Oct. 15, 1935. I. WOLFF 2,017,192

ELECTRICAL NETWORK

Filed Oct. 29, 1932

Fig. 1.

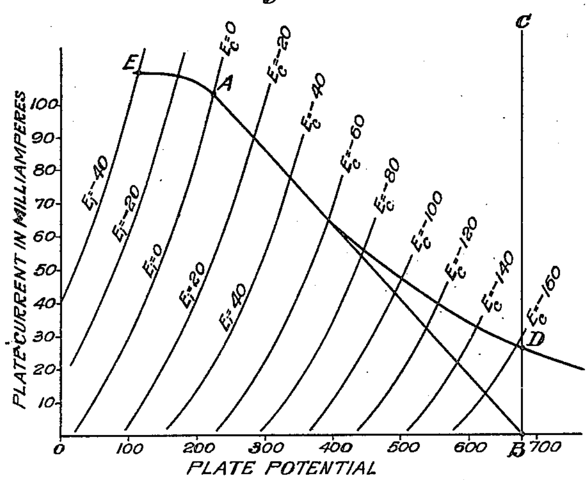


Fig. 2.

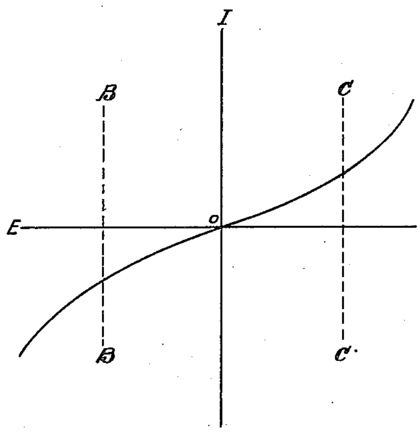


Fig. 3.

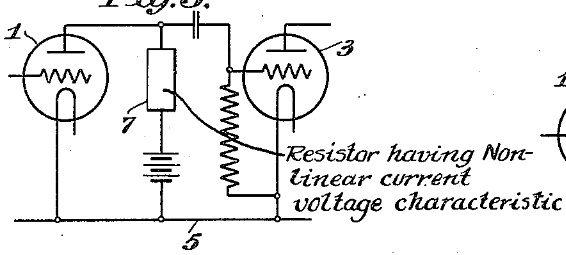


Fig. 4.

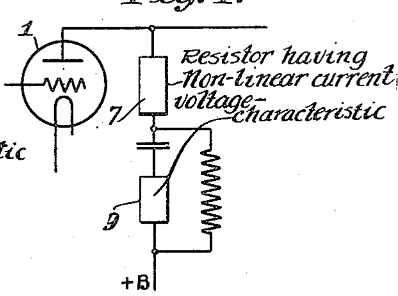


Fig. 5.

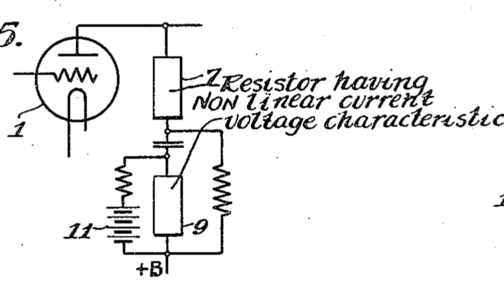


Fig. 6.

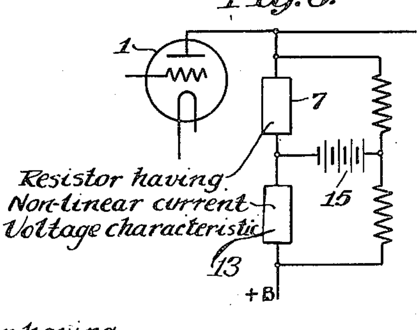
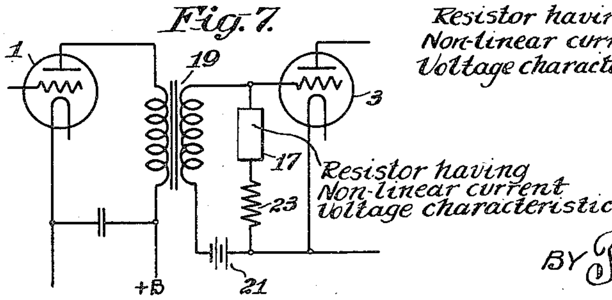


Fig. 7.



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2,017,192

UNITED STATES PATENT OFFICE

2,017,192

ELECTRICAL NETWORK

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Application October 29, 1932, Serial No. 640,249

9 Claims. (Cl. 179—171)

My invention relates to electrical networks and it has particular relation to networks including thermionic tubes.

It is very seldom that an exactly linear relation exists between the potential delivered across a resistance in the plate circuit of a vacuum tube and the voltage available from the preceding tube or circuit. This non-linearity is particularly noticeable when an attempt is made to cover a large swing with the tube or when it is used in such amplifiers as class B amplifiers. The presence of the non-linearity leads to serious harmonics and combination tones in the reproduction of sound and limits the power available from most tubes.

Non-linear distortion in vacuum tube circuits is due, principally, to three causes:

1. Variation in the plate resistance—the resistance normally assuming large values for small plate potentials and decreasing rapidly as the plate potential is decreased.

2. Variable amplification factor. For three element tubes, this is not serious, but in tubes of four or more elements the change in amplification factor may be important.

3. Variable low input impedance—in certain types of amplifiers where the grid is allowed to swing positive, the input impedance of the grid cathode circuit varies with the amplitude of the impressed signals. This is a very serious cause of distortion.

It is, accordingly, an object of my invention to provide an electrical network whereby a thermionic tube may be more efficiently utilized for amplification or other purposes.

Another object of my invention is to provide an electrical network that shall compensate the non-linearity of response of a thermionic tube.

Another object of my invention is to provide means whereby the range of available swing of a tube may be greatly extended so that tubes having smaller plate and filament consumption than have heretofore been used may be made to deliver adequate power.

A still further, and more specific, object of my invention is to provide an electrical network that shall enable a thermionic tube incorporated therein to give greater undistorted output than heretofore.

The foregoing objects and others ancillary thereto I attain, in a preferred embodiment of my invention, by causing the output current of a thermionic tube to traverse an electrical network that does not obey Ohm's law. In other words, in a network constructed and arranged according to my invention, I interpose one of more elements having such characteristics that the rate of change of potential thereacross is not linearly related to the rate of change of current therethrough.

A material that I have found very satisfactory for the purpose is commercially known as "Thyrite," and is described in the McEachron United States Patent No. 1,822,742.

Thyrite, as described in the patent referred to, is a material somewhat similar to dry process porcelain throughout the mass of which appear minute particles of conducting material. It is substantially an insulator at low potentials and becomes a continuously better conductor as the current through it is increased, even in some instances in the ratio of 10,000,000 to one. Thyrite can be constructed to have a law connecting resistance and current through it of the following form over substantial current ranges:

$$R=\frac{C}{I^a}$$

where (C) is a constant depending upon the material, and which determines its resistance for some specified current and (*a*) is another constant which can be varied by different methods of preparing the material and which can range from 0 to some value such as .75. In terms of voltage, R is proportional to

$$E^{\frac{a}{a-1})}$$

where the exponent can vary from 0, which means constant R as in an ordinary wire resistance, to somewhat more than —3. In terms of voltage, current is proportional to

$$E^{\left(\frac{a}{1-a}\right)}$$

where the exponent can be made to vary from 1 to about 3.5.

The material is usually utilized in the form of discs, each face of which is provided with a sprayed metallic coating for contact purposes, but the shape is not a material factor. It should be noted, however, that the resistance of Thyrite varies directly with its thickness, but not inversely with area, as does that of resistor materials, such as carbon, or metals which have heretofore been utilized in coupling networks.

The novel features that I consider characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment, when read in connection with the accompanying drawing, wherein equivalent elements are similarly designated, and in which

Fig. 1 shows a family of plate current-plate potential curves for a typical thermionic tube of the triode type;

Fig. 2 is a curve illustrating the current-potential characteristics of a preferred material, such as Thyrite, and

Figs. 3 to 7 are views of various thermionic tube utilization networks embodying my invention.

Fig. 1 shows a family of plate current plate potential curves for a vacuum tube of the type to which the plate resistance changes, but the amplification factor remains fairly constant. The usual performance of the tube is determined by drawing the straight line AB giving the relation between plate current and plate potential for a fixed resistance. The points of intersection with the different grid potential lines E_c determine the grid potential-plate potential characteristics, the potential across the tube being given by the voltage shown in the abscissae scale and that across the external resistance by the horizontal distance between the line BC and the points of intersection. If the series of grid potential lines are drawn for equal increments of grid voltage, then, in order to obtain a linear relation between voltage developed across the external resistance and grid voltage, the distance between each one of the succeeding intersections and the line BC must differ by a constant amount from the preceding one. Reference to Fig. 1 shows this is not true, and reference to a number of other tube characteristics will show the same effect.

It will, further, be noted that the horizontal distance between successive intersections on the left end of the curve is very nearly the same. Taking this distance, a new line AD may be drawn such that all points of intersection differ by a constant amount. If a resistance existed such that its E—I curve were of the same shape as that shown by the curve AD, where the current is measured as usual and the voltage is measured from some point of intersection of AD produced with the O current axis, non-linear distortion would be eliminated in the region under consideration. Such an E—I curve can be obtained by Thyrite circuits, as will be shown later.

The series of characteristics which have been shown in Fig. 1 are representative of the three element tube. Tubes with more elements show a changing amplification factor as well as a change in plate resistance. A series of curves similar to those shown in Fig. 1 may be drawn, however, and the same procedure can be followed in determining the E—I curve required in the external circuit.

If, in addition to the above types of distortion, the third type, viz., variable low grid-cathode resistance is in effect, a somewhat different family of curves must be drawn to obtain the E—I relation required for correction. As long as the input impedance of the tube under consideration is high or constant, compared to the feeding circuit, E_c is equivalent or, at least, proportional to the voltage E_i developed in the output circuit of the preceding tube when it is feeding into a very large impedance.

A new series of curves might, therefore, be constructed using E_i in place of E_c which would be exactly the same as the series in Fig. 1. If, however, the input impedance of the tube under consideration becomes low compared to the preceding tube output circuit, this relation no longer holds and the E_i family will differ from the E_c family, particularly for positive values of E_c where the drop of impedance becomes of importance. If the output impedance of the tube and the impedance of the feeding circuit are known, the values of E_c corresponding to any value of E_i can be calculated and the E_i family of plate current plate voltage curves can be drawn. The effect will be to crowd the E_i curves closer together for positive values. Using the same procedure as in the preceding cases, a curve EAD can be drawn which represents the E—I relation which must hold in the plate resistance to obtain linear output. This curve differs from that required for the first two types of distortion in that the resistance must increase both for high and low values of the current. A circuit employing Thyrite can be constructed to do this, as will be shown.

The non-linear current-voltage characteristics of Thyrite are exemplified by the curve shown in Fig. 2, from which it will be noted that, although the potential drop across the material increases with increase in current, the rate of increase of the potential decreases as the current increases. It will also be noted, from an inspection of Fig. 2, that the action of Thyrite is reversible, i. e., that it displays the same characteristics irrespective of the direction of flow of current therethrough.

Thyrite may be directly substituted for resistors of the usual type in resistance coupled amplifiers, as clearly shown in Fig. 3 of the drawing which illustrates a plurality of thermionic tubes 1 and 3 having a common cathode connection 5, and being coupled through the medium of a portion of Thyrite 7. A resistance coupled amplifier of the type shown, wherein the coupling resistor is of the usual type, is incapable of distortionless amplification if the grid potentials are such as to cause the tube to work over portions of its characteristic curve which are non-linear. If, however, Thyrite having the proper constants is utilized for the coupling resistor, the value of the resistance decreases with increase in plate current and decreases during decrease in plate current with reference to its steady or DC value, thus compensating the non-linearity of the tube characteristic.

Under certain conditions, it may be desirable to utilize that portion of the I—E curve of Thyrite lying to the left of the origin, as shown in Fig. 2. In such event, the Thyrite is initially biased, as to the potentials indicated by the lines BB or CC, by the application thereto of biasing potential from any convenient source 11.

By reason of the fact that Thyrite shows a symmetrical characteristic for both negative and positive currents, it may be used in connection with elimination or application of predetermined amounts of direct current to obtain a wide variation in resistance-voltage characteristics. An instance of this is shown in Figs. 4 and 5, which represent satisfactory networks. The Thyrite marked "7" is used in the normal fashion, with all the plate current flowing through it, the Thyrite marked "9" has a large condenser in series with it and is shunted by a resistance which is higher than the values assumed by the Thyrite, or which may have a value given to it which will limit the extent to which the resistance of this circuit can increase. When no alternating current is flowing through the vacuum tube, there is a certain drop across the external circuit and a certain voltage across it. The resistance voltage curve of Thyrite 7 is determined by the direct current, while that of Thyrite 9 is determined by the alternating current. As a function of the direct current when an alternating current is applied to the input of the tube, the resistance of Thyrite 9 decreases for both an increase or decrease of direct current in the plate circuit.

As an additional modification, a certain amount of direct current might be applied to Thyrite 9 by means of an external supply source 11, or by some shunt connection from the regular plate supply, and additional modifications in the total resistance-potential characteristic could be obtained. It is evident that this type of connection may be used to obtain a wide variety of characteristics.

It is also feasible to employ a network constituted by a plurality of Thyrite resistors 7 and 13 in series, as shown in Fig. 6 of the drawing, the several resistors being respectively biased in opposite directions by a common source 15.

The arrangement illustrated in Fig. 7 may also be employed, a Thyrite resistor 17 being connected in shunt to the secondary winding of a coupling transformer 19. If desirable, the Thyrite may be polarized by a source 21, an additional current limiting resistor 23 being interposed in series therewith, if desired.

Resistance coupled circuits have been chosen for illustration because of the simple theory involved. Since, however, the use of a transformer merely reflects the resistance characteristics of the secondary circuit back to the primary side, it is evident that any of the results which have been described for resistance coupled circuits can be obtained by the use of a transformer and Thyrite in the secondary circuit and a proper biasing battery.

It will be apparent from the foregoing that a thermionic tube utilization network embodying my invention has many advantages. Much greater undistorted power can be obtained from a thermionic tube than has heretofore been possible and, in fact, by properly choosing the bias potentials applied to my improved coupling resistor and the manner in which one or more resistor elements are connected in the output circuit of the tube, substantially any irregularities in the tube characteristics can be compensated.

Furthermore, my invention is not limited to the use of Thyrite, or an equivalent material as a coupling element between thermionic tubes or as means for compensating undesirable tube characteristics, since many modifications will at once be apparent to those skilled in the art to which it pertains. My invention, therefore, is not to be limited by the specific exemplification chosen for purposes of illustration, but only by the prior art and by the spirit of the appended claims.

I claim as my invention:

1. A thermionic tube utilization network including at least one element which has a hyperbolic resistance-ampere characteristic and means for subjecting said element to a biasing potential, such as to enable the network to operate with a linear response characteristic.

2. In combination, a thermionic tube having non-linear characteristics, an output circuit connected thereto and means having a hyperbolic resistance-ampere characteristic included in the output circuit thereof for introducing distortion of sense opposite that caused by the non-linear characteristics of the tube.

3. A thermionic tube having a plurality of electrodes and a network including at least one resistance element connected between two of the electrodes of said tube, the value of said resistance element being proportional to CI^{-a} over a substantial range, where C represents a constant which determines the resistance when current is unity and a is another constant depending upon the physical structure of the resistance element, and the structure of the tube being such that its normally non-linear characteristic, when operated in the said network exclusive of said resistance element, assumes a linear characteristic by virtue of the introduction of said resistance element into said network.

4. An electron tube network comprising at least one resistance element the resistance value of which decreases more and more rapidly with the passage therethrough of given increments of current, an electron tube having a non-linear relation between potential variations occurring in the output circuit and simultaneous variations occurring in the input circuit, and means including a source of biasing potentials for causing said resistance element to compensate for the non-linear characteristic of said tube.

5. A network including an electron tube and a plurality of resistance elements as defined in claim 4, reactive means inter-connecting said elements in series and means including an ohmic resistor shunting said reactive means and one of said resistance elements for enabling said electron tube to function as though it had a linear characteristic.

6. A network including an electron tube and a plurality of resistance elements as defined in claim 4, reactive means interconnecting said elements in series and means including an ohmic resistor shunting said reactive means and one of said resistive elements, also a source of biasing potential in parallel with one of said resistance elements for enabling said electron tube to function as though it had a linear characteristic.

7. A network including an electron tube, and a plurality of resistance elements as defined in claim 4, said elements being connected in series and being supplied with potential for biasing the same in opposite directions.

8. A network including an electron tube, a coupling transformer and, in shunt with the secondary winding of said transformer, a resistance element as defined in claim 4, the elements in combination having individually such values as to cause the network to operate with a linear response characteristic.

9. The method of extending the range of available swing of an electron tube in a network comprising at least one element which exhibits an hyperbolic resistance-ampere characteristic which includes polarizing said element in such direction and degree as to cause it to compensate for the non-linear characteristic of said tube.

IRVING WOLFF.