Oct. 11, 1932. C. R. KEITH 1,881,657

CIRCUIT FOR ELECTRICAL DISCHARGE APPARATUS

Filed March 24, 1928

FIG. 1.

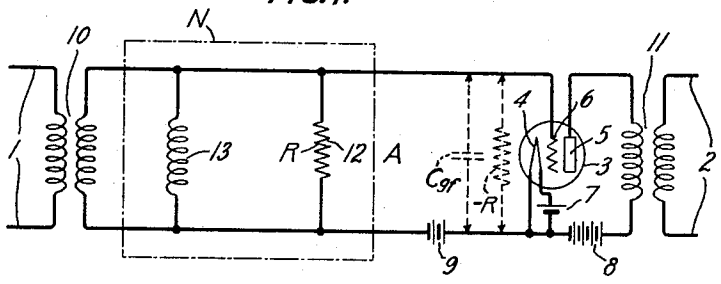


FIG. 2.

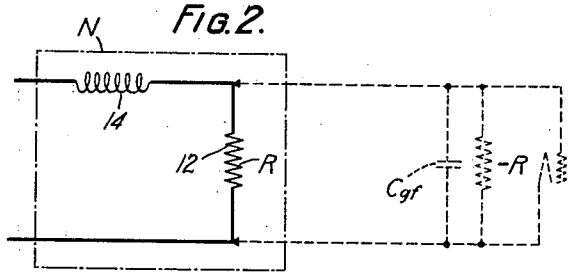
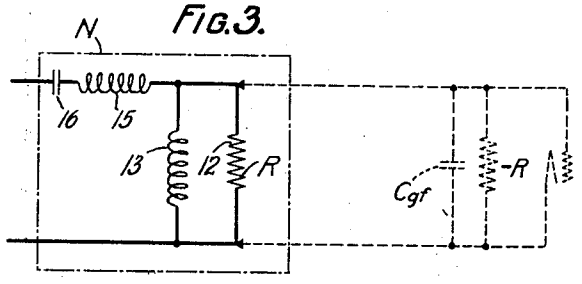


FIG. 3.



INVENTOR
CLYDE R. KEITH

BY H. O. Burgess
ATTORNEY

Patented Oct. 11, 1932

1,881,657

UNITED STATES PATENT OFFICE

CLYDE R. KEITH, OF EAST ORANGE, NEW JERSEY, ASSIGNOR TO BELL TELEPHONE LABORATORIES, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

CIRCUIT FOR ELECTRICAL DISCHARGE APPARATUS

Application filed March 24, 1928. Serial No. 264,496.

This invention relates to circuits for electric discharge apparatus and particularly to circuits for electric discharge apparatus having negative resistance characteristics.

An object of the invention is to make the input resistance of a space discharge device infinite or of a high value for impressed waves of a wide range of frequencies.

A second object is to make the input impedance of a space discharge device high for impressed waves of a single frequency or a band of frequencies.

A related object is to secure in an electric discharge amplifying device an increased degree of amplification as a result of improvement in the input impedance characteristics of the amplifying device.

It is well known that when an incompletely evacuated space discharge device of the three-electrode type, or such a device containing a small quantity of an inert gas, is operated, the ionization of some of the particles of gas between the anode and the control electrode in the device may produce an effective negative resistance between the cathode and the control electrode of the device for impressed waves of alternating current.

In accordance with the present invention this negative resistance to alternating currents in the input circuit of a gaseous three-electrode space discharge device is utilized in making the total input impedance of the device very high for impressed waves of predetermined frequencies, and thus to greatly increase the amplifying power of the device for these frequencies. This is accomplished in part by connecting between the cathode and control electrode of the space discharge device effectively in shunt to the negative resistance path in the input circuit of the device a positive resistance substantially equal in value to this negative alternating current resistance which has the effect of making the net resistance component of the input impedance of the device infinite, or very large, for impressed waves of a wide range of frequencies.

The effect of the resistance component of the input impedance having been thus neutralized, the effect of the reactance component of the input impedance of the device due to the natural capacity between the cathode and control electrode of the device may be effectively annulled by combining with this natural capacity, reactance in the input circuit of the device to form a tuned circuit or filter of such impedance characteristics as to make the total input impedance of the device very high for waves of a single frequency or a band of frequencies. The reactances and resistances forming the tuned circuit or filter, or a portion thereof, may be provided by separate resistance and inductance elements or by utilizing the leakage inductance, distributed winding capacity and resistance of a transformer coupling an incoming signal line or circuit to the input circuit of the space discharge device.

The invention itself and its objects and advantages will be best understood by reference to the following description taken in connection with the accompanying drawing in which:

Fig. 1 shows in schematic form the invention embodied in an amplifier circuit; and

Figs. 2 and 3 show modifications of a portion of the circuit of Fig. 1 which may be utilized to obtain different advantageous results which will be pointed out in connection with the description of the figures.

In Fig. 1 is shown an amplifier circuit A constructed in accordance with the invention connected between an incoming circuit 1 and an outgoing circuit 2. Included in the amplifier circuit A is a three-electrode space discharge amplifying device comprising an envelope 3 enclosing the usual electrodes, a cathode or filament 4, an anode or plate 5 and a grid or control electrode 6. Heating current for the cathode 4 is supplied by a filament battery 7. Space current for the tube is supplied by a source of voltage 8, and negative polarizing potential for the grid 6 by the grid battery 9.

The incoming circuit 1 is effectively connected between the cathode 4 and control electrode 6 of the amplifying tube by input transformer 10, and the outgoing circuit 2 is effectively connected between the anode 5

and the cathode 4 by the output transformer 11. In the input circuit of the amplifier between the input transformer 10 and the input electrodes 4 and 6 of the amplifying tube 3 is connected an impedance network N, which, in the particular modification of the invention shown in Fig. 1, comprises a resistance element 12 and an inductance element 13 in parallel with each other and in series with the cathode 4 and grid 6 of the amplifying tube.

The space discharge amplifying tube of amplifier A is preferably of the gaseous type, that is, the envelope 3 containing the electrodes 4, 5 and 6 is incompletely evacuated, or else, after the envelope 3 is exhausted to a high degree, a very small quantity of an inert gas is inserted therein. The gas pressure in the envelope is preferably of the order of about 10^{-3} mm. of mercury. Such a device may be made to offer an effective negative resistance to alternating currents impressed on the grid circuit of the device, the value of which resistance is substantially independent of capacity coupling effects between the electrodes and the nature of the external circuits coupled to the device. This effective negative resistance, which in the circuits of Figs. 1, 2 and 3 is indicated by the dotted resistance element designated $-R$ between the grid 6 and cathode 5, is produced by the ionization of some of the gas particles in the path between the anode 5 and grid 6 of the tube by the electron current to the anode 5. If the grid is negatively polarized, the positive ions are attracted to the grid 6 causing a current to flow in the grid circuit. When the grid voltage is made more negative the plate current is decreased so that fewer positive ions are produced in the space path and the grid current is reduced. In other words, the grid current has a negative slope. The alternating current resistance of the space path is given by the reciprocal of the slope of the grid current curve, and may be made very high, positive or negative, depending on the value of the plate current and the grid potential.

In the embodiment of the invention being described, the tube 3 and its associated circuits are so designed that the negative resistance effect in the grid circuit of the tube for impressed alternating current waves is obtained at the operating point of the tube. This negative resistance effect is utilized in accordance with the invention for obtaining a very high infinite input resistance for the tube over a wide range of impressed frequencies by making the net resistance effectively in shunt to the negative A. C. resistance $-R$, including the resistance element 12, of substantially the same value as the negative A. C. resistance.

If the tube 3 has enough inter-electrode capacity it may be necessary in order to make the effective input impedance infinite or very high for waves of a particular frequency impressed on its input circuit through input transformer 10, to neutralize the effect of the input reactance of the tube 3 due, for example, to the natural capacity between the grid 6 and the cathode 4, which natural capacity is indicated in Figs. 1, 2 and 3 by the dotted condenser designated C_{gf}, at that frequency. This is accomplished in accordance with the invention by making the external inductance effectively in shunt to the capacity C_{gf}, including the inductive element 13, of such value as to resonate with the capacity C_{gf} at the desired frequency to be amplified.

The effects of the resistance component and reactance component of the input impedance of the amplifier A having been controlled by proportioning the external resistance and reactive elements of the input circuit of tube 3 with respect to the internal characteristics of the tube in the manner pointed out above, it is apparent that the resistance component of the input impedance of the amplifying device 3 will be substantially infinite for all frequencies impressed thereon from the incoming line 1 and the total input impedance of the device will be very high or infinite for impressed alternating current waves of substantially the resonant frequency of the network N in conjunction with the input capacity of the tube. Incoming waves of the resonant frequency from incoming circuit 1 impressed on the input circuit of amplifier A will, therefore, receive greatly increased amplification therein over that of waves of other frequencies. In other words, the amplifier A acts as a very highly selective amplifying circuit for waves of the particular resonant frequency.

The amplifier circuit of the invention has another important advantage in that the input impedance of the amplifier being very high or infinite, the incoming line 1 connected to the input circuit thereof may be terminated in a definite impedance, as this terminating impedance is substantially independent of normal changes in the input impedance of the amplifier.

In Figs. 2 and 3 are shown alternative networks which may be utilized in place of the resonant circuit type of network shown in the circuit of Fig. 1.

The network N of Fig. 2 differs from that of Fig. 1 in that it comprises a series inductance 14 instead of the shunt inductance 13 of Fig. 1. The inductance 14 in conjunction with the grid to cathode natural capacity C_{gf} of the amplifier tube and the other reactance in the input circuit thereof will form a filter of the low pass type, having a cut-off as determined by the relative values of the reactances therein. Such a network when used in the circuit of Fig. 1 will transmit efficiently to the amplifying tube 3 waves

impressed thereon from the incoming line 1 of all frequencies below the cut-off frequency of the filter and will substantially attenuate all frequencies in the impressed waves above that cut-off frequency, the input impedance of the amplifying tube being very high or infinite for waves of all frequencies in the band transmitted by the filter. Therefore, the amplifier circuit will give greatly increased amplification for this band of frequencies over that of impressed frequencies outside the band.

The network N of Fig. 3 differs from that of Fig. 1 in that it comprises in addition to the shunt resistance and shunt inductance element of the latter figure, a series inductance element and a series condenser element. This combination, when used in the circuit of Fig. 1 in place of the resonant circuit network there shown, will form with the natural capacity between the cathode and grid, C_{gt}, of the amplifying tube, a filter of the band pass type having upper and lower cut-off frequencies determined by the relative values of the inductive and capacitive elements in the circuit. This band pass filter will transmit efficiently to the amplifier tube 3 all waves from the incoming line 1 having frequencies within the limits as determined by the cut-off frequencies of the filter and will greatly attentuate all frequencies in the received waves outside these limits. The input impedance of the amplifier A using the band pass type of net work of Fig. 3 will be very high for all impressed frequencies within the band limits, and the amplifier, therefore will selectively amplify in a high degree the selected frequencies for transmission over the outgoing line 2.

Reference is made to Campbell Patents 1,227,113 and 1,227,114, issued May 22, 1917, for details as to the theory and operation of the filters of the type illustrated in Figs. 2 and 3 of the drawing.

As the gas pressure in the usual commercial gaseous tubes are subject to variations due to temperature changes, etc., within the tube, and the value of the effective negative A. C. resistance in such tubes being dependent on gas ionization will vary with changes in gas pressure therein, it may be desirable in order to make the device of the invention more stable to utilize some means therewith for maintaining constant the gas pressure within the tube. Any one of the various methods which have been proposed in the prior art for this purpose may be used. For example, the pressure control means disclosed in Van der Bijl Patent 1,495,279, isued May 27, 1924 will be satisfactory for this purpose.

It is to be understood that the networks illustrated in Figs. 1, 2 and 3 of the drawing are merely typical examples of networks which may be used for accomplishing the purpose of the invention, and that any other suitable type of resonant circuit, low pass filter, high pass filter or band pass filter may be used instead in accordance with the invention.

It is to be understood also that, although to facilitate the description of the invention, separate resistance, inductance and condenser elements have been shown as making up the network N in the various modifications of the amplifier circuit of the invention, to accomplish the results as pointed out, the resistance, leakage inductance or distributed capacity of the input transformer 10 or other coupling device between the incoming line and the amplifier circuit may be utilized to perform part or all of the functions of the separate elements shown.

The system above illustrated and described should be considered merely as typical and not as limiting the invention, the scope of which is defined in the appended claims.

What is claimed is:

1. In combination, a gas-filled electric space discharge device having an input circuit, a cathode and a control electrode, and operating through the effect of gas ionization to produce an effective negative resistance between said cathode and said control electrode for impressed waves of alternating current, and means for making the net input resistance of said device substantially infinite for impressed waves of a wide range of frequencies comprising means having an electrical resistance substantially equal in value to said negative resistance, connected in said input circuit between said cathode and said control electrode.

2. In combination, a gas-filled space discharge device having an input circuit, a cathode and a control electrode, and operating through the effect of gas ionization to produce an effective negative resistance between said cathode and said control electrode for impressed waves of alternating current, and means for making the net input impedance of said device substantially infinite for impressed alternating current waves of a certain frequency range, said means comprising means having an electrical resistance substantially equal in value to said negative resistance, connected in said input circuit between said cathode and said control electrode, and means connected between said cathode and said control electrode and having such a value of reactance as to neutralize substantially in said input circuit the effect of the input capacity of said device for impressed waves of said frequency range.

3. In combination, a space discharge amplifying device containing an inert gas to a pressure in the order of about 10^{-3} mm. of mercury and having an input circuit, a cathode and a control electrode, and operating through the effect of gas ionization to give an effective negative resistance between said cathode and said control electrode for im-

pressed waves of alternating current, and means to improve the amplification characteristics of said device over a range of frequencies comprising means having an electrical resistance substantially equal in value to said negative resistance, connected in said input circuit between said cathode and said control electrode, and means connected in said input circuit between said cathode and said control electrode and having such a value of inductance as to form with the input capacity of said device a tuned circuit resonant at a frequency near the middle of said range.

4. In combination, a space discharge amplifying device containing an inert gas to a pressure in the order of about 10^{-3} mm. of mercury, and having an input circuit, a cathode and a control electrode, said device operating through the effect of gas ionization to produce an effective negative resistance between said cathode and control electrode for impressed waves of alternating current, and means to improve the amplification characteristics of said device over a given range of frequencies, said means comprising means having an electrical resistance substantially equaling in value said negative resistance, connected between said cathode and said control electrode in said input circuit, and reactive elements connected in said input circuit between said cathode and said control electrode and having such values as to form with said resistance and the input capacity of said device a filter offering a high impedance to waves of frequencies within said given range.

In witness whereof, I hereunto subscribe my name this 22 day of March, 1928.

CLYDE R. KEITH.