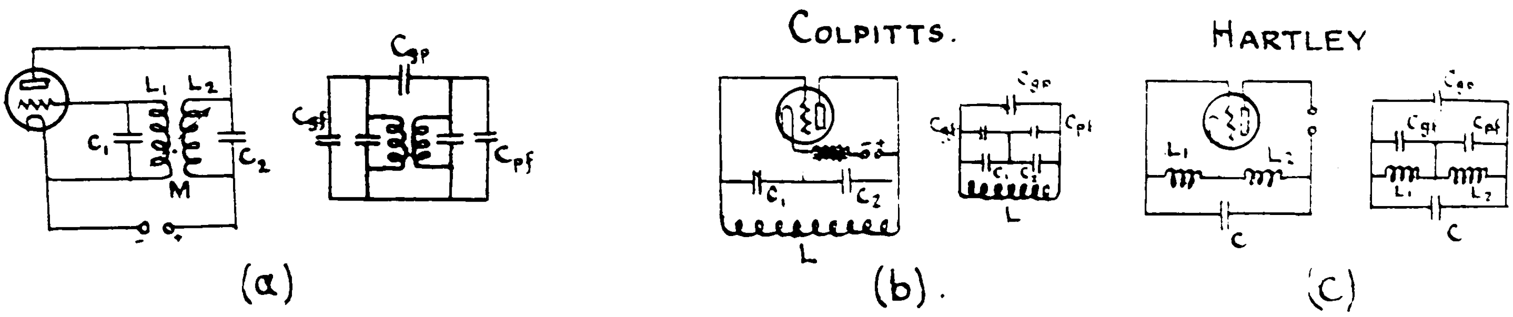


FIG. 4.

In Fig. 4(a) reaction between output and input circuits is obtained through the mutual induction of the two coupled circuits . The condenser across either one of the inductances may be omitted without making impossible the phase relationship between the grid and plate circuits required to produce oscillations . The necessary condition is that the plate current and grid potential must be as nearly in phase as possible . In the diagrams shown, C_{pg}, C_{pf}, and C_{gf} are the small interelectrode capacities between plate and grid, plate and filament, and grid and filament respectively .

Considering the plate circuit L_2C_2 as the oscillating circuit and the grid circuit L_1C_1 as equivalent to a generator representing the effect of the grid circuit potential variations on the plate circuit, the frequency of oscillation of the circuit of Fig. 4(a) is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{1+\frac{r}{r_p}}{L_2C_2}}$$

where r is the resistance of the circuit L_2C_2, and r_p is the plate circuit resistance of the valve . Neglecting these resistances, since the ratio $\frac{r}{r_p}$ is usually very small, we find

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{L_2C_2}}$$

and to obtain the shortest wavelengths this must be a maximum, so that LC must be a minimum .

The oscillation circuit of the Colpitts circuit of Fig. 4(b) is LC_1C_2 , and of the Hartley circuit of Fig. 4(c) is L_1L_2C , neglecting the interelectrode capacities . The manner in which the constants of these circuits may be varied is limited by the fact that the grid and plate circuit LC values must be in proper proportion to each other to maintain oscillations . Also the amplification constant of the particular valve used is a determining factor in fixing these constants . Considering the Hartley circuit, for instance, it may readily be shown that for tubes having a high amplification factor, L_1 should be approximately equal to L_2, while for low μ tubes the best conditions for oscillation require L_2 to be considerably smaller than L_1 . It is also found that, other things being fixed, there will be an optimum value for M, the mutual inductance between input and output circuits .

Considering the equivalent circuit diagrams of Fig. 4(a), (b), (c), which show represented the interelectrode capacities, we see that these capacities produce a number of oscillation circuits in addition to the main resonant circuit. In addition to producing parasitic oscillations these also affect the frequency of the main oscillation circuit, changing it from its simple LC value to a somewhat lower value, or higher wavelength, due to the small added capacities. In the Hartley circuit, the capacity between grid and plate is simply in parallel with the oscillatory circuit capacity C. The g-f and p-f capacities are not so important, as they are smaller in value than the g-p capacity, and affect the grid and plate circuits separately, not the reaction between tham.

In considering the modifications necessary to produce the highest possible frequencies it may be seen from these circuits that, in the limit, the C and L of the oscillatory circuit reduces to the interelectrode capacity of the valve alone and the inductance of the connecting leads. A circuit

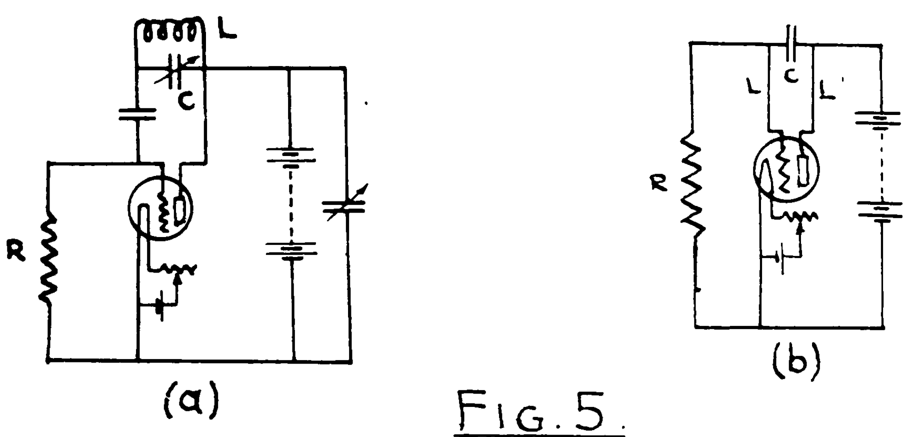


FIG. 5.

particularly adaptable to the production of very short wavelengths is that of Fig. 5(a), sometimes called the "ultraudion" circuit. Reducing the inductance to the smallest possible values results in the circuit of Fig. 5(b), where the leads themselves comprise the inductance of the oscillatory circuit. The condenser is in series with the grid-plate capacity, which is really the limiting factor, since it is of very small value . In practice the impedance of the external capacity is so small as to be negligible in comparison with that of the grid-plate capacity, since it is, in fact, found to be a necessary condition for oscillation that the condenser C be of much greater capacity than C_{gp}, that is, of lesser reactance . Thus the particular virtue of the ultraudion circuit for the production of very short waves lies in the fact that it makes use of the internal grid-plate capacity of the valve as the main capacity of the oscillatory circuit .

The theoretical problems involved in designing a receiver for wavelengths in the neighbourgood of one metre are largely included in the case of the oscillator for these wavelengths . A one metre oscillator having the characteristics of stability of frequency and continuous wavelength control over its range, may be converted into a satisfactory receiver . It may also be pointed out that since the power required on one metre in the receiver need only be sufficient to produce an audible beat note, a good receiver operating on a fundamental of considerably higher wavelength should be satisfactory for one metre reception if it can produce a harmonic on that wavelength . Oscillators operating on a harmonic may also be used for transmission on very short wavelengths, of course, but are not very satisfactory since they are so inefficient, most of the power of necessity being produced at the fundamental frequency of the circuit .

A wavelength of one metre is a frequency of 300,000,000 cycles per second . Ordinary beat frequency reception requires that the beat note be kept within about 5000 cycles of zero beat to remain reasonably audible, so that the transmitted frequency must be kept steady to within 10,000 cycles. This means stability of frequency to within 0.003 % at one metre wavelength . This percentage stability is greater than that of many long wave transmitters, so that it is not likely that beat frequency reception will prove satisfactory for very short waves unless some form of modulation is used .

(ii). Errors in Lecher Wires Wavelength Measurements .

In measuring wavelengths by means of Lecher wires it may be necessary to know the relationship between the spacing of the parallel wires and the natural frequency of the parallel wire circuit, and also whether the resistance of the wires appreciably affects the velocity of the waves, since if it does it will affect the wavelength measurements . The inductance at high frequencies of parallel wires is given by

$$L = 4\, l \log_e \frac{2D}{d} \quad \text{e.m.u.,}$$

and the capacity is given by

$$C = \frac{l}{4\, v^2 \log_e \frac{2D}{d}} \quad \text{e.m.u.,}$$

where l = length of each wire in cms.

D = distance apart in cms.

d = diameter of wire .

v = velocity of waves in cms. per sec.

Hence, $$L\,C = 4\,l \log_e \frac{2D}{d} \cdot \frac{l}{4\,v^2 \log_e \frac{2D}{d}}$$

$$= \frac{l^2}{v^2} .$$

from which it is seen that the wavelength is independent of the diameter and distance apart of the wires . Hence the spacing of the Lecher wires is unimportant . This is only true so long as other conductors are at a distance from the wires which is large compared to their diameter and distance apart .

The slight retardation of the waves due to the resistance of the wires is usually negligible . The expression for the velocity of waves along wires when the resistance is not negligible is

$$v = \frac{1}{\sqrt{LC}}\left(1 - \frac{R^2}{8\omega^2 L^2}\right)$$

$$\text{i.e., } v_R = V_0\left(1 - \frac{R^2}{\omega^2 L^2}\right)$$

where R and L are the effective resistance and inductance in consistent units, per unit length of the wires . The following data give the approximate dimensions for the particular case of the Lecher wires described in the Section on Barkhausen - Kurz oscillations .

$R = 2.2 \times 10^{-4}$ ohms per cm.

$\;\;= 2.2 \times 10^{5}$ e.m.u. per cm.

$D = 4$ cms.

$d = 0.1$ cm.

$L = 4 \log_e \frac{2 \times 4}{0.1} = 0.845$ e.m.u./cm.

and when $\lambda = 100$ cms., $\omega = 2\pi f = 2\pi 3.10^8 = 6\pi 10^8$.

Hence, $$v_R = v_0 \left[1 - \frac{1}{8}\left(\frac{2.2\times10^5}{6\pi10^8\times0.845}\right)^2\right]$$

$$\doteq v_0 \left\{1 - \frac{0.24}{10^8}\right\} .$$

Thus the apparent change in length of the measured standing waves on the Lecher wires due to the slower velocity caused by the resistance of the wires, is quite negligible in the case considered . The error of less than one part in one hundred million is far beyond the accuracy attainable in the actual measurements of the lengths of the standing waves .

(iii). Sizes of Coils and Condensers Required .

To obtain some idea of the values of inductance and capacity required in a wavemeter for ultra short waves of the order of one metre in length, a representative case will be calculated . It is also desirable to have some idea of the mechanical dimensions of the coils and condensers which it will be necessary to use . Suppose the inductance to be used is a single turn coil of one inch diameter . Then,

$$L = 4\pi R\left\{\left(1+\frac{r^2}{8R^2}\right)\log_e\frac{8R}{r}+\frac{r^2}{24R^2}-1.75\right\}\text{cms.},$$

where, R = radius of turn to centre of conductor in cms.

r = radius of cross section of conductor in cms.

In this case, $R = 1.27$ cms.

$r = 0.1$ cm., say,

so that ,

$$L = 4\pi 1.27\left\{\left(1+\frac{0.1^2}{8\times1.27^2}\right)\log_e\frac{8\times1.27}{0.1}+\frac{0.1^2}{24\times1.27^2}-1.75\right\}$$

$= 42.1$ cms. $= 42.1 \times 10^{-9}$ henry $= 0.0421$ microhy.

To obtain a wavelength of one metre with this inductance requires a capacity whose value may be determined from

$$\lambda = 1.884\sqrt{LC} \text{ metres,}$$

where , L = inductance in microhenries .

C = capacity in micromicrofarads .

Hence, using above value of L ,

$$C = \left(\frac{\lambda}{1.884}\right)^2 \cdot \frac{1}{L} = \left(\frac{1}{1.884}\right) \frac{1}{0.0421}$$

$$= 6.69 \text{ micromicrofarads .}$$

This is about the minimum capacity of the smallest available rotating plate type of variable condenser . The General Radio Company Type 368a midget variable condenser has a maximum capacity of 15 mmfds. and a minimum of perhaps 5 or 6 mmfds., so that apparently it should be possible to build the usual coil and condenser type of wavemeter for use on wavelengths down to at least one metre .

(iv). Another Type of Wavemeter .

It should be possible to use a single turn of wire without any condenser to determine wavelengths, resonance being observed by the effect on the plate current meter produced by introducing the coil into the immediate neighbourhood of the oscillator . MacDonald has shown that the natural wavelength of such a single turn circular coil, broken to form a gap at one point, is 7.95 times its diameter .

Thus a one metre wavemeter of this type would consist of a coil $\frac{100}{7.95}$ = 12.6 centimetres, or 5 inches in diameter .

(v). Predetermination of Wavelength of Barkhausen - Kurz Oscillations .

When Barkhausen and Kurz[44] developed their system of producing ultra short wave oscillations by means of valves to which were applied high positive grid voltages and zero or small negative plate voltages, they obtained an approximate formula for calculating the wavelengths of the oscillations so produced . In developing this formula they assumed that the space charge might be neglected, that the valve electrodes were plane surfaces, and that the distance between grid and filament was equal to that between grid and plate . Their formula, based on these assumptions, is as follows :

$$\lambda = \frac{1000 \; d_a}{\sqrt{E_g}} ,$$

where λ is the wavelength in cms., d_a the diameter of the anode in cms., and E_g the grid potential in volts . The cathode and anode are both at zero potential .

Hollmann[9] has developed this relationship by considering the more general case of oscillating electrons moving within the valve in an alternating field rather than in a stationary field . Then by reducing the value of the potential produced by the alternating field to zero, the relation simplifies into that given by Barkhausen and Kurz . Hollmann's derivation is as follows .

If in the calculation we consider instead of the stationary retarding field an alternating field, we may expect theoretically a change in the electron motion and with it a change in the frequency. The complete period is given as the time spent by an electron in the grid-anode and the grid-cathode spaces. It will be assumed that both spaces are equal, so that calculation need be carried out for one space only.

Assumptions :

(1). Anode and cathode potentials are zero.

(2). The grid is located midway between anode and cathode; that is, $d_a = d_c = d$.

(3). The electrodes are plane.

(4). Space charges are disregarded.

(5). The oscillation produces an alternating potential only at the grid; $E_0 = E_m \sin(\omega t + \phi)$. The steady applied grid potential $= E_g$.

Then the electromotive force in the interelectrode space is

$$V = \frac{E_g + E_m \sin(\omega t + \phi)}{d} \quad \text{................ (1).}$$

and the equation for the motion of an electron is found as follows, assuming the electron to obey the law of Newtonian mechanics that force equals mass times acceleration.

In this case the force experienced by an electron of mass m and charge e, moving in an electrostatic field of intensity V, is equal to Ve. Hence Ve = - ma, so that from (1),

$$- e \cdot \frac{E_g + E_m \sin(\omega t + \phi)}{d} = m \frac{d^2x}{dt^2} \quad \text{.......... (2).}$$

Assume that the electron enters the interelectrode space at time t = 0 , with velocity v_0 , and that at this instant also x = 0 . Then from (2) by double integration we can obtain the distance "x" from the grid of the electron at any instant . This is found as follows :

$$-e \cdot \frac{E_g + E_m \sin(\omega t + \varphi)}{d} = m \frac{d^2x}{dt^2}.$$

$$\left\{ -\frac{e}{m} \frac{E_g}{d} - \frac{e}{m} \cdot \frac{E_m}{d} \sin(\omega t + \varphi) \right\} dt = d\left(\frac{dx}{dt}\right)$$

$$\int \left\{ -\frac{e}{m} \cdot \frac{E_g}{d} - \frac{e}{m} \cdot \frac{E_m}{d} \sin(\omega t + \varphi) \right\} dt - \int d\left(\frac{dx}{dt}\right) = 0.$$

$$-\frac{e}{m} \cdot \frac{E_g}{d} \cdot t + \frac{e}{\omega m} \cdot \frac{E_m}{d} \cos(\omega t + \varphi) - \frac{dx}{dt} = \mathcal{C}.$$

$$\therefore v = \frac{dx}{dt} = \frac{e}{\omega m} \cdot \frac{E_m}{d} \cos(\omega t + \varphi) - \frac{e}{m} \cdot \frac{E_g}{d} \cdot t - \mathcal{C}.$$

∴ Substituting t = 0, and x = 0, when $v = v_0$,

$$v_0 = \frac{e}{\omega m} \cdot \frac{E_m}{d} \cdot \cos(\omega\, 0 + \varphi) - \frac{e}{m} \cdot \frac{E_g}{d} \cdot 0 - \mathcal{C}$$

$$= \frac{e}{\omega m} \cdot \frac{E_m}{d} \cdot \cos\varphi - \mathcal{C}.$$

$$\therefore \mathcal{C} = -v_0 + \frac{e}{\omega m} \cdot \frac{E_m}{d} \cdot \cos\varphi.$$

$$\therefore \frac{dx}{dt} = \frac{e}{\omega m} \cdot \frac{E_m}{d} \cdot \cos(\omega t + \varphi) - \frac{e}{m} \cdot \frac{E_g}{d} \cdot t$$
$$+ v_0 - \frac{e}{\omega m} \cdot \frac{E_m}{d} \cdot \cos\varphi.$$

Integrating again ,

$$\int dx = \int \frac{e}{\omega m}\frac{E_m}{d}\cos(\omega t+\varphi)\,dt - \int \frac{e}{m}\cdot\frac{E_g}{d}\,t\,dt$$
$$+\int v_0\,dt - \int \frac{e}{\omega m}\frac{E_m}{d}\cdot\cos\varphi\cdot dt\,.$$

$$x+K = \frac{e}{\omega^2 m}\cdot\frac{E_m}{d}\sin(\omega t+\varphi) - \frac{e}{m}\cdot\frac{E_g}{d}\cdot\frac{t^2}{2} + v_0 t - \frac{e}{\omega m}\cdot\frac{E_m}{d}\cdot t\cos\varphi.$$

$$\therefore x = -\frac{e}{md}\cdot E_g\cdot\frac{t^2}{2} + v_0 t + \frac{e}{md}\cdot E_m\left\{\frac{\sin(\omega t+\varphi)}{\omega^2} - \frac{t\cos\varphi}{\omega}\right\} - K.$$

Since at $t = 0$, $x = 0$,

$$\therefore 0+K = -\frac{e}{\omega^2 m}\cdot\frac{E_m}{d}\cdot\sin(\omega.0+\varphi) - \frac{e}{m}\cdot\frac{E_g}{d}\cdot\frac{0}{2} + v_0\cdot 0 - \frac{e}{\omega m}\cdot\frac{E_m}{d}\cdot 0\cdot\cos\varphi.$$

$$\therefore K = \frac{e}{\omega^2 md}\cdot E_m\cdot\sin\varphi$$

∴ General expression for "x" is

$$x = -\frac{e}{md}\cdot E_g\cdot\frac{t^2}{2} + v_0 t + \frac{e}{md}\cdot E_m\left\{\frac{\sin(\omega t+\varphi)}{\omega^2} - \frac{t\cos\varphi}{\omega} - \frac{\sin\varphi}{\omega^2}\right\}.$$

.... (3) .

A simple solution of this equation for "t" is possible with the following assumptions :

(1). The frequency of the alternating field is determined by the electron frequency . Therefore, if we make $x = 0$ in Eqn.(3), we get the time "t" which corresponds to a half period . For a half period , $\omega t = \pi$.

(2). At the time $t = 0$, that is, at the instant of the passage of the electron through its meshes, the grid receives a negative charge, as most of the electrons strike the grid . At this instant, therefore, E_0 has its maximum negative value,

that is, ϕ must be equal to $-\frac{\pi}{2}$.

Then, since $\omega t = \pi$, and $\phi = -\frac{\pi}{2}$, the duration of a semi-period, τ, is obtained from (3) as follows :

$$0 = -\frac{e}{md}\cdot E_g\cdot\frac{\tau^2}{2} + v_0\tau + \frac{e}{md}\cdot E_m\left\{\frac{\sin\left(\pi - \frac{\pi}{2}\right)}{\omega^2} - \frac{0.\cos\left(-\frac{\pi}{2}\right)}{\omega} - \frac{\sin\left(-\frac{\pi}{2}\right)}{\omega^2}\right\}$$

$$0 = -\frac{e}{md}\cdot E_g\cdot\frac{\tau^2}{2} + v_0\tau + \frac{e}{md}\cdot E_m\left(\frac{1}{\omega^2} - 0 + \frac{1}{\omega^2}\right).$$

$$\frac{e}{md}\,E_g\cdot\frac{\tau^2}{2} = v_0\tau + \frac{e}{md}\cdot\frac{2E_m}{\omega^2}.$$

$$\frac{e}{md}\cdot\left(\frac{E_g}{2} - \frac{2E_m}{\omega^2\tau^2}\right)\tau^2 = v_0\tau.$$

$$\frac{e}{md}\left(\frac{E_g}{2} - \frac{2E_m}{(\omega\tau)^2}\right)\tau = v_0.$$

$$\frac{e}{md}\cdot\left(\frac{E_g}{2} - \frac{2E_m}{\pi^2}\right)\tau = v_0$$

$$\therefore \tau = \frac{v_0}{\frac{e}{md}\left(\frac{E_g}{2} - \frac{2E_m}{\pi^2}\right)} \quad \text{.....................} \quad (4).$$

To evaluate v_0, consider the relation

$$\tfrac{1}{2}\, mv^2 = Fx \quad .$$

In this case $F = Ve$, and $x = d$.

$$\therefore \quad \tfrac{1}{2}\, mv^2 = Ve.d \quad .$$

$$\therefore \quad v = \sqrt{2\, \frac{ed}{m}.\, V} \quad .$$

Substituting the value of V from (1), and putting $t = 0$ and $\phi = -\frac{\pi}{2}$, we have ,

$$v_0 = \sqrt{2\, \frac{ed}{m}\, \frac{E_g + E_m \sin(\omega t + \phi)}{d}} \quad .$$

$$= \sqrt{2\, \frac{e}{m} \left\{ E_g + E_m \sin\left(\omega.0 - \frac{\pi}{2}\right) \right\}}$$

$$= \sqrt{2 . \frac{e}{m} . (E_g - E_m)} \quad .$$

Hence, $v_0 = \sqrt{\frac{e}{m}\, 2(E_g - E_m)}$ .... (5).

If in (4) we substitute the value of v_0 and of the potential in volts, we get the wavelength from

$$\lambda = ct = c.2\tau \text{ .... (6).}$$

Substituting (5) in (4) , and (4) in (6) , we have ,

$$\lambda = c\,.\,2\,.\,\frac{\sqrt{\frac{e}{m} \cdot 2(E_g - E_m)}}{\frac{e}{md}\left(\frac{E_g}{2} - \frac{2E_m}{\pi^2}\right)}$$

$$= \frac{3 \times 10^{10} \times 2 \times \sqrt{2}\, \sqrt{E_g - E_m}\, .\, d}{\sqrt{\frac{e}{m}} \times \frac{1}{2}\left(E_g - \frac{4E_m}{\pi^2}\right)\sqrt{10^8}}$$

$$= \frac{12\sqrt{2}\ 10^{10}\sqrt{E_g - E_m}\ .\ d}{\sqrt{1.765 \times 10^7 \times 10^8}\left(E_g - \frac{4E_m}{\pi^2}\right)}$$

$$= 12\sqrt{\frac{2}{17.65}}\ .\ 10^3\ .\ \frac{\sqrt{E_g - E_m}\ .\ d}{E_g - \frac{4E_m}{\pi^2}}\ .$$

$$= 4.04\ .\ 10^3\ .\ \frac{\sqrt{E_g - E_m}\ .\ d}{E_g - \frac{4E_m}{\pi^2}}\ .$$

so that, $$\lambda = \frac{4040\sqrt{E_g - E_m}\ .\ d}{E_g - \frac{4\ E_m}{\pi^2}} \text{ cms.} \qquad (7).$$

Replacing the electrode space "d" by the anode diameter "d_a" , where $d = \frac{d_a}{4}$ by the original assumption of equal spacings between electrodes, and taking the case where $E_m = 0$, it is found that

$$\lambda = \frac{4040\sqrt{E_g - 0}\ .\ \frac{d_a}{4}}{E_g - \frac{4\ .\ 0}{\pi^2}} = \frac{1010\ .\ d_a}{\sqrt{E_g}} \text{ cms.,}$$

which is the equation given by Barkhausen and Kurz .

A wavelength formula similar to that of Hollmann has been developed by Scheibe [48] for the case of a tube having cylindrical elements . Scheibe's formula is as follows ;

$$\lambda = \frac{4 c r_1}{\sqrt{2 \cdot \frac{e}{m} \cdot V_{fg} \cdot 10^8}} \left\{ f\left(\sqrt{\log_e \frac{r_1}{r_0}}\right) + g\left(\sqrt{\frac{V_{fg}}{V_{fg} - V_{fp}} \log_e \frac{r_2}{r_1}}\right) \right\}$$

where λ = wavelength in cms.

$c = 3 \times 10^{10}$ cms./sec.

$\frac{e}{m} = 1.765 \times 10^7$ e.m.u./gm.

V_{fg} = grid potential with respect to filament in volts .

V_{fp} = plate potential with respect to filament in volts.

r_0 = filament radius in cms.

r_1 = grid radius in cms.

r_2 = plate radius in cms.

$f(x) = x e^{-x^2} \int_0^x e^{u^2} du$.

$g(x) = x e^{x^2} \int_0^x e^{-u^2} du$.

A table of values of these two functions is given in the Appendix (p.134) .

A formula developed by Rostagni[54] attempts to express the wavelength in terms of the volume enclosed by the grid-plate surfaces, and the electron density at the grid . Rostagni's formula is as follows :

$$\lambda = \sqrt{\frac{\pi m v}{e^2 N}} = \frac{3.35 \times 10^6 \sqrt{v}}{\sqrt{N}}$$

where e and m are the charge and mass of an electron , v the volume enclosed between grid and plate , and N the number of electrons in statistical equilibrium between grid and plate .

Since N is a function of both filament current and grid potential, this formula indicates that λ depends upon both of these factors . The quantity v includes the length of the electrodes as a factor, in addition to their spacing, hence λ is also a function of the length of the electrodes . Rostagni states that this formula "agrees well enough" with experience .

All of the above formulae were developed for the case of oscillations in high vacuum tubes . Jonescu[53] has developed a wavelength formula based upon the assumption of the presence of ionized gas in the tube . This formula is :

$$\lambda = \frac{c}{\frac{2}{\pi}\sqrt{\frac{e}{m}\cdot\frac{K}{9\pi}\cdot\frac{V}{r^2}}}.$$

where c is the velocity of light, $\frac{e}{m}$ the ratio of charge to mass of an electron, K is a constant for the gas present, V is the grid potential, and r the grid radius . The gas constant K is equal to $\frac{9\pi r^2 . Ne}{V}$, where N is the number of positive ions around the grid . Hence, substituting this value for K, Jonescu's formula may be re-written :

$$\lambda = \frac{c}{\frac{2}{\pi}\sqrt{\frac{Ne^2}{m}}}.$$

This is similar in form to Rostagni's relationship, but N now represents positive ions instead of electrons, and the dimensions of the tube elements do not appear .

IV . EXPERIMENTAL .

The objective in the following series of experiments was the obtaining of an oscillator operating on a wavelength of less than one metre with an output of at least several watts . Oscillators producing wavelengths of three or four metres were looked upon as preliminary steps , and therefore were not further developed unless they showed promise of producing much shorter wavelengths .

(a). Investigations on Normal Types of Oscillators .

(i). Oscillation Indicators .

Some method of determining when any circuit is oscillating is a necessity in this work . The radiation meter in the antenna circuit is not sufficient, as it is not always desired to have an antenna connected to the oscillator when experimenting . This is an unreliable indication in any case as a circuit may oscillate and yet not produce appreciable radiation either because of the aerial system being out of tune or because of poorly adjusted coupling between antenna and oscillator; or the radiation may not be a measurable quantity due to insufficient sensitivity in the radiation meter .

A wavemeter may be used if it is known that the oscillator wavelength is included in its range, or the Lecher wires described below may be used . A neon tube indicator such as is used for testing automobile spark plugs will also indicate oscillation by glowing when one end is held close to or touched to any part of the oscillating circuit . If it glows too brightly, though, it may be ruined due to puncture of the glass cell at the point of contact . On the other hand unless the radio frequency potential is about 50 volts or more a neon tube will not glow at all, even though the circuit is carrying a heavy current .

One positive means of determining whether a circuit is oscillating or not is to place a high frequency ammeter of the hot wire or thermocouple variety in any part of the closed oscillatory circuit . This has the disadvantage that it may, and in short wave work it was found certainly would, upset the tuning and possibly increase the wavelength appreciably because of its leads . In spite of this fact this method provides one of the best indications of whether or not a circuit is oscillating when testing it for the first time, the actual wavelength at which oscillation takes place being for the moment a minor consideration, so that the added inductance of the meter and its leads does not matter .

The plate circuit milliammeter also provides a very useful means of indicating commencement or cessation of oscillations . There is usually a marked drop in plate current when a valve begins to oscillate and a corresponding increase when it stops oscillating . These variations can be observed on the plate current meter as the tuning of the circuit is altered to stop and start oscillations . When the oscillating energy is very small this is about the only means available for indicating oscillations .

(ii). Wavelength Measurements .

Lecher wires were found to provide a very convenient means of determining wavelengths . The oscillator is coupled to a pair of parallel wires upon which it produces a series of standing waves . Various devices may be used to indicate the location on the Lecher wires of the current nodes of these waves, and their length may then be obtained by direct measurement of the distances between the nodal points thus found .

The Lecher wires used in these tests were set up as shown in Fig. 6 . The wires were made of seven strand cable of #22 bare copper wire, each 14 ft. long and mounted 5 ft. 9 ins. above the floor on supporting stands . Pyrex strain insulators were used at each end . It was later found that solid wire is more satisfactory than the stranded wire, as accurate adjustments of the sliding bridge can be made on it more easily .

The coupling coil L consists of a two turn coil 4" in diameter . C_2 and C_3 are 3 plate variable condensers with a capacity range of about 10 to 40 mmfds. These condensers were mounted just above the single shelf on one of the Lecher wires stands, with 15" spacing between them and leads 15" long from them to the wires .

A vacuum tube indicator was used with a milliammeter in the plate circuit to indicate when the shorting bridge was located at a node on the standing wave . The grid leak and condenser were 2 megohms and 150 mmfds., respectively . The milliammeter had a range of 0 - 0.5 m.a., and the valve used was a UV-199 with $67\frac{1}{2}$ volts on the plate . The plate voltage was not critical but with a meter of the above range $67\frac{1}{2}$ volts gives sufficient deflection to be easily read, the normal plate current being about 3.5 m.a. This apparatus was mounted on a bracket on the Lecher wires stand about 10" below the wires, with the batteries on a second shelf just below the first .

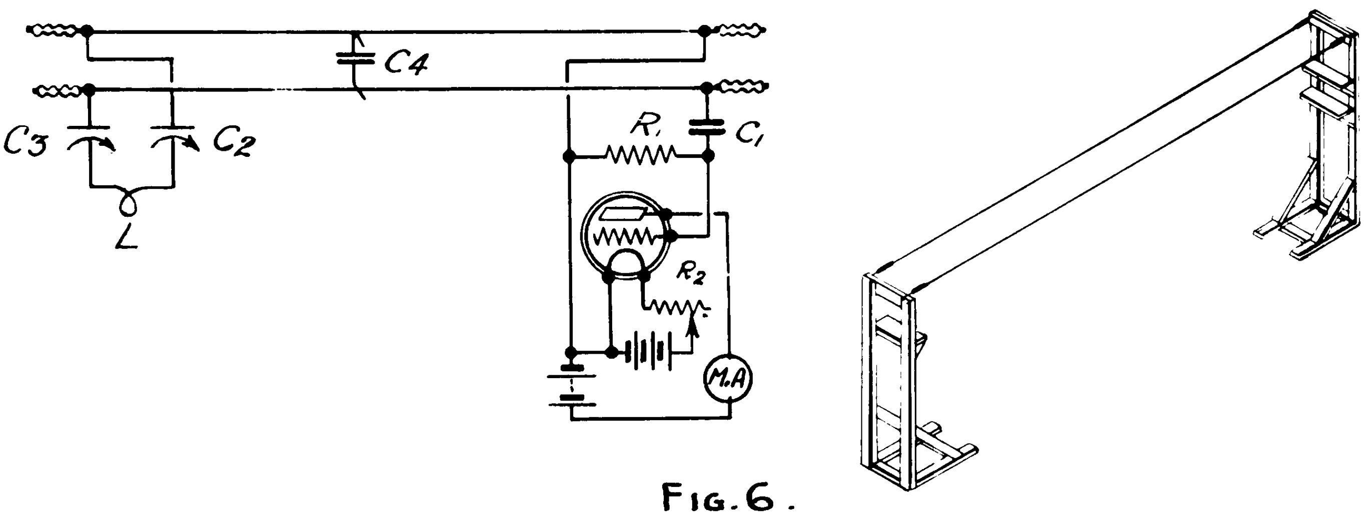


FIG. 6.

The method of operation is as follows :

The oscillator is loosely coupled to the Lecher wires by placing it about 6 inches or more from the coil L . With the shorting bridge removed tune the wires by varying the condensers C_2 and C_3 , until the plate milliammeter deflection is a minimum . This will indicate that the grid of the valve in the indicating circuit is at or near a voltage antinode or loop of the standing wave, thus causing the plate current to decrease . Tuning the wires alters the potential distribution along the wires so as to bring the loop to the grid. The shorting bridge is then placed on the wires and adjusted until the milliammeter again kicks back to a minimum deflection ; the bridge is now located across the points of minimum voltage, that is, the nodes of a standing wave, so that it does not short circuit any voltage between wires . The 0.0005 micro-farad fixed condenser shown in the bridge is not essential and was not always used, but it sometimes gave slightly sharper indications than a straight wire bridge . Thus if two such points be located as described, the distance between them will be one half the wavelength .

A number of alterations were later made in the Lecher wires system . The stands illustrated in Fig. 6 were moved farther apart, extending the wires to a length of 30 feet to enable a greater number of standing waves to be obtained, thus providing a check on results and allowing greater accuracy . With the shorter wires usually not more than three points were obtained, the wavelengths being rather longer than had been expected when the Lecher wires were first set up .

The vacuum tube indicating circuit was removed completely, and a thermocouple galvanometer placed in the shorting bridge to act as an indicator . The maximum deflection of this meter now indicated when the bridge was located at a current loop on the standing wave, since at this point maximum current will flow . The variable condensers were also removed from the other end of the wires, and a single wire tapped from the middle of the two turn coupling coil . Then, instead of loosely coupling the wires to the transmitter, this tap was simply connected to the oscillating circuit with any length of lead wire required .

The distance between the two outside points should represent a complete wavelength and the third point should be exactly midway between the other two if the wave is symmetrical . What actually happened was that the third point was nowhere near half way between the two outer points, but was usually about one third to one quarter of the distance between them . One set of readings was obtained with the two distances equal, thus indicating a symmetrical wave having no prominent harmonics . This was exceptional, however, Fig. 7

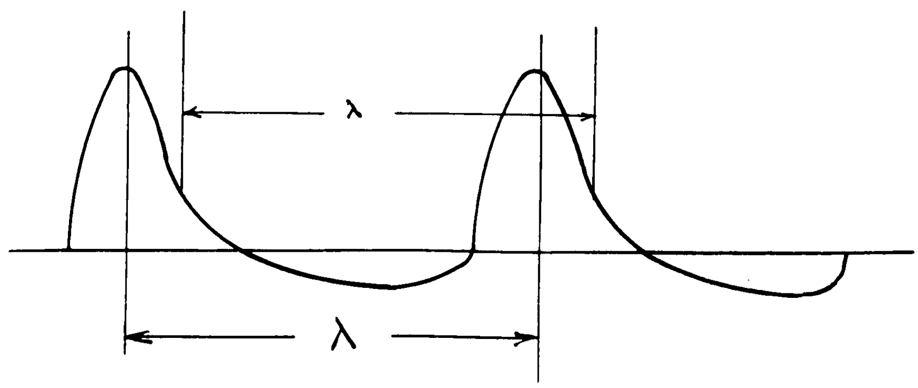


FIG.7.

illustrating what was apparently obtained in the majority of cases . The deflection points appear at the current loops of of the wave, using a thermogalvanometer in the bridge as an indicator, being alternately large sharp indications, and smaller broadly tuned one . These are just the sort of results that were obtained with the Lecher wires, so it seems that the waves produced so far have been distorted by harmonics into more or less this irregular form . The three points obtained on the 14 ft. wires were not enough to verify this fact . With the 30 ft. wires, however, several standing waves could be obtained, and the successive long and short distances were found to check each other very closely .

The following are the measurements of four standing waves of mean wavelength 1.885 metres obtained with the 30 ft.

Lecher wires :	6 ft.	2.3 ins.
	6 "	2.2 "
	6 "	1.7 "
	6 "	2.7 "

These distances all agree within less than one percent of their mean value .

The wires were next set up using solid #16 gauge copper wire instead of the 7/22 stranded wire, as it was found that the bridge did not slide sufficiently smoothly on the stranded wire to give accurate results . They were first coupled to the transmitter by shorting the wires at one end as shown in Fig. 8(a) and running a feeder to the middle of this jumper from the same point on the transmitter as the antenna feeder . This did not give any indications on the thermogalvanometer in the sliding bridge, however, so a single turn coil about 3" in

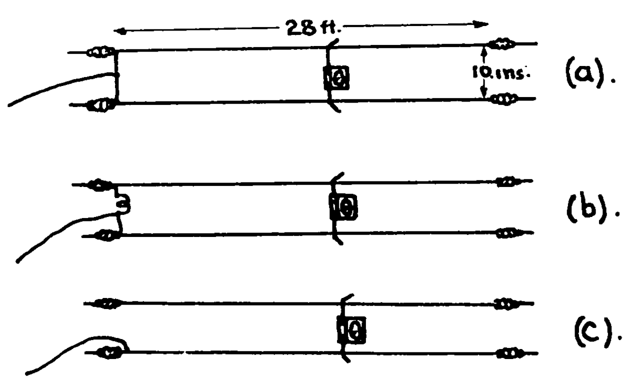


FIG. 8

diameter was bent into the end jumper connection as shown in Fig. 8(b), to produce a voltage difference between the wires . This arrangement gave readable deflections at each standing wave .

It was noticed that when the connection between the two wires was broken there was sufficient potential difference betweem them, due to their capacity, to give a distinct shock on touching both at once . The scheme illustrated in Fig. 8(c) was therefore tried, namely to leave one wire open and connect only the other to the transmitter . This worked very well and gave good deflections . It did not give zero deflection of the thermogalvanometer between nodal points, however, there being always a certain amount of voltage between the wires .

Several wavemeters using tuned circuits and galvanometers to indicate resonance were also constructed for use on very short wavelengths . Calibrations were obtained for these meters by means of Lecher wires and the oscillators described later .

One wavemeter was constructed as shown in Fig. 9, using a Weston Model 425 thermogalvanometer as the indicating device . The capacity was a three plate variable condenser with a range of 9.3 to 39.06 mmfds., and was in series with a coupling coil consisting of a single turn coil 3" in diameter The wavemeter was mounted as shown on a bracket 16" long, the leads being kept as short as possible and the condenser dial mounted on the end of a 9" extension shaft of bakelite to reduce body capacity effects . The range of this wavemeter as calculated from an estimated value of the inductance and the measured value of capacity,

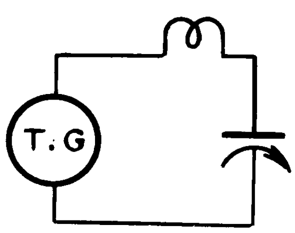
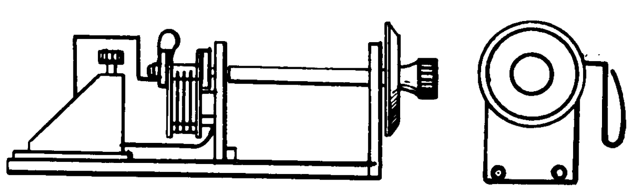


FIG. 9.



should be from 2.72 to 5.57 metres .

By placing the wavemeter of Fig. 9 so that the plane of the coupling coil was horizontal and thus parallel to the plane of the loop formed by the grid wires and bridge in the oscillators using the Mesny circuit, the deflection for any given wavelength could be very greatly increased . This coil, which now consisted of a single turn $2\frac{1}{4}$ ins. in diameter , was therefore bent into the position shown in Fig. 10, in order to get maximum coupling, when necessary to obtain a reading, without turning the wavemeter on its side .

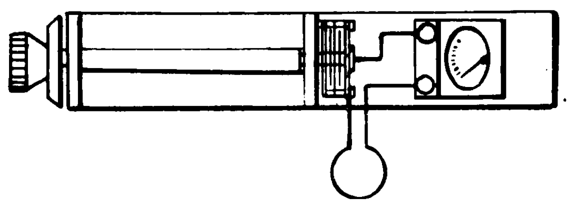


Fig. 10.

Before being calibrated experimentally from the Lecher wires this coil was removed and replaced by a straight wire inductance . The wavemeter now consisted of simply the condenser and thermogalvanometer connected by as short leads

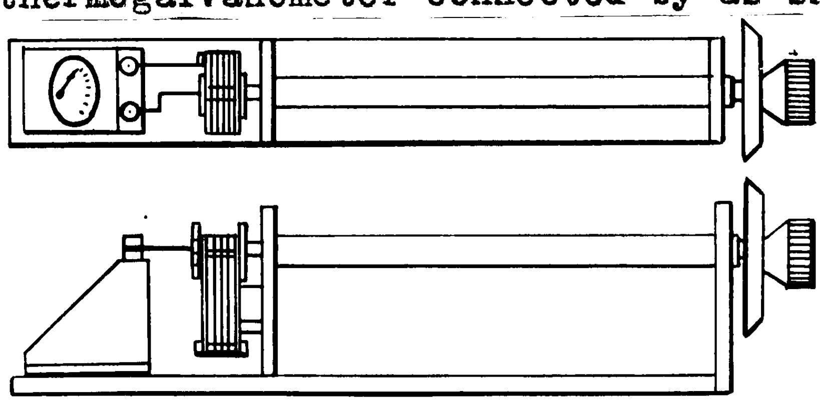


Fig. 11.

as possible, as shown in Fig. 11 . Using the Lecher wires and one of the oscillators, this wavemeter was calibrated and its range found to be from 1.15 to 2.35 metres .

Another wavemeter, shown in Fig. 12, was built and calibrated . Tuning was done by means of two General Radio Co. Type 368 vernier condensers of 50 mmfds. maximum capacity . A Weston Model 425 thermogalvanometer was used as the indicating device . The meter and two condensers were all connected in series, the leads constituting the inductance .

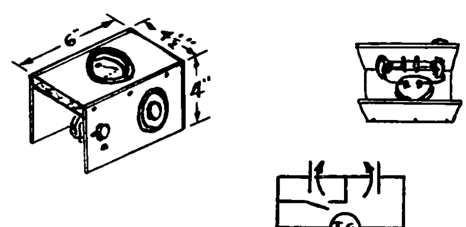


FIG. 12.

A graduated dial was attached to one of the condensers, the other retaining the knob and pointer supplied with it . A number of ranges could thus be obtained by setting the one condenser in any given position and calibrating the wavemeter over the range of the dial on the other . A stud connected to the stator of the first condenser and mounted on the panel as shown, allowed this condenser to be shorted out by turning the pointer on the knob onto this stud, the pointer being connected to the rotor .

The range with one condenser shorted in this manner was found to be about 1 3/4 to 5 3/4 metres, as calibrated on the Lecher wires, and also as checked by comparison over the top of this range with the General Radio Type 458 wavemeter .

With this condenser set at its maximum capacity instead of being shorted the range is about 1¼ to 3½ metres . Very little reduction in wavelength was obtained by decreasing the capacity of this condenser below its maximum setting, and the calibration curve becomes very flat, giving a very small wavelength range and broad tuning .

(iii). Transmitting Oscillators .

The first oscillator tested used the circuit shown in Fig. 13, and was expected to operate at a wavelength of about 1.5 metres . The aerial system consisted of two similar lengths of #8 square copper wire, each 14 3/4 inches long, i.e. one quarter wavelength . They were mounted directly on the terminals of a hot wire ammeter, supporting themselves vertically upwards and downwards as the antenna and counterpoise respectively . Coupling to the oscillator was effected by a single lead to the antenna side of the radiation meter .

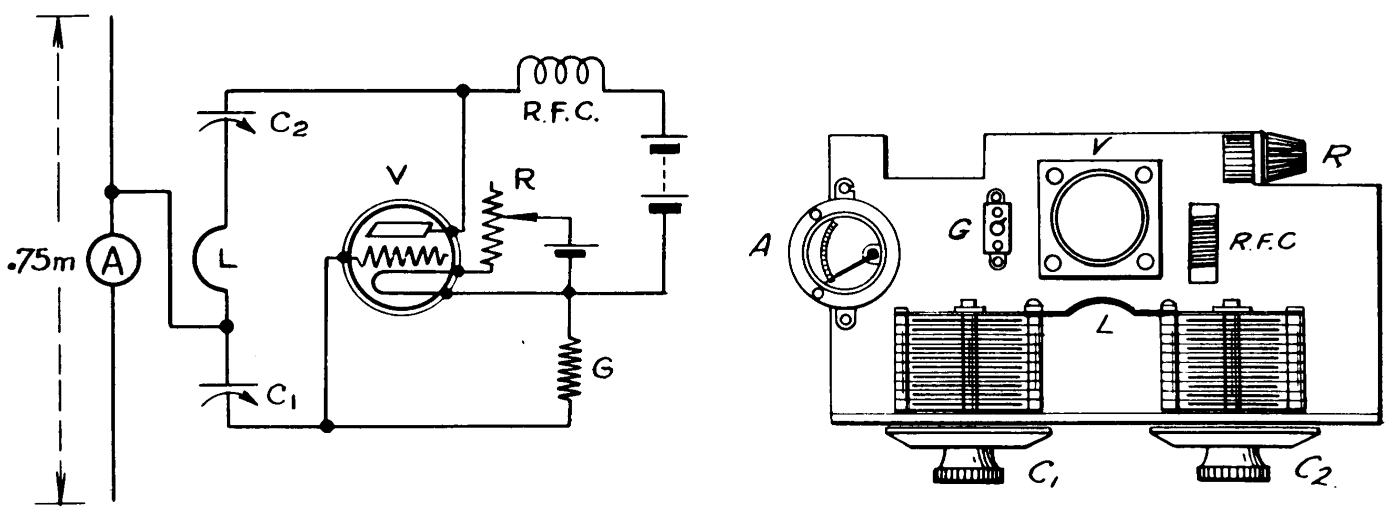


FIG. 13.

The radiation meter used was a 0 - 0.5 ampere hot wire ammeter . A Weston thermogalvanometer was also tried in its place, since it was of lower resistance . The inductance L was a half turn of 3" diameter of #14 bare copper wire supported by the condensers C_1 , C_2 . These condensers were cut down to

13 plates , giving a maximum capacity of about 100 mmfds. The valves used were B.T.H. "B" valves, of which several were tried, a Marconi-Osram VT-1a, and a UX-201a . The filaments were supplied their rated currents from a 6 volt storage battery . A d.c. generator supplied the plate voltage, which was varied from 300 to 700 volts with the tubes used . Sockets were used with all tubes . A variable grid leak of from 0 to 10 megohms was first used, and was later replaced with a resistance box which permitted a variation from 0 to 10,000 ohms . The circuit was also tested with the grid leak shorted , and with and without a radio frequency choke coil in series with the positive lead of the plate supply .

With all of these variations no indications whatever were obtained on any of the radiation meters used . No glow could be obtained anywhere about the oscillating circuit with a Westinghouse neon tube spark-plug tester . Lecher wires and a wavemeter also failed to indicate any oscillations .

The next oscillator circuit tested was that of Fig. 14 . The inductances L_p , L_g consist of the two halves of a 4" bare copper wire loop . A 0.003 mfd. fixed condenser was connected between two of the ends of this loop, the other two being connected across the stators of the variable condenser , this latter connection serving to support the coil . The condenser C_pC_g was a Cardwell 17 plate variable condenser cut down to form two sections as shown . A three element condenser is thus formed consisting of one rotor rotating between two separate stators .

A UX-201a, a B.T.H. "B", a VT-1a, an AT-50 fifty watt valve, and several UV-201a valves were placed in turn in this circuit, but it could not be made to oscillate . The B.T.H. "B" valve was then again placed in the circuit and the half ampere

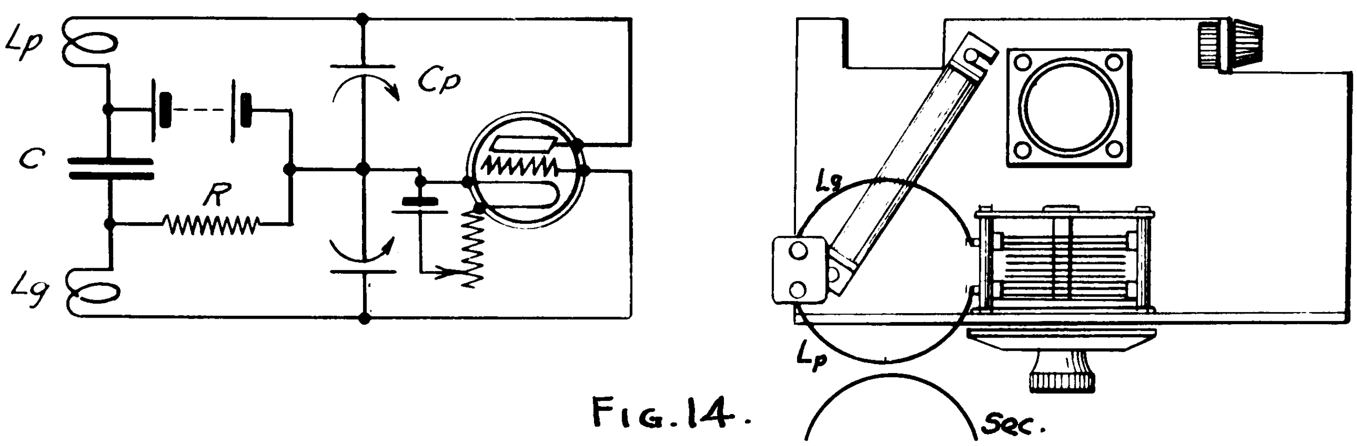


FIG. 14.

hot wire radiation meter replaced by a 115 m.a. thermogalvanometer. When the plate voltage was raised to about 850 volts, so that the plate current increased to 30 m.a. , a radiation of about 40 m.a. was obtained . The "B" valve was then replaced with a UV-201a . With a plate current of about 40 m.a. the radiation now increased to a maximum of 300 m.a. This valve could not however, withstand the high plate voltage necessary to maintain the plate current, and would not remain in steady oscillation for more than a few minutes at a time . Of the other 201a valves then tried, the ones which gave any radiation were those drawing about 40 m.a. plate current .

More power is required to produce oscillation at these short wavelengths than is the case at longer wavelengths, though it was found that once oscillation had started the plate current could be considerably reduced without causing the oscillations to cease . It was possible to decrease the plate current from the 40 m.a. necessary to commence oscillations, to about 30 m.a. by reducing either plate voltage or filament current, without stopping oscillation , although the antenna current varied in proportion to the plate current .

The transmitter of Fig. 13 was again assembled, this time using a UX-210 7½-watt transmitting valve and a 5000 ohm grid leak . Usually it was necessary to draw 45 to 50 m.a. plate current to begin oscillation, though it would sometimes remain oscillating when the plate current was reduced to as low as 35 m.a. The half turn inductance was mounted between the two variable condensers as illustrated in Fig. 15(a) . The maximum wavelength obtained using no aerial was 4.27 metres, but the circuit would not oscillate with the condensers at their minimum capacities, the lowest wavelength at which it would oscillate being 3.91 metres .

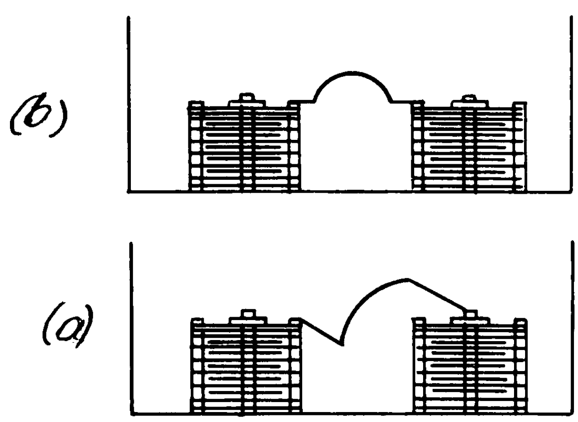


FIG. 15.

It was thought that the wavelength might be lowered by shortening the leads of the inductance . The half turn coil was therefore removed from its position as shown in Fig. 15(a) and replaced as in (b),between the two condenser stators . The maximum wavelength as indicated on the Lecher wires was now 4.06 metres and the transmitter could be made to oscillate at the minimum capacity of the tuning condensers .

Several methods of coupling the oscillator of Fig. 13 to the antenna system were tried , The various arrangements are shown in Fig. 16 . All three methods gave some radiation but the maximum current in the antenna ammeter was obtained with connection (c) . The antenna and counterpoise, each 35½" long, were then gradually cut down to 29", this length giving best results, the maximum antenna current being 0.11 ampere from a UX-201a valve . The single coupling wire in (a) must be connected to the grid end of the coil .

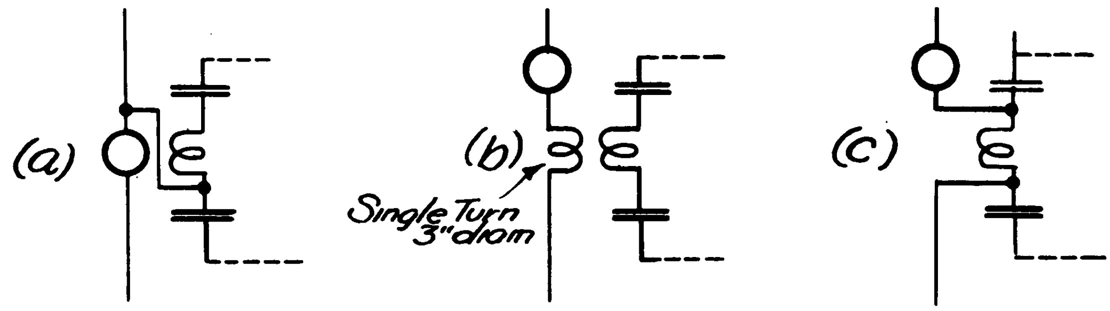


Fig. 16.

A Weston 0 - 1.5 amp. thermoammeter connected in the oscillating circuit showed that the circulating current went up as high as 0.8 ampere when using the UX-201a in this transmitter .

Fig. 17 illustrates another transmitting circuit which was set up and tested, though without results . The inductances L_1 L_2 are single turns 3 inches in diameter with centre taps

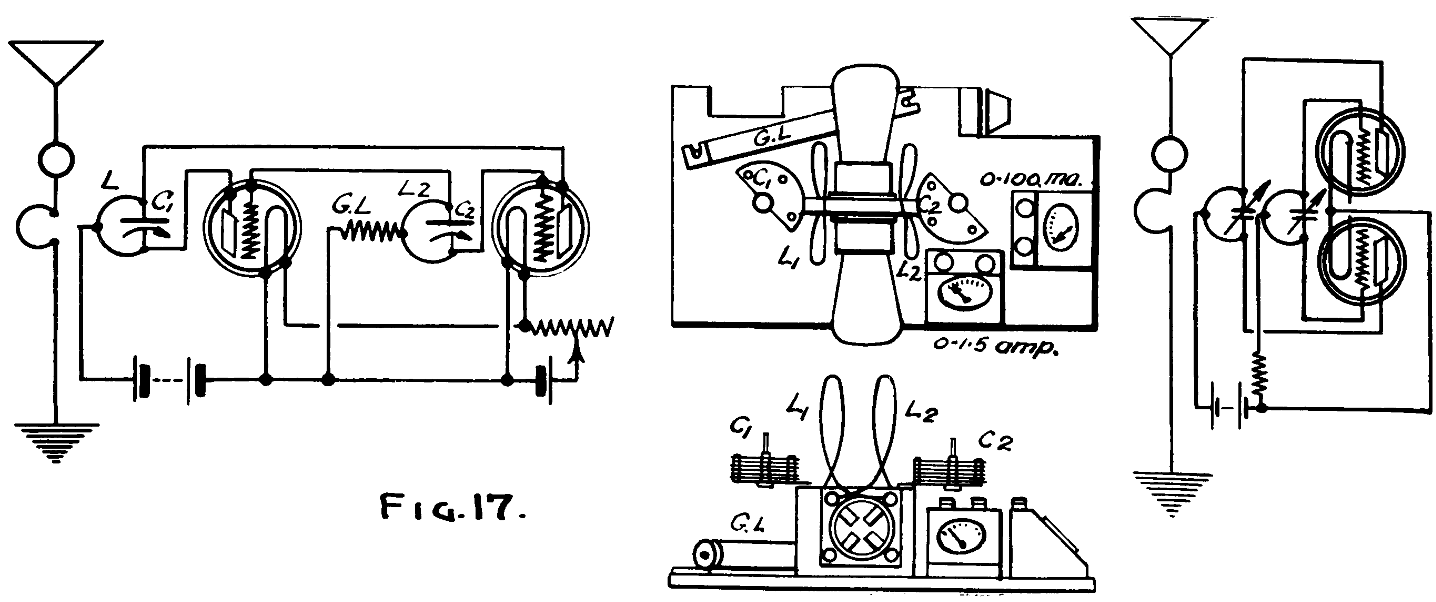


Fig. 17.

connected as shown, and shunted by 3 plate variable condensers. The grid leak resistance is 5000 ohms. UX-201a valves were used, each drawing about 45 m.a. at 250 volts. The minimum wavelength of this transmitter should be approximately 2.5 metres. A thermoammeter was placed in the oscillating circuit between one end of L_1 and C_1 to indicate oscillation, but no deflection whatever was obtained.

An oscillator using the circuit shown in Fig. 18 was then assembled, and performed very well. UX-201a valves, drawing a total of 80 - 90 m.a. on the plates, gave a maximum current of over 1.5 amperes in the oscillating circuit. This was indicated by a 0 - 1.5 amp. thermoammeter connected on one

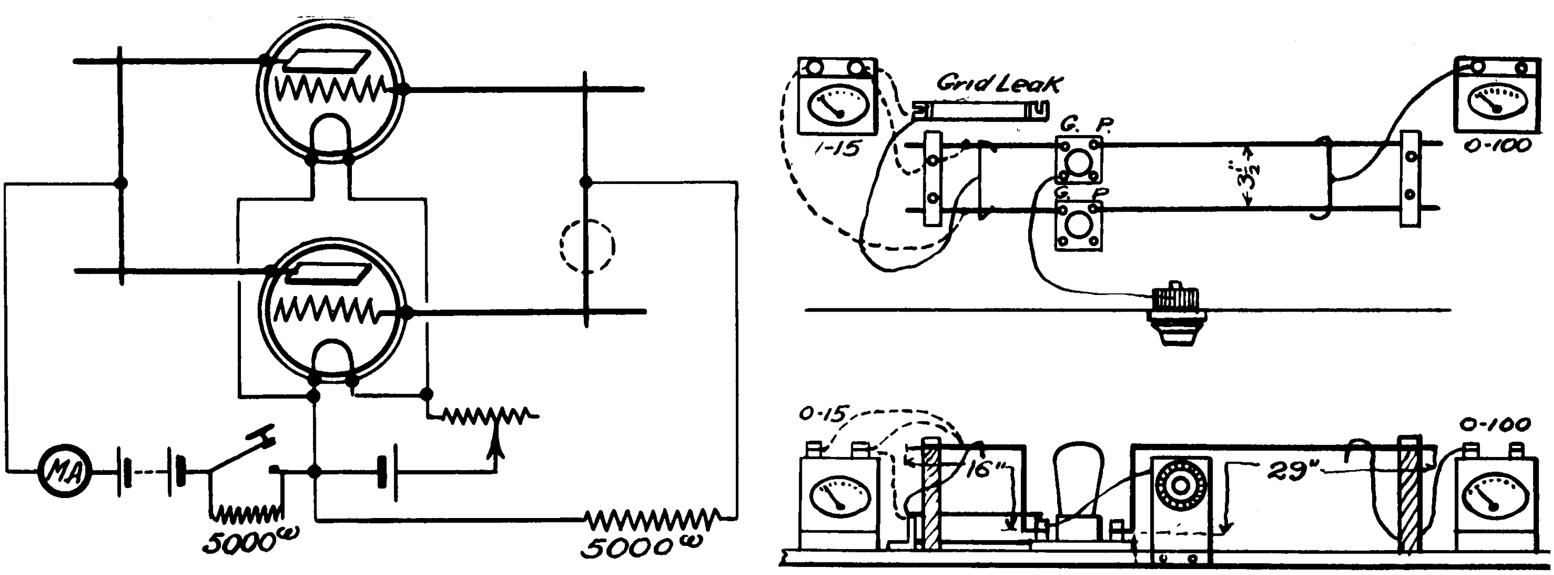


Fig. 18.

side of the sliding bridge on the grid wires. The grid and plate inductances were simply parallel wires mounted as shown. A 5000 ohm grid leak was used.

This oscillator was then set in operation with the bridges across the grid and plate wires set at about half way along them. After measuring the wavelength on the Lecher wires, the outside ends of the grid and plate wires were cut off at the bridges, to determine if the capacity between them had any effect on the wavelength, even though it were shorted by the bridge . The wavelength was then measured again and was found to have become possibly a centimetre shorter on a 3½ metre wavelength . Thus in this case these ends have practically no effect on the oscillating circuit .

With grid and plate wires 16 and 29 inches long, respectively, and with the ammeter in the oscillating circuit as shown in Fig. 18, the maximum and minimum wavelengths obtainable were 3.94 and 2.96 metres respectively . By removing this ammeter and its leads, shown dotted in the sketch, and replacing them with a straight wire bridge shown in full lines in the sketch, the minimum wavelength as measured on the Lecher wires was reduced from 2.96 to 1.885 metres .

Two AT-50 valves were then tested in place of the 201a valves in this transmitter , and when the sliding bridges were moved almost to the ends of the wires, the wavelength being then about 3 metres, the circuit began to oscillate . The oscillatory circuit current was 0.6 amp. The minimum wavelength at which these tubes could be made to oscillate was 2.72 metres, as measured on the Lecher wires .

These valves were then replaced by two 250 watt Marconi-Osram VT-1B valves . The grid and plate wires used were 23 and 29 inches long, respectively, both pairs being spaced 2½ inches apart . No oscillations could be obtained, even with the bridges set at the ends of the wires so as to give the maximum wavelength . A three turn coil 3¼ ins. in diameter was connected across the ends of the plate wires in place of the straight wire bridge, the positive high tension connection being tapped off the middle of this coil . The circuit now oscillated at 4.88

metres as measured on the Lecher wires, and the tank circuit current was over 1.5 amps.

The AT-50 valves were next connected in this circuit, and the plate wires replaced with the three turn coil connected directly between the plates . This arrangement would not oscillate, but when the plate wires were replaced in addition to the coil but without the bridge, an oscillatory current of 0.6 ampere was obtained . The addition of the capacity produced by the two parallel 29 inch wires in parallel with the three turn coil increased the wavelength sufficiently to allow the circuit to oscillate . These plate wires were then again removed and replaced by an air condenser composed of two 2 inch square brass plates spaced 3/4 inch . The circuit still oscillated at about 3.1 metres as indicated on the wavemeter .

From this it is clear that the reason the circuit of Fig. 17, which is the same as the above arrangement, would not operate is that the values of capacity and inductance used were too small for the type of valves used, which would not oscillate at so low a wavelength under these conditions .

The transmitter of Fig. 18 was reassembled and mounted permanently on top of a table 22" by 36" . The grid wires were 12 ins. long spaced 2½" apart, and the plate wires 18" long with the same spacing . The apparatus was arranged as shown in Fig. 19, the valves being mounted upside down and connections made directly to the pins, no sockets being used .

When an aerial one metre long and suspended vertically between floor and ceiling, was coupled to this transmitter, a maximum radiation of 160 m.a. could be obtained at a wavelength of 2 metres , with the two UX-201a valves drawing a total of 90 m.a. on the plates . The antenna was connected to the oscillator as shown with a lead about 4½ ft. long , and the radiation ammeter connected in the centre of the antenna .

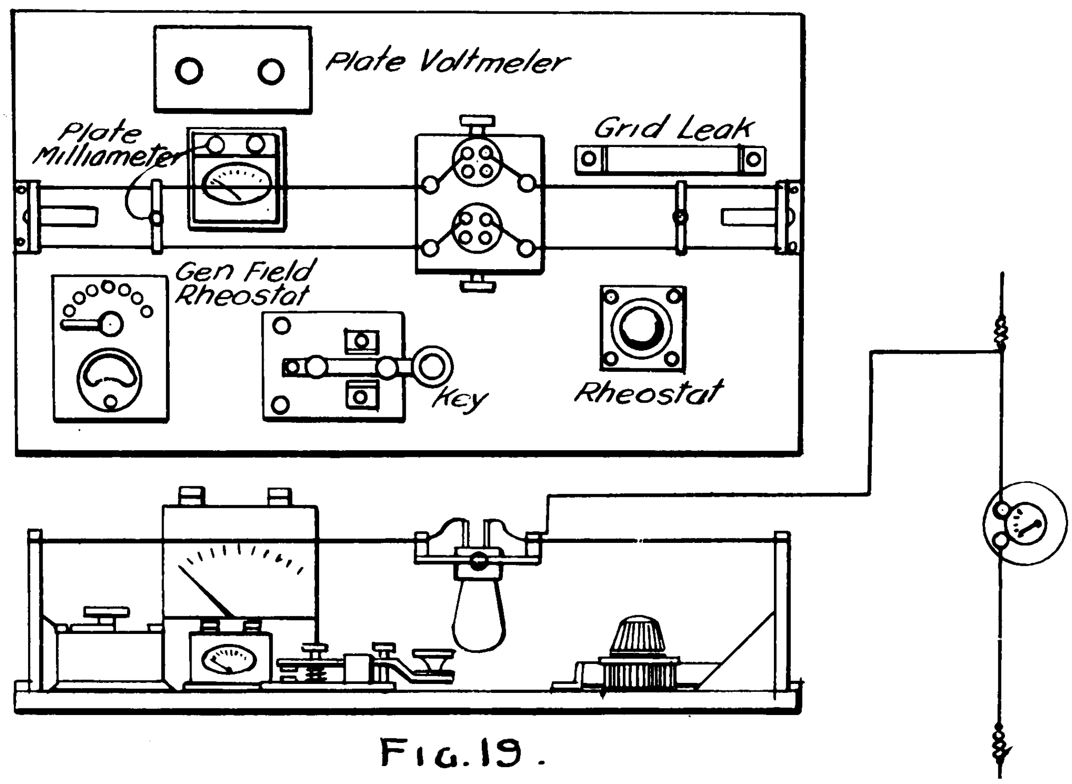


FIG. 19.

Operating the above antenna, one metre long, at a wavelength of two metres, the current and voltage distribution along the wire are as shown in Fig. 20 . Voltage feed was used

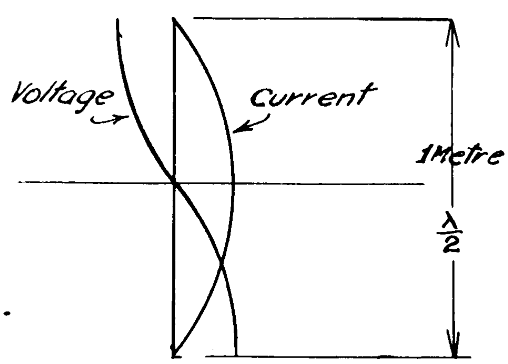


FIG. 20.

and so the feeder had to be connected at either end of the antenna, that is, at the point of maximum voltage . The current is a maximum at the centre so the meter was inserted at that point .

A maximum radiation of 0.24 ampere could be obtained when the plate voltage was increased to give a plate current of just over 100 m.a. The UX-201a valves would not stand the necessary voltage, however, and stopped oscillating almost immediately.

Two UX-210 valves were placed in this transmitter and the same antenna used. At a wavelength of 1.9 metres with 205 m.a. at 475 volts on the plates, a radiation of over 1.6 amperes was obtained, the plates of the valves just turning a dull red. Assuming from the condition of the plates that the 210 valves were operating at an efficiency of 60%, the antenna resistance is found to be about 23 ohms.

Maximum radiation was obtained with the feeder connected to the top of the antenna and hanging so as to make an angle of about 60° with it. It was found that with 1.0 ampere in the antenna the current in the feeder was 0.17 ampere.

The UX-210 valves were found to oscillate with the grid leak open circuited, the plate current under that condition being 20 m.a. at 450 volts. An extremely feeble wavemeter indication was obtained at about 1.4 metres. The faulty grid leak was screwed to the table and so there was a very high resistance path through the wood, this being sufficient to permit the valves to oscillate.

The antenna feeder was then taken off the grid side and attached to one of the plate binding posts on the bracket supporting the valves, as shown in Fig. 21. With the grid leak shorted and the plate voltage increased to 750 volts, the plates drawing 135 m.a., a radiation of 0.42 ampere was obtained at a wavelength of about 2 metres. The plates turned somewhat red with this load, especially the one not tapped to the antenna . Putting in a 5000 ohm grid leak permitted the plate voltage to be increased to 900 volts, the plates drawing

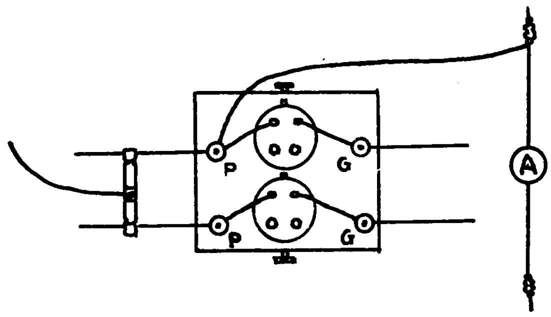


FIG. 21.

95 m.a. and remaining cool . The radiation was now 0.53 ampere . With a plate current of 90 m.a. at 840 volts and using a negative grid bias of 67 volts, the radiation was 0.38 ampere . By decreasing the bias to -22 volts the plate current increased to 130 m.a. at 780 volts and the radiation increased to 0.43 ampere, but the plates heated up .

The most satisfactory operation can therefore be obtained by the use of a grid leak of the proper resistance . Using the 5000 ohm leak the plate voltage was increased to 1050 volts, the radiation going up to 0.6 ampere at the same wavelength of 2 metres . The plate current was 140 m.a.

The parallel plate and grid wires of the transmitter of Fig. 19 were then removed and replaced by short jumpers composed of clips sprung directly across the plate and grid binding posts of the valve shelf, as shown in Fig. 22 . The transmitter now radiated 0.1 ampere at 1.3 metres, the antenna being one half wavelength long, i.e., 0.65 metre . This was with a plate current of about 50 m.a. at 500 volts a.c., and the plates remained cold . When the plate current was increased to 100 m.a. by increasing the voltage to 750, the radiation went up to over 0.3 ampere but the plates became excessively hot .

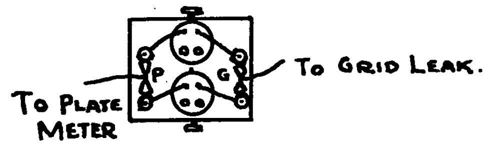


Fig. 22.

The bases of the two UX-210 valves were then removed and the valves replaced with their plates and grids connected by very short leads . By this means it was hoped to reduce the wavelength considerably, but it was found that the circuit would no longer oscillate .

The ultraudion circuit , shown in Fig. 23, was now returned to in an attempt to produce shorter wavelengths than had so far been obtained . A VT-1a valve was first used with a Sangamo .00015 mfd. condenser connected directly to the grid and plate pins of the valve by leads 3/4 inch long . A UX-210 and a UX-201a with their bases removed were also used again in this circuit . The minimum wavelength obtained with the UX-210 was 0.865 metre, with the UX-201a 0.80 metre, and with the VT-1a 0.850 metre . These wavelengths were measured on the Lecher wires, but as will be seen below an error was made in using the Lecher wires due to the presence of harmonics, so that actually the above wavelengths should be doubled . The shorter waves were in all probability present, but as the second harmonic of the higher wave fundamental .

In the diagram of Fig. 23 the oscillating circuit consists of the grid-plate capacity of the valve in series with the external capacity and the inductance of the leads between them . Thus the interelectrode capacity is the main factor in determining the frequency of oscillation . This is the reason why the VT-1a operated at a wavelength lower than the other valves, even though its base was not removed to shorten the leads, this valve having a plate-grid capacity of about half that of the UX-201a .

The base was then removed from the VT-1a valve to determine at just how low a wavelength this valve could be made to oscillate, but sufficient energy output could not be obtained to give readings on the Lecher wires, so that this wavelength was not found . The valve did oscillate, however, a Sangamo .003 mfd. condenser being used between grid and plate with 1100 volts 60 cycle a.c. on the plate, and using a 120,000 ohm grid leak . Oscillation was indicated by a very slight deflection of the radiation meter, which was a Weston 0 - 115 m.a. thermogalvanometer in the middle of an antenna about 15 inches long voltage fed from the grid . The shortest measured wavelength obtained with the VT-1a valve was 1.1 metres .

Condensers of various capacities between .00015 and .01 microfarad were tried between the plate and grid of a VT-1a valve in this circuit . The wavelength remained constant as closely as could be read on the wavemeter, while maximum radiation was obtained using a plate - grid condenser of about .001 mfd. capacity . The radiation remained very nearly constant however for any value of capacity between .0001 and .01 mfd. It was found that the circuit would not oscillate if one of the condenser leads in the oscillating circuit was much longer than the other, that is, if the grid and plate circuit inductances were too much unbalanced . Altering the length of these leads by as little as a millimetre produced a measurable change in wavelength .

A deForest "H" valve, a special short wave valve rated at 150 watts input, was then tested in the ultraudion circuit to determine its lowest practicable operating wavelength . The circuit used is shown in Fig. 23, the grid leak resistance

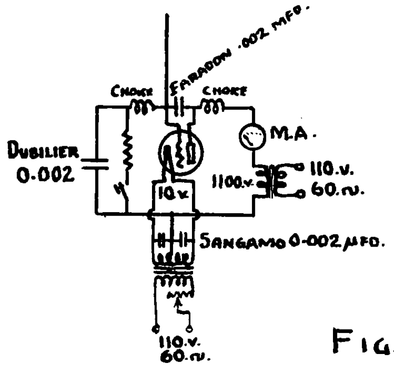


Fig. 23.

being varied from 0 to 120,000 ohms and the plate voltage from 1100 to 1500 volts, a.c. The lowest wavelength obtained was about $2\frac{1}{4}$ metres, or about double the minimum wavelength of the VT-1a .

In calibrating one of the wavemeters by means of an oscillator and Lecher wires, resonance points were observed on the wires at points approximately midway between the half wave points, indicating the presence of a second harmonic . The indications on the thermogalvanometer of the sliding bridge on the Lecher wires were in most cases much smaller at these harmonic points than at the nodal points of the fundamental standing wave . However at a wavelength of about $2\frac{1}{2}$ metres there were four nodal point indications for each standing wave on the wires, the spacing and galvanometer deflection being approximately the same at all points . This was known to be a $2\frac{1}{2}$ metre wave because it was reached by beginning with the oscillator at a wavelength around 5 metres whose length could be determined accurately and checked, and then gradually decreasing it . The $1\frac{1}{4}$ metre second harmonic is therefore present and is almost as strong as the fundamental wave . In the earlier work with the ultraudion the fundamental was considered to be a $1\frac{1}{4}$ metre wave, and when in measuring shorter wavelengths, the harmonic disappeared, the distance between each two nodal points on the Lecher wires was assumed to represent a full wavelength instead of, as it actually was, a half wavelength of the fundamental . There was, very probably, a second harmonic present at each wavelength measured, but it was not of sufficient strength at wavelengths below $2\frac{1}{2}$ metres to give any indication on the Lecher wires thermogalvanometer .

The action of the receiver, as described later, in receiving signals when tuned to $2\frac{1}{2}$, $3\frac{1}{2}$, and $4\frac{1}{2}$ times 1.6 metres, as well as integral multiples, indicates that the 0.8 metre wave which was thought to be the fundamental, was actually present and being radiated by the oscillator, but as a second harmonic of the 1.6 metre fundamental, this being the true wavelength to which the transmitter was tuned, in this case, rather than 0.8 metre as thought when first experimenting .

Using antennae of the dimensions shown in Fig. 24 with a VT-1a valve in the ultraudion circuit operating at a

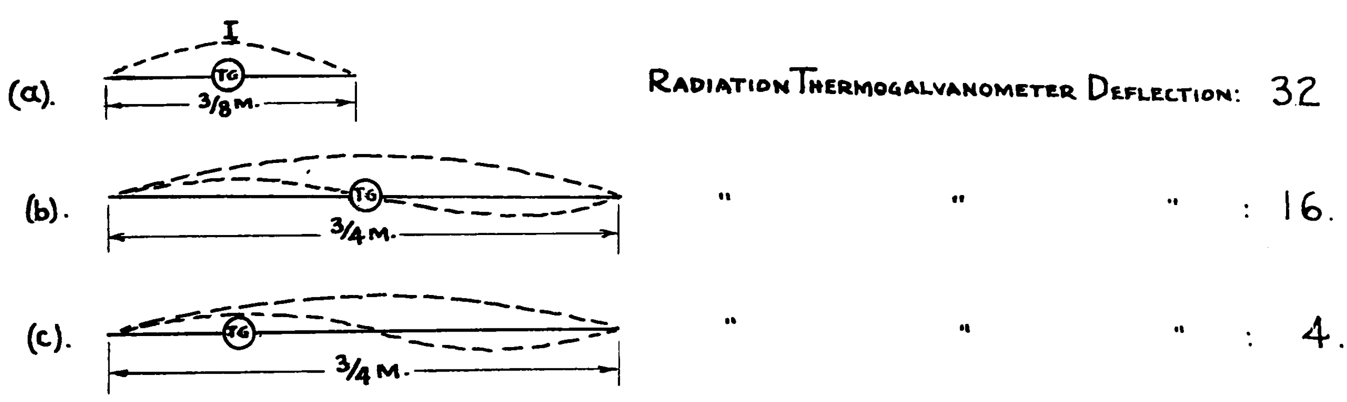
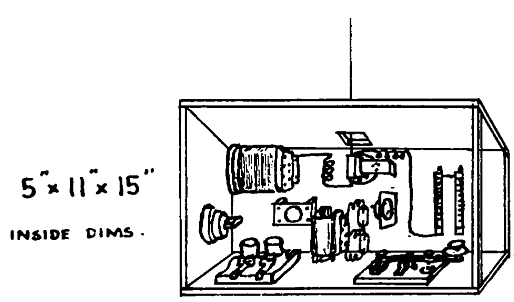


FIG. 24.

wavelength of 1½ metres, the antenna current in each case was as shown in the figure . The readings were obtained on a current squared scale, so that power is directly proportional to them . Considering the radiation resistance in case (b) to be double that in (a), we see that this transmitter gives the same power output at the second harmonic or 3/4 metre wavelength as at its fundamental 1½ metre wave . When the length of the antenna is increased from one quarter of 1½ metres to one half, thus allowing the 1½ metre wave to be radiated as well as the harmonic, the power output at 3/4 metre becomes much less, most of the output being at the fundamental 1½ metre wave .

Being reasonably certain at this stage that a fair amount of power could be fed into an antenna at a wavelength of 3/4 metre, from a transmitter operating at a fundamental of 1½ metres, it was decided to proceed with the construction of a 1½ metre transmitter, using a VT-1a valve as the source of oscillations, and radiate its second harmonic by using a selective radiating system tuned to 3/4 metre .

The complete oscillator and power supply was assembled in one case as shown in Fig. 25, both filament and plate being



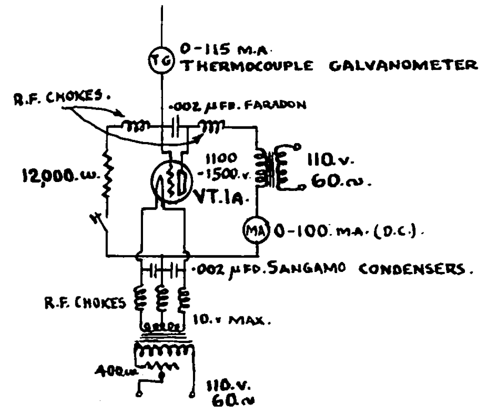


FIG. 25

supplied with alternating current from two transformers mounted with the remainder of the apparatus and fed through a lamp cord and plug which could be connected to any 110 v. 60 cycle source .

The antenna is clipped on to the grid lead through the aperture in the top of the case, it being intended to use a 3/4 metre half wave antenna, that is, an antenna 3/8 metre in length .

A grid condenser was not used, as it was found that increased radiation was obtained without it . The radio frequency choke coils were made of #16 bare copper wire wound with one quarter inch diameter, and were self supporting , no winding former being used . The grid and plate choke coils consisted of about 15 turns each and the filament coils 10 turns .

Using a single straight wire antenna 3/8 metre long with a Weston Type 425 thermocouple galvanometer connected in the centre as the radiation meter, a radiation of over 115 m.a. was obtained from a Marconi-Osram VT-1a valve in this transmitter without overheating the plate of the valve . Considerable variation in operation was observed in testing a number of valves in this transmitter, some supposedly similar valves giving much less radiation than others, and at the same time drawing more plate current and heating more rapidly .

(iv). Receivers .

The first receiver constructed used the circuit shown in Fig. 26 . The antenna was a single wire about seven feet long suspended vertically between pyrex insulators . A UX-201a valve was used . C_1 is a variable condenser with a range of approximately from 15 to 100 mmfds. It is in parallel with an inductance consisting of a 3" diameter coil of three turns .

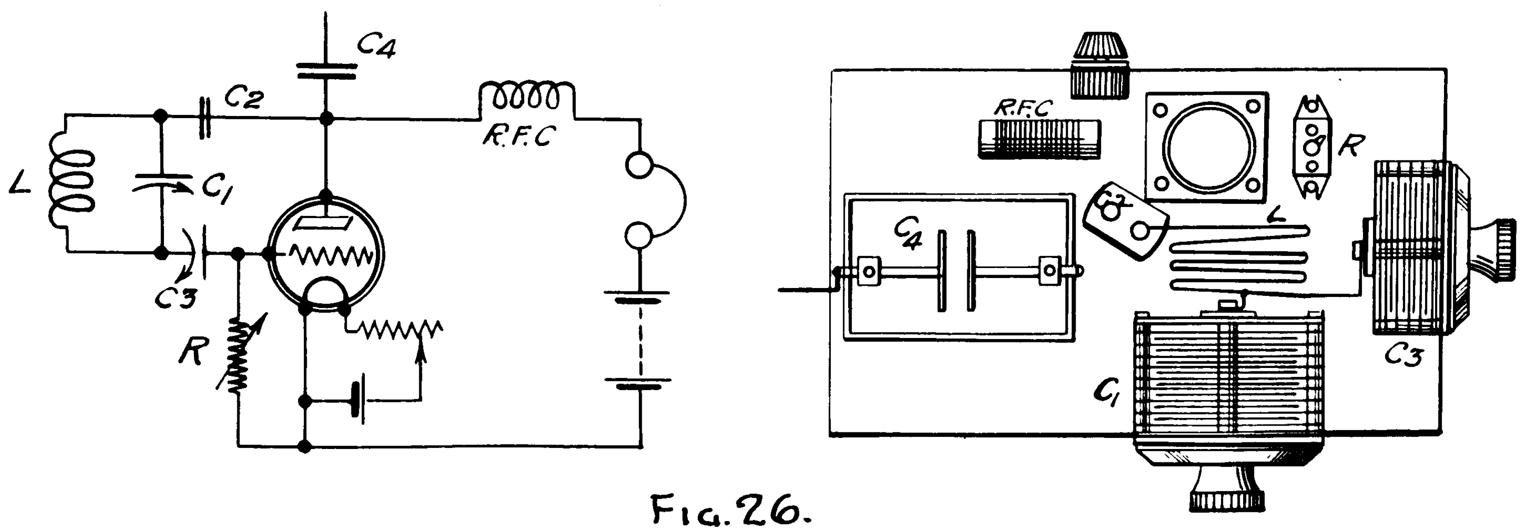


Fig. 26.

C_2 is a 250 mmfd. fixed condenser and C_3 a three plate variable condenser . The antenna series condenser C_4 consists of two brass plates 2" square separated 3/4" in air . The grid leak R is variable up to a maximum of 10 megohms . A radio frequency choke coil of 112 turns of fine wire wound in a single layer on a 3/4" diameter cardboard tube, was connected in the positive plate battery lead .

The receiver was tested using 22½ and 45 volts on the plate of the UX-201a valve, but would not oscillate with either voltage . Bearing in mind that the transmitters had at first failed to oscillate because of insufficient plate current, it was thought that this might possibly be the case with the receiver, though at the higher waves the UX-201a oscillates readily as a detector with 22½ volts on the plate. The plate potential was therefore increased to 67½ volts and this was found sufficient to allow the tube to oscillate over all of the tuning range except about five degrees in one spot . The plate voltage was then increased to 90 volts and the tube could be made to oscillate over the complete tuning range of approximately 3 to 7 metres .

The three turn inductance was now removed and replaced by a 2 turn coil $3\frac{1}{2}$" in diameter, but the receiver would not now oscillate even with 90 volts on the plate of the valve . The 3-plate reaction condenser was replaced by an 11-plate condenser, and this now enabled oscillation to take place over all but a degree or two in one spot on the dial . One turn, half turn, and quarter turn coils of 2" diameter were then connected in place of the two turn coil . The receiver could be made to oscillate over the complete range of all of these when a 150 mmfd. fixed condenser was connected in parallel with the 11-plate reaction condenser .

One stage of audio amplification was added to this receiver and the UX-201a valves replaced by WX-199 valves . The tuning condenser was then replaced by one of 100 mmfds. maximum capacity thus giving slightly broader tuning, as the tuning previously had been entirely too sharp when using the 250 mmfd. condenser . There were now two points on the tuning dial at which the receiver could not be made to oscillate but these were removed by shorting out a portion of the choke coil .

The oscillating circuit of the receiver is made up as shown in Fig. 27, so that the wavelength range should be about from 4 to $7\frac{1}{2}$ metres . This was checked experimentally and the calculated range found to be approximately correct . Signals from the ultraudion oscillator were heard at several points on the receiver within this range . An explanation is therefore necessary as to how reception could be obtained at wavelengths of one or two metres with this same receiver .

When this receiver was being used to receive signals at wavelengths much below 4 metres it was not producing an audible beat note by oscillating close to the transmitted wavelength . What actually took place was that the receiver oscillated at a wave whose length was such that one of its harmonics was at the transmitted wavelength and was of sufficient strength to produce a beat note with it . Thus 0.8 metre is the 5th, 6th, 7th, 8th, and 9th harmonic of 4.0, 4.8, 5.6, 6.4, and 7.2 metres, respectively, all of which wavelengths lie within the range of the receiver and may produce the required harmonic .

Some experiments were then carried out to investigate this explanation . On a test made with the transmitter operating at about 77 centimetres the signals were heard on the receiver at 0, 20, 35, 55, and 77 on the 0 - 100 tuning condenser dial, the reaction condenser not being varied . These settings represent the waves whose 5th, 6th, 7th, 8th, and 9th harmonics are at 77 centimetres, that is, the receiver at these dial settings was tuned to 3.85, 4.62, 5.39, 6.16, and 6.93 metres . This agrees with the receiver's estimated wavelength range . The signals were of about equal intensity at all except the 7th harmonic, which was considerably weaker than the others . Thus even if the true fundamental of the transmitter is at 1.54 metres, as other tests indicate, and the 77cms. is a second harmonic, the 77 centimetre wave must actually be present since beat notes could not otherwise be obtained on the receiver at odd multiples of 77 cms.

An attempt was then made to construct a receiver which would operate with its fundamental wavelength in the neighbourhood of one metre . The ultraudion circuit shown in Fig. 28(a) was first tested . A 250 mmfd. variable condenser was connected

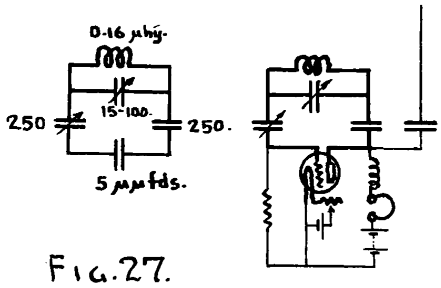


FIG. 27.

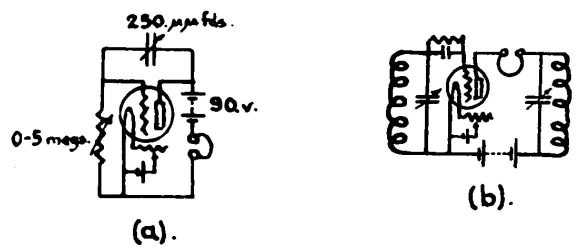


FIG. 28.

between grid and plate of a UV-199 valve by leads about three inches long, a 0 - 5 megohm variable grid leak being used and 90 volts on the plate . This circuit could not be made to oscillate, so the Armstrong circuit shown in Fig. 28(b) was investigated . The grid and plate inductances in this circuit are similar, consisting of single turn coils about one inch in diameter, shunted by 3-plate variable condensers . The condenser across the grid coil had one fixed plate removed, reducing its capacity considerably . This circuit was tested with and without the .00015 mfd. grid condenser and 0 - 5 megohm leak , but it also refused to oscillate . It is more satisfactory, because of the difficulty in obtaining suitable variation in tuning when the inductance is so small, to use the previous method of receiving the very short wave signals, that is, to use a receiver whose fundamental is not at the transmitted wavelength but is a multiple of it, so that the receiver operates by the harmonics of its fundamental beating with the received wave .

As the harmonic method of reception proved quite satisfactory, no further investigations were carried out towards developing receivers which would tune to wavelengths around one metre or less .

(v). Beam Reflectors .

In order to concentrate the maximum amount of energy in the desired direction of transmission, and also to emphasize the second harmonic as much as possible and suppress the fundamental of the oscillator, it was decided to develop some type of reflector antenna to be used with the 1.5 metre oscillator whose second harmonic it was desired to transmit . To this end some beam projectors were built to produce directional radiation at 0.75 metre wavelength .

A parabolic reflector was built of the form illustrated in Fig. 29 . The antenna is located at the focus of the parabola, the reflector wires about its periphery, and wave director wires

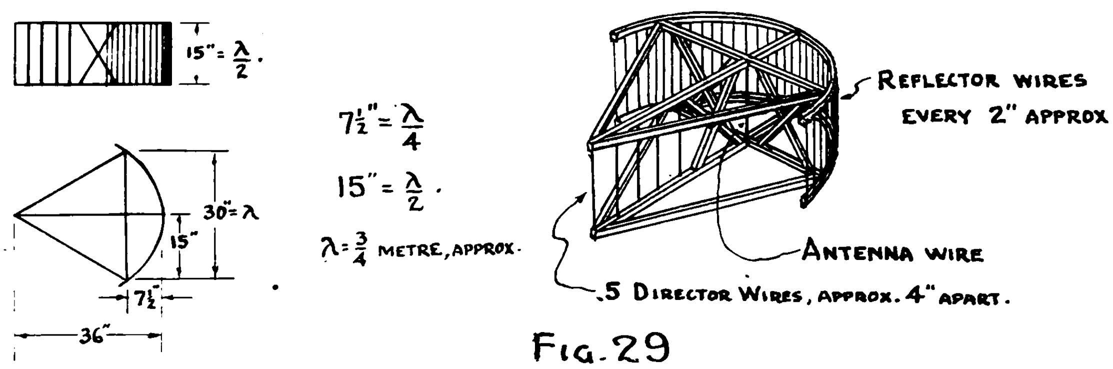


Fig. 29

along its main axis . The projector was designed to operate at a wavelength of 3/4 metre . All wires are 3/8 metre long, or one half wavelength, thus giving a low angle of radiation, and tending to prevent radiation of the 1½ metre wave . With the exception of the antenna, all wires are mounted between strips of celluloid one inch wide by one sixteenth inch thick, this serving both as insulation and mechanical support . The antenna itself is mounted between small bakelite blocks screwed to the wooden framework . All wires are of #16 gauge bare copper .

Another wave projector was built of the form shown in Fig. 30 . In this case the antenna consisted of eight vertical wires spaced 4" apart, and one half wavelength long for operation at 3/4 metre wavelength . Reflector wires were mounted behind the

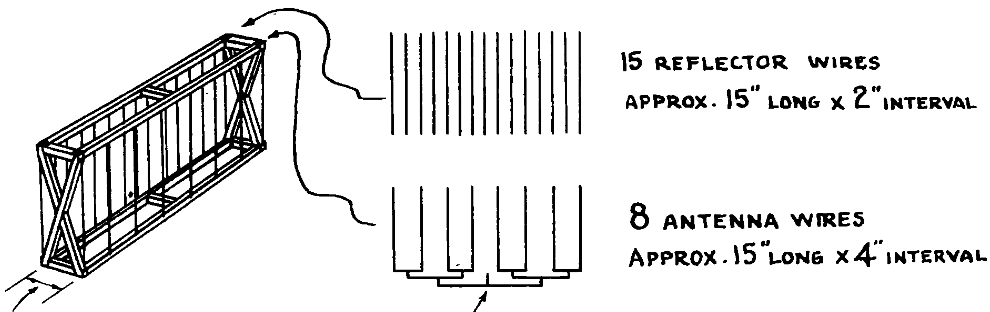


FIG. 30

antenna on the same framework as shown, the separation between the two rows of wires being 4" while the spacing between wires of the reflector was 2" , half the spacing of the antenna wires . No attempt was made to obtain the phase displacement between antenna wires which would give the same effect as the parabolic reflector, as is done in the Marconi directional antenna .

The antenna wires were connected as shown in Fig. 30, thus ensuring exactly the same length of path from the feeder connection to each wire . Both antenna and reflector wires were again mounted between strips of celluloid attached to the wooden supporting framework, each end of the wires being simply hooked through holes drilled in the celluloid .

In both of these wave projectors all reflector or director wires are entirely separate from each other with no electrical connection between them, each wire being a single vertical #16 gauge copper wire insulated at both ends by the celluloid mounting strips .

The results obtained with these beam reflectors are described in the following section .

(vi). Transmission and Reception Tests .

The empirical "r" audibility system for estimating signal intensities is used in this section when comparing strengths of received signals . By this system various degrees of signal strength are denoted as follows :

r1. faint signals, just audible .

r2. weak signals, barely readable .

r3. weak signals, but readable .

r4. fair signals, easily readable .

r5. moderately strong signals .

r6. strong signals .

r7. good strong signals, readable through interference.

r8. very strong signals, audible several feet away .

r9. extremely strong signals .

The first communication tests were carried out with the receiver and transmitter on the first and fifth floors respectively of the same building . The transmitter, that of Fig. 18, was adjusted to a wavelength of about 2.5 metres, using 50 watt valves . Signals could be heard on the receiver of Fig. 26 with any of the four tuning coils, but apparently they were due to the commutator ripple, for when a filter circuit consisting of a 25 henry choke and two 1 mfd. condensers was placed in the plate generator leads, the signals disappeared . When the receiver was moved back to the same floor of the building as the transmitter, signals could again be heard with the filter still connected .

Using UX-210 valves in the transmitter of Fig. 19 an extremely sharply tuned continuous wave whistle could be obtained with the receiver of Fig. 26 . The note was very unsteady, however, the signals being quite unreadable . The wavelength changed sometimes so that the receiver had to be retuned, although the transmitter had not been altered .

The receiver and transmitter were then moved out into the country and set up in the field to determine at what distance communication would be possible with the apparatus in its present stage of development .

The transmitter was mounted immediately inside the door of a small building housing a long wave radio station, and located in a field just east of Ottawa . A vertical antenna was mounted just outside the door with the lead-in running through the open doorway . When first set up the lead-in passed approximately 4" from the door jamb, but after changing the position of the apparatus to allow the lead-in to pass through the centre of the opening, it was found that the antenna current had almost doubled in value . It was also noticed that by placing one's hand in the immediate vicinity of the antenna feeder, the antenna current could be reduced from 1.0 to about 0.5 ampere, but that no such effect was produced by similarly approaching the antenna itself . These effects are due to the distribution of the standing wave altering as the position of surrounding objects changed .

The wavelength used was 1.91 metres but was not steady, and shifted considerably at all times . The received signals had a swinging and fading note, mainly because of this . It was found that by increasing the length of the receiving aerial from one quarter wavelength to one half wavelength, a considerable increase in signal strength resulted .

With the receiver 200 yards from the transmitter the signal strength was about r5 , The antenna current was 0.8 amp. This signal strength remained quite constant until a distance of about half a mile was reached . The oscillator was not quite in resonance with the antenna, however, and was now retuned to bring it into resonance thereby increasing the radiation to 1.1 amperes . This changed the wavelength slightly, and when the receiver was brought in tune again the signals were considerably louder , being about r8 .

At a distance of 1 mile signals were picked up with strength r7, using for the receiving aerial an 18" length of #8 square copper wire . At 1½ miles the best signal strength was still r7, the note being very mushy . Using a 7 ft. aerial running 30° above horizontal, the signal strength at this distance was r7 to r8 . At 2 miles it had dropped to r6 , while at 4 miles signals had just disappeared .

Weather conditions were fair during these tests, with slight rainfall for a short time . The tests were all made in daylight,between 3 and 5 p.m., and the time of year was the middle of September .

The foregoing tests did not yield overly promising results but they were sufficiently encouraging to be followed by tests on a 3/4 metre wavelength . The transmitter of Fig. 25 was used with various antenna systems . The receiver used was that of Fig. 27, the apparatus being assembled on a base beneath which was a sub-base with just enough space between the two to carry the batteries .

Using a vertical straight wire three eighths of a metre long as the transmitting antenna, signals were obtained on the receiver up to about 100 feet distance . With this same antenna turned into the horizontal, signals could only be heard at about half this distance,due probably to upward reflection by the earth . No increase in signal strength was noted when using the Marconi type reflector in place of the single wire antenna, and no directional effect was obtained with it .

With the parabolic reflector as the transmitting antenna system signals were heard over about the same range as before, that is, within a radius of about 100 feet in any direction from the transmitter . The signal strength was greatest with the axis of the reflector parabola at right angles to the direction of the receiver, instead of being greatest when the parabola was pointing towards the receiver . This indicates reflection of the $1\frac{1}{2}$ metre wave due to the wire in the position "B", shown in Fig. 31, acting as a reflector, since it is one quarter of $1\frac{1}{2}$ metres behind the antenna "A" . The other wire "C" , however, would have an equal tendency to produce reflection in the opposite direction, so that the two effects ought to balance out . The remainder of the wires on the parabola should have practically no reflection effect if the oscillator is operating at 1.5 metres only, and in any case would have no

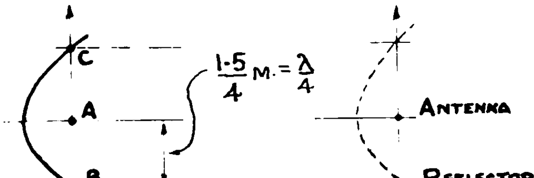


Fig. 31.

tendency to strengthen 75 centimetre signals in the direction shown in Fig. 31 .

With straight wire vertical antennas 3/4 metre long on both receiver and transmitter, so as to obtain operation at $1\frac{1}{2}$ metres, signals could only be heard up to the same distance as before . It was thought that the received energy might perhaps be coming directly from the oscillator instead of being radiated by the antenna . To determine whether the antenna itself was actually radiating or not, some tests were carried out with it disconnected from the transmitter . It was found that whereas with a vertical transmitting antenna 3/8 metre long, signals were heard up to about 50 yards, when this antenna was removed signals could only be heard up to about 10 yards, which is sufficient evidence that the antenna is a useful part of this transmitter .

The VT-1a valves did not stand up very well in operation at these very short wavelengths, even though operated with the plate at a low temperature, i.e., just beginning to turn a dull red with the valve oscillating continuously . One valve failed by the filament fracturing suddenly . It was noticed that the filaments evinced a strong tendency to bow out at the middle due to the attraction of the plate . This was especially evident whenever the plates became very hot, the filament finally touching the grid and thereby further increasing the plate current by shorting the grid leak and stopping the oscillations . The spiral construction of most of the VT-1a filaments allows considerable straightening out and lengthening of the filament as it tends to be drawn towards the plate, and it may touch the grid before it actually breaks . One valve failed immediately after it was put into the socket . The filament jumped to the grid and adhered to it, so that the valve was rendered useless as an oscillator, although the filament would still light .

(b). Investigations on Barkhausen-Kurz Oscillations .

(i). Preliminary Repetition of Earlier Work .

Before commencing the work on Barkhausen-Kurz oscillations some of the oscillator circuits previously described were again assembled and tested . The object was to find the lowest practicable wavelength of available valves in ordinary circuits, and also to overlap with these oscillators the longest wavelengths produced by Barkhausen-Kurz oscillators .

It was intended to begin with an oscillator the wavelength of which could be measured on a General Radio Co. Type 358 five meter wavemeter . As a result of the experience gained in the previous work it was possible to estimate approximately the wavelength of a given circuit from its mechanical dimensions . By using the calibrated Type 358 wavemeter the accuracy of the first wavelength measurements obtained could be relied upon . Then by developing oscillators of continually decreasing wavelength it should be possible to calibrate some form of wavemeters over the complete range of wavelengths produced, from 5 metres down to the shortest waves obtained . By constantly checking the wavelengths it was hoped to avoid that pitfall of some of the earlier investigators, including the writer, of mistaking a harmonic for the fundamental frequency .

The ultraudion circuit of Fig. 1 was used in the first oscillator assembled . The base of a Marconi-Osram "R" type receiving valve was removed and this valve placed in the circuit . The oscillator assembly is shown in the photograph , Fig . 32 .A Sangamo 0.001 mfd. condenser was used as the grid-plate bridging condenser and could be moved along the parallel grid and plate wires shown, to change the wavelength . Positive plate potentials of up to 180 volts were applied, and the grid-filament connection made direct and then through a 0.0005 mfd. condenser and 1 megohm leak, but no indications of oscillation were obtained on the plate circuit milliammeter or with a neon tube .

A UX-201a valve was then tested in the same circuit and oscillations obtained on about 3.5 metres . A 1 meg. grid leak with no grid condenser was used and a 0.001 mfd. Sangamo grid-plate condenser at the end of 5" straight wires connected to the valve socket terminals . Oscillations were indicated by the plate current milliammeter deflection when the G. R. Co. wavemeter was tuned to the bottom of its range .

This oscillator was again tested, using the M-O "R" valve, and was finally persuaded to oscillate by increasing the filament current to 0.72 ampere, with 270 volts on the plate . The plate - grid condenser was located near the end of the parallel wires . The valve would not oscillate with $I_f = 0.7$ amp. or $E_p = 200$ volts with the condenser in this position, but when it was moved to the end of the wires, thus increasing the wavelength of the circuit, oscillations could be obtained with somewhat lower filament current . The circuit would not oscillate even though I_f was increased above its normal value of 0.7 ampere, if the bridging condenser was brought within about 4" of the valve end of the wires .

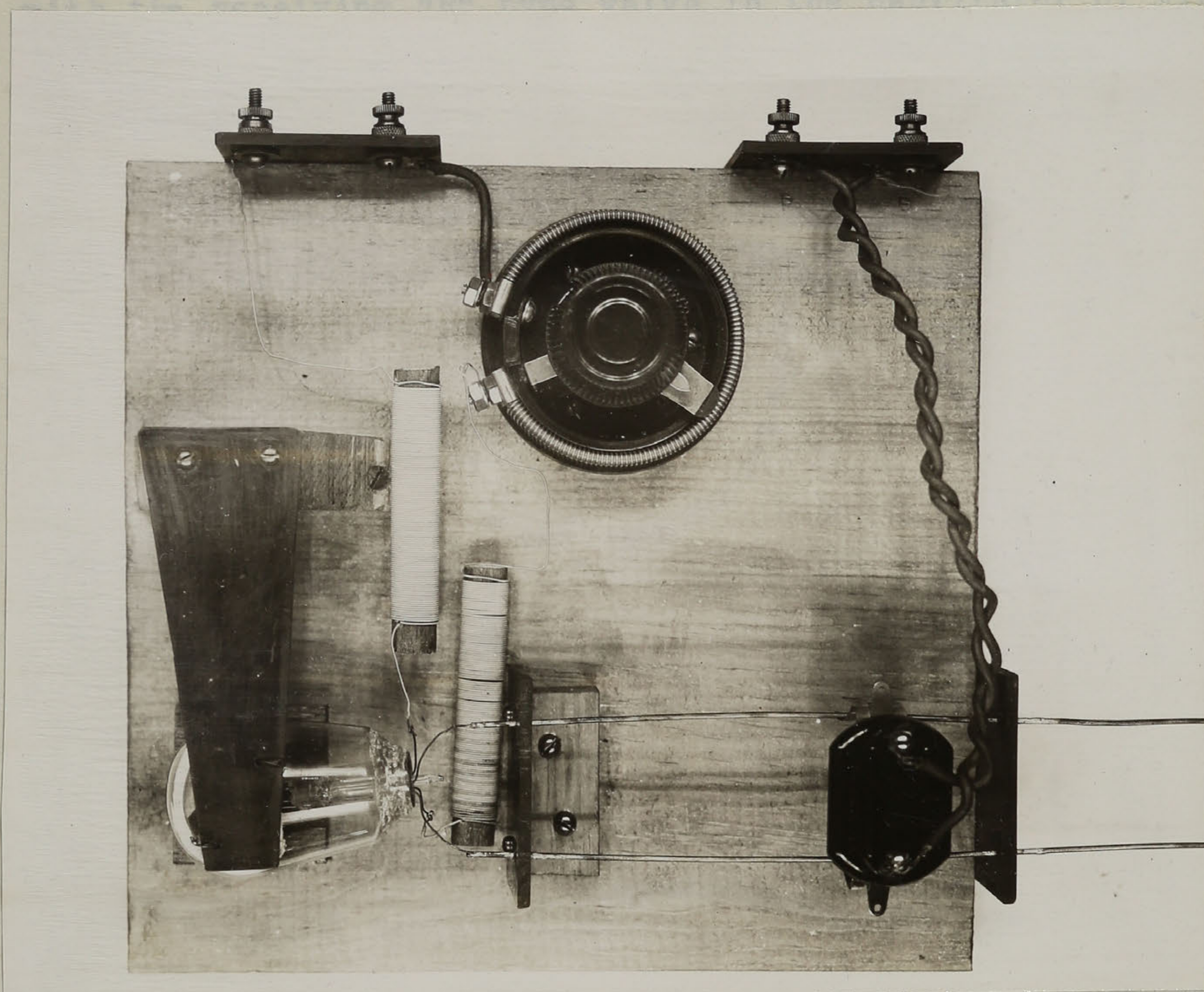


Fig. 32.

Oscillations were indicated at 45° on the G.R.Co. Type 458 wavemeter using a straight wire jumper in a double plug unit (shown as "B" in Fig.43) as the inductance . This represents a wavelength of 1.83 metres .

Oscillations were later obtained down to 1.79 metres with the receiving "R" type valve in the oscillator of Fig. 32 . The shortest wavelength which this valve will produce in this type of circuit, using a small grid-plate condenser such as the Sangamo, is thus about 1 3/4 metres .

A UX-852 (75 watt) valve was then connected in the ultraudion circuit with 500 volts from "B" batteries on the plate, a 0.0005 mfd. grid-plate condenser, and a 50,000 ohm grid leak, but no oscillations were produced . The plate voltage was now increased to 1400 volts from a d.c. generator . A 5 megohm grid leak was used and a 0 - 500 mmfd. Cardwell Condenser connected directly to the plate and grid leads . Oscillations were obtained on $6\frac{1}{4}$ metres, as indicated by the wavemeter . The plate current was 70 m.a. and the filament current 3.2 amps. the grid-plate condenser being set at its minimum capacity .

With E_p = 1250 volts, I_p = 74 m.a., I_f = 3.25 amp., and using three 0.0001 mfd. Sangamo fixed condensers connected in series by as short leads as possible between grid and plate of the UX-852 valve, oscillations were obtained on 2.1 metres . The short wave limit of the UX-852 valve in an oscillatory circuit of this type is therefore approximately 2 metres .

An ultraudion oscillator circuit was now assembled with a de-based UX-210 valve . A 0.0005 mfd. condenser was connected to plate and grid by 1" leads as close as possible to the glass envelope of the valve . A 10 megohm grid leak was used and choke coils inserted in grid, plate and both filament leads . With $E_p = 400$ v., $I_p = 5$ m.a., and $I_f = 1.1$ amp., strong oscillations were obtained on a wavelength of 1.8 metres . The short wave limit of the UX-210 valve in this type of circuit is thus about 1 3/4 metres . This is the same result as was found previously in the earlier work . The limit can be further reduced by using special condensers of extremely small mechanical dimensions inserted inside the valve stem, but without this elaboration the practical lower limit is about 1 3/4 metres .

(ii). Ultra Short Wave Wavemeters .

A series of wavemeters was constructed and calibrated over the entire range of wavelengths produced . These are illustrated in Fig. 43, and their calibration curves given in Plates I and II . They are labeled A, B, C, and D in order of decreasing wavelength range . The first two, A and B, used the condenser of the General Radio Co. Type 358 wavemeter with special coils . The inductance of wavemeter "A" consisted of a rectangular coil 2½" x ¾" of #10 solid copper wire mounted on a double plug unit which fitted the jacks of the condenser . The "B" inductance consisted of a similar plug unit with a straight wire jumper connected between plugs .

Another wavemeter was built using a General Radio Co. Type 368a micro condenser, maximum capacity 15 mmfds., with a rectangular coil 1 3/8" by 1½" as the inductance . Its range was found to be too high, however, being almost all included in that of wavemeter "B", so the inductance was reduced to a straight wire $1\frac{1}{2}$" long . This was wavemeter "C" . The two outer rotor plates of a second G. R. Co. Type 367a microcondenser were removed, leaving only one inner plate rotating between the two stator plates, and the condenser so formed used in wavemeter "D" The soldering lug on the stator was turned towards the rotor shaft and a blob of solder placed to join the rotor bearing to this lug . Thus rotor and stator were shorted through this solder, which formed the inductance . This last wavemeter could not be completely calibrated, as the shortest wavelengths produced did not cover the bottom of its range . Its calibration curve is shown in Plate II .

The Lecher wires used to calibrate wavemeters A and B were those shown in Figs. 39 and 40 . At shorter wavelengths these were inconveniently and unnecessarily large, as several standing waves could be obtained on much shorter wires and the already calibrated wavemeters could be used to ensure that the wavelength measured was the fundamental and not a harmonic of a higher wave . The Lecher wires used to calibrate wavemeters C and D were made of two 35" lengths of #10 solid bare copper wire supported by a valve socket at one end and a thermocouple and microammeter at the other . The wires were spaced $1\frac{1}{2}$" apart by these supports, which can be seen quite clearly in Figs. 41 and 42 .

The thermocouple required 50 m.a. in the heater element to produce a full scale deflection of 114 microamps. on the galvanometer . No deflection was observed on this meter at any time, the current in the Lecher wires apparently being extremely small, so that this meter could not be used to indicate the nodal points of the standing waves . The method used to locate these points was to observe the sharp kick or change of current in the plate milliammeter as the shorting bridge was slid along the wires through each of these points . It is interesting to note that it was found possible to obtain resonance maxima and minima on the plate milliammeter simply by sliding the finger along one of the Lecher wires . Oscillations actually ceased at the minima, so great was the absorption of energy . The same result was obtained by sliding the finger along the grid or plate wires .

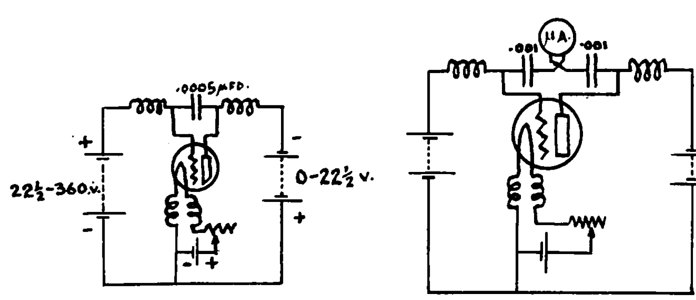
Several methods were employed to couple the Lecher wires to the oscillator . In one method a wire was connected between the grid or plate terminal of the oscillating valve and one end of the Lecher wires through a small capacity . A second method was to put a loop about the valve and connect it to the empty valve socket which supported one end of the wires . Both of these methods produced a deflection in the plate circuit milliammeter when the sliding bridge (a grid leak mounting with a brass shorting rod, shown in Fig. 42) was located at a nodal point of the standing wave, but the deflection was very small and sometimes uncertain . Another method, the one usually adopted, was to run a short feeder wire from the valve to one of the Lecher wires, one end of the feeder wire being clipped on to either grid or plate terminal of the valve socket and the other to the end of one of the Lecher wires, as shown in Figs. 41 and 42 . This method, though not quite so accurate as the others, proved to be the most satisfactory in giving readable deflections, and was therefore generally used .

(iii). Barkhausen-Kurz Oscillators .

Oscillations of the usual type had now been produced of sufficiently short wavelength to overlap the upper wavelength limit of the Barkhausen-Kurz type of oscillations . Attention was therefore turned to Barkhausen oscillators, and it was hoped to obtain an unbroken range from those wavelengths already produced down to the lowest to be obtained .

The first Barkhausen-Kurz oscillator circuit tested was that of Fig.33(a), using a UX-210 valve with its base removed . No results were obtained except a red hot grid and grid currents of over 100 m.a.

A UX-210 valve was next put into the circuit of Fig. 33(b), with a 0-250 m.a. hot wire ammeter between grid and plate in series with two 0.001 mfd. fixed condensers . Parallel wires 3 ft. long spaced 1½ ins. apart were connected to the grid and plate . The ammeter and condensers formed a bridge circuit across these wires and could be slid up and down them to any position desired . Negative plate voltages of 0, 22½, and 45 volts were applied and grid voltages of from 22½ to 270 volts positive . The grid current was over 100 m.a. at 90 volts and burnt out a 250 m.a. hot wire meter at 200 volts , but no indications of oscillation were obtained .



(a) (b).

Fig.33.

Further tests were made on this circuit with a UX-210, a UX-201a, and several "R" valves, with plate voltages of 0, -22½, and -45 v., grid potentials up to 270 volts positive, and filament currents up to considerably over rated values. When the grid side of the parallel wire circuit was made or broken at the bridge contact, very slight deflections were obtained on the thermocouple meter in the bridge. They died away immediately, however, and so were due to transient surges rather than continuous oscillations. No indications of oscillation were obtained.

The above "R" valves all had helical filaments. A "Fotos" valve of the same type but with a straight wire filament was then tested, but with the same lack of results. It was thought that possibly the reason for the failure of the American UX-201a and UX-210 valves to oscillate lay in the fact that they had V-shaped filaments, and that the European "R" valves with straight filament at the centre of a concentric cylindrical plate and grid, might be more successful in producing oscillations, since the Barkhausen action somewhat resembles the magnetron oscillation, and the magnetron requires a symmetrically constructed plate and filament. However, a WD-12 peanut valve having cylindrical electrodes also failed to give Barkhausen oscillations, although of similar construction to the "R" valves.

In all the Barkhausen circuits tested so far, no meter was placed in the plate circuit, as it was expected that a deflection of the grid meter would occur to indicate the commencement of oscillations. It was now found that this was not so, any change in grid current occurring upon commencement of oscillations being quite too small to be observable . A 0 - 1 milliammeter was inserted in the plate circuit of the Fotos R valve in a Barkhausen-Kurz circuit and immediately it was found that oscillations were being obtained, wavemeter C producing a sharp deflection in this meter when tuned to resonance .

Barkhausen oscillations were first observed with this Fotos straight filament "R" valve . The wavelength measured on Lecher wires was 81.8 centimetres . This was carefully checked to make sure that it was the fundamental and not a second harmonic of a 163.6 cm. wave . No deflection whatever could be obtained with the wavemeter tuned to multiples of 81.8 cms., so this was certainly the fundamental .

The UX-201a and UX-210 valves were now tested under similar conditions but could not be made to oscillate .

The Fotos straight filament "R" valve was then set up in the Barkhausen oscillator shown in the photograph of Fig. 41 . The grid voltage was varied from 22½ to 225 volts and the plate voltage left at zero . Values of grid and plate current were read over a range of variation of filament current, and graphs of these quantities plotted for each value of plate voltage . The curves are given in Plates III to XIV, and the data in the Appendix .

A number of very striking facts immediately stand out from these curves . It will be observed that in each case oscillations are indicated by a sharp peak in the plate current curve, but that no such peak is produced in the grid current curve . The grid current curves, shown in Plate III, are, as might be expected, of the same form as normal plate current curves taken with positive plate voltages . The reason why they do not all coincide at the lowest filament currents is that the grid current milliammeter could not be read accurately at the bottom of its range . Also the curves were taken on different days, and the valve characteristics were found to vary somewhat from day to day . It is possible that there were slight kinks in the grid current curves during oscillations which it was beyond the accuracy of the meter to record . The plate current was always very small, a microammeter being required to record it .

Plate IV shows the plate current-filament current characteristics for positive grid voltages of 22½, 45, and 67½ volts . As the grid voltage is increased the plate current decreases (except at "resonance" values) as might be expected, since the higher the potential of the grid for a given filament emission the more electrons will be attracted to it and the fewer will reach the plate . The plate current did not reach a saturation value for any grid voltage or filament current used .

In Plate V the grid voltage was 22½ v. and no oscillations were obtained . When the voltage was increased to 45 the curve of Plate VI was obtained, showing a sudden increase of plate current at $I_f = 0.6$ ampere . It was found that the hump in the curve indicated the presence of oscillations of wavelength 140 cms., but that at values of filament current on either side of the hump no oscillations were produced . Thus in this case the Barkhausen oscillations only occurred within the extremely narrow range of filament current of about 15 m.a. The middle of this range was at 0.6 ampere, which is considerably below the normal filament current for the valve of 0.7 ampere .

Similar graphs were obtained for each of the other cases

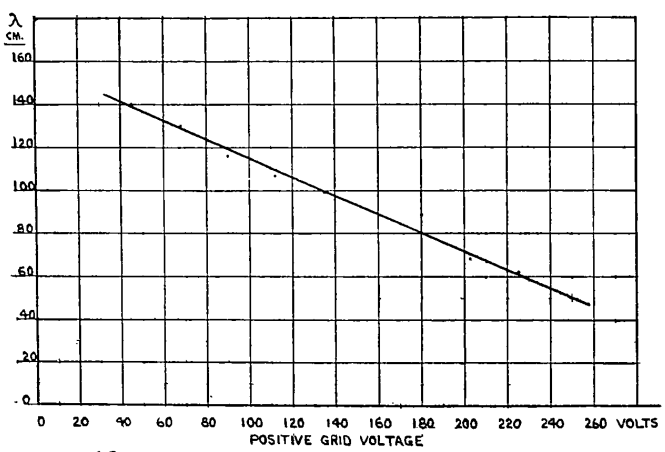


FIG. 33c. *Variation of wave-length with grid potential. Oscillator using B-K circuit with Fotos R valve.* $E_p = 0$ *volts.*

and are shown in the other plates . Plates VIII and IX show two curves taken under the same conditions, both with $E_g = 90$ v. but taken on different days . These illustrate the wide variations which sometimes occur from day to day, due possibly to throwing off of the occluded gases by the tube elements when heated .

The general form of these curves is of an exponential type, as shown in Plate I, rising very steeply as the filament current is increased beyond the normal rated value . When the grid voltage is sufficiently high to produce oscillations, in the case of this valve about 25 volts or more, a very sharp and sudden increase of plate current takes place at certain values of filament current, and it is here that oscillations take place . This maximum occurs at higher values of filament current as the grid voltage is raised, the frequency of oscillation also increasing .

The following table shows the decrease in wavelength as the grid voltage is increased, filament current being adjusted to give maximum plate current in each case :

E_g ...	45	67½	90	112½	135	157½	180	202½	225	volts.
λ ...	140	130	116	107	100	97	81	69	63	cms.

The decrease in wavelength with increasing grid voltage is seen to be fairly uniform,with the exception of one or two values . One cause of wide variation in results was the fact that the valve heated up very quickly at the higher grid voltages, so that readings taken while the valve was hot or after it had been in operation some time did not check with readings taken under similar circumstances while the valve was cold and had been standing idle for several days .

At the higher grid potentials there are two and in some cases three "resonance" peaks in the I_p - I_f curve . It was found that the oscillations had the shortest wavelength at the peak of lowest filament current . The triple peaked curve of Plate XII could not be reproduced several days later under the same circumstances, only two peaks appearing, the smallest being absent . The peaks move to the right as the grid voltage is increased, that is, higher filament current is required to produce oscillations at higher grid voltages . This is due to the fact that, as mentioned before, the normal or non-oscillating plate current becomes less as the grid voltage increases, so that the filament emission must be increased to produce oscillations .

At the highest grid voltages used the grid became white hot, thus supplying a secondary emission current to the plate . The plate current could be reduced by applying negative plate potentials, but this reduced the oscillations to zero if the negative plate voltage was sufficiently great . In Plates XV and XVI a further I_p maximum was observed at higher filament currents but as the grid became nearly white hot and the normal filament current was considerably exceeded at these values, no readings were taken .

The whole I_p - I_f curve is more to the right when the valve filament is first lit, and the peak slowly shifts to the left after the valve has been in operation awhile .

An interpretation of these results is given in a later section .

Several Osram "R" receiving valves were now tested in the Barkhausen-Kurz oscillator of Fig. 41, to see if they would produce oscillations of higher frequency than the transmitting type "R" valves heretofore employed . With 225 volts on the grid in series with a 3000 ohm protective resistance these valves oscillated satisfactorily on about 66 cms. wavelength . This is about the same wavelength as is obtained with the other valves under the same conditions .

A number of UX-201a and UV-201 valves, a UV-200, and a 102-D valve were again tested in the same B-K circuit, with 225 volts on the grid, but no oscillations were obtained with any of them . These valves all have M- or V-shaped filaments .

Some experiments were then carried out on variations of the original circuit .

The condenser bridge across the grid and plate parallel wires of Fig. 33(b) were omitted, leaving the circuit as in Fig. 34 . The choke coils making connections with the grid and

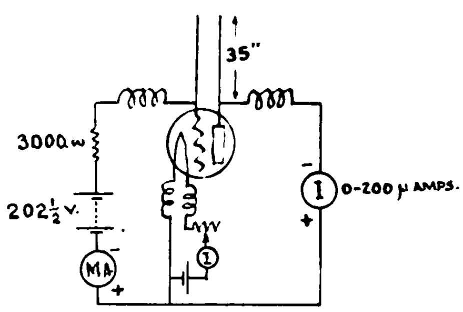


Fig. 34.

plate wires were fastened to an inverted grid leak mounting which could be slid along the wires, the springs of the mounting keeping contact with the wires, as shown in Fig. 41 . It was found that oscillations could still be obtained with the Fotos straight filament "R" valve in this circuit, the wavelength being about 60 - 70 cms. Oscillations were also obtained when the filament polarity was reversed, making the positive filament battery terminal the common connection . The curve of Plate XVI was taken under the above conditions . The difference between the curves of Plates XV and XVI, taken with and without the bridge, respectively, is not any greater than could be accounted for by the variations from day to day in results obtained from identical arrangements . One point of interest is that the wavelength was the same for both peaks of the double-peaked curve of Plate XVI, whereas in the other multiple-peaked curves the wavelength decreased at the lower values of filament current . Oscillations were unstable, however, at the higher values of filament current in Plate XVI as the valve became much overheated, so that the wavelength measurement here was not very reliable .

The parallel grid and plate wires of the circuit of Fig. 34 were now removed, leaving only the Fotos "R" valve in its socket with the choke coils at each terminal, as shown in Fig. 42 . Oscillations were obtained as before, showing that the grid-plate condenser and its connecting parallel wire circuit did not produce the oscillations . The wavelength remained the same as with the wires .

An old war-time G.E.Co. AT-25 valve was then tested in the last type of Barkhausen-Kurz circuit . This valve was of similar construction to the "R" valves previously used, but the cylindrical plate was not mounted concentrically with filament and grid, being offset as shown in

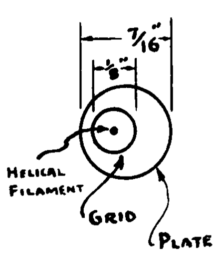


Fig. 35

Fig. 35 . The filament was not straight but a spiral . Oscillations were obtained on a wavelength of 158 cms., but they were very weak and unstable, dying away in a few minutes .

Some tests were then carried out on two UX-222 screen-grid valves in the Barkhausen-Kurz circuit shown in Fig. 36 . This type of valve has a straight filament at the center of cylindrical electrodes . The screen-grid was used as the grid, and the circuit was tried with and without the 0.001 mfd. grid-plate condenser . Grid potentials up to +300 volts were applied, with zero plate voltage, but no oscillations were obtained from either valve .

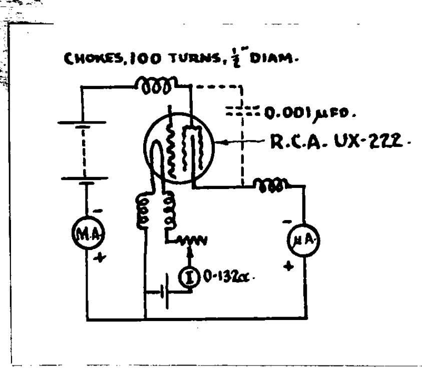


Fig. 36

The same valves were then tested using the control grid as the grid and the screen-grid as the plate . A plate (screen-grid) current of 15 microamps. was obtained, whereas in the first case no plate current was obtained . Again no oscillations were produced, however .

In order to calibrate the "D" wavemeter over the lower half of its range it was attempted to obtain oscillations down to about 40 cms. in wavelength with the "Fotos" valve in the B-K circuit . Grid battery voltages up to +780 volts were applied and negative plate voltages up to -10 volts . Due to a protective series resistance in the grid circuit, when a battery voltage of 780 v. was applied the grid current was limited to 100 m.a., while the voltage actually being applied to the grid was but 500 volts . Even this was too much for the valve, however . No results were obtained except a red hot plate, a white hot grid, and a blue glow due to ionization, but no oscillations were produced .

Various arrangements of grid-plate wires, grid-plate condenser, grid voltage, plate voltage, and filament current, were tried, but the lowest wavelength obtained was 50.8 centimetres, produced by the oscillator of Fig. 42 using the Fotos valve shown in Fig. 41 .

Through the courtesy of the Northern Electric Company, Limited, a number of specially designed valves were constructed . Dimensional details and other data concerning their physical characteristics were accurately ascertained during manufacture . It was expected that the results obtained with these valves in Barkhausen-Kurz circuits would verify or disprove the explanations given for the results obtained previously with other valves . An extensive series of tests and experiments was carried out with them, but the final result was the same in every case - no oscillations could be produced . These valves were designed with the requirements of Barkhausen-Kurz oscillators in mind, but the degree of vacuum obtained was not as high as that in the "R" valves . All of the special valves were "gassy" and tended to become ionized at comparatively low voltages . This may have been the cause of their failure to produce oscillations . Some of them had tungsten filaments and some barium and strontium oxide coated platinum filaments .

Since they failed to generate Barkhausen-Kurz oscillations, no further description of these valves or of the experiments carried out with them will be given here .

Several more R valves were procured at this time, since this was the only type with which any success had been obtained . Further investigations were now carried out with these valves . The case of pure Barkhausen-Kurz oscillations as distinct from Gill-Morrell oscillations was concentrated upon, inasmuch as no external grid-plate oscillatory circuit was connected to the valve . It was hoped to find some correlation between the somewhat discordant findings of other investigators in this field , and to determine to what extent the wavelength formulae given in Section III (v) are applicable .

A complete set of plate current and grid current versus grid voltage curves for various values of filament current up to the rated filament current of 0.7 ampere were first taken for one of the valves . These curves are given in Plates XVII - XVIII. Wavelengths were measured whenever oscillations appeared, the values being included in the curves . It is seen that the appearance of oscillations is accompanied by a marked peak in the plate current curve, but that unless the emission, that is the filament current, is sufficiently great oscillations will not commence,however great the grid potential . Also the slight depression in the grid current curve during oscillations, which was predicted but not observed in the previous experiments, (see p.89), is quite evident here .

In the above and in the following experiments the circuit used was that shown in Fig. 36a . No external grid-plate

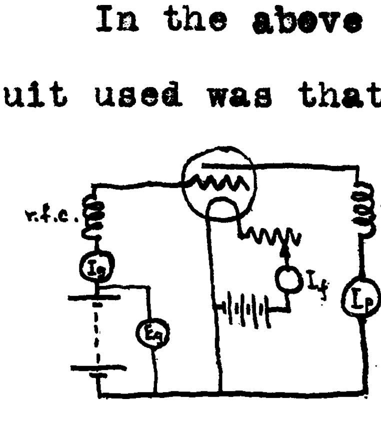


Fig.36a.

circuit was connected to the valve . The plate was joined by short leads through a meter directly to the filament .

A list of the R valves used in the following investigations is given below, together with their internal dimensions, and grid-plate capacities measured at 1000 cycles per second .

Valve	Plate			Grid		G-P Cap.
	Length	Diam.	Rad.	Diam.	Rad.	
1.Osram #33397	1.5cms.	1.0cm.	0.5	0.45cm.	0.225	4.86 μμfds.
2.Osram #10356	1.5	1.0	0.5	0.45	0.225	5.46
3.Osram #51238	1.5	1.0	0.5	0.45	0.225	5.46
4.Osram #47186	1.5	1.0	0.5	0.45	0.225	6.06
5.Osram #6465	1.5	1.0	0.5	0.45	0.225	4.26
6.Osram #55464	1.5	1.0	0.5	0.45	0.225	5.46
7.Cossor #45215	1.5	1.0	0.5	0.45	0.225	4.62
8.Osram #52283	1.5	1.0	0.5	0.45	0.225	5.16
9.Cossor #16049	1.5	1.0	0.5	0.5	0.25	5.46
10.Fotos	1.4	0.9	0.45	0.45	0.225	4.44
11.Ediswan #1505	1.5	1.0	0.5	0.45	0.225	5.76

These valves were placed in succession in the Barkhausen-Kurz oscillator circuit of Fig. 36a and characteristic curves obtained for each of them under various conditions . In the first set of curves, shown in Plates XIX to XXIX, values of grid current, plate current, and wavelength versus grid voltage, were taken with fixed filament current and plate voltage .

A similar set of curves was then taken at constant grid voltage and varying filament current . These are shown in Plates XXX to XXXIV and correspond to the curves given in the earlier Plates V to XVI . The values of grid voltage chosen were those which lay about the middle of the regions of oscillations indicated by the first set of curves (Plates XIX to XXIX) .

These curves show that oscillations occur in definite "regions" . The wavelength varies in some regular fashion for a time as the grid potential is continuously increased, and then suddenly jumps to some other very different value . In some cases this new value is a submultiple of the previous one, but not always . The wavelength then varies uniformly again until another critical grid potential is reached, when again it jumps abruptly to a value of still another magnitude . Sometimes only two regions are found with a gap in between, no oscillations occurring at intermediate grid potentials where the second region would appear .

In general oscillations do not appear until saturation is reached in the valve, or closely approached . One exception to this rule is noted, however, in the case of the Fotos valve (Plate XXVIII) , which commences to oscillate long before saturation is reached .

The general condition of oscillation indicated by these curves is as follows . As saturation is approached in the valve oscillations first appear , the wavelength being in the neighbourhood of 140 cms. As the grid potential is increased, the filament current remaining constant, the wavelength decreases until it reaches about 115 cms. Here it suddenly drops to about half of the latter value, and then continues to decrease as the grid potential is further increased . When the grid potential has reached approximately 80 volts, the wavelength now being 50 cms., a third region of oscillations appears and the wavelength suddenly jumps to 80 cms. or so. Thereafter it drops but a few centimetres until the grid potential reaches 120 volts or more, when oscillations finally cease. As the grid potential is still further increased beyond this third region of oscillations, no more regions are inaugurated no matter how high the potential is raised. With some valves there is no plate current except during oscillations, while with others there is some plate current at all grid voltages but it rises to a marked peak during oscillations. The slight drop in grid current corresponding to the peak in plate current is quite evident in the curves.

The three regions of oscillation are particularly well depicted in the curves of valve #10356, Plate XX. The second region is missing in the other valves. In some cases the third region is greatly extended, particularly in the case of the Fotos valve, Plate XXVIII, where both first and second regions are absent. The two Cosser valves, though apparently similar to the other R valves, failed to produce oscillations. One of them drew some plate current, the other none.

Some of the valves were gassy and gave erratic results. This was evidently the case with valve #47186,whose curves (Plate XXII) are especially irregular. In this case the plate current reversed at times due to positive gas ions being formed and flowing to the plate.

The dropping grid current characteristic of Plate XXI was due to the fact that the filament current fell off to 0.692 ampere at the last of the readings.

The grid and plate current versus filament current curves of Plates XXX to XXXIV are similar to those taken earlier with the Fetos valve . They indicate that the wavelength of the third oscillation region is practically independent of filament current, while wavelengths in the first two regions change with increasing filament current .

(iv). Brief Reception Tests .

A receiver of the Barkhausen type was assembled using an Osram "R" type receiving valve in the circuit of Fig. 37 .

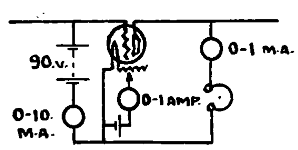


Fig. 37

The Barkhausen oscillator from which it was hoped to receive signals used a similar valve . The receiver could not be made to oscillate, and no signals could be heard at 15 feet from the oscillator . The oscillator was now modulated by means of a buzzer coupled to the plate circuit, but again nothing was heard .

A crystal receiver consisting of a pair of 2000 ohm telephones across a crystal detector and with two 30" lengths of wire as antennae, was assembled and tested but with no results from the buzzer modulated oscillator .

A further reception test between a telephony modulated "R" valve oscillator and a similar receiver was carried out . A pair of telephones and a microphone transformer were connected in series in the plate circuit of each oscillator, so that each oscillator comprised both transmitter and receiver, and would have allowed duplex conversations if communication had been established . Neither transmitter was heard by the other receiver, however, mainly due to the difficulty in synchronizing frequencies . With valves of sufficiently similar characteristics, adjusted to the proper operating potentials, this method of modulation and reception should prove feasible . Both oscillator and receiver were located in the same room during the above tests, with no intervening objects .

Fig. 39

Fig. 38

Fig. 40

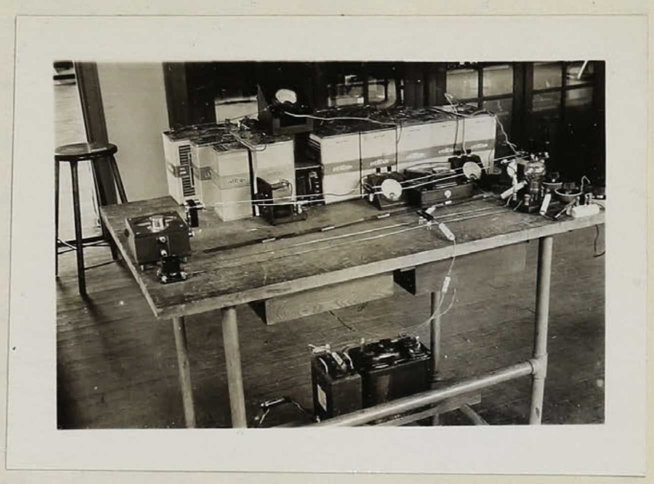


Fig. 41

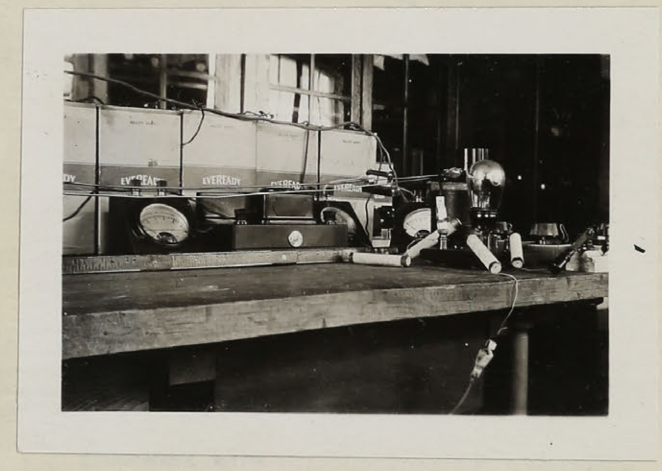


Fig. 42

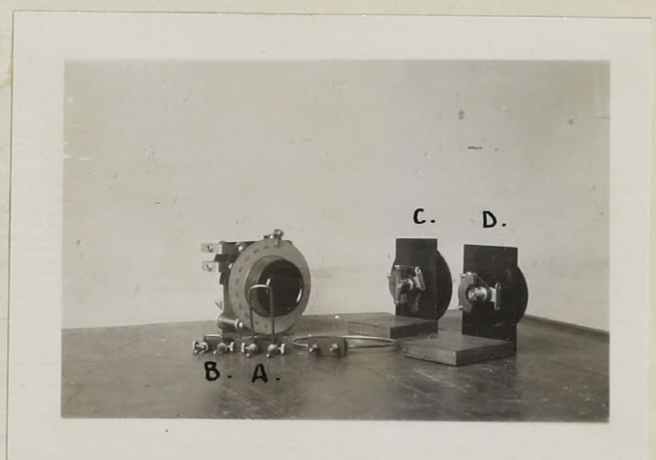


Fig. 43

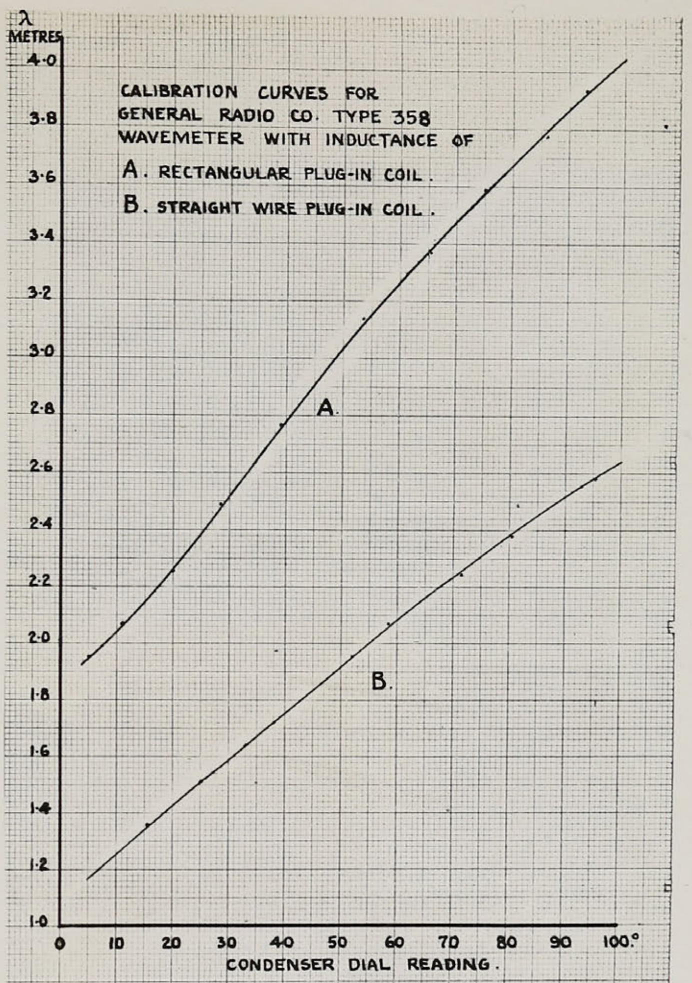


PLATE I.

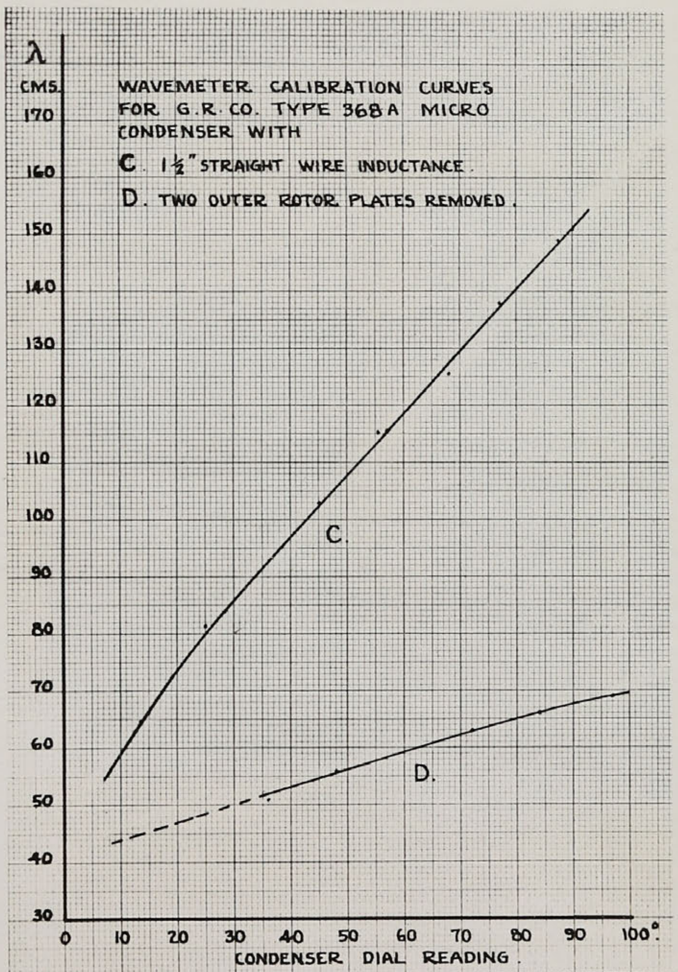


PLATE II.

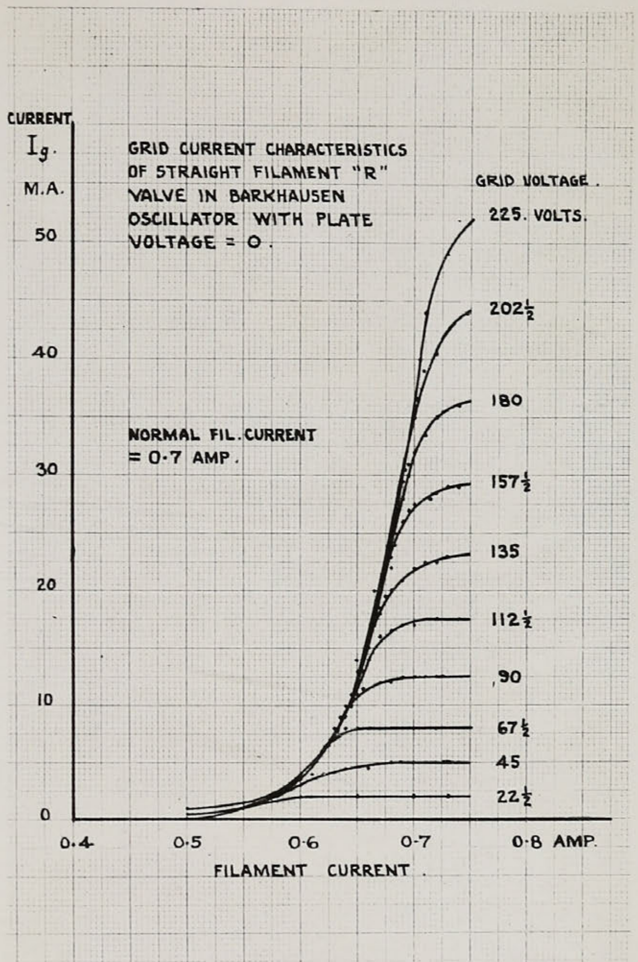


PLATE III.

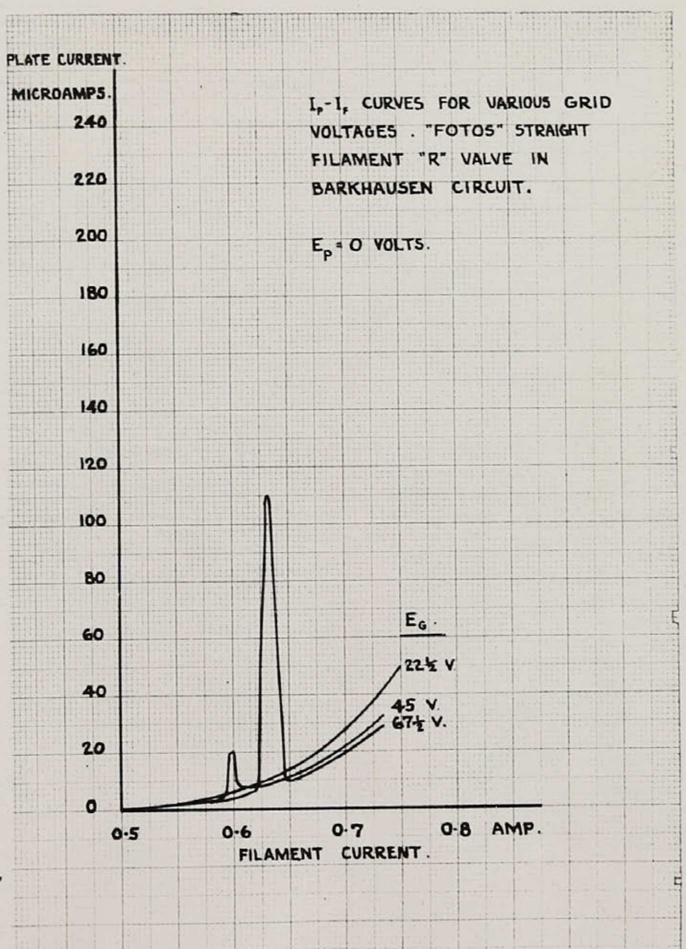


PLATE IV.

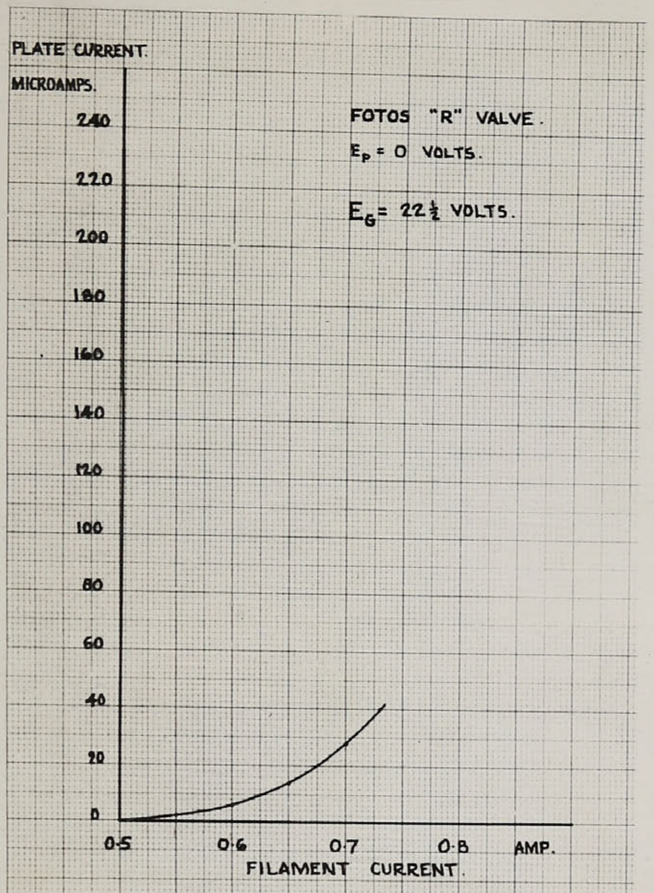


PLATE V.

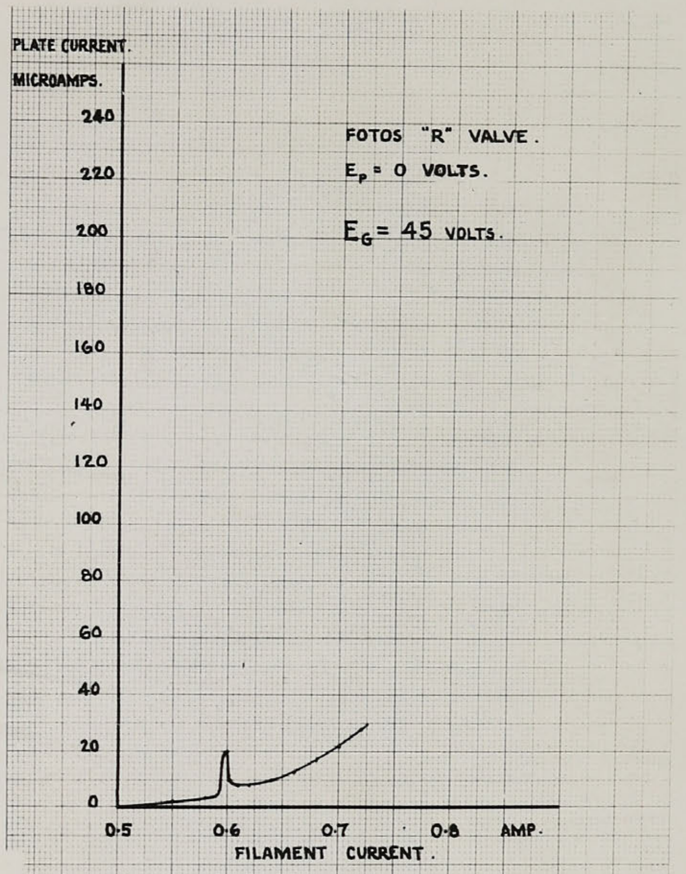


PLATE VI.

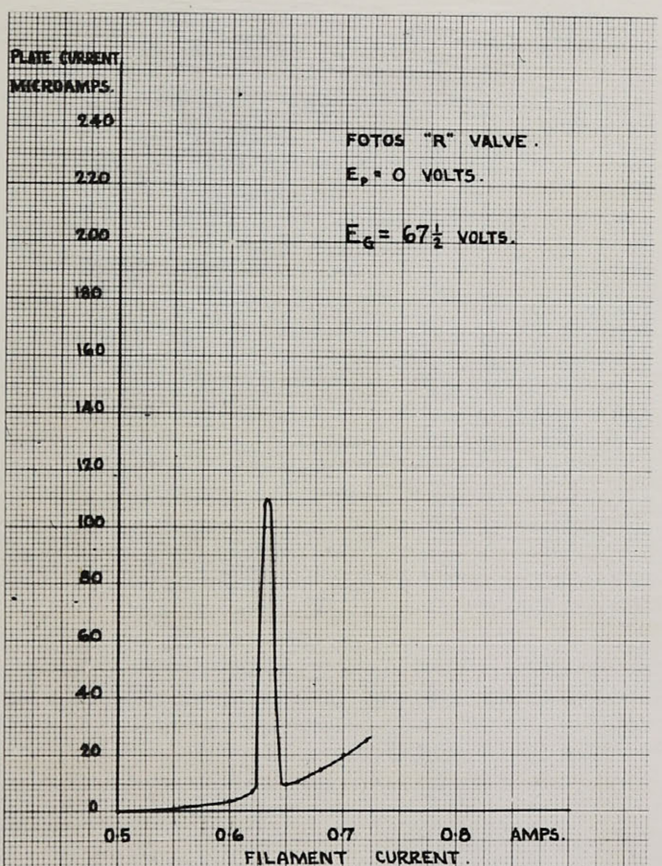


PLATE VII.

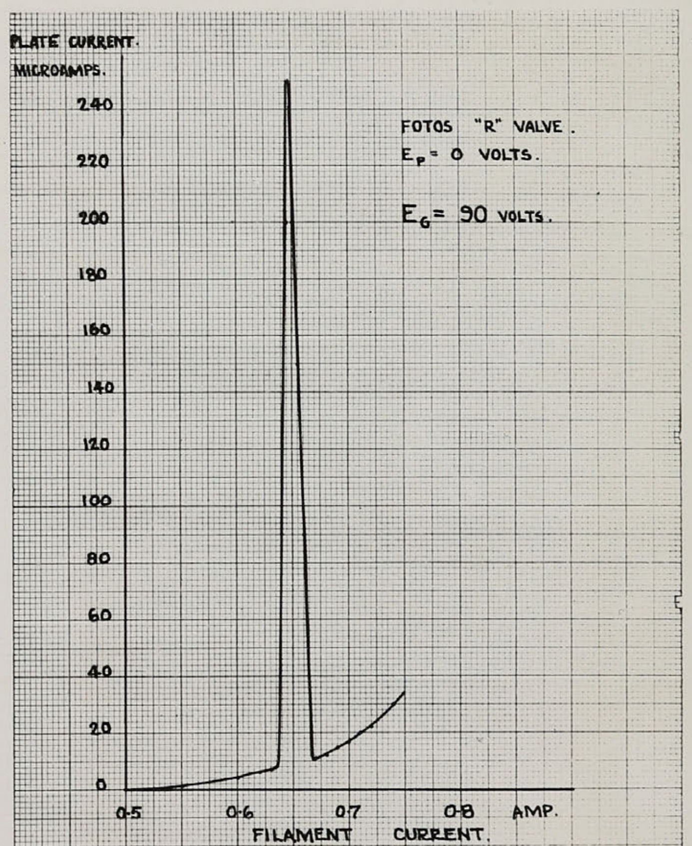


PLATE VIII.

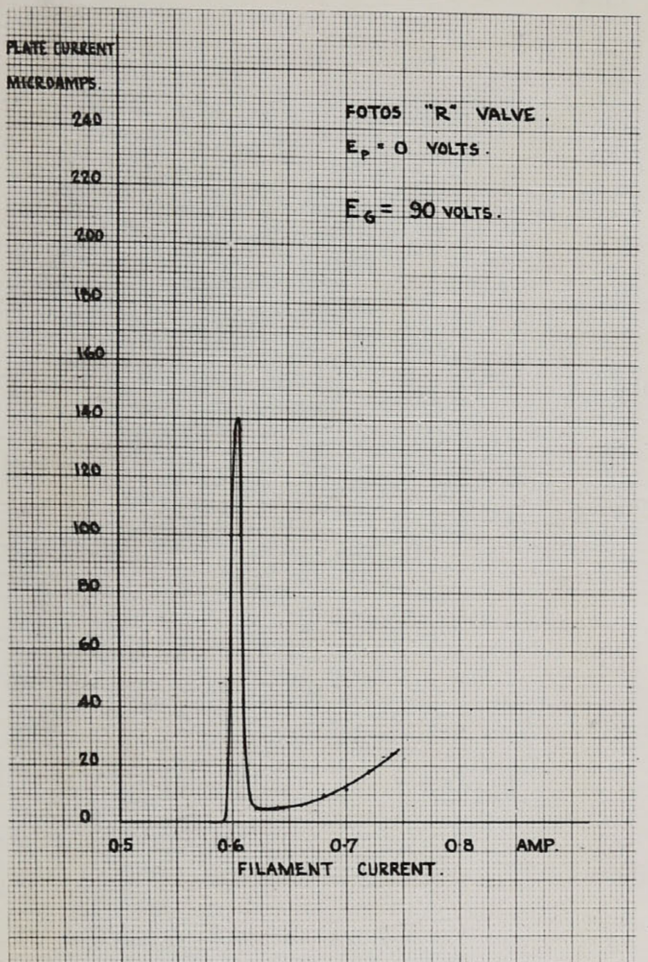


PLATE IX.

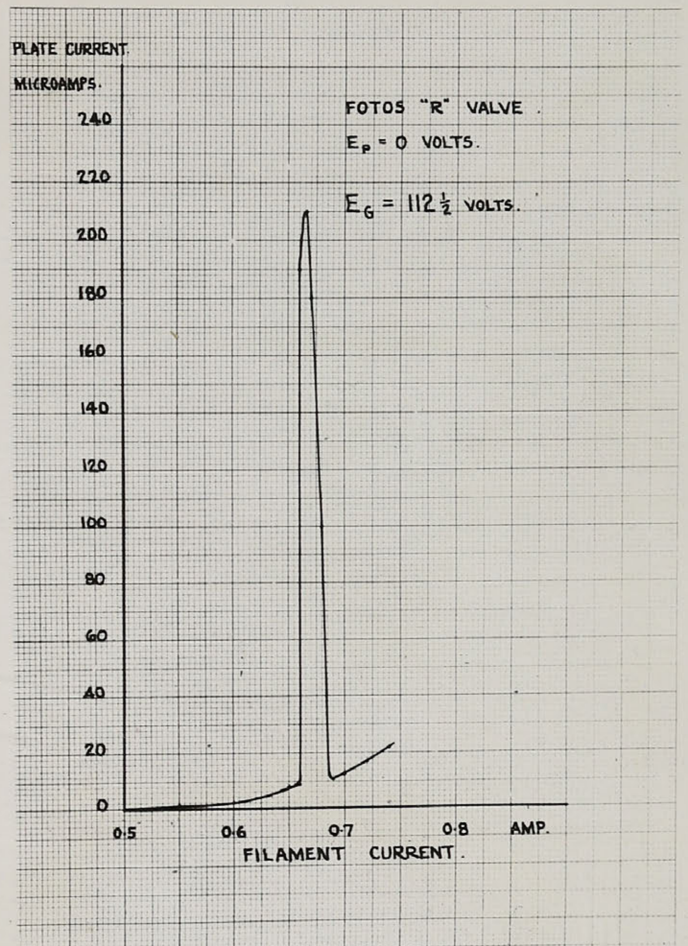


PLATE X.

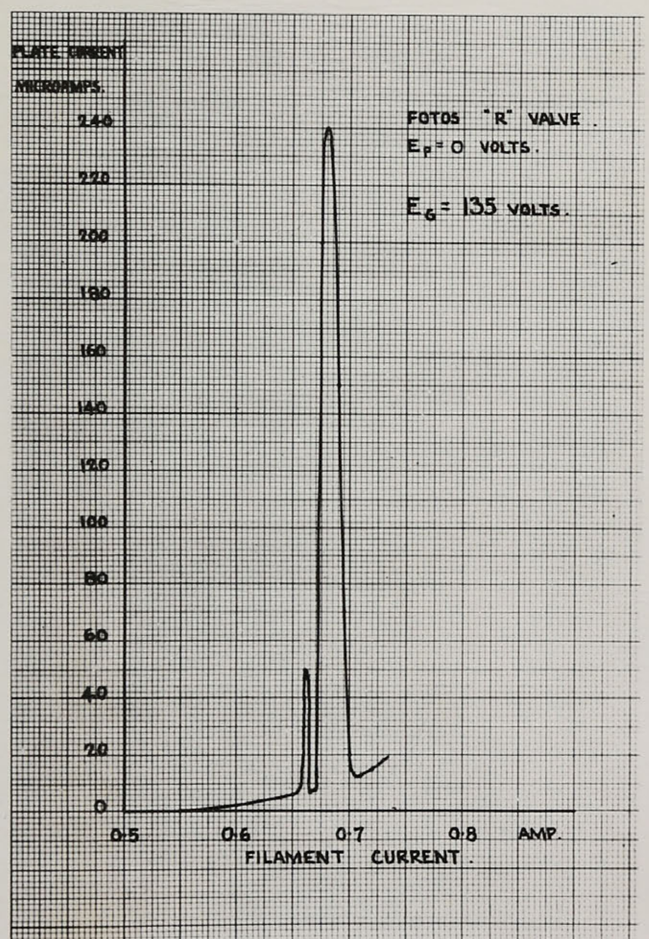


PLATE XI.

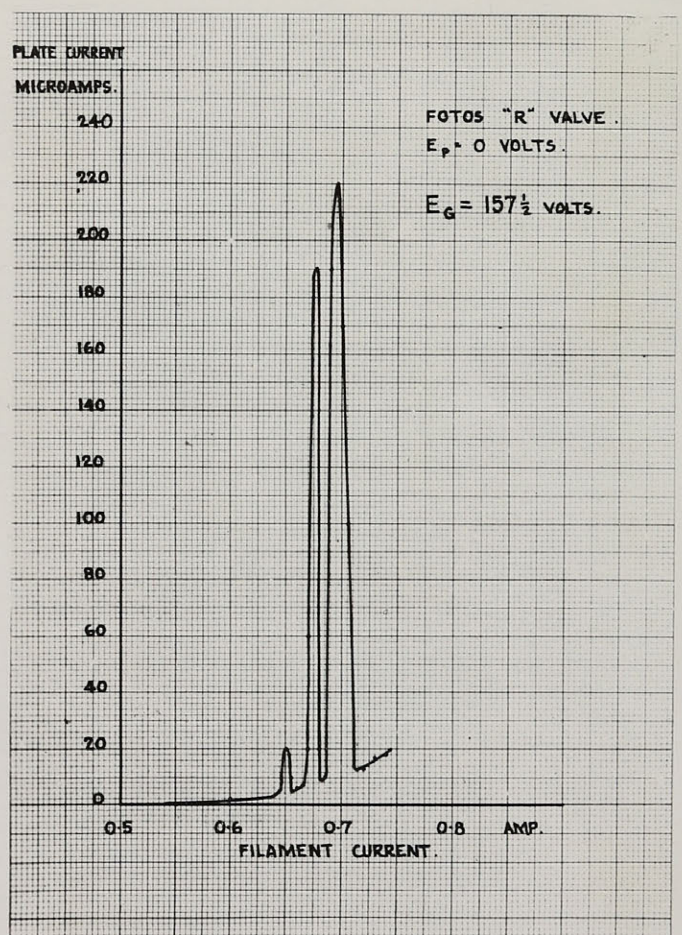


PLATE XII.

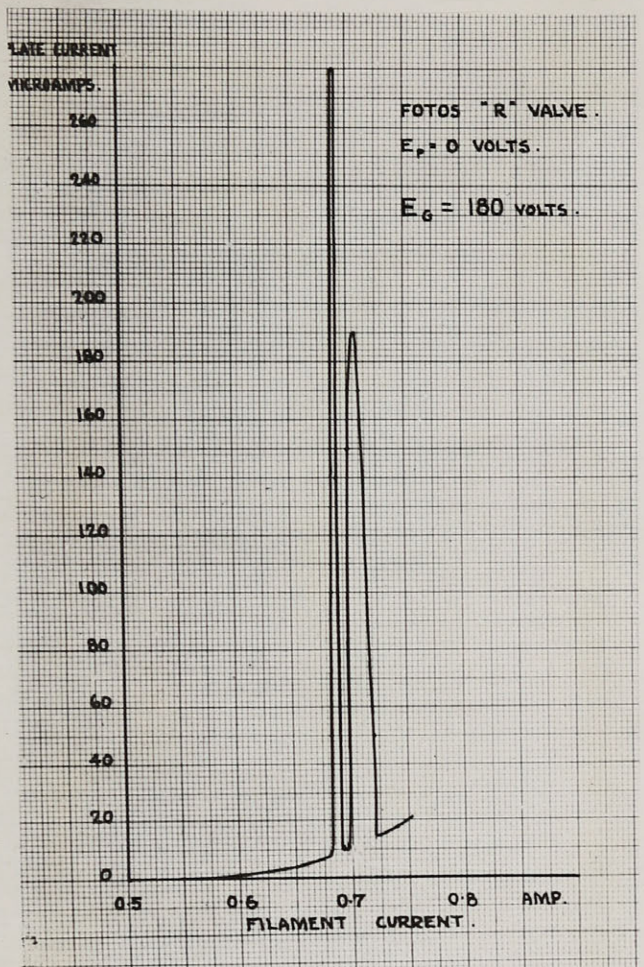


PLATE XIII.

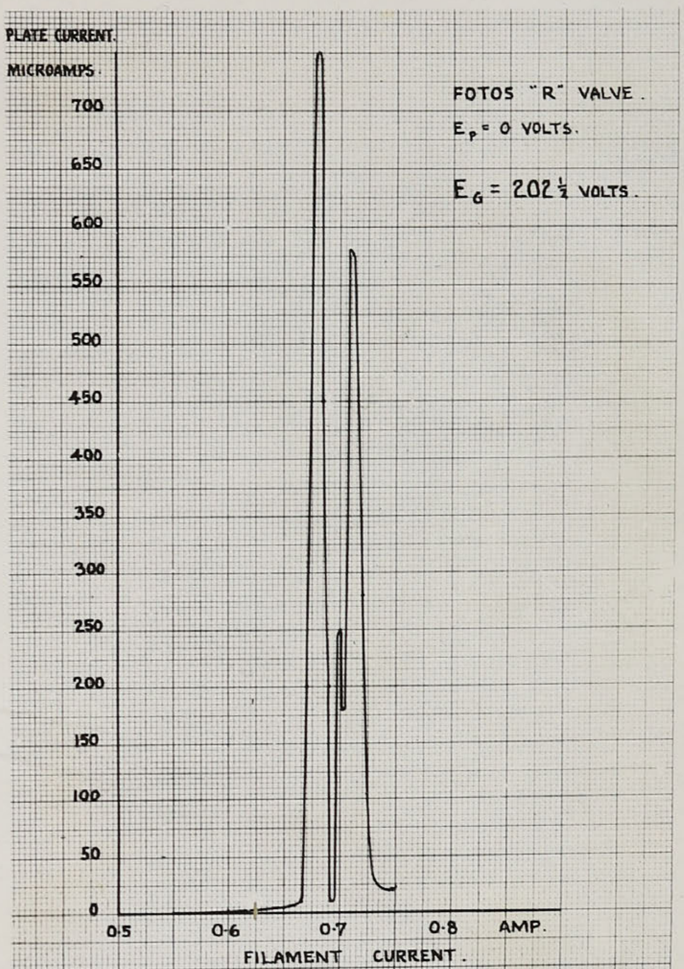


PLATE XIV.

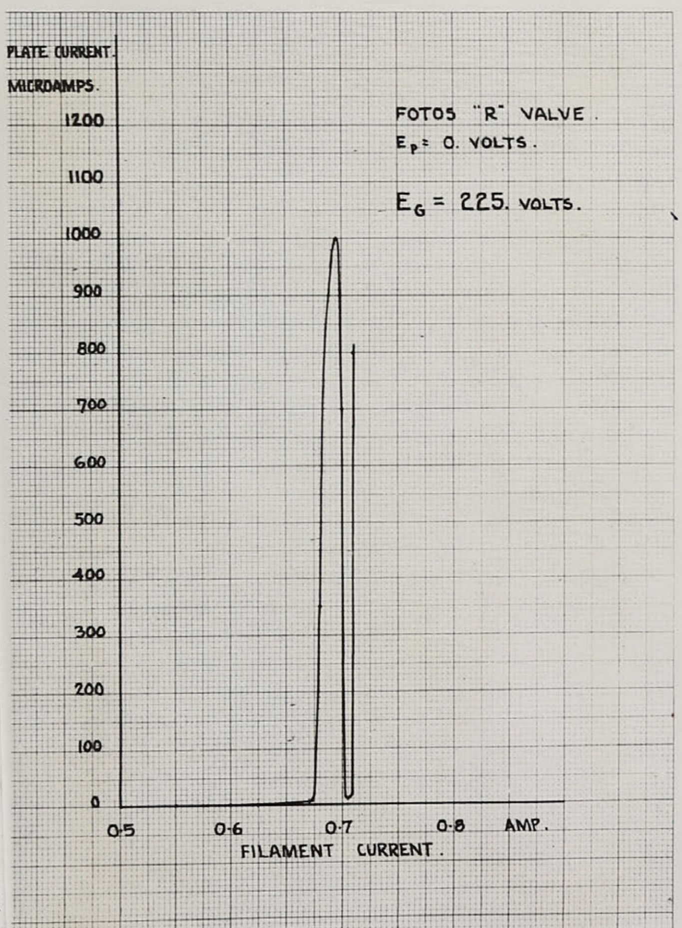


PLATE XV.

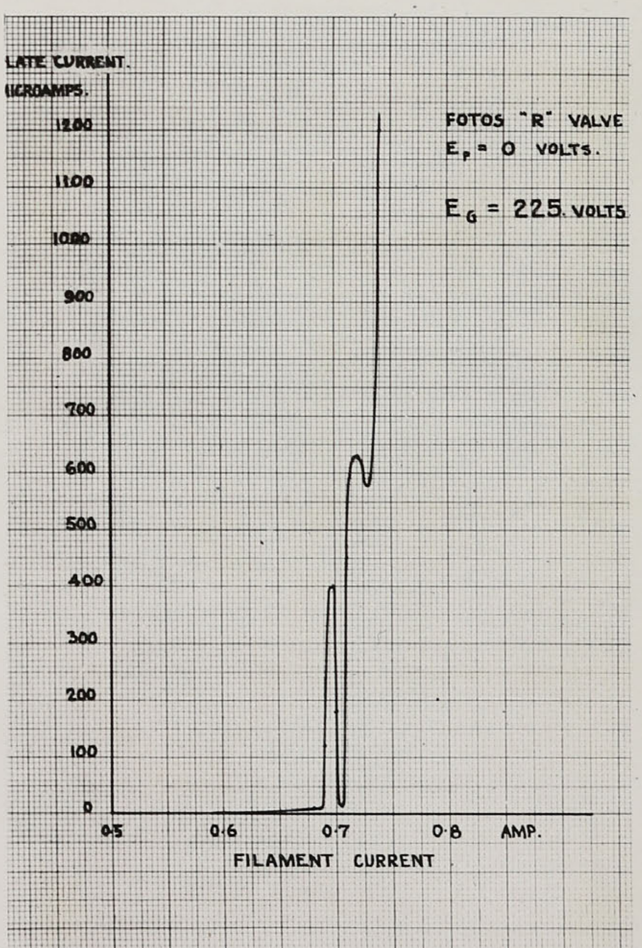


PLATE XVI.

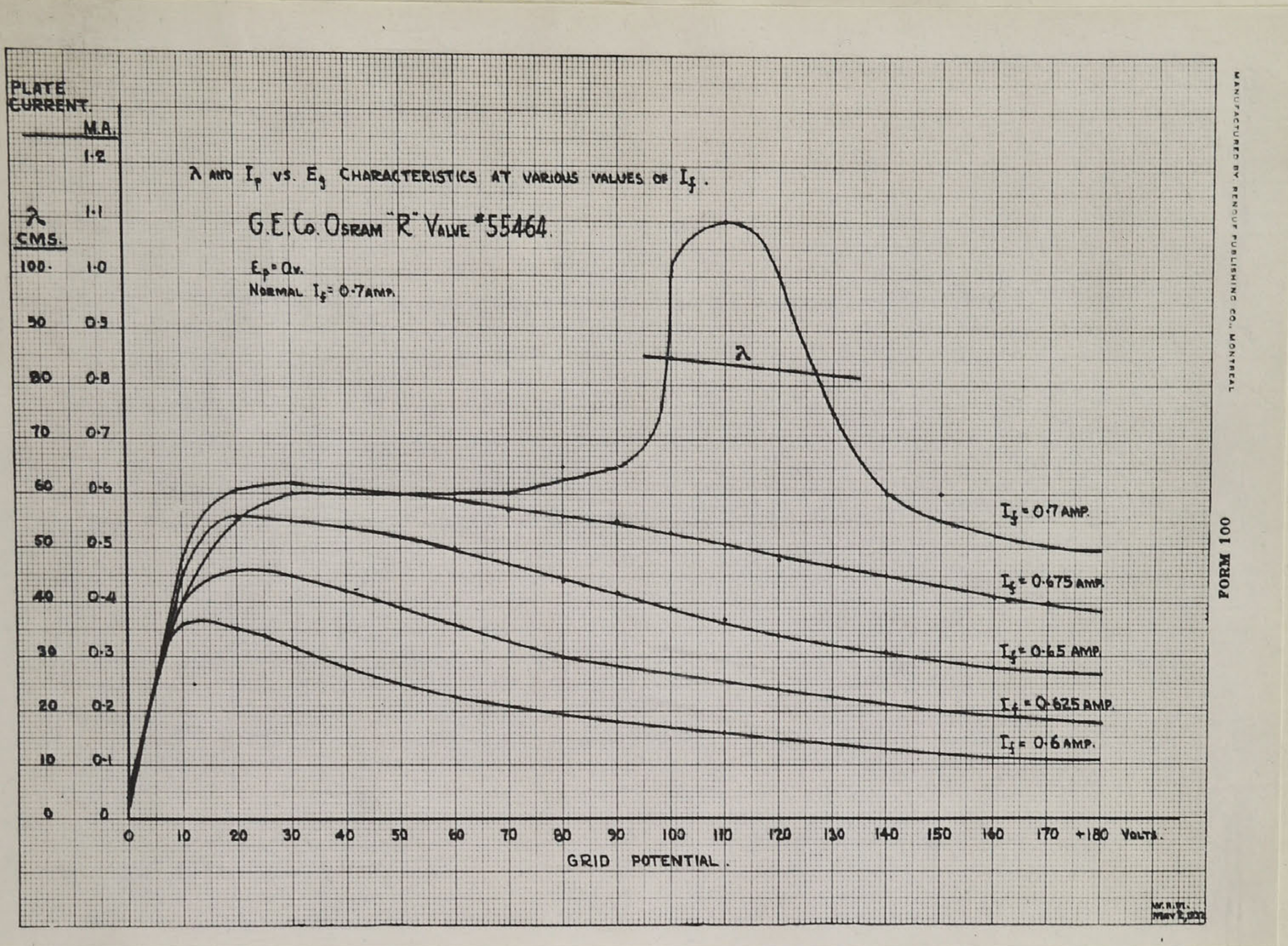


PLATE XVII.

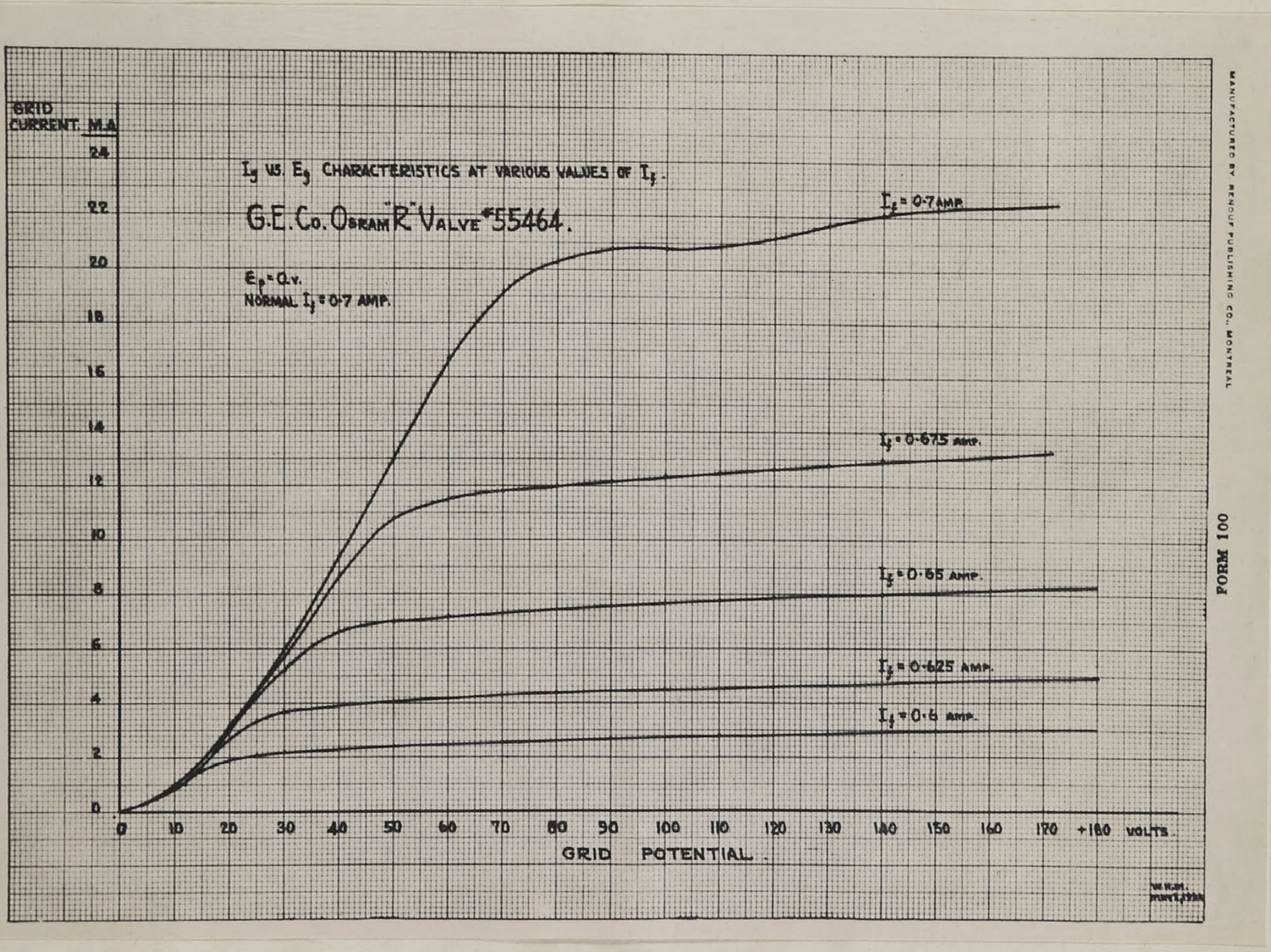


PLATE XVIII.

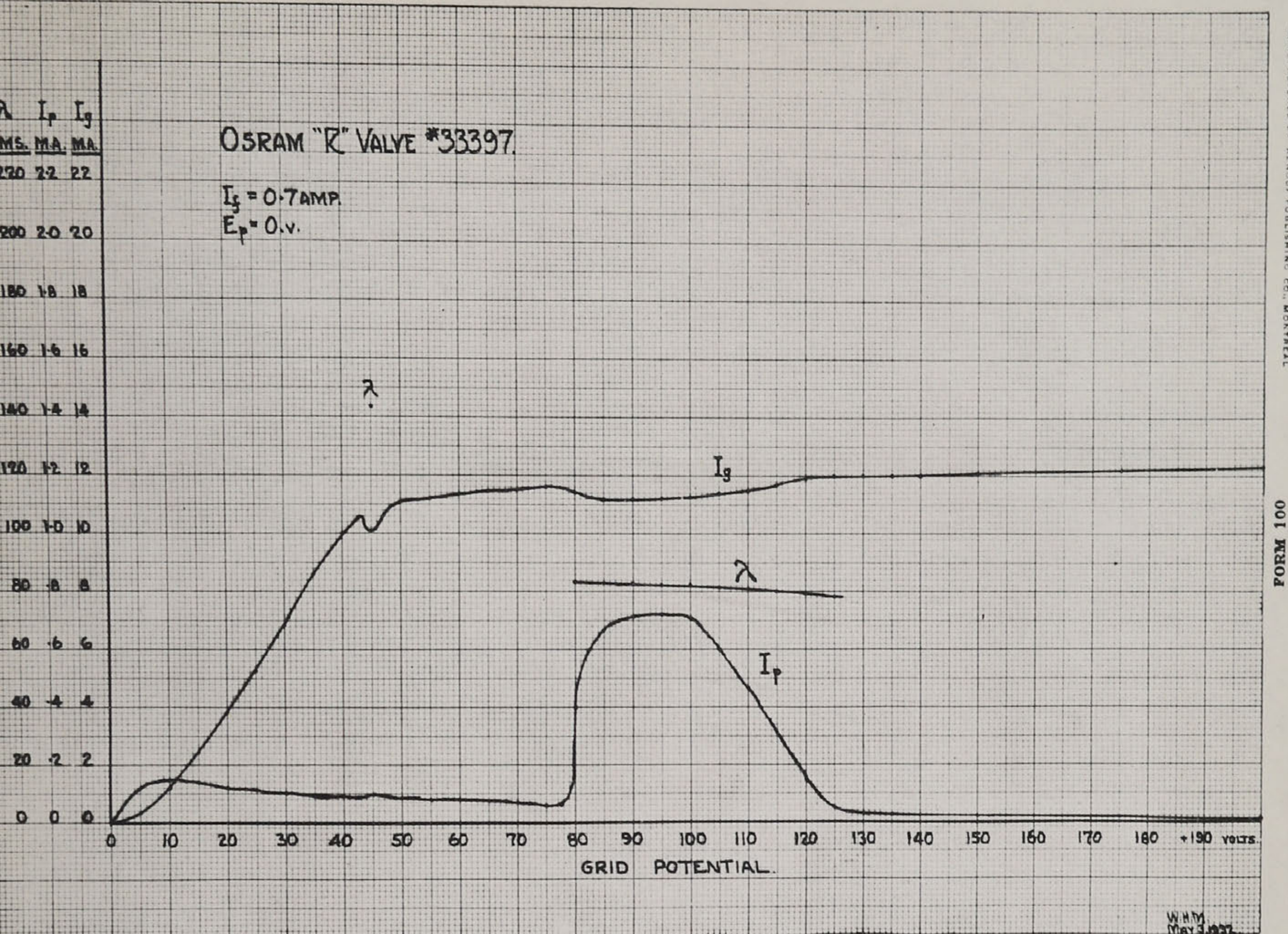


PLATE XIX.

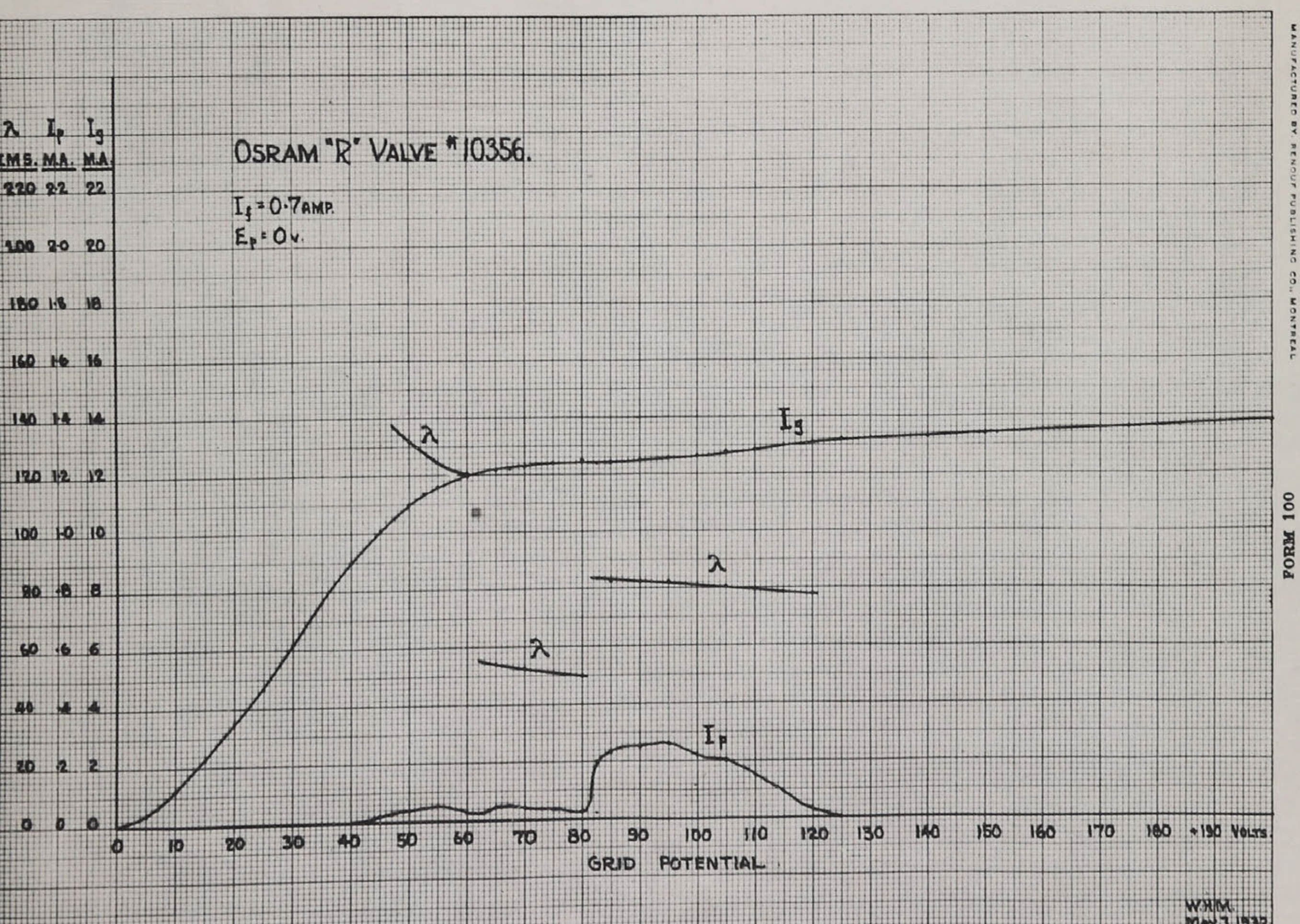


PLATE XX.

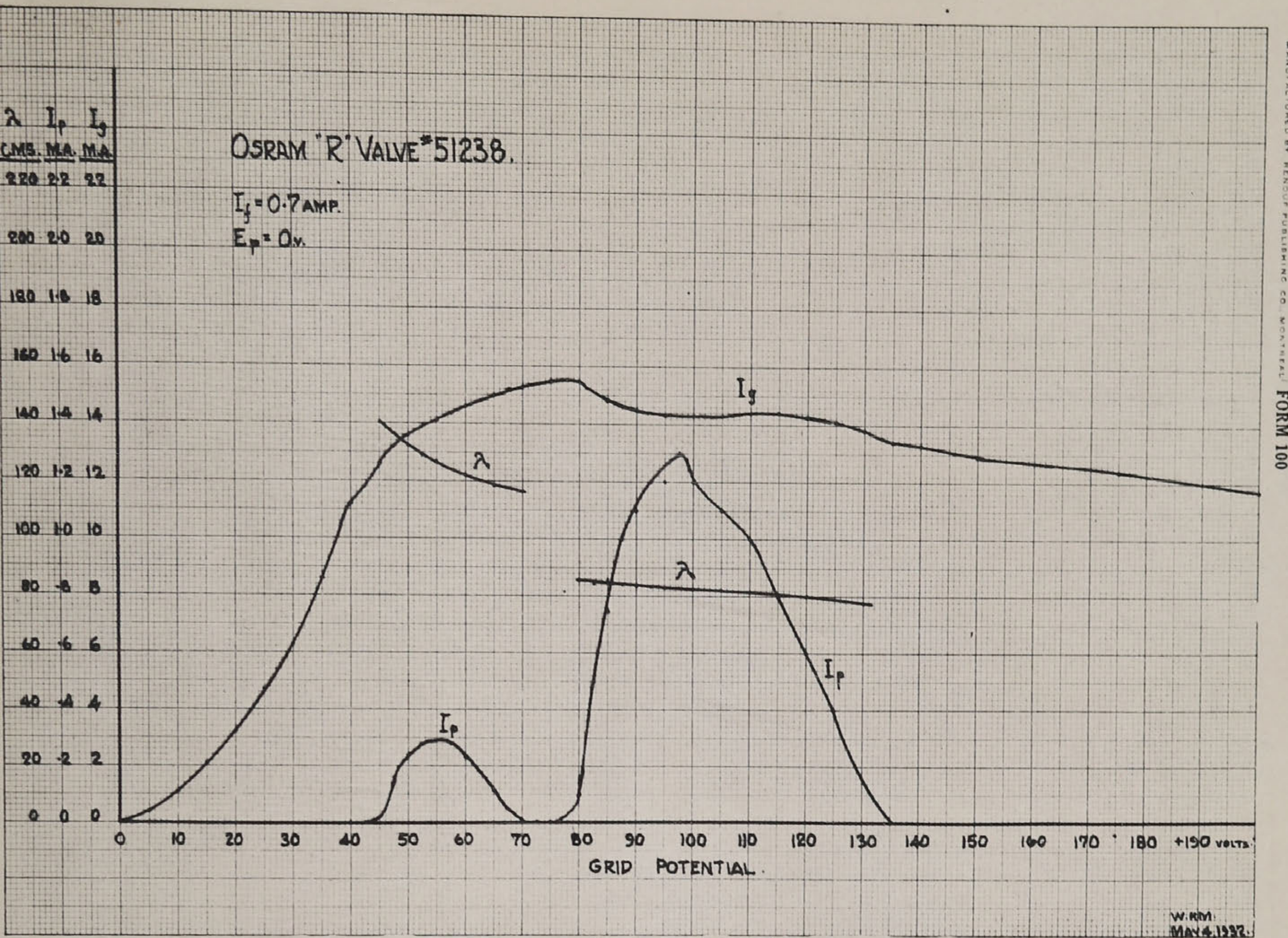


PLATE XXI.

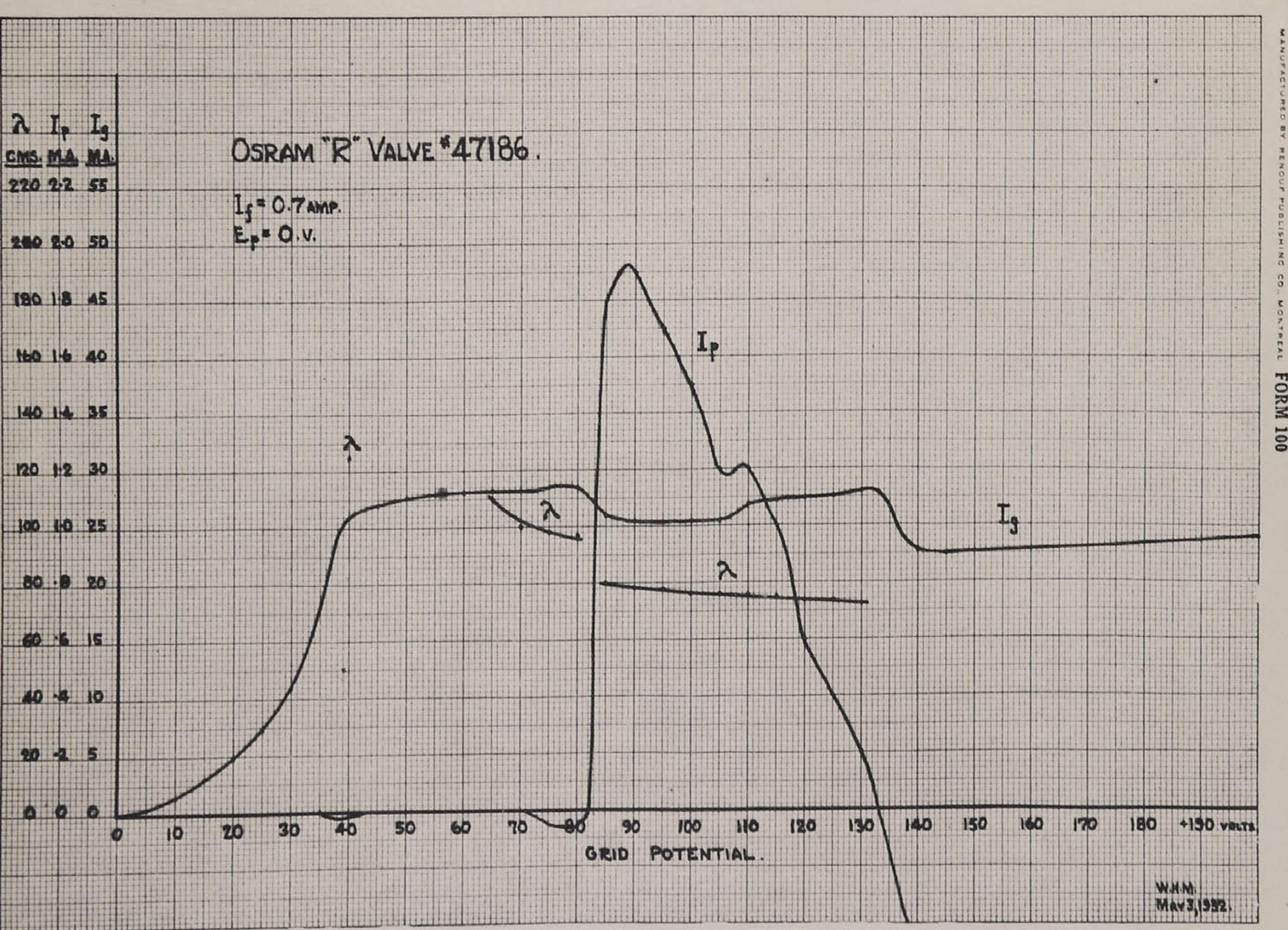


PLATE XXII.

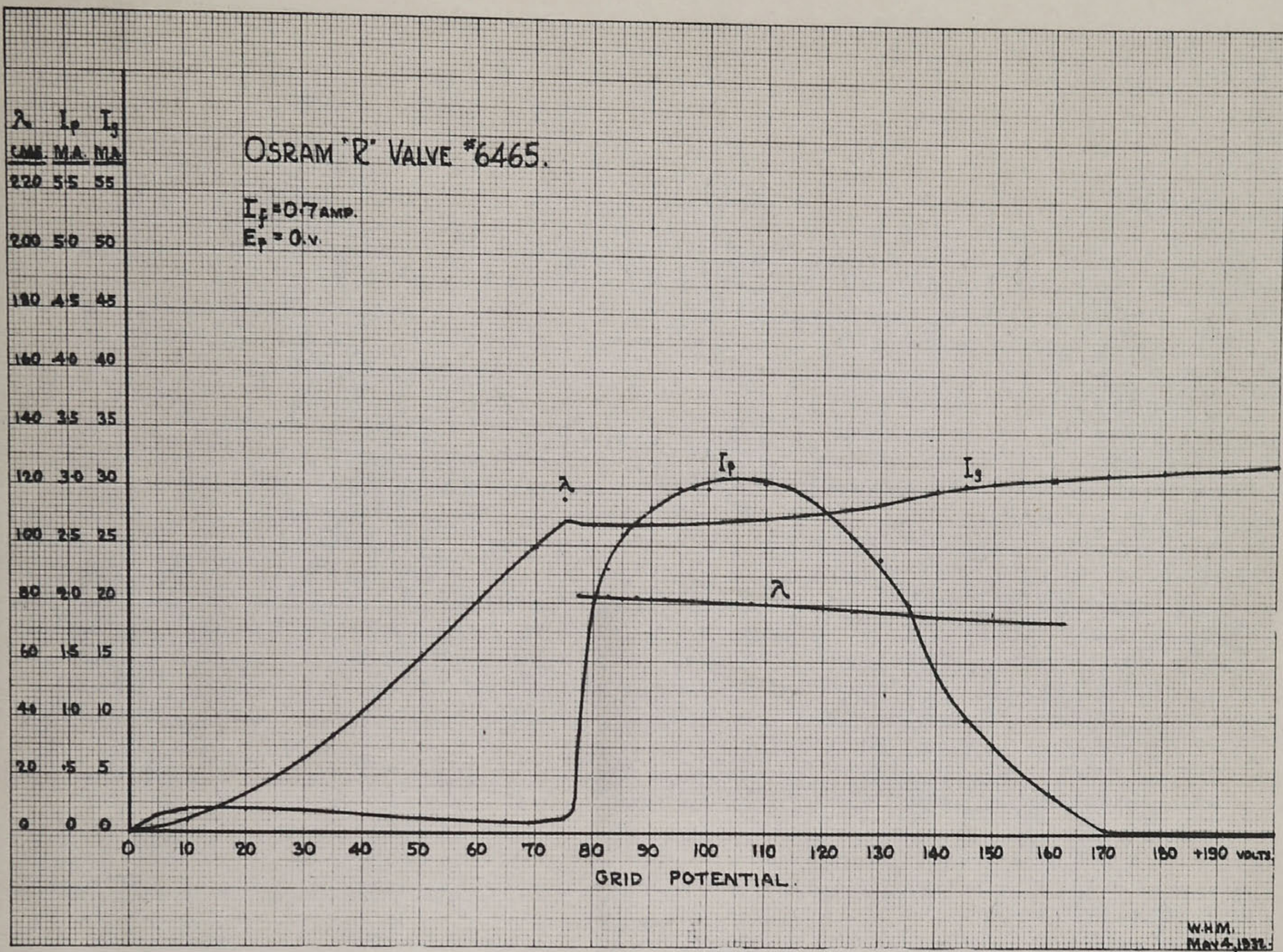


PLATE XXIII.

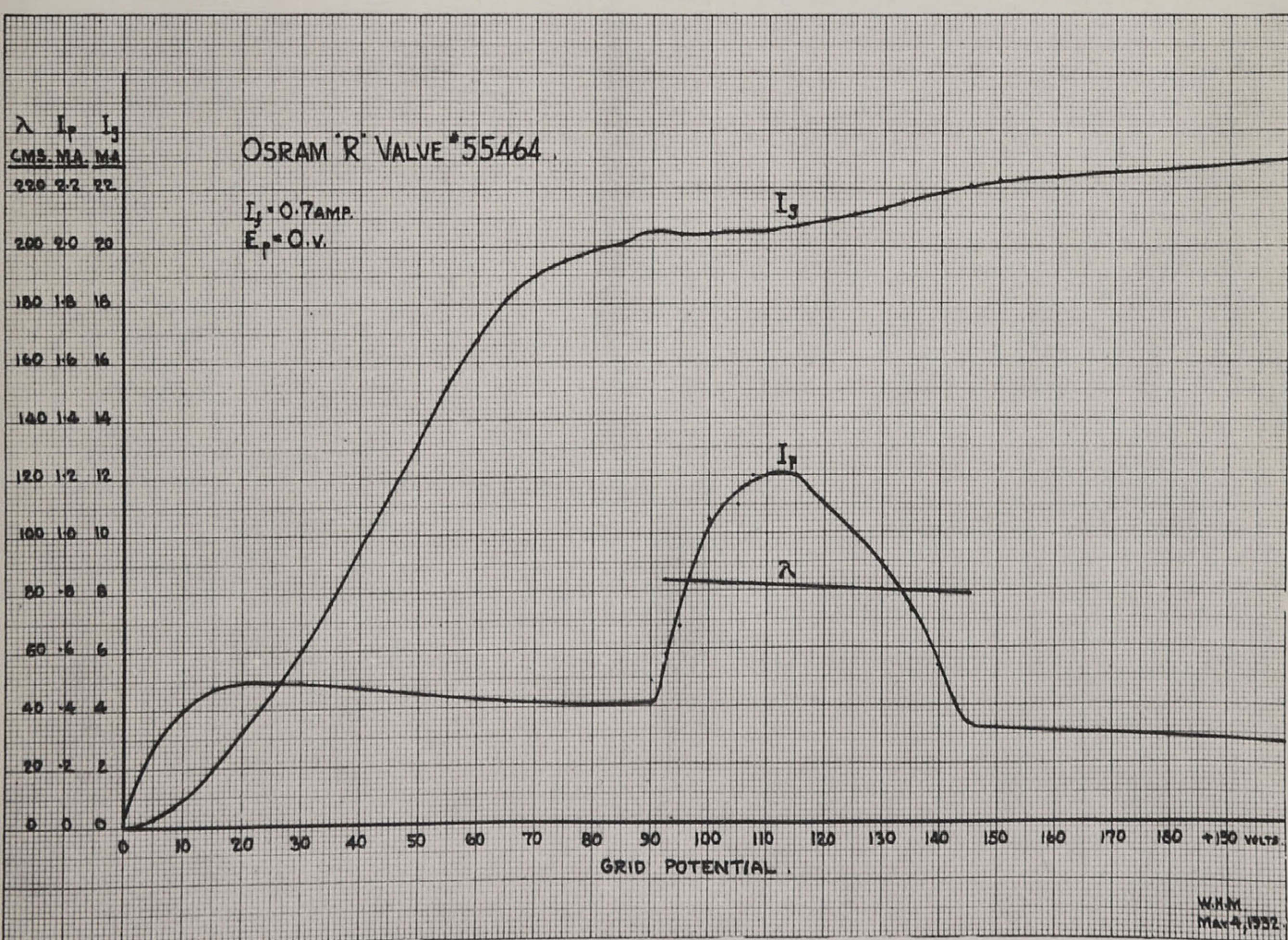


PLATE XXIV.

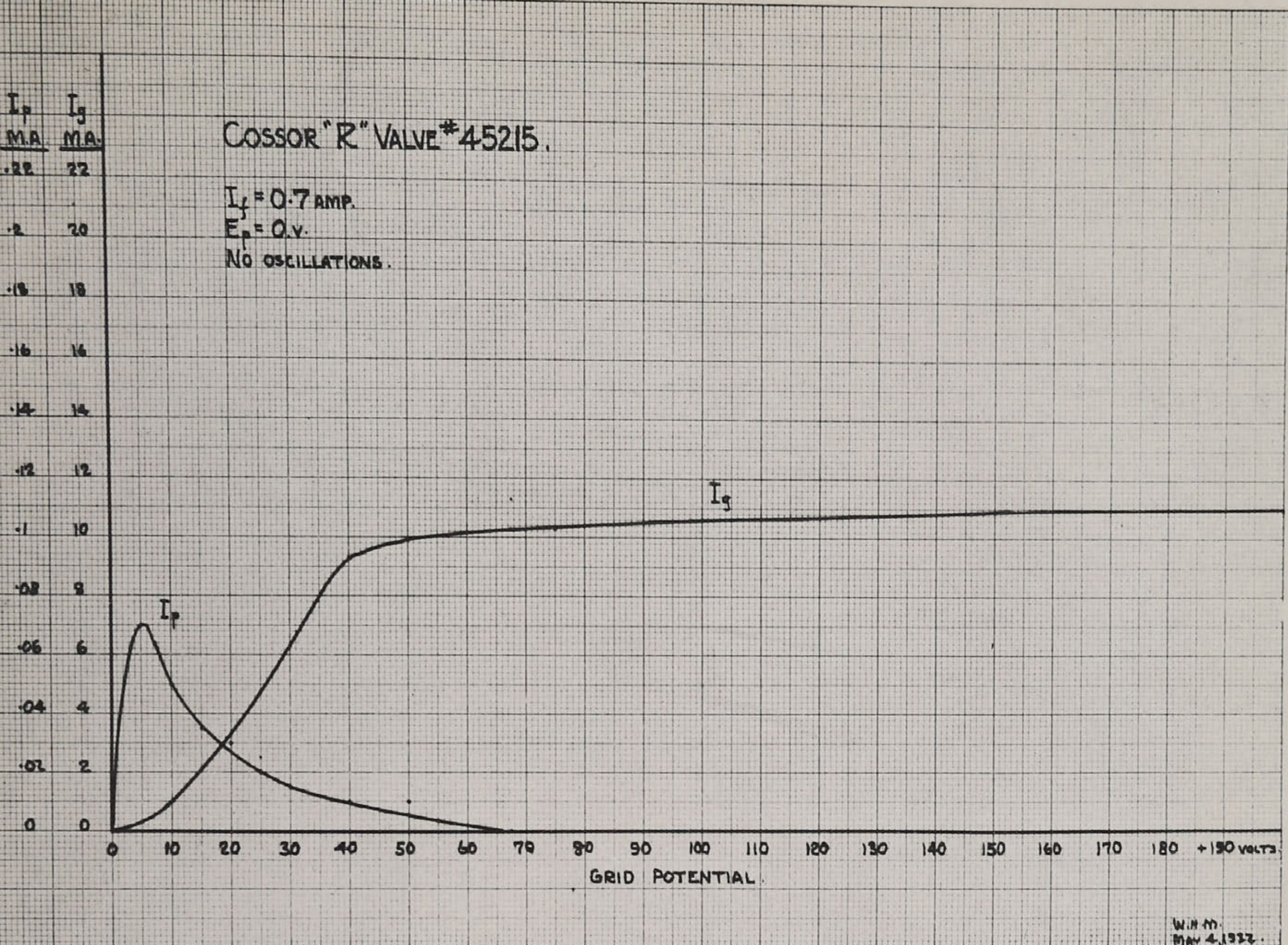


PLATE XXV.

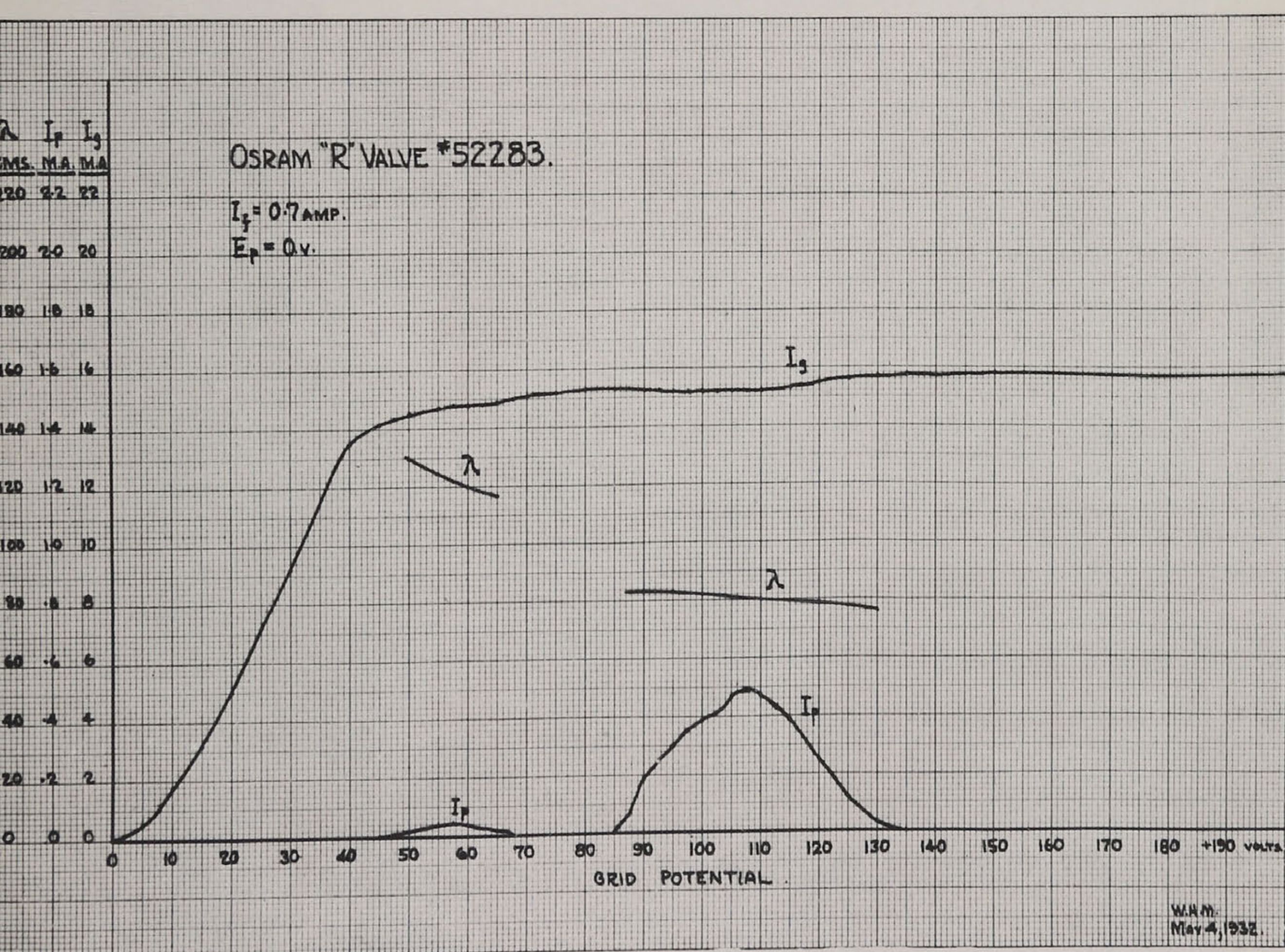


PLATE XXVI.

MANUFACTURED BY RENOUF PUBLISHING CO. MONTREAL FORM 100

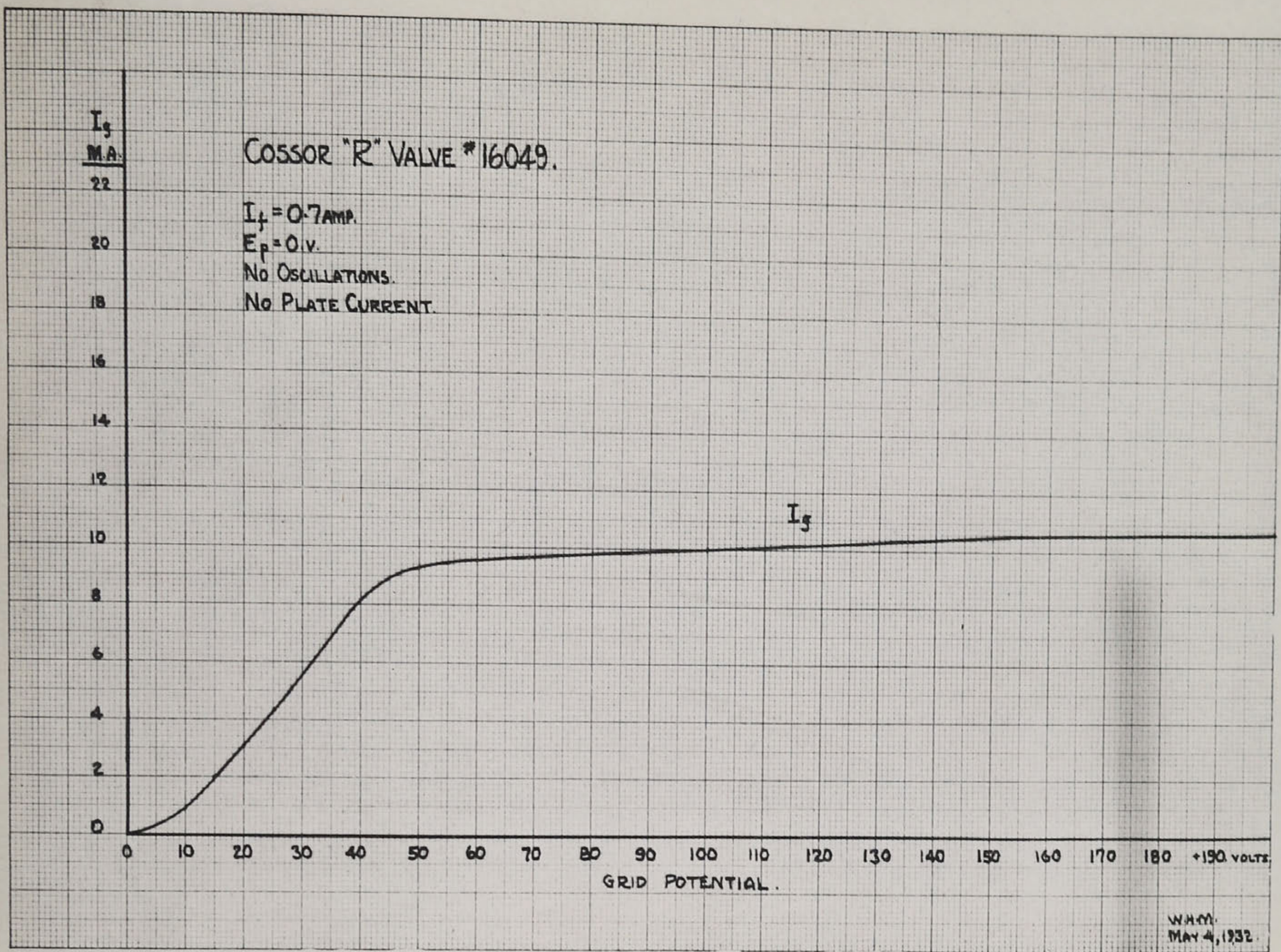


PLATE XXVII.

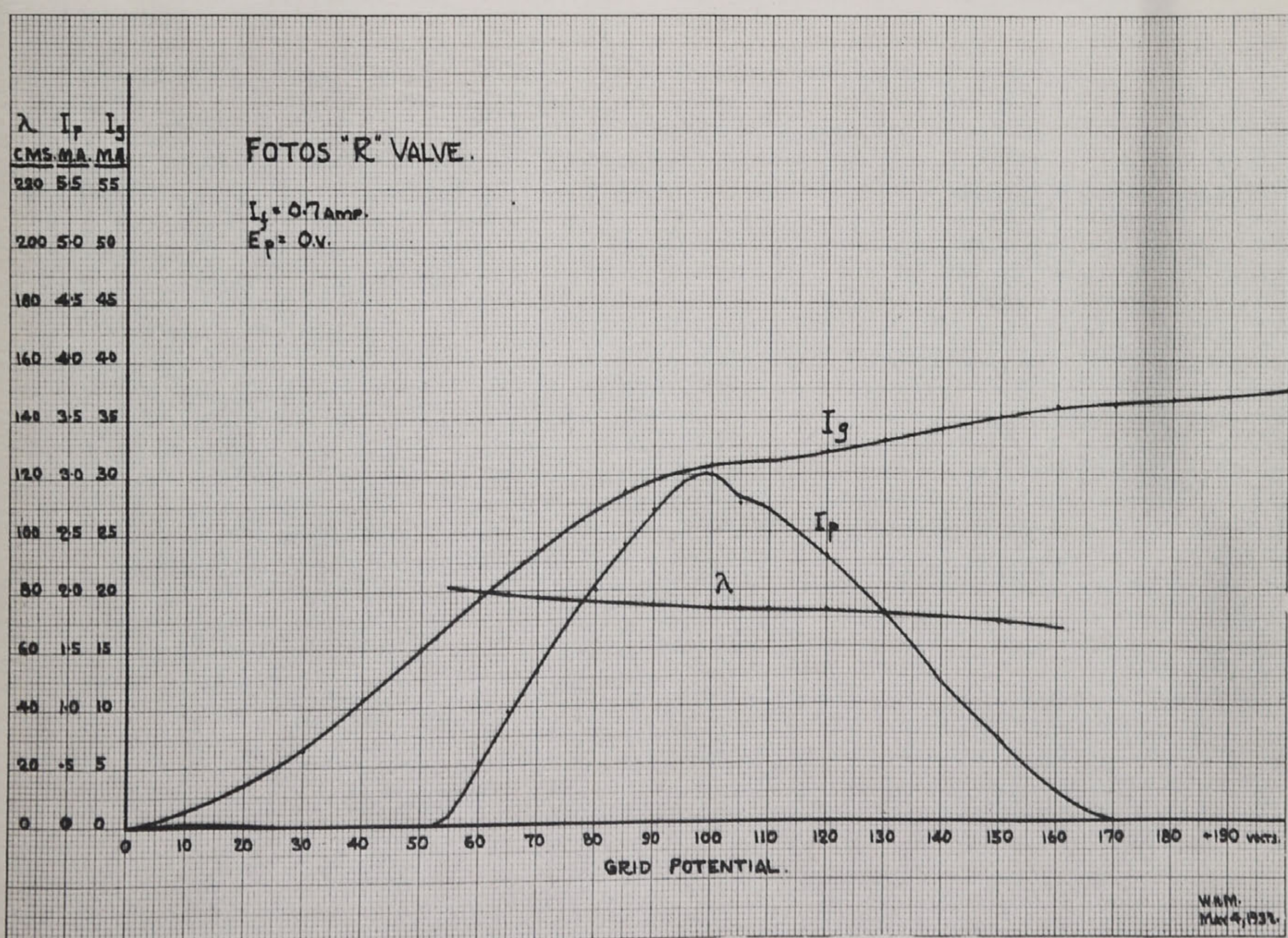


PLATE XXVIII.

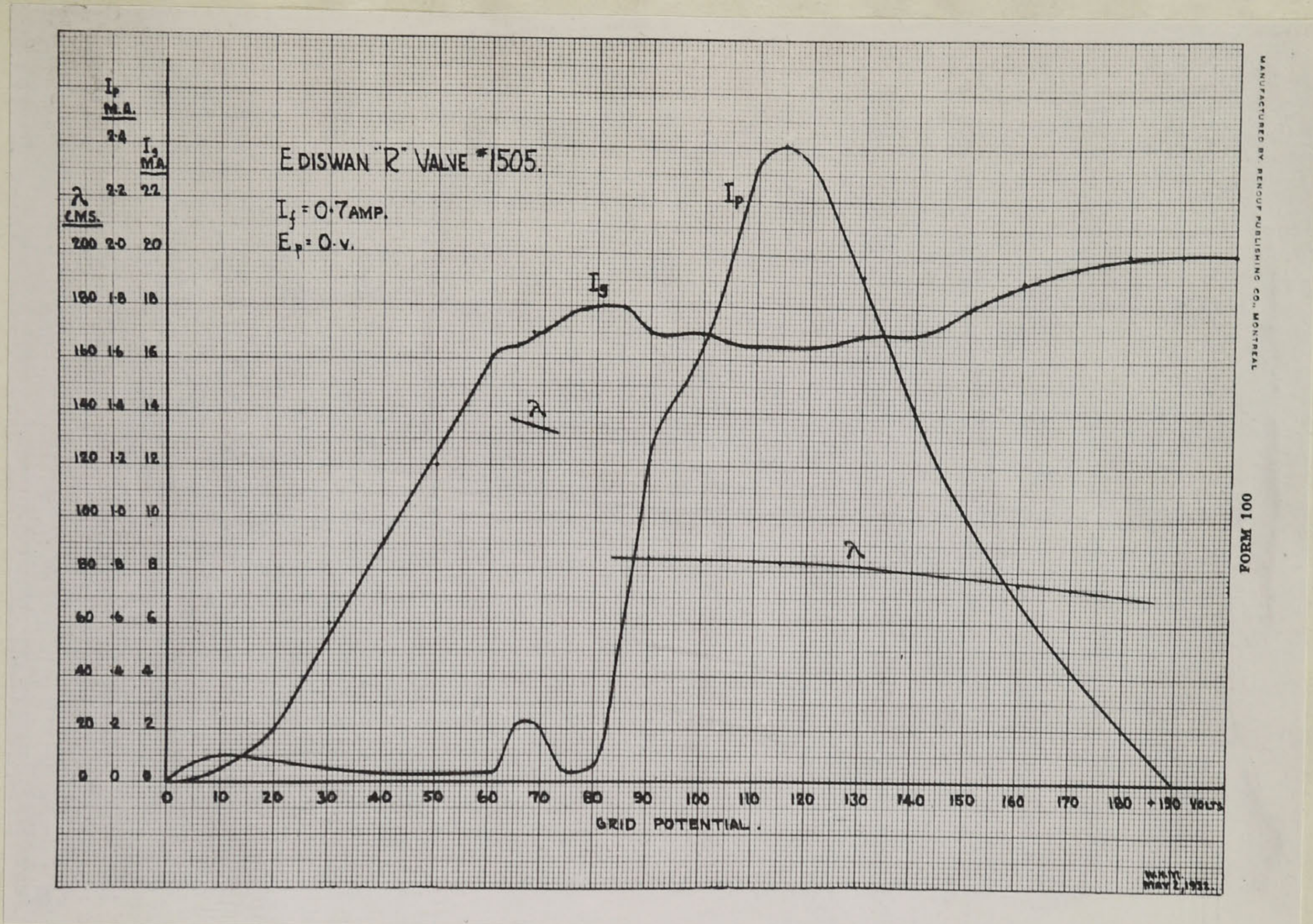


PLATE XXIX.

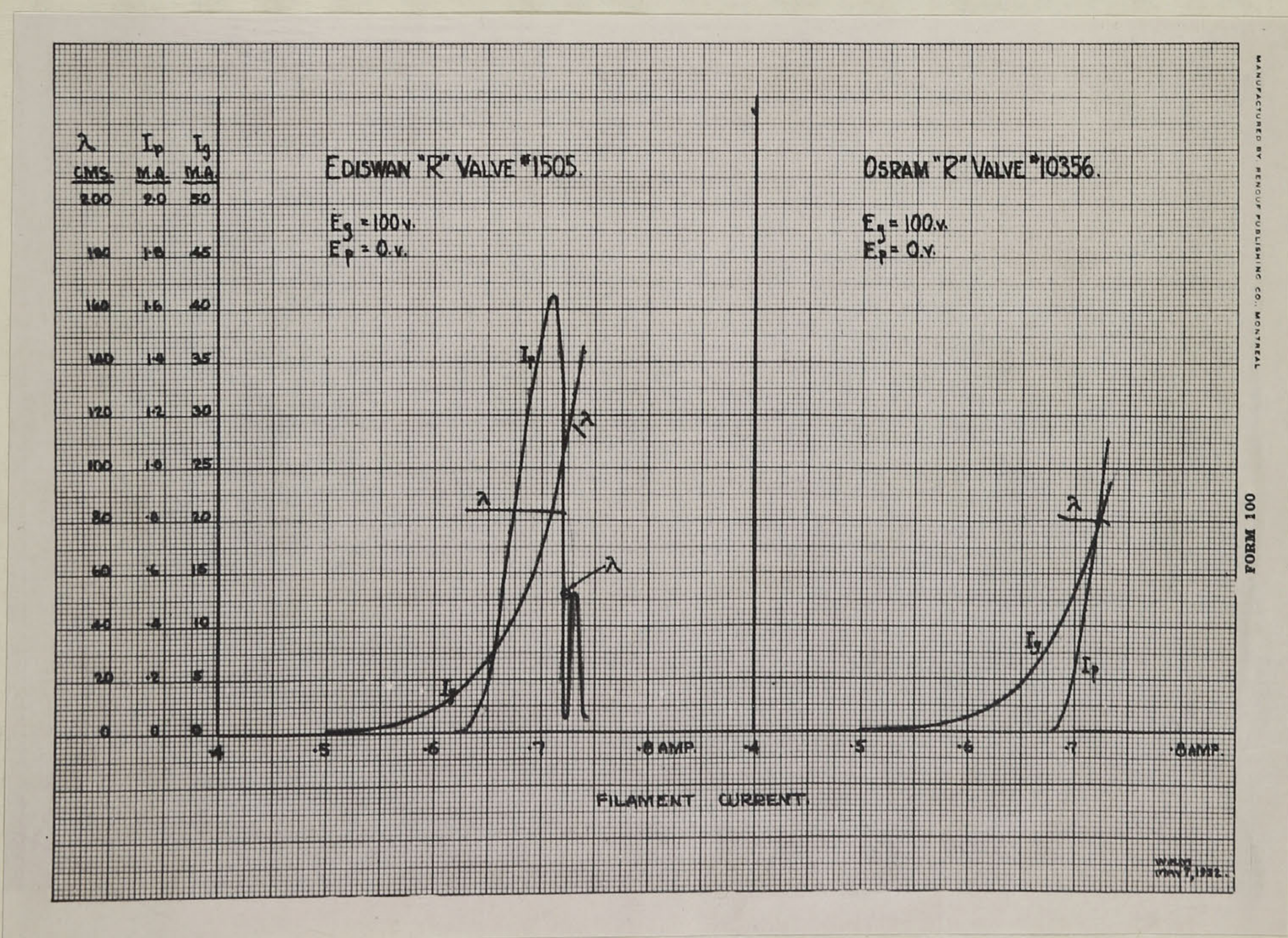


PLATE XXX.

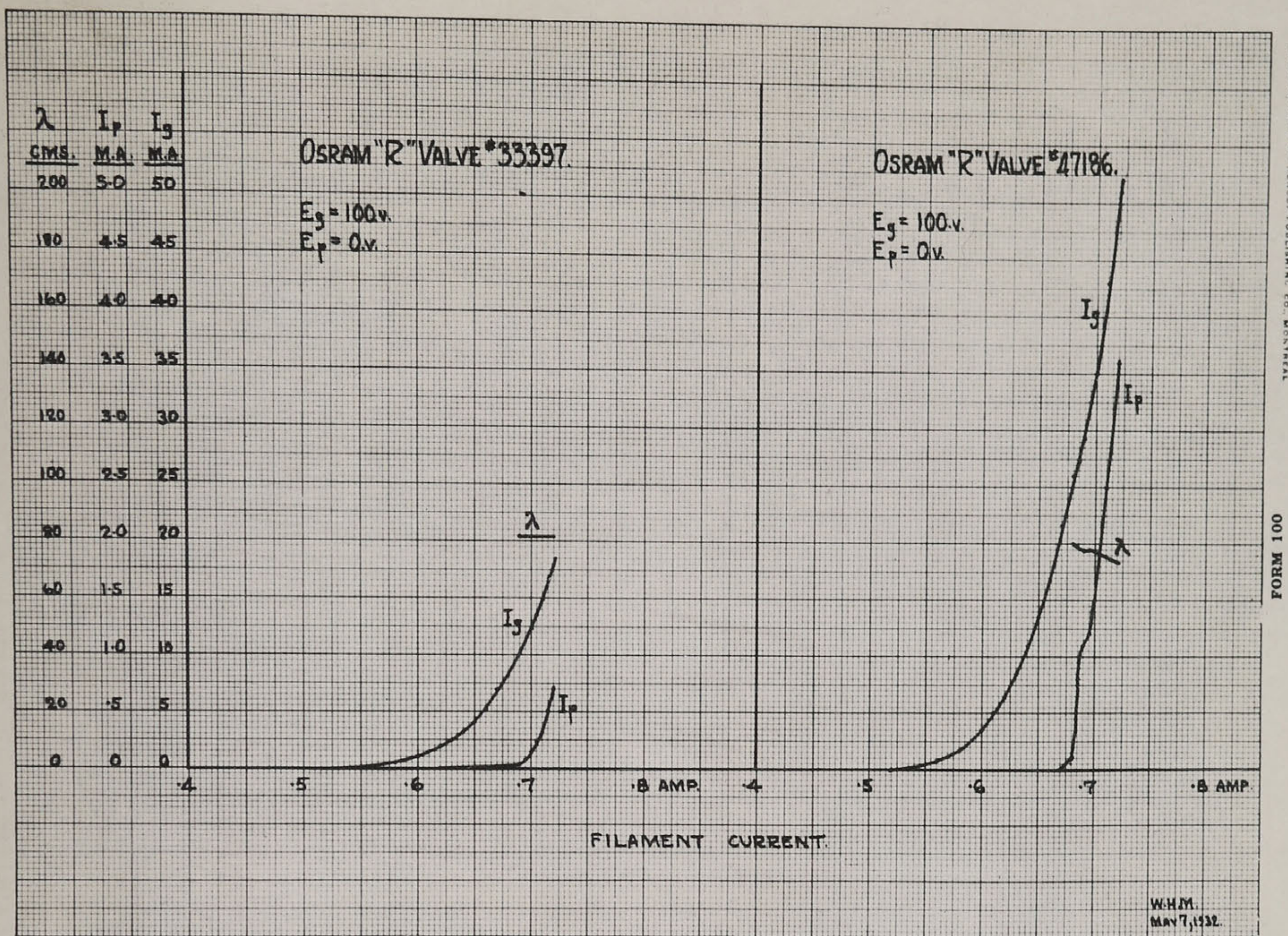


PLATE XXXI.

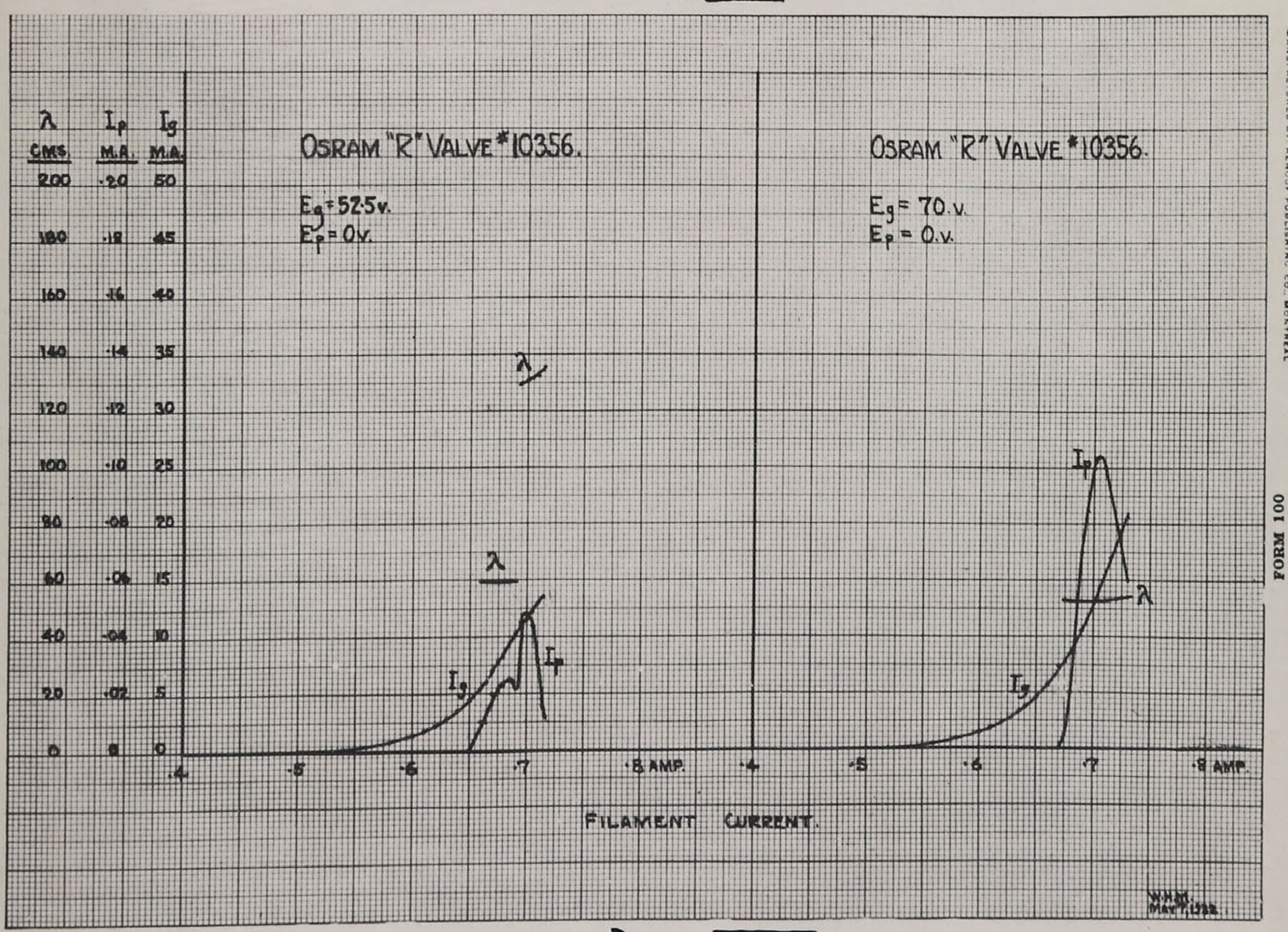


PLATE XXXII.

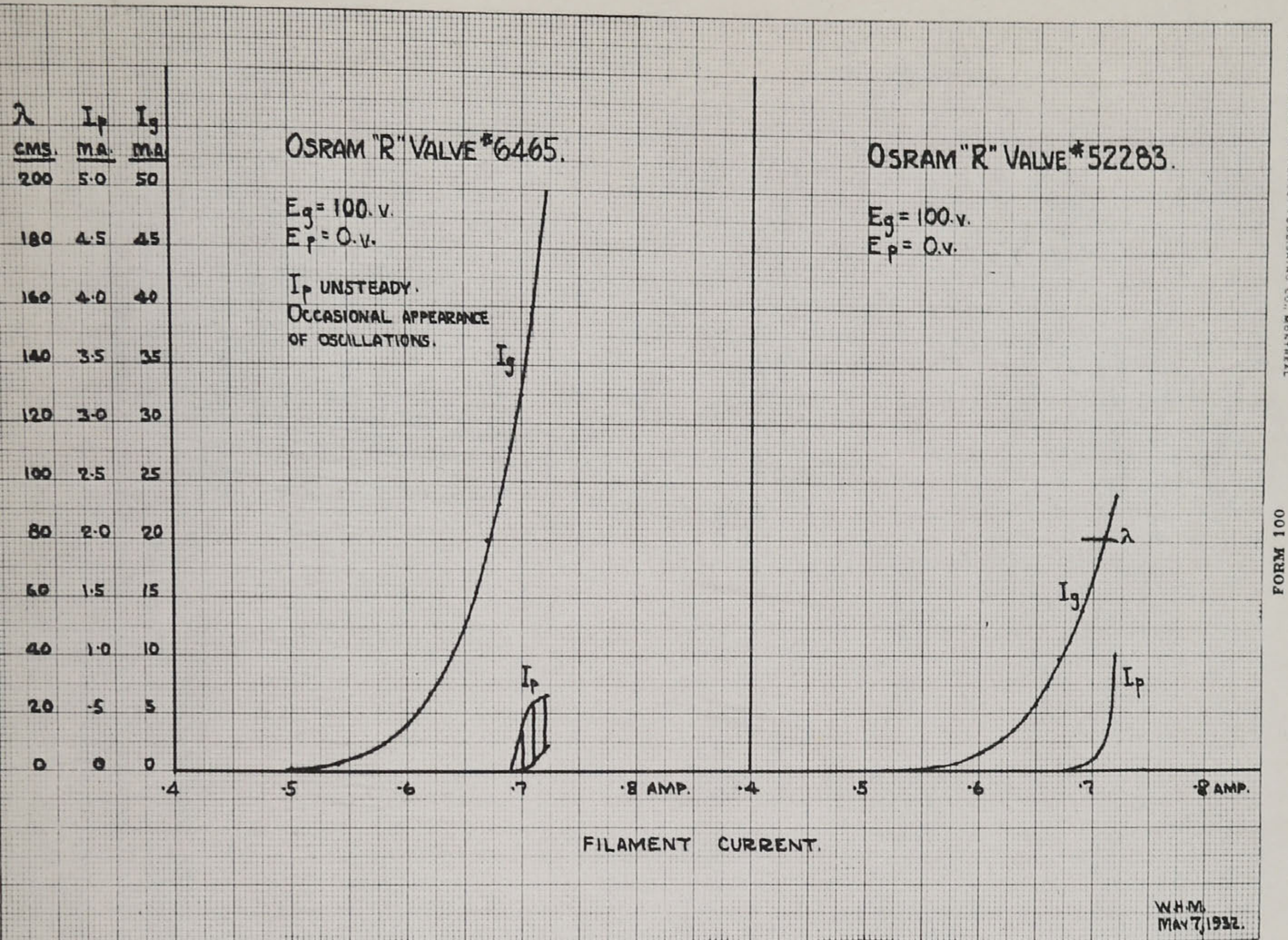


PLATE XXXIII.

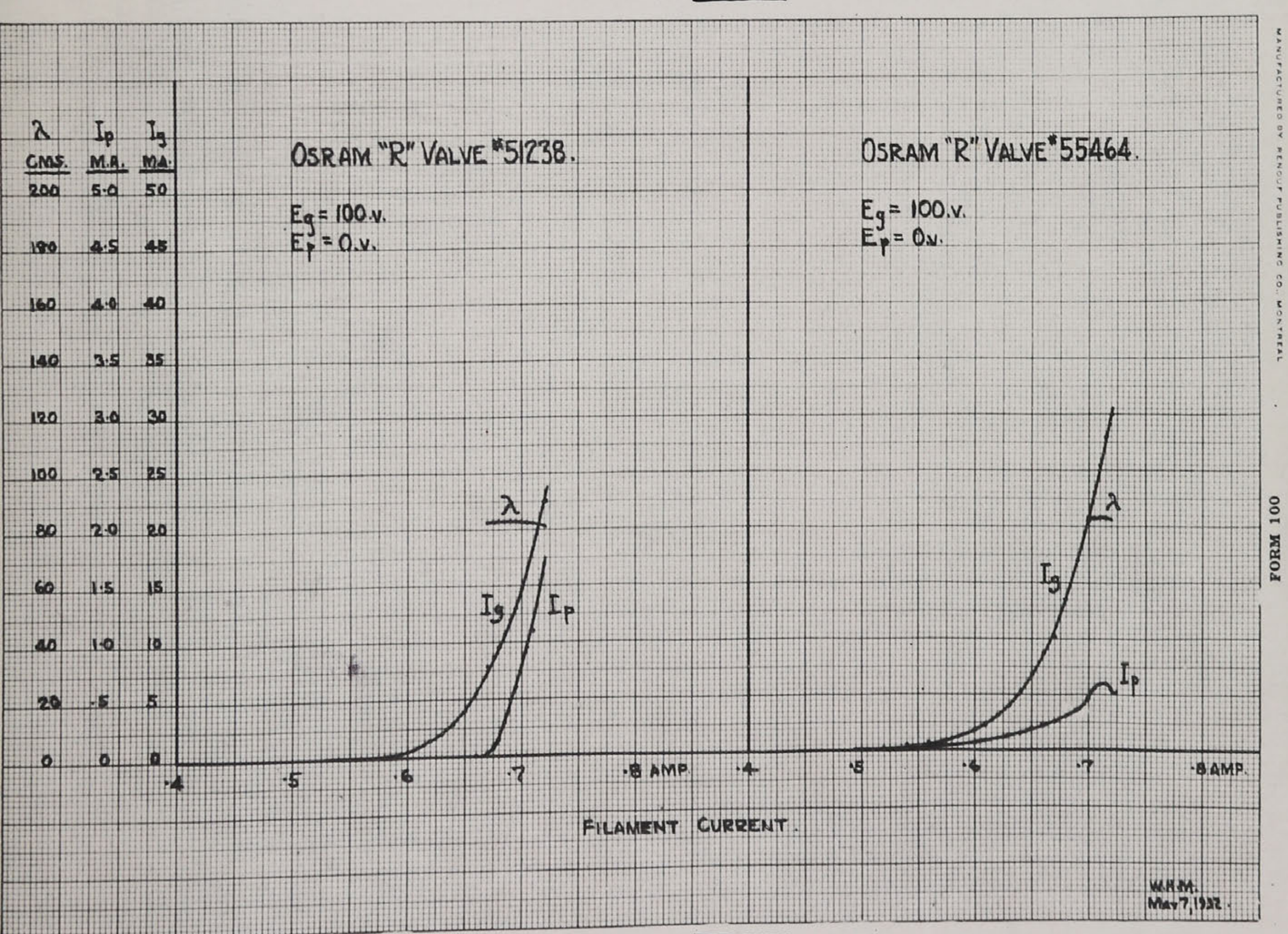


PLATE XXXIV.

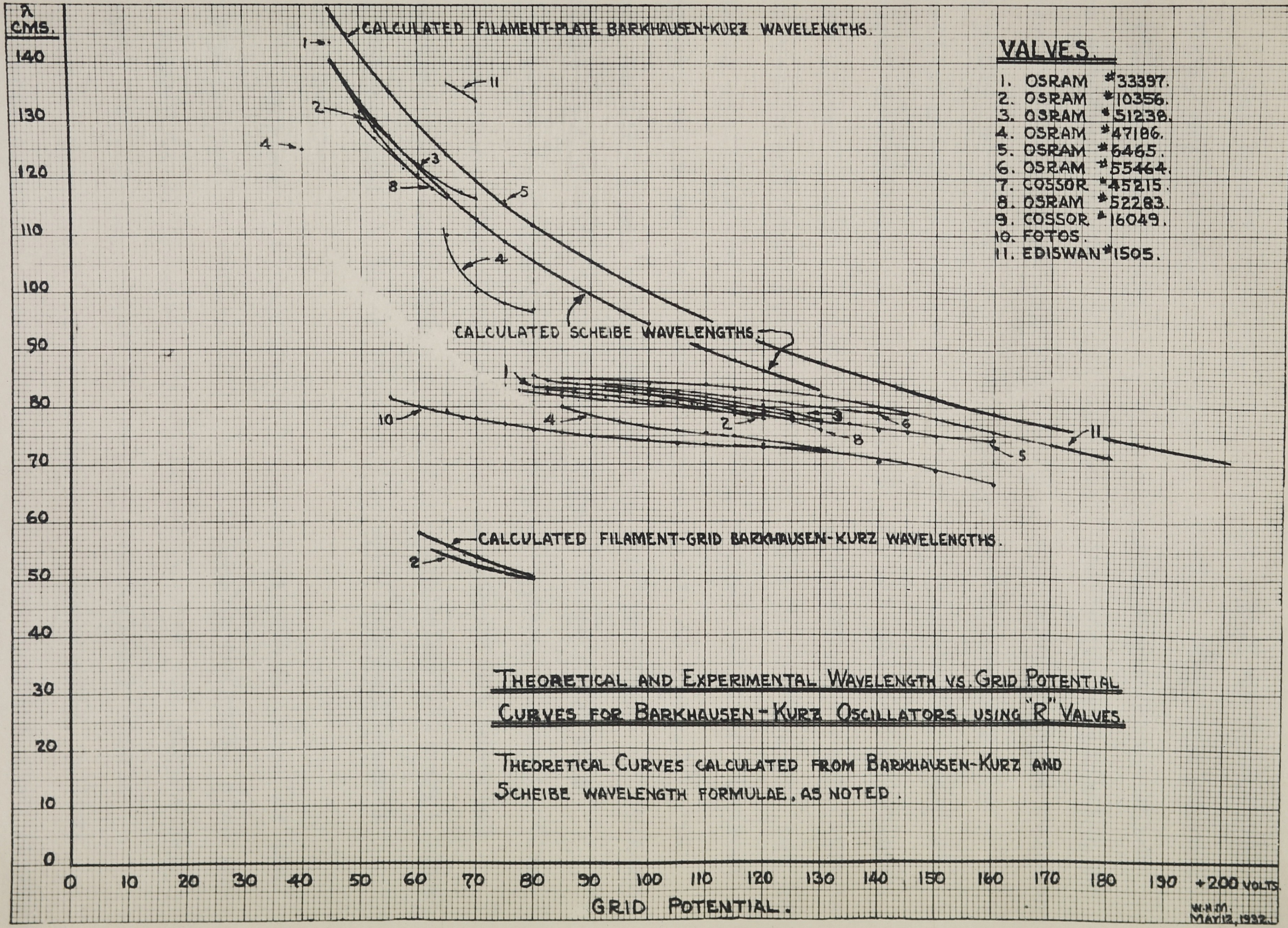

λ CMS.
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
CALCULATED FILAMENT-PLATE BARKHAUSEN-KURZ WAVELENGTHS.
CALCULATED SCHEIBE WAVELENGTHS
CALCULATED FILAMENT-GRID BARKHAUSEN-KURZ WAVELENGTHS.
VALVES.
1. OSRAM #33397.
2. OSRAM #10356.
3. OSRAM #51238.
4. OSRAM #47186.
5. OSRAM #6465.
6. OSRAM #55464.
7. COSSOR #45215.
8. OSRAM #52283.
9. COSSOR #16049.
10. FOTOS.
11. EDISWAN #1505.
THEORETICAL AND EXPERIMENTAL WAVELENGTH VS. GRID POTENTIAL CURVES FOR BARKHAUSEN-KURZ OSCILLATORS, USING "R" VALVES.
THEORETICAL CURVES CALCULATED FROM BARKHAUSEN-KURZ AND SCHEIBE WAVELENGTH FORMULAE, AS NOTED.
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 +200 VOLTS.
GRID POTENTIAL.
W.H.M. MAY 12, 1932.

PLATE XXXV.

V. DISCUSSION ON BARKHAUSEN-KURZ OSCILLATIONS.

The theory of these oscillations given by Barkhausen and Kurz, and extended by Hollmann, Scheibe, Gill and Morrell, and others, does not explain the extraordinary effects which were obtained in this investigation. The usual explanation of a cloud of electrons oscillating back and forth between filament and plate, accelerated by the attraction of the grid, is insufficient to explain why the oscillations should occur at several definite values of filament current and not in between these values. Breit[36] describes the production of oscillations by a method somewhat similar to that used by the author, but he obtains oscillations within only one narrow range of filament current, while in the author's experiments oscillations were found to take place over several very narrow ranges of filament current each about 15 to 20 m.a. wide. No satisfactory explanation is found by Breit, although several possibilities are suggested. The effect somewhat resembles the numerous resonance potentials which are found in gaseous discharge tubes. The valves used in these experiments were all high vacuum tubes, however.

The several regions of oscillation which occur as the grid potential is varied with fixed filament current, also do not appear to be amenable to explanation from the simple B-K theory. The Barkhausen-Kurz formula indicates a single continuous wavelength curve as shown in Plate XXXV, p.103j. The curves obtained experimentally are each divided into several discrete sections, and these do not coincide with the B-K curve. The explanation does not lie in the presence of Gill-Morrell oscillations, with an external tuned circuit resonant at several frequencies, since there is no external tuned circuit .

Nevertheless it will be seen from the following that the existing theory is adequate to explain the experimental results observed, the complete explanation being a combination of the various proposed theories .

The first region of oscillations, commencing at grid potentials in the neighbourhood of +45 volts, is a region of pure electronic (Barkhausen-Kurz) oscillations, and takes place in the filament-plate space . It follows the B-K wavelength relationship reasonably well, as can be seen from an inspection of the curves in this region in Plate XXXV . The curves do not coincide, however, the experimental wavelengths being about 8% shorter than those calculated from the B-K formula . This is explained by the fact that the B-K formula is not strictly accurate for valves with cylindrical electrodes, since it was derived for the case of plane electrodes, thereby simplifying the calculations but introducing an error when applied to the cylindrical case . If the constant in the formula is empirically modified to make the calculated and experimental values of wavelength agree for some arbitrary value of E_g, it will be found that substituting this new value of constant in the formula will give a wavelength curve which agrees very closely with experiment . This value of constant is later found to be the value derived theoretically by Scheibe in his formula .

The second region of oscillations consists of pure electronic oscillations taking place in the filament-grid space . Wavelengths are considerably less than half those of the first region, hence they cannot be harmonics of the first region .

By substituting the grid diameter for the plate diameter in the B-K formula we find that calculated wavelengths agree with experimental as closely as in the first region . Experimental values are again slightly shorter than those calculated, for the same reason .

The third region of oscillations consists of Gill-Morrell oscillations, with the grid and plate electrodes forming the tuned circuit . This is why the wavelength in this region is so nearly constant, merely dropping a little as the grid potential is increased (see Plate XXXV) instead of following the B-K curve . It was at first thought that the resonant circuit might consist of the parallel wire leads between the electrodes and the valve pins, but a calculation of the inductance of these leads gave a value of 0.09 microhy. This in combination with the measured grid-plate capacity gives a wavelength of 60% higher than that observed . Hence the "external" tuned circuit does not include the leads, but consists only of the grid and plate elements themselves .

Several isolated wavelength values will be noted in Plate XXXV . These were instances of oscillations occurring at single critical values of grid potential . Oscillations in these cases were unstable and tended to die away . At the values of grid potential at which oscillations changed from one region to another conditions were also unstable, the wavelength tending to jump from one region to the other .

Plates XXX to XXXIV show that the wavelength of the third, or Gill-Morrell, region is practically independent of filament current, as would be expected , since it is fixed by the natural period of resonance of the grid-plate system . The gassy valve, #47186, is again erratic, however . Wavelengths in the Barkhausen-Kurz regions do vary with filament current, but not in a regular manner, sometimes decreasing (e.g. valve #1505) and sometimes increasing (e.g. valve #10356 with E_g=52.5v.) with increasing filament current . The increase in wavelength or decrease in frequency as the filament current is increased, agrees with some calculations made by F.W.Sears[41] . In an analytical investigation of Barkhausen-Kurz oscillations, Sears finds that the effect of increasing space charge is to decrease the frequency . Since the space charge is proportional to the filament current, this finding is in agreement with some of the experimental results of the author .

Wavelengths calculated from Scheibe's formula lie along a curve similar in form to that of Barkhausen-Kurz, but are in closer agreement with experimental values . This is to be expected since the Barkhausen-Kurz formula was developed for the simplified case of a valve with plane electrodes, whereas the Scheibe formula was developed for cylindrical electrodes . All of the R valves investigated have the cylindrical type of electrode structure . Since all of the quantities in the Scheibe formula are constants for a given valve, except the grid voltage, this formula can be written in the same form as the B-K formula, the only difference being that the constant which has a value of 1000 in the B-K formula has a value of 944 in the Scheibe relationship .

The Rostagni wavelength formula (see p.39a) is not of much value since the quantity N, the number of electrons in the grid-plate space, is difficult to evaluate accurately . If N is considered to be directly proportional to I_g, then the wavelength calculated from this formula would vary very little with E_g, since I_g increases but slightly beyond the saturation value . On this account it was thought that this formula might be applicable to the oscillations of the third region, but this proved not to be the case .

Jonescu's formula (see p.39b) could not be applied to the cases investigated here since nothing was known of the gas content of the valves . If K, the gas constant, is determined experimentally to make the formula fit an experimental value, this formula then becomes identical with that of Barkhausen-Kurz.

Wavelengths found experimentally for the gassy valve #47186 did not agree with the formulae, as can be seen from Plate XXXV . The third region wavelengths were similar to those of the other valves, however, thus providing additional evidence to verify the fact that wavelengths in this region are controlled by a tuned circuit . The ionized gas renders the electron oscillations quite erratic, but does not affect the frequency of the resonant grid-plate circuit . The erratic results in the first two regions indicate that the wavelengths of oscillation in valves containing an appreciable amount of gas cannot be represented completely by a formula as simple as that of Jonescu .

Since there was no method of measuring any alternating potential E_0 which may have been produced at the grid, Hollmann's variation of the B-K formula (see p.39) was not made use of. The insertion of appropriate values of E_0 in Hollmann's formula would allow theoretical curves to be obtained which would more closely agree with each individual experimental curve . The presence of this alternating potential at the grid is another cause of variation in the experimental curves of the pure Barkhausen-Kurz regions .

VI. RESUME OF RESULTS OBTAINED .

A great amount of detail has been gone into in this dissertation, and a lot of time has been spent in recounting unsuccessful experiments as well as those which yielded results . It was considered best to cover all the work done as completely as possible, and to provide a permanent record of it . The difficulties which arose time after time due to apparently inconsequential details make quite clear the importance of not neglecting any of these .

The following sections summarize and discuss the results obtained and the conclusions drawn from the investigations described herein .

(i). Summary on Ultra Short Wavelength Measurements .

It was found entirely practicable to construct wavemeters using rotating plate type condensers for use in measuring wavelengths down to below 50 centimetres . Calibration can readily be done by means of Lecher wires . The main point to be observed is that the condensers must have very smoothly running bearings which do not allow any side or end play . Ordinary commercial midget variable condensers allow the plates to jump slightly without changing the dial reading, so that accurate calibration is not possible . Where extreme precision is not required they are satisfactory, however . The wavemeter inductance for the shortest wavelengths degenerates into the shortest possible connection between the condenser plates .

Lecher wires were shown to provide a satisfactory means of determining wavelengths of the order of 5 metres and less. The most convenient arrangement is to use the Lecher wires as a primary standard and the usual type of absorption wavemeter as a secondary standard from which series of measurements can be made rapidly. It is important to make the wires long enough to obtain several standing waves. This is in order to increase the accuracy by taking the average of a number of half wavelengths, and also to provide an indication of the presence of prominent harmonics.

Various methods of coupling Lecher wires to oscillators were investigated. Where the output of the oscillator is several watts or more, the best method is to couple loosely a single turn coil to the oscillator inductance and run a lead from the coil to the wires. Nodal point indications can then be obtained very conveniently by sliding a sensitive thermocouple and galvanometer along the wires and observing the deflections.

Where the energy produced by the oscillator is extremely small, as in the case of Barkhausen-Kurz oscillations, it is necessary to determine the nodal points by observing the deflection of the plate current meter as the shorting bridge is slid along the wires. In this case the coupling coil can be placed about the valve itself.

(ii). Summary on Transmission of Ultra Short Waves .

The shortest wavelength produced was 50 centimetres . It required the background of all the previous work before this wavelength was finally reached and could be relied upon to be the fundamental of the oscillator which produced it . The power available on this wavelength was but a very small fraction of a watt . The oscillator was of the Barkhausen-Kurz type .

(a). Normal Types of Oscillators .

The objective aimed at in the initial investigations (see p.8) was the development of an oscillator which could be used to transmit signals over a distance of 12 miles on a wavelength of the order of 100 cms. or less . While this specific objective was not reached, a certain amount of success was nevertheless attained . It was succeeded in receiving signals on a wavelength of 1.9 metres up to a distance of 2 miles . If further tests had been carried out with the larger transmitting valves on wavelengths of 3 or 4 metres, reception would doubtless have been obtained at the desired distance, since other investigators have since successfully communicated over much greater distances using wavelengths of this order . It was desired in these investigations to obtain as short a wavelength as possible, however, and so no further work was done on the longer waves other than to produce and measure them .

Results obtained with reflectors were inconclusive, due to the fact that they were used with oscillators operating at a multiple of their resonant wavelength . The energy produced by the oscillator on the required harmonic was insufficient to give a noticeable directional effect from the reflector .

It was found that oscillators of the usual types may readily be modified to produce ultra short waves down to about 4 metres in length without radical changes other than reducing the inductance and capacity to small values . By exercising especial care in keeping all leads as short as possible and using a circuit, such as the ultraudion or Mesny, which is particularly well adapted to the production of very high frequencies, small American valves may be made to oscillate down to about 2 metres in wavelength . European valves, due to their lower interelectrode capacity, will go somewhat lower then this . The shorter wavelength limit of these circuits with standard commercial valves is a little under one metre . However, this is possible only with small valves, and then only by removing the valve bases and using condensers of very small mechanical dimensions . No wavelength control remains, due to the necessity of reducing everything to the smallest possible dimensions .

(b). Barkhausen-Kurz Oscillators .

The production of short wavelengths by the method of Barkhausen and Kurz was investigated . It was found that this method enabled much shorter wavelengths to be obtained than could be produced by the usual type of oscillator having high positive plate potentials . Only certain types of valve will produce oscillations by this method, i.e., those having straight or nearly straight cylindrical or spiral cathodes at or near the centre of cylindrical grids and anodes, although not all symmetrical structure valves of this type will produce Barkhausen oscillations . No large valves of this kind were available to carry out high power tests with this type of circuit .

The filament of the valve is not necessarily of tungsten as some writers have stated, since B-K oscillations were obtained with a UY-227, which has an indirectly heated oxide coated cathode, but tungsten is greatly to be preferred due to its more uniform emission . Small amounts of gas in the tube will not prevent oscillations, but tend to make them erratic .

Existing theories of the mechanism of Barkhausen-Kurz oscillations were investigated and the various wavelength formulae checked against the experimental results obtained . It was shown that the several wavelength formulae could be reduced to the same form as the original Barkhausen-Kurz formula . This original relationship was found to hold approximately for true electron oscillations, but it was found that Gill-Morrell oscillations also appeared even when no grid to plate Lecher wire system was connected to the valve . The production of G-M oscillations under these circumstances is explained .

(iii). Summary on Reception of Ultra Short Waves .

It was found advisable for reception purposes on less than 100 centimetres wavelength to use a receiver operating on a fundamental of 4 metres or more rather than to attempt to obtain one operating on a fundamental of one metre or less . Harmonics of the receiver fundamental produce a beat note with the received signal, giving satisfactory reception and at the same time allowing the receiver to be tuned over a wide range . Some form of modulation should be used in the transmitter to permit satisfactory reception, as it is difficult to obtain a high degree of stability of frequency on wavelengths of the order of one metre or less . All apparatus should be mounted absolutely rigid and no vibration of valves or oscillatory circuits should be possible .

The field of Barkhausen-Kurz type receivers was not investigated very completely, and it is possible that receivers of this variety may be much more satisfactory than the usual type for reception below one metre . Later investigations by Okabe[52] indicate that this is so .

VII. FUTURE WORK AND POSSIBILITIES .

It is suggested that in future work on ultra short waves, it may be profitable to investigate the action of high power vacuum tubes in Barkhausen-Kurz circuits . Valves of one to five or ten kilowatt rating should give considerable power if they can be made to oscillate in a circuit of this nature, and would greatly facilitate reception and distance tests .

The use of directive radiating systems has been investigated to some extent elsewhere with very promising results, and would undoubtedly provide a profitable field for further investigations . The same is also true of directive receiving systems .

Investigations are being carried out by the General Electtic Company and others on the magnetron oscillator, but in this, as in every other type of oscillator so far investigated, it is found that by the time a wavelength as low as fifty centimetres is produced, the power available has been reduced to but a fraction of a watt, or at most to a very few watts .

It would seem advisable, therefore, to give more attention to the production of wavelengths of this order by means of high power oscillators operating at a multiple of this wavelength, and then emphasizing the desired harmonic and suppressing the others . Whether any work has been done or not in this direction is not known, but it seems that it might prove a field worth investigating .

As regards the present applications and future possibilities of these high frequencies of the order of 500 megacycles, there is at present no practical use being made of them . One possibility is their use as a direction finding aid to navigation, either water or air, this being suggested by the fact that the size of a complete directive transmitter and reflecting antenna system is comparable with the dimensions of a large size searchlight .

Considerable interest has been aroused in medical circles lately as to the possibilities of using intense fields of frequencies of this order for the treatment of certain maladies, usually by the production of artificial fevers . Some work in this direction is now in progress in a number of laboratories, and investigations are being carried out on the effect of these frequencies on various solutions, such as blood solutions . Investigations are also being made[59] on the selective heating effect of various frequencies,with a view to the production of localized temperature rises in particular parts without affecting surrounding parts .

A few years ago the General Electric Company built a five metre oscillator using about ten kilowatts, which produced some remarkable effects . Meters in the neighbouring rooms were burnt out; a standing arc was produced at the end of a single rod in resonance with the transmitter; sausages could be cooked by simply hanging them over this rod; observers noted that their body temperature rose and found that the temperature of the blood had actually been made to rise slightly .

A report was recently published [51] of tests made by the International Telephone and Telegraph Company in which high quality two-way telephony was carried out across the English Channel on a wavelength of 18 centimetres . Three dimensional parabolic reflèctors were used for sending and receiving at both ends, and the power radiated was about half a watt . Freedom from static and fading is claimed . Similar results have also been achieved by Marconi in Italy, where duplex telephony was carried out over twenty five miles of open water on a wavelength of 50 centimetres .

Bearing these facts in mind, it will be of interest to observe what phenomena are produced when we obtain a few kilowatts of high frequency energy oscillating on a fifty centimetre wavelength .

VIII. BIBLIOGRAPHY.

1. QST. a. Oct.1924.
   b. Jan. 1925.
   c. Mar. 1925.
   d. Apr. 1925.
   e. Sept.1925.

2. Popular Radio. Aug. 1926.

3. Radio Review. Sept. 1920.

4. Arthur Bramley. Jour.Frank.Inst., pp.151-158. Aug. 1928.

5. O.Pfetscher. Phys.Zeits., pp.449-478. July 15,1928.

6. H.Wechsung. Zeits.f.Hochfreq., pp.176-83. June,1928.

7. H.E.Hollmann. Elekt.Nach.Tech., pp.268-75. July,1928.

8. W.Wechsung. Zeits.f.Hochfreq., 32, 58-65. Aug.1928.

9. H.E.Hollmann. Proc.I.R.E., p.229. Feb.1929.

10. M.Ritz. L'Onde Elect., 7, 488-99. Nov.1928.

11. Zeits.f.Hochfreq., 32, 172. Nov. 1928.

12. Kinjiro Okabe. Proc.I.R.E., April 1929.

13. K.Kohl. Zeits.f.Tech.Phys., 9, pp.472-473, 12. 1928.

14. B. van der Pol. E.W.&W.E., pp.9-12. Jan.1929.

15. G.A.Beauvais. Bull. de la Soc.Franc. des Elec., May,1929.

16. W.Ludenia. Elekt.Nach.Technik, 6, pp.248-249. June,1929.

17. Nichols and Tear. Phys.Rev., June,1923 .

18. E.Lecher. Wied.Ann., 41, p.850. 1890.

19. S.G.Starling. Elec. and Mag., Ch.XIV.

20. Brooks and Poyser. Mag. and Elec., 1912. p.607.

21. C.R.Englund. Bell.Sys.Tech.Jour., July,1928.

22. E.Busse. Zeits.f.Hochfreq., 31, pp.97-105. April,1928.

23. M.A.Lewitsky. Phys.Zeits., 28, pp.821-825. Dec.1,1927.

24. Rubens and Hollnagel. Phil.Mag., 19, 761. 1910.

25. Wood. Berl.Ber., 52, 1122, 1910.

26. Glagolewa-Arkadiewa. Nature, 113, 640. 1924.

27. W.C.White. G.E.Review. Vol.19, 771, 1916.

28. H.Hertz. a. Nature, 39; pp.402,450,547. 1889.
b. Wied. Ann., 1. 1889.

29. O.J.Lodge. Nature,41, pp.368,462. 1890.

30. Von G.Potapenko. Zeits.f.Tech.Phys., p.542. Nov.1929.

31. W.Hahnemann. Elekt.Nach. Tech., 6, pp.365-374. Sept.1929.

32. Smith-Rose and McPetrie. Exptl. Wireless and W. Eng.,
a. pp.532-542. Oct.1929.
b. pp.605-619. Nov.1929.

33. E.D.McArthur. Elec.Rev., pp.303-306. Aug.24,1928 .

34. P.Knipping. Zeits.f.Hochfreq.Tech., pp.1-12. July,1929.

35. A.Hund. U.S.Bur.Stds., Sci.Paper #491. 1924. pp.487-540.

36. G.Breit. Jour.Frank.Inst., p355. Mar.1924.

37. Ronold King. Rev.Sci.Inst., pp.164-180. Mar.1930.

38. B.Majumdar. Ind.Jour.Phys. pp.77-94. Vol.III,Pt.I, 1928.

39. Gogate and Kothari. Ind.Jour.Phys., pp.349-58. Jan.31,1930.

40. A.Esau and W.M.Hahnemann. Proc.I.R.E., p.471. Mar.1930.

41. Francis W.Sears. Jour.Frank.Inst., pp.459-472. Apr.1930.

42. W.C.White. Electronics. pp.34-36. April,1930.

43. C.R.Englund. Proc.I.R.E., Nov.1927.

44. H.Barkhausen and K.Kurz. Zeits.f.Phys. 21, 1. 1920.

45. Gill and Morrell. Phil.Mag. 44, 161. 1922;49,369,1925.

46. Yagi. Proc.I.R.E. June,1928.

47. S.Uda. Proc.I.R.E. May,1927.

48. A.Scheibe. Ann.d.Phys., 73, 4. 1924. p.54.

49. Kapzov and Gwosdower. Zeits.f.Phys., 45, 1927. p.114.

50. Nichols and Tear. Astrophys.Jour., pp.17-37. Jan.1925.

51. "Telephony on 18 Cms." Wireless World. pp.392-394. April 15, 1931.

52. K.Okabe. Proc.I.R.E., June, 1930.

53. Th.V.Jonescu. Comptes Rendus, p.575. Vol.193. Oct.12,1931.

54. Ant.Rostagni. Comptes Rendus, p.1073. 193,22. Nov.30,1931.

55. Gutton,C. and Beauvais,G. Comptes Rendus, Nov. 3,1931.

56. W.H.Moore. Jour.Frank.Inst., 209. pp.473-484. April,1930.

57. W.H.Moore. Can.Jour.of Res., Vol.4, No.5. May,1931.

58. G.Potapenko. Phys.Rev., Vol.39, No.4. Feb.15,1932.

59. J.C.McLennan and A.C.Burton . Can.Jour.of Res., Nov.1931.

VIII. APPENDIX .

1 . Calibration of Wavemeter " A " , consisting of condenser of General Radio Co. Type 358 wavemeter and rectangular coil inductance, 2½" x 3/4" .

Scale Reading.	Wavelength.
5.0°	1.955 metres.
7.5	1.991
11.0	2.07
20.0	2.255
28.5	2.489
39.0	2.768
53.5	3.140
65.5	3.368
75.0	3.591
86.0	3.774
93.1	3.937

2 . Calibration of Wavemeter " B " .

consisting of General Radio Co. Type 358 wavemeter condenser and straight wire plug-in inductance .

Scale Reading .	Wavelength .
7.8°	121.9 cms.
15.5	135.9
25.	151.2
33.	164.0
38.	172.0
52.	195.5
58.5	207.0
71.5	224.5
80.5	238.0
93.	255.5
95.5	258.0

3 . Calibration of Wavemeter " C " .

consisting of General Radio Co. Type 368a, 0-15 mmfd. variable condenser and 1½"long straight wire inductance .

Scale Reading .	Wavelength .
90.°	151. cms.
87.5	149.
77.	138.
68.	125.5
57.	115.6
45.	102.9
38.5	95.3
28.5	83.8
25.	81.3
19.	72.4
15.	66.1
13.5	64.7
12.5	62.9
8.	55.9

4. Calibration of Wavemeter " D " .

consisting of General Radio Co. Type 368a , 0-15 mmfd. variable micro-condenser with two outer rotor plates removed, and blob of solder between rotor and stator as inductance .

Scale Reading .	Wavelength .
97.°	69. cms.
84.	66.1
72.	62.9
48.	55.9
36.	50.8

5. Fotos R valve . E_g = $22\frac{1}{2}$ volts.

E_p = 0 volts. R_g = 6000 ohms in series with grid battery .

G - P bridge 76 cms. from socket . No oscillations .

I_f	I_p	I_g
0.5 amp.	0.0 microamp.	0.0 m.a.
.55	2.	1.
.6	6.	2.
.65	14.	2.
.7	28.	2.
.73	40.	2.

6. Fotos R valve . E_g = 45 volts .
E_p = 0 volts . R_g = 6000 ohms in series with grid battery .
Wavelength = 140 centimetres .

I_f	I_p	I_g
0.5 amp.	0. microamp.	0.5 m.a.
.55	2.	1.
.58	3.	2.
.59	4.	3.
.6	20.	3.
.602	10.	3.
.61	8.	4.
.62	8.	4.
.64	10.	4.5
.66	13.	4.5
.68	17.	5.
.7	22.	5.
.72	28.	5.

7. E_g = 67.5 volts . Wavelength = 130. cms.

I_f	I_p	I_g
.5 amp.	0. microamp.	.5 m.a.
.55	1.	1.
.6	3.5	3.5
.62	7.	6.
.625	50.	6.5
.63	100.	7.
.632	110.	7.
.64	50.	8.
.65	10.	8.
.66	11.	8.
.67	13.	8.
.68	15.	8.
.7	20.	8.
.72	25.	8.

8. E_g = 90 volts. Wavelength = 115.6 cms.

This curve was taken several days later than 9 .

I_f	I_p	I_g
.5 amp.	0. microamp.	1. m.a.
.55	1.	1.5
.6	4.	4.
.62	6.	6.
.63	7.	8.
.635	8.	9.
.64	90.	9.
.645	200.	10.
.647	250.	10.5
.65	200.	11.
.655	150.	11.5
.66	90.	11.5
.67	11.	12.
.68	12.	12.
.69	15.	12.5
.70	17.	12.5
.71	20.	12.5
.72	22.	12.5
.74	30.	13.

9. E_g = 90 volts. Wavelength = 146 cms.

I_f	I_p	I_g
.58 amp.	0. microamps.	6. m.a.
.59	0.	7.5
.598	50.	9.
.6	100.	9.9
.607	140.	10.
.608	100.	10.2
.61	50.	10.5
.621	5.	11.
.64	5.	11.5
.66	6.	11.5
.68	10.	11.5
.7	12.	11.5
.72	18.	12.
.74	24.	12.

10. E_g = $112\frac{1}{2}$ volts. Wavelength = 107. cms.

I_f	I_p	I_g
.5 amp.	0. microamp.	0. m.a.
.55	1.	1.
.6	2.	3.
.65	8.	11.
.659	9.	14.
.66	190.	14.
.666	210.	15.
.67	180.	16.
.68	100.	16.5
.69	11.	17.
.7	13.	17.
.72	17.	17.5
.74	22.	17.5

11. E_g = 135. volts. Wavelength = 100. cms. at higher peak, and = 85. cms. at lower peak .

I_f	I_p	I_g
.5 amp.	0. microamp.	0.5 m.a.
.55	0.	1.
.6	2.	4.
.65	6.	12.
.66	30.	15.
.661	50.	15.5
.665	7.	17.
.67	8.	18.
.672	100.	18.5
.675	200.	19.5
.68	240.	20.
.69	150.	21.
.7	20.	22.
.71	13.	22.5
.72	15.	22.5
.73	18.	23.

12. E_g = $157\frac{1}{2}$ volts .

Wavelengths = 97, 82, and 69 cms., at highest, middle, and lowest filament currents, respectively.

I_f	I_p	I_g
.5 amp.	0. microamp.	0. m.a.
.55	0.	1.
.6	2.	4.
.64	3.	10.
.645	5.	11.
.651	20.	12.
.655	10.	13.
.656	5.	13.
.66	6.	16.
.665	7.	17.
.667	7.	18.
.669	20.	18.5
.67	60.	20.
.677	190.	20.5
.68	20.	22.
.683	9.	24.
.69	190.	26.
.696	220.	27.
.7	170.	27.5
.706	100.	27.6
.714	13.	28.
.72	13.	28.5
.73	17.	29.
.74	18.	29.

13. E_g = 180. volts .

Wavelengths = 89 and 80 cms. at higher and lower I_f resonance points .

I_f	I_p	I_g
.5 amp.	0. microamp.	0. m.a.
.55	0.	1.
.6	1.	4.
.65	4.	13.
.68	8.	23.
.681	9.	24.
.683	50.	25.
.684	100.	25.5
.688	280.	27.
.69	140.	28.
.692	10.	29.
.695	10.	30.
.7	150.	32.
.707	190.	33.
.71	170.	33.5
.72	50.	35.
.725	15.	35.5
.74	18.	36.

14 . E_g = $202\frac{1}{2}$ volts.

Wavelength = 67 cms. at lowest filament current peak .

I_f	I_p	I_g
.5 amp.	0. microamp.	0.5 m.a.
.55	1.	1.
.6	2.	4.
.65	4.	14.
.665	10.	20.
.67	200.	20.5
.68	750.	24.
.685	450.	27.5
.69	200.	29.5
.692	10.	30.5
.7	250.	35.
.702	180.	36.
.708	580.	39.
.72	280.	40.5
.747	20.	44.

15. E_g = 225. volts .

Wavelength = 63. centimetres .

I_f	I_p	I_g
.5 amp.	0. microamp.	0. m.a.
.55	0.	1.
.6	1.	4.
.65	2.	14.
.67	6.	20.
.673	7.	21.
.68	350.	24.
.695	1000.	31.
.7	700.	35.
.705	10.	40.
.71	800.	44.

16. E_g = 225 volts.

Wavelength = 67 cms. at both points of oscillation .

I_f	I_p	I_g
.5 amp.	0. microamp.	0. m.a.
.55	0.	1.
.6	1.	4.
.65	4.	15.
.68	10.	27.
.687	11.	31.
.69	120.	32.
.698	400.	36.
.7	180.	39.
.704	15.	42.
.71	450.	44.
.72	630.	47.
.73	580.	49.
.74	1200.	52.

Table of Values of f(x) and g(x) in Adolf Scheibe's wavelength formula (p.39a) .

x	f(x)	g(x)
0.	0.	0.
0.1	0.00993	0.010
0.5	.21228	.289
0.8	.42568	.998
1.0	.53808	2.03
1.2	.60872	4.088
1.5	.64237	12.190
1.8	.62419	40.36
2.0	.60268	98.01
3.0	.534	- -
4.0	.516	- -
5.0	.510	- -
7.0	.504	- -
∞	.500	- -

ULTRA SHORT RADIO WAVES

by

W. H. MOORE, B.Sc.

Reprinted from the Journal of the Franklin Institute,
Vol. 209, No. 4, April, 1930.

ULTRA SHORT RADIO WAVES.

BY

W. H. MOORE, B.Sc.,

Physics Department, McGill University, Montreal, Canada.

INTRODUCTORY.

The term short waves is a rather indefinite one, and has generally been considered to mean wave-lengths of less than one hundred meters. It is a purely relative term, of course, and when we say ultra short waves, we use an even less definite term, of the second order of relativity, so to speak.

At the Hague Conference held in September, 1929, it was decided by international agreement to adopt officially the following nomenclature for the classification of wave-lengths.

Long.	3000 meters up
Medium.	200–3000 meters
Intermediate.	50– 200 meters
Short.	10– 50 meters
Ultra short	less than 10 meters.

The scope of this paper is confined to the ultra short wave band, and deals mainly with wave-lengths of the order of one meter or less.

EARLY EXPERIMENTS.

The production of very short electromagnetic waves is not at all a recent development. In Hertz's original experiments in 1888 he employed one oscillator which operated on a wave-length of 60 centimeters.[1] This particular oscillator consisted of two copper sheets each 40 centimeters square and 60 centimeters apart connected to two polished gilt balls two or three centimeters apart. Spark coil excitation was used to set the system in oscillation, and the wave-length determined by calculation from the mechanical dimensions of the circuit.

Lodge in 1890 obtained oscillations in a single metallic sphere five centimeters in diameter, but found it much easier to obtain oscillations with larger spheres.[2] Sir J. J. Thompson has shown that the oscillations from pole to pole of a charge upon a conducting sphere causes radiation of wave-length equal to 1.4 times the diameter of the sphere. Thus in the case of Lodge's five centimeter sphere the wave-length was seven centimeters.

Nichols and Tear[3] in 1923 published the results of some work in which a method of obtaining electrical oscillations was developed by which wave-lengths down to 1.8 millimeters were produced. In this system the oscillator consisted of two tiny tungsten cylinders which formed the electrodes of an oil-immersed spark gap. In the particular oscillator with which the 1.8 millimeter waves were obtained, these cylinders were 0.2 millimeter long and 0.2 millimeter in diameter, separated by a gap of 0.01 millimeter. The system was excited by applying a potential of 30,000 volts at frequencies of 500 to 1000 cycles to the oscillator, a water resistance, and a condenser, all in series. A radiometer type of receiver was used.

The longest heat waves so far measured have a wave-length of about 0.3 millimeter. Thus there remained to be explored a gap extending from 0.3 to 1.8 millimeters, to complete the spectrum between heat and electromagnetic waves.

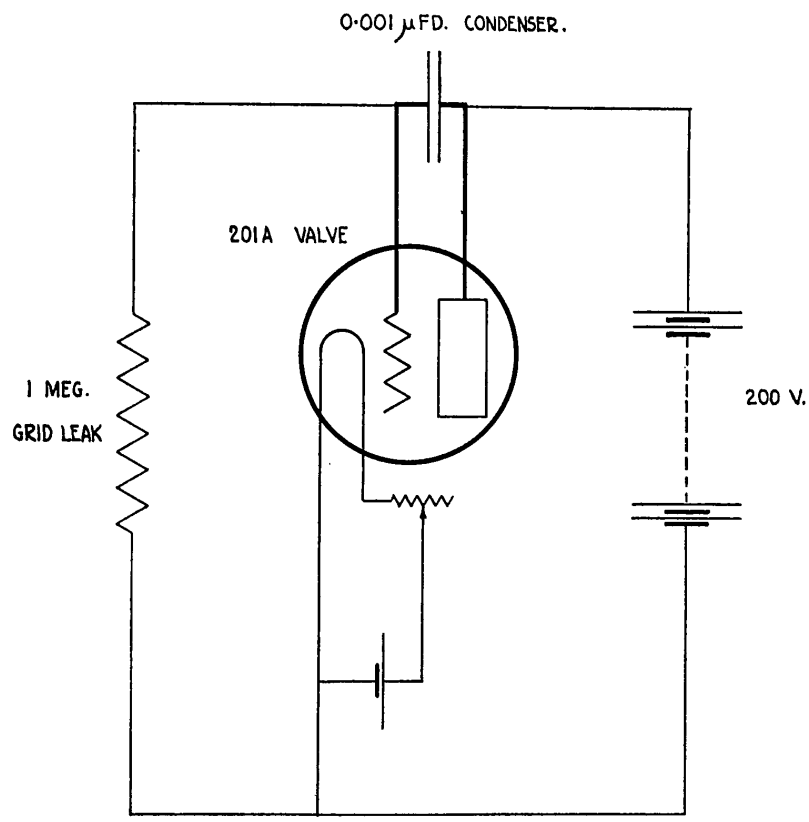
Within the last few years experiments carried out by a number of investigators have resulted in the closing of this gap, and over a narrow overlapping band of wave-lengths it is now possible to produce oscillations by either heat or electrical methods. This work has been mainly done by extending the lower limit of electric waves, as it is found that above about 0.3 millimeter in wave-length oscillations are more easily produced by electrical than by thermal methods.[4] Glagolewa-Arkadiewa has obtained waves down to 0.082 millimeter in length by electrical means.[5] She used as oscillators finely divided metallic particles suspended in a viscous oil. A coating of the resulting gummy mixture was applied to the surface of a wheel rotating between the sparking electrodes.

TYPES OF VALVE OSCILLATORS.

Turning now to electron tube oscillators we find that investigations have been carried out along a number of lines with a view to producing electrical oscillations of shortest possible wave-length.

It has been found by a number of experimenters that stable oscillations may be obtained down to about two meters in wave-length using standard types of vacuum tubes and simply reducing the constants in conventional types of oscillating circuits. Below about two meters major difficulties begin to appear. High power tubes can no longer be used because the dimensions of the valve elements themselves are

FIG. 1.

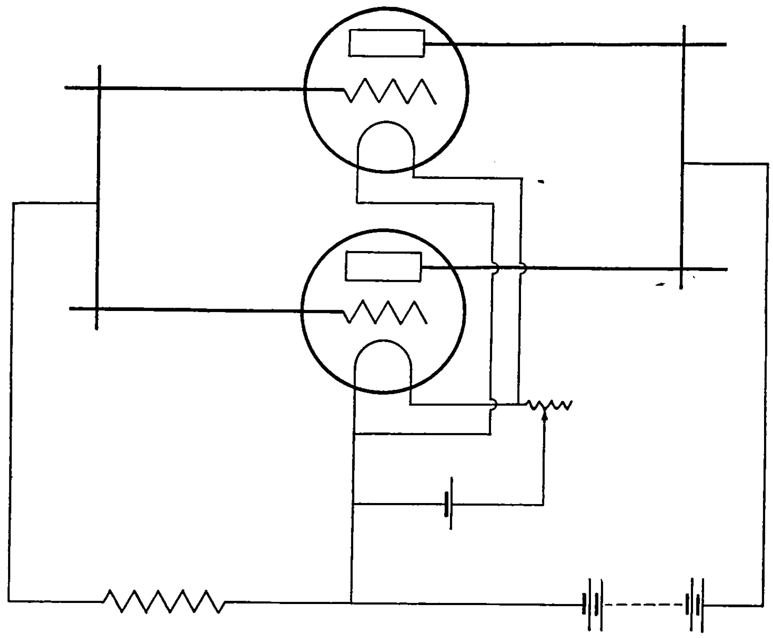


ULTRAUDION OSCILLATOR.

sufficiently great, even though the external oscillating circuit be reduced to the smallest possible mechanical dimensions, to maintain the natural wave-length of the circuit at some value possibly in the neighborhood of three or four meters. One is thus compelled to use low power valves, usually either five or seven and a half watt transmitting valves, or else receiving tubes.

By removing the four prong base of a standard 201a type vacuum tube and connecting a mall 0.001 microfarad fixed condenser between the grid and plate leads as close as possible to the glass envelope, a short wave oscillator is obtained which will give wave-lengths down to below one and one-half meters (Fig. 1). This circuit is really the familiar ultraudion circuit,

Fig. 2.



MESNY ULTRA SHORT WAVE CIRCUIT.

the oscillating circuit being reduced to the capacity of the fixed condenser in series with the internal grid-plate capacity of the valve and the inductance of the two short straight wires, each possibly an inch long, making connections with the grid and plate.

In an oscillator of this type the oscillations are not very stable, and the wave-length is not variable since the tuning of the circuit is fixed at a value determined largely by the internal interelectrode capacity of the valve. By extending the length of the grid and plate wires and moving the fixed condenser up and down these wires the wave-length may be varied and adjusted, but this immediately increases its length to two meters or more.

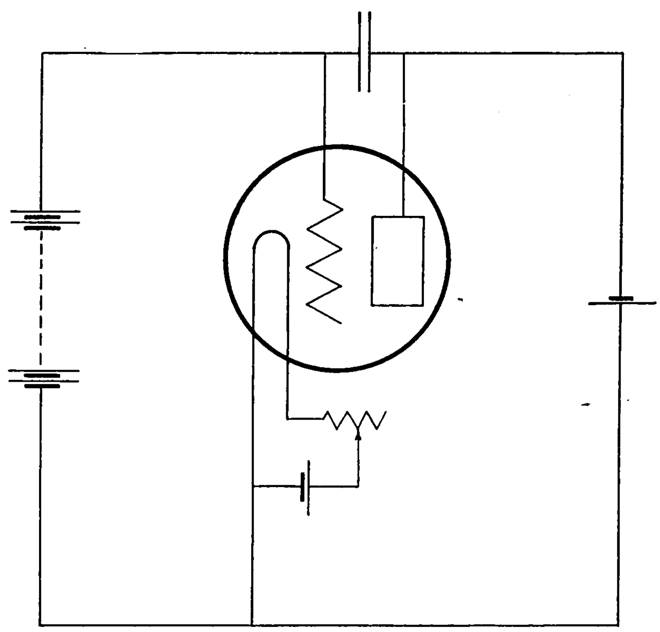
The push-pull circuit developed by Mesny has been widely used in experimental work, and produces somewhat more stable oscillations than the above circuit as well as allowing greater control at shorter wave-lengths Fig. 2). This circuit uses two vacuum tubes whose grids and plates are paralleled through inductances, the center tap of each of which is connected to the filament. The grid and plate inductances usually take the form of parallel straight wires joined by a shorting bridge. With this circuit stable oscillations may be obtained down to below one meter, and the wave-length can be varied by sliding the bridges along the grid and plate wires.

Positive potentials are applied to the plates in these oscillators, and either grid biassing batteries, grid leaks, or simply a straight wire connection to the filament is used. Oscillation takes place and is produced in the usual way as in circuits operating on the longer wave-lengths, the wave-length being determined by the values of inductance and capacity in the external circuit, and also by the fixed grid-plate capacity of the particular tube in use.

In an article written by C. R. Englund[6] a considerable amount of experimental work is described from which the conclusion is reached that with ordinary commercial vacuum tubes now on the market the lower limit attainable is a wave-length of about one and a half meters. This agrees with the investigations carried out by the author for the Research Council of Canada during the summers of 1926 and 1927. In these experiments an oscillator was obtained working on a wave-length of less than one hundred centimeters, but by the time the wave-length is reduced to a value as short as this, the oscillating circuit has been reduced to the smallest possible mechanical dimensions, almost no variation or control of frequency is possible, and the oscillations are sometimes none too stable. The types of circuits used were mostly more or less conventional circuits with the inductances and capacities reduced to very small values. The oscillating circuit inductance usually degenerated into straight wire leads joining a small capacity to the grids and plates by the shortest possible route.

A distinctly different type of high frequency oscillator was developed by Barkhausen and Kurz about 1920.[7] The usual plate and grid potentials were reversed in polarity, a high positive voltage being applied to the grid and a small negative or zero voltage being applied to the plate (Fig. 3). It

FIG. 3.



CIRCUIT FOR THE PRODUCTION OF BARKHAUSEN-KURZ AND GILL-MORRELL OSCILLATIONS

was found that this connection could be used to produce extremely high frequencies, wave-lengths of the order of one-half meter and less being obtained. The explanation was that the oscillations took place entirely within the tube, and consisted of pure electron field vibrations about the grid. The hot filament emitted clouds of electrons in the usual way, and these electrons were drawn at a high velocity towards the positively charged grid. A large proportion pass through the grid spaces, are repelled by the negative anode, again attracted through the grid, and repeat the process. Thus the frequency of oscillation is largely determined by the time required for the individual electrons to traverse the interelectrode spaces. This in turn depends on the applied field, so that the frequency is considerably affected by the potentials used. No external oscillating circuit is used and the constants of the external circuit do not affect the wave-length generated. The amount of energy radiated by an oscillator of this type is, as might be expected, a very small quantity and can scarcely be considered to be of value except for measuring purposes.

In experimenting with the Barkhausen-Kurz type of oscillations two other investigators, Gill and Morrell, found a third type of oscillation produced.[8] Using a circuit of the Barkhausen variety (Fig. 3), having positive grid potentials and negative plate potentials, oscillations were obtained having the properties of the usual type of circuit in which regeneration builds up oscillations in a resonant circuit. In the Gill-Morrell experiments the values of inductance and capacity in the external circuit control the frequency. Wave-lengths obtained are considerably lower than those obtained with the first type of circuit in which positive plate potentials are used.

Another system which has been investigated for the production of very high frequency oscillations uses the magnetron vacuum tube. It is found that a two element vacuum tube may be made to generate oscillations under certain circumstances. If the anode consists of a circular cylinder with the cathode a long straight wire filament at its center, the superimposition of an electromagnetic field of uniform strength with its direction parallel to that of the filament, will, if the field is strong enough, prevent electrons from the filament from reaching the plate, and they will move in circular orbits whose diameter is less than that of the plate. It is found, however, that there is sometimes a small radio frequency current flowing to the plate which may be detected on hot wire meters. Japanese investigators have used this fact to obtain some promising developments in the production of very short wave-lengths.[9] A minimum wave-length of 5.6 centimeters was obtained. To get the shortest possible waves the anode diameter had to be reduced and this decreased the intensity of the oscillations. It was found that the wave-length could be calculated approximately from the semi-theoretical formula $\lambda = 2ct$, where c is the velocity of light and t is the time taken for an electron to travel across the anode-cathode space. A receiver of the Barkhausen type was employed.

FREQUENCY DETERMINATION.

When a circuit has been obtained which gives stable oscillations at high frequency, the problem still remains to find out exactly what this frequency is. In the case of the oscillators of Hertz, Lodge, Nichols and Tear, and other extremely high frequency oscillators of that type, the frequency was determined by calculation from the measured constants of the circuit. This can be done with whatever type of oscillator is used, but it is usually desirable to have some convenient method of accurately determining wave-lengths by comparison with some calibrated variable standard. The usual method of loosely coupling a calibrated circuit, consisting of a known value of inductance and capacity to the oscillating circuit, can be more or less satisfactorily used down to about two meters. The indication of resonance is obtained either from a thermocouple or hot wire instrument in the wavemeter circuit, or from the deflection of the plate current meter in the oscillator circuit as the two circuits come into resonance. However, the mechanical dimensions of the capacity and inductance of this type of wavemeter become very small when one gets down to about two meters. Using a General Radio Company vernier condenser having five semi-circular plates about one and a half inches in diameter, maximum capacity 15 micromicrofarads, to obtain a wave-length of two meters would require an inductance of a single turn coil approximately one inch in diameter. It is obvious that to produce any measurable indication of resonance with an oscillatory circuit of similar dimensions, quite tight coupling must be employed between wavemeter and oscillator. This, of course, introduces errors into the readings, and it can readily be seen that the constants necessary to obtain a wavemeter of this type to measure waves 100 centimeters or less in length, would require impracticably small values of inductance and capacity. By far the most satisfactory method of measuring these short waves is to use the arrangement devised by Lecher. A pair of parallel wires is coupled to the oscillator and standing waves produced. A shorting bridge on these Lecher wires is slid backwards and forwards and indicates the position of the nodes and antinodes of the standing waves. The wave-length is thus determined by direct measurement of the distances between these points. This type of wavemeter is not as simple as it may sound, if very accurate results are desired, but a number of refinements can be introduced. The indications of nodal points may be obtained either by observing the deflection of the plate current meter in the oscillator, or by using an indicating device directly in the shorting bridge on the Lecher wires. If the latter method is used, a small correction must be introduced due to the effect of the thermocouple, neon tube, or other indicating device used in the bridge. Wave-lengths down to a few centimeters in length may be readily measured with the Lecher wires type of wavemeter.

POWER OBTAINABLE.

In the oscillators of Hertz, Lodge, and Nichols and Tear, the amount of power radiated is extremely small. Very delicate receivers can give measurable indications of reception up to distances of only a few meters. With what we shall call the normal type of valve oscillating circuits, that is, those in which oscillations are built up at the natural period of the circuit by regenerative action, the maximum power available is of the order of a fraction of a watt, since to produce waves as low as 100 centimeters, the smallest type of receiving tubes must be used.

With Barkhausen-Kurz types of oscillators the amount of power obtained has, so far, been very small, since low power valves have been used in the experiments. It would seem that greater power might be obtained by the use of high power valves in a circuit of this nature. The Gill-Morrell type of oscillations have been obtained with considerable intensity, as compared with Barkhausen-Kurz oscillations, but the maximum amount of power involved is still a matter of but a few watts. Here again there appears to be room for investigation with high power vacuum tubes.

The magnetron oscillator was originally developed on a high power scale, tubes having been designed to operate at power frequencies with an output of many kilowatts. As the frequency is increased, the dimensions of the tube must be decreased, so that less power can be used. However, at a wave-length of 40 centimeters, sufficient oscillating energy can still be produced (probably a few watts) to enable readable signals to be heard at a maximum distance of one kilometer.[10] In this particular experiment the actual wave-length employed was 41 centimeters and the anode voltage 1,000, with 900 cycle modulation. Single Hertzian resonators were employed at both transmitter and receiver, with the addition of a parabolic reflector and collector at the transmitter and receiver respectively. A system of director chains and wave canals was also employed with a very marked improvement in results. These consist of a series of Hertzian resonators, that is, simply full or half wave vertical antennæ, mounted along the axis of the parabola of the reflector. The receiver consisted of a crystal detector at the center of the Hertzian resonator, with a three-stage amplifier for the modulation frequency. A Barkhausen type of receiver has also been employed with somewhat better results in detecting modulated waves in the neighborhood of 1.5 meters.

Modern investigators have been able to obtain a considerable amount of power on centimeter waves by the use of high frequency sparks, and in one case a radiation of fifty watts on a wave-length of 28.6 centimeters has been obtained,[11] using shock excitation from high frequency sparks.

REFLECTORS AND BEAM SYSTEMS.

An extensive series of investigations carried out at Tohoku Imperial University, Sendai, Japan, have demonstrated the practicability of using parabolic reflectors and wave directors on wave-lengths below five meters.[10, 12] The above experiment on 41 centimeters by the same investigators shows that the types of reflectors and directors already developed can be very readily employed, and with great advantage, in conjunction with oscillators producing waves less than 100 centimeters in length.

POSSIBILITIES.

As regards the present applications and future possibilities of these high frequencies of the order of 500 megacycles, there is at present no practical use being made of them. One possibility is their use as a direction finding aid to navigation, either water or air, this being suggested by the fact that the size of a complete directive transmitter and reflecting antenna system is comparable with the dimensions of a large size searchlight.

Considerable interest has been aroused in medical circles lately as to the possibilities of using intense fields of frequencies of this order, for the treatment of certain maladies. Some work in this direction is now in progress, and investigations are being carried out on the effect of these frequencies on various solutions, such as blood solutions.

A couple of years ago the General Electric Company built a 5 meter oscillator using about ten kilowatts, which produced some remarkable effects. Meters in the neighboring rooms were burnt out; a standing arc was produced at the end of a single rod in resonance with the transmitter; sausages could be cooked by simply hanging them over this rod; observers noted that their body temperature rose and found that the temperature of the blood had actually been made to rise slightly.

Bearing these facts in mind it will be of interest to observe what phenomena are produced when we obtain a few kilowatts of high frequency energy oscillating on a fifty centimeter wave-length.

REFERENCES.

1. H. HERTZ. Nature, **39**, pp. 402, 450, 547 (1889), and Wied. Ann., **1**, 1889.
2. O. J. LODGE. Nature, **41**, pp. 368, 462. 1890.
3. E. F. NICHOLS AND J. D. TEAR. The Physical Review, p. 587, June, 1923. Vol. **21**, No. 6.
4. RAWLINS AND TAYLOR. Infra-Red Analysis of Molecular Structure. C.U.P., 1929.
5. GLAGOLEWA-ARKADIEWA. Nature, **113**, 640. 1924.
6. C. R. ENGLUND. The Short Wave Limit of Vacuum Tube Oscillators. Proc. I. R. E., Nov. 1927.
7. H. BARKHAUSEN AND K. KURZ. Zeits. f. Phys., **21**, 1. 1920.
8. GILL AND MORRELL. Phil. Mag. **44**, 161, 1922; **49**, 369, 1925.
9. K. OKABE. Proc. I. R. E., April, 1929. On the Short Wave Limit of Magnetron Oscillators.
10. H. YAGI. Proc. I. R. E., June, 1928. Beam Transmission of Ultra Short Waves.
11. E. BUSSE. Zeits. f. Hochfrequenztechnik. **31**, pp. 97–105. April, 1928. Method of producing very short electric waves by means of high frequency sparks.
12. S. UDA. Proc. I. R. E., May, 1927. High Angle Radiation of Short Electric Waves.

The Effect of Drawing on the Temperature Coefficient of the Electrical Resistivity of Constantan. R. S. J. SPILSBURY. (*Jour. Sci. Instr.*, Nov., 1929.) The author has found the temperature coefficient of electrical resistance of commercial constantan (copper-nickel) wire to vary from a positive value of 60 millionths per degree Centigrade to a negative value of 80 millionths. To get wire with a coefficient not greater than 10^{-6} a search had to be made for a sample meeting this requirement. Composition and heat treatment together do not fix the coefficient. A wire having a negative coefficient of 4^{-6} was drawn down from .03 in. to .004 in. and then annealed at 800° C. Its coefficient, measured at intermediate diameters gradually sunk to -26^{-6} per degree. Another sample having a positive coefficient of 58^{-6} when its diameter was .036 in., upon being drawn to .004 in. and annealed at 600° C., suffered a reduction of its coefficient to 31^{-6} per degree. In both cases the effect of drawing was to reduce the value of the coefficient. Whatever the cause may be it is not due to the production of a surface layer during annealing because cleaning the surface with emery paper causes only a slight change in the coefficient. "The principal practical deduction is that where fine wire is required it is necessary to start with material of positive coefficient. This is somewhat unfortunate, as the bulk of the commercial material shows a negative value." G. F. S.

The Rate of Transformation of Radium D. MRS. PIERRE CURIE AND MISS IRENE CURIE. (*J. de Phys. et le Rad.*, Nov., 1929.) The time required for radium to diminish to half of its original quantity is taken as 16.5 years. This was obtained from a study of the rate at which polonium formed in radium D initially free from it. For fifteen years from April, 1910, to January, 1926, observations have been in progress bearing on the period in question. From these results the conclusion that the previously adopted period is too small and that it is at least 19 years.

In a paper recording experiments made by herself but by a different method Miss Irene Curie obtains about 23 years as the half-period. The cause of the two different results, 19.5 years and 23 years is not known. G. F. S.

LANCASTER PRESS, INC.
LANCASTER, PA.

NATIONAL RESEARCH COUNCIL
of CANADA

A PARTICULAR CASE OF HIGH FREQUENCY ELECTRON OSCILLATIONS

By W. H. Moore

CANADA

Reprinted from the
CANADIAN JOURNAL OF RESEARCH
4: 505-516. 1931

Reprinted from Canadian Journal of Research, Volume 4, May 1931.

A PARTICULAR CASE OF HIGH FREQUENCY ELECTRON OSCILLATIONS[1]

By. W. H. Moore[2]

Abstract

In experimenting with oscillators operating at wave-lengths of 100 cm. and less, an unusual case of oscillations was observed. With high positive grid potential and zero plate potential in a three-electrode valve, oscillations were produced at certain critical values of filament current. The frequency of oscillation was highest at the lowest filament current. An explanation of the effect is suggested.

Introduction

Several distinctly different methods have been developed for the production of short radio waves of the order of 100 cm. or so in wave-length. Oscillations in resonant circuits tuned to the desired frequency can be produced by spark coil excitation. Some types of conventional triode valve oscillatory circuits may be modified to oscillate at these very high frequencies. The magnetron, a device consisting of a diode vacuum tube upon which is superimposed a magnetic field, was originally developed for use at ordinary power frequencies, but has proved very successful in producing high frequencies of the order of 500 megacycles. A circuit arrangement using three-electrode vacuum tubes with high positive grid potentials and zero or small negative plate potentials, was found by Barkhausen and Kurz (1) in 1920 to produce oscillations at wave-lengths in the neighborhood of one metre and less.

These various methods of producing oscillations have not proved equally adaptable to the different portions of the short wave-length end of the radio spectrum. Oscillations at wave-lengths of one and one-half metres and more are most satisfactorily produced by means of the three-element vacuum tube, used in circuits which take advantage of the negative resistance characteristic of the valve to return energy, through some form of coupling, from the output to the input circuits. The magnetron oscillator covers an overlapping field of usefulness which extends down to waves of five centimetres or so in length. Barkhausen oscillators have been successfully developed for waves of from 150 cm. down to a few centimetres in length. For the shortest radio waves yet measured, between a few centimetres and a fraction of a millimetre in wave-length, spark excitation of small metallic particles has been the only successful method of production as yet devised.

This paper describes some experimental work carried out by the writer while investigating the Barkhausen type of oscillator, operating at wave-lengths between 50 and 150 cm.

[1] *Manuscript received February 28, 1931.*

Contribution from the Department of Electrical Engineering, McGill University, Montreal, Canada. A summary of this paper entitled "Centimetre Radio Waves" was presented before the Royal Society of Canada, in Montreal, May, 1930.

[2] *Engineer, Transmitter Development Department, Marconi Company, Montreal.*

Barkhausen-Kurz Oscillations

A number of workers have investigated Barkhausen oscillations since they were first discovered. The circuit generally employed for their production is that shown in Fig. 1, or some modification of it. The wave-length obtained with this type of circuit does not depend upon the external circuit, but is determined by the particular valve used and the amount of positive grid potential applied to it.

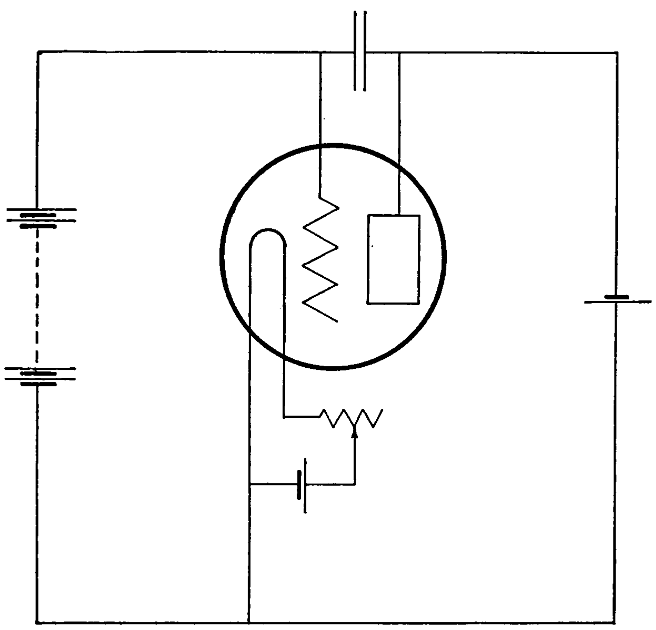


FIG. 1. *Circuit for generating Barkhausen-Kurz oscillations.*

The explanation given by Barkhausen to account for the production of oscillations under these circumstances was as follows. The electrons emitted by the filament are attracted by the positively charged grid. Some of these electrons actually strike the grid, but most of them pass through the grid interstices. They are now acted upon by the repelling force of the negative plate, towards which they are moving, and by the attractive force of the positive grid, away from which they are travelling. Both of these forces tend to retard the electrons, and will eventually reduce their velocity to zero, and then cause them to accelerate in the opposite direction. On returning through the grid spaces and moving towards the filament, the electrons will then be decelerated by the negative space charge or cloud of electrons about the filament. Thus again their velocity will be reversed, and the oscillatory motion about the grid repeated. The period of oscillation of this electron cloud will therefore be determined by the grid potential, which controls the velocity of the electrons, and by the distance between electrodes, which determines the length of the traverse. This, briefly, is a qualitative explanation of the mechanism of Barkhausen oscillations.

Apparatus

The circuit used in obtaining the curves appended to this paper is that shown in Fig. 1. A "Fotos" R type valve, of European manufacture, was used throughout these tests. It had a straight tungsten wire filament, with a helical grid and cylindrical plate mounted symmetrically about it. A number of other valves, both European and American types, were tried but most of them refused to oscillate in the Barkhausen circuit. Of those that did oscillate, the Fotos valve was the only one which was really satisfactory in producing stable oscillations which could be reproduced readily over a considerable range of wave-lengths.

The valve was mounted in a socket in all the experiments. Choke coils consisting of about 100 turns of No. 30 copper wire wound on half-inch wooden dowel pins, were connected in plate, grid, and filament leads, but their effectiveness is somewhat doubtful. Two parallel wires, each 35 in. long, were connected to the grid and plate terminals of the valve socket, and supported at their far end by the terminals of a second valve socket, which was used only as a support for these wires. An inverted grid-leak mounting could be slid to any position along these wires, and its springs were used to carry the connections from the plate and grid choke coils to the parallel wires.

In earlier experiments a small fixed condenser was used as the sliding bridge on the plate-grid wires, but this was not connected when the curves given in this paper were taken. In later experiments the parallel wires themselves were also omitted and the grid and plate choke coils connected directly to the valve socket, oscillations still being obtained as before.

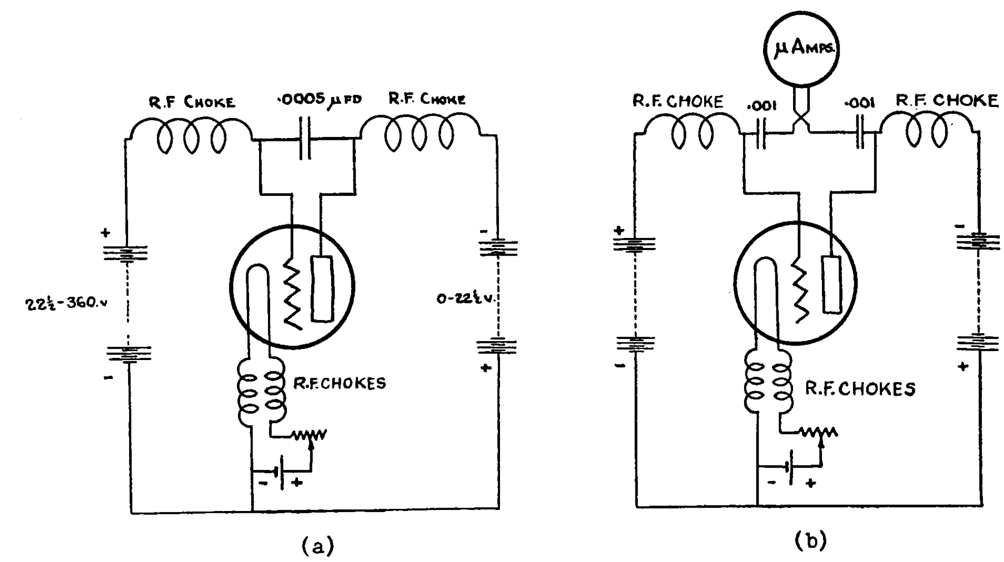


FIG. 2. *Circuits used in first experiments.*

Wave-length measurements were made by means of a Lecher wire system, and also by means of several small wave-meters calibrated against the Lecher wires. Resonance was indicated by a deflection on the plate current meter when either Lecher wires or wave-meter was coupled sufficiently closely to the valve and tuned to the wave-length of the oscillations.

When once a certain band of wave-lengths had been covered by the oscillator it was found very convenient, for further work within that band, to use a wave-meter previously calibrated from the Lecher wires, instead of using the wires directly for all wave-length determinations. The lowest range wave-meter constructed covered a range of from 45 to 70 cm. in wave-length. This particular meter consisted of a General Radio Company Type 368*a* microcondenser with the outer two of the three rotor plates removed. The soldering lug on the stator was turned towards the rotor shaft and a globule of solder placed between the end of the lug and the metal bushing carrying the rotor. This globule of solder comprised the inductance of the wave-meter.

Several other wave-meters were constructed and calibrated by means of Lecher wires and Barkhausen and other oscillators. The wave-length range covered by these meters was from 45 cm. to over 4 metres. This provided at the top of the band covered a considerable overlap over the bottom of the range of a General Radio Company Type 358 short wave wave-meter. The overlap permitted a convenient check on the measurements made.

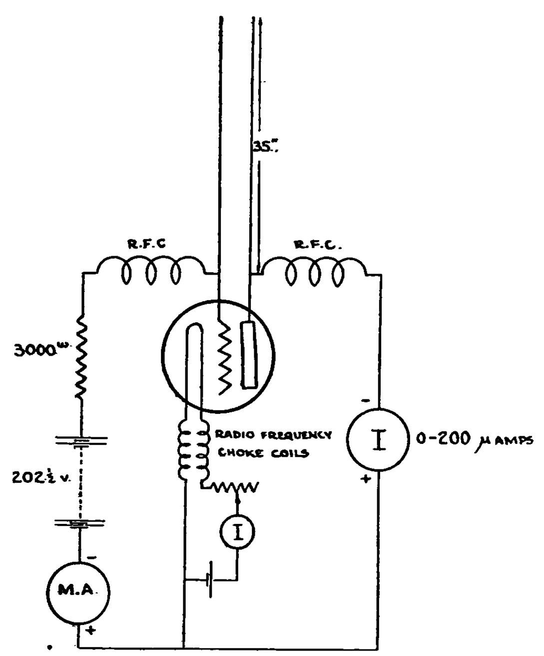


FIG. 3. *Modified circuit used in later experiments.*

This series of wave-meters is of particular interest inasmuch as it permitted a positive check to be maintained at all times on the wave-lengths produced. The fundamental wave-length of oscillation of any particular circuit could always be ascertained definitely, with no possibility of mistaking a harmonic for the fundamental. It was a common error in early work of the author and of others to mistake, for instance, a 75-cm. wave indicated on Lecher wires, for the fundamental, whereas this was actually the second or higher harmonic of a true fundamental of 150, 225, or even 300 cm. It was mainly a matter of taking the requisite amount of care to determine which was the true fundamental, of course, but it was an extremely simple matter to be in error by a factor of two or three. By utilizing a series of wave-meters covering from the shortest waves produced up to four or five metres, it was possible to determine very rapidly whether a 75-cm. wave whose presence was indicated, was a harmonic of a higher wave-length fundamental, or was itself the fundamental. The accuracy of these wave-meters is no greater than the accuracy of the Lecher wires from which they are calibrated, but their usefulness lies in the fact that they indicate but one wave-length at a time, will seldom indicate a harmonic at all unless its intensity be very great, and in any case can immediately be tuned to double or three times the wave-length to determine whether a higher wave is present or not.

Preliminary Experiments

The first tests were carried out with the circuit of Fig. 2 (a). No indications of oscillation were observed, however, the only effect produced being overheating of the valve due to excessive grid current. The valve used was a

UX-210 with its base removed. A 0-100 m.a. meter was connected in the grid circuit.

A Marconi-Osram "*R*" valve was then tested in the circuit of Fig. 2 (*b*). Two Sangamo 0.001-microfarad condensers were connected between plate and grid with a thermocouple and microammeter connected between them. Choke coils were connected in plate, grid, and filament leads as shown. The grid potential was varied from 22.5 to 300 volts positive, and the plate potential from 0 to 45 volts negative, but no current was observed in the 0-75 microampere meter connected across the thermojunction.

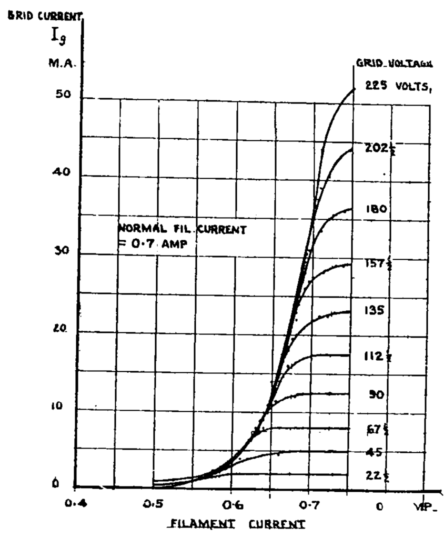


Fig. 4. $I_g - I_f$ *characteristics of Fotos straight filament R valve with* $E_p = 0$ *volts.*

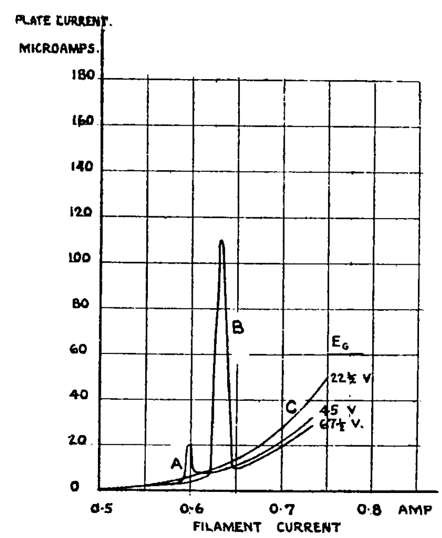


Fig. 5. $I_p - I_f$ *characteristics of Fotos R valve.* $E_p = 0$ *volts,* $\lambda = 140$ *cm. at* $E_g = +45$ *volts.* $\lambda = 130$ *cm. at* $E_g = +67.5$ *volts.*

A *UX*-210 valve was next put into this circuit. The grid current was greater than 100 m.a. at 90 volts, but no indications of oscillation were obtained on the bridge thermocouple meter in the grid-plate circuit. A 6000-ohm resistor was connected in series with the grid to limit the current at the higher voltages.

When the grid side of the parallel wire circuit was made or broken at the bridge contact, very slight deflections were obtained on the thermocouple meter. These deflections, of the order of 10 or 15 m.a., died away immediately and no constant readings could be obtained. They probably were due to transient oscillations set up in raising the grid to the potential of the battery.

The *R* valves used heretofore had helical filaments. A Fotos valve of the same type but with a straight wire filament was then tested, but with the same lack of results. It was thought that possibly the reason for the failure of the American *UX*-201*a* and *UX*-210 valves to oscillate lay in the fact that they had V-shaped filaments, and that the European *R* valves with a straight filament at the centre of a concentric cylindrical anode and grid, might be more successful in producing oscillations, since the Barkhausen action somewhat resembles the magnetron oscillation, and the magnetron requires a symmetrically constructed plate and filament. This appears to be the case, as the *UX*-201*a* and *UX*-210 valves could not be made to oscillate in Barkhausen circuits while the *R* valves eventually could. However, a *WD*-12 valve having cylindrical electrodes also failed to produce Barkhausen oscillations, although it was of similar construction to the *R* valves.

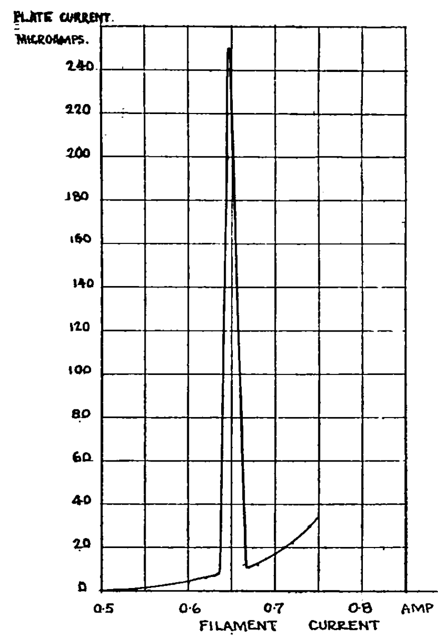


FIG. 6. $I_p - I_f$ *characteristic of Fotos R valve.* $E_p = 0$ *volts.* $E_g = +90$ *volts.* $\lambda = 115.6$ *cm.*

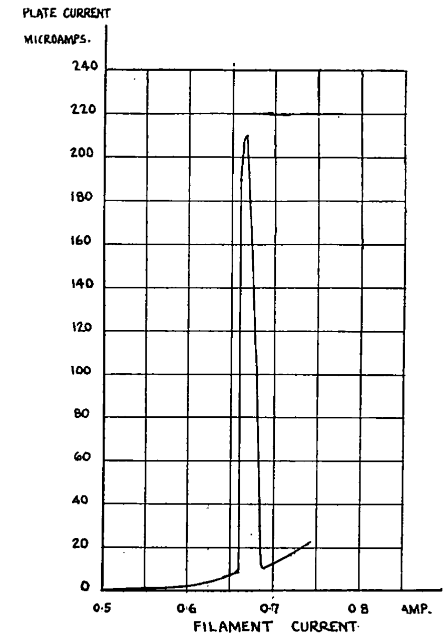


FIG. 7. $I_p - I_f$ *characteristic of Fotos R valve.* $E_p = 0$ *volts.* $E_g = +112.5$ *volts.* $\lambda = 107$ *cm.*

In all of the Barkhausen circuits tested so far, no meter was placed in the plate circuit, as it was expected that a deflection of the grid meter would occur to indicate when the circuit began to oscillate. It was now found that this was not so, any change in grid current occurring upon commencement of oscillations being quite too small to be observable. A 0-1 m.a. meter was inserted in the plate circuit of the Fotos *R* valve in a Barkhausen circuit and immediately it was found that oscillations were being obtained, the wave-meter producing a sharp deflection in this meter when tuned to resonance.

The wave-length measured on Lecher wires was 81.8 cm. This was carefully checked to make sure that it was the fundamental and not the second harmonic of a 163.6-cm. wave. No deflection whatever could be obtained with wave-meters tuned to multiples of 81.8 cm., so this was certainly the fundamental. In this particular case the bridge on the grid plate wires was placed about 50 cm. from the valve socket, and the following readings were recorded:

I_p	I_g	I_f	E_p	E_g	I_o
0.6 m.a.	35.0 m.a.	0.68 amp.	0 volts	+112.5 volts	0 m.a.

I_o was the reading of the thermogalvanometer in the grid-plate wires bridge.

The Fotos straight filament R valve was then set up in the Barkhausen oscillator. The grid voltage was varied from $22\frac{1}{2}$ to 225 volts and the plate voltage left at zero. Values of grid and plate current were read over a range of variation of filament current, and graphs of these quantities plotted for each value of plate voltage. (See Fig. 4-13.)

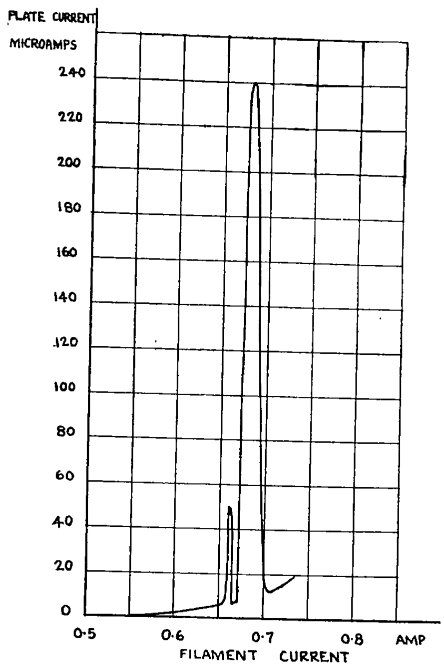


FIG. 8. *$I_p - I_f$ characteristic of Fotos R Valve. $E_p =$ 0 volts. $E_g = +135$ volts. $\lambda = 85$ cm. at lower peak and 100 cm. at higher peak.*

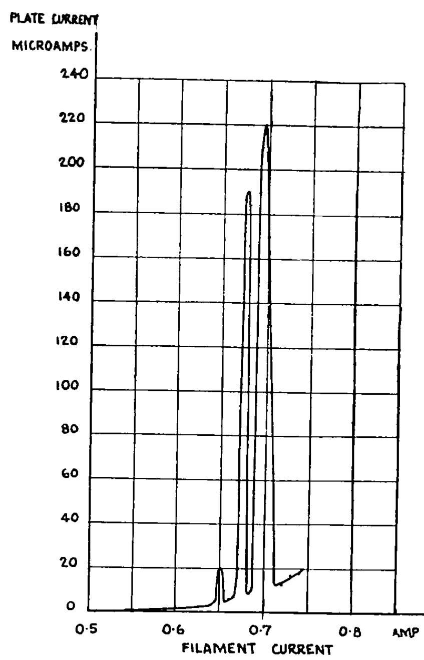


FIG. 9. *$I_p - I_f$ characteristic of Fotos R valve. $E_p =$ 0 volts. $E_g = 157.5$ volts. $\lambda = 69$, 82 and 97 cm. at lowest, middle and highest peaks, respectively.*

Peculiarities Observed

A number of very striking facts immediately stand out from the curves of Fig. 5-13. It will be observed that in each case oscillations are indicated by a sharp peak in the plate-current curve, but that no such peak is produced in the corresponding grid-current curve. The grid-current curves (Fig. 4), are, as might be expected, of the same form as normal plate-current curves taken with positive plate voltages. They do not all coincide at the lowest filament currents because the grid-current milliammeter used could not be read accurately at the bottom of its range. Also the curves were taken on different days, and the valve characteristics were found to vary somewhat from day to day. It is possible that there were slight kinks in the grid-current curves during oscillation which it was beyond the accuracy of the meter to record. The plate current was always very small, a microammeter being required to register it.

Fig. 5 shows the plate current-filament current characteristics for several positive grid voltages. As the grid voltage is increased the plate current decreases (except at "resonance" values), as might be expected, since the higher the potential of the grid for a given filament emission the more electrons will be attracted to it and the fewer will reach the plate. The plate current did not reach a saturation value for any grid voltage or filament current used.

When the grid voltage was 22½ no oscillations were obtained (curve C, Fig. 5). When the voltage was increased to 45, curve A of Fig. 5 was obtained, showing a sudden increase of plate current at a filament current of 0.6 ampere. It was found that the hump in the curve indicated the presence of oscillations of wave-length 140 cm., but that at values of filament current on either side of the hump no oscillations were produced. Thus in this particular case the Barkhausen oscillations occurred only within the extremely narrow range of filament current of about 15 m.a. The middle of this range was at 0.6 ampere, which is considerably below the normal filament current (0.7 ampere) for this valve. Similar graphs were obtained for each of the other cases and are shown in the other figures.

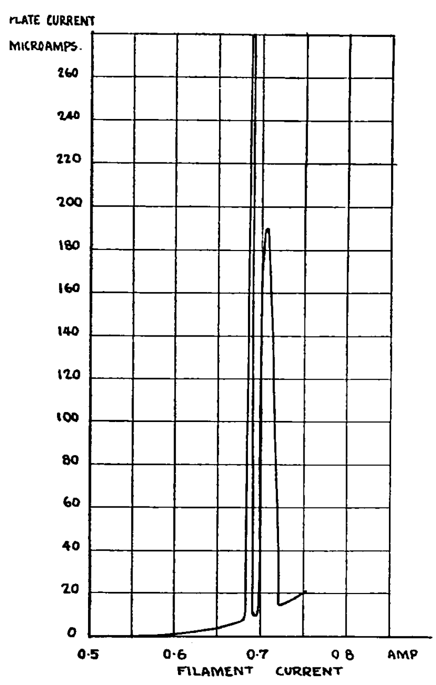


FIG. 10. *$I_p - I_f$ characteristic of Fotos R valve. $E_p = 0$ volts. $E_g = +180$ volts. $\lambda = 80$ and 89 cm. at lower and higher value of I_f, respectively.*

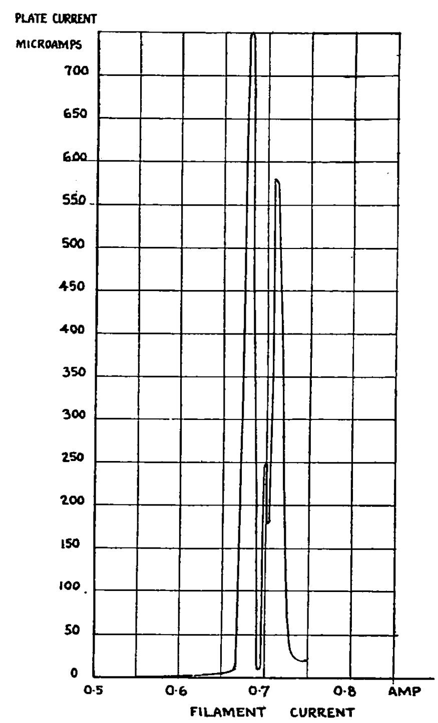


FIG. 11. *$I_p - I_f$ characteristic of Fotos R valve. $E_p = 0$ volts. $E_g = +202.5$ volts. $\lambda = 67$ cm. at peak of lowest I_f.*

The general form of the $I_p - I_f$ curves is somewhat of an exponential type, rising very steeply as the filament current is increased beyond the normal rated value. When the grid voltage is sufficiently high to produce oscillations, in the case of this valve about 25 volts or more, a very sharp and sudden increase of plate current occurs at certain values of filament current at which oscillations take place. This maximum occurs at higher values of filament current as the grid voltage is raised, the frequency of oscillation also increasing.

The decrease in wave-length as the grid voltage is increased, other factors remaining constant, is illustrated in Fig. 14. It is seen to be fairly uniform, practically linear in fact, with the exception of a few points. One cause of wide variation in results was the fact that the valve heated up very quickly at the higher grid voltages, so that readings taken while the valve was hot, or after it had been in operation some time, did not check with readings taken under similar circumstances while the valve was cold and had been standing idle for several days.

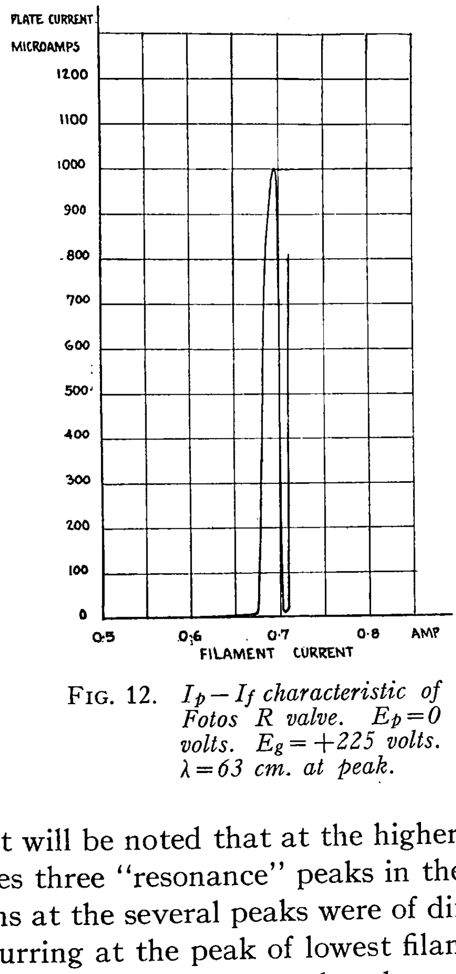


FIG. 12. *$I_p - I_f$ characteristic of Fotos R valve. $E_p = 0$ volts. $E_g = +225$ volts. $\lambda = 63$ cm. at peak.*

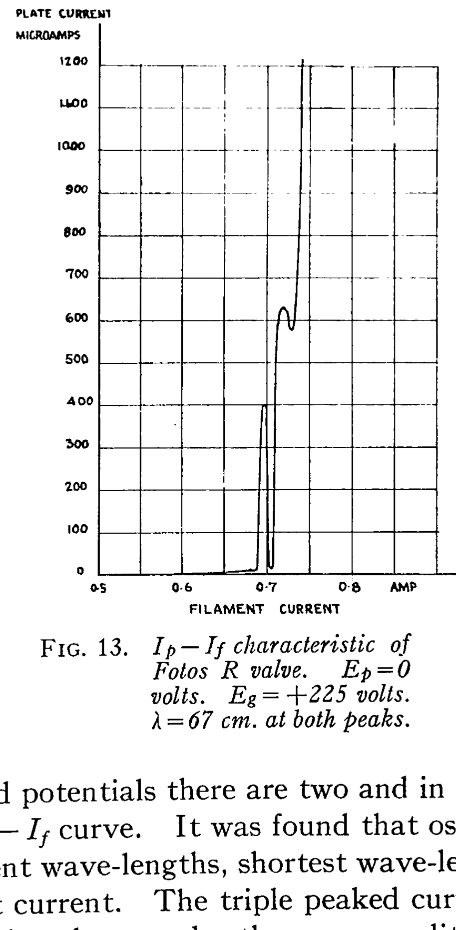


FIG. 13. *$I_p - I_f$ characteristic of Fotos R valve. $E_p = 0$ volts. $E_g = +225$ volts. $\lambda = 67$ cm. at both peaks.*

It will be noted that at the higher grid potentials there are two and in some cases three "resonance" peaks in the $I_p - I_f$ curve. It was found that oscillations at the several peaks were of different wave-lengths, shortest wave-length occurring at the peak of lowest filament current. The triple peaked curve of Fig. 9 could not be reproduced several days later under the same conditions, the smallest peak not appearing. The peaks move to the right as the grid voltage is increased, that is, higher filament current is required to produce oscillation at higher grid voltages. This is probably due to the fact that, as mentioned before, the normal or non-oscillating plate current becomes less as the grid voltage increases, so that the filament emission must be increased to produce oscillations.

At the highest grid voltages used the grid became white hot, thus supplying a secondary emission current to the plate. This plate current could be reduced by applying negative plate potentials, but this reduced the oscillations to zero if the negative plate voltage was sufficiently great. In Fig. 12 and 13 a further

I_p maximum was observed at higher filament currents, but as the grid became excessively hot and the rated normal filament current was considerably below these values, no readings were taken.

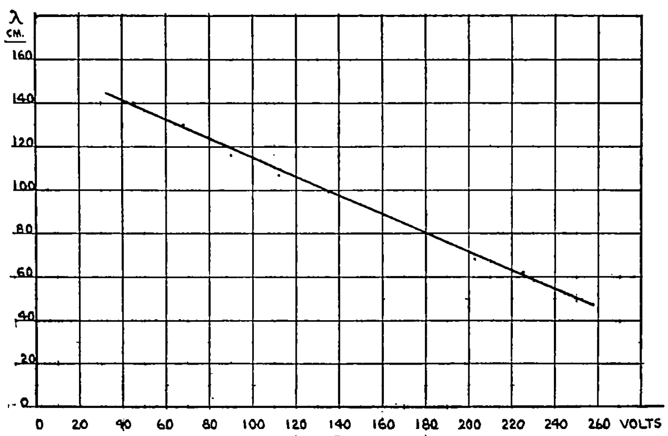


FIG. 14. *Variation of wave-length with grid potential. Oscillator using B-K circuit with Fotos R valve.* $E_p = 0$ *volts.*

The whole $I_p - I_f$ curve is more to the right when the filament is first lit, and the peak slowly shifts to the left after the valve has been in operation awhile. The effect produced is as though the filament current increased slightly as the valve warmed up. Thus this creepage may cause the plate current either to increase or decrease, depending upon the side of the peak to which the filament current is adjusted. The curves shown in the figures were taken under steady state conditions, that is, the valve was allowed to warm up before any readings were taken.

Further Experiments

The Fotos straight filament *R* valve was later placed in the circuit of Fig. 2 (*b*) and the condenser bridge across the grid and plate parallel wires omitted, leaving the circuit as in Fig. 3. It was found that oscillations could still be obtained with this circuit, the wave-length being about 60 to 70 cm. Oscillations were also obtained when the filament polarity was reversed, making the positive filament battery terminal the common connection. The curve of Fig. 13 was taken under these conditions, and it is evident that the removal of the condenser bridge did make some change in the circuit. However, the difference between the curves of Fig. 12 and 13, taken with and without the bridge, respectively, is not any greater than could be accounted for by the variation from day to day in results obtained from identical arrangements. The wave-length was the same for both peaks of the double-peaked curve of Fig. 13 whereas in the other multiple-peaked curves the wave-length decreased at the lower values of filament current. Oscillations were unstable, however, at the higher values of filament current in this case, as the valve became greatly overheated, and the wave-length measurement here was not very reliable.

The parallel grid and plate wires of the circuit of Fig. 3 were then removed, leaving only the Fotos *R* valve in its socket with the choke coils at each terminal. Oscillations were obtained as before, showing that the grid-plate condenser and its associated parallel wire circuit did not produce the oscillations. The wave-length remained the same as with the wires.

Discussion

The explanation given by Barkhausen for this type of oscillation does not explain the effects observed in the experiments outlined here. The usual explanation of a cloud of electrons oscillating back and forth between filament and plate, accelerated by the attraction of the grid, is insufficient to explain why the oscillations should occur at several definite values of filament current and not in between these values. Breit (2) describes the production of oscillations by a method somewhat similar to that used by the author but he obtains oscillations within only one narrow range of filament current, while in the author's experiments oscillations were found to take place over several very narrow ranges of filament current each about 15 to 20 m.a. wide. No satisfactory explanation was found by Breit, although several possibilities were suggested. The effect seems to resemble somewhat the numerous resonance potentials which are found in gaseous discharge tubes. The valves used in these experiments were all high vacuum tubes, however.

The change in wave-length as the filament current is increased and another point of oscillation is reached is insufficient to permit considering that oscillations now take place between grid and plate, or between filament and grid, instead of between filament and plate as at first. Also the wave-length increases with increasing filament current instead of decreasing, as would be the case if oscillations took place between grid and plate or filament and grid. This increase in wave-length or decrease in frequency as the filament current is increased, agrees with some theoretical calculations made by F. W. Sears (9). In an analytical investigation of Barkhausen oscillations Sears finds that the effect of increasing space charge is to decrease the frequency. Since the space charge is proportional to the filament current, this finding is in agreement with the experimental results of the author. The experimental results of most other investigators (1, 4, 8) disagree with this, however, and indicate the reverse to be the case, that is, frequency increases with increasing filament emission. It is possible that two distinct types of oscillation may occur, even under similar conditions, the effect of variation in space charge being opposite in the two cases.

If it is considered that the oscillations which occur at the lowest value of filament current take place in the interelectrode space between the plate and a layer at some distance from the filament, a possible explanation of the increase in wave-length with increasing filament current may be given. As the initial velocity of the electrons leaving the filament is increased by raising the filament current, they tend on rebounding from the plate to penetrate farther and farther into the cloud of electrons forming the space charge between filament and grid. Thus the path travelled in each cycle of oscillation increases in length, so that the time taken for each oscillation becomes greater and therefore the wave-length increases. This does not explain why oscillation takes place only at definite filament currents. Possibly the grid and plate elements act as tuned circuits, resonant at certain fixed frequencies whose values are determined by the capacity between the two, which is in turn dependent on the number of electrons moving about in the interelectrode spaces. Thus if we consider the grid and plate each to have definite values of inductance, with which is associated the capacity between them, then this system will be resonant at some specific frequency. If the natural period of the system happens to correspond to the periodic time of a large number of the electrons travelling back and forth between filament and plate, stable oscillation of the electron cloud will be set up. If the filament current is now increased, the periodic time of both the electrons and the grid-plate circuit will be altered, so that they will no longer be in resonance and continuous oscillations will not be produced. As the filament current is further increased another point may be reached where they will again come into resonance and set up and maintain oscillations.

At the higher filament currents the electron cloud is denser, which means that the interelectrode capacity is greater and hence the wave-length correspondingly greater or the frequency less. This is what was actually found to be the case experimentally, the highest frequency occurring at the lowest filament current. The above explanation appears adequate, therefore, to fit the facts.

The author's results explain the action of an "electronic ampli-detector" described by K. Okabe (7). Okabe found that when using a receiver with a circuit of the Barkhausen type, the intensity of the received signal increased from zero to a sharp maximum and then decreased to zero again as the filament current of the receiver valve was varied from 0.62 to 0.63 ampere. The valve being in oscillation within this narrow region of filament current, as described herewith by the author, would explain the increased sensitivity of the receiver over the range of oscillation. The graph of received signal intensity versus filament current given by Okabe corresponds closely to the form of the author's $I_p - I_f$ curves.

Acknowledgment

The author wishes to express his appreciation to Dr. F. S. Howes of the Department of Electrical Engineering, McGill University, for his interest and assistance in this work.

References

1. Barkhausen, H. and Kurz, K. Physik. Z. 21: 1-6. 1920.
2. Breit, G. J. Franklin Inst. 197: 355-358. 1924.
3. Gill, E. W. B. and Morrell, J. H. Phil. Mag. 44: 161-178. 1922; 49: 369-379. 1925.
4. Hollman, H. E. Ann. Physik, 86: 129-187. 1928.
5. Kapzov, N. Z. Physik, 49: 395-427. 1928.
6. Moore, W. H. J. Franklin Inst. 209: 473-484. 1930.
7. Okabe, K. Proc. Inst. Radio Engin. 18: 1028-1037. 1930.
8. Scheibe, A. Ann. Physik, 73: 54-88. 1924.
9. Sears, F. W. J. Franklin Inst. 209: 459-472. 1930.