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CIRCUIT ARRANGEMENT FOR AMPLIFYING ULTRA
HIGH FREQUENCY ELECTRICAL OSCILLATIONS
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Fig. 1.

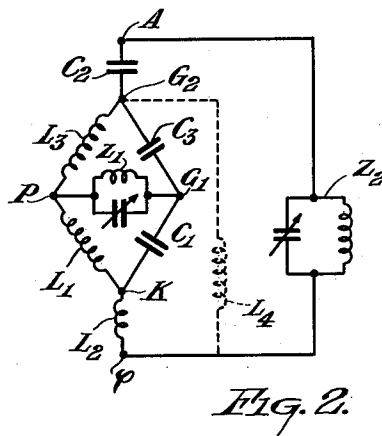
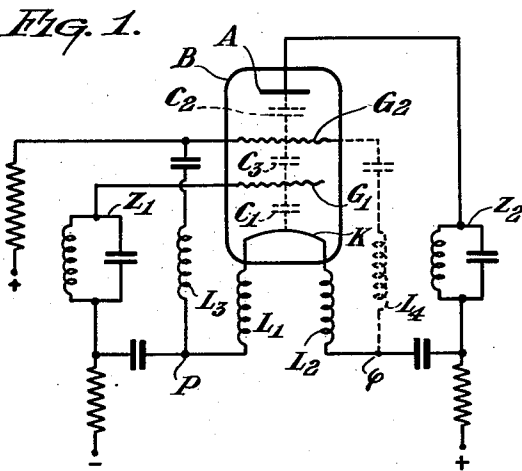


Fig. 3.

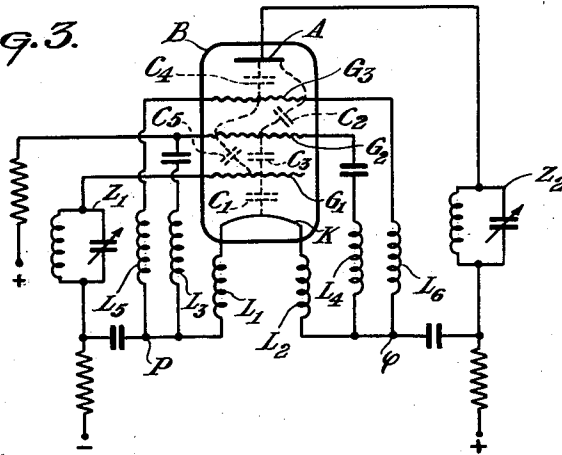
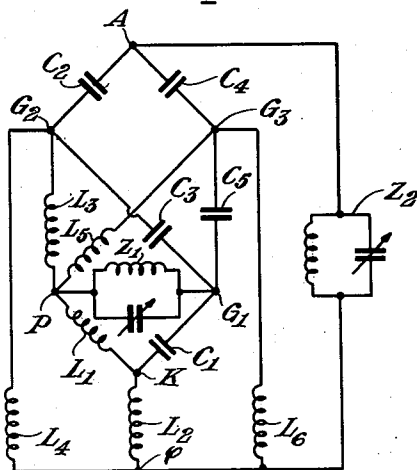


Fig. 4.



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CIRCUIT ARRANGEMENT FOR AMPLIFYING
ULTRA HIGH FREQUENCY ELECTRICAL
OSCILLATIONS

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This invention relates to a circuit arrangement for amplifying ultrahigh-frequency electrical oscillations comprising a discharge tube having a cathode, an input electrode, an output electrode and one or more auxiliary electrode(s) interposed between the input electrode and the output electrode.

Such arrangements suffer from the drawback that the discharge tube brings about a considerable damping of the input impedance connected between the input electrode and the cathode. This damping is due to two different causes.

Primarily a phase displacement occurs, due to the transit time of the electrons, between the voltage of the input electrode and the current brought about by this voltage in the space between the cathode and the input electrode. As a result thereof the influence current flowing to the input electrode has a component which is in phase with the voltage of the input electrode and involves the so-called transit-time damping or electron damping.

Secondly damping occurs due to the backcoupling brought about by cooperation of the natural capacities between the electrodes of the tube and the natural inductances of the supply conductors for these electrodes. This damping may be called lead damping.

Thus, for instance a damping of the input impedance is caused by the natural inductance of the cathode lead in cooperation with the natural capacity between the cathode and the input electrode. The cathode current in fact brings about, across the said inductance, a high-frequency voltage which is leading in phase by about 90° with respect to the voltage of the input electrode and involves a current from the cathode to the input electrode through the said capacity, which current leads in phase by about 180° with respect to the voltage of the input electrode and consequently involves a damping of the input impedance.

It is known to remove this damping by equipping the cathode with at least two supply leads, which are entirely separated from each other in regard to high frequency, and by connecting it with respect to high frequency, through one of these supply leads, (the input cathode lead) to the input electrode through the intermediary of an input impedance and, through another supply lead (the output cathode lead), to the output electrode through the intermediary of an output impedance.

In addition to the aforesaid damping owing to the inductance of the cathode lead also undamp-

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ing of the input impedance can be brought about in a similar manner under certain conditions. If, for instance, an auxiliary electrode having a positive potential (screen grid) is provided between the input electrode and the output electrode, the natural inductance of the supply lead to this auxiliary electrode, in cooperation with the natural capacity between the auxiliary electrode and the input electrode, will yield undamping of the input impedance. In fact, the voltage loss brought about by the current of the auxiliary electrode through the natural inductance of the supply lead sets up a voltage at the auxiliary electrode, which is lagging in phase by about 90° relatively to the voltage of the input electrode and consequently involves a current to the input electrode through the capacity between the auxiliary electrode and the input electrode, which current is substantially in phase with the voltage of the input electrode and consequently involves undamping of the input impedance. This undamping, however, is generally much smaller than the damping caused by the inductance of the cathode lead.

It has already been proposed to increase the damping thus brought about by inserting an additional inductance in the screen grid lead of a pentode. This expedient is of particular importance for push-pull amplifiers comprising two amplifying systems incorporated in one tube, since in this case the alternating current carrying part of the cathode leads may be very short, so that the damping caused by the inductance of the cathode leads is small.

Again, when making use of a discharge tube whose cathode is equipped in the aforesaid manner with two supply leads entirely separated from each other with respect to high frequency, it has already been proposed to realise an increased undamping of the input impedance by connecting to the cathode, through the intermediary of the output-cathode lead, an auxiliary electrode placed between the input electrode and the output electrode, and by inserting an additional inductance in the part of this connection located between the cathode and the tapping leading to the output impedance. This artifice has an effect similar to the insertion of an additional inductance in the circuit of the auxiliary electrode, but in the sense that in this case not only the current of the auxiliary electrode but also the current of the output electrode traverses the additional inductance, so that a much stronger undamping is obtained at a given value of the additional inductance.

By the said expedients for increasing the un-

damping it can be ensured that a negative resistance is created in parallel with the input impedance, as a result of which the influence of the electron damping on the input impedance, which damping occurs between the input electrode and the cathode, is at least partly made up for.

Another evil experienced in amplifying ultra-high frequency oscillations is the appearance of a reaction of the high-frequency voltage, which is set up across the output impedance, on the input impedance. This reaction involves intercoupling of the input and output impedance, due to which these impedances can no longer be adjusted each individually. In discharge tubes comprising one or more auxiliary electrodes between the input electrode and the output electrode the direct reaction through the natural capacity between the output electrode and the input electrode is practically of no importance. In this case the reaction is brought about rather indirectly and more particularly by the fact that a current traversing the capacity between the output electrode and an auxiliary electrode brings about a voltage across the natural inductance of the supply conductor to this auxiliary electrode, which voltage involves a current through the capacity between the auxiliary electrode in question and the input electrode.

Various expedients are known for removing the said reaction. The present invention has for its object to provide a novel and extremely simple means for removing the reaction in circuit arrangements comprising a discharge tube whose cathode is equipped in the aforesaid manner with at least two supply leads which are entirely separated from each other in regard to high frequency. Another object of the invention consists in simultaneously decreasing the damping exerted by the tube on the input impedance.

According to the invention at least one of the auxiliary electrodes is connected to the cathode through the input cathode lead and at least one of the inductances, which are naturally available on both sides of the tapping leading to the input impedance in the connection(s) extending from one or more auxiliary electrode(s) through the input-cathode lead to the cathode and/or at least one of the inductances which, as the case may be, are naturally available on both sides of the tapping leading to the output impedance in the connection(s) extending from one or more auxiliary electrode(s) through the output-cathode lead to the cathode and/or at least one of the capacities, which are naturally available between the cathode and the input electrode, between each auxiliary electrode and the input electrode and between each auxiliary electrode and the output electrode, is increased, by adding an additional inductance or capacity, to such a degree as to remove at least substantially the reaction of the high-frequency voltage, which appears across the output impedance, on the input impedance.

In order that the invention may be clearly understood and readily carried into effect it will now be described more fully with reference to the accompanying drawing given by way of example.

Fig. 1 represents an amplifying circuit arrangement for ultra-high frequency oscillations comprising a discharge tube B. The tube B has a cathode K, an input electrode (control grid) G1 and an output electrode (anode) A. The control grid G1 and the anode A is pro-

vided an auxiliary electrode (screen-grid) G2 having a positive bias. The cathode K is equipped with two supply leads which are entirely separated from each other in regard to high frequency and connected through one of these supply leads (the input cathode lead) through the intermediary of an input impedance Z1 to the control grid G1, which connection includes a blocking condenser which constitutes a short-circuit in regard to the oscillations to be amplified. The cathode is connected through an output impedance Z2 to the anode A through the intermediary of the second supply lead (the output cathode lead). This connection also comprises a blocking condenser which constitutes a short-circuit in regard to the oscillations to be amplified, the control-grid G1 being negatively biased and the anode A being positively biased in the usual way. The natural inductances of the input and output cathode-lead are designated L1 and L2 respectively. The oscillations to be amplified are supplied to the impedance Z1, whereas the amplified oscillations are taken from the impedance Z2.

According to the invention the screen-grid G2 is connected through a blocking condenser to the cathode through the intermediary of the input-cathode lead. The natural inductance of the part of this connection located between the screen-grid G2 and the tapping P leading to the input impedance is represented by L3.

The natural capacity between the cathode K and the control-grid G1 is represented by C1, the natural capacity between the anode A and the screen-grid G2 being represented by C2 and that between the screen-grid G2 and the control-grid G1 by C3.

The amplified voltage appearing across the output impedance Z2 reacts upon the input impedance Z, since the capacity C2 is traversed by a current which involves a voltage across the inductance L3, whereupon this voltage brings about again a current through the capacity C3.

Fig. 2 represents the substitution diagram of the arrangement shown in Fig. 1. From this substitution diagram it appears that the elements L1, L3, C1 and C3 constitute a Wheatstone bridge. When this bridge is in equilibrium the reaction of the output voltage on the input impedance is entirely neutralised.

Therefore, according to the invention, at least one of the elements L1, L2, C1 and C3 is increased, by adding an additional inductance or capacity, to such a degree that $L1C1 = L3C3$, so that the bridge is in equilibrium.

It might be expected that in the circuit set out above lead damping occurs in parallel with the input impedance, because the voltage set up across the inductance L1 brings about a current through the capacity C1. It appears, however, that this damping, in the case of equilibrium of the bridge, is just made up for by the undamping resulting from the cooperation of the inductance L3 and the capacity C3. Consequently, the aforesaid arrangement has the favourable property of the lead damping being zero.

It is self-explanatory that the bridge constituted by the elements L1, L3, C1 and C3 must be in equilibrium when the arrangement is in operation. However, the value of the capacities C1 and C3 depends on the working state of the tube, for instance on the biases of the control-grid and the screen grid. Hence, it is not feasible exactly to meet the required equilibrium condition for all working conditions. To reduce this draw-

back as much as possible it is advisable to connect the screen-grid G2 also through the intermediary of the output-cathode lead to the cathode K, as shown in dotted lines in Figs. 1 and 2. The natural inductance of the part of this connection located between the screen-grid G2 and the tapping Q leading to the output impedance Z2 is represented by L4 in the drawing.

The inductance L4 is now preferably made as small as possible and more particularly small with respect to at least one of the inductances L1, L2 and L3. This can be achieved by making the connection between G2 and Q as short as possible, for instance by bringing the tapping Q as close as possible to the screen grid G2. The effect of this expedient consists in that the diagonal G2K of the bridge is short-circuited, as it were, so that a lower voltage is set up across this diagonal due to which the reaction voltage set up across the input impedance Z1 in the case of the bridge being out of equilibrium is likewise reduced. Otherwise the effect of the circuit is not affected by providing the aforesaid second screen-grid cathode connection.

In the aforesaid arrangement, in which a tetrode is used to constitute the discharge tube, it is not feasible by artificially increasing one of the inductances or capacities to bring about negative lead damping without interfering with the equilibrium of the bridge, as a result of which the effect of the electron damping might at least partly be made up for. This is feasible when making use of a pentode, as will be explained by reference to Figs. 3 and 4.

Fig. 3 represents an arrangement according to the invention, in which the discharge tube comprises the aforesaid electrodes and in addition a second auxiliary electrode (suppression grid) having cathode-potential in regard to direction current. The suppressor grid G3 is connected to the cathode K both through the intermediary of the input cathode lead and through the intermediary of the output cathode lead. The natural inductance of the part of the connection, through the intermediary of the input cathode lead, located between the suppressor grid G3 and the tapping P leading to the input impedance is represented by L5, whereas the natural inductance of the part of the connection, through the output-cathode lead, located between the suppressor grid G3 and the tapping Q leading to the output impedance is represented by L6. The natural capacity between the suppressor grid G3 and the anode A is represented by C4, whereas the natural capacity between the suppressor grid G3 and the control grid G1 is represented by C5. The natural capacity between the grids G2 and G3 plays only a minor part in regard to the effect aimed at and for this reason it is not further considered.

Besides the aforesaid reaction resulting from cooperation of the elements C2, L3 and C3 a reaction similarly occurs in the arrangement shown in Fig. 3 as a result of cooperation of the elements C4, L5 and C5.

Fig. 4 represents the substitution diagram of the circuit arrangement shown in Fig. 3 from which it appears that this arrangement comprises two partly coinciding Wheatstone bridges one of which is constituted by the elements L3, C3, L1 and C1 and the second consisting of the elements L5, C5, L1 and C1. By establishing equilibrium in both bridges, consequently by making $L1C1=L3C3=L5C5$ the reaction might be entirely neutralised, while neutralising at the same

time, similarly to the arrangement represented in Fig. 1, the lead damping.

When wanting a resulting negative lead damping for complete or partial compensation of the electron damping this can be achieved by bringing the two bridges out of equilibrium in an opposite sense, but in such a manner as to neutralise as yet the reaction as a result of the joint effect of the two bridges. To this end L3C3 is preferably made larger than L1C1, and L5C5 smaller than L1C1. The comparatively high value of L3 required for this purpose leads in a manner known per se (increase of the inductance of the screen-grid lead) to undamping of the input impedance Z1.

In the circuit represented in Fig. 3 the inductances L4 and L6 are preferably made as small as possible and this for the same reasons stated already in regard to the inductance L4 in the circuit represented in Fig. 1.

Otherwise the desired effect i. e. neutralisation of the reaction with simultaneous complete or partial compensation of the electron damping can be achieved, in principle, by artificially increasing each of the inductances L1—L6 and each of the capacities C1—C5 or a plurality of these inductances and capacities.

Furthermore, it is not essential for the obtaining of the effect in question that the two auxiliary electrodes (G2 and G3) should be equipped with two connections to the cathode, it being imperative only that at least one of the auxiliary electrodes (consequently G2 or G3) is connected to the cathode through the intermediary of the input cathode lead, whereas the second auxiliary electrode may then be connected at will to the cathode through the intermediary of the input or output cathode lead or through the intermediary of both leads.

What we claim is:

1. An arrangement for amplifying ultra-high frequencies comprising an electron discharge device having in successive arrangement a cathode, a grid, an auxiliary grid and an anode, said cathode being provided with first and second supply leads electrically separated with respect to high frequencies, the interelectrode capacity between said cathode and grid constituting a first capacitance and the interelectrode capacity between said grid and auxiliary grid constituting a second capacitance, an input impedance connected between said grid and said first lead, an output impedance connected between said anode and said second lead, a first conductor connected at one end to the junction of said first lead and input impedance and capacitively coupled at the other end to said auxiliary grid, and a second conductor connected at one end to the juncture of said second lead and output impedance and capacitively coupled at the other end to said auxiliary grid.

2. An arrangement as set forth in claim 1 wherein a first inductor formed by the self inductance of said first lead, a second inductor formed by the self inductance of said first conductor, said first capacitance and said second capacitance constitute the respective arms of a bridge across whose output diagonals is connected said input impedance and across whose input diagonals is coupled said output impedance, said first and second inductors and said first and second capacitances of said bridge having values at which said bridge is substantially in equilibrium, a third inductor formed by the self inductance of said second lead in series with a fourth inductor formed by the self inductance of said second con-

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ductor being connected across the input diagonals of said bridge thereby minimizing the effect of any unbalance in said bridge.

3. An arrangement as set forth in claim 2, wherein the fourth inductor has a value which is small relative to the value of said second inductor whereby the input diagonals of said bridge are effectively short circuited.

4. An arrangement for amplifying ultra-high frequencies comprising an electron discharge device having in successive arrangement a cathode, a grid, a first auxiliary grid, a second auxiliary grid and an anode, said cathode being provided with first and second supply leads electrically separated with respect to high frequencies, the interelectrode capacity between said cathode and grid constituting a first capacitance, the interelectrode capacity between said grid and said first auxiliary grid constituting a second capacitance, the interelectrode capacity between said grid and said second auxiliary grid constituting a third capacitance, an input impedance connected between said grid and said first lead, an output impedance connected between said anode and said second lead, a first conductor connected at one end to the junction of said first lead and input impedance and capacitively coupled at the other end to said first auxiliary grid, a second conductor connected at one end to the juncture of said second lead and output impedance and capacitively coupled at the other end to said first auxiliary grid, a third conductor connected between said junction and said second auxiliary grid, and a fourth conductor connected between said juncture and said second auxiliary grid.

5. An arrangement as set forth in claim 4 wherein a first inductor formed by the self inductance of said first lead, a second inductor formed by the self inductance of said first conductor, said first capacitance and said second capacitance

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constitute a first bridge, and the first inductor, a third inductor formed by the self inductance of said third conductor, said first capacitance and said third capacitance constitute a second bridge having output diagonals in common with said first bridge, said input impedance being connected across said common output diagonals, said output impedance being coupled to the input diagonals of both said first and second bridges, a fourth inductor formed by the self inductance of said second lead in series with a fifth inductor formed by the self inductance of said second conductor being shunted across the input diagonals of said first bridge, the fourth inductor in series with a sixth inductor formed by the self inductance of said fourth conductor being shunted across the input terminals of said second bridge.

6. An arrangement as set forth in claim 5 further characterized in that said first and second bridges are arranged to be unbalanced in opposite senses whereby the total effect thereof on the input impedance is substantially eliminated.

7. An arrangement as defined in claim 6 wherein the values of the fifth inductor and the sixth inductor are small relative to that of the second and third inductors respectively, whereby the respective input terminals of said first and second bridges are effectively short circuited.

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REFERENCES CITED

The following references are of record in the file of this patent:

FOREIGN PATENTS

Number	Country	Date
544,641	Great Britain	Apr. 22, 1942