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The development and uses of the audion

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THE DEVELOPMENT AND USES OF THE AUDION

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The Development and Uses of the Audion

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Jen Ming Woo.

The Development and Uses of the Audion

I Introduction

1 A general statement is given as an introduction

2 The fundamental principle in the construction of audion is manifested by the electron theory.

3 An historical review is made over the earliest experiments on the emitted gases surrounding the incandescent filament. J. A. Fleming discovered that the gas emitted by the filament is a carrier of negative electricity.

4 J. J. Thomson investigated and proved that the negative carrier of electricity is in the form of a free electron.

5 Richardson established a law in terms of a formula to govern the intensity of the electron current; that is, the latter is proportional to the temperature of the filament.

6 J. A. Fleming made the practical application of a vacuum tube, containing an incandescent filament and an anode plate, in detecting an electromagnetic wave.

7 Definition of an audion.

8 Lee De Forest conducted a series of experiments leading to the later practical application of the audion in radio-telephony.

9 Irving Langmuir founded a second law to govern the intensity of the electron current. This law states that the intensity of the electron current is not only limited by the temperature of the filament but also by the space between the filament and the anode plate in the audion.

10 All other conditions affecting the electron current have to be eliminated.

II The Principles in the Construction of an Audion

1 (a) The electron is probably the ultimate unit in building up an atom.

(b) An electron cannot be considered as a ponderable mass; but in fact, it constitutes the flowing current. The forces of attraction and repulsion between electrons are utilized in the audion.

(c) The characteristic curve shows that electron current in the audion does not obey ohm's law of resistance; and 10 electrons passing through the space per unit of cross section per unit of time is equivalent to one ampere.

(d) Two fundamental curves of the electron current are made use of in the construction of an audion.

2 The audion is used as a rectifier in receiving an alternating electromagnetic wave at high potential.

3 (a) The limitation of space charge leads to the development of the pliotron, and audion of three electrodes.

(b) The actions and functions of the pliotron are mathmatically discussed, when an alternating current is impressed upon it.

(c) A qualitative analysis of the characteristic curve (fig.V) facilitates the comprehension of its functioning and enables us to apply the local voltage to the pliotron.

(d) The function of a condenser connected in series with the grid of a pliotron is carefully analyzed.

(e) A summary of functions and properties of a pliotron is made.

4 (a) Secondary emmission is the basic principle in the construction of a dynatron. The corpuscular emmission from a Röntgen tube is identified with the secondary emmission of electrons in the dynatron.

(b) The properties and functions of the characteristic curves of

a dynatron is studied in detail.

5 The principle in the construction of a pliodynatron is the same as that of a pliotron. The properties and functions of the pliodynatron are discussed in detail.

III The Uses of the Audion.

1 (a) A general study of a typical radio circuit of coils and condenser is given.

(b) The methods of coupling radio circuits are four in number, and the reactions among the circuits are determined by their resistances. A beat note may be produced by a "close" coupling system.

(c) A discussion of the method of tuning two currents is given.

2 The kenotron is used as a detector in radio-telephony and radio-telegraphy.

3 (a) A pliotron may be simultaneously used as a detector and generator to produce beat notes.

(b) It is shown how to adjust a pliotron for amplification or rectification in receiving an undamped electromagnetic wave.

(c) A detailed study is given of a pliotron in receiving an undamped wave.

(d) The pliotron has solved the most difficult problem of controlling the large output current in radio-telephony.

(e) A detailed study of the uses of the pliotron in radio-t telephony and radio-telegraphy.

4 The dynatron is used as a detector or an oscillator in radio telegraphy and telephony. It is a powerful amplifier.

5 The pliodynatron is used as detector or oscillator and proven to be the most efficient device for radio-telephony.

6 The audio is also extensively used in the physical laboratory

IV Conclusion.

1 Comparative study between the audion and other devices is given to show how the former is constructed without much mechanical complexity.

2 The future development of the audion depends on the pliodynatron.

J. I. Woo.

The Development and Uses of the Audion

Chapter I

It is intensely interesting thing as a student of science to know what has made radio-telegraphy and telephony possible in these days of wireless communication. In order to appreciate the intrinsic value of this knowledge,it is invariably true that one should be able to perceive the fundamental principle in directing its development,and the functions of the various instruments which have been invented and successfully employed in radio-work. Today there are many kinds of oscillators used to generate the electromagnetic wave,rectifiers or detectors to detect the incoming wave and amplifiers to increase the amplitude of the current or the voltage. So it is beyond the scope of this paper to describe all of them.

Above all it is of still greater importance to ascertain how the audion which could embody these three characteristics in itself came into existence,and attains its industrial application and usefulness. Not only has it replaced other instruments in the radio-work on account of its simplicity,but the very principle that justifies its claim of superiority over others is a truely different one. The principle is the one manifested by the electron theory. We,therefore,may trace back to the original idea,the development and construction of the present audion.

It has been known for many years that the air surrounding an incandescent metal is a conductor of electricity. In 1880 the earliest experiments performed by Elster and Geitel,on incandescent metallic wires under different gas pressures and various temperatures of the heated wire,established the result that more positive ions are emitted under high gas pressure,and more negative ones under very low pressure. . Four years later Thomas Edison studied

and observed the similar discharge of negative electricity in a vacuum which contained an incandescent wire and anode electrode. On connecting the electrode plate, through an ammeter, to the negative end of the filament, no current was observed; but, if the plate was connected to the positive end, a small current could be produced. This so called Edison effect immediately attracted wide attention and much consideration among physicists and investigators; although Edison himself had never attempted to explain or to make any use of his discovery. Among all the investigators J. A. Fleming was the most prominent. From 1890-1896 he investigated and described it in detail and concluded that this small current flowing in the evacuated space between the incandescent wire and anode plate is due to the negative carrier of electricity emitted from the filament; but, in the same period (1892), L. Zehnder was the first one who introduced the idea of using the vacuum tube as a detector ("Wied. Annalen" 1892 page 77).

In 1899 Sir J. J. Thomson (Phil. Mag. 48,547) made the epoch-making discovery of the electron and asserted that the negative electricity given off by the filament is in the form of free electrons of a mass about 1/1845 of that of an hydrogen atom.

In 1903 (Phil. Trans. 201,516) Richardson made use of the new discovery of the electron theory of metallic conduction in explaining electron emission from a heated metal. However, before Richardson formulated his theory there already existed a theory concerning free electrons moving in metals under electric force, these being in constant vibratory motion similar to that of the molecules of a gas. He reasoned that if this is the case with electrons in a metallic conductor the conditions under which the molecules change from the liquid or solid into a vapor must be applicable to the escape of electrons. Since the vapor pressure is

directly proportional to the square root of the temperature after the molecules have overcome the surface tension, the average velocity of the vibratory motion and the numbers of the electron must also increase with increasing temperature. The number of electrons which have obtained the necessary critical velocity to escape will increase very rapidly and regularly with the temperature. *"These considerations are strictly analogous to those of the evaporation of a liquid, so that the number of electrons escaping should increase with the temperature according to the same laws as those governing the increase of the vapor pressure of a liquid as the temperature is raised." The vapor pressure (p) of a substance varies with the temperature (T) according to a relation of the form $P = A\sqrt{T}\, e^{-\frac{\lambda}{T}}$ where A is a constant, λ is the latent heat of evaporation of the liquid (or solid), and e is the base of the natural system of logarithms. Richardson reached the conclusion that the current from an incandescent metal should increase according to an equation of a similar form, namely $i = a\sqrt{T}\, e^{-\frac{b}{2}}$. Here i is the current per square centimeter at the temperature T, and b is a constant which is half the latent heat of evaporation of the electrons. He called the electron current "thermionic" and his assumption indicates (1) that the electronic emission constitutes the current of the Edison effect, and (2) that the incandescent metal at a given temperature emits electrons at a definite rate which is independent of the electrical field around the heated body. He confirmed his theoretical equation by conducting one experiment to determine the relation between the saturation current from a heated platinum wire and a cylinder around it.

In 1907 J. A. Fleming made a practical application with a vacuum tube which he called the "oscillation valve" which acts as a trapper of electrons; that is to say the electron can only

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* Gen. Electrical Review page 327, May 1915. I. Langmuir.

flow from the filament to the anode plate but not in the opposite direction. Therefore, half of the transmitted electromagnetic waves is quenched and the current is then transformed into a damped unidirectional current made up of impulses which may be detected when a telephone is connected in series with the plate circuit.

An audion is then simply a glass bulb highly exhausted of air, containing a metallic filament (hot or negative electrode) and metals in either a fine wire mesh or a plate(cold or positive electrodes). The earliest type of the audion was the same as that of Fleming's oscillation valve or sometimes called"vacuum tube". It has been frequently used in the detection of electromagnetic waves like other detectors of crystals and metallic filings,or electrolytic detectors.

In 1915 Lee De Forest (Electrical World page 465-6, 1915) advanced a further step in the development of the audion with an extensive study of the vacuum tube. He accidentally made the discovery that when a second anode was inserted between the hot cathode and cold anode of the usual vacuum bulb,on connecting the secondary receiver circuit,L C (fig.I),to the second anode or grid circuit,G C C′,a musical tone was detected instead of the hissing sound from an arc transmitting station,by varying the the filament current B′ and battery B of the telephone circuit. The pitch of this note could be varied by varying the capacity of the condenser,C,in shunt with the secondary,L, of the receiving circuit. This experimental discovery indisputabley proves that the tri-electrode valve is an oscillator in itself. When two audions are connected in cascade a set of impulses set up in the second audion reacts in turn upon the first circuit through the transformer M (fig.II),and the latter produces a beated note which

is repeated in the second audion and heard in the telephone circuit. But there is always a certain amount of reaction in the first audion which could be elminated by shunting the heavy retardation coil, L_6, battery, B_4 and telephone receiver, T, circuit by a small condenser C_6. This beated note has a power many hundred times that of the initial high-frequency power in either oscillating circuit alone. This significant observation clearly proves that the audion is an amplifier acting as a relay for radio-telegraphy and telephony. His brilliant work marked a distinct era in the wireless world; he said, "the audion combines at once the point of simplicity, reliability, sensitiveness, sharpness of tuning and tonal selectivity."

Within the same year (Gen. Elect. Review page 327-39, May 1915) Irving Langmuir carried out some experiments on the thermionic currents across the highly evacuated space in a tungsten lamp. According to the theory of Richardson the thermionic current must be exceedingly great when the temperature of tungsten reaches its melting point; but in fact, beyond a certain temperature, the plate current does not increase in the lamp in accordance with the prescribed law, which is not due to any failure of the filament to emit electrons, but due entirely to an inability of the space around the filament to carry the currents with the limited space and the potential available in the lamp. This phenomena may be explained in this way, that more electronic charges are emitted by the filament at high temperature than the anode can absorb, and so some of the extra electrons are compelled to return to the filament. A theoretical discussion on the effect of the space charge led Irving Langmuir to develop two formulae by which the maximum current through a space may be determined:--$i = \frac{\sqrt{2}}{9}\sqrt{\frac{e}{m}}\frac{V^{3/2}}{x^2}$, where e is the charge on an electron, m the mass of an electron,

V the potential difference between the parallel plates and x the distance between the plates. If numerical values are substituted for $\frac{e}{m}$, and $i = 2.33 \times 10^{-6} \frac{V^{3/2}}{x^2}$. In the case of a wire and cylinder the maximum current is determined by the following equation:-- $i = \frac{2\sqrt{2}}{9}\sqrt{\frac{e}{m}}\,\frac{V^{3/2}}{r}$. or $i = 14.65 \times 10^{-6} \frac{V^{3/2}}{r}$. The thermionic current is thus proven not only a function of the temperature but also of the space charge, dependent on the voltage, or shape and size of the anode.

The occluded gases of the incandescent metal must be entirely eliminated so that the current carrying capacity of the space should not be affected or increased by such gases as they always tend to neutralize the charge of the electrons. If this point is carefully observed all the irregularities of the thermionic current are found to disappear, and large current density can be obtained and potential difference of more than 100,000 volts may be applied without any losses due to positive ionization. .. Positive ionization at high temperature of the filament may cause the disintegration of the latter, and the result will be the final emission of the electrons from the cathode under the influence of the positive ion bombardment. These electrons, which constitute the so-called delta rays, with high initial velocity of escape from the cathode, are capable of charging up a third electrode in this space to a potential of 10 or 15 volts negative with respect to the cathode. With all these previous theories and knowledge confirmed by the different experiments it remains clear that the fundamental principle in constructing an audion is that of pure electronic motion which can be arrested and put to do work at will by the various devices.

Chapter II

The Principles in the Construction of the Audion

Now the question arises as to how the electron acquires its energy which sets it in motion to do the work. It is necessary for us to consider more or less the present theory concerning the ultimate nature of ponderable matter. A molecule may be composed of several atoms. An atom was formerly considered to be the smallest quantity of an element that could exist. Recent researches reveal the fact that in the structure of matter electrons are associated in a definite number with a positively charged nucleus. So long as none of the component electrons are severed from an atom, the latter possesses no detectable electrical charge. Suppose an electron carrying the smallest known charge of negative electricity be detached from the atom, then the atom becomes a a positive ion exhibiting all the properties of a positively charged body; but on the other hand if an electron be added to the normal uncharged atom, the latter, in this state, possesses a negative charge and is termed a "negative ion". In brief the positive ion possesses a deficiency of electrons and the negative ion an excess of electrons; or in other words ionization of atoms is brought about by disruption so that they attain electrical properties. The disruption of an atom may be accomplished by either chemical or mechanical processes.

Although a number of congregated electrons go ultimately to make up a particle and even exhibit inertia or mass when subjected to electrical repulsion by other electrons, and the amount of their inertia depends upon the velocity with which they are moving, yet they have no recognizable mass in the sense that ponderable matter has mass, and we, therefore, should consider electrons in terms of electricity. In this way we can comprehend in some measure the

extreme mobility which they possesses as compared with solid bodies. The conduction of electricity is accomplished by the motion of carriers of electricity and since a number of electrons constitute such a kind of motion, an electrical current may be considered as the motion of electrons carrying negative electricity. We now accept the theory that the flow of electricity is a movement of electrons. In the case of a vacuum tube where little gas ionization is possible it is considered that a spontaneous dissociation of electrons from the atoms of the incandescent metal does actually take place at high temperature. A costant stream of free electrons from the filament neutralizes the positive ions of the filament deficient in electrons. After the disruption of the metal in a vacuum tube the electron carriers obey the law that like charges repel and unlike attract and the motions made use of in an evacuated tube are due to such attractions and repulsions.

It has already been shown in the above discussion that the strength of electron current is limited in two ways: First by the temperature limitation of the filament (fig.III) and second by the so-called space charge. There is a curious property of the electron current that the conductivity of the space between the filament and the plate is not constant; that is to say the apparent resistance, the ratio of applied E. M. F. to its current, is not constant: it does not obey Ohm's Law of resistance. When an E. M. F. is impressed upon the plate circuit P (fig.VI) and the temperature of the filament is kept constant, the curve between plate potential and plate current is ~~as it is~~ shown in fig. IV. During the first increase in voltage, the plate current is low, indicating a high value of resistance, and after the critical point B is passed the plate current rapidly increases, indicating a much lower resistance. The dotted line shows the temperature limitation; and so a further increase in voltage does not increase the plate current without

raising the filament temperature. A mathematical analysis of curve AC indicates that the number of electrons, that is the plate current, is roughly proportional to the square of the field intensity, $i = 14.64 \times 10^{-6} \frac{1}{r} e^{3/2} = k(e)^{2}$. Thus the amount of current passed per second between the space varies directly with the supply of electrons and it is found that 10^{19} electrons passing each second from filament to plate through a cross section of one centimeter are equivalent to one ampere.

In order to obtain the relation between the plate current and filament current, another characteristic curve is drawn as shown in Fig.III by keeping plate potential constant and varying the filament current with various values of plate current. It is easy to see that if the filament current is increased beyond the point B there will be no increase in plate current without increasing the plate potential; and this is shown by the dotted line FB' called "space limitation". If then the plate current should obey the square law, namely current (i) proportional to the square of field intensity, it is necessary that the filament current I should be maintained as large as OG, where the curve ADF is taken for the maximum value of F which is to be used, and OB when ADF is to be used. These two characteristic curves are ingeniously made use of in the construction of the kenotron and pliotron.

It has been pointed out that the electronic current in a vacuum possesses unilateral conductivity; and any device which allows a current to pass in only one direction and wholly or partially obstructs the flow in the opposite direction is called a rectifier. The kenotron is practically the same as Fleming's oscillation valve, a rectifier working as an extremely high vacuum. This word is derived from the Greek kenos, empty space (vacuum), and tron, instrument. The principles involved in its construction

imply (1) extremely high vacuum; (2) electronic discharge; (3) the valve action of the electron current; (4) non-constant conductivity of the electron current as shown by the characteristic curves; (5) design of the vacuum, that is the length of incandescent metal, the space between electrodes and the size of anode plate. The cathode and anode in the kenotron are placed much closer together than in the oscillation valve on account of its high order of vacuum and the effect of the space charge, and in this way it is possible to obtain large current at low drop of voltage like an ordinary valve in which normal gas ionization is necessary. Its important properties are:-(1) An ability to rectify currents of extremely high or low frequency, (2) its capacity of rectifying currents at 180,000 volts or even greater with proper design, (3) its perfect stability in current, so that when a number of kenotrons are connected in parallel each one will take its proper share of the current, unlike other kinds of rectifiers. So if a kenotron is connected with any alternating E. M. F. as in fig. VI it serves to detect and rectify the current into a pulsating direct one.

It is recalled that by virtue of the space charge effect no more electrons are absorbed by the anode electrode and excess ones return to the filament. From this point of view it is evident that if a third body charged either negatively or positively is inserted in the space it will tend to repel and attract the excess electrons respectively. This three-electrode valve is called a "pliotron" from Greek word "pleion" signifying "more" and therefore an "instrument for giving more" or an amplifier. The valve filament is usually made of tungsten; the grid is a fine mesh of tungsten, nickel or copper wire; and the anode of nickel or aluminum plate. In the case of the kenotron the plate current is found to be proportional to the square of the plate potential; and then in the

pliotron the plate current is not only a function of plate potential but of the potential of both plate and grid, the third charged body. That is $I = 14.45 \times 10^{-6} \frac{L}{R}(E + kE)^{3/2} = K(E_B - kv_{11})^2$, where k has a value between 5 and 40 and is dependent upon the space between the grid, the diameter of wire and the distance between the grid and filament.

The fundamental actions of pliotron must be clearly understood before any one is able to make use of it. Just before the controlling member is introduced into the vacuum, when every point in the space has some potential between the cold anode and filament, the filament is heated and plate battery connected. Now if the grid is inserted in the space and captures electrons, the potential at this point is thus much lowered. With external alternating E. M. F. the grid finally becomes either positive or negative to the filament, but always negative to the plate P. This has been experimentally proven by E. H. Armstrong (Electrical World December 12, 1914). Suppose the grid is sufficiently charged with negative electricity by an external E. M. F., the electron current to the anode plate will be entirely cut off; if the grid is charged positive with respect to the filament the electron current will be enhanced. In fact, the grid is employed to open and close the plate circuit or to change its resistance. For the pliotron we may have three characteristic curves (1) plate-voltage to plate current; (2) grid-voltage to grid-current; and (3) grid-voltage to plate-current. Although these curves are inter-dependent; the first two become self-evident if the last one (upon which the relaying and amplifying actions are solely based) is carefully studied. The grid-potential to plate-current is obtained by keeping filament temperature and plate potential at some constant values and varying the values of positive and negative grid potential. It is observed that the plate current fig. V reaches its maximum or is wholly obstructed by three volts positive or five negative of grid potential respectively, when

the plate voltage is from 45 to 200. On the straight portion of the curve A to B the plate current is equally increased or decreased, if an alternating E. M. F. of not too great value is applied to the grid and filament circuit.

However, the grid (input) circuit usually consists of two potentials, one constnat F and the other variable V. The current in the plate (output) circuit may then be expressed as $I = a(E_o + V)$ given by John Mills in his book "Radio Communication"; where $E_o =$ $(gE + F)$. If $V = E\sin(wt)$.is impressed upon the grid circuit and substituted for V in the above formula, $I_B = aE_o^2 + aE^2/2 + 2aE_oE \sin(wt)$ $+ E^2 \cos(2wt)/2$. This shows that the former factor represents an amplified repetition of the input current and the latter represents a double frequency of the input current. When this sinusoidal voltage is impressed upon the grid three subsequent effects come into existence:-(1) input current is repeated with amplification; (2) producing a sinusoidal current in the output; (3) to cause a change in frequency which can be eliminated by having a proper value of the external plate resistance. Before we proceed further in the discussion of the relation between the output current and input potential, let us make a qualitative analysis (fig.V) which will facilitate comprehension of the functions of the pliotron.

If a constant voltage of grid circuit is adjusted to a fairly high negative potential as indicated by point (a), a few positive volts of the incoming wave will permit a large increase of plate current as indicated by de. On the other hand, if the incoming wave is negative and of same magnitude, the plate current is reduced to zero as at point (a') with a relatively smaller amount of decrease (d'n or ep) as compared with its increase. Hence, if the grid and filament are connected to any alternating current or to the secondary terminals of a receiving tuner, the current is not only rectified

but also amplified and charges the telephone condenser C_2 (fig. VII) which discharges through the telephone, probably in one direction. If the grid potential E is given a positive value corresponding to the point c the action of valve is reversed, that is sr is greater than qr or the decrease in the output current is greater than its increase. When the grid potential is adjusted with a value corresponding to point b, it is evident that f'm is equal to fb. So for any grid potential along the curve AB the plate current is equally increased and decreased; and the incoming radio frequency current is simply repeated in the plate circuit with increased amplitude owing to the amplifying action of the valve. It is self-evident that at either point A or C a distorted current is produced and rectified in the output circuit; but along the straight portion of the curve B a distortionless current is produced in the output circuit. In the latter case a cascade amplification may be secured by proper connections between a number of pliotrons; which will be described further on in this paper. Since the grid circuit may, by the Edison effect, derive a potential from the filament, the input circuit is sometimes employed without any battery by simply a proper adjustment of the filament temperature and the plate current. According to the curve of fig. V the amount of energy in the output is supplied by the local batteries of the grid and plate circuits; and for the greatest output current the external resistance (which reduces the effect of double frequency produced by the impressed alternating E. M. F. on the grid) should be made equal to the internal resistance of the pliotron. The extreme mobility of electrons under the influence of positive and negative electrostatic fields makes it possible for us to secure the relaying action both at audio and at radio frequencies. Audio frequency means a wave of frequencies which could be detected by our ears; while the latter is

that of an electromagnetic wave to which the ears could not respond. Whether the pliotron is operating as a detector or as an amplifier only depends upon the adjustments of grid potentials on the characteristic curve.

Another quite important thing to be considered here is that, if the grid circuit is connected with a condenser in series (fig.VII), what is the real function of the latter? It is known that a condenser is used to store up electrical energy. So the grid condenser is inserted in the circuit to store up the charges furnished by the currents which are rectified by the valve action; and the complex actions of the pliotron itself demand a more clear and definite explanation in regard to the manifold functions of the grid condenser. Using the fundamental curve (fig.V), we may assume that, when a negative incoming wave charges the grid condenser, there is no current between the grid and filament; but when a positive incoming wave charges the grid condenser the electrons are drawn into the grid and locked there. Then, with a group of such waves impressed upon the grid, we naturally expect a uni-directional charge of increasing strength gradually piling up in the grid condenser, which is negative on the grid side and causes a steady decrease in the plate current. With this property of the condenser damped oscillations of the incoming wave may be repeated at an audio frequency in the output circuit. Of course, the grid condenser will perform the very same duty with no difference whether grid potential is adjusted for amplification or for rectification.* "At the termination of a group of incoming oscillations," said Elmer E. Bucher, "the charge in the grid condenser leaks off either through the valve itself, or through a special leak resistance of several thousand ohms shunting the grid condenser. The grid then returns to normal potential and likewise the plate current. It is

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* Vacuum Tubes in Wireless Communication. By E. E. Bucher. 1918

evident that each spark at the transmitter eventually reduces the telephone current at the receiver. In other words, the telephone current varies as the spark frequency of the transmitter."

From the foregoing we may conclude that with a pliotron. (I):- (a) when the grid potential is fixed at point "a" (fig.V) and the impressed current is not too small, a rectified and distorted current at audio frequency is produced in the plate circuit; (b) when the grid is used with or without a constant potential along the curve AB, depending upon whether the impressed current is small or large, the current is simply repeated with increased amplitude at radio frequency in the plate circuit. (II) The grid circuit is connected in series with a condenser:- (a) when a constant potential is set at the point A and the impressed current is quite small; a distortion and rectified current is produced at audio frequency in the plate circuit; (b) whether the grid is to be used with or without a constant potential, designed by the curve AB, depends upon the impressed current, whether small or large. With both arrangements the currents of audio and radio frequencies are produced in the plate circuit. In either cases (I) or (II) an audio current is produced over the duration of a group of oscillations and affects the telephone receiver once for each wave train. (III) In receiving either damped or undamped oscillating waves the resultant radio or audio frequency components of the plate current of the first valve can be impressed upon the input circuit of the second one by tuning the latter to the former for further amplification. (IV) Either the resulting radio or audio frequency currents or both simultaneously can be impressed upon the grid of the same valve; and the grid circuit is thus reenforced. This is called the regenerative amplification method. (V) As it has been found that there is a radio frequency current of the grid circuit repeated in the plate

circuit, we may utilize it to produce beat notes, or the so-called "heterodyne"effect, by transfering a part of the energy back to the grid circuit through a coupling system. It is clear that we may use the same valve to produce damped oscillations. (V) The combined operations of generation, amplification and beat reception can be performed in a single vacuum tube simultaneously. These are the principal functions of a pliotron and we see that the controlling member, the grid, directs the motion of the electrons. But this is not a region in which the tri-electrode valve exercises its specific functions; and with slight modification the pliotron actually enters another stage of development. These transformed pliotrons are named dynatrons and pliodynatrons, and they are more powerful instruments than the pliotron.

The dynatron is composed of three electrodes in a evacuated tube like the pliotron. But at a certain voltage it acts as an ordinary kenotron; while at a greater voltage the plate circuit has a negative resistance, that is to say the plate current decreases as the plate potential is increased and so the current flows in the wrong direction. The word "dynatron" is drived from the Greek word "dynamis", which means power. The paths of the electrons from the filament to the plate in a dynatron are confined to a center hole and numerous smaller holes in the anode A (fig.XIII). This device depends on a principle which has been explained by different writers on the basis of a secondary emission of electrons from a plate within a certain range of plate potential, which is always lower than the anode potential. It is claimed that, when a primary electron from the incandescent filament F (fig.XIII) impinges on the plate P with high velocity, a secondary emission of electrons ensues and the latter are absorbed by the anode A. It is known that each primary electron may liberate as many as 20 secondary electrons.

For example, in a Röntgen ray tube we all know that, when X rays strike metals or gases, a secondary emission of three kinds takes place, namely, scattered X-rays, characteristic X-rays which differ for different materials, and corpuscular rays consisting of negatively charged bodies. Important facts are:-(1) the secondary rays are polarized, (2) the intensity of emission of the corpuscular rays is directly proportional to the atomic weight of the materials and of the distance between the primary and secondary plate and (4) the corpuscules are deflected by a magnetic field at right angles to their path. We have a similiar set of phenomena in a dynatron to those of X-rays; and for a dynatron we use metals of high atomic weight in order to obtain a copious emission of corpuscules while the other two secondary rays are neglegible. We, therefore, may conclude that a secondary emission in the dynatron forms a condition analogous to that of the X-ray tube; and the electrons of secondary emission identify themselves with the corpuscules.

Let us now consider the characteristic curve of the operating dynatron with its functions. The characteristic curve is obtained by a gradual increase of plate potential (P) by moving the point T (fig.XIII) upwards, while the other things remain constant. When the plate acquires a potential more than 25 volts, the primary electrons from the filament with a high velocity begin to impinge on the plate P; and the secondary electrons from the atoms are thus liberated and readily received by the anode A of higher potential. As the potential is further increased, there will be more primary electrons moving toward the plate; and since one electron liberates more than 20 electrons the secondary electrons are naturally increased by multiplication. Thus the current of the anode A is greatly increased. The plate loses more and more electrons, and finally becomes negative with respect to the anode A. The current

is apparently reversed. This reversed current is indicated by the portion ABC (fig.VIII) on the curve. When the plate and anode reach the same potential the anode A can absorb no more electrons; the plate then acts as usual, that is it gradualy becomes positive again and the current in the plate is increased as indicated by CDF. Near 100 volts for the plate the number of secondary electrons leaving the plate is equal to the number of primary electrons entering it. At more than 100 volts the secondary electrons exceed the primary electrons, and the plate current is reduced to zero; and then the plate current again becomes positive with respect to the filament. In the dynatron the anode A does not act like the grid in the pliotron: it is simply a true anode at a sufficiently positive potential to receive the secondary electrons. *"It acts, therefore, in a manner very roughly analogous to the electrical behavior of the Poulsen arc and is capable of being an amplifier or oscillator. The arc, however, has a negative resistance characteristic only for increasing current, but acts as an open circuit for decreasing current. The dynatron has a stable negative resistance in either case. Furthermore, the dynatron has no hysteresis or lag, but responds instantaneously, because it does not depend on gas ionization, as does the arc." It is easy to see that if a straight line is drawn perpendicular to ABC representing some positive value of resistance inserted in the plate circuit, a resultant resistance B'BB" is secured. Then the plate circuit characteristic will be represented by the dotted curve OB'BE and a very small change of voltage in the neighborhood of the value, B, will cause a very great change of current in the anode circuit as indicated by B'B". An amplification of as much as 1,000-fold is obtained. The dynatron with plate voltage corresponding to the point B acts like the grid of a pliotron; and if an oscillating coil is included in the plate

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* Radio Telephony by A. N. Goldsmith.

circuit it will produce in the latter an undamped alternating current. Currents at all frequencies between less than one cycle per second and 50,000,000 cycles per second can be generated with the dynatron whose output is as much as 500 watts.

Since the electrons of secondary emission depend upon the number of the primary electrons;we may employ a grid used in the pliotron to control the number of electrons emitted from the filament to the plate in a dynatron. This tube of four electrodes is called pliodynatron,which owing to its negative resistance enhanced by the amplifying power of the grid makes a powerful amplifier. In the simple pliotron either a positive or negative potential of the grid causes an increase or decrease in the plate current respectively. In the pliodynatron,when the grid is positively charged more electrons move toward the plate ,resulting in the greater emission of the secondary electrons;and thus the plate current is decreased,and the anode current is increased. Conversely, the grid ,when negatively charged ,has a reverse effect on the plate and anode. Now,if the plate voltage is adjusted to the point B (fig. VIII)a slight decrease of plate voltage effected by the grid voltage means a very large increase for the plate current;while a slight increase of the plate voltage results in a great decrease for the plate current,which in turn means a large increase for the anode current. So the anode-plate circuit actually constitutes an alternating or pulsing current instead of the filament and plate circuit at in the pliotron. Thus it becomes possible to control the output of the tube by varying the grid potential;the pliodynatron is a very efficient oscillator and is used in the radio telephony.

Chapter III

The Uses of the Audions.

All the fundamental principles in the construction of a vacuum tube have been definitely brought out before us;and the operating features to a greater extent have been considered. But the uses of the vacuum tubes must be given fuller consideration. Before we take up the uses of the tubes we must consider (1) the oscillating circuit consisting of a condenser and an induction coil,and (2) the coupling systems;for these are indispensable for the production of an alternating current and constitute a part of the radio transmitting and receiving sets and wave meters. A typical radio circuit comprises an inductance coil,a condenser,and a source of electromotive force in series. An electromotive force of sine-wave form may come from a small coil in which an alternating electromotive force is induced by the current in a neighboring circuit. The reactance of this kind of circuit is $(wL-\frac{1}{CL})$. If two circuits are in series and the resistance is a negligible part of the total impedance (except at resonance),the inductive reactance,wL,is the predominating portion of this at high frequencies,and the capacitive reactance predominates at low frequencies. The reactance of a parallel circuit is $(\frac{1}{wL}-wC)$. The inductive susceptance $\frac{1}{wL}$,predominates at low frequencies,and the capacitive susceptance wC,at high frequencies. If two series circuits are coupled,or a series and parallel circuit are coupled;the interference of the undesired waves may be sppressed and eliminated by tuning one of the circuits to the latter.

In general,there are four methods of coupling of the circuits for the transference of energy:-(a) By direct connection across an inductance coil or direct doupling;(b) by electromagnetic induction; (c) by inductive coupling; (d) by direct connection across a condenser or capacitive coupling. When the reactance of one circuit

in the coupling system greatly increases the total impedance of two circuits and thus affects the current flowing in the other, the coupling is said to be "close". When the reaction of one circuit upon the other is negligible, the coupling is "loose"; and the energy is merely transfered from the primary to the secondary circuit. Since a circuit of an induction coil and a condenser is an oscillating circuit, the antenna circuit may be coupled to the latter and the incoming waves are reproduced. In any circuit we may have two kinds of oscillations; one is produced by the circuit itself or the "free" or "natural" oscillations of the circuit without any supply of the external alternating E. M. F.; on the other hand the "forced" oscillations are those impressed on the circuit by an external alternating E. M. F. A high frequency current of decreasing amplitude which makes it different from that of the sine-form is called a damped or oscillatory current. The damping of the current is caused by the resistance of the circuit in which a current is surging back and forth. An undamped current is an alternating current of equal amplitude. If the current of the transmitting or incoming wave (either damped or undamped) is of such high frequency that the ear can not respond; and if this alternating current is to be detected it is necessary for us to combine two currents of slightly different frequencies to produce beat notes of audible frequencies. The beat notes necessitate two currents of radio frequencies, and the problem of obtaining the latter is solved by the vacuum tube.

A circuit is coupled for the reception of the incoming wave, and by varying its inductance and capacity a point may be reached where the frequency of the circuit is the same as that of the incoming wave. The current then attains its maximum. This is called tuning or getting a state of resonance of the circuits. When the

impressed E. M. F. has the frequency of resonance, the impedance is merely the resistance of the circuit. For all other values of the impressed frequency the impedance is composed of resistances and reactances. The current of the damped E. M.F. at resonance does not reach its maximum as in the case of an undamped E. M. F. A wave meter is a circuit of known frequency tuned to the other circuit whose frequency is to be determined. The wave length can be thus easily calculated.

The kenotron is only used as a rectifier to convert the currents of radio frequencies into decaying direct currents, which are detected by the telephone. This decaying action is affected by the presence of a constant current flowing in the filament-plate circuit. When the constant current flows in the same direction as that of the incoming current, the plate-filament current is increased; and vice versa. The value of the constant current is set at the point on the characteristic curve, fig.III, corresponding to B where the increase in the plate current is greater than its decrease. A simple receiving set with kenotron rectifier used in radio telegraphy is shown in fig.VI. The antenna A and the primary L are connected to the earth F. The antenna or open circuit is coupled to the receiving or closed circuit LC. The decaying uni-directional current over each group of the incoming oscillations produces one "click" or sound in the telephone as shown by fig. VI. The plate current is first set to a value corresponding to B at the lower bend fig. IV, and then the current of the filament is fixed by varying the resistance R until the maximum current of the incoming oscillations is obtained. The resistance between the plate and filament is high, and so the L is designed for the production of a maximum potential by a given group of incoming oscillations; and the best result is thus secured. The filament F at the positive

half of the incoming oscillation will wholly obstruct the electorn current flow in the circuit C'LPF and reinforce the plate current through the telephone. The value of the condenser C is adjusted until a maximum response is obtained. Of course,the best result is only obtained through constant trial,because the plate voltage sometimes depends on whether the signals are strong or weak.

The pliotron used as an oscillation detector can be connected in a number of ways. A simple arrangement is shown in fig.I; but the more efficient method of connection for a single tube is shown in fig. VII. The operating feature,the adjustments of the voltages and tuning the circuits have been given in the previous discussion. The circuit suggested by Armstrong is called the "regenerative system of amplification." We have shown that a pliotron (through the use of a grid condenser during the reception of damped oscillations) is used as a detector whose plate current varies simultaneously at an audio and radio frequency. As shown by the characteristic curve any potential in synchronism with the grid potential can be employed to re-inforced the latter above and below the maximum value supplied by the incoming wave. A still greater change in the telephone current may then take place. This regeneration is accomplished by impressing the audio and radio frequency current separately or simultaneously back upon the grid through any one of the four coupling systems as mentioned in the above; and thus the amplitude of audio frequency current and the oscillations of radio frequency current are increased. It must be kept in mind that the plate and grid really constitute a condenser which is utilized in a capacitive coupling. The amplification of the plate current depends upon whether the reactance voltage of the coil L (fig.VII) assists or opposes the voltage of the local battery B combined with the valve actions of the characteristic curve.

We must now analyze the action of the reactance potential L upon the grid negative charge. In the first place we may imagine a negative charge impressed upon the grid. By the valve action of the tube the plate current is decreased; but,if the induced voltage L is in the same direction as the voltage of the battery B the plate potential is increased,drawing more electrons out of the filament to the grid and locked in the latter by virtue of the self-capacity of the plate and grid. This increased negative charge on the grid is bound to produce a still further decrease in the plate current,which simply means still more energy transfered from the plate to the grid circuit than if the reactance were not present. In the second place suppose the grid positively charged. Exactly the reverse is then the case,that is the increase of the plate current would be still greater than if the reactance L were absent; or in other words the energy is transfered back from the grid to the plate circuit. At the end of this cycle some electrons are accumulated in the grid condenser and at the termination of a wave train the electron current of increasing amplitude during the successive cycles leaks off the grid through the resistance R in shunt with the grid condenser. It is clear that the external alternating current is simply re-oscillated by the grid-filament circuit at increased amplitude and with prolonged frequencies. The rectifying action,during the reception of damped oscillations,occurs at audio frequencies. This shows that the current of the plate oscillatory circuit must be set in phase with the incoming oscillations of the grid by means of the electrostatic regenerative coupling. However,a condenser may be placed in shunt with L in order to rectify the incoming wave of lower frequency corresponding to a longer wave length. With the other methods of coupling the fundamental action of the plate is the same. If it is desired to impress the audio frequency of the plate current upon the

grid, the plate circuit is electromagnetically coupled to the receiving circuit in which the secondary is shunted with a condenser (fig. VII dotted line) and the amplification is secured. And if both audio and radio frequency are to be impressed upon the grid it is only necessary to have the plate circuit coupled electromagnetically and inductively with the grid circuit.

The battery B' is closed and the correct degree of incandescence is obtained by trial or by a small ammeter connected in series with the battery. The voltage of B is a known value necessary for the current operating characteristic. Then the open and the closed circuits are tuned to the distant transmitted wave of low or high frequency. The value of L is usually relatively large in comparison with the capacity C_3. Finally the plate circuit is coupled through the regenerative transformer I until the maximum strength of signals is obtained. With a capacity C_3 of .001 microfarad the transmitted wave of lower frequency characteristic of wave lengths longer than 10,000 meters can be detected. With a little modification the receiving set may be arranged.in many different ways. In the case of regenerative cascade amplification the plate circuit of the first valve is inductively tuned to the grid circuit of the second valve (fig.II); but a coil is inserted in series with the grid in each valve, and a battery B_3 is connected in shunt with the condenser. With very slight change of setting the audio frequency current may be amplified by the regenerative cascade method.

The pliotron detector as used in the reception of undamped or continuous waves is unique in its function. As is stated in the above, in order to produce a beat note two currents of slightly different frequency are required . The pliotron has the unsurpassed ability to produce beat notes from currents of 500,000 cycles per second, while a mechanical device such as the tone-wheel is only

practicable for radio reception at 25,000 to 60,000 cycles per second. If a current of say 100,000 cycles per second is superimposed upon another current of 101,000 per second, the resultant current or beat notes will be 1,000 per second. One of the alternating currents may come from the external source and may be impressed upon either an open or closed circuit through the inductive coupling. Since the plate current is composed of the audio and radio frequency currents, the external current may be replaced by the latter as in the case of regenerative amplification; and thus the damped current of beat notes is obtained. The process of producing this kind of current is called a heterodyne process. The only difference between the regenerative and the heterodyne system is:-(a) In the former case the couple between the grid and plate circuit is "loose" while in the latter it is "close". (b) For the regenerative purpose the frequencies of the grid current generated from the oscillations of the plate current and repeated back to the latter, must be the same as that of the incoming current. But for the heterodyne the grid and incoming currents must be of slightly different frequencies. (c) The constant grid potential must be large enough for the rectification. The heterodyne combines in a single tube the functions of regenerative amplification, the generation of local oscillations, the production of beats and their detection.

It has been stated that a sudden variation of plate voltage due to the induced voltage in L (fig.VII), and the resulting change of the plate current through the inductive coupling (PS), sets the grid circuit L"C,S in oscillation. The grid then acts to vary the plate current at radio frequency. This self oscillation of the grid circuit is only possible by transferring a part of energy liberated by the plate circuit back to the grid; this part of energy may be equal to or exceed that applied to the grid circuit. The frequency of the oscillations is equal to the natural frequency of the grid

circuit, if the capacity of the valve (grid to filament) is less than C_1; otherwise the frequency is determined by the reactance of the plate circuit. In the previous discussion we say that the electrons are gradually piled up in the grid condenser; and the plate current is reduced during the reception of the damped current, which in turn reduces the amplitude of the grid circuit oscillations. But as soon as the electrons entering the grid condenser are equal in number to those leaking off the grid through the valve itself or through the resistance, R (of several hundred thousand ohms fig.VII), the grid circuit, (fig.IX O) then oscillates steadly. When the oscillations generated by the grid circuit become steady and repeated in the plate circuit as shown by O_2; the incoming oscillations, whose frequency differs slightly from the grid oscillations and does not interfere with the latter, change the grid potential and are amplified through the regenerative coupling l. Simultaneously these amplified oscillations interact with the grid oscillations producing the beats by the "close" effect of the coupling as indicated by O_4. The beats alternately increase or decrease the grid potential above and below the steady grid oscillations of O_1. The amplitude of the grid-filament potential is thus changed as indicated by O_5, which is repeated in the plate circuit as shown by O_6. It is evident that the amplitude of the repeated radio frequency plate current varies at an audio frequency, and the approximate telephone current is that of O_7. A telephone receiver coupled to the circuit will receive the current at an audio frequency; for the plate current is an almost simple harmonic alternating current. It is clear that if it is desired to use the tube oscillator in the transmitting set we only have to couple the grid circuit to a microphone circuit instead of the antenna circuit, and the plate circuit to the latter. This microphone circuit contains a battery; and the alternating current

is produced by the modulation of the human voice (fig.X).

For longer wave length 6,000 and 10,000 meters, the tuning for the grid and plate circuits is done principally at the condensers C_1 and C_3; which are varied simultaneously. But the capacity of the condenser is always very low. The coupling of the plate and grid circuits is carefully adjusted for maximum reception. The plate circuit in fig.VII is tuned to the incoming signal by L, C_3, P (C_3 may by fixed), and the grid circuit by L'', S, C_1. A fixed capacity can also be found for condenser C and C_2 approximately .00003 and .001 microfarad respectively. Condenser C_2 acts as a by-pass for the radio frequency current around the head telephone and battery. The primary coil of the regenerative couple P is a part of the tuning circuit. In the audic frequency tuning, the telephone must form a separate circuit containing a condenser and heavy coil which is electromagnetically coupled to the plate circuit. The coupling between the antenna and grid circuit is omitted, and so the latter is directly connected to the former. By heterodyne beats we can eliminate at will the undesired wave by (a) radio frequency tuning, (b) change of the note, and (c) audio frequency tuning. The audio or radio frequency current may be still further amplified by the cascade connection in which the beat phenomena is omitted; but the primary and secondary of the electromagnetic couple of the first valve must be shunted by the condensers, and the inductive coupling of the first and seond valves is earthed. The cascade for the employment of the heterodyne beats is connected in the same way as for the regenerative amplification.

In the wireless telephone the vacuum tube not only occupies an important place but has solved the most difficult problem of modulating or controlling the large powers employed at the transmitter by the usual telephone microphone, which at its best can only handle

from one-half to one ampere of current. Although there are various types of high power microphones they are not very satisfactory, involving as they do much mechanical complexity owing to their inherent imperfections and large heat production;while with the vacuum tube the ordinary microphone transmitter such as employed in the land line telephony is sufficiently good. The oscillations generated by the grid circuit at radio frequency are not those of the audio frequency of the human voice but only pulses of direct current traversing the telephone receiver. If the amplitude of the radiated energy is modulated at an audio or vocal frequency through the microphone (fig.X),the amplitude of the rectified telephone current will be varied at a corresponding vocal frequency. Then the diaphragm of the telephone will vibrate at the same rate as the diaphragm at the transmitter. The secret success of controlling the output current is attributed to the fact that a very small change of the grid potential will cause a relatively large variation of the plate current according to the characteristic of grid potential-plate current (fig.V). So a small current in the microphone circuit varied by the human voice at vocal frequencies will make the grid potential rise and fall accordingly.

The microphone circuit may be either coupled to the grid,or antenna circuit,to produce variations of grid potential corresponding to the amplitudes of speech . The radiophone transmitter shown in fig.X was suggested by White of the General Electric Company. The plate circuit is fed at X Y with a direct current of high voltage. The output of the pliotron T is fed into the plate circuit of the pliotron T' through the audio frequency transformer PS. The secondary of this transformer is shunted by the condenser C, which acts as a practically perfect by-pass for the radio frequency curents in the plate circuit T without passing any appreciable

quantity of audio frequency current from S_1. The valve T produces the oscillations which are transferred to the antenna by the loose inductive coupling of L L_1 and L L_2. The advantage of this arrangement is that the control of the potential is very stable. The plate potential of the oscillator T is varied by the potential of the grid which is directly affected by the current from the microphone circuit P B T. A large amount of energy has to be transferred to the plate circuit T' for the antenna radiation, and hence the amplifier, T', is necessary. S_1, S X', y', and XY leads are fed from an especial designed transformer. Fig. XI indicates another method of setting. The grid and plate circuits are electromagnetically coupled at L_1 and L, both circuits being tuned to a given frequency of oscillation by the condenser C and the inductance L_1 L. This is a long coil tapped at the center to the filament. When C is tuned a large amount of energy is drawn from the grid to the antenna and radiated in the form of electromagnetic waves. With the good design of the induction coil L_1 L, two or three hundred volts may be impressed upon the grid and a very great modulation of the antenna current thus secured. Valves employed for the generation of radio frequencies at high powers have grid potentials of 150 volts negative, and the plate potentials may attain 2,000 volts or more. There are numerous methods of connection as in the case of regenerative amplification. The circuits by Espenchied for simultaneous telephonic transmission and reception is shown in fig. XII * "The output of the radio frequecy alternator A is amplified by the bulb V_1, the carrier wave being modulated at a radio frequency by the microphone T through the coupling L. The output circuit of V_1 is coupled to the input circuit of the valve V_2, the output circuit of which is inductively coupled to the antenna through the transformer P,S. A balancing-out circuit

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* Vacuum Tubes in Wireless Communication By Elmer E. Bucher.

shunted across circuit X including the condenser C and the coupling M serves to impress a modulated radio frequency current on the input circuit of the detection tubes V',V". Thus currents of the transmitter frequency which may be induced in the antenna W' are balanced out leaving the receiving system free to respond to waves of a frequency differing from that employed in the antenna system W. Correct phase relation of the opposing currents is obtained by means of the condenser C. Now it is also possible to send both telegraphic and telephonic messages by the same electromagnetic wave which contains both audio and radio frequencies and is detected by the two circuits simultaneously.

The dynatron is used as a detector and oscillator based on the characteristic curve. The dynatron of fig. XIII when it is used as detector has its plate circuit coupled inductively to the antenna circuit;but as an oscillator the plate circuit is coupled to the microphone circuit. The plate potential is adjusted by moving the sliding contact T fig. XIII over the high voltage battery B until the point C or A is rached (fig. VIII). A group of the incoming oscillations is rectified in the same way as by the pliotron. When the circuit including the telephone T and the condenser C is tuned to the desired audio frequency and coincides with the group frequency of the incoming oscillations,the sensitiveness of the system becomes very great. The selectivity is also greater than in the case of the pliotron,for the damping is not increased by the dynatron which therefore consumes no energy on account of having a negative resistance. The dynatron is set for producing the beats of the self heterodyne system. When a dynatron is connected in parallel with the grid circuit of the pliotron,the energy lost by the latter is compensated by the former;and if the plate circuit of the pliotron is connected in parallel with the plate circuit of the dynatron the

direct current voltage amplification can be increased from 12-fold for the pliotron to 624-fold for the circuit of pliotron and dynatron.

The pliodynatron as a detector for radio frequency currents is shown in fig.XIV. The operating voltage is set corresponding to point A or B (fig.VIII). A circuit is inserted to increase the selectivity of the circuit or to amplify the incoming oscillations. The circuit is thus set on the verge of oscillation for the reception of damped waves, or set into oscillation for the production of heterodyne beats. Final tuning is made between the plate and grid circuit which are tuned simultaneously to the incoming oscillations, which are thus greatly amplified. The pliodynatron as an oscillator in the transmitting set is shown in fig. XV. The potential variations corresponding to speech are placed upon the grid by an audio frequency impulse through the magnetic coupling L. It is claimed that radio telephony over 16 miles is easily accomplished by a single pliodynatron with ten watts of power. It is doubtless true that if pliodynatron are connected in cascade like pliotrons the radio telephony over thousands of miles can be achieved and even more efficiently than with the pliotron.

There are many other important uses of vacuum tubes. In the physical laboratory where a small direct current of a few milliamperes at very high voltage is required; the kenatron serves the purpose well. In spectroscopic work the pulsating effect of the current is entirely eliminated with proper connections of the circuit. The combination of kenatron and transformer may be used to replace the static machines and the still more mechanical rectifiers that are used to produce high voltage direct current for X-Ray tubes and precipitation of dust and smoke. These vacuum tubes are thus used to produce direct current at high voltage.

Chapter IV

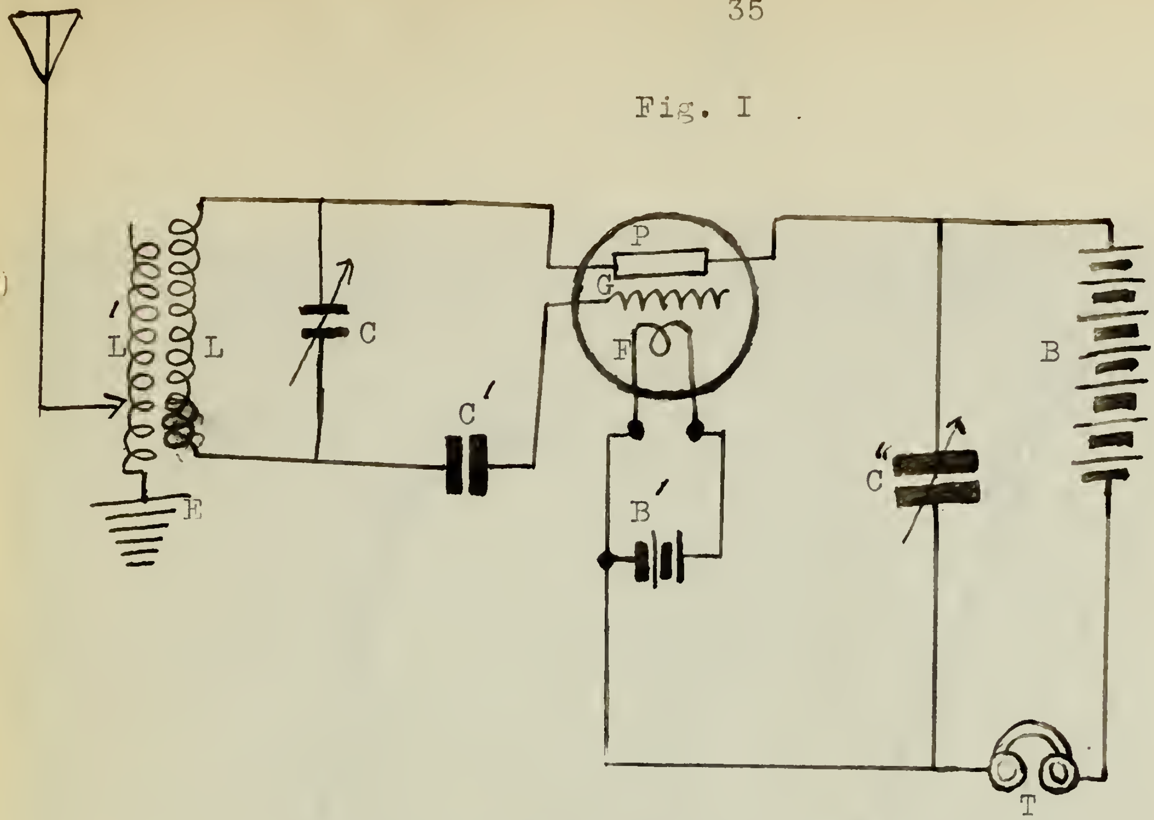
Vacuum tubes have thus far been proven to be the simplest and yet the most powerful instrument in the development of radio-telegraphy and telephony. There is the generator of radio frequency oscillations of Duddell-Poulsen arc, which has been used in the past years and regarded as the most simple among the other three types of generators; viz (1) the multiplication of frequency within the machine of Goldschmidt, (2) the multiplication of frequency outside the machine of the Arco alternator and (3) the direct generation of frequency in the machine of the Alexanderson alternator. Although the newer, and high powered arcs are employed for radio telegraphy, yet the life of the arc is limited and possesses no power of self-amplification and detection. A detector of either crystals or metallic filings or some other has to be supplied for the arc generator. In radio telephony the arc generator is greatly embarrassed by the difficulty in controlling the output current, implying a very laborious construction of microphone transmitter or arc circuit itself. In general, the arc generator is more complex in mechanical structure than the vacuum tube, and requires an elaborate cooling system. Although the large current of the output circuit of the vacuum tube leads to the device of heat-resistance, it is comparatively simple in its construction.

In regard to the other types of generators mentioned in the above, it is needless to speak about the limitation of cycle production but the most cumbersome construction is involved along with tremendous mechanical labour. The amplification of the current generated by these generators can only be produced by a certain magnetic amplifier specially prepared. When the vacuum tubes are used as generators the filament current and the reactions of the coupling system on the oscillator must be kept constnat; otherwise

the frequency emitted by the generator is subjected to a variation and the beat reception is not feasible. Again the atomspheric disturbances (stray interferences) have been greatly modified by the appearance of the vacuum detector and oscillator.

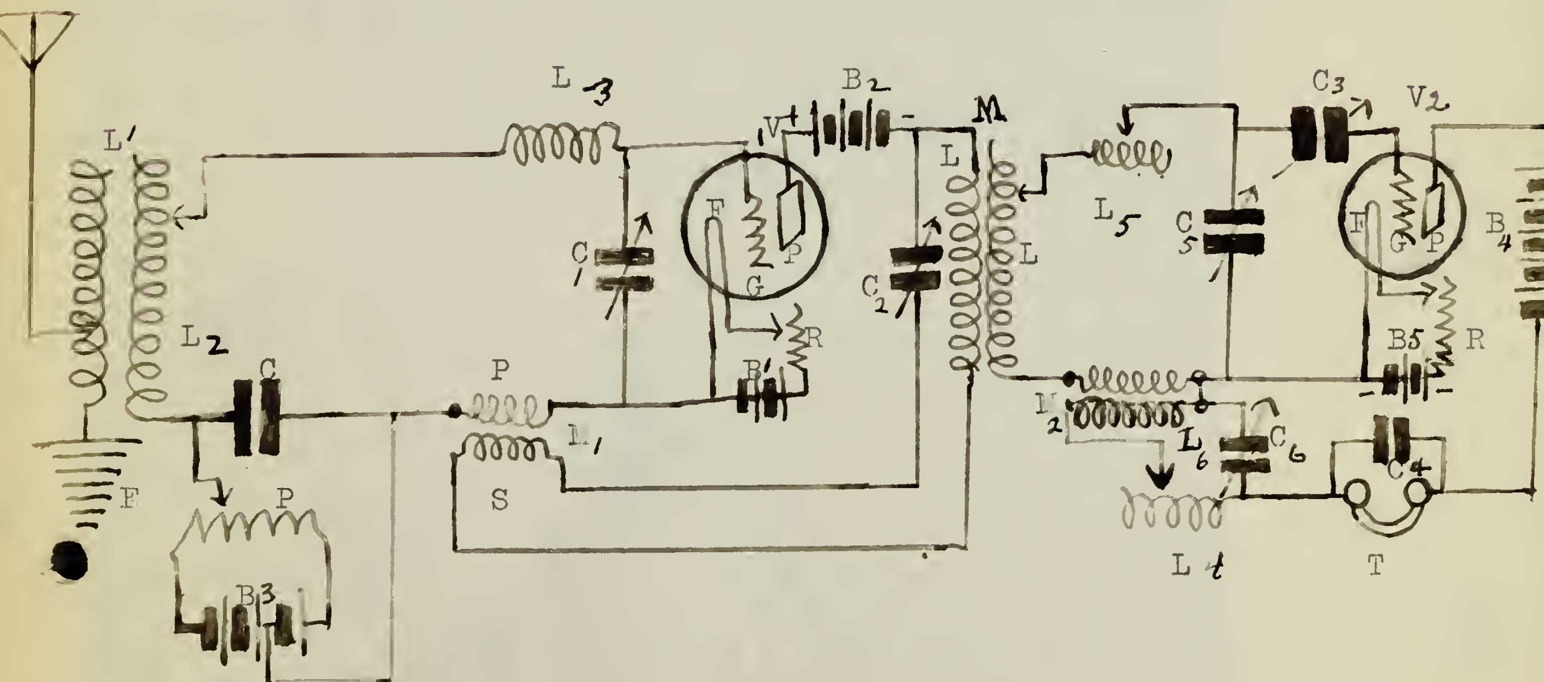
With the introduction of the vacuum tube enter radio dancing and singing which are distinctly heard hundreds of miles away from the transmitting station. The pliotron is used in radio telephony at a distance of from 6 to 7 thousand miles;and in the near future all news may be distributed to rural districts throughout the world by means of radio telephony. Though the sensitiveness,the selectivity and all other qualities are unsurpassed by the other generators, detectors or amplifiers,the further development of the tube is likely to depend on the pliodynatron. The pliodynatron has the characteristic of large negative resistance and therefore is a powerful amplifier. It is a very efficient oscillator with very little or no loss of energy;and the control of its grid potential is perfectly stable,and so the speech (which is transmitted by means of the electromagnetic waves generated by the grid) is articulate and clear. Truely,the electrons in the form of the electric current make a profound success in radio communication.

Fig. I

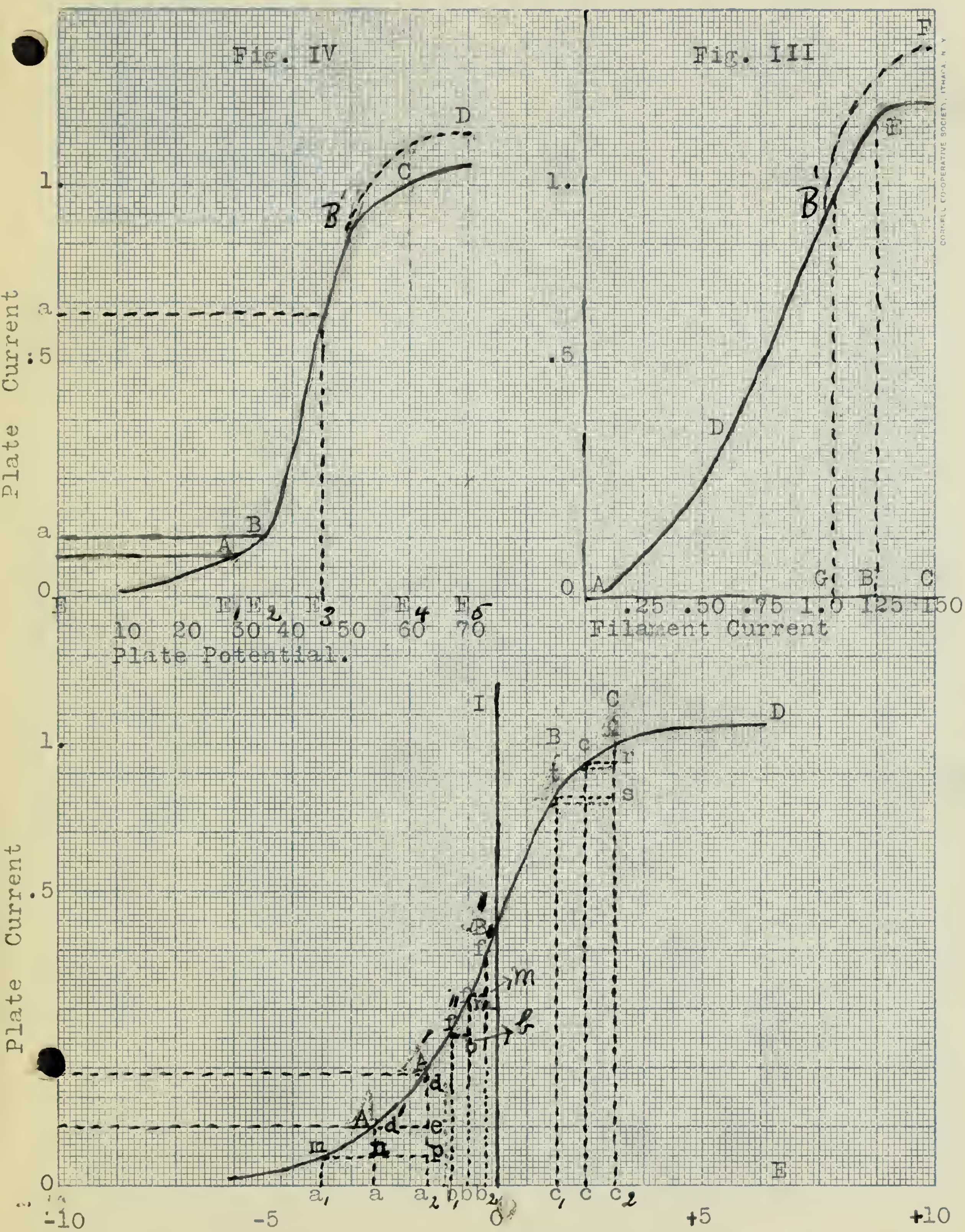


Lee de Forest Ultraudion Circuit

Fig. II

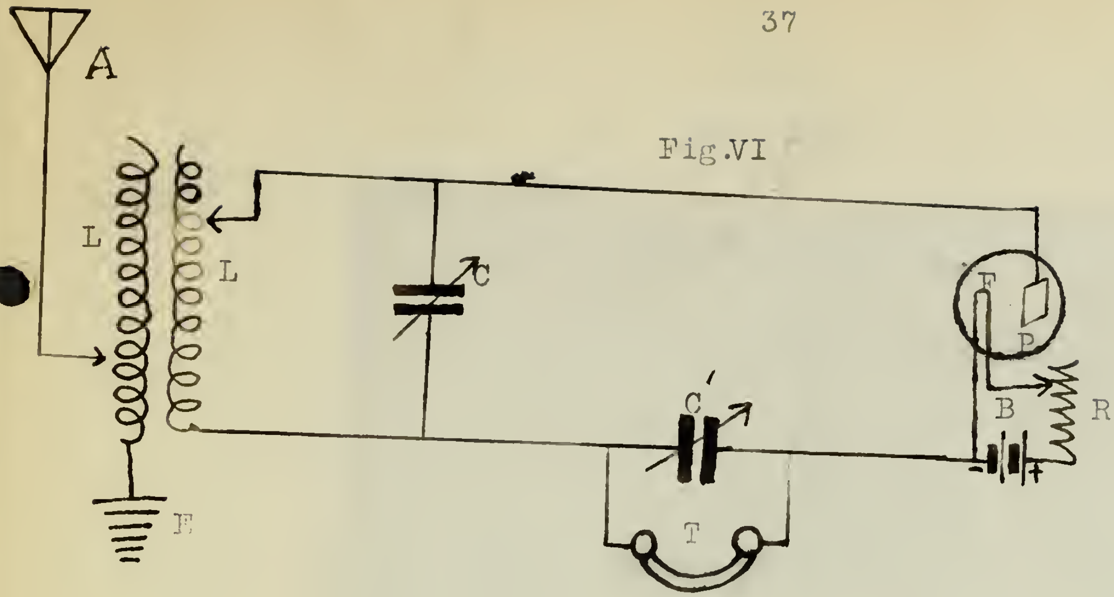


Combined regenerative and cascade systems for the reception of continuous waves.



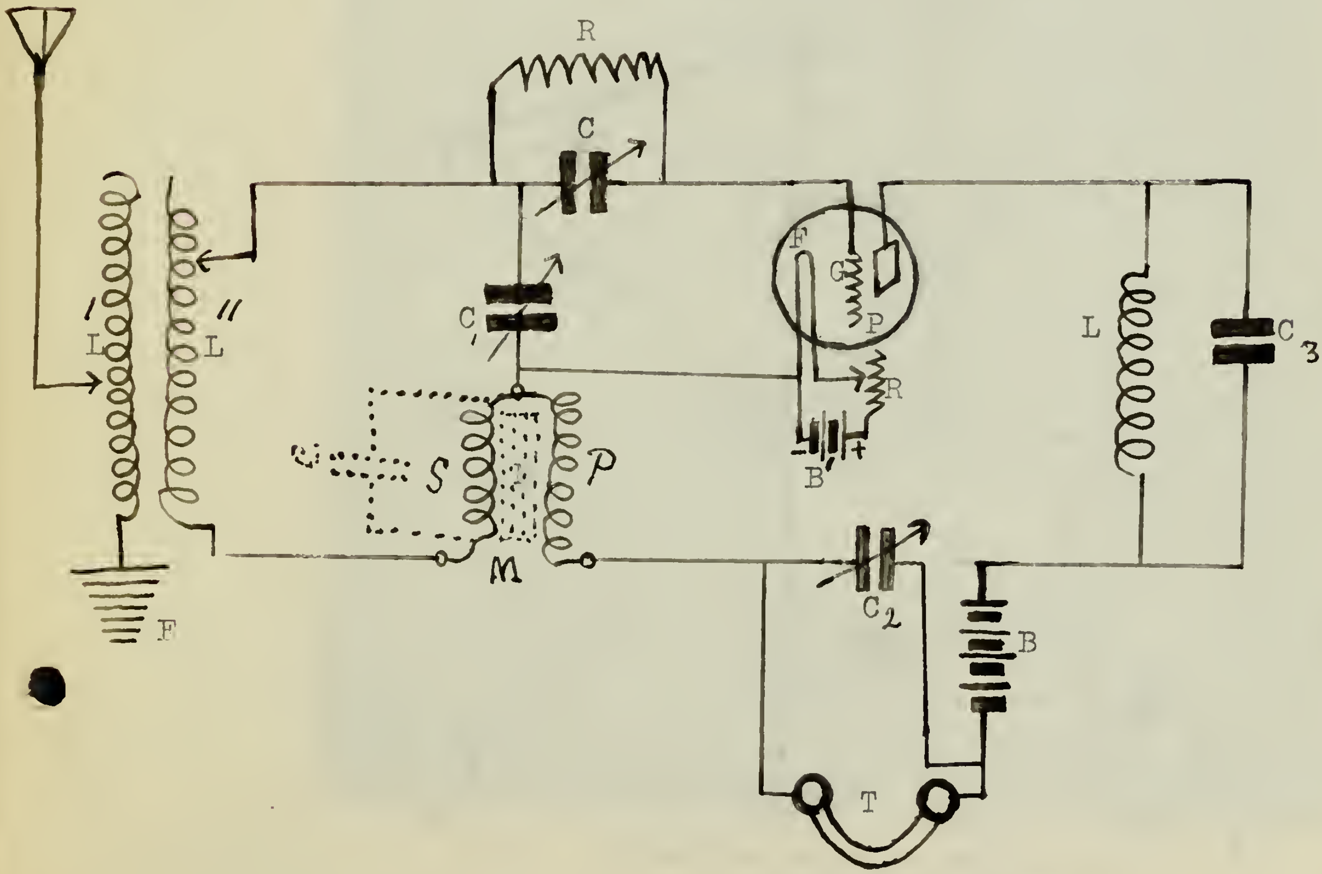
Constant Grid Potential Fig. V

Fig.VI



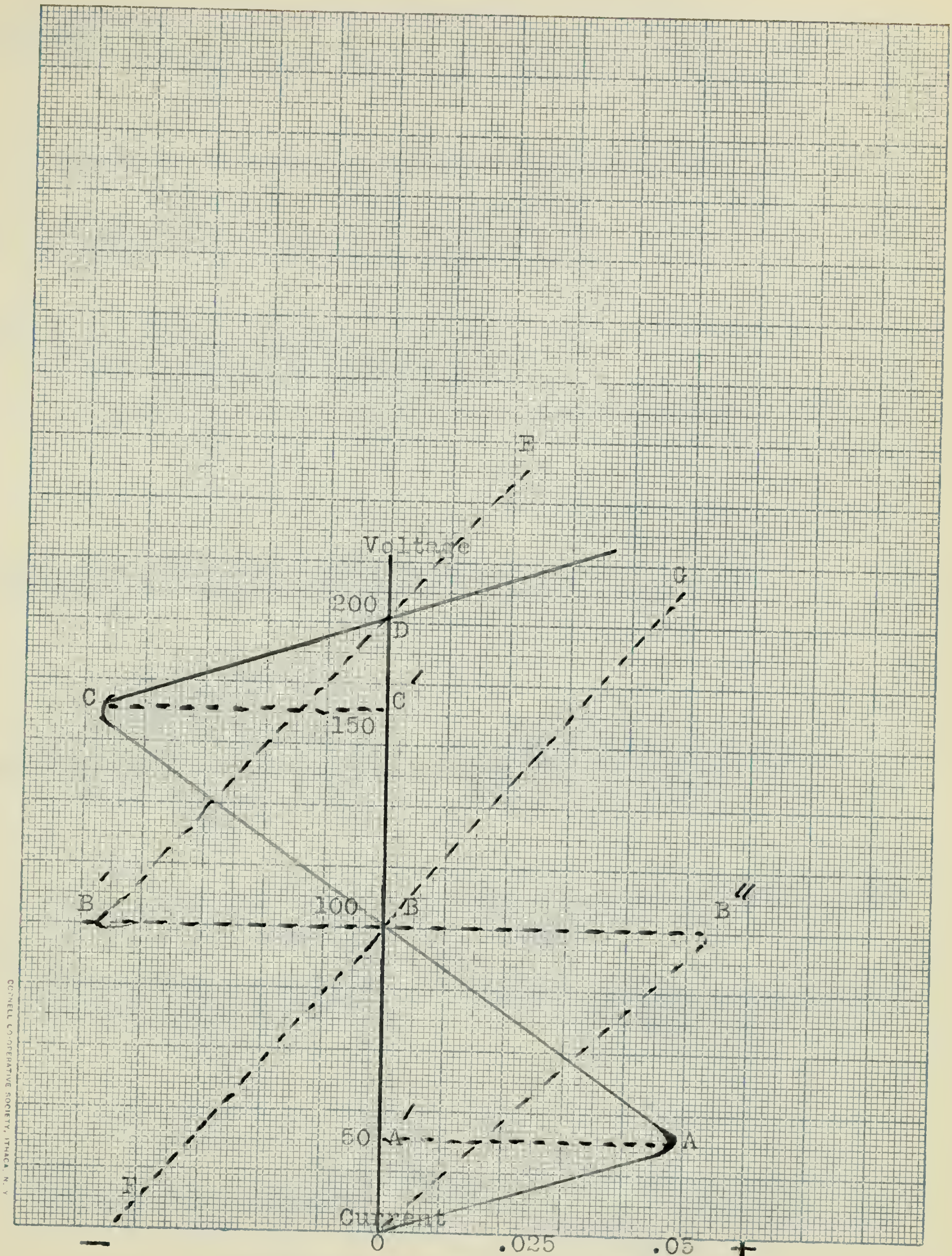
Kenatron detector

Fig. VII



Pliotron detector

Fig. VIII



Dynatron voltage amplifier characteristics.

Fig. IX

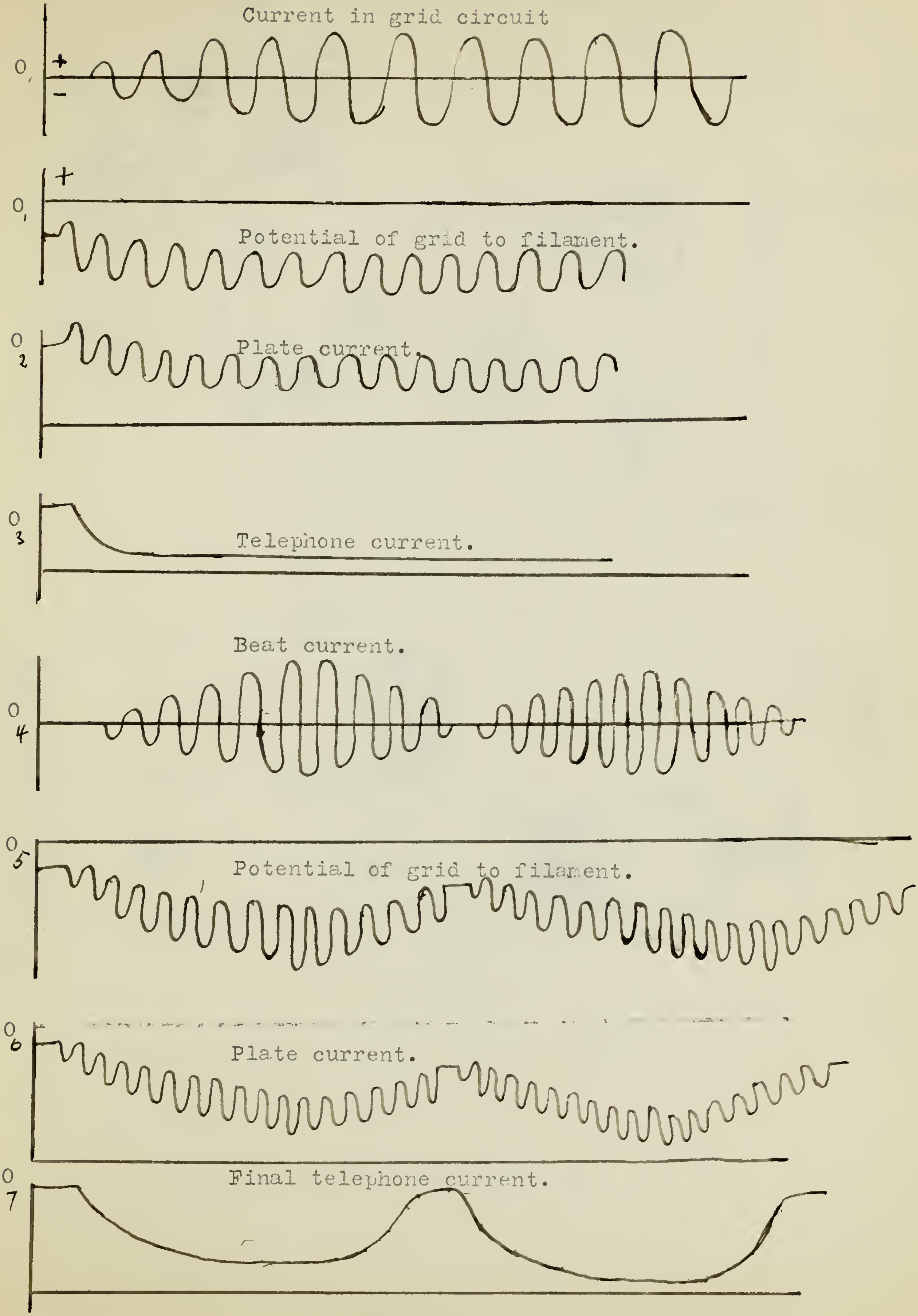
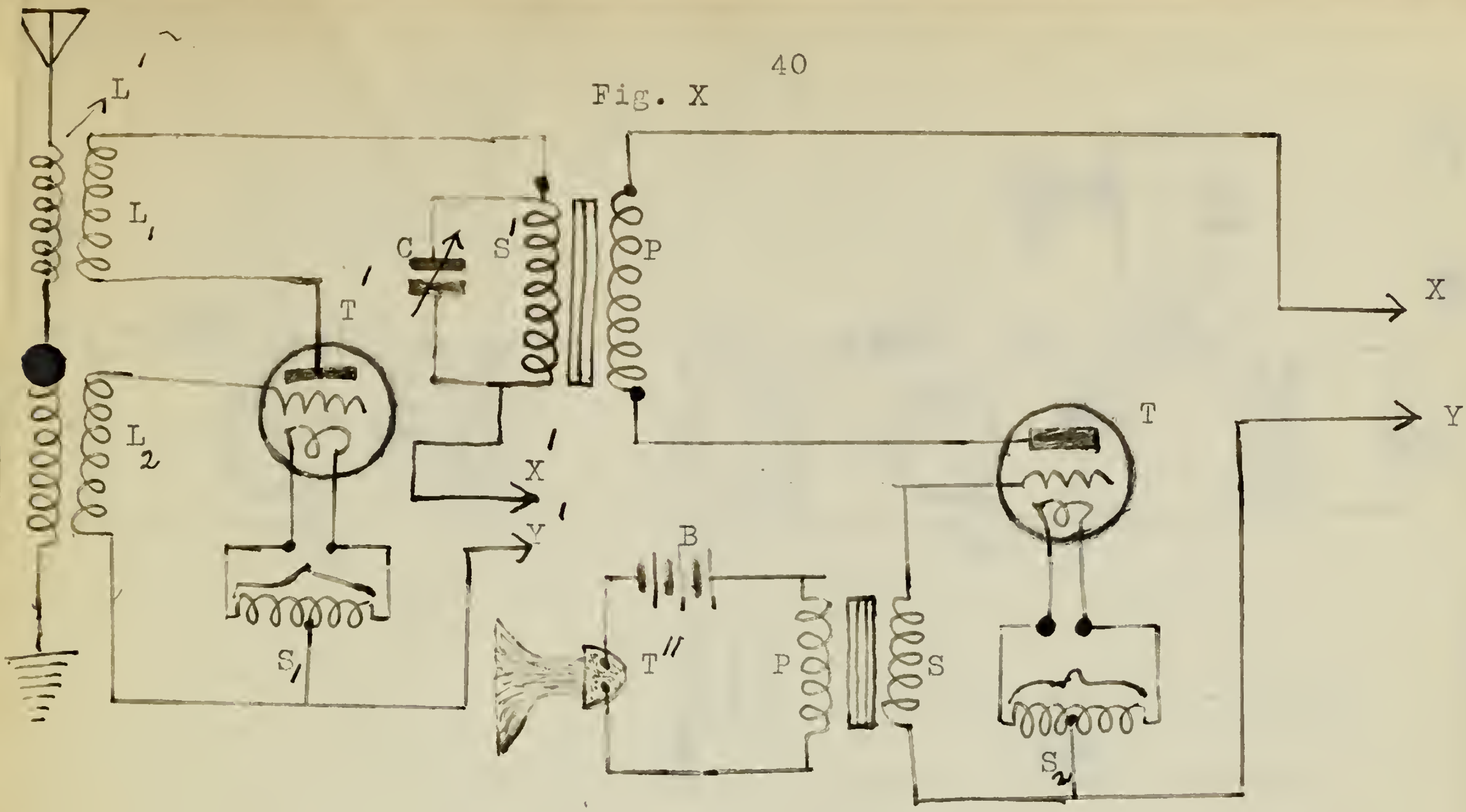
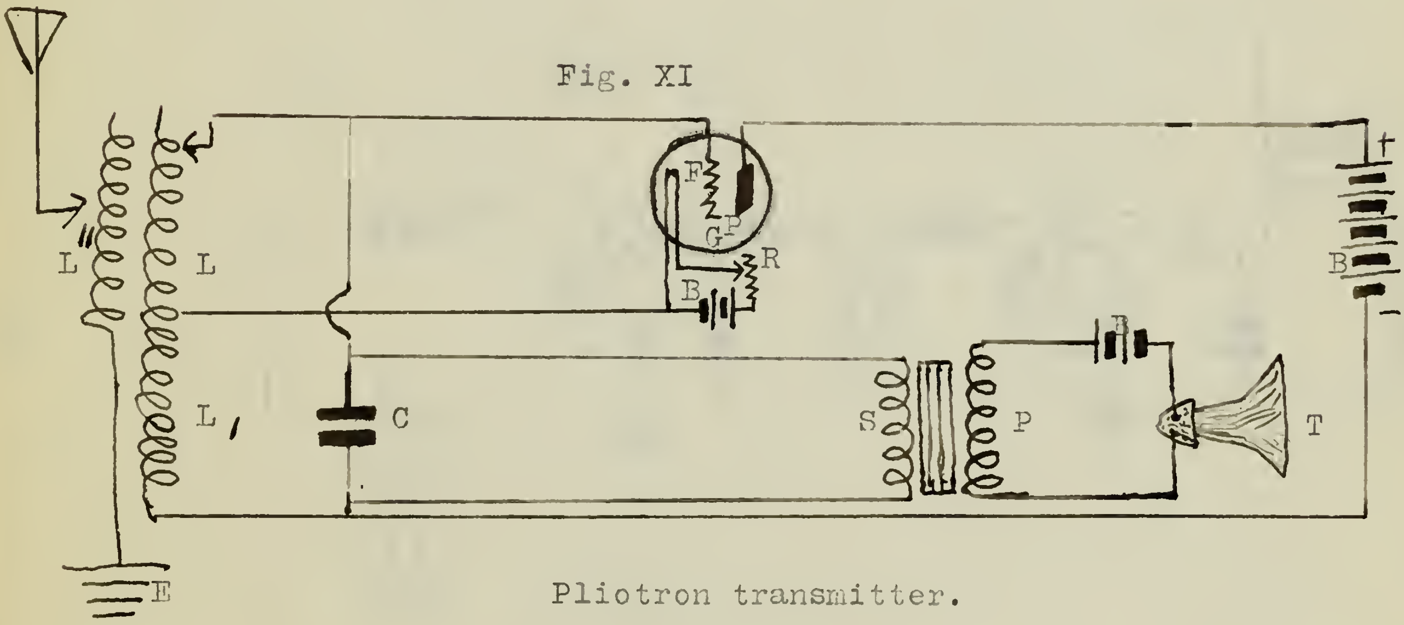

Current in grid circuit
Potential of grid to filament.
Plate current.
Telephone current.
Beat current.
Potential of grid to filament.
Plate current.
Final telephone current.

Fig. X



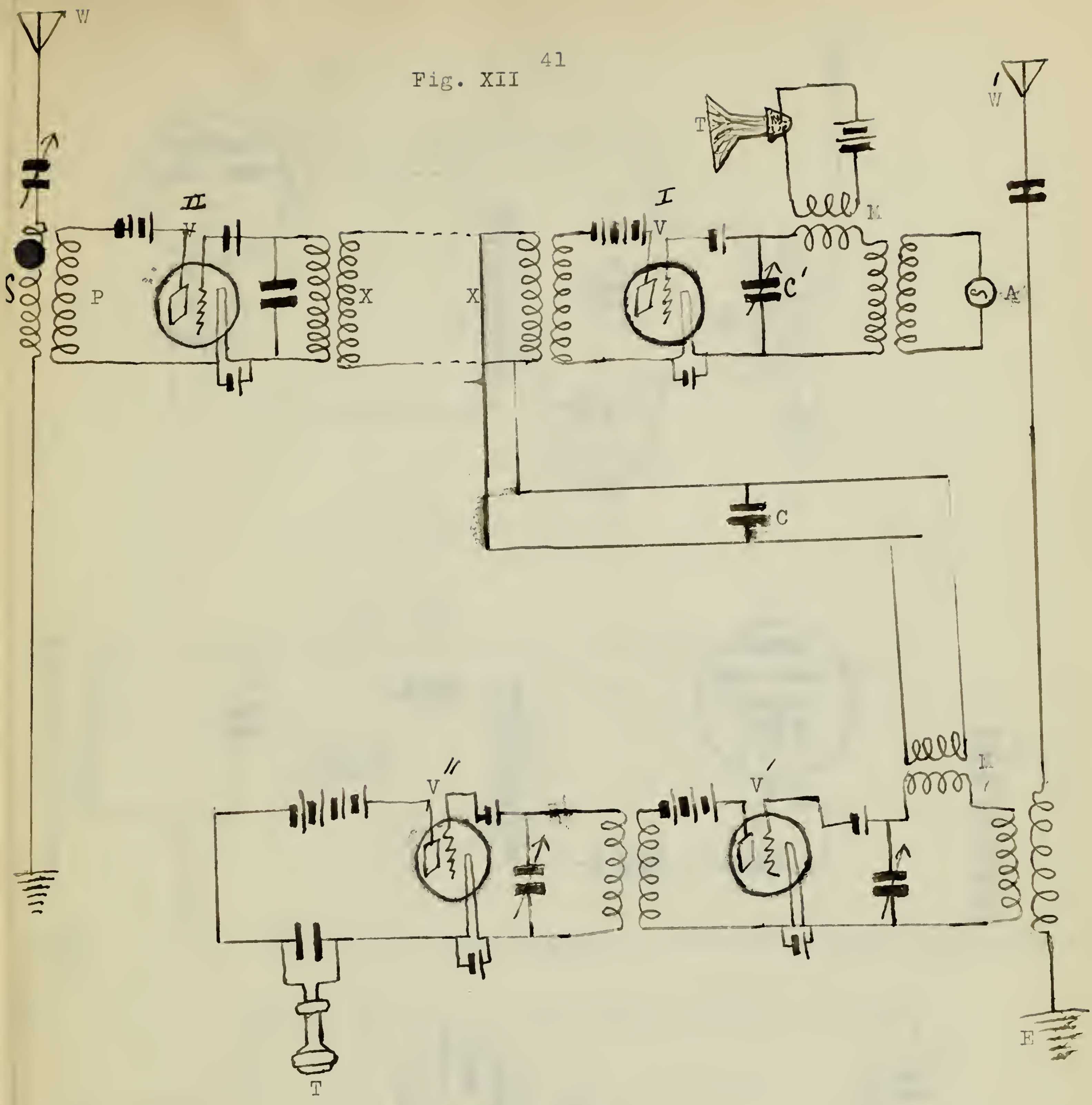
Pliotron oscillator used in the transmitting set.

Fig. XI



Pliotron transmitter.

Fig. XII



Espenchied's method of simultaneous telephonic transmission
and reception.

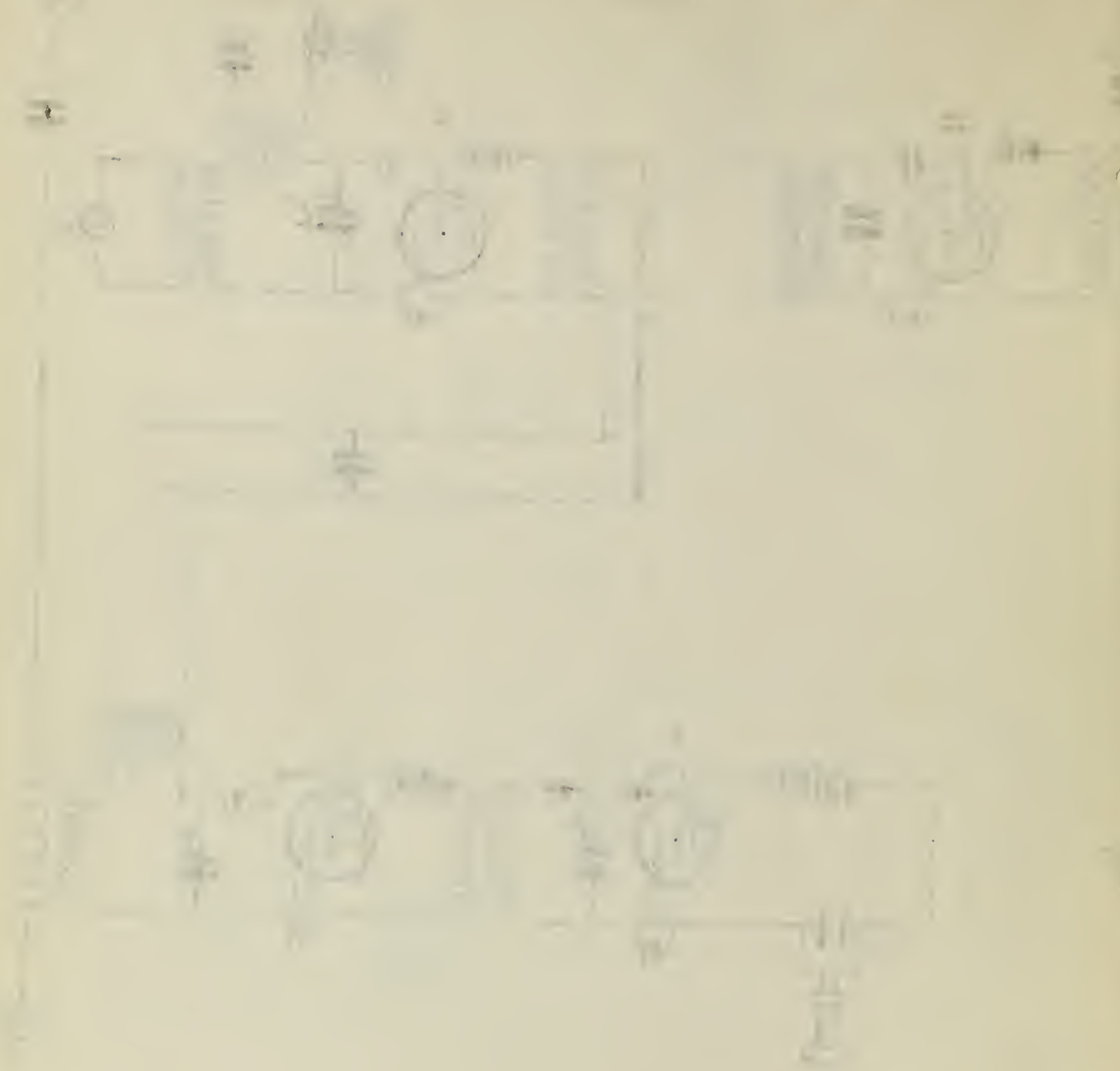
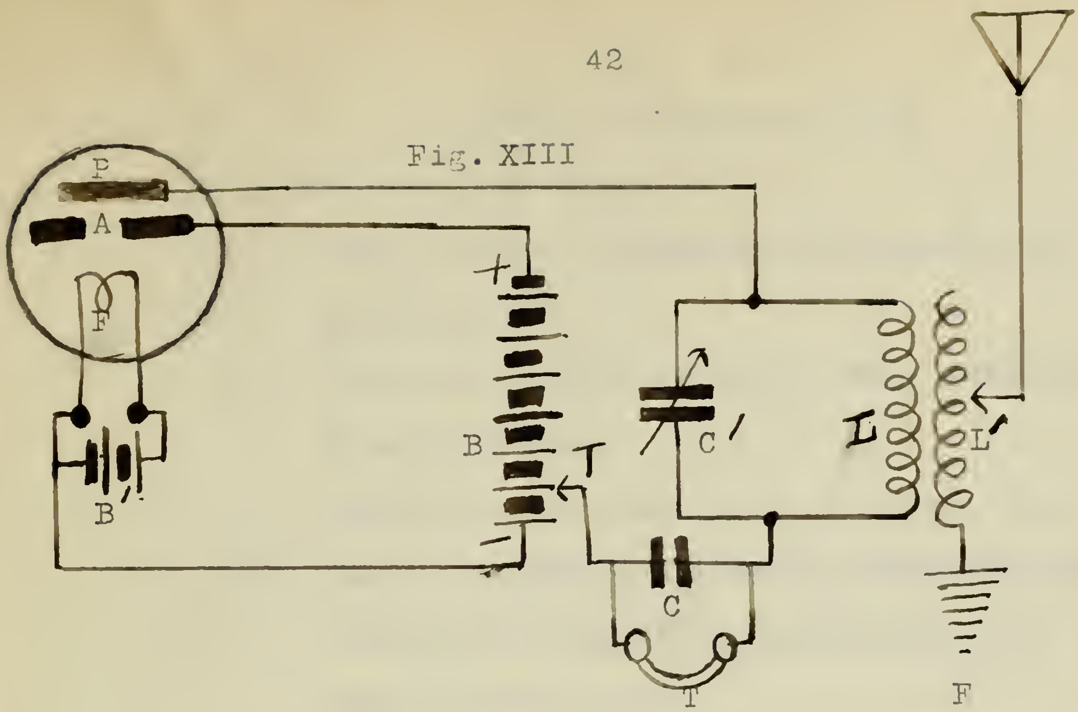
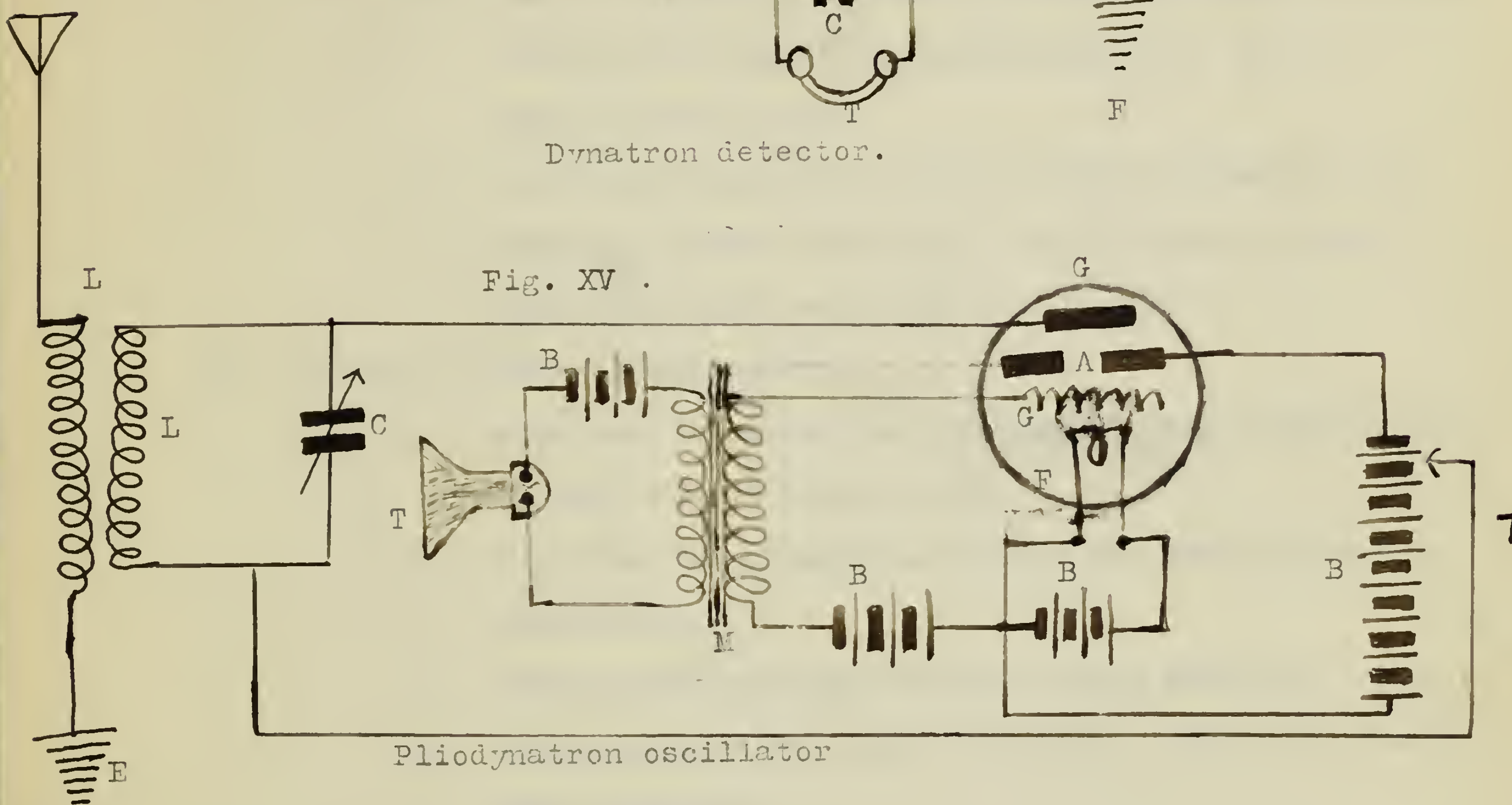


Fig. XIII



Dynatron detector.

Fig. XV .



Pliodynatron oscillator

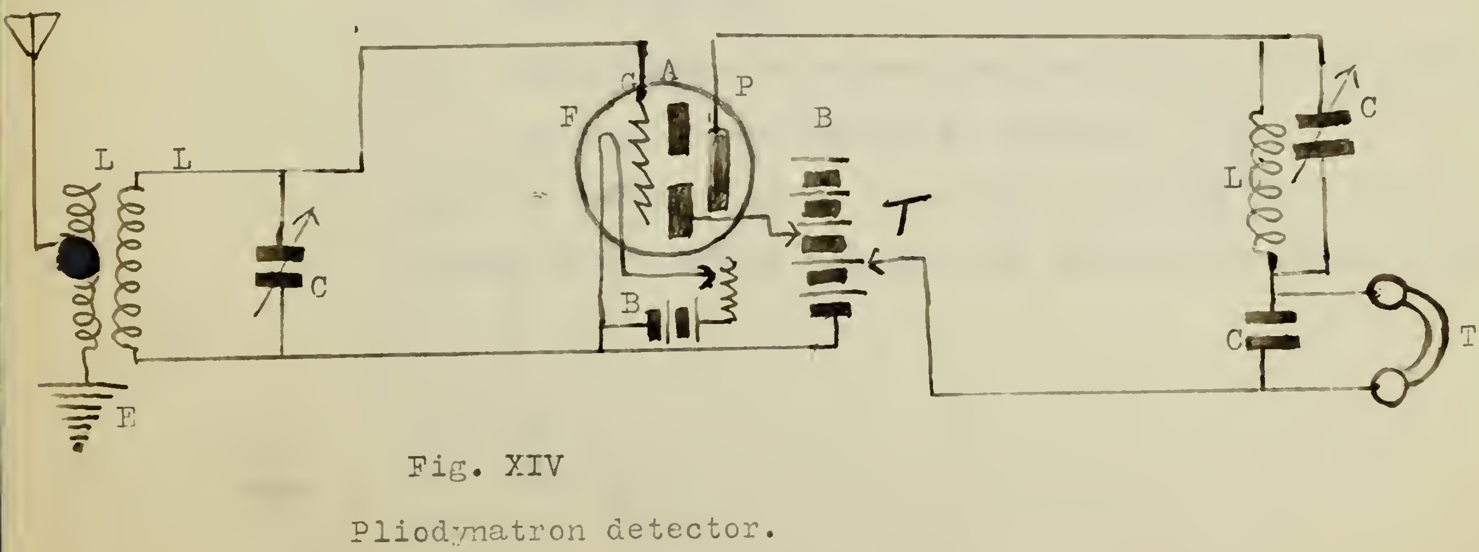
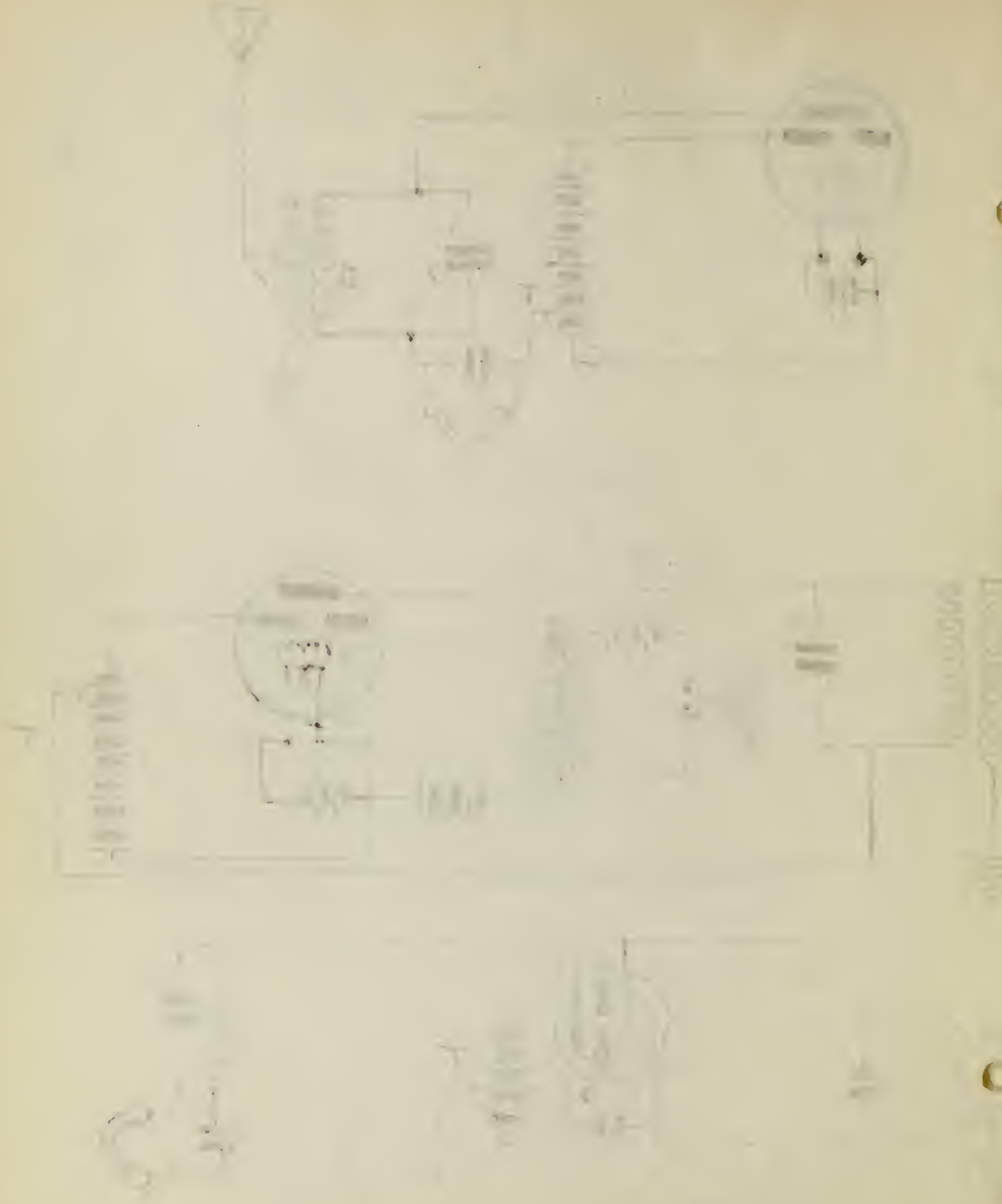


Fig. XIV

Pliodynatron detector.



A List of Reference Books

I Books of Greater Importance :-

1 Vacuum Tubes in Wireless Communication, Elmer E. Bucher, 1918.

2 The Principles of Electric Wave Telegraphy, J. A. Fleming, 1906.

3 Radio Communication, First Edition, John Mills, 1917.

4 Radio Telephony, Alfred N. Goldsmith, August 10, 1918.

5 Practical Wireless Telegraphy, Elmer E. Bucher Second edition 1917.

6 Wireless Telegraphy, Charles Brain Hayward, 1918.

7 Manual of Radio Telegraphy and Telephony, Samuel Shellburne Robinson, 1918.

II Books of Lesser Importance :-

1 Wireless Telegraphy and Telephony simply explained, Alfred Prowell Morgan, 1916.

2 Wireless Telegraphy and Telephony, Henry Eccles William, 1916.

3 Wireless Telegraphy, William Henry Marchant, 1914.

4 Principles of Wireless Telegraphy, George W. Pierce, First edition.

5 Experimental Wireless Stations; their theory, design and operation, Philip E. Edelman, 1914.

All the books given in the above list have been read except I (1) and II (2), (4), (5) which were partly studied

I Periodicals of Greater Importance

A Scientific American Supplement :-

1 Wave Detectors for Wireless, J. A. Fleming. 84:357-8 December 8, 1917.

2 Thermoionic Detector. 84:277-8 November 3, 1917.

3 Problems in Wireless Telegraphy, J. A. Fleming, 75:301-3 May 10, 1913.

B Electric World:-

1 Pure Electron Discharge and its Applications in Radiotelegraphy and Radiotelephony, I. Langmuir 65:1247 May 15,1915.

2 Operating Features of the Audio, E. H. Armstrong 64: 1149-1152 December 12, 1914.

3 Ultraudion Detector for Undamped Waves, Lee De Forest. 65:465-6 February 20, 1915.

4 Kenotron,a Hot Cathode Rectifier, Dushman 65:659-60, March 13,1915.

5 Telegraphy Telephony and Signals, Irving Langmuir 65:1247 May 15, 1915.

6 Resonance in Radio-telegraphy, J. Hettinger 63:421-3 481-7, February 1914.

C General Electrical Review:-

1 A new Device for Rectifying High Tension Alternating Currents, Dr. Saul Dushman, March 1915.

D Scientific American:-

1 Principles of Radiotelephony, J. L. Hogan Jr. 112:286-1, March 27, 1915.

E Electrician:-

1 Theoretical Discussion of the Audion, Marious Latour, December 1, 1916.

II Periodicals of Lesser Importance :-

A Scientific American Supplement:-

Wireless Communication and Aeronoutics, W. Dubillier, 78: 189-90 September 19, 1914.

2 Radiotelegraphy; its Uses and Possibility in the War, G. E. Mitchell 86;88-90, August 10, 1918.

3 Improvements in Radiotelegraphy and Radiotelephony, W. H. Eccles 77:346-7, 1914.

4 Wireless Transmission of Energy, E. Thomas. 79:252-3 270-1, April 17, 1915.

B Electric World:-

1 Goldschmidt System of Radiotelegraphy, E. E. Mayer, 63: 640-1 March 21, 1914.

2 Discharge Tube used as a Wireless Valve, 66:1269-70, December 4, 1915.

3 Wireless Telegraphy Receivers for Use in Cable Telegraphy, L. W. Austin and L. Cohen 69:714 April 14, 1917.

4 Stray Interferences in Radiotelephony, A. N. Goldsmith, 71:784 April 13, 1918.

5 Double-Audion Type of Receiver, A. H. Taylor, 65:652-5 March 13, 1915.

C Scientific American :-

1 Progress in Radiotelephony, J. L. Hogan Jr. 114:82-3 Jan. 15, 1916.

2 Long Distance Wireless Telegraphy: Distance achieved in recent Tests 113:319 October 9, 1915.

D Electrician :-

1 On the Wave Length and Radiation of Loaded Antenna, Balth Van der Pol. September 7, 1917.

All the articles given in the above list have been read by the writer of this thesis.