Feb. 3, 1931. F. H. DRAKE 1,791,236

ELECTRICAL CIRCUIT AND TRANSFORMER THEREFOR

Filed May 4, 1928 2 Sheets-Sheet 1

Fig. 1.

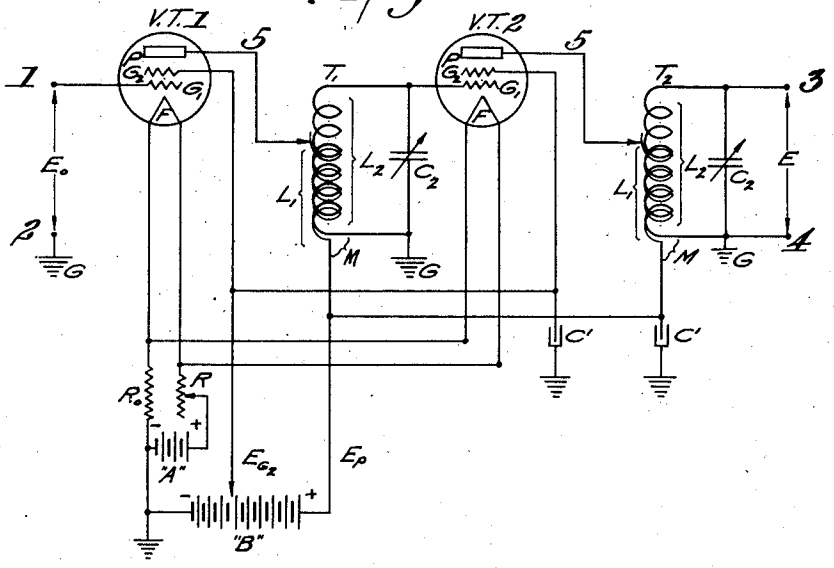
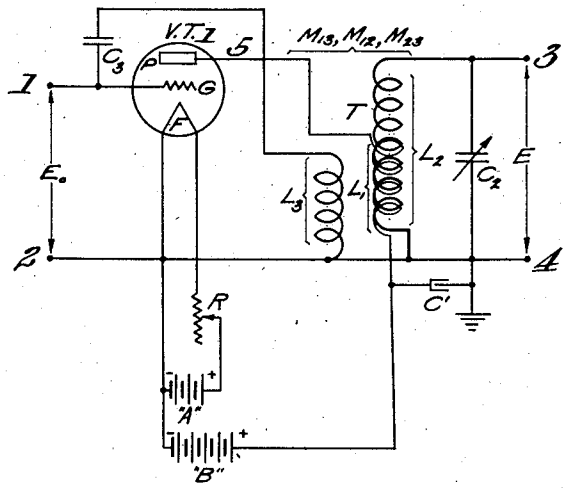


Fig. 2.



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Fig. 3.

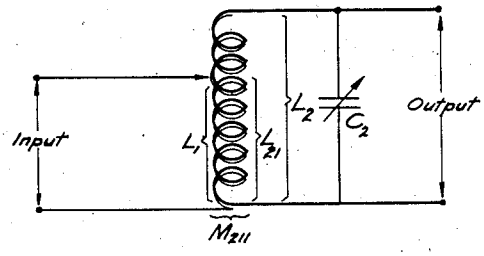


Fig. 4.

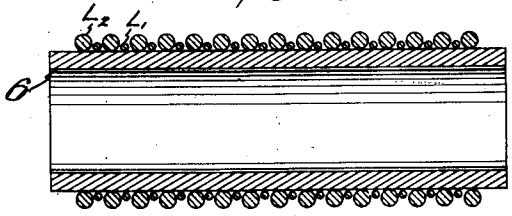
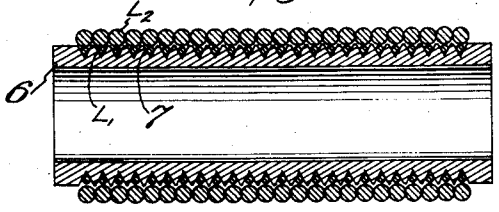


Fig. 5.



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UNITED STATES PATENT OFFICE

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ELECTRICAL CIRCUIT AND TRANSFORMER THEREFOR

Application filed May 4, 1928. Serial No. 275,177.

This invention relates to electrical systems or circuits of which a typical example, with reference to which the invention will hereafter be described, is an electrical amplifier circuit of the type employing one or more electron or vacuum tubes such as are commonly known as "audions", "triodes", "tetrodes", and the like, and suitable for use in radio receiving sets. It relates also to an electrical transformer suitable for use in such a circuit or system, for example as a coupling means between tubes of the foregoing types, and in particular, also, to a radio frequency transformer proportioned, designed, and constructed according to a novel manner, and which is suitable for use in such electrical circuits or systems.

In electrical amplifiers of the foregoing type, especially in tuned radio frequency amplifiers for example, it is frequently desirable to employ coupling means or coils of the so-called auto-transformer type; that is, a single coil one portion of which constitutes the input coil of the transformer, and another portion of which, perhaps including the first portion, acts as the output coil of the transformer. An advantage of such an auto-transformer coil is that the impedances of the portions thereof may be readily adjusted according to input and output requirements. For example, in the case of certain tubes, the input and output impedances of the appropriate portions of the transformer may be approximately adjusted or equated to the tube input and output impedances with which they are associated, in order to produce high amplification, or the input impedance of the transformer may be made lower than the output impedance of the tube with which it is associated, so as to improve selectivity. Moreover, by using such auto-transformer coils it is possible to obtain a very high degree of coupling between the input and output circuits, for example by using a 1:1 turn ratio, without introducing such undesirable capacity and resistance effects in the secondary as may be entailed by the use of conventional transformers having separate primary and secondary coils. For example, such an auto-transformer is highly desirable for use in connection with a radio frequency amplifier employing electron tubes of the type having a high output impedance, such as the so-called "high mu" tubes, or such as tetrode tubes of the screen grid type.

In spite of the advantages of using auto-transformers in association with electron tubes of the types referred to, a number of difficulties are commonly encountered. For example, it is difficult or impossible to use common "B"-batteries, or a common socket-power source of "B" supply, in multi-stage amplifiers having auto-transformer coupling, without the use also of additional pieces of apparatus. Since in almost all practical multi-stage electrical amplifiers it is necessary or desirable to use common sources of direct current potential for the anodes of the several stages, various ways of accomplishing this purpose in auto-transformer coupled amplifiers have been attempted. For example, in order to isolate the potential of the anode of a tube from the grid of a succeeding tube, it has been proposed to use a blocking condenser inserted between the high potential secondary terminal of the coupling transformer and the control element of the succeeding tube, a grid biasing resistance between the grid and filament of this tube being then also required. Another method which has been proposed is to insert a blocking condenser between the plate of the first tube and the high potential primary terminal of the auto-transformer, direct current being then fed to the plate through a suitable radio frequency choke coil. Neither of these methods of employing auto-transformer coupling between cascaded tubes in a multi-stage amplifier having common sources of direct current potential for the anodes of the several stages has proven altogether satisfactory in practice. Among other reasons, each of the foregoing methods requires the use of at least two additional pieces of apparatus for each amplifier stage and the former method makes it impractical to ground the tuning condenser without the use of an additional high capacity by-pass condenser connected between the low potential end of the secondary and ground.

I have found that it is possible to construct

a circuit having all of the advantages and electrical simplicity of an auto-transformer coupled circuit in addition to the advantage of being able to employ common sources of direct current potential for the anodes of the several stages, without the disadvantages of the systems above referred to.

I will now describe my invention in connection with the accompanying drawings in which Figure 1 represents a multi-stage electrical amplifier system including two high impedance tubes of the tetrode type arranged in cascade according to my invention; Figure 2 illustrates my invention as applied to a triode tube arranged in an electrical amplifier circuit of the balanced type; Figure 3 illustrates diagrammatically a transformer according to my invention; and Figures 4 and 5 are specific examples of structural details of such transformers arranged according to my invention.

Referring now to Figure 1 the tube VT_1 is the first tube of a multi-stage electrical amplifier and is provided with anode or plate, P, control element or grid G_1, electron emitting element or cathode, F, and a fourth electrode in the form of a second grid G_2. The input voltage Eo is applied between the input terminals 1 and 2 connected to the control grid and ground, or between the control grid and cathode if a "C"-battery is employed as the grid biasing means. A transformer T_1 has a winding L_2, tuned by variable condenser C_2, and connected between the control grid G_1 and cathode F of the second tube VT_2 of the multi-stage amplifier. The winding L_2 consists of wire of gauge relatively large compared to the gauge used for L_1, and is associated and coupled by mutual inductance M with a twin winding, L_1, consisting of wire of small gauge. This winding may be wound from the cathode or ground terminal of the coil L_2 to any desired distance toward the high potential terminal thereof. The transformer consists, accordingly, of a winding L_2 of relatively large wire and a winding L_1 of relatively small wire closely associated and coupled with a part or all of the winding L_2, and forming a twin winding therewith. The low potential terminal of the winding L_1 is connected through the "B"-battery or equivalent source of direct current potential to the cathode F, and the lead 5 from the anode, P, is connected to a suitable point in the winding L_1, or may be connected to a variable tap on this winding as shown. The relatively small winding L_1 thus serves to supply direct current potential to the anode or plate of the first or input tube VT_1, and is accordingly herein designated as the "potential winding". The winding L_2 of relatively large wire carries the main resonant current in the tuned secondary circuit L_2—C_2, and is therefore herein termed the "current winding".

The second tube, VT_2, of the multi-stage amplifier may, if desired, be supplied with a similar transformer T_2, having an input or potential winding L_1 and an output or current winding L_2. The winding L_2 may be tuned by variable condenser C_2, as before, the output voltage between the output terminals 3 and 4 being designated as E. Any number of amplifier stages may be cascaded in such a multi-stage amplifier, and the last of these may suitably work into a detector stage, or whatever other load may be desired. When such an amplifier is employed in a radio receiving set, the terminals 1 and 2 may be the "antenna" and "ground" terminals, and the terminals 3 and 4 may be connected to the detector. It will be seen that the cathodes of the several tubes are connected to a common "A"-battery, or other source of direct current (a battery being shown by way of example); or the cathodes may assume the form of alternating current filaments or may be of the indirectly heated type, in which latter cases the grid bias may be supplied by well known methods. A common "B"-battery, or equivalent source of direct current potential, may be connected between the terminals A— and Ep; and the grids G_2 may be given a suitable potential by an appropriate connection of the terminal E_{G2}, as, for example, by a connection to the "B"-battery. One or more by-pass condensers C′ may be associated with the foregoing connections to the appropriate current sources for example as indicated in the drawing. The grids G_1, may be biased negatively with respect to the cathodes by means of resistance R_0, or by other well known means; a rheostat, R, may also be included in the cathode circuit if desired.

Figure 2 shows an electrical amplifier circuit including a tube VT_1 of the triode type provided with anode or plate, P, control element or grid, G, and electron emitting cathode or filament, F. The input of the amplifier is connected to the terminals 1 and 2. A transformer T is associated with tube VT_1 in the amplifier, and comprises a winding L_1 of gauge relatively small compared with the gauge employed for the winding L_2. The winding L_1 forms a twin winding with a suitable portion of the winding L_2, and is arranged to supply direct current potential to the anode P. Its lower terminal is connected to the cathode through a "B"-battery or equivalent direct current source, as shown. The winding L_2 may be tuned by a variable condenser C_2.

A tube of the triode type ordinarily has inter-electrode capacities, particularly a capacity between anode and control element, which are apt to produce disturbing feedback effects in an amplifier circuit with which the tube is associated. These inter-electrode capacities are also frequently aug-

mented by stray external capacities between leads, etc. In order to reduce or eliminate the flow of regenerative or retroactive currents due to this capacitive coupling between the output and input circuits of the amplifier, it has heretofore been proposed to employ a balancing circuit arranged to feed back to the input circuit additional currents of the proper phase and amplitude to oppose undesired retroactive currents. According to my invention I may employ a balancing winding L_3 connected to the cathode, and coupled to the windings L_1 and L_2 of the transformer in the reverse sense, or having its connections reversed, so that the mutual inductances M_{13} and M_{23} are negative in sign. This balancing winding L_3 may then appropriately be connected to the grid G through a balancing condenser C_3, the winding L_3, mutual inductances M_{13} and M_{23} and capacity C_3, being so proportioned and arranged as to feed back on to the grid C currents of the proper phase and amplitude to reduce or suppress the effects of currents flowing through undesired capacitive coupling between the output and input circuits. I prefer to employ the additional balancing winding L_3 rather than to reverse the connections to L_1 and connect C_3 to a point on L_2, since in the latter arrangement the capacity between the windings L_1 and L_2 acts to produce undesirable effects.

Figure 3 illustrates in detail a transformer arranged according to my invention, the coil L_2 consisting of relatively large wire, and the coil L_1 being wound as a twin-winding with coil L_2 and consisting of wire conspicuously smaller in gauge than that employed in the winding L_2. L_1 is wound so as to form a twin winding with so much of the winding L_2 as is desired. The winding L_1 may therefore extend a part or all of the way along the winding L_2. The wire forming the winding L_2 is made relatively large because it carries the main resonant current of the tuned circuit L_2—C_2, and the wire forming the winding L_1 is preferably conspicuously smaller in gauge, since its function is merely to supply direct current potential to the anode of the input tube, and to form a coupling to the main current-carrying winding L_2. The input and output connections to these windings may be arranged as indicated. A "twin-winding" as the term is herein employed, may be defined as one where the primary winding L_1 is wound turn by turn in the same sense along and with the corresponding turns of the secondary winding as shown; so that if L_{21} is the inductance of the portion of the secondary winding along which the primary extends, L_1 is the inductance of the primary winding, and M_{211} is the mutual inductance between L_{21} and L_1 then L_{21} and L_1 are approximately equal to each other and to M_{211}.

Figures 4 and 5 are cross sections of typical examples of transformer structures embodying the invention as above described. In Figure 4 the turns of the winding L_1 are interposed between those of the winding L_2, the two wires being wound side by side upon a suitable form 6, and constituting only a single layer. In Figure 5 the fine wire L_1 is wound in a groove 7, which may advantageously be of V shape, in the form 6, while the current winding L_2 is wound over the winding L_1 in the same groove.

The use according to my invention of a potential or input winding of relatively or conspicuously smaller gauge wire than the wire employed for the current winding associated with the resonant circuit is desirable in order that the power factor and physical dimensions of the transformer may be kept down to values approximating those of a simple auto-transformer. For example, with a current winding of #28 enamel wire I have found, in a specific case, that an input or potential winding of #36 enamel wire is suitable. In a construction similar to that shown in Figure 4, the resultant power factor of the current winding, in one specific physical transformer, was found to be increased by less than ten per cent over its value when no potential or input winding was present. On the other hand, when the input winding is of a gauge near to that of the current winding, the power factor of the current winding is found to be increased by many times this amount, this effect being due both to the presence of additional conductor in the field and to the fact that the form factor of the coil is necessarily much inferior for the same diameter of coil.

A twin winding of the type described above is found to be superior to the ordinary type of primary or input winding in that capacity between any turn of the potential winding and the corresponding secondary turn involves no current flow, due to the fact that the two turns are at the same alternating current potential. The effective capacity of the secondary of such a twin winding transformer is therefore less than in the case of an ordinary transformer having primary and secondary windings on separate forms, unless in such a case the primary winding is made of considerably smaller diameter than the secondary winding. In the latter case the electro-magnetic coupling between primary and secondary windings is unavoidably reduced, which may be highly undesirable. For high coefficients of coupling, therefore, a twin winding transformer of the type described above is in general found to have substantially lower capacities and capacity couplings than transformers of ordinary construction.

As specific examples of results obtained with a twin winding transformer of the type

described above, the windings consisting of wire of conspicuously different gauges, I may give the following constants which I have successfully employed in a transformer used in connection with a commercial tetrode:

L_1=85 turns #36 enamel on 1½" form
L_2=85 turns #28 enamel on 1½" form

When measured in a round copper shield 3" long x 3" in diameter, this transformer showed the following radio frequency resistance values (R_2) for the winding L_2:

At 550 meters R_2=4.1 ohms
At 300 meters R_2=6.8 ohms

With the winding L_1 entirely removed, the corresponding values for the radio frequency resistance of L_2 were:

At 550 meters R_2=3.9 ohms
At 300 meters R_2=6.2 ohms

These figures show that the use of the relatively fine wire primary gives a transformer of substantially as high merit as a simple auto-transformer, it having been determined that the inductance of L_2 is not sensibly altered by removal of the fine winding.

Another specific example is as follows:

L_1=85 turns #34 enamel wire on 1½" form
L_2=85 turns #28 enamel wire on 1½" form

Measured in the same way the radio frequency resistances were:

At 550 meters R_2=4.8 ohms
At 300 meters R_2=7.4 ohms

With the fine winding L_1 removed the corresponding resistances are:

At 550 meters R_2=4.4 ohms
At 300 meters R_2=6.4 ohms

From a comparison of the foregoing figures showing the relative resistances of the transformer secondary for the two sizes of primary wire, the advantage of a substantial or conspicuous difference in the size of wire used for the input and output windings of the transformer is apparent. As the size of the wire in the primary winding approaches the size of the wire in the secondary winding, the secondary resistance increases, and this increase is due to at least two factors, namely (1) because the coil without the primary has a poorer form factor due to the increased spacing of the secondary turns to accommodate the primary turns and (2) because the amount of conductor near the secondary winding is increased and the eddy-current losses are consequently larger.

The foregoing details of constructions and constants are merely specific examples according to my invention, which is not limited thereto. Moreover, its application is not limited to electrical circuits of the type illustrated, these being chosen merely as examples of the many applications of my invention. Many variations and modifications of the specific circuit arrangements and transformer constructions described herein, fall within my invention.

I claim:

1. An electrical amplifier system, comprising, in combination, a tube having at least an anode, a cathode, and a control element; a transformer having a current winding consisting of relatively large wire and a potential winding consisting of relatively small wire wound turn by turn in the same sense along and with corresponding turns of at least a part of said current winding to form a twin winding therewith; and means associated with said potential winding and said tube and adapted to permit the application of a direct current potential between the anode and cathode of said tube.

2. An electrical amplifier system, comprising, in combination, a tube having at least an anode, a cathode, and a control element; a transformer having a current winding consisting of relatively large wire and a potential winding consisting of relatively small wire wound turn by turn in the same sense along and with corresponding turns of at least a part of said current winding to form a twin winding therewith; a source of direct current potential; and connections including said potential winding for applying said direct current potential between the anode and cathode of said tube.

3. A multi-stage electrical amplifier comprising, in combination, a tube having at least an anode, a cathode, and a control element; a transformer having a current winding consisting of relatively large wire and a potential winding consisting of relatively small wire wound turn by turn in the same sense along and with corresponding turns of at least a part of said current winding to form a twin winding therewith; a connection from the cathode of said tube through a source of direct current potential to said potential winding, and a connection from said potential winding to the anode of said tube; a tuning condenser connected across the terminals of said current winding to form a tuned circuit; and a second tube having its input terminals associated with and fed from said tuned circuit.

4. A multi-stage electrical amplifier circuit comprising, in combination, a plurality of tubes each having at least an anode, a cathode, and a control element; an electrical coupling system interposed between two of said tubes and including a transformer having a current winding consisting of relatively large wire and a potential winding consisting of relatively small wire wound turn by turn in the same sense along and with corresponding turns of at least a part of said current winding to form a twin winding therewith; a common source of direct current potential for said tubes; and connections whereby said source of direct current potential is connected

between the anode and the cathode of each of said tubes, the connection to the anode of the first of said tubes including said potential winding.

5. A multi-stage electrical amplifier comprising, in combination, a tube having an anode, a cathode, a control grid, and a second grid; a transformer having a current winding consisting of relatively large wire and a potential winding consisting of relatively small wire wound turn by turn in the same sense along and with corresponding turns of at least a part of said current winding to form a twin winding therewith; a connection from said cathode to said anode through a source of direct current potential and through said potential winding; a second tube having an anode, a cathode, a control grid, and a second grid; connections whereby said current winding of said transformer is associated with said control grid and cathode of said second tube; and means for applying a bias to said second grid.

In testimony whereof, I affix my signature.

FREDERICK H. DRAKE.