July 10, 1928. 1,677,090

L. M. HULL

VACUUM TUBE CIRCUITS

Filed Jan. 17, 1927 2 Sheets-Sheet 1

Fig. 1.

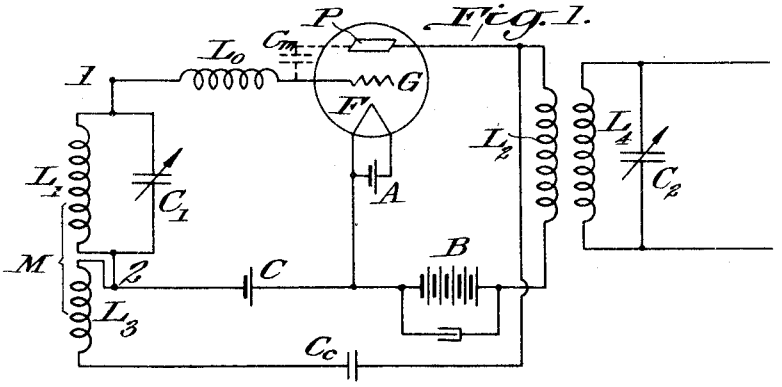


Fig. 2.

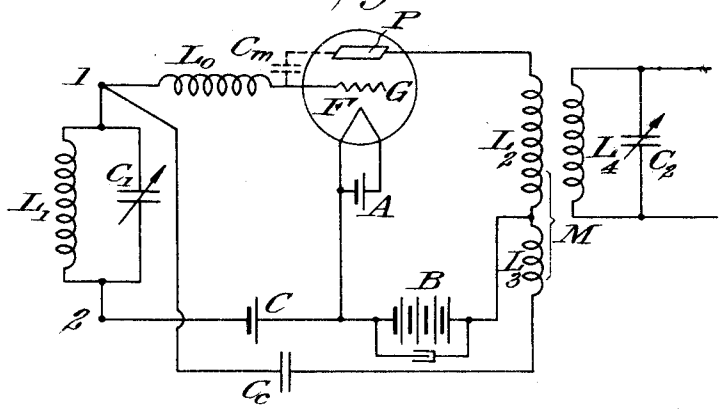
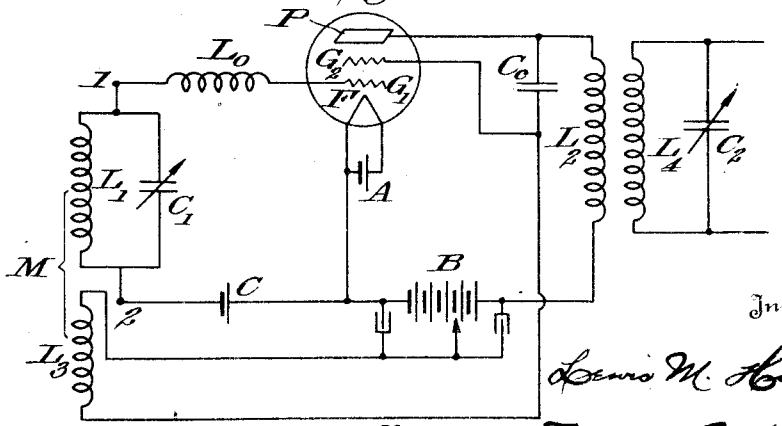


Fig. 3.



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2 Sheets-Sheet 2

Fig. 4.

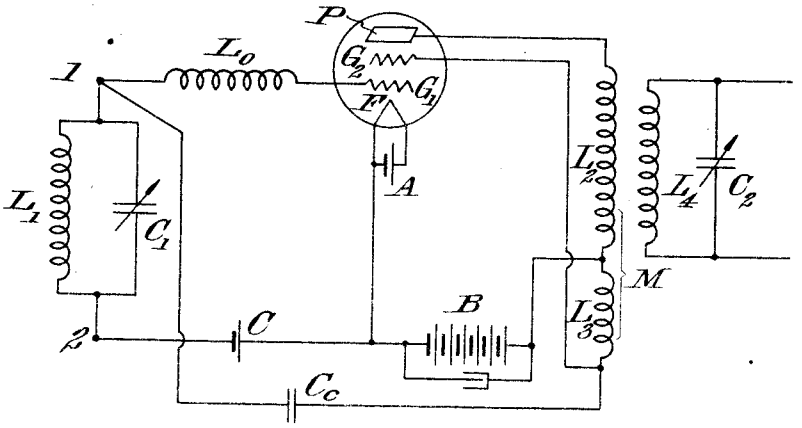
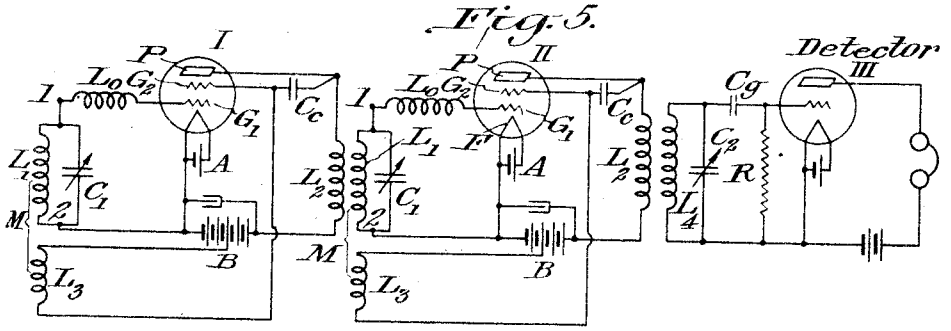


Fig. 5.



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UNITED STATES PATENT OFFICE.

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VACUUM-TUBE CIRCUITS.

Application filed January 17, 1927. Serial No. 161,664.

This invention relates to electrical amplifier circuits of the type suitable for use with vacuum tubes. A vacuum tube of the type herein referred to comprises an emitting cathode, usually assuming the form of a heated filament and hereafter so designated; an anode or plate electrode; and control means which may include a single control grid, or which may include a primary control grid and a second grid, for example an emission-shield or auxiliary control grid. In the latter case the vacuum tube is of the so-called "four-electrode" type.

Such a vacuum tube is ordinarily operated in connection with an input circuit connected between the filament and the control grid, and an output circuit connected between the plate and the filament. It is well known that coupling between the output and input circuits may cause undesirable retroactive or feed-back currents, and even self-oscillation. This coupling may be through the inherent tube capacities, and leads, and so forth, but capacity between the control grid and the plate of the vacuum tube is largely responsible for the undesirable currents due to coupling between the two circuits, even in tubes of the four-electrode type.

Various methods of compensating the effects of this grid-plate capacity have been proposed; for example feeding back a compensating current onto the grid through a compensating capacity in series with a coil closely coupled to a coil in the input or output circuit.

I have found that such systems may be attended by considerable disadvantages, especially in so far as they require the use of close or substantially unity coupling between coils in the input or the output circuit. For example, it is desirable for many purposes to employ a high-impedance output circuit. This is especially true in the case of a four-electrode vacuum tube in which a positively-biased emission-shield grid is employed. The impedance of the output circuit should, of course, be approximately equal to the internal impedance of the tube, and in the case of a four-electrode tube this may be of the order of, say, 250,000 ohms. If an output circuit of this type includes a closely coupled compensating coil the resistance and eddy-current losses are often so high as to offset the advantages which might otherwise arise from the use of a high-impedance circuit.

My invention applies to vacuum tube amplifiers of both the three-electrode and the four-electrode type, but is of particular advantage in connection with amplifiers employing a high impedance input or output circuit, as in some applications of the four-electrode tube. It obviates the necessity for employing closely coupled coils in the input or output circuit, and consequently prevents losses and reduction of amplification due to increased resistance and to eddy currents.

These and other undesirable effects in all hitherto known amplifier systems which are balanced to suppress interaction between input and output circuits, are, so far as I am aware, largely due to the fact that the disturbing couplings inherent in such systems are essentially capacitive, consisting, as previously described, of internal tube capacities augmented by external stray capacities. I have found that it is possible to simplify the problem of suppressing interaction between the input and output circuits by so changing the essential character of this inherent coupling between the circuits that it is no longer purely capacitive within the operating frequency range. I accomplish this by the addition to a vacuum tube amplifier of an inductive element which is so related to the input and output circuits as to cause the retroactive or feed-back currents to flow through an inductance in series with a capacity, instead of through a capacity alone. This I may accomplish by including a self-inductance in the connection between the high-potential side of the input circuit (i. e. the side which is at a high alternating current potential with respect to the filament) and the control grid of the vacuum tube. I can then impress a compensating potential upon either the high-potential terminal of the input circuit or upon the plate by means of a series circuit including a compensating condenser and a coil having relatively loose coupling with a coil in either the input or the output circuit, as may be appropriate. I may thus obtain a substantial or complete compensation of the undesirable or disturbing potentials caused by the flow of currents through grid-plate capacity of the tube. I have obtained satisfactory results with a cou-

pling of the order of about 50% to 60%. Even in the case of a high-impedance input or output circuit this degree of coupling does not necessarily cause an undesirably high resistance, and does not injuriously reduce the amplification.

Figure 1 illustrates one embodiment of my invention. Figure 2 illustrates another embodiment thereof. Figure 3 shows an embodiment of my invention including a four element or four-electrode vacuum tube. Figure 4 shows another embodiment of my invention including such a tube. Figure 5 shows a cascaded arrangement employing circuits similar to those shown in Figure 3.

In Fig. 1 I have shown my invention applied to a vacuum tube of the three-electrode type. A tuned input circuit, L_1—C_1, is connected between the two input terminals 1 and 2. Terminal 2 is connected to the filament F, a "C" battery being used if desired. The high-potential input terminal, 1, is connected to the grid of the tube through the self-inductance Lo. Cm represents capacity between grid and plate of the tube. A plate inductance, L_2, is connected between plate and filament of the vacuum tube and may be coupled to a tuned circuit or tuned transformer secondary, L_4—C_2. The "B" battery and by-pass condenser may be arranged as usual. Compensating coil L_3 is coupled to coil L_1 in the input circuit. There is a series connection from L_1 through compensating coil L_3 and compensating condenser Cc to the plate. Coils L_1 and L_3 are coupled together with relatively loose coupling, which may suitably be of the order of about 50% to 60%, and in such a sense as to impress upon the grid a compensating potential of the proper phase to compensate the disturbing potential due to coupling through capacity Cm and inductance Lo in series therewith. Cc or other circuit element may be adjusted to give the proper amplitude to this compensating potential.

While my invention is not dependent upon theory, I believe that the mathematical conditions for complete compensation, in the arrangement of Fig. 1, may be expressed as follows:

$$(1)\quad \frac{M}{L_1}=\frac{Cm}{Cc},$$

and

$$(2)\quad Lo=\frac{L_1L_3-M^2}{M}$$

where the symbols represent the numerical magnitudes of the inductances and capacities of the several circuit elements.

In Figure 2 I have also shown my invention applied to a three-electrode tube, but in this case the compensation is brought about by means of a series circuit from the high-potential input terminal, 1, through compensating condenser Cc and compensating coil L_3 to the plate coil L_2. L_2 and L_3 may be coupled relatively loosely, as before, a co-efficient of coupling of from 50% to 60% being suitable. They are wound so as to impress upon the terminal, 1, a compensating potential of the proper phase to compensate the disturbing potential due to coupling through the intra-electrode capacity in series with inductance Lo.

In a similar manner, the mathematical conditions for complete compensation, in the arrangement of Figure 2, may be expressed as follows:—

$$(1)\quad \frac{M}{L_2}=\frac{Cm}{Cc}$$

$$(2)\quad Lo=\frac{L_2L_3-M^2}{M}$$

In Fig. 3 I have shown a four-electrode vacuum tube amplifier involving the arrangement of Fig. 1. In addition to the compensation effected by the series circuit Cc—L_3, this arrangement has the advantage that by connecting the positively-biased emission-shield grid, G_2, to the filament through coil L_3 an alternating potential is impressed upon grid G_2 in such phase as to cause it to exert an auxiliary control effect, and thus modify the amplification of the vacuum tube in a predetermined manner, the extent of this modification depending upon the control constants of the tube and the relative values chosen for the inductances L_1, L_2 and L_3.

In Fig. 4 I have shown a four-electrode vacuum tube amplifier involving the arrangement of Fig. 2. By this arrangement also the compensating coil L_3 is caused to exert an auxiliary control effect, as in the arrangement of Fig. 3.

In Fig. 5 I have shown two four-electrode vacuum tube amplifier stages, I and II, each involving the arrangement of Fig. 3, working into a detector stage III.

It is obvious that a vacuum tube amplifier embodying my invention may vary considerably from the specific arrangements herein set forth. The invention extends to all arrangements in which a self-inductance is connected between the primary control element and the high-potential input terminal, in order to assist in the compensation of a vacuum tube amplifier, or to improve the operation thereof.

I claim:

1. An electrical amplifier including a vacuum tube, an input circuit, an output circuit, elements producing capacitive coupling between said circuits, a circuit for compensating said capacitive coupling including in series a compensating coil coupled to one of said circuits and a compensating condenser connected to the other of said circuits, and an inductance connected to a control element

of said vacuum tube in such a manner that retroactive currents flowing through said capacitive coupling must also flow through said inductance in series therewith.

2. An electrical amplifier circuit comprising a vacuum tube including anode, cathode, and control means, an input circuit connected between said control means and said cathode, an output circuit connected between said anode and said cathode, a compensating circuit connected between said input and output circuits and including in series a compensating coil coupled to one of said circuits and a compensating condenser connected to the other of said circuits and an inductance connected between the high-potential terminal of said input circuit and said control means.

3. An electrical amplifier circuit comprising a four-electrode vacuum tube including anode, cathode, control grid and a second grid, an input circuit connected between said control grid and said cathode, an output circuit connected between said anode and said cathode, a compensating circuit including an inductance and a capacity connected in series between said input and output circuits, said inductance being coupled to an inductance in one of said circuits, a connection from said second grid to said cathode through said compensating circuit coil to produce an auxiliary control effect, and an inductance connected between the high-potential terminal of said input circuit and said control grid.

4. An electrical amplifier circuit comprising a vacuum tube including a cathode and at least two high-potential electrodes of which one constitutes an anode and another constitutes a control element; a circuit connected between said cathode and one of said high-potential electrodes; a second circuit having one terminal connected to said cathode and another terminal connected through an inductance to another high-potential electrode to provide a composite inductive and capacitive coupling between said input and output circuits; and a compensating circuit for compensating said composite coupling comprising a coil coupled to a coil in one of said circuits between said cathode and a high-potential electrode and connected through a condenser to another high-potential electrode.

5. An electrical amplifier circuit comprising a vacuum tube including at least an anode, a cathode, and a control electrode; an input circuit associated with said cathode and control electrode; an output circuit associated with said cathode and anode; and means for compensating capacitive coupling between said output and input circuits comprising an inductance connected in series between one terminal of said input circuit and said control electrode and a capacity connected between a terminal of said inductance and a coil coupled to a coil of said output circuit.

6. An electrical amplifier circuit comprising a vacuum tube including an anode, a cathode, a control grid and a second grid; an input circuit connected between said control grid and said cathode and including an inductance; an output circuit connected between said anode and said cathode and including an inductance; a compensating circuit connected between said input and output circuits and including in series a compensating coil coupled to one of said inductances in one of said circuits and compensating capacity connected to the other of said circuits; an inductance connected between the high potential terminal of said input circuit and said control grid; and means for imparting a positive bias to said second grid.

7. An electrical amplifier circuit comprising a vacuum tube including at least an anode, a cathode and a control element; an input circuit having one terminal connected to said cathode and including an inductance; an output circuit associated with said tube and including an inductance; a third inductance connected between the high potential terminal of said input circuit and said control element; and a compensating circuit connected between said input and output circuits and comprising capacity connected to one of said circuits and a fourth inductance coupled to said inductance in the other of said circuits.

In testimony whereof, I affix my signature.

LEWIS M. HULL.