Feb. 17, 1931. F. H. DRAKE ET AL 1,792,970

ELECTRICAL AMPLIFIER CIRCUIT

Filed May 4, 1928 2 Sheets-Sheet 1

Fig. 1.

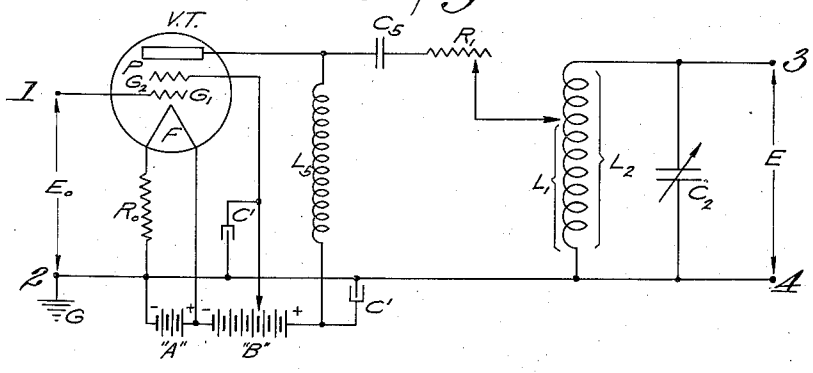


Fig. 2.

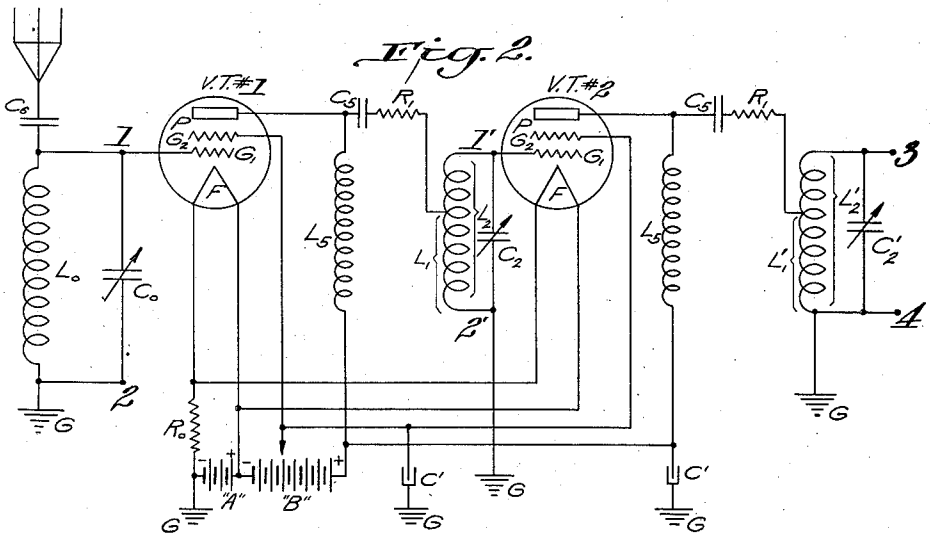
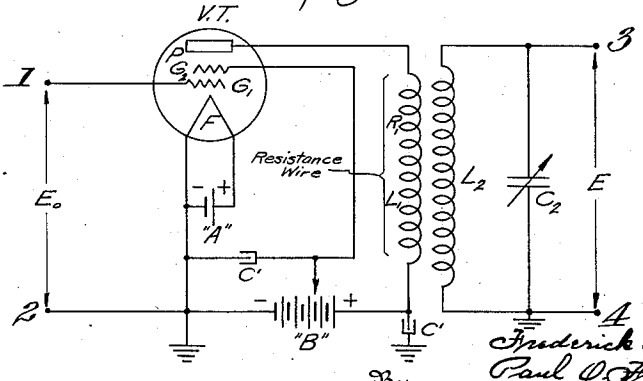


Fig. 3.



Inventors:
Frederick H. Drake,
Paul O. Farnham,
By Cushman & Brickenstein,
Attorneys.

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Fig. 4.

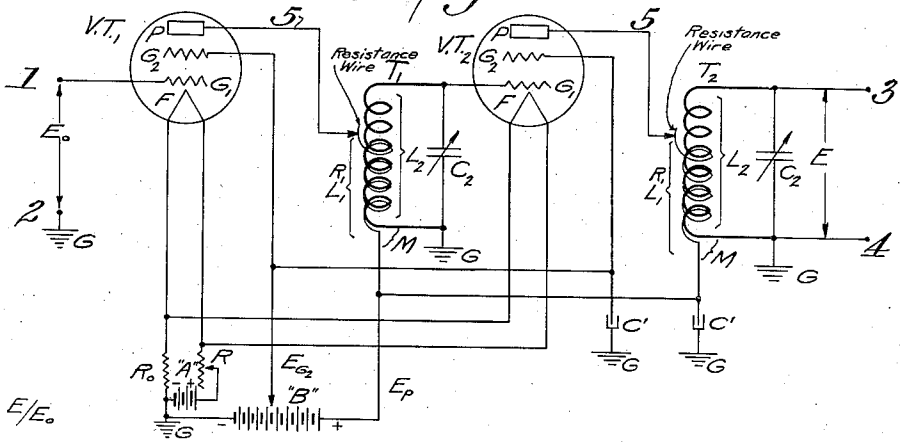
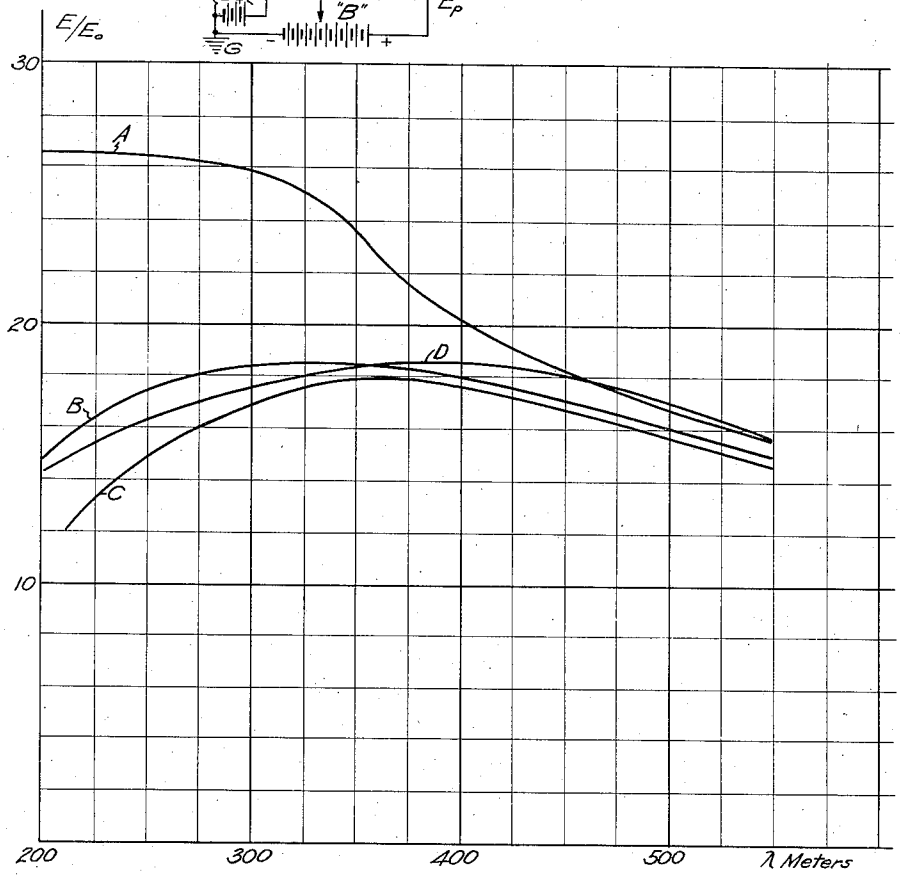


Fig. 5.



Inventors:
Frederick H. Drake,
Paul O. Farnham,
By Byrnes Townsend & Brickenstein,
Attorneys

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UNITED STATES PATENT OFFICE

FREDERICK H. DRAKE AND PAUL O. FARNHAM, OF BOONTON, NEW JERSEY, ASSIGNORS TO RADIO FREQUENCY LABORATORIES, INC., OF BOONTON, NEW JERSEY, A CORPORATION OF NEW JERSEY

ELECTRICAL AMPLIFIER CIRCUIT

Application filed May 4, 1928. Serial No. 275,179.

This invention relates to electrical amplifier circuits adapted for use in association with vacuum or electron tubes of high impedance, such as the so-called tetrode or double-grid tube. A tube of this type may be operated according to either of two methods, which are frequently designated as the "shield-grid" method and the "space-charge" method. In operation according to the former method the inner grid of the tube is employed as the control element while the outer grid, which in certain commercial constructions may almost completely surround and shield the anode, is given a positive bias or has applied to it a positive direct current potential by a connection to the "B"-battery or socket-power device, or by any other suitable means. In operation according to the latter method the outer grid of the tube, that is, the grid adjacent or surrounding the anode, is employed as the control element while the inner grid of the tube has applied to it a positive potential.

Our invention is applicable to electrical amplifier circuits employing tetrode or double-grid tubes designed to operate according to either one or both of the foregoing methods, but we have found it to be especially applicable to amplifier circuits employing four element tubes of the shield-grid type, i. e. to tubes designed to operate according to the first method described above. Our invention will therefore be hereafter described with reference to this application of the invention by way of specific example.

In electrical amplifier circuits designed to operate at radio frequencies, and especially in such circuits of the usual type in which the coupling system between adjacent tubes, or one or more of the resonant circuits associated with a single tube, includes fixed inductances tuned by variable tuning capacities, the voltage amplification of the amplifier is ordinarily considerably higher at short wavelengths than at long wavelengths. Thus, in the case of the present broadcast range of wavelengths, say from approximately 200 to 550 meters, a single electrical amplifier stage employing a tetrode of the shield-grid type may give a voltage gain or amplification of the order of say 30–60 at about 200 meters, depending on the particular tube and circuit employed, and this amplification may decrease rapidly throughout the broadcast range, so that the voltage amplification at about 550 meters may be of an order of magnitude of about 6–20. The foregoing figures, are, of course, subject to variation with the tube, circuit, and circuit constants, and it is not possible to give any accurate generalized figures. However, if the voltage amplification (hereinafter designated as E/Eo, where E is the voltage across the output terminals of the amplifier and Eo is the voltage across the input terminals of the amplifier) is plotted as ordinates against wavelength as abscissæ, the resulting curve representing the amplification characteristic of the amplifier will, in general, have a relatively steep slope. That is, the amplification will be relatively high at short wavelengths and will fall off continuously and rapidly, becoming relatively low at long wavelengths. A typical amplification curve of this type for a tetrode amplifier is shown at "A" in Figure 5, as will be hereafter more fully explained.

It is undesirable for an electrical amplifier to possess an amplification characteristic of this type, for a considerable number of reasons. For example, a radio receiving set including such a radio frequency amplifier, if designed for proper amplification at the longer wavelength end of its range, will prove to be excessively sensitive toward the shorter wavelength end of its range. In the case of such a radio frequency amplifier the high short-wavelength gain may tend to make the whole amplifier unstable, and may even cause it to break into oscillations at shorter wavelengths, due to stray capacitive and inductive couplings in the amplifier which couplings increase with frequency and are a maximum of the short-wavelength end of the range.

In order to overcome the foregoing difficulties, and others which are attendant upon an amplification characteristic of the usual type, it is desirable for an electrical amplifier to have an amplification characteristic which remains of substantially the same order of

magnitude over a pre-determined range of wavelengths, i. e. the amplification characteristic curve should preferably be substantially flat or constant, and in many cases it is even desirable that the amplification or gain should be less at short wavelengths than at longer wavelengths in order to produce substantially equal stability of the amplifier throughout its wavelength range.

We have found that the above described and other difficulties may be substantially overcome, and that the amplification characteristic of such an electrical amplifier may be materially modified in a desirable manner, over wide limits of wavelength, by the use of resistance of proper value or magnitude, arranged in proper manner, as will be hereafter described, in the plate or output circuit of the tube.

Referring now to the drawings, Figure 1 illustrates diagrammatically an electrical amplifier circuit including a single double-grid tube, and arranged according to our invention. Figure 2 represents a cascaded or multi-stage radio frequency amplifier embodying the circuit of Figure 1 and arranged according to our invention. Figure 3 represents another form of electrical amplifier arranged according to our invention and employing a single tube of the double-grid type. Figure 4 represents still another electrical amplifier circuit to which our invention is applicable. Figure 5 illustrates certain typical amplification characteristic curves which will be hereafter explained.

Referring now to Figure 1, VT is a vacuum or electron tube provided with an anode or plate, P, a cathode or filament, F, and two grid electrodes, G_1 and G_2. One of these grid electrodes, G_1, constitutes the control element of the tube, and the other grid electrode, G_2, which may partially or completely surround the anode or plate, P, has applied to it a positive direct current potential by a suitable connection to the "B"-battery, B, or otherwise. The input terminals for the amplifier are 1 and 2, 1 being connected to the control element, G_1, and 2 being connected to ground and to the cathode, F, thru grid biasing resistance R*o*. A "C"-battery may be alternatively employed for biasing the grid G_1 if desired, the terminal 2 being then connected to the cathode. The input voltage, E*o*, is the voltage across these input terminals. The cathode, F, may be heated either by direct or alternating current, or may be of the separate heater type, but is here illustrated as being operated from an "A"-battery, A. The terminal 2 may be grounded as shown at G, as described above. The plate or output circuit includes an inductive impedance, L_2, which is tuned by the tuning condenser C_2. This inductance L_2 is arranged so as to constitute an auto-transformer, the entire inductance, or any desired portion thereof, constituting the effective secondary L_2, of the transformer, across which the tuning condenser C_2 is connected; and a portion of this inductance, L_1, or the whole inductance if desired, constituting the effective primary of the auto-transformer. The lower terminal of the auto-transformer may be connected to ground. The anode, P, is supplied with direct current potential from the "B"-battery, B, through radio frequency choke coil L_5. C_5 is a coupling or blocking condenser of low radio frequency impedance. It serves to keep the direct current potential of the anode from the windings of the transformer L_1—L_2. The plate circuit of the tube, i. e. the primary of the output circuit of the amplifier, thus includes the inductance L_1. It also includes resistance, here shown at R_1, of a proper value to produce the desired favorable modification of the amplification characteristic of the amplifier, as will be more fully explained hereafter. The resistance R_1 in this output circuit primary may be either lumped or distributed throughout the circuit as by inclusion in the self-resistance of coil L_1, as will be later more fully explained. When it has the form of a separate resistance, R_1, as shown in Figure 1, it may, of course, be connected on either side of the primary inductance L_1, i. e. it may be connected between the cathode, F, and coil L_1. It may also be either adjustable or fixed, as is especially described hereafter. The output terminals of the amplifier are 3 and 4, and output voltage, E, is the voltage across these terminals.

Figure 2 represents a multi-stage radio-frequency amplifier according to our invention, as embodied in a radio receiving set. The antenna or other collecting device is connected through capacity C*o* and coil L*o* to ground. The tuned input circuit L*o*—C*o* includes the coil L*o* and the variable tuning condenser C*o*. The amplifier is here illustrated as comprising two tubes, VT #1 and VT #2, although it may of course include any desired number of tubes. The circuit for each of these tubes is arranged substantially as shown in Figure 1, the input terminals of the first tube being the terminals 1 and 2 of the tuned circuit L*o*—C*o*, and the input terminals of the second tube being the terminals 1′ and 2′ of tuned circuit L_2—C_2. The output terminals of the radio frequency amplifier are 3 and 4, i. e. the terminals of the tuned circuit L'_2—C'_2, and may be connected to a detector or any other desired load. It should of course be understood that in such multi-stage arrangements it is possible to employ common "A" and "B" batteries for the several stages, and one suitable method of doing this is illustrated in Figure 2. The grids may be biased by a common "C"-battery or by the voltage drops across a biasing resistance R*o* as shown, or in any other suitable manner. The batteries or biasing resist-

ances may be supplied with suitable by-pass condensers as is well understood in this art. Although "A" and "B" batteries and a biasing resistance are herein illustrated as means for supplying heating current to the cathodes, space current to the anodes and positive bias to the second grids, and negative bias to the control grids, respectively, it should be understood that any other suitable means of supplying these currents and potentials may be employed instead of the means herein illustrated. For example, socket-power devices may be suitably employed, or alternating current or separately heated cathodes may be employed. In a multi-stage arrangement such as that shown in Figure 2 the several tuning condensers may be grounded as shown.

Figure 3 illustrates an alternative circuit arrangement for an electrical amplifier according to our invention. This circuit is substantially similar to the circuit represented in Figure 1, except that in this case the auto-transformer L_1—L_2 of Figure 1 is replaced by a transformer having separate primary and secondary windings L_1 and L_2 as shown in Figure 3. In this arrangement, it is of course possible to employ a separate resistance R_1, which may be lumped or not, in the plate circuit of the vacuum tube (i. e. in the output circuit primary), together with the primary L_1, and connected on either side thereof, as in the arrangement of Figure 1. We prefer, however, in the arrangement of Figure 3, to introduce the resistance, R_1, of required magnitude, into the output circuit primary by winding the primary coil L_1 with wire of suitable resistivity. For example, we may employ high resistance wire such as "nichrome" or other commercial resistance wire, for this purpose. In this arrangement the resistance R_1 is accordingly constituted, either wholly or in part, as desired, by the self-resistance of the primary or plate coil, L_1. We may, of course, combine a primary, L_1, of high self-resistance with an external or separate resistance, R_1, in order to bring the total resistance of the plate circuit to the required value.

Figure 4 represents an alternative arrangement employing the invention described and claimed in the copending application, Ser. No. 275,177, filed May 4, 1928, of Frederick H. Drake. In this arrangement the auto-transformers T_1 and T_2 include a current winding, L_2, which carries the main resonant current of the tuned circuits L_2—C_2 this current winding being composed of relatively large wire, and a twin potential winding L_1, which is closely associated and coupled with the winding L_2, or at least with a part thereof, and which serves as a means for applying the requisite direct current potential to the anodes, P, this potential winding being composed of relatively small or fine wire. This arrangement forms the subject matter of the above-mentioned copending application, Ser. No. 275,177, and is not claimed herein; but we have found that it may be adapted to the present invention by winding the fine coil, L_1, with wire of such resistance as to fulfill the requirements herein described, or by connecting in series with the fine potential winding L_1 a lumped resistance R_1, of such a value as to fulfill these requirements.

It should, of course, be understood that any of the circuit arrangements illustrated herein, or variations thereof as indicated, are applicable not only to electrical amplifiers including a single stage, but to such amplifiers of the multi-stage type including any desired number of tubes or stages.

Figure 5 shows typical single-stage amplification characteristic curves A, B, C and D obtained by plotting the amplification or gain, E/Eo, as ordinates against wavelength as abscissæ. Curve A represents a curve derived from experimental measurements on an electrical amplifier circuit including a tetrode arranged as shown in Figure 4, the fine winding L_1 being composed, however, of copper wire of negligible resistance, and not therefore embodying our invention. In this circuit the following constants for the output transformer L_1—L_2, were employed:

L_1=55 turns No. 36 copper wire wound on 1½″ form.

L_2=85 turns No. 28 copper wire wound on 1½″ form.

Curve B represents the amplification characteristic curve, as obtained experimentally, for a single stage electrical amplifier circuit according to Figure 4, and embodying our invention. The output transformer and circuit had the following constants:

$\left.\begin{matrix} L_1 \\ R_1 \end{matrix}\right\}$ = 55 turns No. 36 nichrome wire wound on 1½″ form and having self-resistance of 575 ohms.

L_2=85 turns No. 28 copper wire wound on 1½″ form.

It will thus be seen that curve B was obtained experimentally with an electrical amplifier circuit in which R_1 was constituted by the self-resistance of the twin winding L_1 of the auto-transformer L_1—L_2 of Figure 4. It will be noticed that the amplification curve of this amplifier has been substantially equalized over the wavelength range from 200–550 meters, in a highly desirable manner, by the use of resistance R_1 as described. Moreover, this modification of the amplification curve has been accomplished by a reduction in the short wavelength gain of the amplifier without substantial or serious decrease of its amplification at longer wavelengths.

Curve C is a curve obtained with a circuit similar to that of Figure 4, except that instead of winding the coil L_1 with fine resistance wire, this coil was composed of fine cop-

per wire and a separate lumped resistance R_1 was connected in series therewith between the coil L_1 and the anode. The constants of this circuit were as follows:

L_1=55 turns #36 copper wire wound on 1½" form.

L_2=85 turns #28 copper wire wound on 1½" form the winding L_1 constituting a twin winding with a part of L_2.

R_1=230 ohms, lumped resistance, connected between L_1 and the anode.

Curve D is a curve obtained with a circuit similar to that shown in Figure 1, the constants being as follows:

L_1=L_2=80 turns #30 copper wire on 1¼" form.

R_1=127 ohms lumped resistance connected between L_1 and the anode.

It will be noted that in this particular instance the variable tap on L_1 was at the top of the coil.

The foregoing circuits and constants are, of course, merely typical examples illustrative of our invention, which is not limited thereto.

The desired modification or correction of the amplification curve of an electrical amplifier according to our invention may be obtained by the use of a lumped resistance R_1 in the plate or output circuit primary of the amplifier whether the resistance R_1 takes the form of a separate resistance connected in series with the primary, L_1, on either side thereof, or is distributed in the primary circuit, as by including the resistance R_1 in the self-inductance of the primary L_1. Although either of these arrangements produces the desired result, in general, in order to obtain the same degree of desirable modification of the amplification curve by the two arrangements, somewhat different values or amounts of resistance in the plate circuit will be required. Moreover, the effect of a given magnitude or value of the resistance R_1 depends somewhat on the other constants of the circuit. For example, referring to the arrangement shown in Figure 1, the larger is the portion of the coil L_2 which is included as the effective primary, L_1, of the auto-transformer of L_1—L_2 for any given constant value of resistance R_1, the greater is usually the effect of this resistance in decreasing the short wavelength gain of the amplifier without substantially affecting its long wavelength gain.

It is not possible to give any numerical value for the resistance R_1 which is applicable to all circuits including our invention, since the value of this resistance must depend upon and be adapted to the constants of the tube and of the circuit, including the value of the inductance L_1 as explained above. Our invention extends to all cases in which the resistance of the plate circuit (i. e. output circuit primary) exceeds the normal self-resistance of this circuit when L_1 is wound with low resistance wire such as copper, by any amount sufficient to produce a favorable modification of the amplification characteristic of the amplifier. However, we may state that, in general, for any particular circuit and tube, we prefer to employ, according to our invention, a resistance R_1 of such value that the amplification of the electrical amplifier circuit remains of substantially the same order of magnitude over a predetermined wavelength range over which the amplifier is designed to operate. Within these limits the amplification may remain substantially constant, but it is also within the definite contemplation of our invention that the resistance R_1 may have such a value that the amplification is actually lower at short wavelengths than at long wavelengths, in order to produce increased stability of the amplifier, or that the amplification is somewhat higher at short or at intermediate wavelengths than it is at long wavelengths in order to produce increased sensitivity at these wavelengths if desired. By amplification, or an amplification characteristic curve, which remains of substantially the same order of magnitude over a predetermined wavelength range, or which remains substantially constant over such a range, we do not mean an amplification or amplification curve which is actually flat or constant, but refer to amplification, or an amplification characteristic curve, such as that represented by curves B, C and D of Figure 5.

Circuits according to the present invention, in which resistance of required or predetermined value is included in the plate or primary circuit of the electrical amplifier output, as herein described, in order to effect a desirable modification of the amplification characteristic curve of the amplifier, should, of course, be distinguished from balanced circuits of the type described and claimed in the copending application of Frederick H. Drake, Ser. No. 275,178, filed May 4, 1928, in which resistance is included in the primary of a balanced circuit in order to produce a controlled resistance balance or unbalance of desired character while permitting a reactive balance or desired approach thereto. The present invention does not relate primarily to such balanced circuits of the type having a controlled resistance balance or unbalance, but relates more especially to circuits, such as those described herein, in which the effect of the resistance depends upon complicated mathematical considerations which we have not as yet completely worked out, but is probably, in general, according to our best present knowledge, a combination selective coupling and loss effect of a character depending upon the circuit and tube constants in the manner described above.

According to our invention the resistance, R_1, of the value described above, may of course be variable as indicated in Figures 1

and 4, either at the will of the operator or by a manufacturer's or laboratory adjustment of the amplifier to produce the desired modification of the amplification characteristic thereof, or may be fixed at a predetermined value which is arrived at either emperically or by calculation in the design of the amplifier, as is shown in Figures 2 and 3.

By a "transformer" as the word is used in the specification and claims herein, we include both an auto-transformer of the types shown in Figures 1, 2 and 4 and a transformer having separate primary and secondary windings as shown in Figure 3. By the word "resistance" as used herein we include both a variable or adjustable resistance and a fixed resistance, unless otherwise specifically designated.

The foregoing details of constructions and constants are merely specific examples according to our 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 our invention. Many variations and modifications of the specific circuit arrangements and transformer constructions described herein, fall within our invention.

Our invention is not limited to the particular circuit arrangements or circuit constants given herein, since these are merely illustrative of the invention, but extends to suitable modifications and variations thereof embodying the teachings of the foregoing specification.

We claim:

1. An electrical amplifier circuit comprising, in combination, an electron tube including an anode, a cathode, a control grid, and a second grid; an input circuit associated with said control grid; means for imparting a positive potential to said second grid; and a tuned output circuit associated with said anode and cathode, said output circuit primary including inductance and resistance of such a value in excess of the normal inherent self-resistance of said circuit, said resistance being of such magnitude that its presence in the output circuit effects a substantial reduction in the amplification of signals at the lower range of the wave-length band to which the output circuit may be tuned, while causing approximately no change in the amplification at the upper range.

2. An electrical amplifier circuit comprising, in combination, an electron tube including an anode, a cathode, a control grid, and a second grid; an input circuit associated with said control grid; means for imparting a positive potential to said second grid; and a tuned output circuit associated with said anode and cathode, said output circuit including inductance and resistance of a value such that the amplification of said amplifier circuit remains of substantially the same order of magnitude over a predetermined range of wavelengths.

3. An electrical amplifier circuit comprising, in combination, an electron tube including an anode, a cathode, a control grid, and a second grid; an input circuit associated with said control grid; means for imparting a positive potential to said second grid; and a tuned output circuit associated with said anode and cathode, said output circuit including inductance and resistance of a value such that the amplification of said amplifier circuit remains substantially constant over a predetermined range of wavelength.

4. An electrical amplifier circuit comprising, in combination, an electron tube including an anode, a cathode, a control grid, and a shield-grid; an input circuit connected between said control grid and said cathode; means for imparting a positive potential to said shield-grid; and an output circuit associated with said anode and said cathode and including a tuned radio frequency transformer having primary inductance connected between said anode and said cathode to form a plate circuit for said tube, said plate circuit having resistance of such value that the amplification of said amplifier circuit remains of substantially the same order of magnitude over a predetermined range of wavelength.

5. An electrical amplifier circuit comprising, in combination, an electron tube including an anode, a cathode, a control grid, and a shield-grid; an input circuit connected between said control grid and said cathode; means for imparting a positive potential to said shield-grid; and a tuned output circuit associated with said anode and said cathode and including a tuned radio frequency transformer having primary inductance connected between said anode and said cathode to form a plate circuit for said tube, said plate circuit having resistance of such value that the amplification of said amplifier circuit remains substantially constant over a predetermined range of wavelength.

6. An electrical amplifier system, comprising, in combination, a tube having at least an anode, a cathode, a shield-grid, and a control element; and a transformer having a current winding consisting of relatively large wire and a potential winding consisting of relatively small wire closely associated and coupled with at least a part of said current winding and forming a twin winding therewith, said potential winding being associated with a source of direct current potential and with said anode and cathode of said tube in the plate circuit thereof and having resistance of such a value in excess of the normal inherent self-resistance of said circuit as to have approximately no effect upon the amplification of signals at the upper range of the wavelength band to which said output cir-

cuit may be tuned and to effect a substantial reduction in the amplification of signals at the lower range thereof.

7. 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 resistance wire closely associated and coupled with at least a part of said current winding and forming a twin winding therewith; a condenser shunted across one of said transformer windings and adjustable to tune said amplifier over a band of wavelengths, a connection from said cathode to said anode through a source of direct current potential and through said potential winding and forming the plate circuit of said tube; 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 tube; and means for applying a bias to said second grids; said resistance wire winding in said plate circuit of said first tube having such a value in excess of the normal inherent self-resistance of said circuit as to produce a substantial reduction in the amplification of signals falling within a limited predetermined range of less extent than the band of wave-lengths to which said amplifier may be tuned.

8. A multi-stage electrical amplifier comprising, in combination, a tube having an anode, a cathode, a control grid, and a second grid; a tuned transformer having a current winding and a potential winding consisting of relatively small resistance wire closely associated and coupled with at least a part of said current winding and forming a twin winding therewith; a connection from said cathode to said anode through a source of direct current potential and through said potential winding and forming the plate circuit of said tube; 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 grids; said resistance wire winding in said plate circuit of said first tube having such a value that the amplification of said amplifier circuit remains of substantially the same order of magnitude over a predetermined range of wavelengths.

9. A multi-stage electrical amplifier comprising, in combination, a tube having an anode, a cathode, a control grid, and a second grid; a tuned transformer having a current winding consisting of relatively large wire and a potential winding consisting of relatively small resistance wire closely associated and coupled with at least a part of said current winding and forming a twin winding therewith; a connection from said cathode to said anode through a source of direct current potential and through said potential winding and forming the plate circuit of said tube; 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 tube; and means for applying a bias to said second grids; said resistance wire winding in said plate circuit of said first tube having such a value that the amplification of said amplifier circuit remains substantially constant over a predetermined range of wavelength.

In testimony whereof, we affix our signatures.

FREDERICK H. DRAKE.
PAUL O. FARNHAM.