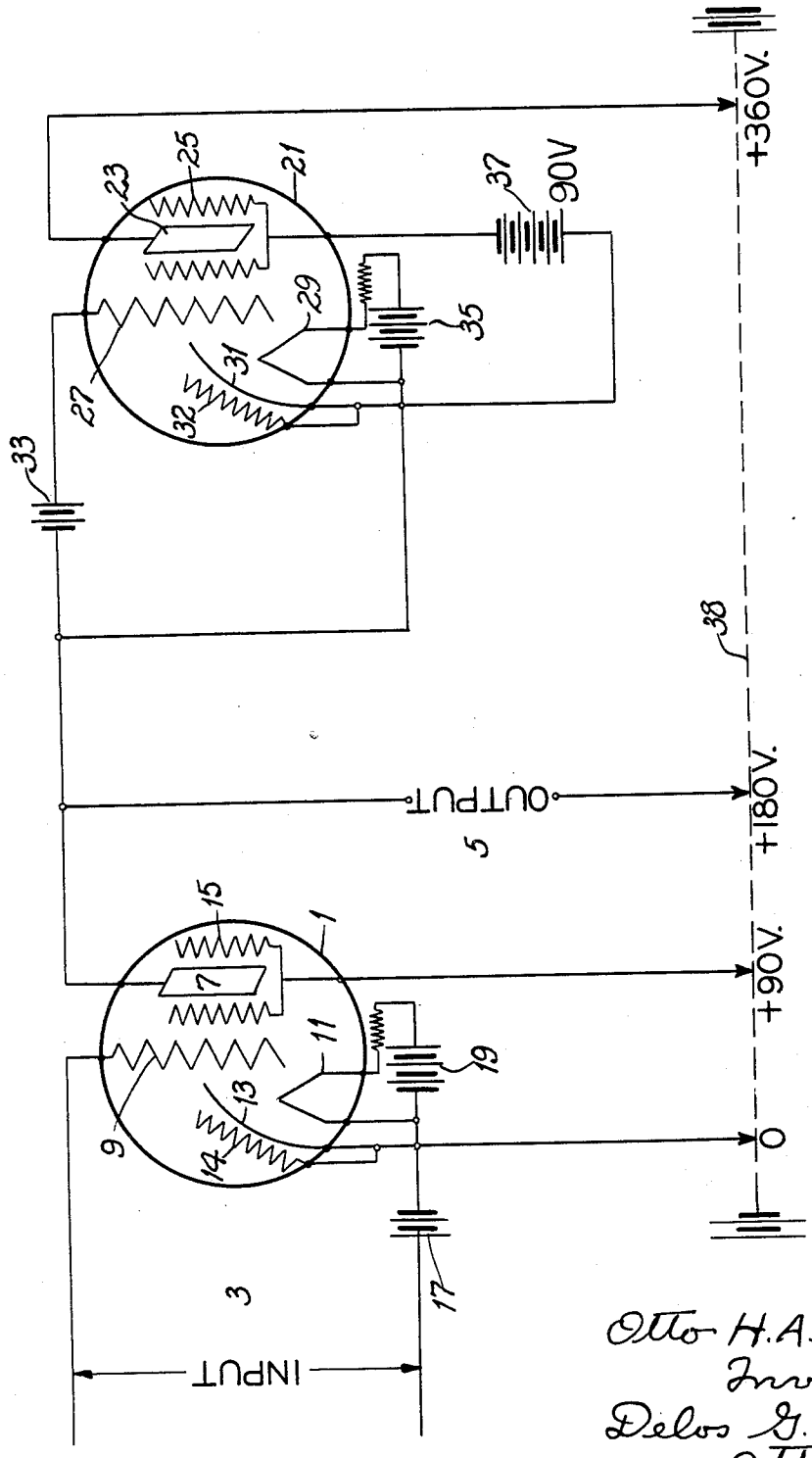
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ELECTRICAL SYSTEM

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ELECTRICAL SYSTEM

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This invention relates to electrical systems, and with regard to certain more specific features to amplifying and regulating systems.

Among the several objects of the invention may be noted the provision and arrangement of apparatus which shall realize a larger portion of the theoretical amplification factor of amplifying apparatus than has heretofore been possible without the use of excessive supply voltages; the provision of apparatus of the class described which shall minimize the effect of fluctuations in supply voltages; the provision of means of the class described which reduces the number of electrical amplifying units (tubes or cells) required to obtain a given amplification; the provision of apparatus of this class which shall reduce the amount of distortion for a given amplification; and the provision of apparatus of this class which is relatively simple to construct and operate. Other objects will be in part obvious and in part pointed out hereinafter.

The invention accordingly comprises the elements and combinations of elements, features of construction, and arrangements of parts, which will be exemplified in the structures and systems hereinafter described, and the scope of the application of which will be indicated in the following claims.

The single figure of the accompanying drawing is a diagrammatic layout of one of various possible embodiments of the invention.

Using the circuits heretofore employed in connection with voltage amplifying thermionic tubes photo-electric cells, glow tubes and the like, it has not been possible (especially in the cases of tubes having a high amplification factor), without forcing a given tube in some respect, to achieve in practical operation even an approximation of the theoretical amplification factor of the tube. The term "tube" is here used as exemplary of the other forms of amplifiers herein intended to be covered. Sometimes the actual amplification factor has been increased in the direction of the theoretical factor by employing excessively high resistance loads in the system, but this has almost invariably resulted in output distortion or necessitated excessive voltage supplies. The effect of minor variations in the plate voltage source was also unduly emphasized. With this invention, a relatively constant output voltage may be obtained under conditions involving a fluctuating voltage source. This feature of the invention applies to circuits generally, both amplifying and otherwise.

The characteristics of an operating thermionic or like tube or cell depend upon two sets of conditions, namely, the conditions existing within the tube itself and the circuit exterior to the tube. It has been my observation that the relatively small amplification previously obtained has, in large measure, been caused by the fact that the output circuit of a voltage amplifying tube, (as well as of tubes performing analogous functions) usually contained an ohmic external load resistance, that is, a resistance which varies substantially in accordance with ohm's law. For example, the type "57" thermionic tube now on the market has characteristics substantially as follows:

Theoretical amplification factor (F_t) of the order of 1,500.

A. C. plate resistance (R_l) of the order of 1,500,000 ohms.

Plate current (I_p) . . . 2.5 milliamperes.

Reasonable plate supply voltage (E_t) . . . 360 volts.

Plate voltage drop (E_p) . . . 180 volts.

From the above plate current (I_p) and plate voltage drop (E_p), the normal external plate circuit resistance (R_x) may be calculated from ohm's law, namely,

$$R_x=\frac{E_t-E_p}{I_p}$$

Thus:

$$R_x=\frac{360-180}{.0025}=72{,}000 \text{ ohms.}$$

The actual amplification realized (F_a) may be calculated from the above data by use of the relationship:

$$F_a=\frac{R_x}{R_i+R_x}\times F_t$$

Thus:

$$F_a=\frac{72{,}000}{1{,}500{,}000+72{,}000}\times 1{,}500=68.7$$

This factor, 68.7, as a practical matter, is thus the highest amplification factor that can be secured, under the conditions stated, while the theoretical value is of the order of 1,500. It is therefore clear that, when ohmic or linear resistance loads are used in the plate circuit of a tube, only a fraction of the theoretical amplification factor is attained.

The present invention overcomes these difficulties by utilizing a non-ohmic or non-linear external resistance in the plate or anode circuit

of the amplifying tube, cell or the like. By the use of such a non-ohmic external resistance load, the plate current may be maintained at substantially a uniform level, regardless of the variations in plate voltage, and the theoretical amplification factor more fully realized.

As a comparative example, consider as substituting for the 72,000 ohm resistance above, a duplicate, type "57" thermionic tube, which itself constitutes a non-ohmic or non-linear resistance. Then, the actual amplification factor achieved will be:

$$\frac{1,500,000}{1,500,000+1,500,000}\times 1,500=750$$

The value, 750, represents an increase of over one thousand percent of voltage amplification over the ohmic resistance circuit described above.

The type "57" tube above referred to is of the class which functions as a non-linear resistance because it is designed with a relatively high dynamic or A. C. plate resistance (for instance, 10^6 ohms) and a relatively low static plate resistance (for instance, 75,000 ohms). Dynamic plate resistance is defined as the ratio of a small change in plate voltage to the resulting small change of plate current, and static plate resistance is defined as the ratio of total plate voltage to total plate current. It will be understood that any tube or resistance inherently corresponding to the functions of the type "57" tube and which makes plate current substantially independent of impressed plate voltage is suitable.

The above example of the invention is by no means the optimum, as by suitable choice of the non-ohmic resistance, the actual amplification factor can be made to approach very closely to the theoretical value. For instance, I have obtained 1430 amplifications out of a maximum which is claimed to exceed 1500 in one type "57" tube, its dummy or non-ohmic resistance tube operating in a direct coupled voltage amplifying circuit. The tube functioning as the non-ohmic external load resistance needs not be identical with the amplifying tube which it serves and it may be chosen, designed and/or arranged to permit the amplifying tube to operate according to various requirements.

There are many further advantages to the use of a non-ohmic resistance in the plate circuit of the tube. For instance, formerly, when using an ohmic resistance, plate currents could not be maintained constant with varying plate supply voltages, for the resistance was constant and the circuit obeyed ohm's law, and as the supply voltage varied, the plate current through the external resistance also varied causing the variations to appear in the output circuit. In voltage amplification circuits, in particular where a number of tubes were required to be operated in cascading sequence in order to achieve the desired total amplification, it is well known that the more tubes that were used, the greater was the distortion in the final output, as well as the complication of control. The use of the non-ohmic external load resistance avoids difficulties of this nature by reducing the number of tubes required and by increasing the linearity of the ratio of output to input.

The non-ohmic or non-linear resistance may take the form of a suitably designed thermionic tube of the diode, triode, screen grid, or pentode type, or analogous varieties, or it may constitute a photoelectric cell, mercury vapor or other glow tube, or the equivalent. One primary requirement is that it correspond to the nature of the type "57" tube above set forth. It may be external to the primary amplifying tube, or it may be made integral therewith, as within the same bulb or unit chamber.

Referring to the drawing, type "57" thermionic tubes have been used to illustrate the invention, but it is to be understood that they may also represent photoelectric cells, glow tubes and the like, herein considered to be equivalents. Numeral 1 indicates, for example, a thermionic tube used as an amplifier between the input circuit 3 and a voltage output circuit 5. The tube is of the pentode type having a plate or anode 7, a screen grid 15, a control grid 9, a filament 11, a cathode 13 and a suppressor 14. A battery 17 is used for biasing the grid 9 and a battery 19 for heating the filament 11.

Instead of using a linear or ohmic resistance as an external load resistance in the circuit of the anode 7, in accordance with the above considerations I use a second thermionic tube 21 of the above characteristics, having for example, a plate or anode 23, a screen grid 25, a grid 27, a filament 29, a cathode 31 and a suppressor 32. A battery 33 is used to bias the grid 27 of the tube 21. A battery 35 is used for heating the filament 29 and a battery 37 applies voltage to the screen grid 25. A 360-volt plate supply is taken from a source 38 which also supplies the 90-volt and 180-volt taps to the screen grid 15 of tube 1 and the output 5, respectively.

It will be observed from the circuit diagram, that the amplifier really constitutes a symmetrical, four-armed bridge circuit; two of the symmetrical arms are of the type "57" tubes 1 and 21; the other two arms are sections of the anode battery 38. The output 5 constitutes the bridge. Now the current through each section of the battery and through each tube is identical, since they are all effectively in series, and since the output load is assumed to be of infinite resistance (voltage output), any drop in battery voltage would be expected to occur symmetrically between the two battery sections and hence between the two tubes, so that the only result would be an equal drop in plate voltage of each tube, which would leave the balance unaffected. And, since the tubes have equal voltages impressed on corresponding elements, any tube drift may be expected to be balanced out.

From the above, it will be seen that the thermionic tube 21 is effective as an external dummy and load resistance for the thermionic tube 1, the tube 21 being inherently of the non-ohmic or non-linear type.

It is to be understood that photoelectric cells, glow tubes or the equivalent may be substituted for either or both of the thermionic tubes 1, 21 and that the thermionic tubes shown are only exemplary of the class of apparatus to be used in carrying out the invention. The tube or resistance 21, as above made clear, is one in which the inherent ratio of dynamic or A. C. plate resistance to static plate resistance is of an order adapted to produce a plate current substantially independent of impressed voltage.

As examples of advantageous applications of the invention may be noted the use with direct coupled voltage amplifying circuits wherein the controls are exceedingly simplified by its use; also in condenser and dynamic microphone amplification, to the control of thyratrons, in connection with photoelectric cells responding to fast changes in light intensities by amplifying

the minute currents to magnitudes detectable by ordinary means, to cathode ray oscillographs, to vacuum tube circuits which displace electrometers where potentiation is the principal criterion and many others which will suggest themselves from the above.

The drawing herein illustrates another general feature as follows:

The battery 38 constitutes an auxiliary voltage supply or source for the tubes 21 and 1 and, as is clear, this is an inherently fluctuating source. The tube 1 is in series with the tube 21 so far as the circuit of battery 38 is concerned. The output 5 is, in effect, connected across tube 1. It will thus be observed that the fluctuating voltage of the section of battery 38 which is to the right of the output circuit connection passes through the non-linear resistance (tube 21) and, as a result, the variation in current which this fluctuating battery voltage component might otherwise engender, is prevented. Inasmuch as the tube 1 has a fixed resistance, this constant value of the battery component of current flowing through the fixed resistance of tube 1 effects only a constant voltage component on the output 5. Thus these fluctuations of the voltage of said battery section do not impress themselves as fluctuations in the output voltage. This principle may be used in circuits generally by feeding any source of fluctuating voltage through a non-linear resistance of the type described herein and then feeding the resulting constant current serially into any constant resistance. Then if the output voltage circuit is connected across said last-named resistance, the output voltage will be substantially constant, even with a fluctuating source voltage, because the constant current, flowing through the constant resistance effects a constant voltage, according to ohm's law.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As many changes could be made in carrying out the above constructions and arrangements without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. In combination, an input circuit, amplifying means fed thereby, an anode in the amplifying means, an output circuit connected with said anode, a non-linear resistance connected to said anode and comprising an electrical element itself having an anode of which the ratio of dynamic to static resistance is of an order adapted to effect a current which is substantially independent of voltage, whereby a substantial increase is effected in the linearity of amplification between said input and output circuits, and electrical means connecting said amplifying means and said output circuit and the non-linear resistance.

2. In an electrical system, amplifying means comprising an anode, an anode circuit, an output circuit connected with and fed by said anode circuit, said output circuit being responsive primarily to voltage change, and a non-linear resistance connected with the anode and having a branch arrangement with respect to the output circuit, said resistance having a plate for receiving space current and having a ratio of dynamic plate resistance to static plate resistance adapted to effect a plate current, the value of which is substantially independent of plate voltage, whereby voltage amplification between said input and output circuits is made substantially linear.

3. In an electrical system, a voltage source, a circuit supplied by said source, a non-linear resistance in said circuit, said resistance being characterized by the fact that the current therethrough is substantially independent of the voltage impressed thereon, another resistance in series with said non-linear resistance, and a voltage output circuit connected across said second resistance, said non-linear resistance comprising an electric element having an anode, the ratio of dynamic resistance to static resistance of which is adapted to effect a current, the value of which is substantially independent of voltage.

4. In an electrical system, a four-armed bridge circuit, electric elements constituting two arms, one of said elements receiving energy from the other, anodes for said elements adapted to receive space currents, an anode power source having sections constituting the other two arms of said bridge circuit, the current through each section of the power source and said electric elements being identical, the electric elements and sections being in series, and an output bridge connected to a point between electric elements on the one hand and to another point between said power source sections on the other hand, the output load having a substantially high resistance and said element which receives energy from the other having a ratio of dynamic to static resistance adapted to effect a flow of current which is substantially independent of voltage.

5. In an electrical system, a four-armed bridge circuit, electric elements forming two arms of said circuit, plates in the elements adapted to receive plate currents for which the ratio of dynamic plate resistance to static plate resistance is of an order adapted to produce a plate current which is substantially independent of impressed plate voltage, electrical energizing means having energizing sections constituting the other two arms of said bridge circuit, the current through each of the energizing sections of the energizing means and the electric elements being identical, the electric elements and sections being in series, and an output bridge connected to a point between the electric elements on the one hand and to another point between said energizing sections on the other hand, the output load having a substantially high resistance.

6. In an electrical system, a symmetrical, four-armed bridge circuit, one of the arms of said circuit having at least one electrical element therein, an anode in said element, the second symmetrical arm of said circuit being in series with said first-named arm and having a second electrical element therein receiving the current output of said first-named element, energizing means having sections connected in series to each other and with said elements, and the output circuit constituting a bridge between a point on the one hand which is in the circuit between said elements and to another point which is between said sections on the other hand, said second electrical element having a ratio of dynamic to static resistance adapted to effect a flow of current which is substantially independent of voltage.

7. In an electrical system, a symmetrical, four-armed bridge circuit, one of the arms of said circuit having at least one electrical element

therein, an anode in said element, the second symmetrical arm of said circuit being in series with said first-named arm and having a second electrical element therein receiving the current output of said first-named element, energizing means having sections connected in series to each other and with said elements, and a voltage output circuit constituting a bridge between a point on the one hand which is in the circuit between said elements and to another point which is between said sections on the other hand, said second electrical element having a ratio of dynamic to static resistance adapted to effect a flow of current which is substantially independent of voltage.

8. In an electrical system, a symmetrical, four-armed bridge circuit, one of the arms of said circuit having at least one electrical element therein, an anode in said element, the second symmetrical arm of said circuit being in series with said first-named arm and having a second electrical element therein receiving the output of said first-named element, energizing means having sections connected in series to each other and with said elements, and the output circuit constituting a bridge between a point on the one hand which is in the circuit between said elements and to another point which is between said sections on the other hand, said elements having plates in which the ratios of dynamic plate resistance to static plate resistance are of the order adapted to produce plate currents which are substantially independent of impressed plate voltages.

9. In an electrical system, an input circuit, amplifying means connected thereto, an anode in the amplifying means, an anode circuit connected with said anode, an output circuit connected with said anode circuit and a non-linear resistance in said anode circuit, said output circuit and said resistance having a branch arrangement, said non-linear resistance having a plate adapted to receive a space current and in which the ratio of dynamic plate resistance to static plate resistance is of the order adapted to produce a plate current which is substantially independent of impressed plate voltage, whereby substantial linearity is maintained between voltage changes in said input and output circuits.

10. In an electrical system, an input circuit, amplifying means connected thereto, an anode in the amplifying means, an anode circuit connected with said anode, an output circuit connected with said anode circuit and a non-linear resistance in said anode circuit, said output circuit and said resistance having a branch arrangement, said non-linear resistance having a ratio of dynamic to static resistance of the order adapted to produce a current therethrough which is substantially independent of voltage thereon, whereby substantial linearity is maintained between voltage changes in said input and output circuits.

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