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[54] **HIGH POWER AUDIO AMPLIFIER HAVING FEEDBACK PROVIDED BY A WINDING CO-FILAR WITH AN OUTPUT TRANSFORMER PRIMARY WINDING**
14 Claims, 2 Drawing Figs.

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[51] **Int. Cl.** **H03f 1/36,** H03f 3/28
[50] **Field of Search** 330/81, 82, 98, 119, 99, 122, 123

[56] **References Cited**
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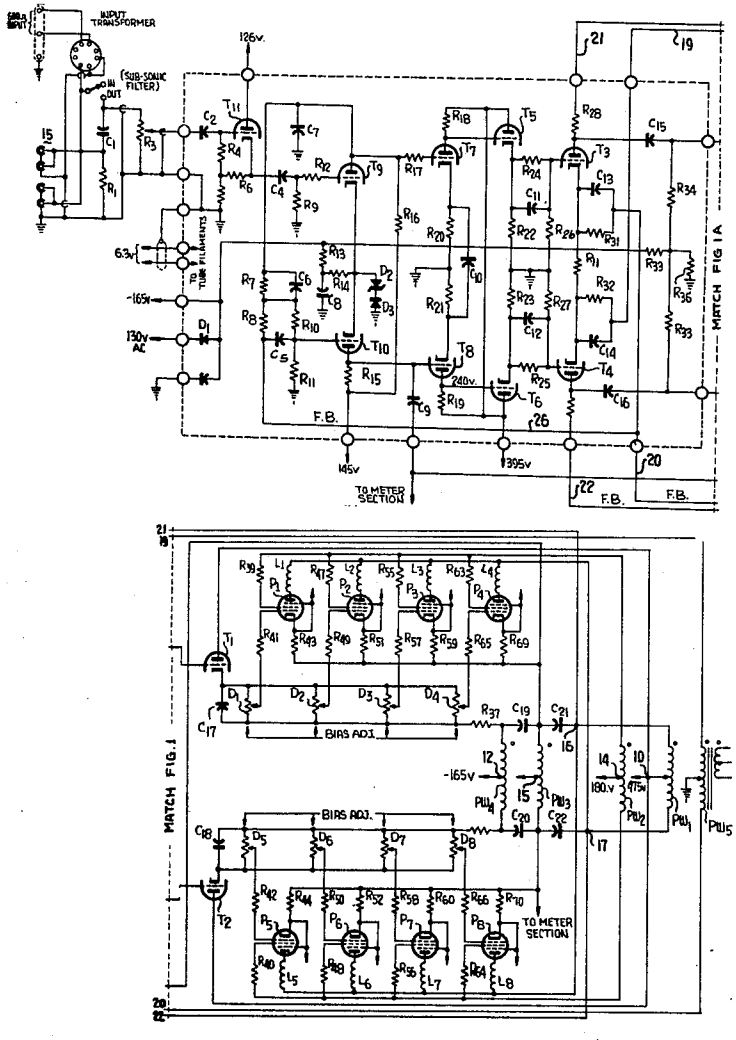
ABSTRACT: A high-power audio amplifier employing both cathode and anode load unity coupled cofilarly wound transformer primary windings, providing negative feedback by means of a transformer winding which is cofilar with respect to the output windings and have the same number of turns. Individual tube bias controls are employed for all output tubes.



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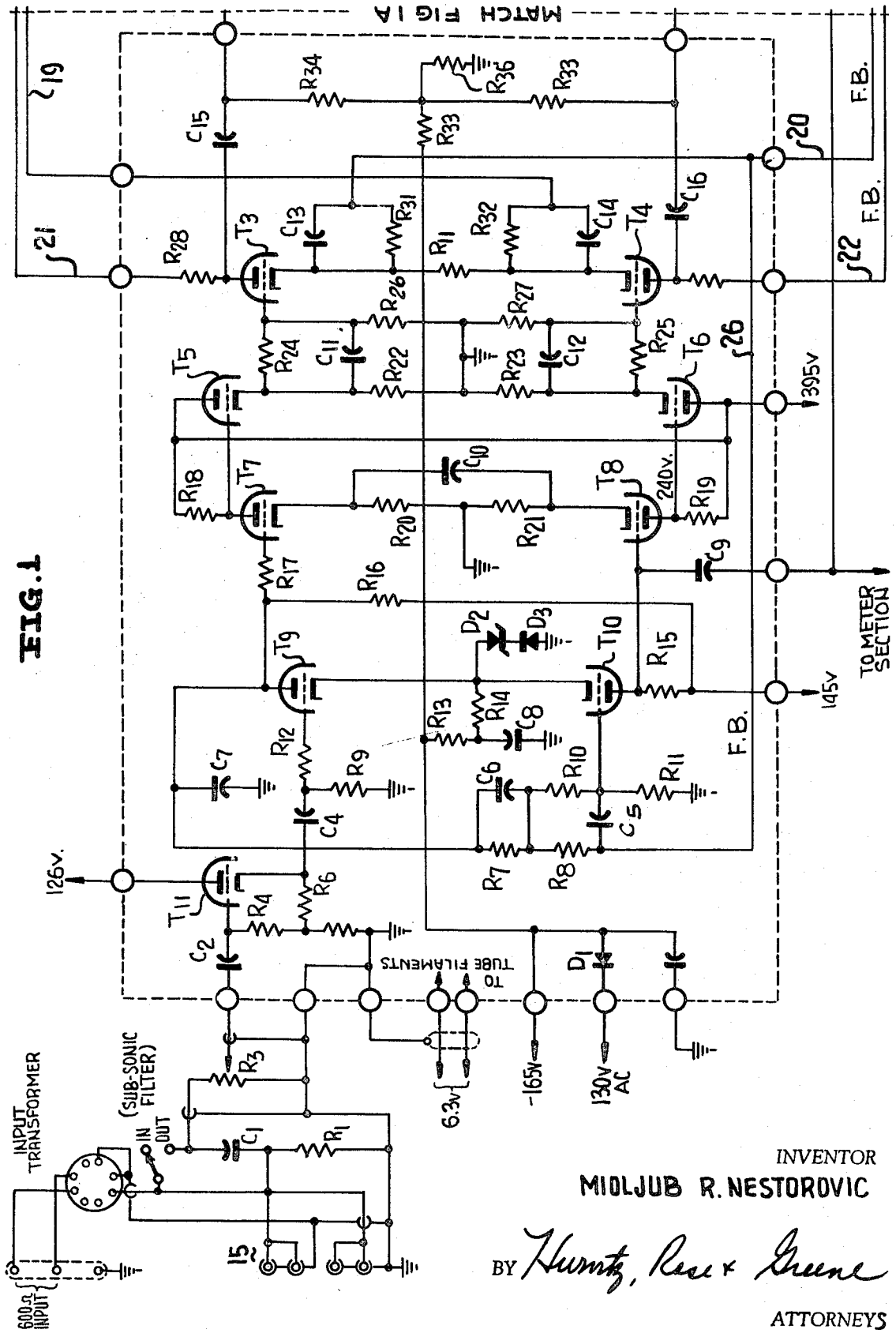

FIG. 1

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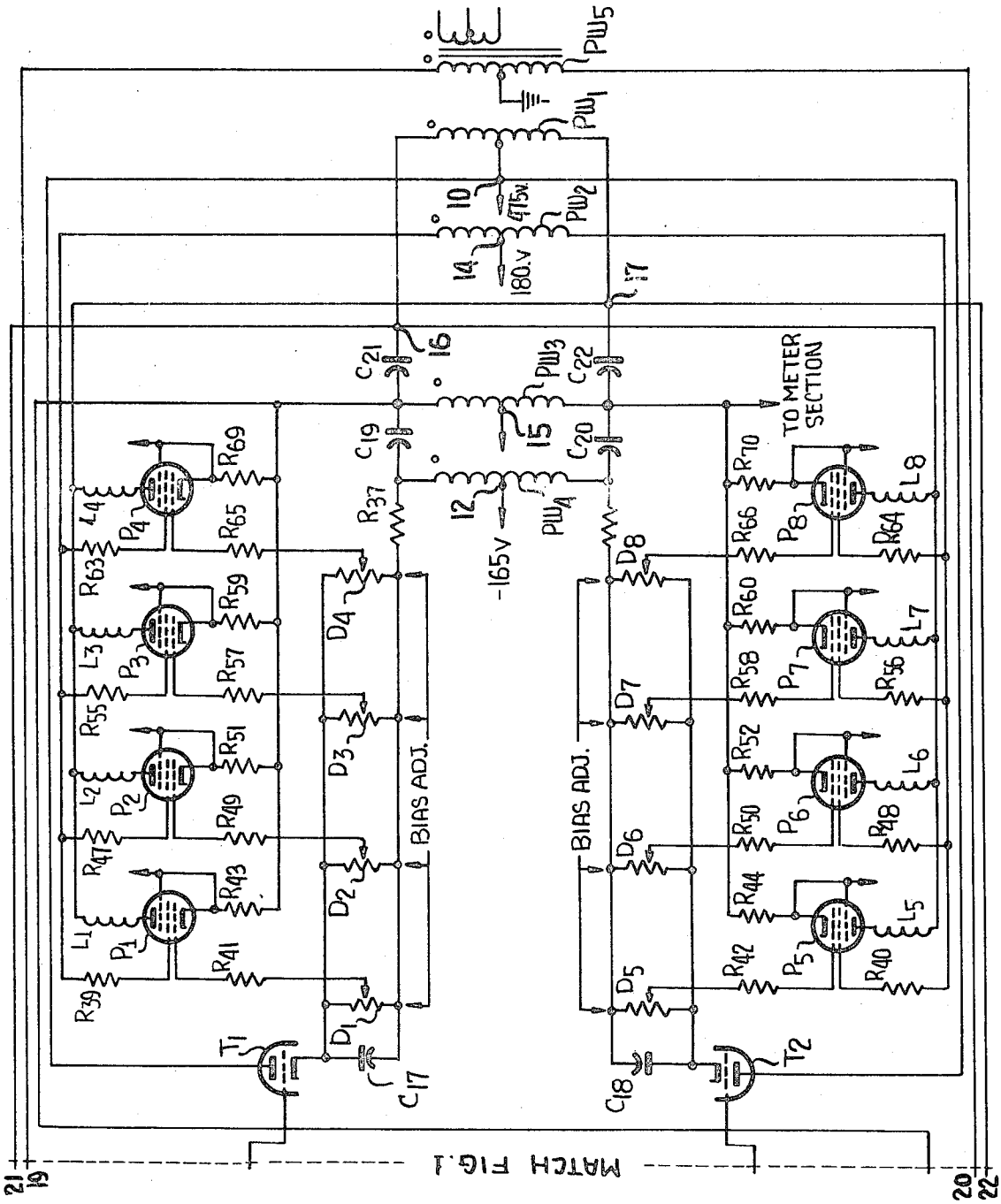

FIG. 1A

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HIGH POWER AUDIO AMPLIFIER HAVING FEEDBACK PROVIDED BY A WINDING CO-FILAR WITH AN OUTPUT TRANSFORMER PRIMARY WINDING

BACKGROUND OF THE INVENTION

The amount of negative feedback which can be applied in a power amplifier using an output transformer is limited at high frequencies by the leakage inductance between the primary and feedback windings of the output transformer, since this introduces phase shift. Feedback is usually taken from a secondary winding, or from a tertiary winding closely coupled with a secondary winding. On the latter basis, the maximum amount of stable feedback obtainable is about 25 db. The actual amount attainable may be less, depending on the quality of the output transformer and the parameters of the amplifier circuitry.

The amount of feedback attainable may be increased by deriving feedback from the primary winding. But, in so doing, second harmonic distortion is increased, because the current flowing through the primary winding causes a voltage drop across the resistance of the primary winding, which is high in second harmonic distortion. This is not reduced in proportion to amount of feedback.

The present invention solves the problem of increasing feedback with consequent decrease of all forms of distortion, by employing a feedback winding cofilarly wound with the primary and having the same number of turns, and therefore having the same phase and voltage as the primary, but carrying essentially no current. The distortion caused by current flow in the primary winding resistance no longer affects feedback voltage. It is then possible by means of the present invention to utilize up to 40 db. of negative feedback, with excellent stability resulting in extremely low nonlinear distortion.

The amplifier of the invention employs four pentodes connected in parallel on either side of the push-pull unity coupled circuit. These pentodes are normally not quite identical, therefore DC balance circuitry is provided for each of the tubes. This circuitry is unusual in that the drive stage is directly coupled to each of the output tubes and at the same time allows independent bias adjustment for each of the output tubes.

SUMMARY OF THE INVENTION

A wideband audio unity coupled pentode power amplifier, having very low distortion, attained by negative feedback applied by a primary filar winding having the same number of turns as the primary winding, and having unity coupled plate, cathode and screen grid primary windings. This invention represents an improvement over the U.S. Pat. to Frank McIntosh No. 2,646,467 issued Jul. 21, 1953, and the U.S. Pat. to Frank McIntosh No. 2,477,074, issued Jul. 26, 1949.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1 and 1A comprise a schematic circuit diagram of an amplifier according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to drawing 1A, consider first the output stage. Triodes T_1 and T_2 are push-pull driven cathode follower drivers, having their anodes directly connected to 470 v. terminal **10**. The cathode of T_1 is connected for AC through audio bypass capacitor C_{17} and a resistance R_{37} to a primary winding PW_4, which in turn has a center tap **12**, connected to **−165** v. Across C_{17} are connected in parallel four potentiometers D_1, D_2, D_3, D_4. The net DC voltage appearing at the cathode of T_1 is −42 v. No audio signal appears across D_1, D_2, D_3, D_4, because of C_{17}, but a DC voltage of 22 v. does appear, and any part of this can be taken off by sliders to provide adjustable bias, separately, for pentodes P_1, P_2, P_3, P_4, respectively. Duplicate circuitry applies to T_2 and to pentodes P_5, P_6, P_7, P_8, which provide the alternate halves of a push-pull pair, operating class AB.

The plates of P_1, P_2, P_3, P_4 are all connected directly in parallel and to one side of primary winding PW_1, and the plates of P_5—P_8, inclusive, are similarly connected to the other side of PW_1. The latter has a center tap at 470 v.

The screen grids of P_1—P_8 are supplied with **+180** v. from center tap **14** of a screen grid push-pull primary winding PW_2, cofilarly related turn for turn with winding PW_1 and otherwise not coupled thereto. The cathodes of P_1—P_8 are connected to primary winding PW_3, the center tap **15** of which is connected essentially to ground, 1.2 v. volts DC appearing at the end terminals of PW_3. It follows that the cathode and the screen grid of each of P_1—P_8, inclusive, are always at the same AC voltage, although at different DC voltages. This is per se well known. See the McIntosh patents. PW_3 is cofilarly wound with PW_1 and also its end terminals are coupled to the end terminals of PW_1 by coupling capacitors C_{21}, C_{22}, which have negligible impedance at the audio frequencies of interest. The plates winding PW_1 by virtue of cross connection of its end terminals to P_1—P_4, and to P_5—P_8, via leads **16**, **17**, maintains the cathodes of P_1—P_4 at the same AC voltage as the anodes of P_5—P_8, and the cathodes of P_5—P_8 at the same AC voltage as the anodes of P_1—P_4. This latter feature represents the essence of the classic McIntosh amplifier.

AC signal to the control grids of P_1—P_8 occurs via cathodes of the tubes T_1 and T_2 which are bootstrapped loaded by winding PW_4, filarly wound with PW_1 and having the same number of turns. The end terminals of PW_4 are connected to the grids of P_1—P_4 through R_{37}, and potentiometers D_1—D_4. An identical arrangement is provided for the other side of the push-pull array. The DC biases on the control grids are individually adjusted by potentiometers D_1—D_8, using a milliammeter, not illustrated, which can be connected in turn parallel to the cathode resistors (R_{43}, R_{51}, R_{59}, R_{69}, R_{44}, R_{52}, R_{60}, R_{70}) of the output tubes P_1—P_8. Thereby it assures that the DC, no signal current is divided evenly on each tube.

A fifth, feedback winding is provided, PW_5, which is filarly wound with PW_1 and has the same number of turns as PW_1 and which supplies its voltage via leads **19**, **20**, in an external feedback loop, now to be described.

The triodes T_1, T_2 are driven by triodes T_3, T_4, respectively. The latter are anode loaded, and capacitively coupled to the grids of T_1, T_2, and constitute a bootstrapped balanced driver stage. The anode of T_3 is connected via resistance R_{28} and one side of winding PW_1 to a positive supply 470 v. via center tap **10**. The anode of T_4 is connected via resistance R_{29} and the other side of winding PW_1 to center tap **10**. The elements in the cathode circuit of T_3 and T_4, resistors R_{11}, R_{31}, R_{32} and bypass capacitors C_{13} and C_{14} not only set up the correct bias for the operation of T_3 and T_4 but in connection with PW_5 provide a local balanced unity coupled feedback loop.

T_5 and T_6 are connected as a balanced cathode follower and drive the grids of T_3 and T_4. The resistors R_{22}, R_{24}, R_{26} and symmetrically R_{23}, R_{25} and R_{27} form a voltage dividing network to set the grid bias of T_3 and T_4. The large capacitors C_{11} and C_{12} bypass the resistors R_{24} and R_{25} respectfully at audio frequencies.

T_7, T_8 form a differential amplifier with the anodes directly coupled to the grids of T_5, T_6. The phase inverter composed of triodes T_9, T_{10}, is provided with input signal from single ended isolation cathode follower stage T_{11}. One side of PW_5 drives the grid of the triode T_{10}. Therefore, we have a differential amplifier, used here as a phase inverter, in which one side (T_9) is driven with the signal from the cathode of the T_{11} while the other side (T_{10}) is driven by the overall Unity Coupled Negative Feedback loop derived from PW_5.

In a broad sense, the invention involves a push-pull class AB to B amplifier, having cathode and anode loads, unity coupled, which are so connected that the anode of each tube is maintained at the same AC voltage as the cathode of the tube, on the opposite side of the unity coupled push-pull arrangement which contains internal negative feedback. External negative feedback circuits as well as local feedback loops are derived from a unity coupled primary cofilarly winding.

OPERATION

Reviewing now in somewhat more detail the operation of the present system, and commencing now at the input end of the amplifier, the input signal enters the amplifier either via the front panel input jacks or via the input jacks, **15**, on the rear panel of the unit. All input jacks are in parallel. Capacitor C_1, in conjunction with the volume control R_3, form a 6 db. per octave, subsonic filter, which can be disconnected by switch S_1.

One-half of the twin triode T_{11} is used, and this half is connected as a cathode follower; the second section is not used. The primary function of this stage is to isolate the input from the feedback loop, thereby resulting in no change in distortion at higher frequencies and a better square wave response independent of the setting of the volume control R_3.

T_9, T_{10} are connected to form a differential amplifier which acts as a phase inverter. The signal is capacitively coupled from the input cathode follower T_{11} through C_4 to the grid of T_9. The overall Unity Coupled Negative Feedback (32 db.) is fed onto the grid of T_{10} using the elements R_8, R_{10}, C_5 and R_1, as a dividing network. The elements R_7, C_6 and C_7 are arranged to feed a portion of the feedback voltage to the plate of T_9. This local feedback loop is incorporated to give a better balance of AC voltages at the plates of the differential amplifier for frequencies up to 100 kHz.

The zener diode D_2 (10 volts) in series with diode D_3, is used to protect the cathodes of T_9, T_{10} against a potential exceeding the cathode-filament insulation limits. This is required since upon initial turn on, before T_9, T_{10} begin conduction, the potential at the cathodes of T_9, T_{10} would be **−165** v. if the diodes D_2 and D_3 were not incorporated. With the addition of the diodes D_2 and D_3, at initial turn on, the Zener diode conducts and a potential of −10 v. is present on the cathodes of T_9 and T_{10}. As the tubes begin conducting, the potential on the cathodes reaches +0.9 v. and the diodes are no longer conductive. Resistors R_{13} and R_{14} provide the cathode current path to the **−165** v. supply.

The signal output of T_9, T_{10} is directly coupled to the grids of T_7, T_8, a differential amplifier. Any AC unbalance present in the signal from T_9, T_{10} is reduced to less than 1 percent at the plates of T_7, T_8. The high value cathode resistors R_{20} and R_{21} are used to allow DC self balance for T_7, T_8. The capacitor C_{10} acts as an AC short circuit between the cathodes causing the complete circuit to act as a differential amplifier.

From the plates of T_7, T_8, the signal is then directly coupled to the grids of T_5, T_6, which forms a balanced cathode follower. This circuitry is used to provide a low impedance source for feeding the signal to T_3, T_4. The elements R_{24}, C_{11} and R_{26} on one side and symmetrically R_{25}, C_{12} and R_{27} on the other side form a filter which adjusts the phase characteristic at low frequencies for stable operation of the amplifier. At the same time, the resistors R_{24} and R_{26} on one side and symmetrically R_{25} and R_{27} on the other side act as a DC voltage dividing network to apply the proper bias voltage to the grids of T_3, T_4.

The signal is next directly coupled to the twin triode T_3, T_4, which is a bootstrapped balanced driver stage. The plate load resistors for this stage R_{28} and R_{29}, are bootstrapped to the output transformer plate primary winding, thus allowing very high stage gain and large output voltage swing. The driver stage tubes T_3, T_4 have on their cathodes a local balanced Unity Coupled Negative Feedback loop derived from a winding which is unity coupled with the primary of the output transformer. This local feedback loop (6 db.) besides reducing the nonlinear distortion and improving the balance of the AC drive voltages, adjusts the phase characteristic of the driver and output stages at high frequencies so that the main loop of Unity Coupled Negative feedback (32 db.) can be applied around the entire amplifier to the grid of T_9 with complete stability.

From the plates of T_3, T_4, the signal is then fed through C_{15} and C_{16} to the grids of T_1, T_2 which is a balanced cathode follower. In the cathode circuits of T_1, T_2, there are four potentiometers on each side (D_1, D_2, D_3, D_4, and D_5, D_6, D_7, and D_8) bypassed by C_{17} and C_{18}. With the arrangement used in the cathode circuits of T_1, T_2, it is possible to directly couple the cathode follower to the output tubes and at the same time, adjust the bias individually for each of the output tubes, for optimum balance of zero signal plate current.

The output tubes P_1—P_8 are operated as a parallel push-pull unity coupled, output stage, operating class AB. The resistors in the first grid of each output stage tube (R_{41}, R_{49}, R_{57}, R_{65}, R_{42}, R_{50}, R_{58}, R_{66}), along with the inductors in the plate of each tube of the output stage (L_1 through L_8), the resistors in the cathode of each tube of the output stage (R_{43}, R_{51}, R_{59}, R_{69}, R_{44}, R_{52}, R_{60}, and R_{70}) and the resistors in the screen grid of each tube in the output stage (R_{39}, R_{47}, R_{55}, R_{63}, R_{40}, R_{48}, R_{56} and R_{64}) have been incorporated to stop oscillation of any individual tube due to the parallel configuration. The amount of current flowing through each tube in the output section is checked by measuring the voltage drop across the cathode resistor of each tube individually. By use of the switch S101 (Meter Range switch) and front panel meter M101, not illustrated, each tube can be individually measured, and by means of the potentiometers previously mentioned (D_1 to D_8), adjusted.

Five windings are filarly wound as the primary of the output transformer (including the winding for negative feedback). Sections of the primary and secondary are interwound to achieve maximal coupling, and balance between windings while keeping shunt capacitance low. Where coupling is particularly critical, such as between plate and cathode winding of the primary and the winding for the cathode follower driver, coupling is improved by the capacitance coupling of the windings in phase (C_{19}, C_{20}, C_{21} and C_{22}). It is important to stress that the winding for the negative feedback be filarly wound with the rest of the primary windings but not capacitively coupled to any winding at the primary. The reason for this is that the voltage used as negative feedback should be in proportion to, and as similar as possible to the total current of the output stage. This technique of applying feedback, called Unity Coupled Negative Feedback, makes possible the use of up to 40 db. of total feedback with excellent stability, and nonlinear distortion is reduced to below 0.1 percent.

By means of the output impedance selector switch, not illustrated, it is possible to choose any one of six output impedances (1, 4, 8, 16, 50 or 64 ohms).

I claim:

1. A power amplifier, including:

a first vacuum tube having a first anode, cathode, screen grid and control grid;

a second vacuum tube having a second anode, cathode, screen grid, and control grid;

a transformer including a first primary winding having a predetermined number of turns, a center tap, and first and second ends;

a source of supply voltage connected to said center tap;

means connecting said first and second ends of said first primary winding to said first and second anodes, respectively;

a second primary winding of said transformer having said predetermined number of turns, a center tap, and first and second ends, said second primary winding being cofilarly wound with said first primary winding, the center tap of said second primary winding being DC connected to ground;

means connecting said first and second ends of said second primary winding to said first and second cathodes, respectively;

means for capacitively coupling said first and second ends of said first primary winding to said second and first ends, respectively, of said second primary winding to maintain the cathode of each of said vacuum tubes at the same AC potential as the anode of the other;

a third primary winding of said transformer having a center tap and first and second ends, the center tap of said third primary winding being connected to a reference point;

means connecting said first and second ends of said third primary winding to said first and second screen grids, respectively, in such sense as to provide on the screen grid of each tube the same phase as exists on the cathode of that tube, said third primary winding being cofilarly wound with said first and second primary windings and having said predetermined number of turns; and

input means connected in driving relationship to said first and second control grids.

2. The combination according to claim 1, wherein said input means includes a drive amplifier for said power amplifier connected in driving relation to said first and second control grids;

a fourth primary winding of said transformer having said predetermined number of turns and cofilarly wound with said first primary winding;

means deriving external feedback voltage for said drive amplifier from said fourth primary winding;

a common core for all said primary windings; and

a secondary winding of said transformer wound on said core.

3. A power amplifier including:

a plurality of first vacuum tubes having each a first anode, cathode, screen grid and control grid, the same plurality of second vacuum tubes having each a second anode, cathode, screen grid and control grid;

means connecting all said first anodes to a common anode terminal;

means connecting all said second anodes to a common anode terminal;

a transformer, a first push-pull primary winding of said transformer connecting said common anode terminals;

means connecting all said first screen grids to a first common screen grid terminal;

means connecting all said second screen grids to a second common screen grid terminal;

a second push-pull primary winding of said transformer cofilar with said first primary winding, having the same number of turns as said first primary winding, and connecting said common screen grid terminals;

means for maintaining the screen grid of each said tubes at the same AC voltage as its cathode;

means for driving all said first control grids in opposite phase to all said second control grids, said last means including first and second push-pull direct coupled cathode followers connected in driving relationship with said first and second plurality of vacuum tubes, respectively;

potentiometer bias means for permitting individual adjustment of the biases of said control grids to provide the same no signal current for each vacuum tube;

capacitively bypassed cathode resistances for said cathode followers; and

means for providing bootstrap loading for said cathode followers, said last means including a third push-pull primary winding of said transformer filarly wound with and containing the same number of turns as said first primary winding and AC coupled to cathodes of said cathode followers.

4. The combination according to claim 3, wherein is further provided a fourth push-pull primary winding of said transformers connected between the cathodes of said tubes and a point of reference potential and arranged to maintain each of the cathodes of said plurality of first vacuum tubes at the same AC potential as the anodes of said plurality of second vacuum tubes and to maintain the cathodes of said plurality of second vacuum tubes at the same AC potential as the anodes of said plurality of first vacuum tubes.

5. The combination according to claim 4, wherein is further provided a fifth feedback push-pull primary winding of said transformer filarly wound with and containing the same number of turns as said first primary winding, providing unity coupled negative feedback for all said first and second output vacuum tubes.

6. An amplifier, including a vacuum tube having a plate, a control grid and a cathode, a load for said vacuum tube, comprising:

a first primary winding of an output transformer;

a feedback circuit for said vacuum tube including a further primary winding of said output transformer cofilar with said first primary winding and having the same number of turns; and

means providing drive signal to said control grid, said last named means including said first primary winding, wherein said means providing drive signal is a vacuum tube having a cathode load, said cathode load comprising said first primary winding.

7. The combination according to claim 6, wherein said cathode load includes an AC bypassed potentiometer resistance in series with said first primary winding, and wherein said control grid is driven from a variable tap on said potentiometer resistance.

8. A power amplifier, comprising:

amplifier means having an input circuit for receiving input signals to be amplified and an output circuit for providing amplified versions of said input signals;

a transformer including first and second cofilar primary windings;

input means including said first primary winding for applying said input signals to said input circuit;

means for connecting said second primary winding in negative feedback relation between said output circuit and said input means, wherein said first and second primary windings have the same number of turns, and wherein said amplifier means includes at least one vacuum tube having an anode, a cathode, and a control grid, said input circuit including a variable resistor connected to said control grid, and wherein said input means includes a cathode follower for providing said input signals and an AC bypass capacitor connected across said variable resistor and in series between said cathode follower and said first primary winding.

9. A power amplifier, comprising:

amplifier means having an input circuit for receiving input signals to be amplified and an output circuit for providing amplified versions of said input signals;

a transformer including first and second cofilar primary windings;

input means including said first primary winding for applying said input signals to said input circuit; and

means for connecting said second primary winding in negative feedback relation between said output circuit and said input means, wherein said first and second primary windings have the same number of turns, and wherein said amplifier means includes a plurality of vacuum tubes, each vacuum tube having an anode, a cathode and a control grid, said input circuit including a plurality of variable resistors, each variable resistor connected to a respective control grid, and wherein said input means includes a cathode follower for providing said input signals and an AC bypass capacitor connected in parallel across all of said variable resistors and in series between said cathode follower and said first primary winding.

10. A power amplifier circuit, comprising:

a first plurality of vacuum tubes and a second equal plurality of vacuum tubes, all of said vacuum tubes including an anode, a cathode, and a control grid;

means for AC coupling the anodes of said first plurality of vacuum tubes to the cathodes of said second plurality of vacuum tubes, and for AC coupling the anodes of said second plurality of vacuum tubes to the cathodes of said first plurality of vacuum tubes;

a transformer including first and second cofilar primary windings, said windings each having the same number of turns, a center tap, and first and second ends;

means for connecting the center taps of said first and second primary windings to respective DC reference potentials;

means for driving said first and second pluralities of vacuum tubes in push-pull relation, said means for driving including first and second cathode follower means for providing respective portions of a push-pull AC signal to be amplified, means for AC coupling said portions to respective ends of said first primary winding, and means for connecting said first end of said first primary winding to the control grids of said first plurality of vacuum tubes and for connecting said second end of said first primary winding to the control grids of said second plurality of vacuum tubes; and

means for connecting said first and second ends of said second primary winding to said means for driving in negative feedback relation.

11. The circuit according to claim **10** wherein said means for AC coupling includes: third and fourth primary windings of said transformer, each cofilar with and having the same number of turns as said first and second primary windings, said third and fourth primary windings each having a center tap and first and second ends; means for connecting the anodes of said first plurality of vacuum tubes to said first end of said third primary winding and for connecting said anodes of said second plurality of vacuum tubes to the second end of said third primary winding; means for connecting the cathodes of said first plurality of vacuum tubes to the first end of said fourth primary winding and for connecting the cathodes of said second plurality of vacuum tubes to the second end of said fourth primary winding; means for capacitively coupling the first end of said third primary winding to the second end of said fourth primary winding; and means for capacitively coupling the second end of said third primary winding to the first end of said fourth primary winding.

12. The circuit according to claim **11**, wherein said vacuum tubes each includes a screen grid, and wherein said transformer further includes a fifth primary winding having the same number of turns as and cofilar with said first, second, third and fourth primary windings, said fifth primary winding having a center tap connected to reference potential, a first end connected to each screen grid in said first plurality of vacuum tubes, and a second end connected to each screen grid in said second plurality of vacuum tubes.

13. A power amplifier, including:

a plurality of first vacuum tubes having each a first anode, cathode, screen grid and control grid, the same plurality of second vacuum tubes having each a second anode, cathode, screen grid and control grid;

means connecting all said first anodes to a common anode terminal;

means connecting all said second anodes to a common anode terminal;

a transformer;

a first push-pull primary winding of said transformer connecting said anode terminals;

means connecting all said first screen grids to a first common screen grid terminal;

means connecting all said second screen grids to a second common screen grid terminal;

a second push-pull primary winding of said transformer cofilar with and having the same number of turns as said first primary winding and connecting said first and second common screen grid terminals;

means including said second primary winding for maintaining the screen grid of each of said tubes at the same AC voltage as its anode;

means for driving all said first control grids in opposite phase to all said second control grids, said last means including push-pull connected drive vacuum tubes, potentiometer bias circuits for individually adjusting the biases of said control grids to provide the same peak voltage at all said screen grids, and capacitively bypassed cathode resistances for said drive vacuum tubes; and

means providing negative feedback for all said first and second vacuum tubes, said last means including a feedback push-pull primary winding of said transformer filarly wound with and containing the same number of turns as said first primary winding and connected to said control grids.

14. The combination according to claim **13**, wherein is further provided a further push-pull primary winding connected between said cathodes and a point of reference potential, means including said further primary winding for maintaining each of the cathodes of said plurality of first vacuum tubes at the same AC potential as the anodes of the plurality of second vacuum tubes and the cathodes of the plurality of second vacuum tubes at the same AC potential as the anodes of the plurality of first vacuum tubes.