Sept. 16, 1941. C. F. STROMEYER 2,256,177

THERMIONIC TUBE AND CIRCUIT

Filed March 29, 1939

Fig. 1A

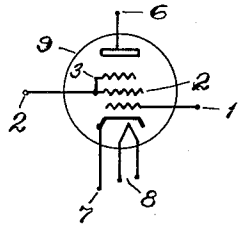


Fig. 2A

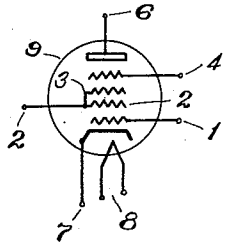


Fig. 3A

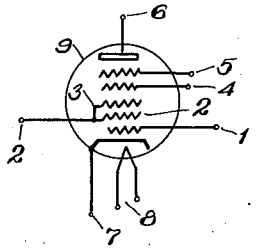


Fig. 1B

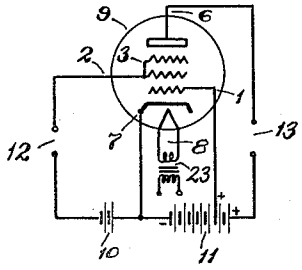


Fig. 2B

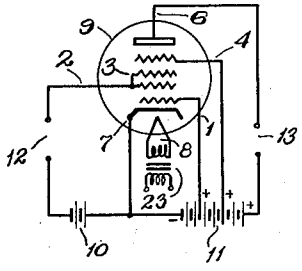


Fig. 3B

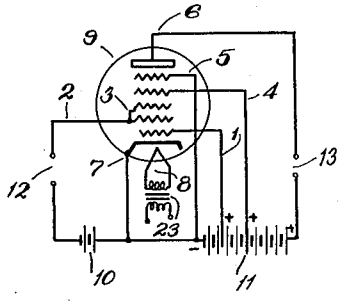


Fig. 4

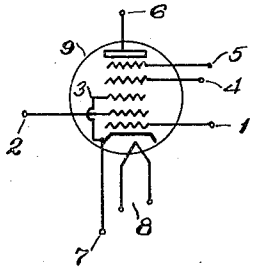


Fig. 6

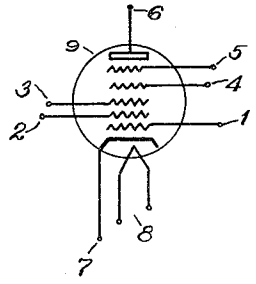
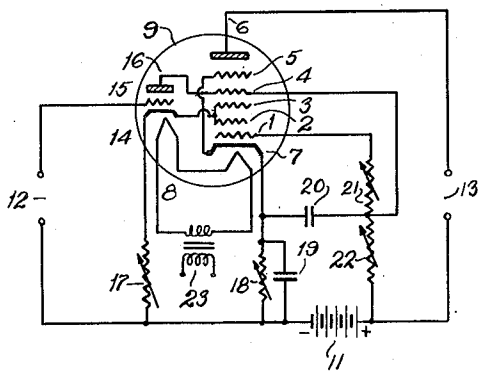


Fig. 6



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THERMIONIC TUBE AND CIRCUIT

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Application March 29, 1939, Serial No. 264,689

19 Claims. (Cl. 250—27)

This invention relates to thermionic tubes and especially to such tubes utilizing a space-charge electrode to provide a large virtual cathode. This invention also relates to the associated circuits for the purpose of amplifying, detecting, frequency converting signals, and to produce local oscillatory energy with such tubes.

Since the amplifying capability of a thermionic tube is proportional to its plate transconductance, other factors being equal, there is a constant quest to improve this control factor. To merely proportionately enlarge the tube elements is not the improvement intended here, for that would be like enlarging a given design of a motor which would result in increasing its power but it does not necessarily follow that its efficiency would be improved. This tube design problem usually resolves to the question of obtaining greater transconductance per-mil plate current without increasing the cathode heating power and without appreciably increasing the structural size.

A conventional method is to reduce the cathode to control grid clearance and use a grid wire having the smallest diameter possible. It is obvious that this method is limited by structural requirements such as needed rigidity and practicable clearance to avoid shorting of the tube elements, by excessive variations in characteristics of tubes of a given design, and by grid emission.

Another method is to provide a large so-called virtual cathode which effectively has much greater area than its associated real cathode. The control grid may be as close to the virtual cathode as desired with no danger of shorting since the virtual cathode is an imaginary surface situated in space. Grid emission is minimized because the control grid is not close to the hot cathode. A virtual cathode can be readily formed by using a positive grid, known as a space-charge grid, preferably adjacent to the cathode, that is between the cathode and control grid. The virtual cathode considered herein is an imaginary surface exhibiting cathode characteristics, located in the space between the space-charge grid and the next succeeding positive grid, all points of which are at the minimum space potential. By correctly positioning and proper design of the electrodes, a virtual cathode of large area may be had. Such space charge tubes can be made with very high ratio of transconductance per-mil plate current. In spite of this, such tubes have not met with conspicuous commercial success. Probably the chief reason for this is because of the manufacturing difficulty of obtaining uniform tube characteristics among tubes of a given design. The percentage variation is much greater than with tubes of conventional construction not using such virtual cathodes and its cause can only be partly attributed to mechanical displacement of the elements. My invention provides a practical solution to this basic difficulty.

Application of space-charge tubes to circuits is seriously limited due to their relatively high inter-electrode capacities, particularly the control electrode to anode. Another difficulty is the problem of obtaining a satisfactory so-called variable-mu characteristic to provide a remote plate current versus control grid voltage characteristic for minimizing cross modulation effects, without seriously reducing the transconductance. My invention also provides solutions to both of these problems. A tube to be later described in detail embodies these teachings. This particular tube is intended for general radio frequency amplification and detection applications. The effective grid-plate capacity of this tube is so low that conventional high Q input and output circuits may be used without inter-action between these circuits. A stage gain improvement of five times can be realized. This tube also has an overall remote plate current versus control grid voltage characteristic.

An object of this invention is to minimize variations in characteristics of tubes utilizing a large virtual cathode by a special arrangement of electrode elements.

Another object of this invention is a method for coupling tube elements so as to minimize inter-action between the associated input and output circuits.

Another object of this invention is a method for coupling tube elements so as to minimize loading of the associated input circuit.

Still another object of this invention is a method for coupling tube elements so as to provide an overall remote plate current versus control grid voltage characteristic without requiring a so-called variable-mu action with the tube elements that produce relatively high transconductance.

In the drawings—

Fig. 1A is a schematic diagram showing an arrangement of several electrodes according to the invention, and Fig. 1B is the same schematic showing how it may be used in a simple amplifying circuit.

Fig. 2A and Fig. 3A are also schematic dia-

grams showing other arrangements of several electrodes according to the invention, and Fig. 2B and Fig. 3B are the same schematics, respectively, showing how they may be used in a simple amplifying circuit.

Fig. 4 and Fig. 5 are also schematic diagrams showing two further arrangements of several electrodes according to the invention.

Fig. 6 is a schematic diagram showing a coupling arrangement of several electrodes and a simple amplifying circuit according to the invention.

Referring to Fig. 1A, an evacuated envelope 9 encompasses the tube's inter-electrodes. Cathode 7, heated by heater 8, supplies a source of emitted electrons. Grid 1 is a space charge grid and when proper positive potential is applied thereto, a virtual cathode is established somewhere in the space between this grid and anode 6. Grid 2 is a control grid. A special grid 3 is connected to the control grid. This arrangement may be considered a triode type of a space charge tube with the addition of the special grid, the action of which will be described later. Fig. 1B shows how this same tube may be used in a simple amplifying circuit where the input signal is impressed across terminals 12 and the output taken off terminals 13. Items 10, 11 and 23 are potential sources for operation of the device.

Reoccurring reference numerals in all the figures refer to like elements and will not be repeatedly described.

Fig. 2A and Fig. 2B are similar to Fig. 1A and Fig. 1B but with the addition of screen grid 4. This arrangement may be considered a tetrode type of a space charge tube with the addition of the special grid 3. The virtual cathode in this tube is established somewhere in the space between the space charge grid 1 and the screen grid 4.

Fig. 3A and Fig. 3B are similar to Fig. 2A and Fig. 2B but with the addition of a suppressor grid 5. This arrangement may be considered a pentode type of a space charge tube with the addition of the special grid 3.

Fig. 4 is similar to Fig. 3A but the special grid 3 is connected to cathode 7 instead of control grid 2. This modification may likewise be used with tubes arranged according to Figs. 1A and 2A.

Fig. 5 is similar to Fig. 3A but the special grid 3 terminates independently of the other grids instead of being connected to control grid 2, in order that it may be connected at will to the control grid 2, cathode 7, space charge grid 1, or to a low negative or positive potential with relation to the cathode. This modification may likewise be used with tubes arranged according to Fig. 1A and Fig. 2A.

The word "grid" used herein is for illustration purpose and in no manner limits the invention to any particular physical structure of the electrode. Any known arrangement of an electrode structure which controls the number, velocity or direction of electrons traveling between cathode and anode may be applicable to the word grid as used herein.

I believe the theory of how the special electrode just described minimizes the variation in transconductance of such devices to be somewhat as follows: The position of the virtual cathode which is established somewhere in the space between the space-charge grid and anode or screen grid, may be considered at an imaginary surface described by all points that are at the minimum-space-potential within the space. In the ideal case for maximum control, the control grid should be located just beyond this imaginary surface, and it should provide a controlling field which conforms to the configuration of this surface. In the practical case, this imaginary surface is far removed from being a smooth plane and its configuration and position varies considerably among tubes of a given design. This results in variations of transconductance-per-mil plate current. As the potential gradient on the anode or screen grid side of the control grid is lowered, the shape of the virtual cathode becomes more uniform and its position more consistent. In many instances low anode or screen voltage is not desirable and often considerations of size limit the maximum permissible distance between elements. The special grid located between the control grid and anode or screen grid can effectively lower the potential gradient immediately following the control grid without reducing the transconductance-per-mil plate current. If the special grid is so designed with relation to the control grid that its effect on the plate transconductance is much less than that provided by the control grid, and if it is connected to the control grid, the transconductance-per-mil plate current may be higher than tubes of similar design but without the special grid. The special grid may be connected to the cathode or some low positive or negative potential. However, when the special grid is connected to the control grid an additional improvement in minimizing characteristic variation is realized. This can be explained by the fact that the depth of the controlling field is increased, which makes the tube less critical to displacement and to irregularities in the shape of the virtual cathode. This method of minimizing characteristic variations is indeed simple and highly effective, making it possible to manufacture very high transconductance tubes nearly commensurable with the percentage variation as in making ordinary triodes or pentodes.

From the foregoing it is seen that a purpose of the special grid is to produce a low potential gradient immediately following the virtual cathode. Another purpose is to increase the depth of signal control region directly following the virtual cathode. It is evident that a compromised condition is preferable because should the gradient beyond the virtual cathode be made too flat, the control factor suffers. These statements may seem vague but the art is far too new to attempt mathematical expressions for optimum conditions in terms of parameters of tube elements and potentials. It should be sufficient to say that a purpose of the special grid is to produce a low potential gradient for a substantial distance immediately following the virtual cathode. In the case of a medium size tube, this distance might be .025" and the average slope may be only a fraction of the voltage on the succeeding positive electrode. It also should be sufficient to say that a purpose of the special grid is to increase the depth of the signal control region immediately following the virtual cathode. In the case of a medium size tube, this depth might be .025".

In order to avoid unnecessary experimentation by those skilled in the art to determine how my invention may be applied in a practical application, I will now set forth several specific details of one design. The tube in question is arranged like Fig. 3A and measured in a circuit like Fig. 3B. An indirectly heated electron emitting

cathode .030" in diameter is surrounded by concentric grids of the helical type, each supported at their major diameter by two lateral posts. Certain details of these grids follow:

Grid #	Major diameter	Minor diameter	Helical wire diameter	Turns per-inch
	Inches	*Inches*	*Inches*	
1	.220	.150	.002	60
2	.320	.310	.003	40
3	.420	.360	.004	25
4	.530	.415	.004	56
5	.640	.600	.006	18

A circular plate of .910" diameter surrounds the grids. These tube elements are supported in such manner as to be insulated from each other except the number of terminating leads are lessened by internally connecting grid #3 to grid #2, and grid #5 to cathode. The effective length of these elements is .800" and the cathode coating band length is .590". It is preferable to shield the plate in such manner as to minimize electronic bombardment of the envelope. In order to readily evaluate the improvement in plate transconductance compared with one of the most popular standard contemporary pentodes made in this country, known as type #6K7G, the following figures are given:

Operation and characteristics	New tube	6K7G
Heater power	1.2	1.89 watts.
Plate volts	250	250 volts.
Screen volts	100	125 volts.
Space-charge grid volts	30	
Plate current	6.0	10.5 ma.
Screen current	2.3	2.6 ma.
Space-charge grid current	5	
Plate resistance	0.6	0.6 megohm.
Transconductance	13,000	1650 μmhos.
Transconductance per-mil plate current	2,170	157.
Transconductance per-mil cathode current	980	126.

The figures for the type 6K7G are taken from its published rating and figures for the special tube are approximate average values taken from a quantity of tubes made according to this design. The improvement in transconductance is approximately eight times. The improvement in transconductance per mil-plate current is approximately fourteen times. The improvement in tranconductance per-mil total cathode current is approximately eight tin.es. The actual space between the cathode sleeve and #1 grid wire is .058" for the new tube; and for the 6K7G, whose sleeve is usually .045" diameter and minor #1 grid diameter .080", is actually .0145". This is a four times improvement in cathode to #1 grid clearance.

Tubes of this type, however, have disturbingly high effective inter-electrode capacities. The limitation of amplifying tubes, particularly with relation to grid-plate capacity, is well recognized. Since this capacity appears to the associated circuits effectively as a value equal to the grid-plate capacity times the gain of the tube, it is apparent that the general usefulness of high transconductance tubes is limited unless this capacity is made extremely small or nullified. Also the high inter-electrode capacities and transconductance cause the input admittance to be high, resulting in a further limitation due to loading of the input circuit. These difficulties may readily be overcome by employing a special coupling arrangement of tube elements as shown in Fig. 6.

Referring to Fig. 6, evacuated envelope 9 encompasses two sets of electrodes, comprising a driver set having a cathode 14, signal control grid 15, and anode 16, and an output set having the same electrode arrangement as described in Fig. 3A. Cathode 14 is connected internally to grids 2 and 3, anode 16 to grid 4, and grid 5 to cathode 7. These internal connections lessen the number of base terminals required and minimize stray lead capacity and inductance. Cathode 14 returns to a negative pole of the potential source 11 by the series impedance 17. Element 17 is represented as an impedance for illustrative simplicity and, of course, it may be any type of a known series load, tuned or untuned. Cathode 7 returns to a negative pole of the potential source 11 by the series impedance 18, and this element is by-passed by condenser 19. Bias voltage for the grids 15 and 2 are provided by the voltage drops across the elements 17 and 18. This coupling of an input set of elements to an output set, and bias arrangements, are similar to my United States Patent No. 2,154,783. Any known input device may be connected across terminals 12 to impress the input signal between grid 15 and a negative end of the potential source 11. Any known output device may be connected between terminals 13 to provide a work load between anode 6 and a positive end of the potential source 11. Rather than show the potential feeds for grid 1 and grid 4 as merely taps from the potential source 11, one practical method of supplying the grids from one point of potential is shown. Grid 1 returns to the potential source via resistors 21 and 22. Grid 4 returns to the potential source via resistor 22 which is by-passed to cathode 7 by condenser 20 in order to make the potential on grid 4 substantially constant. If the tube is correctly designed no loss is suffered due to the resistor 21 being un-by-passed. In fact, with some designs, an increase in gain will result if resistor 21 is left un-by-passed. Heater 8 renders cathodes 7 and 14 emissive.

The advantages of this coupling arrangement are many. Due to the degenerative repeating action of the driver, resulting in a gain less than unity, its effective input admittance as it appears to the input device is very low. Since the input of the output section is shunted by a relatively low impedance element 17, its high input admittance is no longer troublesome. The result is that the driver section effectively isolates the impressed input circuit from the output load circuit so as to reduce inter-action between these circuits to a minimum. Also the loading of the impressed input circuit is very small. When it is desirable to have a remote overall plate current versus control grid voltage characteristic to minimize cross modulation, it is not necessary to use a so-called variable-mu action in the output section for the desired characteristic may be obtained by proportioning the plate current cut-off rate of the individual sections and by proper selection of elements 17 and 18. This flexibility permits the use of a sharp plate current cut-off output section and a variable-mu type driver. The advantage of this arrangement is that a much higher overall transconductance-per-mil plate current can be obtained and with better consistency of characteristics.

It is obvious from the foregoing that it is not essential to have the two sections of tube ele-

ments in one envelope. Separate tubes may readily be used. It is also obvious that this coupling arrangement is not limited to repeating signals of a particular band of frequencies, for it may be used to repeat impulses of audio or radio frequency. This coupling arrangement is not limited solely to amplifying signals for it may also be used for detector and frequency converter signals and to produce local oscillatory energy.

What I claim is:

1. A thermionic tube having a cathode capable of emitting electrons and an anode, a space-charge grid capable of producing a virtual cathode in the space between the space-charge grid and anode when a positive potential is applied to the space-charge grid, at least one signal-control grid between the space-charge grid and anode, an auxiliary grid between the signal-control grid and anode, a direct connection between the signal-control grid and the said auxiliary grid.

2. A thermionic tube having a cathode capable of emitting electrons and an anode, a space-charge grid capable of producing a virtual cathode in the space between the space-charge grid and anode when a positive potential is applied to the space-charge grid, at least one signal-control grid between the space-charge grid and anode, an auxiliary grid directly between the signal-control grid and anode, a direct connection between the auxiliary grid and cathode.

3. A thermionic tube having a cathode capable of emitting electrons, a screen grid, and an anode, a space-charge grid capable of producing a virtual cathode in the space between the space-charge grid and screen grid when a positive potential is applied to the space-charge grid, at least one signal-control grid between the space-charge grid and screen grid, an auxiliary grid between the signal-control grid and the screen-grid, a direct connection between the signal-control grid and the said auxiliary grid.

4. A thermionic tube according to claim 3 with the addition of a suppressor grid located between the screen grid and anode.

5. A thermionic tube having a cathode capable of emitting electrons, a screen grid, and an anode, a space-charge grid capable of producing a virtual cathode in the space between the space-charge grid and screen grid when a positive potential is applied to the space-charge grid, at least one signal-control grid between the space-charge grid and screen grid, an auxiliary grid between the signal-control grid and the screen grid, a direct connection between the auxiliary grid and cathode.

6. A thermionic tube according to claim 5 with the addition of a suppressor grid located between the screen grid and anode.

7. A thermionic tube having a cathode capable of emitting electrons, a screen grid, and an anode, a space-charge grid capable of producing a virtual cathode in the space between the space-charge grid and screen grid when a positive potential is applied to the space-charge grid, at least one signal-control grid between the space-charge grid and screen grid, an auxiliary grid between the signal-control grid and anode to produce a lower potential gradient in the space immediately following the signal-control grid than there would be if the said auxiliary grid were not present.

8. A thermionic tube according to claim 7 with the addition of a suppressor grid located between the screen grid and anode.

9. A thermionic tube having a cathode capable of emitting electrons and an anode, a screen electrode capable of accelerating the electrons passing through or around the screen electrode when a positive potential is applied thereto, a space-charge electrode capable of establishing a virtual cathode between this electrode and the screen electrode when a positive potential is applied to the space-charge electrode, a control electrode located in the space between the space-charge electrode and the screen electrode capable of controlling the number of electrons arriving at the anode when signal impulses are applied to the signal-control grid, at least one additional electrode in the space between the space-charge grid and screen electrode to produce a lower potential gradient in the space immediately following the signal-control electrode than there would be if the said additional electrode were not present.

10. A thermionic tube having a cathode capable of emitting electrons and an anode, a screen electrode capable of accelerating the electrons passing through or around the screen electrode when a positive potential is applied thereto, a space-charge electrode capable of establishing a virtual cathode between this electrode and the screen electrode when a positive potential is applied to the space-charge electrode, a control electrode located in the space between the space-charge electrode and the screen electrode capable of controlling the number of electrons arriving at the anode when signal impulses are applied to the signal-control grid, at least one additional electrode in the space between the space-charge grid and screen electrode to further control the number of electrons arriving at the anode when signal impulses are applied to the said additional electrode and to produce a lower potential gradient in the space immediately following the signal-control electrode than there would be if the said additional electrode were not present.

11. A thermionic tube comprising a driver set of electrodes and an output set of electrodes, the driver set including at least an electron emitting cathode, a signal-control electrode and an anode; the output set including an electron emitting cathode and an anode, a space-charge electrode capable of establishing a virtual cathode between this space-charge electrode and the second mentioned anode, a control electrode located between the said space-charge electrode and the second mentioned anode, at least one additional electrode located in the space between the said space-charge electrode and the anode to produce a lower potential gradient in the space immediately following the said control electrode than there would be if the said additional electrode were not present; a direct electrical connection between the first mentioned cathode and the said control electrode.

12. A thermionic tube according to claim 11 in which the driver set of electrodes are of the variable mu type providing a remote anode current versus signal-control electrode characteristic.

13. A thermionic tube having a driver set of electrodes and an output set of electrodes, the driver set including at least an electron emitting cathode, a signal-control electrode and an anode; the output set including an electron emitting cathode, a screen electrode, an anode, a space-charge electrode capable of establishing a

virtual cathode between this space-charge electrode and the screen electrode when a positive potential is applied to this space-charge electrode, a control electrode located between the space-charge electrode and the screen electrode, and at least one additional electrode adjacent to the said control electrode, a direct electrical connection joining the first mentioned cathode to the said control electrode and to the said additional electrode, and another direct electrical connection joining the first mentioned anode to the said screen grid.

14. A thermionic tube according to claim 13 connected in a wave repeating circuit comprising a signal input device connected between the signal-control electrode and ground, an output device connected between the anode of the output section and a positive pole of a potential source, a load element connected between the cathode of the driver and ground, a connection between the cathode of the output section and ground, positive potentials applied to both the space-charge electrode and the screen electrode.

15. A thermionic tube according to claim 13 connected in a wave repeating circuit comprising a signal input device connected between the signal-control electrode and a negative pole of a potential source, an output device connected between the anode of the output section and a positive pole of the said potential source, a load element connecting the cathode of the driver to a negative pole of the said potential source, a connection between the cathode of the output section and a negative pole of the said potential source, a resistor connected between the space-charge electrode and a positive pole of the said potential source, a connection between the screen electrode and an intermediate tap on the said resistor, and a condenser shunting the said tap to ground or to a point at the minimum signal potential.

16. A thermionic tube according to claim 13 connected in a wave repeating circuit comprising a signal input device connected between the signal-control electrode and a negative pole of a potential source, an output device connected between the anode of the output section and a positive pole of the said potential source, a load element connecting the cathode of the driver to a negative pole of the said potential source, a connection between the cathode of the output section and a negative pole of the said potential source, and positive potentials applied to both the space-charge electrode and the screen electrode.

17. A thermionic tube according to claim 13 connected in a wave repeating circuit comprising a signal input device connected between the signal-control electrode and a negative pole of a potential source, an output device connected between the anode of the output section and a positive pole of said potential source, a load element connecting the cathode of the driver to a negative pole of said potential source, a connection between the cathode and the output section through a resistor element shunted by a condenser to a negative pole of said potential source, and positive potentials applied to both the space-charge electrode and the screen electrode.

18. In an electrical system, a first thermionic tube, a second thermionic tube; said first tube having an electron emitting cathode, at least a signal-control electrode and an anode; said second tube having a space charge electrode, a control electrode, an anode, and at least one additional electrode positioned to make the potential field immediately following the said control electrode less than if the said additional electrode were not present; a short circuit connection between the cathode of the first tube and the said control electrode; a source of anode potential supply; means for connecting the anodes of each of said valves to a positive terminal of said source; a circuit connecting the cathode of the first valve to a negative terminal of said source and including a load element in series; a circuit connecting the cathode of the second tube with a negative terminal of said source, whereby potential for biasing the control electrodes is obtained by utilizing voltage existing between the cathode of each valve and a negative end of said source; a circuit connecting the said signal-control electrode to a negative terminal of said source and including in series circuit elements for introducing an input signal; and means for connecting the said space-charge electrode to a positive terminal of said source.

19. In an electrical system according to claim 18 in which the elements of the first thermionic tube are arranged to provide a variable mu characteristic so that the trans-conductance of the second tube can be gradually controlled by varying a negative potential in series with the circuit connecting the signal-control electrode of the first tube to a negative terminal of the source of anode potential supply.

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