Aug. 2, 1938. J. H. O. HARRIES 2,125,719

ELECTRON DISCHARGE TUBE

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Fig. 1

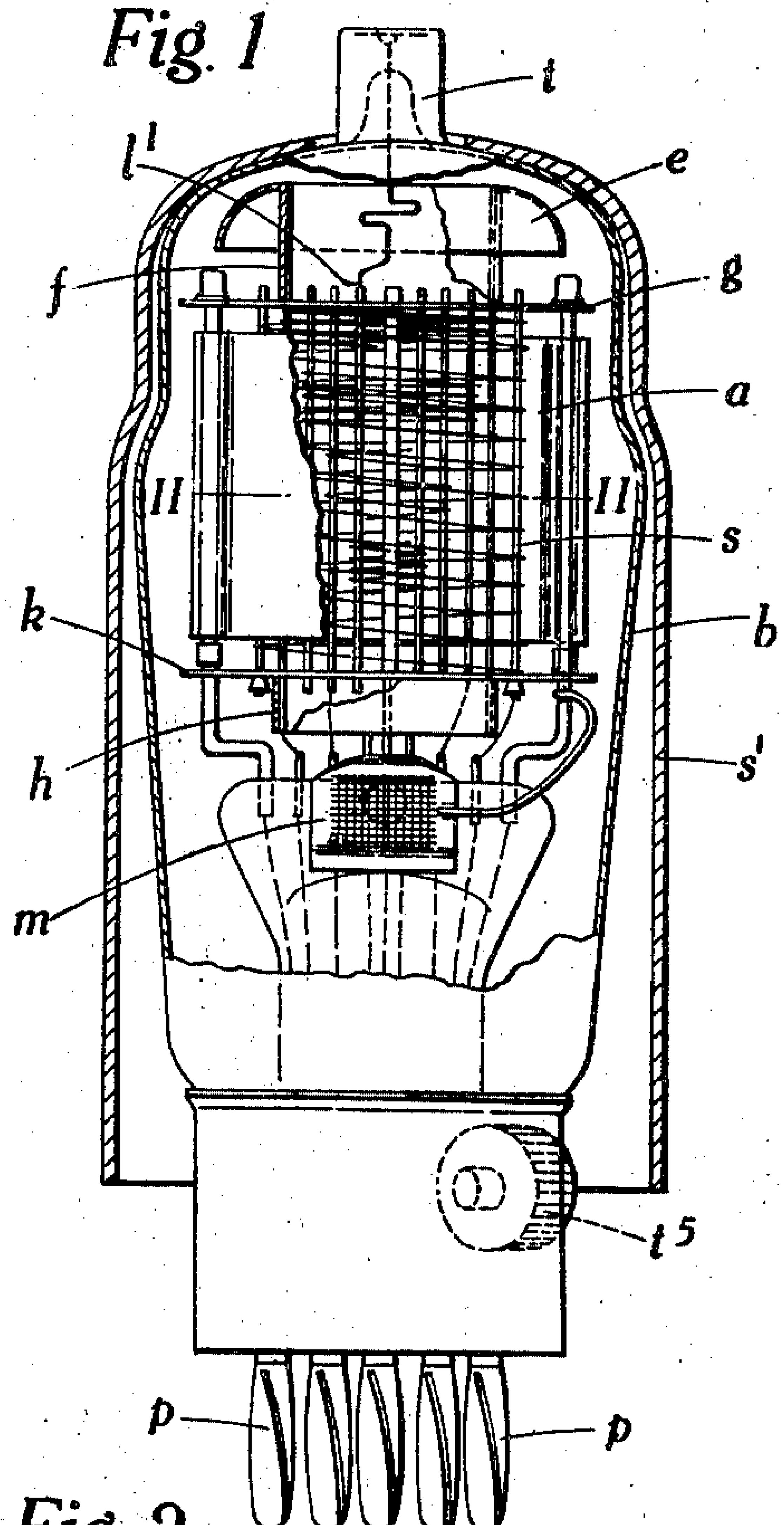
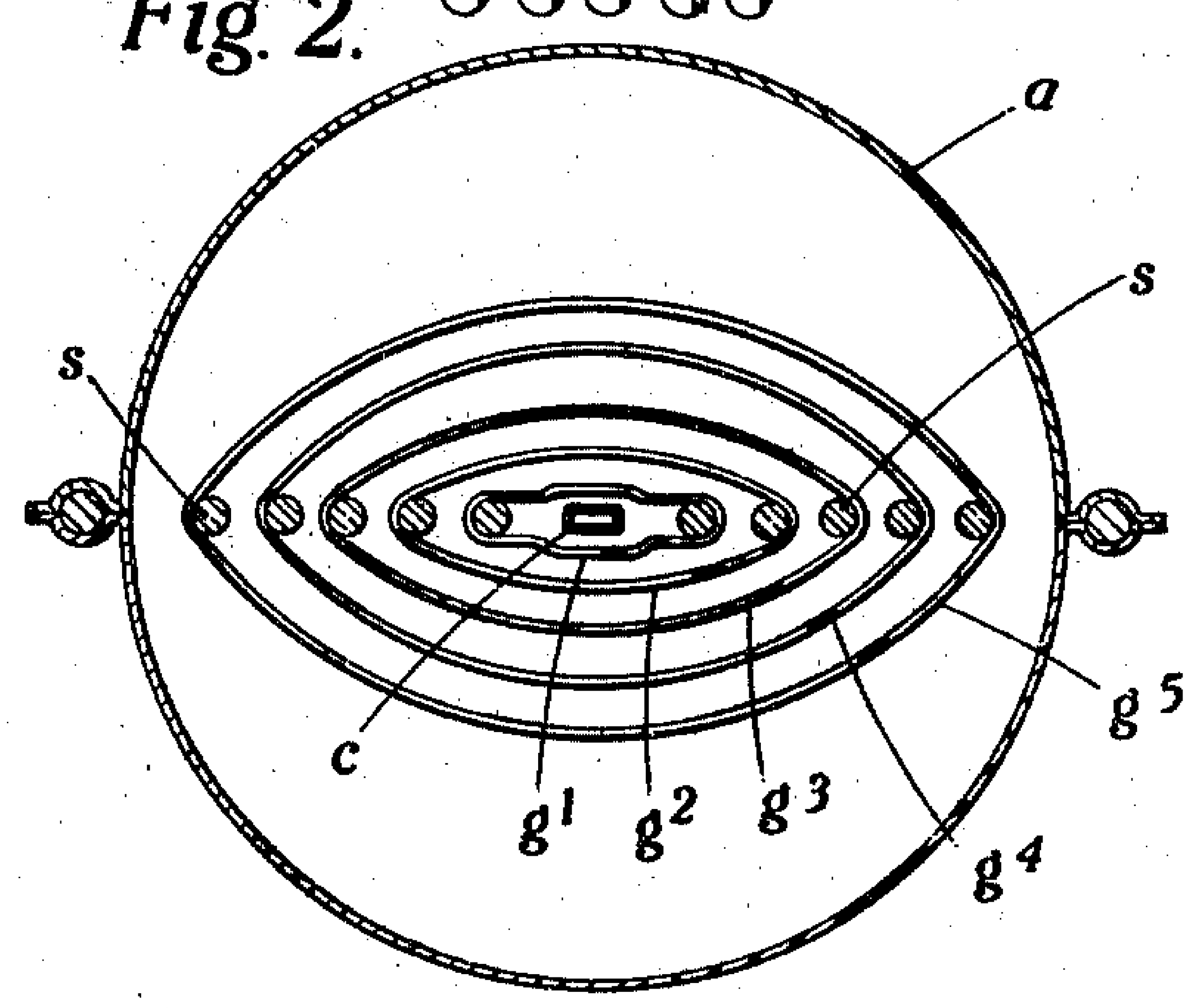


Fig. 2.



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ELECTRON DISCHARGE TUBE

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Fig. 3.

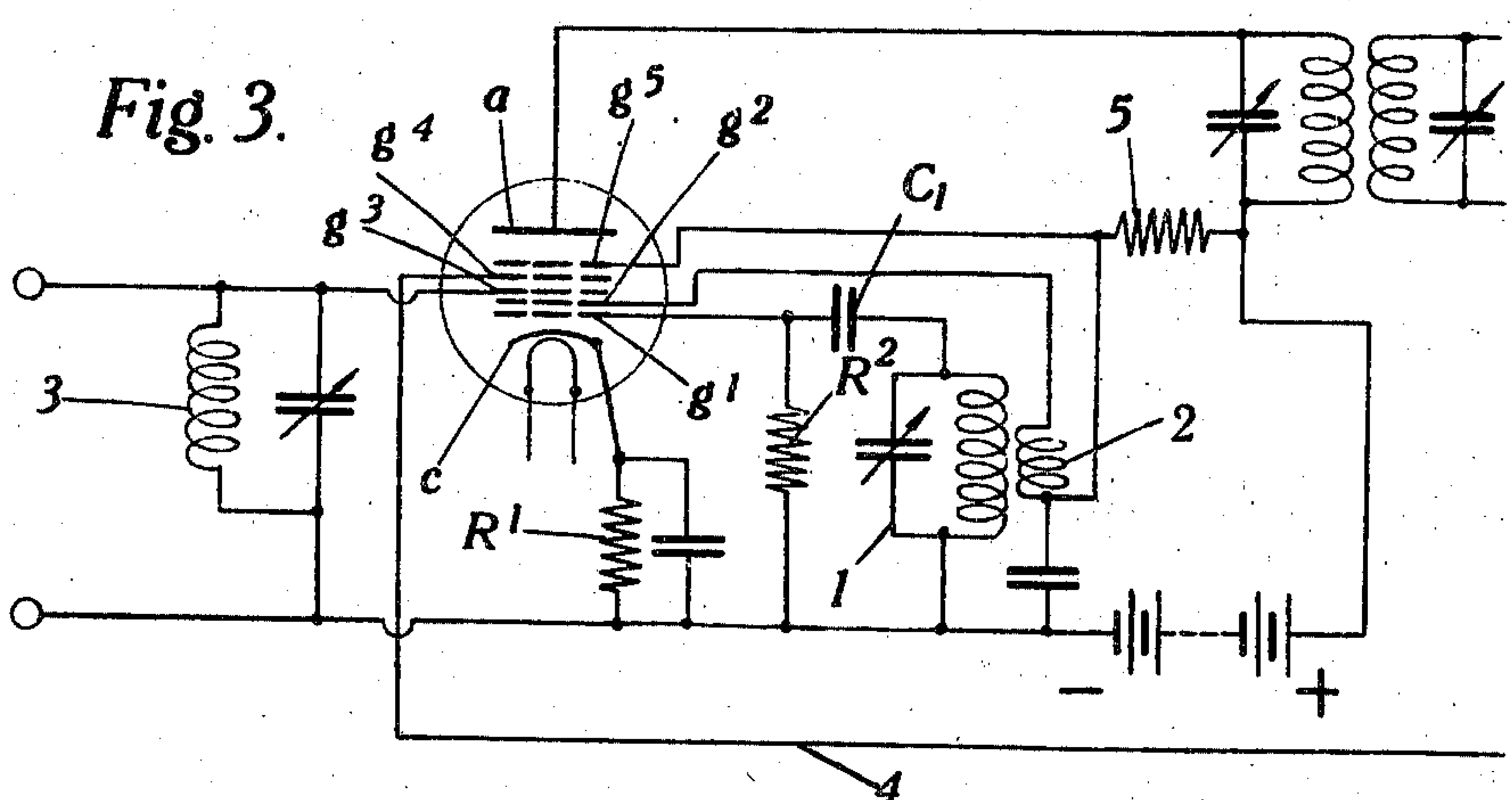

Fig. 4.

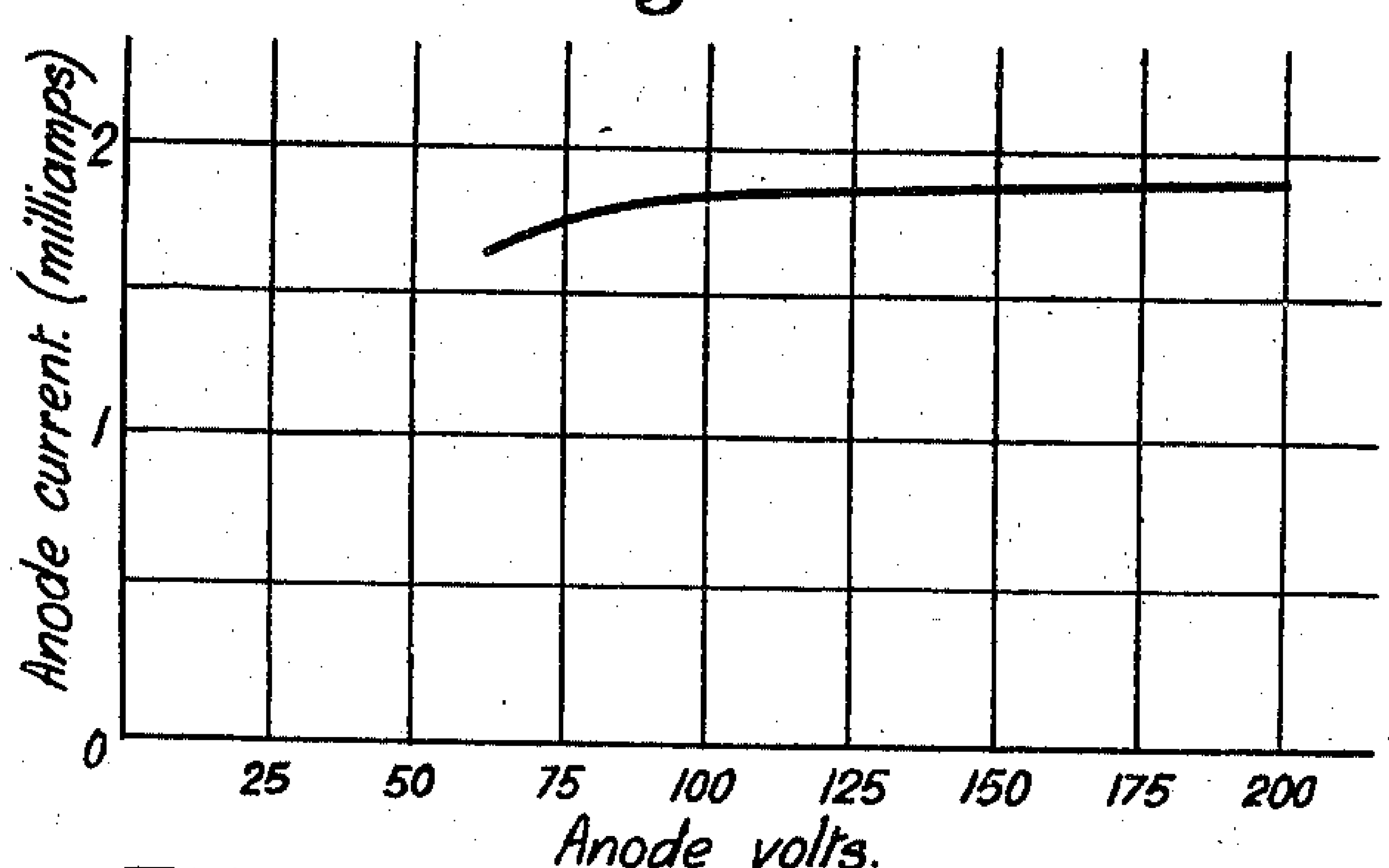

Fig. 5.

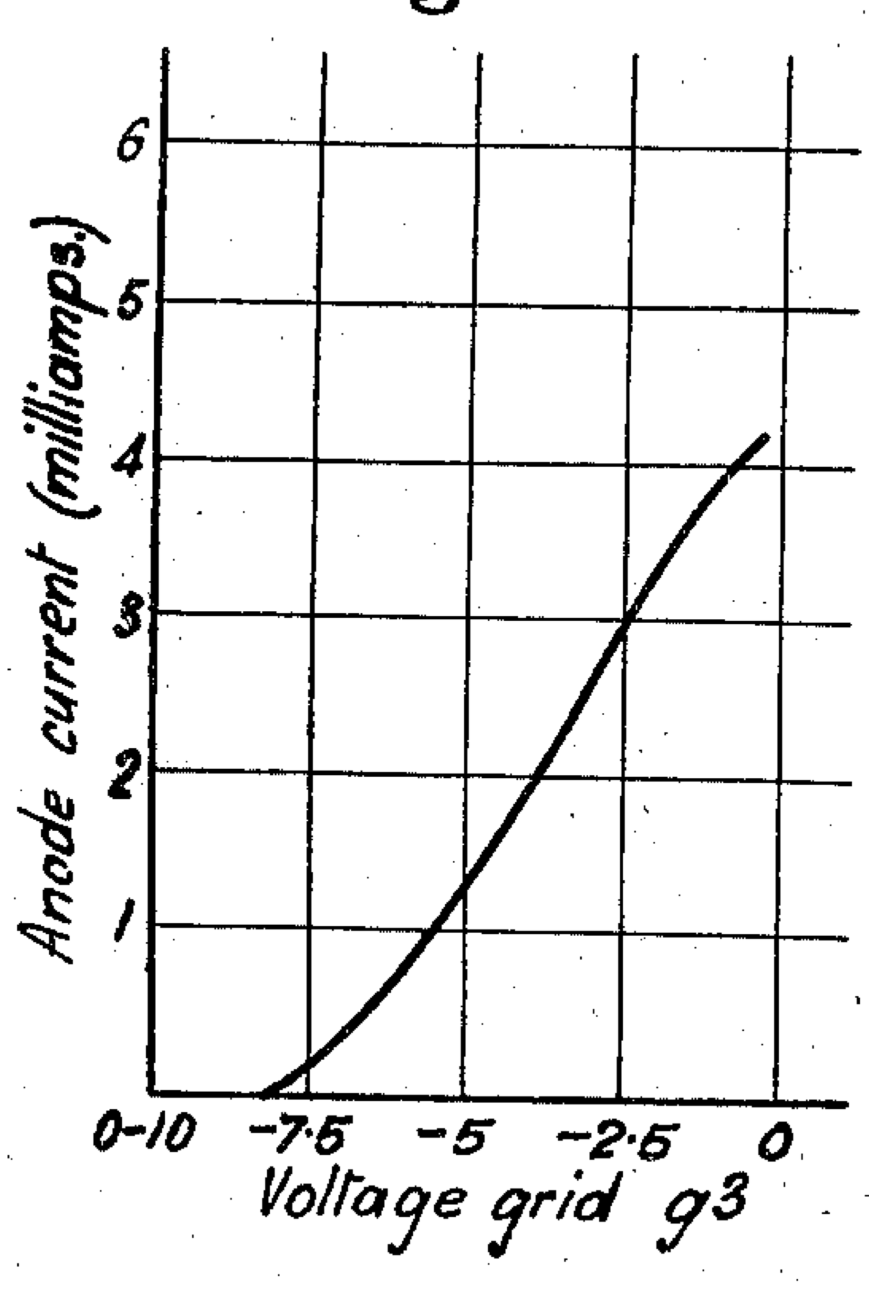

Fig. 6.

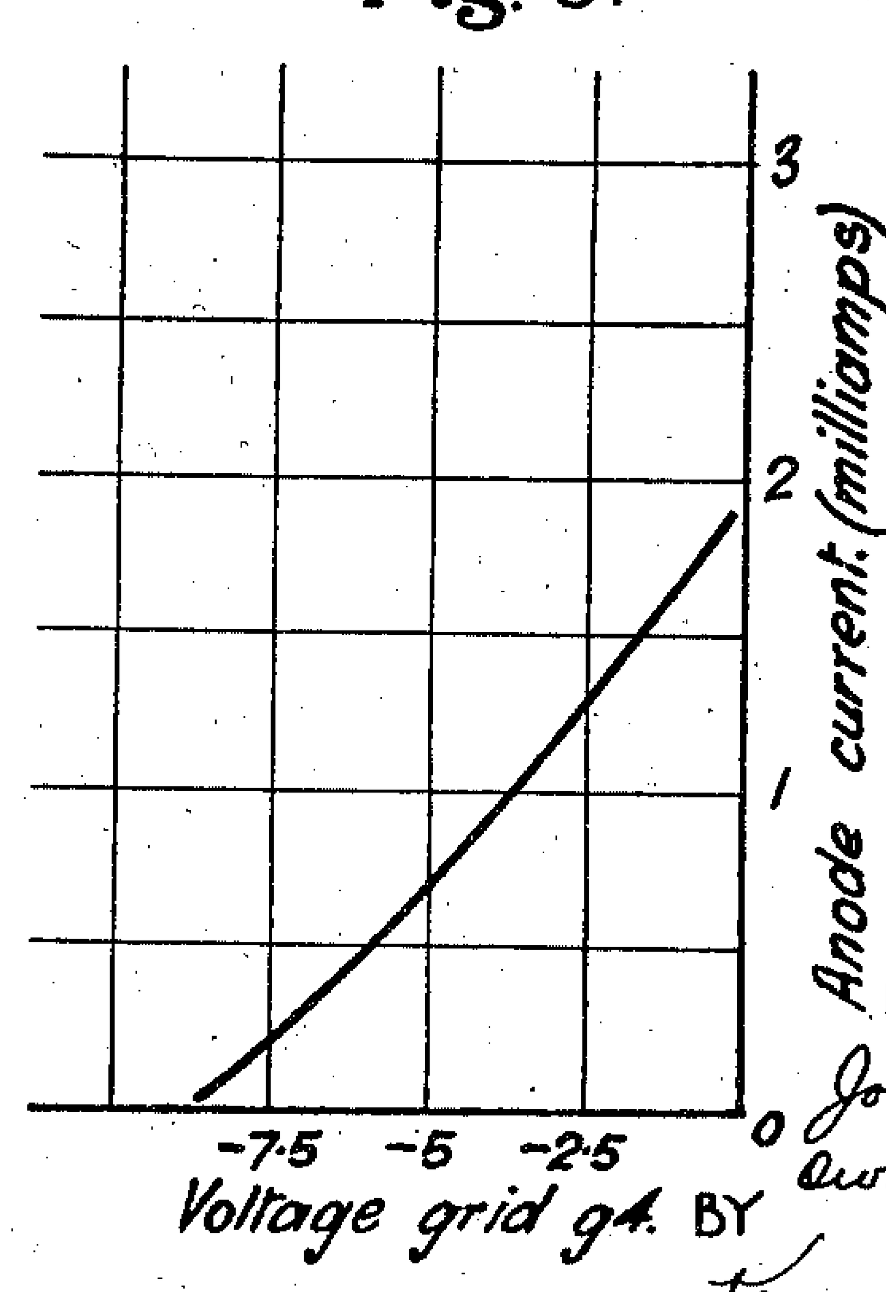

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Fig. 7.

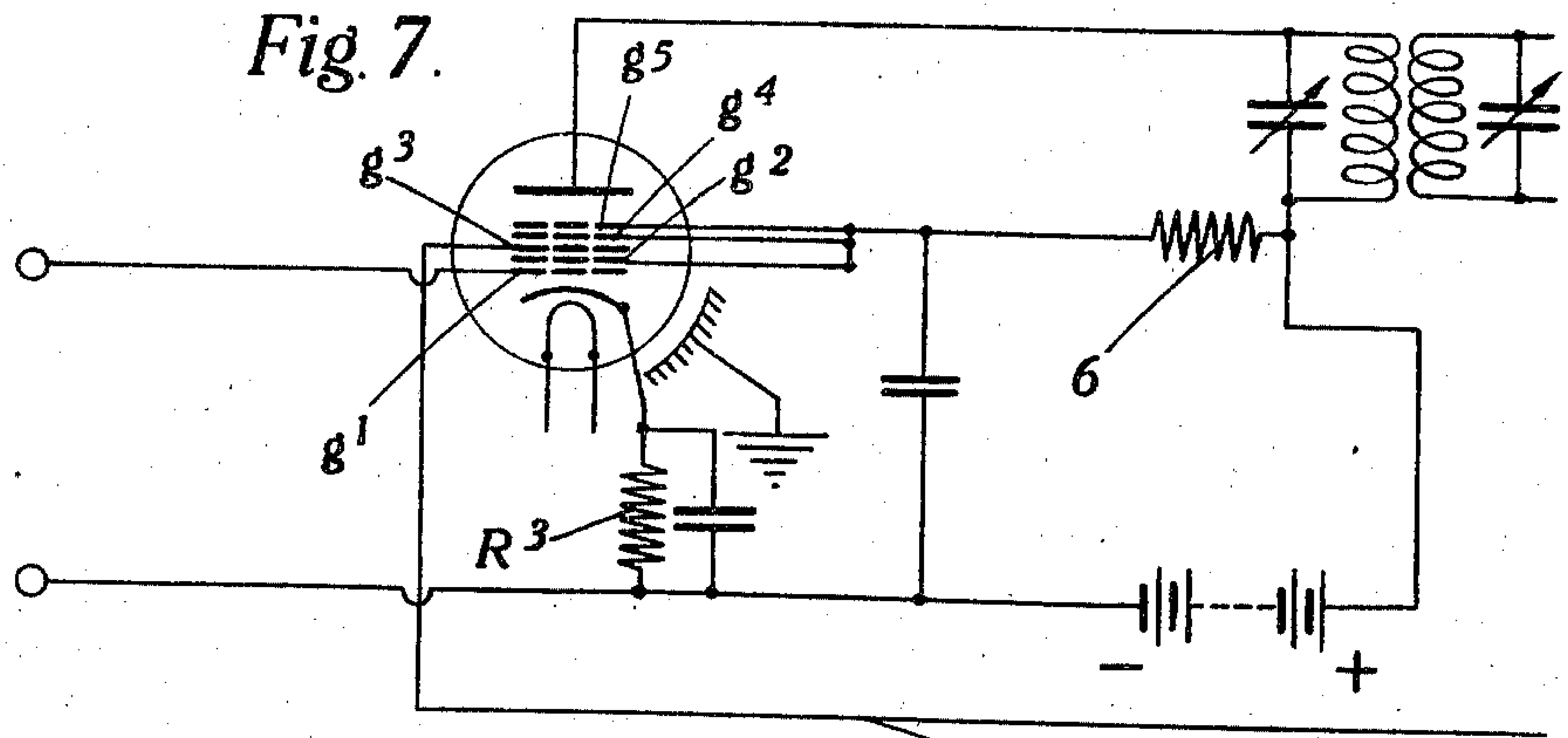

Fig. 8.

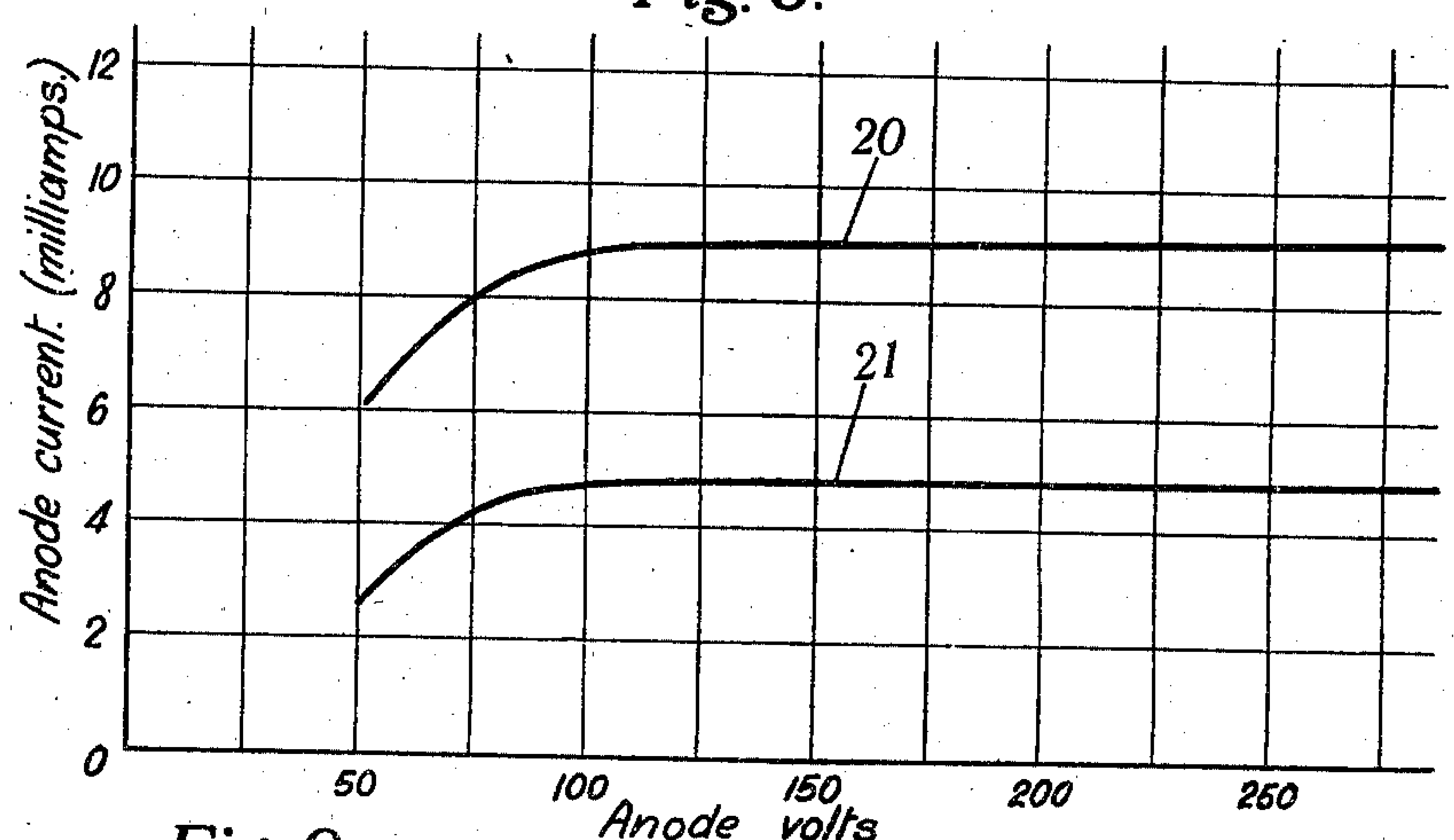

Fig. 9.

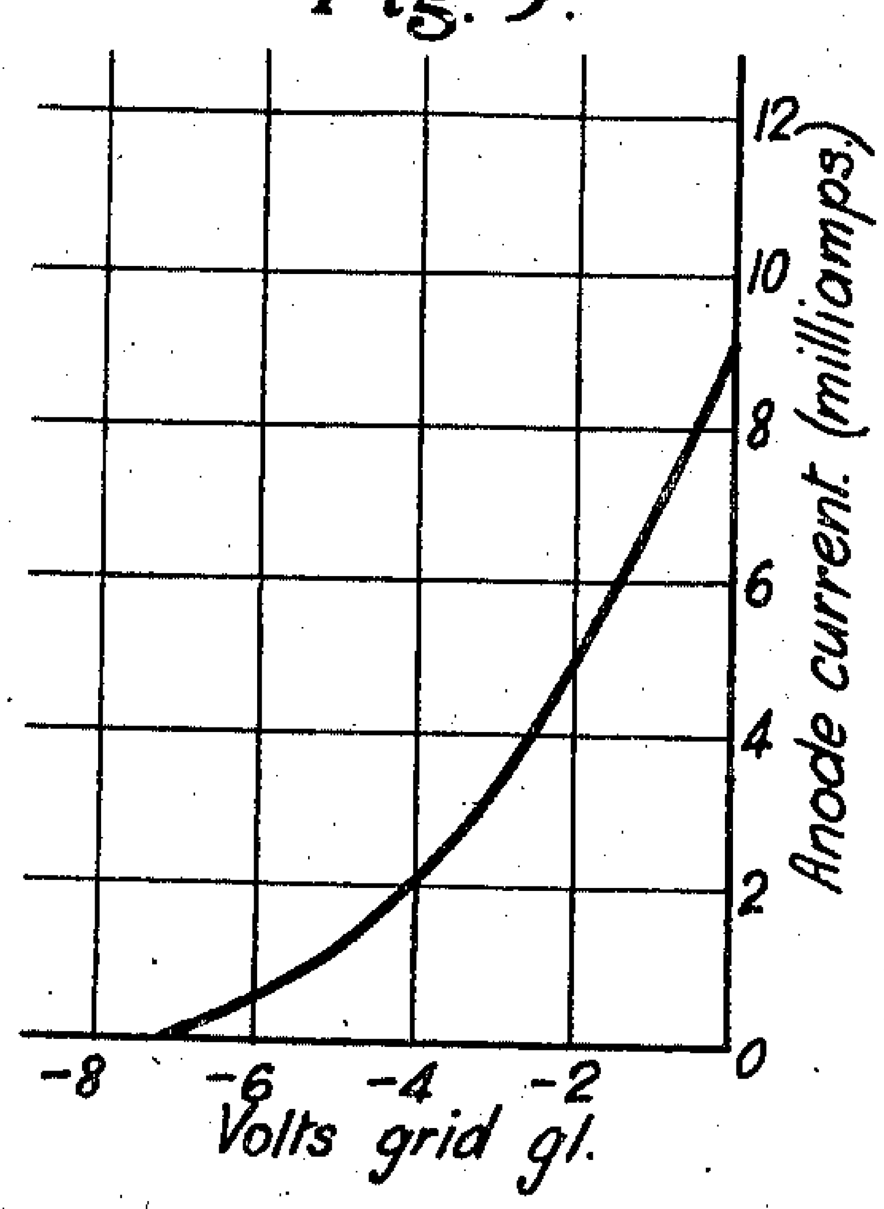

Fig. 10.

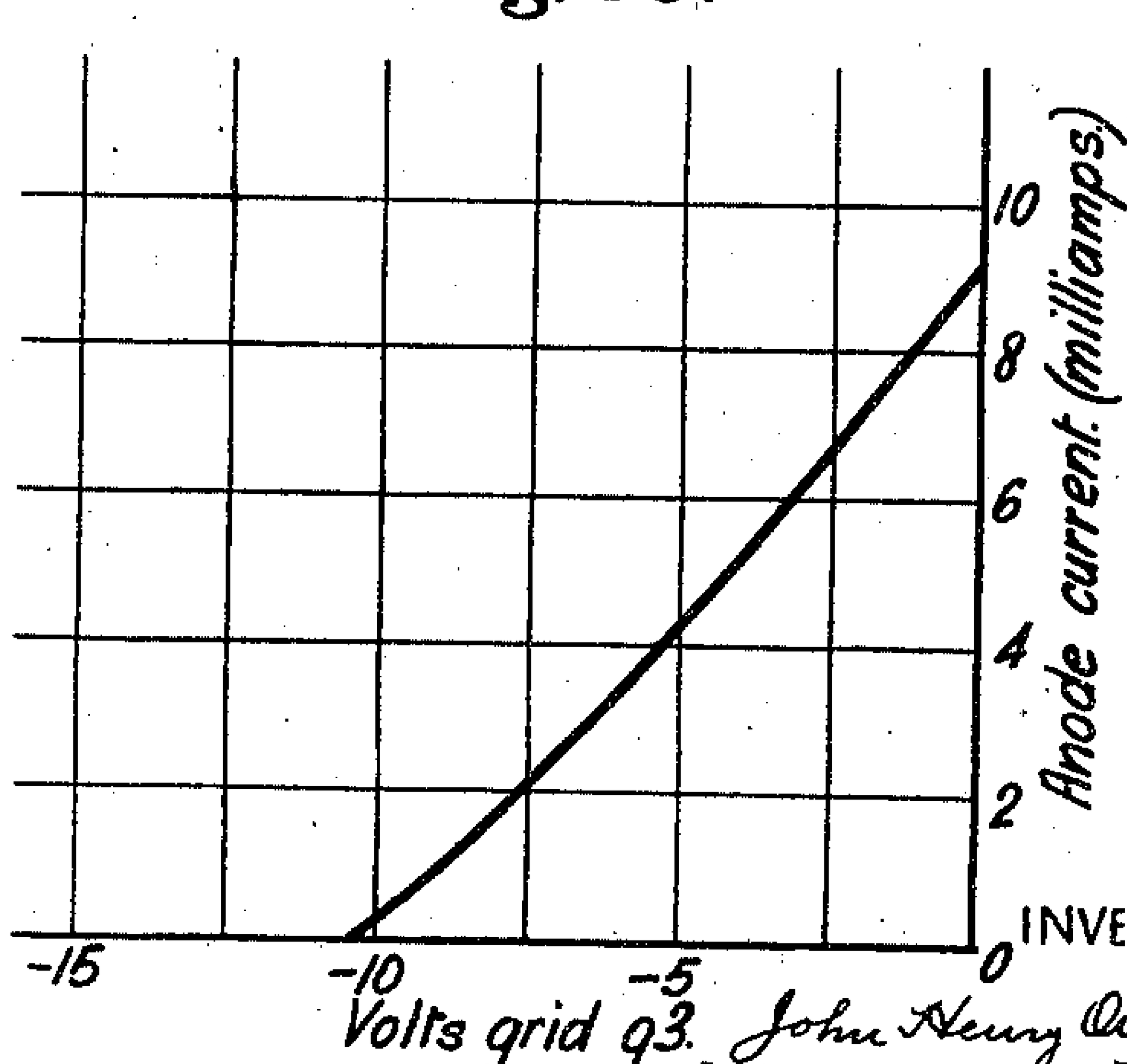

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Fig. 11

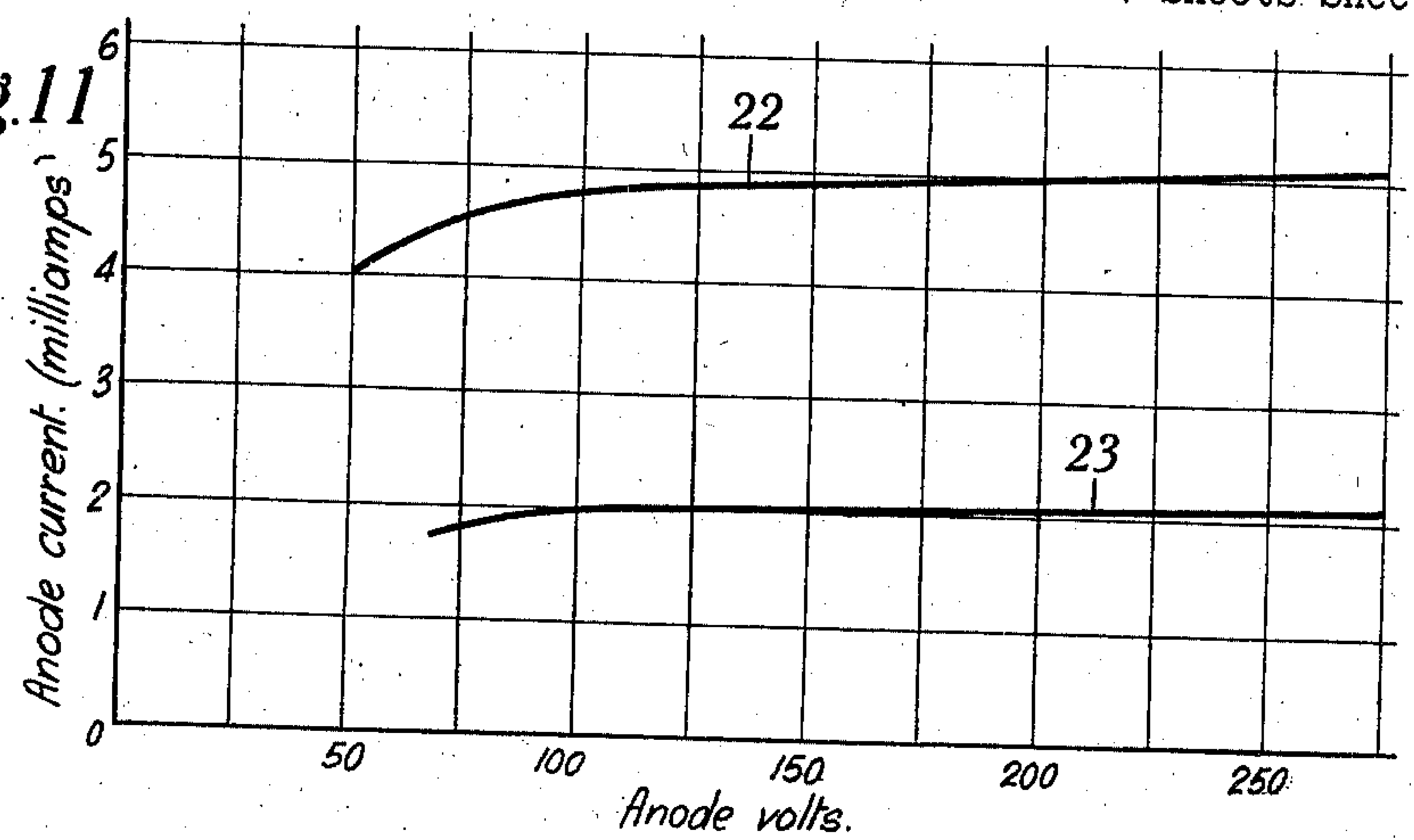

Fig. 12.

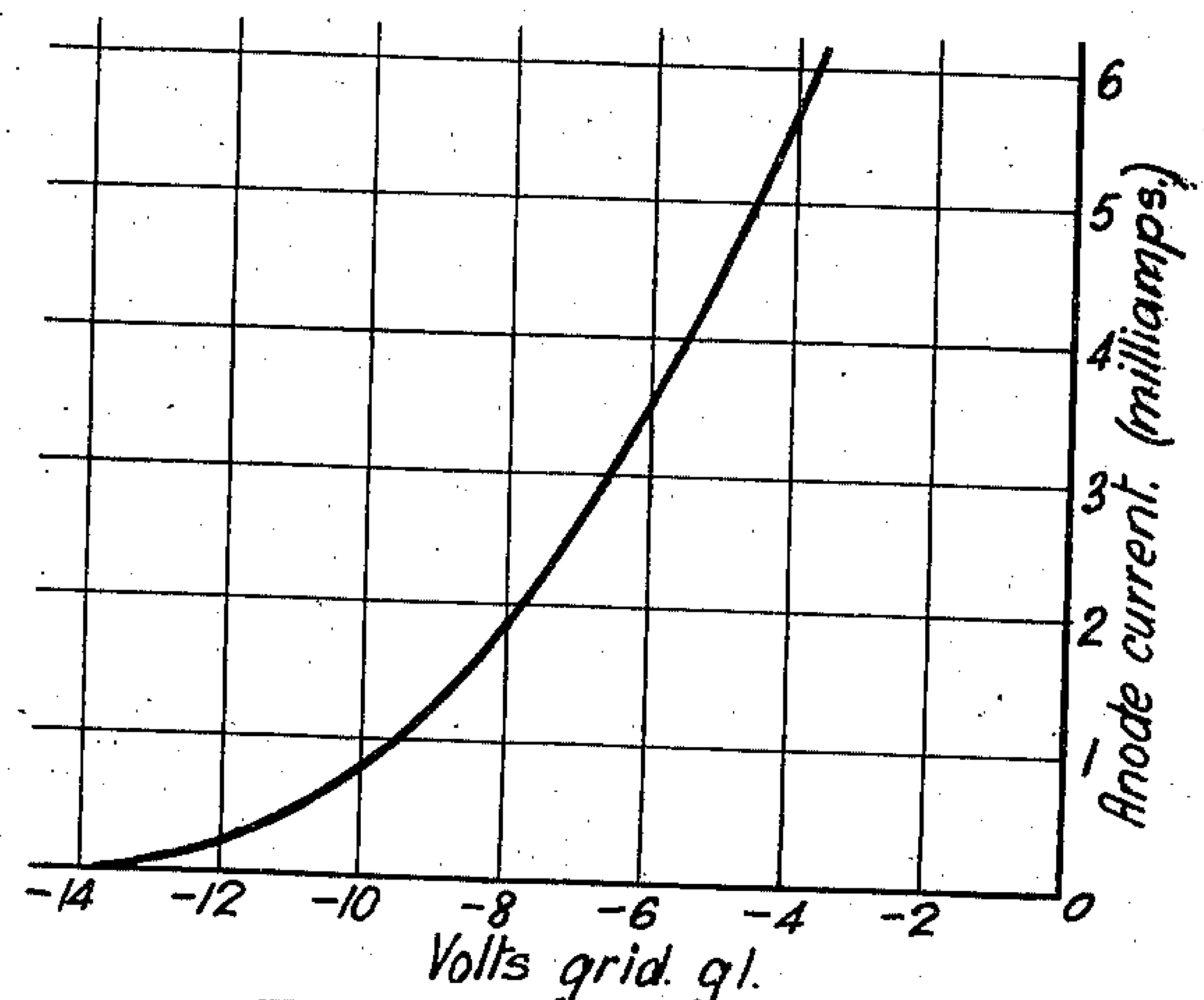

Fig. 13.

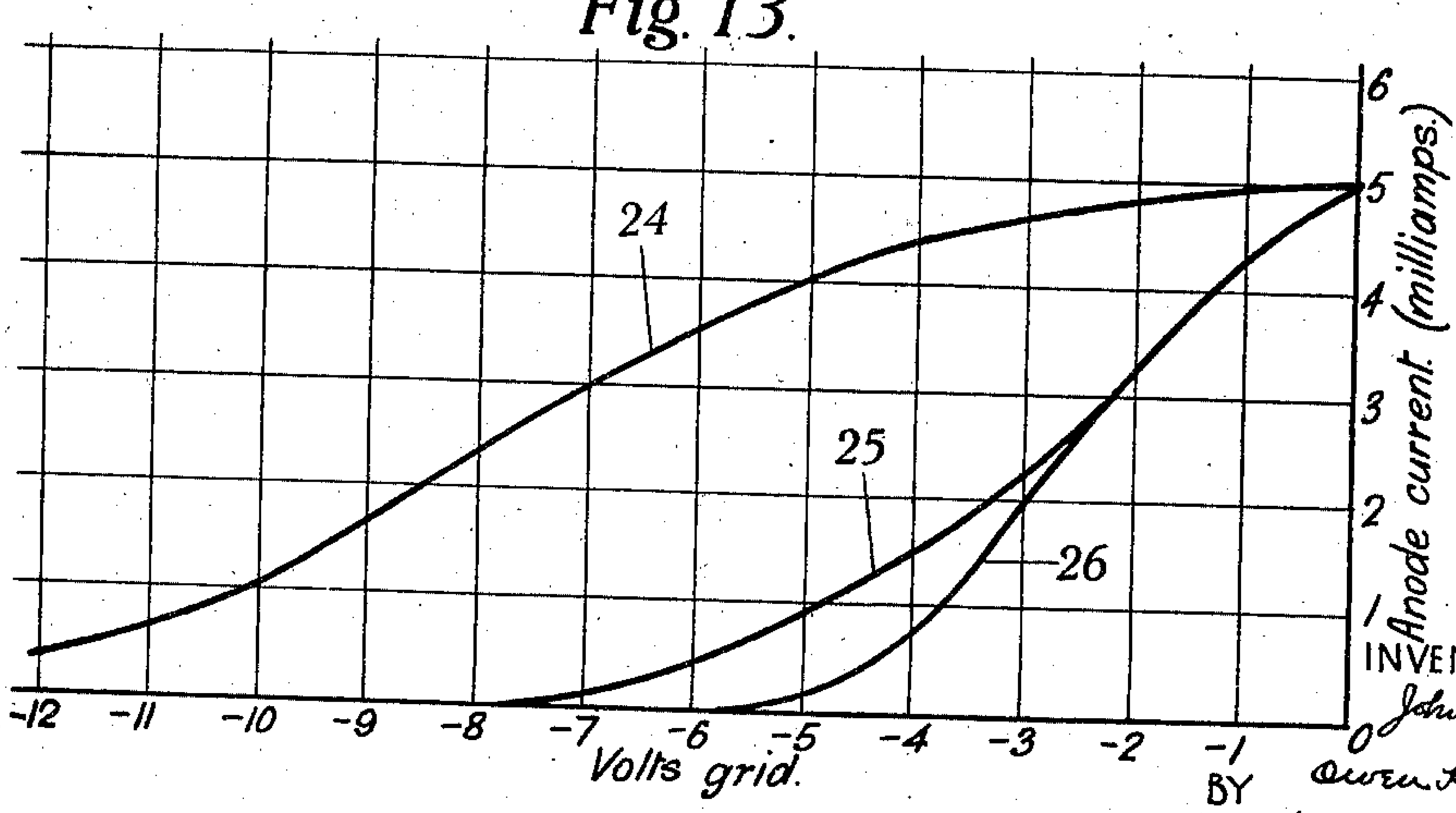

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Fig. 14.

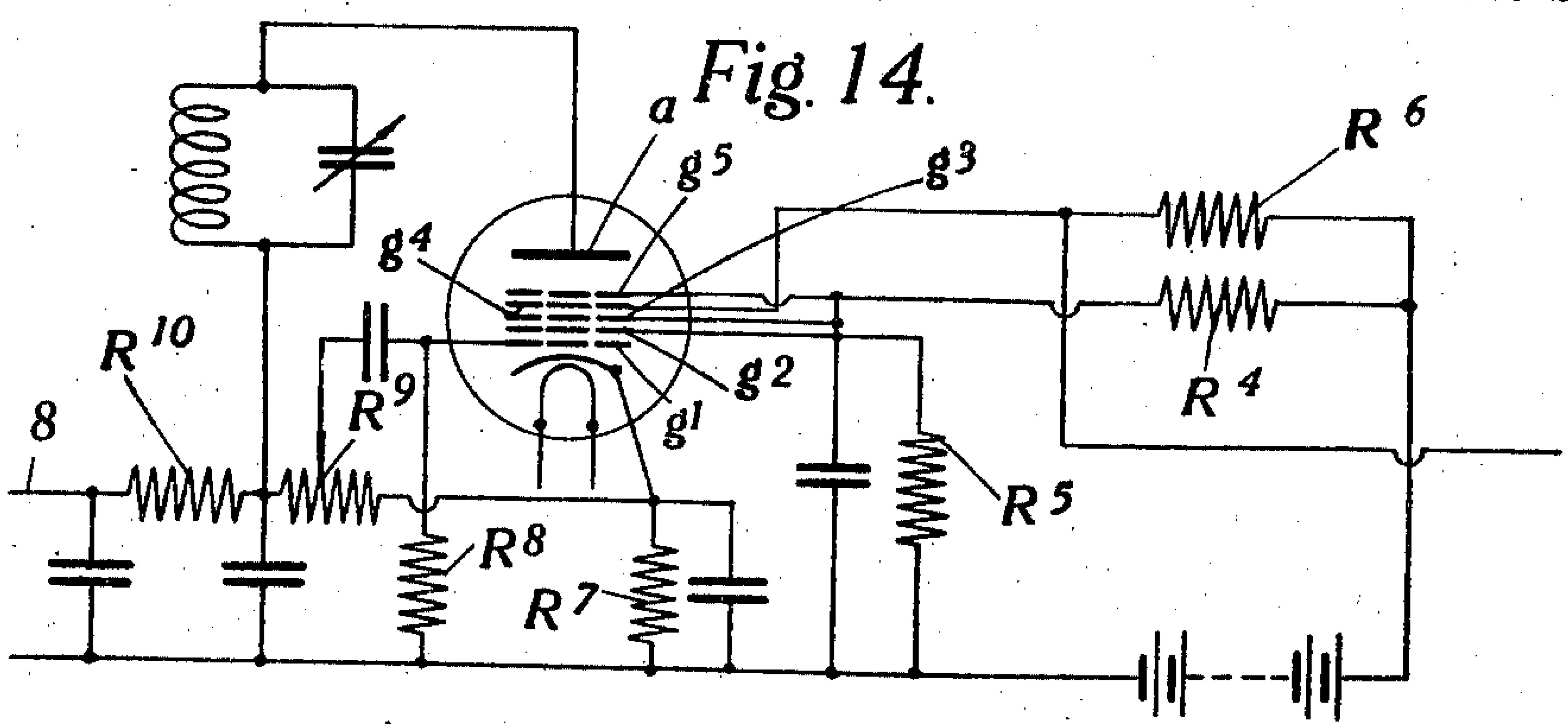

Fig. 15.

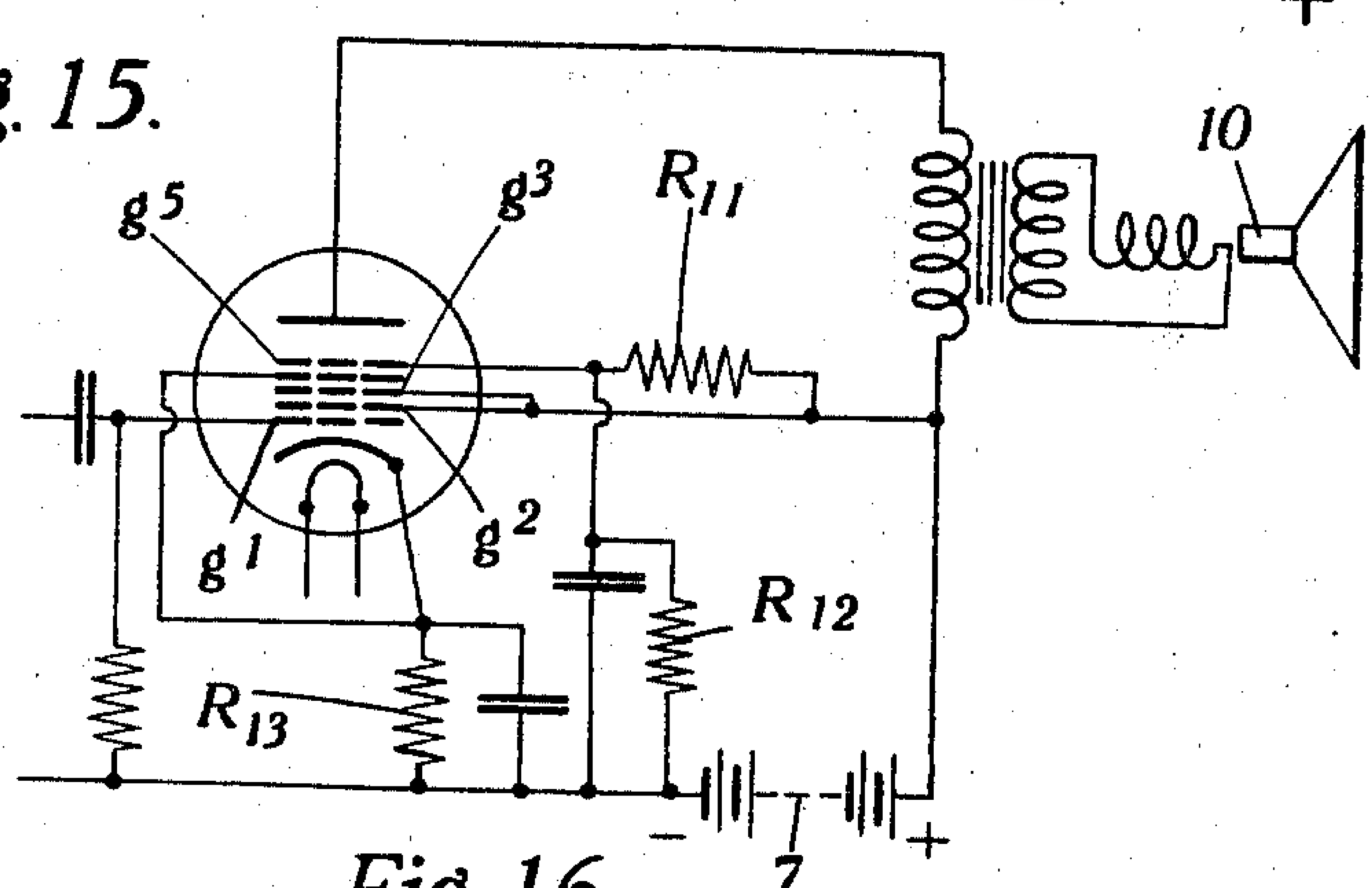

Fig. 16.

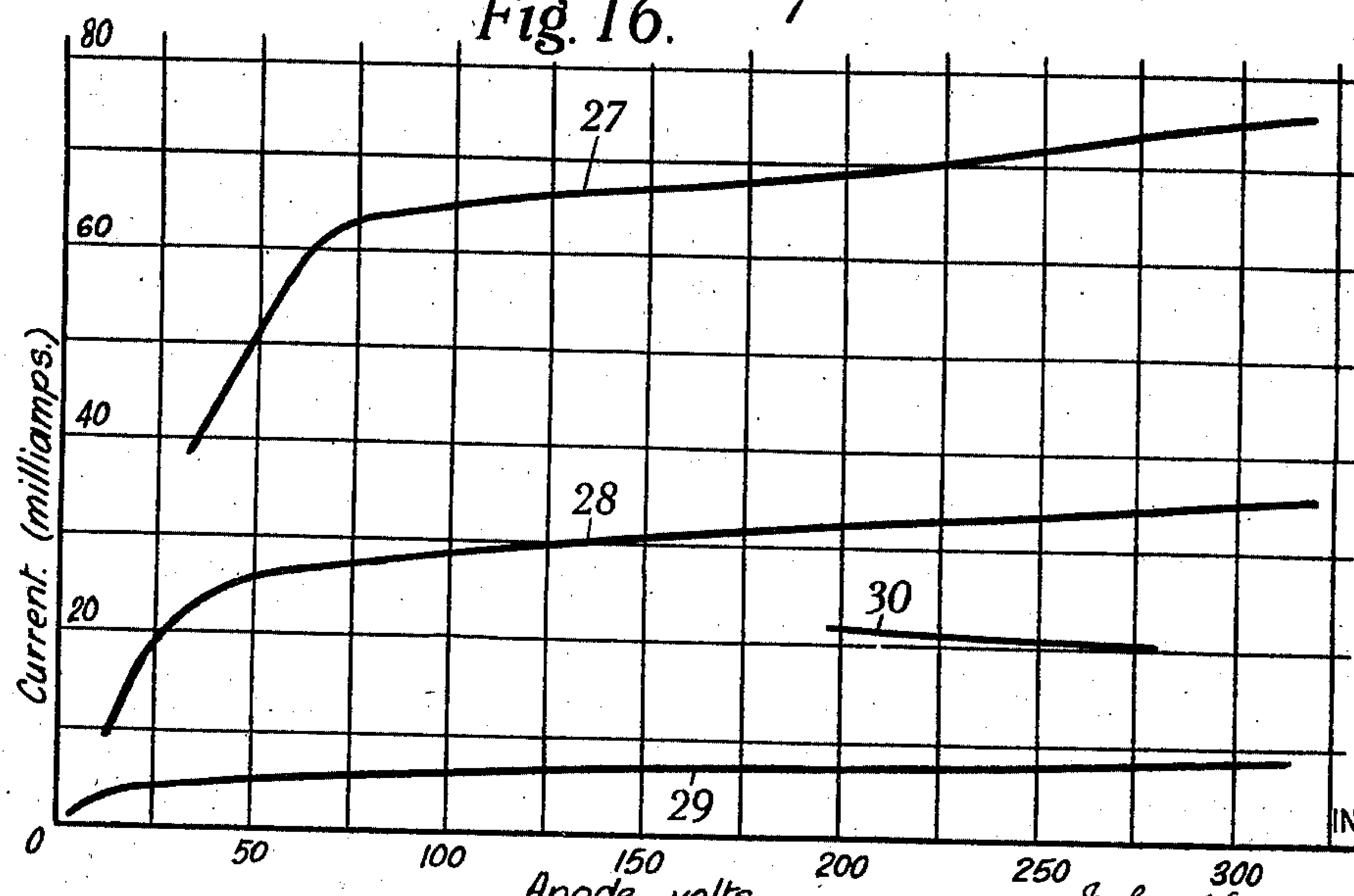

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Fig. 17.

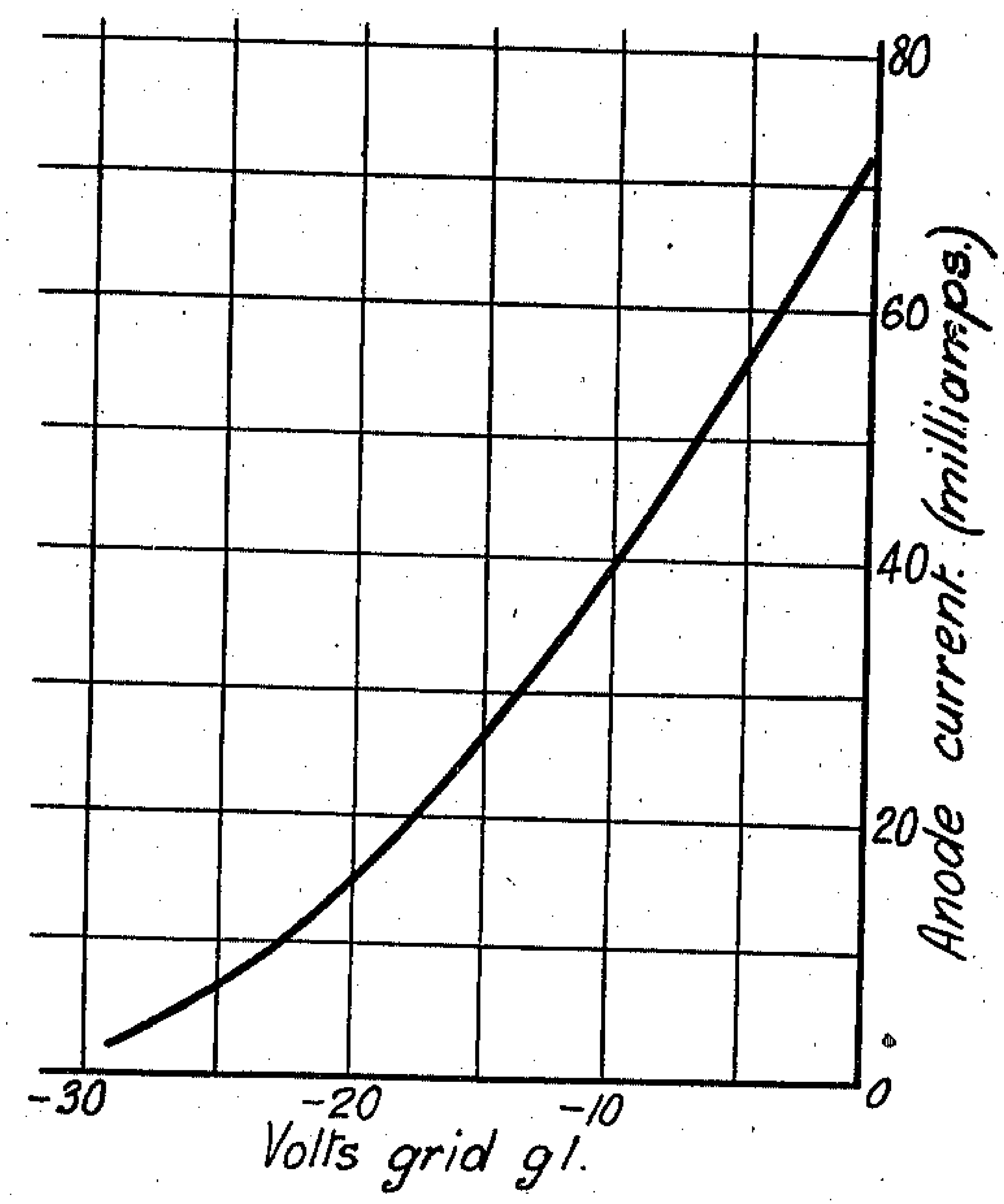


Fig. 18.

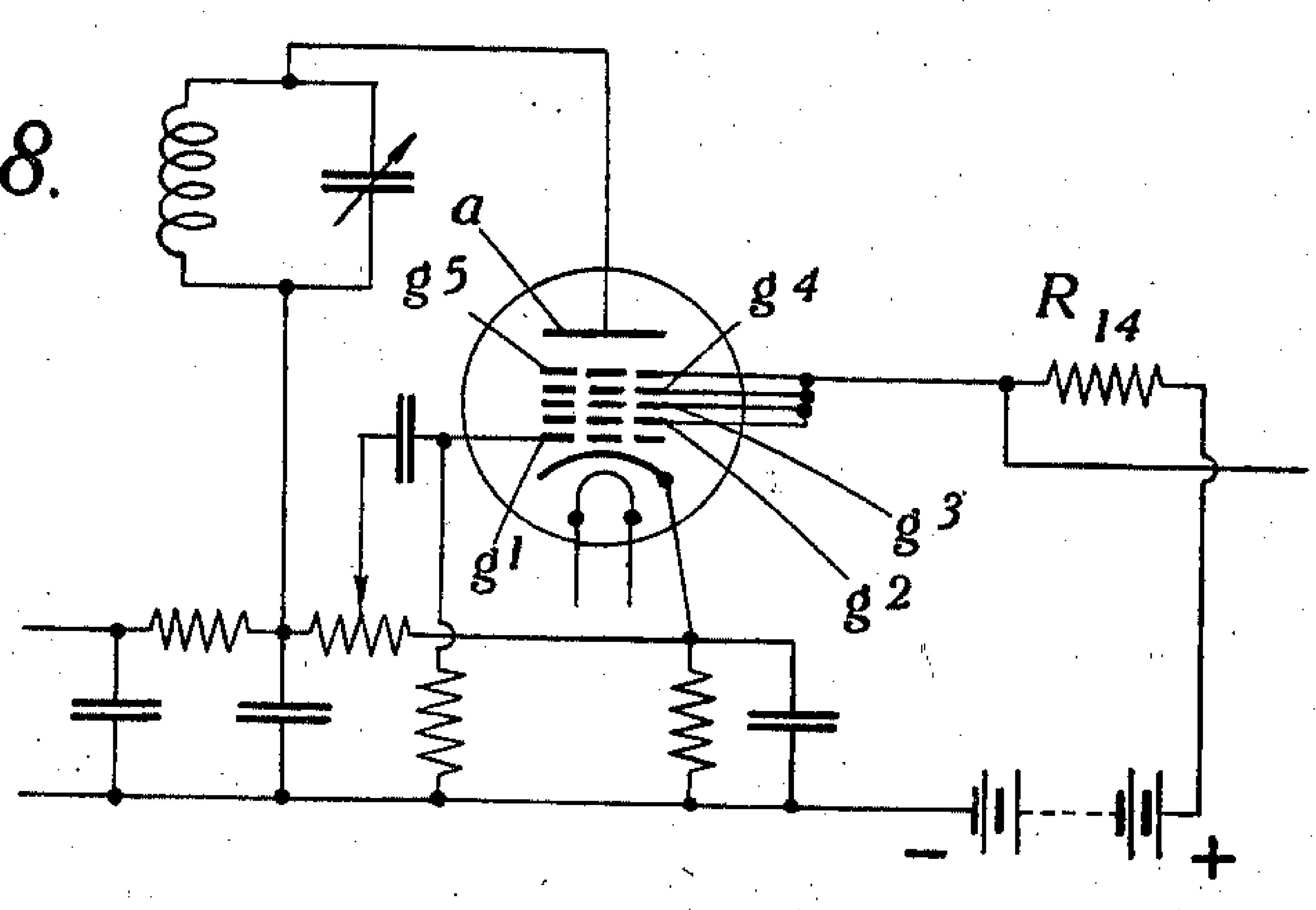
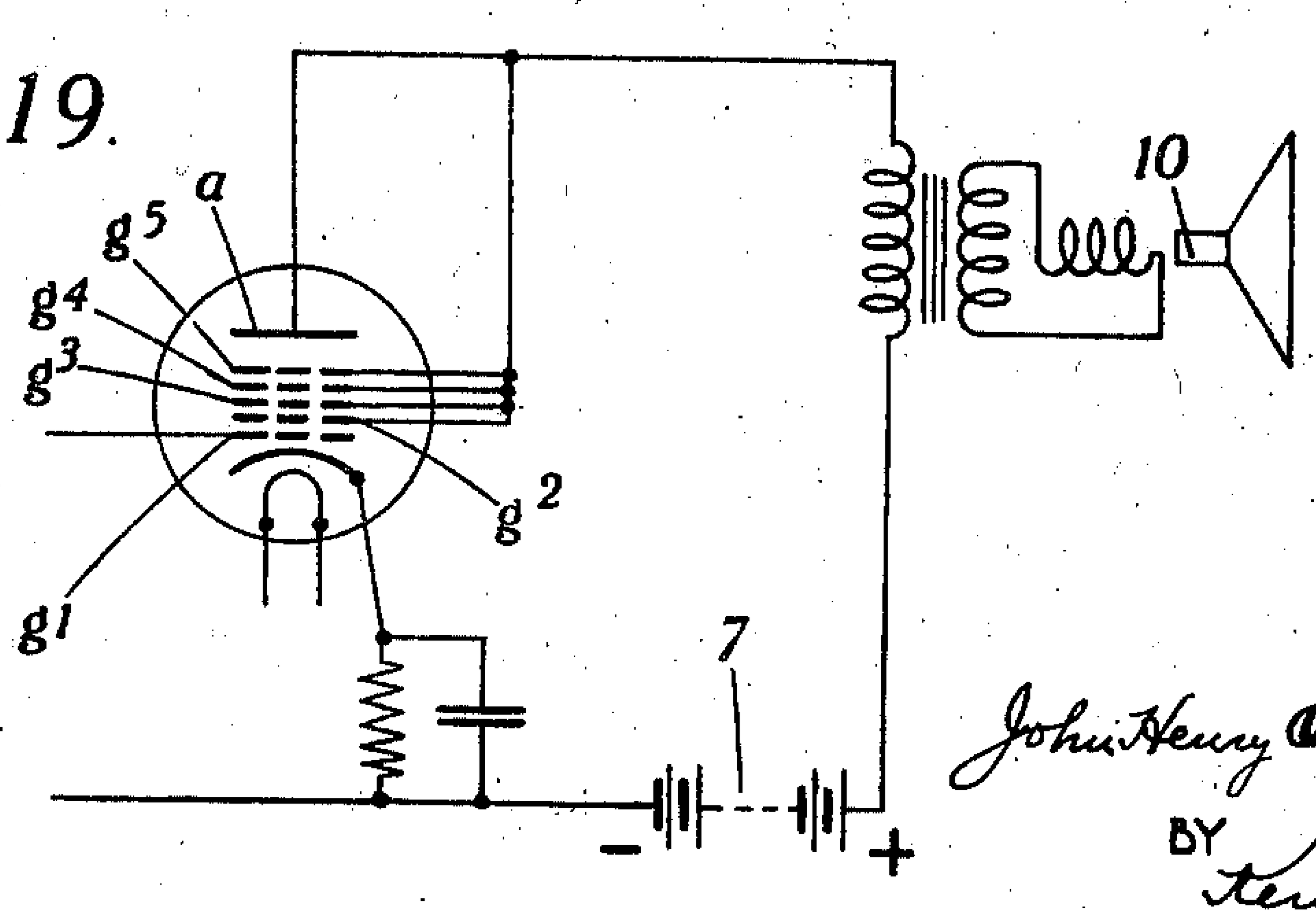


Fig. 19.



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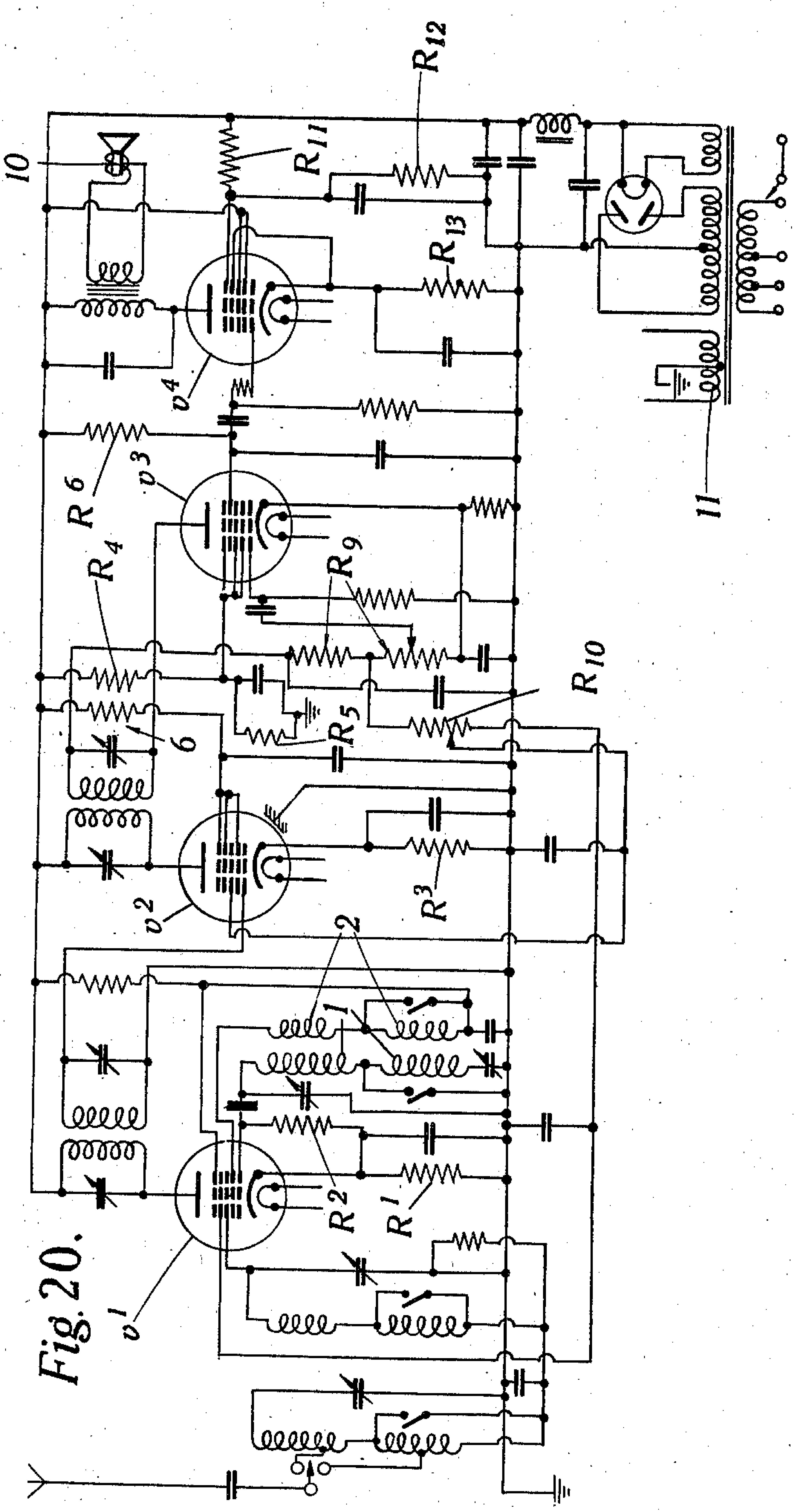

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Patented Aug. 2, 1938 2,125,719

UNITED STATES PATENT OFFICE

2,125,719

ELECTRON DISCHARGE TUBE

John Henry Owen Harries, Frinton-on-Sea, England

Application December 12, 1936, Serial No. 115,509
In Great Britain August 24, 1934

14 Claims. (Cl. 250—27.5)

This invention relates to electron discharge tubes, and comprises matter divided from application for Letters Patent, Serial No. 47,042, filed October 28th, 1935.

The main object of this invention is to provide a form of discharge tube capable of use in various stages of a radio receiver or similar apparatus, such as thermionic amplifiers for television work, and indeed in the extreme case to provide a tube which may be employed, so to speak, as a universal or "all-stage" tube, whereby a single embodiment may be employed without any alteration in each of the several stages of a multi-tube radio receiver; furthermore, the invention aims at producing a form of discharge tube which is very convenient for use as the tube in a single tube frequency converter such as is employed in supersonic heterodyne receivers.

The purpose of the invention may be appreciated more clearly from a brief consideration of the principal requirements which must be met by a universal or "all-stage" discharge tube which is required to operate efficiently in all the stages of a radio receiver.

First of all, in a single tube frequency converter stage of a supersonic heterodyne receiver, the one tube has to serve as a detector as well as a generator of the local oscillations. In particular it is found necessary to provide for very complete electrical separation between the signal frequency and the oscillation circuits. The oscillator must be stable and its frequency shift with gain control must be negligible. In modern receivers it is desirable to provide for automatic gain control which can be regulated so as to provide approximately zero gain without disturbing the local oscillations. Again, the anode impedance should not be less than one million ohms, while the initial anode current should be as small as possible, preferably not greater than 1.5 to 2.0 milliamperes at maximum gain. Finally, the conversion conductance should be as high as is compatible with low cross-modulation which should be a maximum at high gain.

The present invention aims at providing very complete separation between the oscillator and signal frequency circuits without employing the usual method of screening in the tube itself, and thus by means largely, if not entirely, independent of frequency changes.

The requirements in a tube to enable it to act satisfactorily in the intermediate frequency and in the radio frequency amplifier stages are briefly as follows:—

The anode to control grid capacity should be very small. It is found that with modern high gain tubes the anode to control grid capacity should certainly not be greater than 0.02 mmfd. to 0.005 mmfd. for operation at intermediate frequencies of the order of 110 kilocycles per second. At higher intermediate frequencies of the order of 450 kilocycles per second, instability commences to appear, and then the anode to control grid capacity should not be greater than about 0.0015 mmfd. Again, the anode impedance should not be less than one million ohms. Theoretically it should not be less than five times the anode load. If it is less than one million ohms, selectivity and amplification are adversely affected in practice. The initial anode current should be of the order of 7.5 milliamperes. The screen current should be as low as possible and not more than about one quarter to one third of the initial anode current. It is not desirable to have mutual conductance much greater than about 2 milliamperes per volt in intermediate frequency amplifiers. Owing to commercial limitations and difficulties in screening in radio receivers it is particularly important in radio frequency stages that cross-modulation should be a minimum when the gain is maximum, that is to say at low automatic gain control voltages. The considerations here are the same as those applying to the frequency converter stages.

In audio frequency amplifier stages high impedance operation is often necessary, and the possibility of gain control on audio frequency by varying the function of one of the grids in the tube is desirable.

In a detector stage it is desirable to provide a triode or high impedance low frequency amplifier stage in the same envelope in the diode. If low frequency amplifier stages are used the magnification should be 5 or 6 times in the case of a triode, and as much as 40 or more times in the case of a high impedance tube. However, small separate diodes are very easily made and are very cheap, and have certain advantages in the circuit, so that they may be used instead of employing a combined detector and amplifying tube.

In a power output stage the tube must give an adequate output to operate a loud speaker with a peak voltage on the control grid of not more than about 15 to 20 volts. Distortion must be as low as possible, which implies in practice that in the output stage the undesirable effects of secondary electron emission from the anode to the next electrode should be reduced as much as possible.

Finally, as regards automatic gain control, the circuit should be capable of controlling the output and maintaining the diode voltage at a value not greater than 10 volts. Higher values tend to produce whistling, and of course, overloading of the intermediate frequency amplifier. Distortion and cross-modulation must be kept at a minimum. As mentioned above, it is sometimes useful to apply the automatic gain control to an audio frequency tube as well as to the radio frequency tubes. Cost and reliability are basic considerations so that consequently receivers generally are furnished with extremely simple automatic gain control circuits that must operate adequately from the lowest input voltage to the receiver which will operate the diode effectively up to an input of as much as two or three volts which may be set up by a strong local station. Quiescent automatic gain control circuits giving interchannel suppression are desirable.

It will be appreciated therefore that the factors to be taken into consideration in producing a satisfactory universal tube for the purpose indicated are numerous and complicated, but nevertheless the present invention has solved the problem satisfactorily.

The universal tube is very attractive from the points of view of manufacture, servicing and use. In the first two directions it is possible very greatly to decrease costs. From the point of view of the using, it becomes very easy to obtain replacements compared with the existing system of using a number of different types of tube in each receiver. It is not difficult to design a universal tube, for example, by employing a large number of different elements in one bulb or envelope. Such a tube, however, would be so complicated to manufacture, and probably so unreliable when manufactured as to be quite impracticable.

It is required not only to produce a universal tube, but to give with it a performance at least as high, or even higher than that obtainable with the non-universal tubes commonly in use. The performance, as already indicated, must include all the many various and complicated functions of the modern superheterodyne receiver, while at the same time the tube must be cheap and simple enough to be employed in cheap and simple receivers. The requirements that it must give automatic volume control frequency changing, diode detection, with straight line characteristics and so forth are extremely difficult to fulfil in one simple tube, and it has been found that they are only fulfilled by quite a definite type of tube construction which will be described hereinafter.

It will be seen that whereas it would not be difficult, as mentioned above, to produce a universal tube by means of an expensive construction embodying all the elements of a large number of different tubes mounted in one envelope of a universal tube, it is very difficult to obtain a simple construction capable of performing all these very diverse functions. It has however been found possible, in accordance with the present invention, to produce a tube which consists merely of an extremely simple construction of concentric grid electrodes around a cathode and an anode enclosing said grids; these electrodes are so formed that when different potentials are applied to them, and when they are connected in different ways, the electrical characteristics of the tube are changed. In this way the use of a number of different elements of different types of tube in the one envelope is avoided. Not only are a number of different special characteristics available with a simple tube, but these characteristics are actually those which give the best possible efficiency in each of the various stages of modern radio receivers, even of the most complicated type.

It may be mentioned that the requirements of each stage of a radio receiver may be represented as optimum values. For example, there is an optimum value of mutual conductance for each stage, and it is desirable for the anode to control grid capacity to be low in audio frequency as well as in radio frequency stages. These optimum requirements are fulfilled by tubes constructed in accordance with the present invention, in spite of the fact that the novel tubes are of extremely simple construction, and are readily capable of commercial manufacture. The main advantage of the present invention, therefore, lies in the extreme simplicity of the tube and of the circuits in which it is to be used, and the remarkable fact that such a simple arrangement gives all the desired optimum characteristics for each stage of modern complicated radio receivers. These desired optimum characteristics may be varied to suit given circumstances by varying the configuration, including the mesh spacing of the electrodes of the tube.

In view of the above considerations, according to the present invention, an electron discharge tube, having at least four concentric grid electrodes around the cathode and an enclosing anode, has the second grid counting from the cathode, constructed with a more open mesh than the first grid from the cathode, while the third grid from the cathode is made with a closer mesh than the first grid, and the fourth or any other grid further from the cathode than the first three grids is made with a mesh more open than any of those first three grids. The first grid counting from the cathode is constructed to have an appreciable controlling action on the anode current, its surface in the path of the discharge being spaced from the cathode by a distance of the order of 0.3 millimetre, and it is made with a mesh closer than of the order of 10 turns per centimetre, and consists of wire having a diameter of about 0.1 millimetre; the third grid from the cathode has a mesh closer than of the order of 10 turns per centimetre, and is made of wire also having a diameter of about 0.1 millimetre, so that it also has an appreciably controlling action on the anode current; the second grid, also made of wire of a diameter of about 0.1 millimetre, has a mesh not closer than about of the order of the 10 turns per centimetre, while the fourth grid has a mesh not closer than of the order of about 8 turns per centimetre. The distances between the surfaces of the grids in the path of the discharge are approximately equal and of the order of 1 to 2 millimetres.

In the case of a five-grid tube the fifth grid, which is placed immediately next to the third grid counting from the cathode, is made of substantially the same size wire and with the same mesh as the third grid.

The grid nearest to the cathode, which, when the tube is used in a single stage frequency changer circuit, is connected as the oscillatory control grid, has its lead taken out of the envelope of the tube at the opposite end to that at which the leads of the remaining electrodes are taken out. The grid next to the cathode and the third grid from the cathode have substantially the configuration mentioned above, and the mutual conductance for the former grid is not less than of the order of 1 milliampere per volt, and for the latter grid not less than 0.25 milliampere per volt. The arrangement may be such that in the absence of a metal screen placed externally to, and in close proximity to the envelope of the tube, the capacity between the grid next to the cathode and the anode is not less than of the order of 0.007 to 0.001 mmfd.

The grid electrodes have an elongated shape in transverse section, and for convenience of manufacture their profiles may be given the shape of circular arcs. A dished electrostatic screen, extending into close proximity with the inner wall of the envelope, is attached to the outer end of the grid assembly so as to shield the grid nearest to the cathode from the outer surface of the anode.

In producing a tube particularly suitable for the purpose set out above, it has been found of advantage to set the anode of the tube at a distance from the nearest grid electrode which is substantially the "critical" distance in the sense defined in my patents, Nos. 2,045,525, 2,045,526 and 2,045,527. In said patents, it is explained that if the anode of a tube were placed at various distances from the electrode nearest to it, the positions and spacings of the other electrodes and the operating constants of the tube being otherwise unchanged, a curve could be plotted showing the relationship between the varying distances of the electrode and what is termed the breakdown voltage, that is the anode voltage at which the anode current reaches its saturation value. Such a curve shows that if the anode distance is reduced from rather a large value, the breakdown voltage decreases to a minimum but that it increases again as the anode is moved nearer to the adjacent electrode. This result is due to the effect of secondary electron emission from the anode. The distance apart of the anode and the next electrode yielding minimum breakdown voltage is termed the "critical" distance in said patents, and this is the sense in which the expression "critical distance" is used in this present specification. It is also shown in my said prior patents that the characteristics of the tube are sometimes improved by arranging that the positive potential on the grid electrode nearest to the anode is lower than that on grids further from the anode.

Minor modifications may be made in the tube to suit various characteristics. Thus, the mesh of the various grid electrodes, that is to say, the number of turns per centimetre in the coils forming the grids, may be varied, and the spacing may be varied to suit different conditions. Thus, the grid nearest to the cathode may be of the sharp cut-off type and any of the other grids, particularly for use in an automatic gain control electrode, may, if desired, be constructed to have a variable-mu characteristic.

The invention will now be more fully described with reference to the annexed drawings, which show an embodiment of a tube, in accordance with the present invention, with certain explanatory diagrams and certain circuit diagrams in which the tube may be employed, and in which:—

Figure 1 is an elevation with the external screening shield shown in section and parts of the other electrodes cut away to show the details of construction;

Figure 2 is a horizontal section on the line II—II in Figure 1, of the electrode system, to a yet larger scale than Figure 1, the electrodes in Figure 2 being shown approximately three times their actual size;

Figure 3 is a circuit diagram showing the tube connected as a single tube frequency changer;

Figures 4, 5, and 6 show different characteristics of the tube when operating under the conditions shown in Figure 3;

Figure 7 shows the tube connected as an intermediate frequency amplifier;

Figures 8, 9, and 10 illustrate different characteristics of the tube utilized in the circuit diagram of Figure 7;

Figures 11, 12, and 13 show different characteristics of the tube utilized when the tube is connected as a radio frequency amplifier;

Figure 14 shows the tube connected as an effective tetrode acting as a detector amplifier;

Figure 15 is a circuit diagram of the tube connected in a power output stage;

Figures 16 and 17 show characteristics of the tube utilized in the circuit shown in Figure 15;

Figure 18 is a circuit diagram of the tube connected as an effective triode acting as a detector amplifier;

Figure 19 is a circuit diagram of the tube connected as a plain triode; while

Figure 20 is a complete circuit diagram of a supersonic heterodyne radio receiver, comprising four of the universal tubes connected respectively as in Figures 3, 7, 14 and 15.

In Figures 1 and 2 full details are shown of a tube with a cylindrical anode *a*, an indirectly heated cathode *c* of the usual British type with a 4-watt heater, and five grids between these two electrodes, viz., g^1, g^2, g^3, g^4 and g^5. In the actual sample, the cathode *c* is rectangular in cross-section, the sides being 1.5 milimetres and 1 millimetre in length. The diameter of the anode *a* may be taken as 27 millimetres and the rest of the dimensions in Figures 1 and 2 are to scale. It will be noted that in plan view the first grid g^1 is of flattened shape, while the rest of the grids appear as two circular arcs passing around the supports *s*, all of which are nickel rods of a diameter of 0.75 millimetre. The spacing of the electrodes may be varied to suit different conditions, but in the sample described the respective radii of curvature of the arcs of the grids g^2, g^3, g^4, g^5, are 10, 10.6, 11.5 and 14 millimetres. The distances from centre to centre of the supporting rods for the grids g^2, g^3, g^4 and g^5 are respectively 10, 14, 18 and 22 millimetres, while in the case of grid g^1 this distance is 6 millimetres. The minor axes of grids g^2, g^3, g^4, g^5 are respectively 3.7, 7.4, 10 and 12 millimetres and the parallel sides of the grid g^1 are 2 millimetres apart. The mesh of the different grids may also be varied to suit different conditions. In the sample taken, they vary from about 5.5 turns per centimetre in the grid g^5 to 15 turns per centimetre in the grid g^3, the spacing in the grid g^2 being 7.1 turns per centimetre, that of the grid g^1, 12 and that of the grid g^4, 14 turns per centimetre. All the grids are wound of molybdenum wire, the diameter of the wire of g^1 being 0.08 millimetre, that of the grids g^2, g^3, g^4, 0.1 millimetre and that of the grid g^5, 0.15 millimetre. The first grid g^1 has a lead l^1 going to the upper terminal *t*. The lead for the grid g^5 next to the anode is taken out at a side terminal t^5, whereas the leads for the other three grids, the anode, cathode and heater are taken out to the seven pins *p*. The side terminal may, of course, be omitted and a base used with one additional pin. The grids g^1, g^2, g^3, g^4, g^5, are wound uniformly, but if it is desired to provide a variable-mu or remote cut-off characteristic, one of the grids, for example the grid g^3, may have some turns omitted along its length.

The screening is very simple and is effective because of its exact position and the wide spacings involved. When the tube is used as a voltage amplifier and the anode to control grid capacity must be a minimum, an external screen s^1 is employed fairly closely conforming to the upper part of the glass bulb *b*. The internal screen consists of an upper screen *e* of dished shape with a hollow central portion *f* supported on a mica bridge plate *g* extending across the electrode assembly. The dished screen *e* extends approximately into the neighborhood of the inner wall of the bulb *b*. There is also a lower hollow screen *h* supported from a second mica bridge plate *k* and surrounding the lower ends of the grid assembly. A getter support is shown at *m*. In such a tube, with the external screen s^1 in position, the anode to control grid capacity is about 0.001 mmfd. The anode is cylindrical and is widely spaced from the outermost grid g^5 as seen in Figure 2. It is of blackened nickel to reduce the secondary emission from it and this tends to flatten the minimum portion of the distance curve. The anode is spaced substantially at the critical distance from the outermost grid g^5.

A tube constructed in the way described and illustrated in Figures 1 and 2 has the desirable properties of a universal valve as already set out above. In particular, the capacity between the grids g^1 and g^3 is small compared with that between the grids g^2 and g^3, the ratio between these capacities being such that when the grids g^1 and g^2 are connected as oscillator electrodes as will be described with reference to Figure 3, the oscillator circuits are not coupled to the radio-frequency input circuit to an undesirable extent and "locking-in" is avoided. This desirable ratio is obtained because the grid g^1 is connected to the terminal *t* at the top of the bulb *b* whereas the leads from the grids g^2 and g^3 are taken out at the lower end of the bulb. When a universal tube is to serve without alteration as a screened amplifier as well as a frequency converter, the first grid g^1 must have its lead taken out at the opposite end from the other electrodes or the capacity between the grid g^1 and the anode *a* under screened amplifier conditions will not be low enough.

In Figures 3 to 19 of the drawings, some possible forms of connection of the tube when used for different purposes are illustrated.

In Figure 3, the connections of the tube as a single tube frequency changer are shown. The grids g^1, g^2 operate respectively as the control grid and anode grid of the oscillator part of the valve, the tuned oscillator circuit **1** being connected to the grid g^1, and the anode circuit feedback coil **2** being connected to the grid g^2. The grid g^3 is the input grid for the signal frequency and is connected directly to the tuned input circuit **3**. The grid g^4 is the automatic gain control grid separate from the input grid and is connected directly to an automatic gain control bus bar **4**. Alternatively, the functions of the grids g^3 and g^4 may be interchanged. Either of these grids may be wound nonuniformly so as to give a variable-mu cut-off characteristic and then both the signal frequency and the automatic gain control voltages may be applied to the same grid. The anode *a* is coupled to the next stage, for example, the intermediate frequency amplifier in the ordinary way.

The grid g^5 is connected through a break-down resistance **5** and is a positive screening grid. The oscillator potentials on the grids g^1 and g^2 are in opposite phase and the ratios of the capacities between the grids g^1 and g^2 and the grid g^3 (or g^4) are such that the oscillator circuits **1**, **2** are not coupled to the radio frequency circuit to an undesirable extent. This method of balancing out the feed back is found to be better than screening and is not affected by frequency. In this case, with the tube constants as described with reference to Figure 1, the operating conditions are as follows:—The anode voltage is 250 and the break-down resistance **5** has a value of about 60,000 ohms so that a steady potential of about 100 volts is applied to the grids g^2 and g^5. The cathode bias resistance R^1 is 200 ohms and the grid leak resistance R^2, 15,000 ohms. The condenser C_1 is 0.001 mfd. The anode current in the absence of an automatic gain control voltage is from 1.5 to 2.0 milliamperes. The cathode is at about 3 volts positive and the current flowing to the grid g^2 is about 9 milliamperes. The internal alternating current resistance of the tube is 1 million ohms. The conversion conductance with zero automatic gain control voltage is about 0.7 to 0.8 milliampere per volt.

Certain characteristics utilized when the tube is connected as in Figure 3 are shown in Figures 4 to 6. Figure 4 shows the anode current, anode voltage characteristic with the internal alternating current resistance at one million ohms, as mentioned above. The grid g^1, owing to the form of connection shown in Figure 3, acquires a potential of −5 volts. The grid g^4 shown connected to the automatic gain control bus bar **4** in Figure 3, is connected to the cathode while obtaining the characteristic curve shown in Figure 4, so as to be at zero potential, whereas the grids g^2 and g^5 are connected together and maintained at 100 volts. The current to the grid g^5 is 0.04 milliampere. The current to the grid g^2 is 7 milliamperes.

Figure 5 shows the characteristic with the anode current plotted against the varying potential of the input grid g^3. The curve is taken with the tube oscillating with an anode potential of 250 volts, the grid g^4 as in the case of Figure 4 being at cathode potential, the grids g^2 and g^5 connected together maintained at 100 volts, and the grid g^1 at approximately −5 volts. The slope of the curve in Figure 5 is of course proportional to the conversion conductance of the tube.

In Figure 6 the characteristic is shown with the anode current plotted against the voltage of the grid g^4 with respect to the cathode as it would be varied by the automatic gain control, in order to show the cut-off of the tube under these conditions. For the purpose of determining this characteristic, the tube is operated without self-bias. The potentials of the anode and of the grids g^1, g^2 and g^5 are as in Figure 5, while the input grid g^3 is at about −2.8 volts.

In Figure 7, the connections are shown for a controlled gain voltage amplifier suitable for use in the intermediate stage of a supersonic heterodyne receiver. The tube is in effect a tetrode as the first grid g^1 acts as the input grid, the third grid g^3 as the automatic gain control grid, while the other three grids g^2, g^4 and g^5 are connected directly together and through a resistance **6** to the high tension source so that they act as positive screening grids. The anode to control grid capacity with the external screen in position is about 0.001 mmfd. It will be noticed that here again separate grids are used for the gain control and for the input voltage. The mutual conductance is reduced proportionally to the reduction in anode current which occurs as the gain control grid is made more negative. This method avoids the amplitude distortion which accompanies the method of gain control by means of a variable-mu characteristic. If the tube has the dimensions described with reference to Figure 1, the following gives the operating conditions:—The anode voltage is 250. The breakdown resistance 6 has a value of 60,000 ohms and the cathode bias resistance R_3 is 150 ohms. The voltage of the grids g^2, g^4 and g^5 is between 60 and 70 volts. If the grid g^3 is at the same potential as the cathode, the mutual conductance of the tube is of the order of 2.2 milliamperes per volt and the anode current about 7.5 milliamperes. The internal alternating current resistance of the valve is about 1 million ohms. It is important to note that as increasingly negative automatic gain control voltages are applied to the grid g^3, the current flowing to the grid g^2 will increase and therefore the screen voltage on the grid g^2 will be reduced. The total current taken by the valve will also fall owing to the reduced positive field acting on the cathode space charge with the particular configuration of the grids provided. Also, the cathode bias due to the voltage drop across the resistance R_3 will be reduced proportionally. In this way, the operating cathode bias remains at the correct value with respect to the screen voltage at all values of the negative automatic gain control voltage on the grid g^3. This is an important property of the tube when employed in this circuit. If methods of producing the necessary grid bias had been used, other than a cathode resistance, then the cathode or grid bias would not have taken automatically a suitable value for all values of the automatic gain control voltage.

Certain characteristic curves obtained from the tube under the conditions shown in Figure 7 are illustrated in Figures 8 to 10, and illustrate the above stated facts. In Figure 8, two characteristic curves, 20 and 21 are shown to illustrate the relation between the anode current and the anode voltage. In the curve 20 the voltage applied to the grid g^1 is that of the cathode, and in curve 21 the voltage of the grid g^1 is −2.2.

Figure 9 is the characteristic curve showing the anode current when the anode voltage is 250, as mentioned above, and the voltage of the grid g^1 is varied. The slope of this curve gives the mutual conductance which, as mentioned above, is of the order of 2.2 milliamperes per volt.

In Figure 10 the curve illustrates the anode current with the voltage of the grid g^3 varied and the voltage of the grid g^1 maintained at cathode voltage.

Further characteristic curves of the tube are shown in Figures 11 to 13, when the tube is connected as a voltage amplifier for use in a radio frequency stage. Figure 11 comprises two anode current, anode voltage characteristics 22, 23, the former being taken with the grid g^1 at −4.5 volts and the latter with the grid g^1 at −7 volts with respect to the cathode. Figure 12 shows the anode current plotted against the voltage of the grid g^1. Figure 13 comprises three curves, 24, 25 and 26. The curve 24 shows the conditions when the grid g^3 is maintained at cathode potential, the voltage of the grid g^4 being varied and plotted horizontally. The curve 25, on the other hand, shows the voltage of the grid g^4 maintained at cathode potential and that of the grid g^3 varied and plotted horizontally. The curve 26 shows the conditions when the grids g^3 and g^4 are kept at the same potential, which is varied as shown by the horizontal scale.

In Figure 14, the tube is shown connected as a single valve detector amplifier, the tube serving as a tetrode. The anode a of the tube operates as a diode on a virtual or floating space-charge cathode formed between the grids and anode. The grids g^2, g^3, and g^5 are connected together as positive screening grids, being connected to a potential divider R_4, R_5 across the high tension source, while the grid g^4 serves as the anode of the amplifier part of the valve. This form of connection gives a magnification of up to the order of 40 times. The automatic gain control connection is made at 8, for example, to the line 4 in Figures 3 and 7. If, again, the tube has the dimensions as in Figure 1, the operating conditions are as follows:—The anode voltage is 250. The voltage divider resistances R_4 and R_5 are respectively 250,000 and 50,000 ohms so as to produce a potential of about 40 volts on the grids g^2, g^3, g^5. The resistance R_6 which serves as the resistance coupling the valve to the next stage has a value of 30,000 ohms, while the cathode bias resistance R_7 is 1,000 ohms. The grid leak resistance R_8 may be 1 million ohms. The diode load resistance R_9 is 500,000 ohms and the automatic gain control filter resistance R_{10}, 1 million ohms. The efficiency of rectification is high, of the order of 96 per cent.

In Figure 15 the tube is shown connected to act as a power output tube. The external screen is not used but the tube so connected has a low anode to control grid capacity. The grid g^1 is the input grid and the grids g^2, g^3 and g^5 are positive screening grids connected to a potential divider R_{11}, R_{12} connected across the high tension source 7. A loud speaker 10 is shown transformer-coupled to the anode circuit of the tube. With the tube illustrated in Figure 1, the operating conditions are as follows:—The steady potential of the anode a and of the grids g^2 and g^3 is 250 volts and that of the grid g^5 is about 70 volts. The cathode bias resistance R_{13} is 250 ohms. The anode current is 32 milliamperes and the mutual conductance of the order of 3 milliamperes per volt. The cathode bias is about 12 volts and the tube should be capable of giving a power output of the order of 2 to 3 watts with a load of about 6,000 ohms.

In Figures 16 and 17 certain characteristic curves of the tube are shown when operating under the power output conditions illustrated in Figure 15.

In Figure 16 the three curves 27, 28 and 29 are three anode current-anode volt characteristics with the grid g^1 maintained respectively at the cathode potential, −12 volts and −24 volts with respect to the cathode. The curve 30 shows that the total current flowing to the screens plotted vertically against the anode volts plotted horizontally in all the curves in Figure 16 the grid g^4 is kept at cathode potential.

Figure 17 shows the relation between the anode current and the voltage of the grid g^1.

In Figure 18, the tube is shown connected as a single tube detector amplifier actually operating as a triode. g^1 is the input grid, the anode a acts as a diode and the output is taken off from the remaining four grids g^2, g^3, g^4 and g^5 connected together. With the tube shown in Figure 1, the operating conditions are much the same as stated in connection with Figure 14, except that the potential divider R_4, R_5 is omitted and the coupling resistance R_{14} may conveniently have a high value, for example, of 50,000 to 100,000 ohms.

Figure 19 shows the tube connected as a plain triode employed for example as an output tube. The grid g^1 is the input grid, the remaining four grids g^2, g^3, g^4 and g^5 are all connected direct to the anode a and with it form the output electrode.

Figure 20 shows the circuit connections of a complete supersonic heterodyne receiver. The tube v^1 is connected as a single-tube frequency changer precisely as shown in Figure 3. The tube v^2 is an intermediate frequency amplifier connected exactly as shown in Figure 7. The tube v^3 is a combined detector and amplifier connected as a tetrode in precisely the manner shown in Figure 14, while the tube v^4 is a power output tube connected exactly as shown in Figure 15. The circuit is shown with the ordinary antenna tuning arrangements and the ordinary mains power unit for the high tension supply with a winding 11 supplying the current to the heaters of the cathodes of the tubes. Also the frequency changer tube v is shown with switching arrangements for changing the range of wave-lengths. The circuit connections will be apparent after examination of Figures 3, 7, 14 and 15 since the same reference characters have been used for corresponding parts.

It will be easily appreciated that the same form of tube could not be used in all the circuits if they had not the following characteristic features. In the case of the frequency changer tube v^1, the first grid g^1 has its lead taken out at the top of the bulb b and is prevented from producing serious "lock-in" by means of the capacity ratio of the grids as described instead of by shielding. Since the first grid g^1 is connected to the terminal t at the top of the bulb b, that is to say, at the opposite end to that at which the anode a is connected, the same construction of tube can therefore be used as the intermediate frequency amplifier v^2. By the provision of several grids it is possible to employ the same construction of tube as the combined diode and tetrode amplifier v^3. The potential of the grid g^5 while sufficiently high to serve as an anode break-down voltage, low compared with the voltage of the high tension source used in the receiver and compared with the voltage of the anode a and the other positive grids, is nevertheless low enough to allow of a critical anode distance within the dimensions of a bulb of convenient size so that the advantages of the anode critical distance as regards power output and low distortion level are retained. Furthermore, owing to the provision of a number of grids, there is a grid in the case of the frequency converter and intermediate frequency valves, which is nearer the anode than the control or oscillatory grids and is available as an automatic gain control electrode.

I claim:

1. An electron discharge tube having a cathode, at least five concentric and successive co-extensive grids enclosing said cathode and an anode enclosing said grids and being spaced at the critical anode distance from the nearest of said grids, the first grid counting from the cathode having an appreciable controlling action on the anode current, the grid surface in the path of the discharge being spaced from the cathode by a distance of the order of about 0.3 mm. and having a mesh closer than the order of 10 turns per cm. of 0.1 mm. diameter wire, the third and fourth grids counting from the cathode having meshes closer than the order of 10 turns per cm. of .1 mm. diameter wire thereby having appreciable controlling action on the anode current, the second grid counting from the cathode being of mesh not closer than about the order of 10 turns per cm. of .1 mm. wire, the fifth grid having mesh not closer than the order of about 8 turns per cm. the distances between the faces of the grids in the path of the discharge being approximately equal and of the order of 1 to 2 mm.

2. An electron discharge tube according to claim 1 characterized by screens internal and external of the tube envelope, the internal screen having a part of its surface close to the wall of the envelope and approximating in curvature to the curvature of the envelope and the exterior screen enclosing and fitting closely to that part of the envelope close to said part of the surface of said internal screen.

3. An electron discharge tube according to claim 1 in which certain of the grid electrodes are oval in contour and have their profiles define arcs.

4. An electron discharge tube according to claim 1 characterized by having the control electrode so spaced from the cathode and of such mesh that the mutual conductance is of the order of at least one milliampere per volt.

5. An electron discharge tube according to claim 1 characterized by having the grid electrode nearest the cathode so spaced therefrom and of such mesh that with positive potentials of the order of 250 volts on the succeeding electrodes, the anode current is not less than the order of 30 milliamperes.

6. An electron discharge tube having a cathode, at least four concentric and successive co-extensive grids enclosing said cathode and an anode enclosing said grids and being spaced at the critical anode distance from the nearest of said grids, the first grid counting from the cathode having an appreciable controlling action on the anode current, the grid surface in the path of the discharge being spaced from the cathode by a distance of the order of about .3 mm. and having a mesh closer than the order of 10 turns per cm. of 0.1 mm. diameter wire, the third grid counting from the cathode having its mesh closer than the order of 10 turns per cm. of .1 mm. diameter wire thereby having appreciable controlling action on the anode current, the second grid counting from the cathode being of mesh not closer than about the order of 10 turns per cm. of .1 mm. wire, the fourth grid having its mesh not closer than the order of about 8 turns per cm. the distances between the faces of the grids in the path of the discharge being approximately equal and of the order of 1 to 2 mm.

7. An electron discharge tube according to claim 6 characterized by screens internal and external of the tube envelope, the internal screen having a part of its surface close to the wall of the envelope and approximating in curvature to the curvature of the envelope and the exterior screen enclosing and fitting closely to that part of the envelope close to said part of the surface of said internal screen.

8. An electron discharge tube according to claim 6 in which certain of the grid electrodes are oval in contour and have their profiles define arcs.

9. An electron discharge tube according to claim 6 characterized by having the control electrode so spaced from the cathode and of such mesh that the mutual conductance for said control grid is of the order of at least one milliampere per volt.

10. An electron discharge tube according to claim 6 characterized by having the grid electrode nearest the cathode so spaced therefrom and of such mesh that with positive potentials of the order of 250 volts on the succeeding electrodes, the anode current is not less than the order of 30 milliamperes.

11. An electron discharge tube having a cathode, at least four concentric and successive grids enclosing said cathode, and an anode enclosing said grids, the second grid counted from the cathode having a mesh more open than that of the first grid counted from the cathode, the third grid counted from the cathode having a mesh closer than that of the first grid and a grid further from the cathode than said first three grids having a more open mesh than any of the said first three grids.

12. An electron discharge tube according to claim 11 wherein the fourth grid has a mesh of the same order as the third grid.

13. An electron discharge device according to claim 1 wherein the tube, when employed with the second, fourth and fifth grids at potentials below about 80 volts, has an anode current of the order of not more than 10 milliamperes and an anode resistance to alternating current, with an operating anode potential of the order of 250 volts, of the order of 1 megohm, the third grid being grounded and the control grid having a negative potential of the order of 1 volt thereon, and a mutual conductance of the order of 1.5 milliamperes per volt and so that when the fourth grid is grounded, the anode current is of the order of not more than three milliamperes, the mutual conductance of the said third grid is of the order of one-quarter to 1 milliampere per volt, the anode resistance to alternating current and the mutual conductance of the first grid being the same and further, so that with a potential of 250 volts on the anode and the second and third grids the negative potential of the order of 10 to 20 volts on the first grid with the fourth grid grounded and a potential of the order of 70 volts applied to the fifth grid, the mutual conductance is of the order of 2 to 4 milliamperes per volt and the anode current is of the order of 30 to 40 milliamperes, the knee of the anode-voltage anode-current characteristic occurring at an anode voltage not greater than about 100 volts.

14. An electron discharge tube having a cathode, at least five concentric and successive coextensive grids enclosing said cathode and an anode enclosing said grids and being spaced at the critical anode distance from the nearest of said grids, the second grid counted from the cathode having a mesh more open than that of the first grid counted from the cathode, the third grid counted from the cathode having a mesh closer than that of the first grid, the fourth grid counted from the cathode having a mesh closer than that of said first grid and the fifth grid having a more open mesh than any of said other grid electrodes, said grids being so related that the tube, when employed with the second, fourth and fifth grids at potentials below 100 volts, has an anode current of the order of not more than 10 milliamperes and an anode resistance to alternating current, with an operating anode potential of the order of 250 volts, of the order of 1 megohm, the third grid being grounded and the control grid having a negative potential of the order of 1 volt thereon, and a mutual conductance of the order of 1.5 milliamperes per volt and so that when the fourth grid is grounded, the anode current is of the order of not more than three milliamperes, the mutual conductance of the said third grid is of the order of one-quarter to 1 milliampere per volt, the anode resistance to alternating current and the mutual conductance of the first grid being the same and further, so that with a potential of 250 volts on the anode and the second and third grids, a negative potential of the order of 10 to 20 volts on the first grid with the fourth grid grounded and a potential of the order of 70 volts applied to the fifth grid, the mutual conductance is of the order of 2 to 4 milliamperes per volt and the anode current is of the order of 30 to 40 milliamperes, the knee of the anode-voltage anode-current characteristic occurring at an anode voltage not greater than about 100 volts.

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