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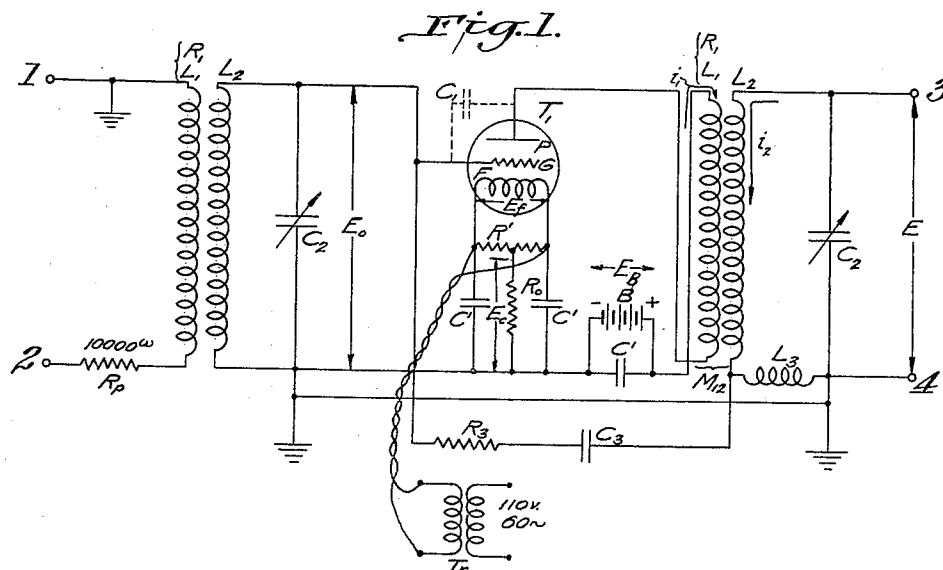
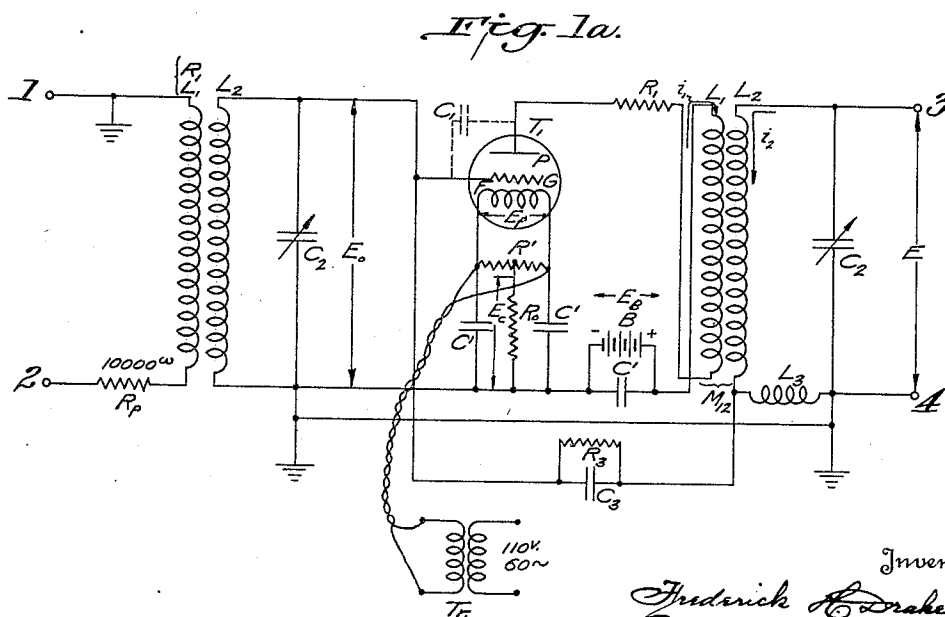
F. H. DRAKE ET AL

1,833,638

ELECTRICAL AMPLIFIER CIRCUIT

Filed June 7, 1928

4 Sheets-Sheet 1



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Fig. 1b.

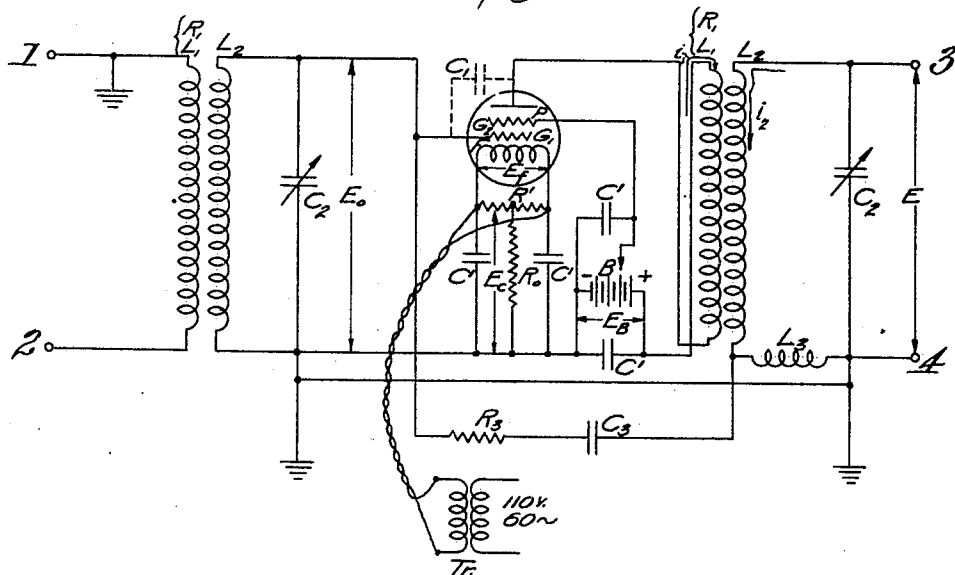
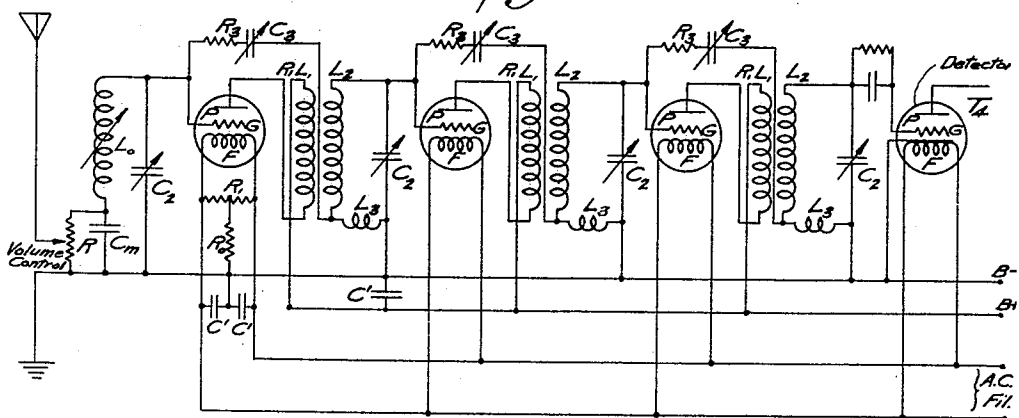


Fig. 2.



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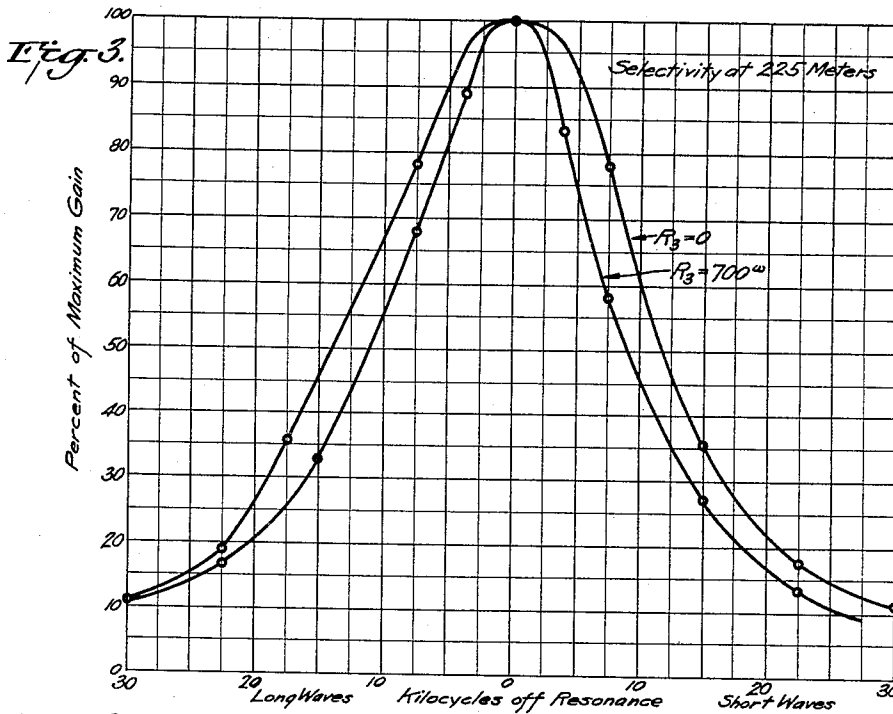
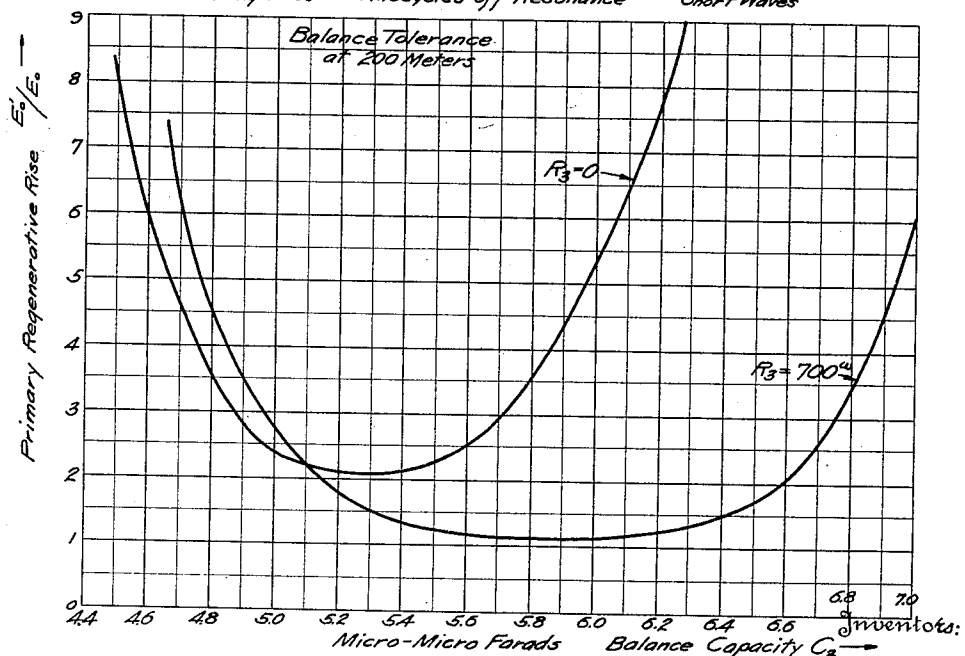


Fig. 4.

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Nov. 24, 1931.

F. H. DRAKE ET AL

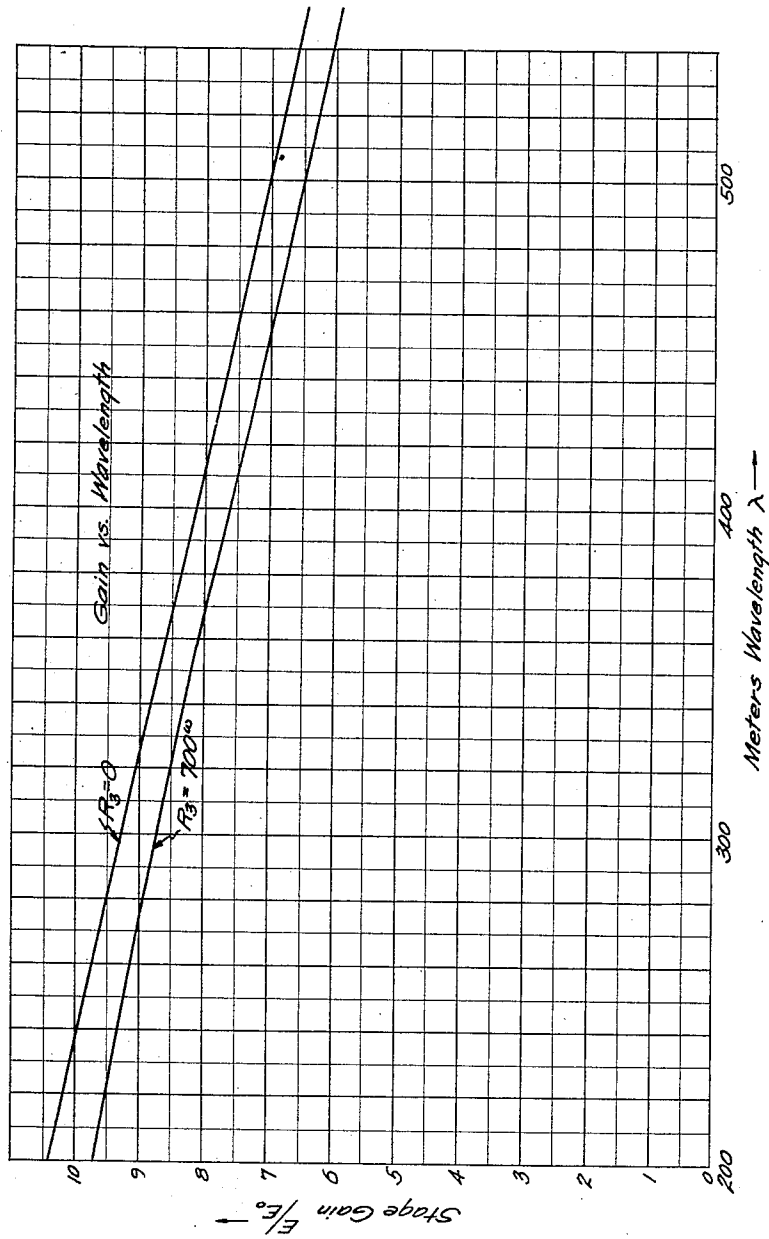
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ELECTRICAL AMPLIFIER CIRCUIT

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Fig. 5.



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UNITED STATES PATENT OFFICE

FREDERICK H. DRAKE AND PAUL O. FARNHAM, OF BOONTON, NEW JERSEY, ASSIGNORS,
BY MESNE ASSIGNMENTS, TO RADIO CORPORATION OF AMERICA, OF NEW YORK,
N. Y., A CORPORATION OF DELAWARE

ELECTRICAL AMPLIFIER CIRCUIT

Application filed June 7, 1928. Serial No. 283,624.

This invention relates to electrical circuits, and especially to electrical amplifier circuits, and the like; of the type employing electron or vacuum tubes including an electron emitting element or cathode, an electron receiving anode or plate, and one or more additional elements which are ordinarily in the nature of grids or the like. Such tubes are commonly designated as audions, triodes, tetrodes, and so forth. The invention is an improvement upon the invention described and claimed in United States Patent No. 1,672,811 to Lewis M. Hull, issued June 5, 1928, and on the invention described and claimed in co-pending application of Frederick H. Drake, Serial No. 275,178, filed May 4, 1928, patented June 17, 1930, No. 1,764,552; and relates more particularly to an electrical amplifier circuit including means adapted to reduce or suppress certain effects other than desired forward repeater action of the tube, and adapted especially to reduce or suppress effects due to the flow of retroactive or regenerative currents arising out of capacitive coupling between the output and input circuits associated with such a tube, this capacitive coupling including particularly capacity between the anode and control element of the tube, and capacity due to connections and circuits associated with said anode and control element.

Referring now to the drawings, Figure 1 represents one specific embodiment of the invention, showing its application to a single stage radio frequency electrical amplifier including a three-electrode tube. Figure 1a shows an alternative arrangement to that of Figure 1. Figure 1b shows an arrangement similar to that of Figure 1, but including a four-element or tetrode tube of the "double-grid" type. Figure 2 shows one specific embodiment of the invention as applied to a radio receiving set including a multi-stage radio frequency amplifier. Figures 3, 4 and 5 are graphic representations showing certain

effects upon selectivity, balance tolerance, and gain characteristic, respectively, arising out of the use of the present invention in certain specific instances.

Referring now to the particular circuit arrangement shown in Figure 1, T_1 is a tube of the three-electrode type, including an anode P, control element G, and cathode F, the latter being, in this particular instance, an alternating current filament heated by current from any suitable source, such as 110 volt 60 cycle house-lighting source, as indicated. In this case the step-down transformer Tr is employed, and the filament is shunted by the resistance R' . Each side of the filament is by-passed to ground by condensers C' as shown. The grid G may be biased negatively to any desired value with respect to the cathode by means of the resistance R_0 . L_1-L_2 constitutes an input transformer of which the primary L_1 may be associated with any desired source of electrical currents to be amplified, a connection to the plate circuit of a preceding tube being indicated, by way of example, by the inclusion between input terminal 2 and coil L_1 of an equivalent plate-resistance R_p equal to, say, 10,000 ohms, and by the connection to ground of the input terminal 1. The secondary L_2 is tuned by variable tuning condenser C_2 , the voltage across which, represented by E_0 , constitutes the input voltage of the amplifier stage, being applied to the stage between the grid G and ground and measured when the tube is unlighted. The output circuit includes a transformer L_1-L_2 , provided with primary winding L_1 connected (together with a suitable source of potential such as the "B"-battery B shunted by by-pass condenser C') between cathode and anode of the tube, and a secondary winding L_2 coupled thereto. L_1 and L_2 are so connected and wound as to have effectively negative mutual inductance $M_{1,2}$ between them, that is, L_1 and L_2 are wound in the same sense, connections to L_1 being reversed, or alterna-

tively, L_1 and L_2 are wound in opposite sense, connections being normal. A tertiary coil L_3 , which may be an element of the output transformer, as described and claimed in copending application of Frederick H. Drake and William D. Loughlin, Ser. No. 275,449, filed May 5, 1928, is included in the tuned secondary circuit $L_2-L_3-C_2$, and preferably has negligible or substantially zero electromagnetic coupling with the coils L_1 and L_2 , for example being arranged with its axis at right angles to the axes of L_1 and L_2 . The junction of the coil L_3 and the secondary tuning condenser C_2 is grounded, as shown, and is thus connected to the cathode F which is by-passed to ground. The output voltage of the amplifier stage is the voltage E across the output terminals 3 and 4. The ratio E/E_0 therefore represents the gain or voltage amplification of the amplifier stage, and a curve obtained by plotting E/E_0 against wave-length (λ) is the gain or amplification curve of the amplifier.

In such an electrical circuit including an inductive, tuned, plate circuit, the capacitive coupling, C_1 , between anode P and control element G, together with the associated stray capacities, produces feed-back or retroactive currents which tend to cause regeneration, instability, and oscillation, as is well understood. This effect is, of course, greater at short wavelengths than at long wavelengths since the impedance of C_1 decreases with increasing frequency. In certain types of amplifier circuits, also, for instance circuits involving fixed inductances tuned to resonance at different wavelengths by variable condensers, the amplification of the stage tends to vary with wavelength, assuming large values at the shorter wavelengths and smaller values at the longer wavelengths, all within the range of a given variable tuning condenser in combination with a given fixed coil. From the standpoint of stability and an economical design it is in general preferable to have substantially uniform amplification over the wavelength range used. In order to obtain this, it is, therefore, advantageous not only to suppress retroactive effects which would normally increase the overall amplification by regeneration, and thus produce instability, but, in addition, to further modify the behavior of the stage in such a way that the net amplification at the shorter wavelengths is as low as, or even less than, the theoretical or so-called "repeater amplification" of a tube and transformer.

In order to balance the amplifier circuit as regards the capacitive currents fed back through the capacity C_1 due to the current flowing through the tuned output circuit $L_2-L_3-C_2$, it has been proposed to employ a balancing circuit arranged between the grid G and the junction of coils L_2 and L_3 in the tuned circuit, and including capacitive impedance, such as C_3 , as described and claimed

in the above referred to United States Patent No. 1,672,811, to Lewis M. Hull. By the use of this balancing circuit, a substantial reactance balance of the circuit, as regards the secondary current i_2 flowing in tuned circuit $L_2-L_3-C_2$, may be obtained in accord with the following equation:

$$\frac{C_3}{C_1} = \frac{M_{12}}{L_3}$$

wherein

C_1 represents inter-electrode capacity between anode and control element of the tube, plus stray capacities of leads, connections, sockets, and so forth.

C_3 represents the balancing capacity

M_{12} represents the mutual inductance between coils L_1 and L_2

L_3 represents the self-inductance of the coil L_3

This equation, when approximately fulfilled, results in a substantial suppression of all first-order regenerative effects in the stage.

It has further been proposed (as described and claimed in the above-mentioned copending application of Frederick H. Drake, Ser. No. 275,178, filed May 4, 1928) to produce a controlled resistance unbalance in the presence of a substantial reactance balance, in such an amplifier network, by the inclusion in the primary or anode circuit of suitable resistance R_1 . This resistance R_1 may be of any value in excess of the normal self-resistance of the primary circuit when L_1 is wound with low-resistance wire, but is preferably of such value as to produce a flattening or increased uniformity in the gain or amplification curve of the amplifier, as described above, by reducing the amplification at short wavelengths without substantially affecting the amplification of longer wave-lengths. In Figure 1 the resistance R_1 is shown as comprised by the distributed self-resistance of the primary coil L_1 , this coil being wound, for example, of suitable resistance wire. R_1 may, however, alternatively be comprised wholly or in part by a separate lumped resistance included in circuit with the primary coil L_1 . The inclusion of resistance in the primary or anode circuit, as described, whether distributed or lumped, results in certain marked advantages over the arrangement employing merely a reactance balance as regards the secondary current, these advantages being explained in the above-mentioned copending application.

We have now found that a number of very considerable additional advantages may be obtained by the use of resistance R_3 of suitable value, suitably arranged, in the balancing circuit R_3-C_3 , as shown. According to our invention, this resistance in the balancing circuit may be of any desired value in excess

of the normal self-resistance of this circuit including the physical condenser C_3 , but in a preferred arrangement, the amount of this resistance, R_3 , may be so adjusted as to produce, to a greater or less degree, the results shown in Figures 3, 4 and 5, retaining at the same time the advantages arising from the use of R_1 , and is accordingly of such value as to partially or wholly overcome the resistance unbalance of the network produced by the resistance R_1 in the primary circuit, thereby producing (to any desired degree) a resistance balance of the network not only in the presence of a substantial reactance balance thereof, but also in the presence of the added resistance R_1 . The advantages arising from the use of resistance R_1 in the primary circuit in excess of the normal resistance thereof, as described and claimed in the above-mentioned copending application of Frederick H. Drake, Ser. No. 275,178, filed May 4, 1928, are thus retained, according to the present invention, but certain marked additional advantages are also obtained, as will be hereafter more particularly described in connection with Figures 3, 4 and 5.

As a specific example, only, and without in any way limiting the invention thereto, we may give the following constants for the resistance-capacity balance network of the radio frequency amplifier shown in Figure 1.

R_1 } = 20 turns #35 Nichrome wire on 1" form, with 1" winding space, having radio frequency resistance of 150 ohms at $\lambda = 200$ meters wavelength.

$L_2 = 87$ turns #30 enameled copper wire, close wound on $1\frac{1}{4}$ " form. (Where L_1 and L_2 apply to both the input and output transformers.)

$L_3 = 50$ turns #30 enameled copper wire, close wound on $\frac{1}{8}$ " form.

$R_3 = 700$ ohms in series with C_3 .

$C_3 = 6.1 \mu. \mu. f.$

Tube = UX-226 (8.4 $\mu. \mu. f.$ average grid-plate capacity)

R_o set to give grid bias = -6 volts = E_g

$E_b = 94$ volts

$E_t = 1.5$ volts

$R' = 50$ ohms

$C' = .5 \mu. f.$

Figure 1a represents an alternative arrangement to that of Figure 1, R_1 being constituted by a separate lumped resistance in series between a low-resistance coil, L_1 and the anode, rather than by the distributed self-resistance of the primary as in Figure 1, and R_3 being arranged in parallel with the balancing capacity C_3 . Either of these variations may, of course, be employed without the other. Although the mathematical condition for ideal resistance balance of the network theoretically requires that R_3 be in shunt with C_3 , we find that, in general, the

balance obtained in practice by the use of the resistance R_3 in series with C_3 is preferable. The inherent resistance of C_3 may, of course, in either the series or shunt arrangements, be made to include a part or all of the necessary resistance, R_3 .

Figure 1b shows one of the several arrangements according to which the circuit of Figure 1 may be applied to a double-grid tube. The inner grid G_1 is here used as the control element while the outer grid G_2 has applied to it a positive bias in order to reduce the capacity between anode and control grid. Since this capacity is not always thus wholly eliminated, for example where the outer grid G_2 constitutes a volume control electrode as described and claimed in copending application of Frederick H. Drake, Ser. No. 281,936, filed May 31, 1928, the use of a balanced circuit according to the present invention is found desirable. An alternative arrangement is to employ the outer grid G_2 as the control element and apply a positive bias to the grid G_1 . The present invention may be applied to this arrangement as well. Other arrangements involving tetrodes, to which the present invention is applicable, are described in the above-mentioned United States Patent No. 1,672,811, to Lewis M. Hull, and application of Frederick H. Drake, Ser. No. 275,178, filed May 4, 1928.

Figure 2 represents the circuit of Figure 1 as applied, in one suitable manner, to the radio frequency amplifier of a radio receiving set. The tubes T_1 , T_2 and T_3 may suitably be UX-226 tubes, and T_4 a UX-227 tube, for example; in which case the constants of the several circuits may suitably be the same as before. The input system may be of any desired form, and is here shown, by way of illustration only, as that described and claimed in copending application of Frederick H. Drake and William D. Loughlin, Ser. No. 285,886, filed June 16, 1928. In this case the constants of the input system may suitably be as follows:

$C_m = .001 \mu. f.$

$L_o = 240 \mu. h.$ max. 170 $\mu. h.$ min.

$R = 50000$ ohms volume control

The condensers C_2 are ganged and operated from a single control; the condenser C_2 in the input system being aligned with the others for any given antenna constants by means of the trimming inductance L_o . The output from the detector tube T_4 may suitably go to an audio frequency amplifier and loud speaker, as is well understood. The grids are biased by means of the resistance R_o ; a suitable source of alternating current is applied to the terminals marked A. C. Filament, and a suitable source of potential is applied between the terminals marked "B+" and "B-". Bypass condensers C' may be used in any required manner, for example as shown.

The specific circuits and constants herein

shown and described are examples, only, of circuits embodying the present invention, which is in no way limited thereto. We have found that in certain cases, for example, it is desirable to employ UX-227 or other tubes, instead of UX-226 tubes, since the former tubes have lower grid-plate capacity. Tubes of the direct current filament type, obviously, may also be employed. Either socket-power devices or batteries may be used to supply the necessary potentials, and the grids may be biased in other ways, or left unbiased if desired. Other variations in the circuit arrangements may, of course, be made equally with those mentioned. Obviously R_1 , R_3 and C_3 may be either fixed or adjustable in each case.

Certain of the advantages arising from the use of the present invention are illustrated in Figures 3, 4 and 5. Figure 3 shows two selectivity curves obtained by plotting the gain (in percent of gain at resonant frequency) against the number of kilocycles off resonance, for the circuit tuned to resonance at $\lambda=225$ meters wavelength. The curves were taken with a circuit having the constants given above in connection with Figure 1, C_3 being set by forward aural balance. It will be noted that $R_3=700$ ohms, for the other particular circuit constants in this example, gives markedly increased selectivity over $R_3=0$ (i. e. when the present invention is not employed). With this value of $R_3=700$ ohms there is the further important advantage that the residual signal as C_3 is adjusted for balance is materially less than the lowest residual signal obtainable when $R_3=0$.

Figure 4 shows two curves representing the balance tolerance, with and without the use of the present invention, for the particular case of the circuit constants referred to. The curves are obtained by plotting E_0/E_o (where E_0 is the "max.max." voltage across the input tuning condenser for optimum setting of both tuning condensers with the tube lighted) against the value of the balance capacity in micro-micro-farads, all at $\lambda=200$ meters wavelength, which is in general the most critical portion of the range of an amplifier of this type designed for broadcast reception. It will be observed that for $R_3=0$ (i. e. when the present invention is not employed) the primary regenerative rise, i. e. E_0/E_o , due to the unbalanced primary current, i_1 in the coil L_1 , is nowhere less than 2. That is, even when the circuit is completely balanced for reactance by adjustment of C_3 , the primary regenerative rise is sufficient to double the gain at short wavelengths. Moreover, the balance tolerance is seen to be very narrow, and it is found in practice that such a narrow tolerance does not, in commercial work, accommodate the extreme variations in tube capacities. For example, although the average grid-plate ca-

capacity of the UX-226 tubes is approximately $8.4 \mu\mu.f$, the commercial variation in this capacity is about $\pm 1 \mu\mu.f$, so that in the commercial building of radio receiving sets embodying amplifiers of this type it is desirable to provide a sufficient balance tolerance to accommodate this variation in commercial tubes. Referring to the curve $R_3=700$ ohms (which is a specific example of a curve obtained with certain constants according to the present invention) it will be seen that over a considerable range of balance capacity the ratio of E_0/E_o is substantially equal to unity, which means that there is substantially no primary regenerative rise. This condition is highly desirable, since it produces a substantially truly one-way amplifier i. e. one which is perfectly balanced over the wavelength range for which it is intended, and in which there is substantially no regeneration or retroaction (the amplifier being of course properly by-passed and shielded). It will be observed that the ratio is substantially equal to unity over a sufficient range of balance capacity to accommodate the commercial variation in tube grid-plate capacity, so that when the circuit is once balanced for any particular tube, it remains balanced for any substituted tube, and not only does not oscillate, but is substantially a non-regenerative one-way amplifier circuit. Moreover, by still further increasing R_3 and varying the other constants of the circuit, the amplifier can be made to degenerate, especially at short wavelengths (i. e. the ratio E_0/E_o can be made less than unity), which is found to be desirable in certain cases.

Figure 5 shows gain curves for circuits having the constants given above in connection with Figure 1, but having $R_3=0$ and $R_3=700$ ohms, respectively. The curves are obtained by plotting the single-stage gain E/E_o , against wavelength in meters, over the wavelength range of 200-550 meters. It will be observed that substantially the same desirable and advantageous shape and slope of gain curve obtained by the use of the invention described and claimed in the application of Frederick H. Drake, Ser. No. 275,178, filed May 4, 1928, may be retained when the present invention is employed, while the added advantages described in connection with Figures 3 and 4 are obtained.

The invention is not limited to the use of R_3 of such a value as to produce a complete resistance balance of the network, but extends to all cases in which the resistance of the balance circuit, including the balance capacity, C_3 , is increased beyond the normal resistance (due to dielectric loss, and other resistance) of the capacitive impedance (whether a physical condenser or so-called "natural" capacity) in the balance circuit; although this increased resistance of the bal-

ance circuit may be incorporated, if desired, in the capacitive balance impedance by making its self-resistance greater than normal. The other specific circuit arrangements and circuit constants described herein, are merely examples of the present invention, which includes many variations and modifications thereof, and is limited only by the teachings of the foregoing specification, by the prior art, and by the following claims:

Claims:

1. An electrical amplifier stage comprising, in combination, a vacuum tube including at least an anode, a cathode, and a control grid; an input circuit for said stage connected to said control grid; an output circuit including an output coupling coil and resistance in excess of the normal resistance of said coupling coil connected between said anode and said cathode; a tuned circuit including in series a second coil coupled to said output coil, a tuning condenser, and a third coil having negligible electromagnetic coupling with said output coil; and a balancing condenser and resistance connected between said control grid and the junction of said second and third coils.

2. An electrical amplifier stage including a vacuum tube having at least an anode, a cathode, and a control grid; an input circuit associated with said control grid; a tuned output circuit including in series a tuning condenser having one terminal connected to said cathode, and two coils having negligible electromagnetic coupling with each other, one of said coils being coupled to a coil in a circuit including resistance in excess of the normal resistance of said coupling coil and connected between the said anode and cathode; and a capacitive and resistive impedance connected between said control grid and one of said coils at such a point that said stage may be balanced to reduce retroactive effects due to coupling between said output and input circuits.

3. A multi-stage electrical amplifier circuit comprising, in combination, a plurality of electron tubes each including at least an anode, a cathode, and a control electrode; an input circuit associated with the cathode and control electrode of the first of said electron tubes; a coil and resistance in excess of the normal resistance of said coil associated with the anode and cathode of said first tube; a second coil electromagnetically coupled to said first coil in the reverse sense and having one terminal connected to the control electrode to the second of said electron tubes; a third coil having one terminal connected to a second terminal of said second coil and a second terminal connected to the cathode of said second tube, said third coil having negligible electromagnetic coupling with said second coil; a balancing circuit including capacitive and resistive impedance, said bal-

ancing circuit being connected between said control electrode of said first tube and the junction of said second and third coils; a tuning condenser connected between said first terminal of said second coil and said second terminal of said third coil and across the control electrode and cathode terminals of said second tube; and a connection to ground common to said cathodes of said first and second tubes and to the junction of said tuning condenser and said third coil.

4. A balanced electrical amplifier circuit including a tube having at least an anode, a cathode, and a control grid; capacitive coupling between said anode and control grid; a coil connected in the anode circuit of said tube; a second coil coupled to said first coil; a third coil constituting with said second coil serially connected elements of a resonant output circuit; a balancing capacitive impedance connected between said control grid and a point in said output circuit, the ratio of said balancing capacitance to said coupling capacitance between anode and control grid being substantially equal to the ratio of the mutual inductance between said second coil and said first coil in the anode circuit, to the self-inductance of said third coil, to produce a substantial reactance balance of the electrical network for currents in said resonant output circuit; resistance added to said anode circuit in excess of the normal self-resistance thereof and of an order effective to substantially reduce the amplification at the shorter wave lengths; and means for producing a substantial resistance balance of said electrical network in the presence of said substantial reactance balance thereof and in the presence of said added resistance in the anode circuit.

5. An electrical amplifier circuit comprising, in combination, a vacuum tube including at least an anode, a cathode, and a control grid; an input circuit associated with said control grid; an anode circuit connected between said anode and cathode and including an output coil and resistive impedance in excess of the normal self-resistance of said coil; a second coil coupled to said output coil; a third coil connected in series with said second coil but having substantially negligible electromagnetic coupling therewith; and a balance circuit connected between said control grid and the junction of said second and third coils, and including a balance capacity and resistive impedance in excess of the normal resistance of said balance capacity.

6. An electrical amplifier circuit comprising, in combination, an electron tube including at least an anode, a cathode, and a control means; an input circuit associated with said control means; a circuit associated with said anode and cathode and including a coil; a second coil coupled to said first coil and arranged so as to have effectively negative mutual inductance therewith; a third coil con-

5 nected to said second coil but having substantially negligible electromagnetic coupling therewith; a connection including capacitive impedance between said control means and the junction of said second and third coils; and a connection between said cathode and said third coil; the resistive impedance of said circuit associated with said anode and cathode of said tube being of such value as to reduce the short wavelength amplification of said amplifier without substantially affecting the long wavelength amplification thereof, and the resistive impedance of said balance connection being of such value as to substantially increase the selectivity and balance tolerance of said amplifier.

7. An electrical amplifier stage comprising, in combination, a vacuum tube including at least an anode, a cathode, and a control grid; an input circuit for said stage connected to said control grid; an output circuit including an output coupling coil, and resistance in excess of the normal resistance of said coupling coil connected between said anode and said cathode; a tuned circuit including in series a second coil coupled to said output coil, a tuning condenser, and a third coil having negligible electromagnetic coupling with said output coil; and a balancing condenser and resistance connected in series between said control grid and the junction of said second and third coils.

8. An electrical amplifier stage comprising, in combination, a vacuum tube including at least an anode, a cathode, and a control grid; an input circuit for said stage connected to said control grid; an output circuit including an output coupling coil, and resistance in excess of the normal resistance of said coupling coil connected between said anode and said cathode; a tuned circuit including in series a second coil coupled to said output coil, a tuning condenser, and a third coil having negligible electromagnetic coupling with said output coil; and a balancing condenser and shunt resistance connected between said control grid and the junction of said second and third coils.

9. An electrical amplifier stage comprising, in combination, a vacuum tube including an anode, a cathode, a control grid, and a positive auxiliary grid, an input circuit for said stage connected to said control grid; an output circuit including an output coupling coil, and resistance in excess of the normal resistance of said coupling coil connected between said anode and said cathode; a tuned circuit including in series a second coil coupled to said output coil, a tuning condenser, and a third coil having negligible electromagnetic coupling with said output coil; a balancing condenser and resistance connected between said control grid and the junction of said second and third coils; and means

for varying the potential of said positive grid to control the gain of the stage.

10. A multi-stage electrical amplifier circuit comprising, in combination, a plurality of electron tubes each including at least an anode, a cathode and a control electrode; an input circuit associated with the cathode and control electrode of the first of said electron tubes; a coil and resistance in excess of the normal resistance of said coil associated with the anode and cathode of said first tube; a second coil electromagnetically coupled to said first coil in the reverse sense and having one terminal connected to the control electrode to the second of said electron tubes; a third coil having one terminal connected to a second terminal of said second coil and a second terminal connected to the cathode of said second tube, said third coil having negligible electromagnetic coupling with said second coil; a balancing circuit including capacitive and resistive impedance, said balancing circuit being connected between said control electrode of said first tube and the junction of said second and third coils; a tuning condenser connected between said first terminal of said second coil and said second terminal of said third coil and across the control electrode and cathode terminals of said second tube.

In testimony whereof, we affix our signatures.

FREDERICK H. DRAKE.
PAUL O. FARNHAM.