July 26, 1949. F. H. McINTOSH 2,477,074

WIDE-BAND AMPLIFIER COUPLING CIRCUITS

Filed Dec. 22, 1948 4 Sheets-Sheet 1

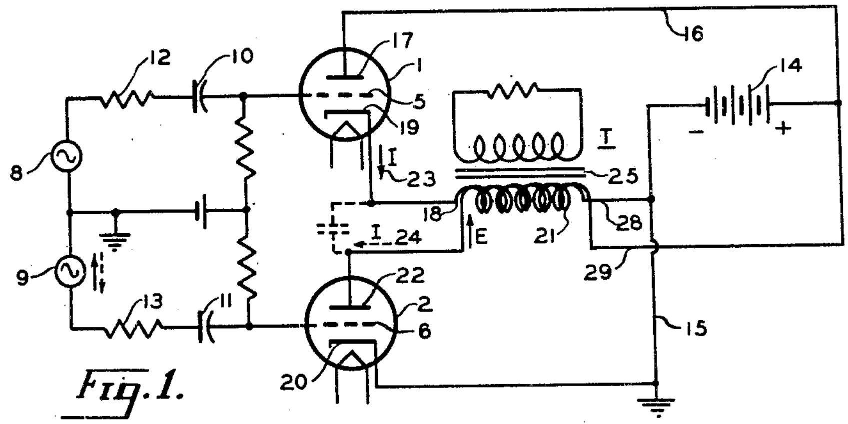

Fig. 1.

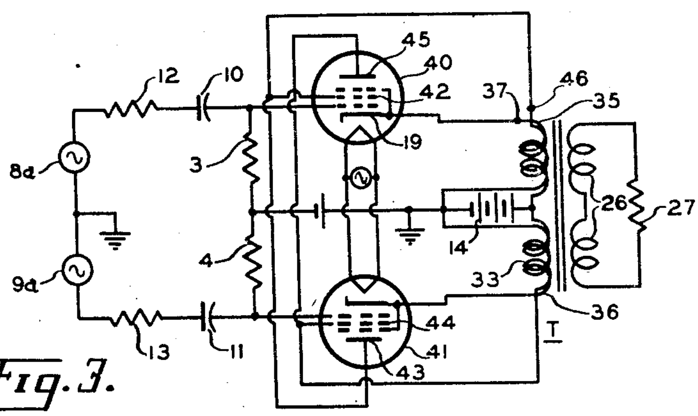

Fig. 3.

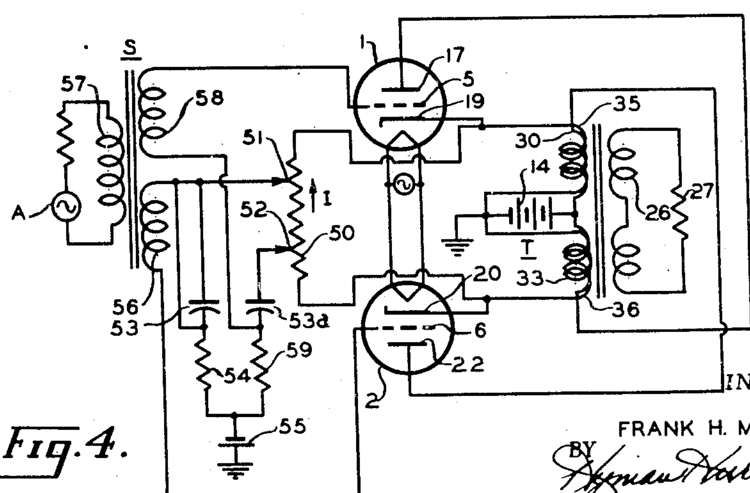

Fig. 4.

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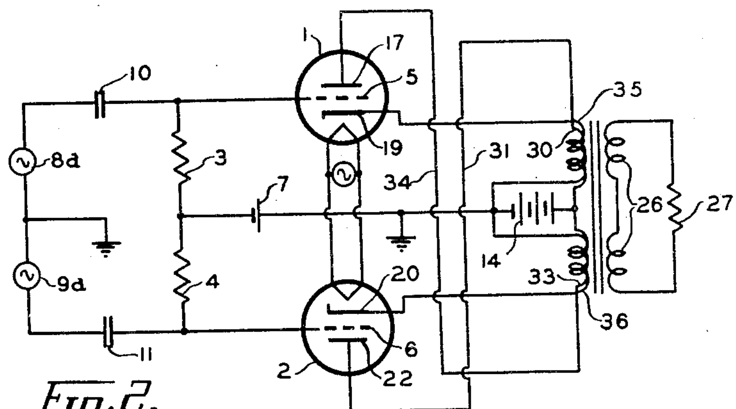

Fig. 2.

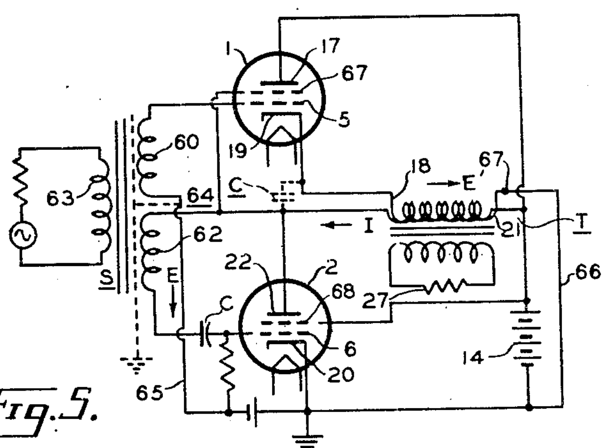

Fig. 5.

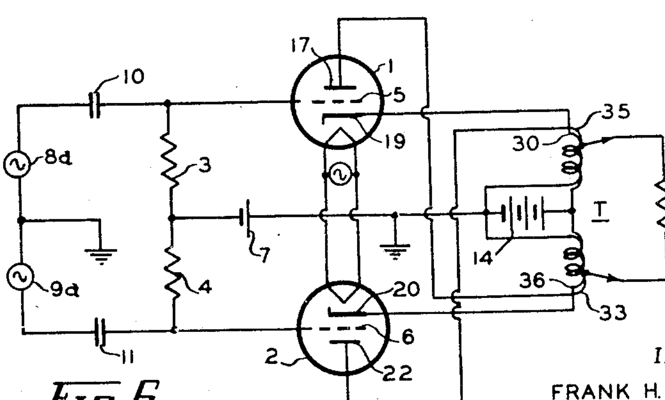

Fig. 6.

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WIDE-BAND AMPLIFIER COUPLING CIRCUITS

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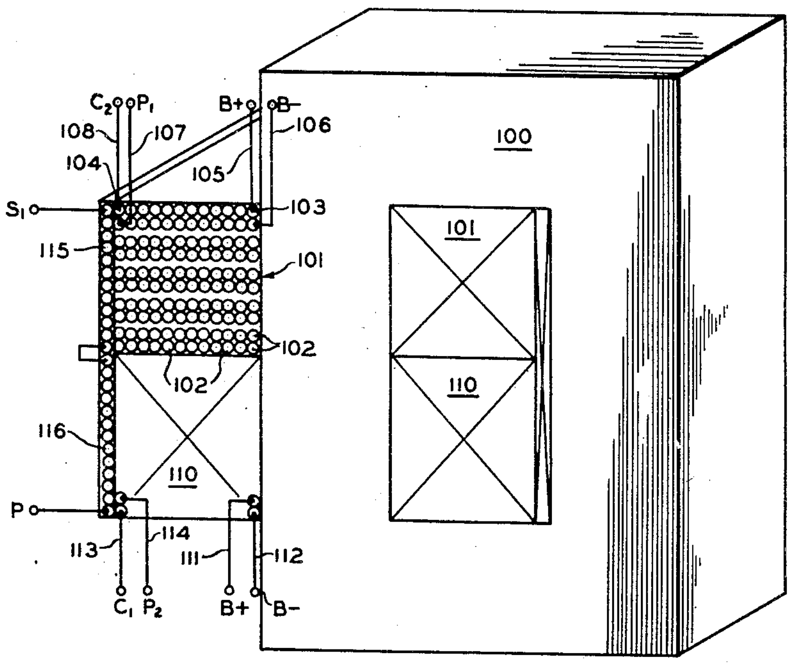

Fig. 7.

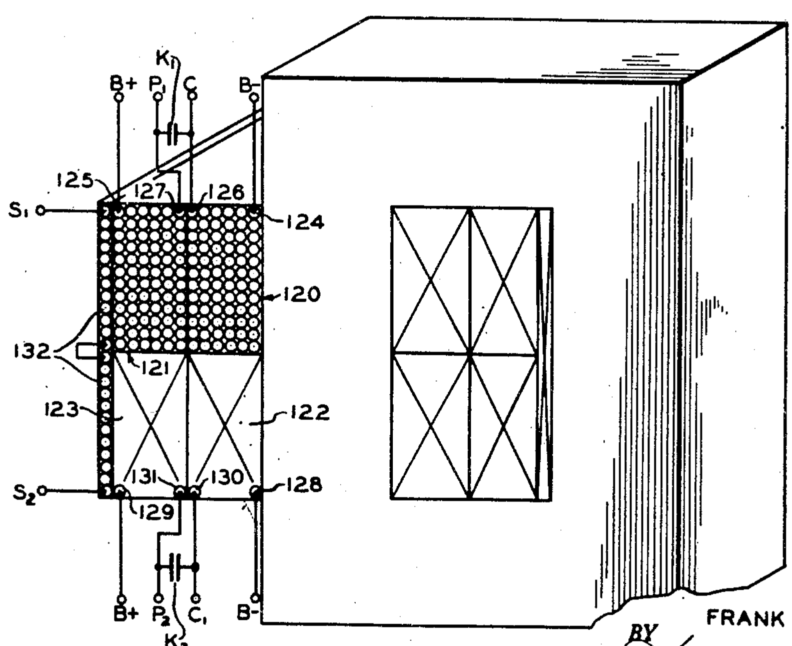

Fig. 8.

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WIDE-BAND AMPLIFIER COUPLING CIRCUITS

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4 Sheets-Sheet 4

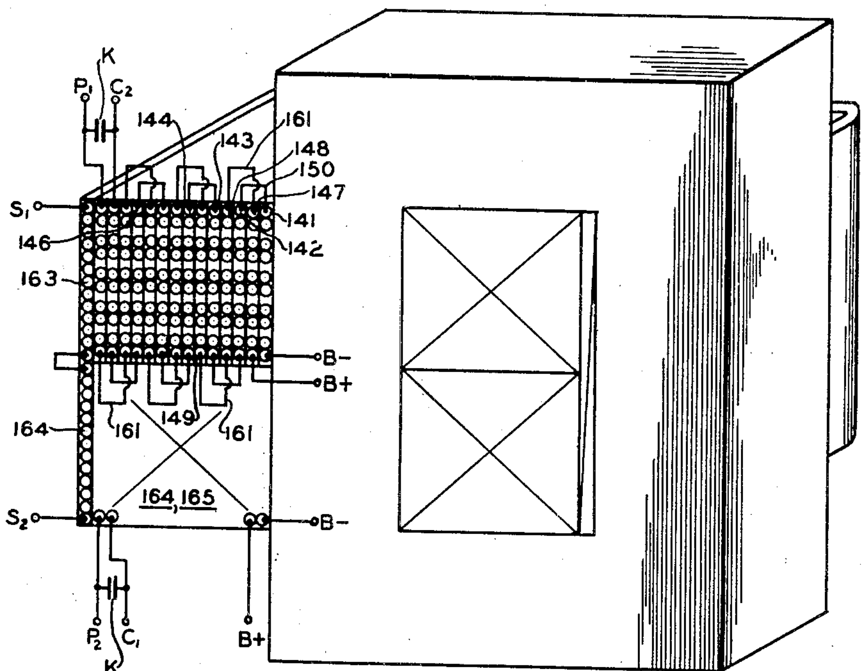

Fig. 9.

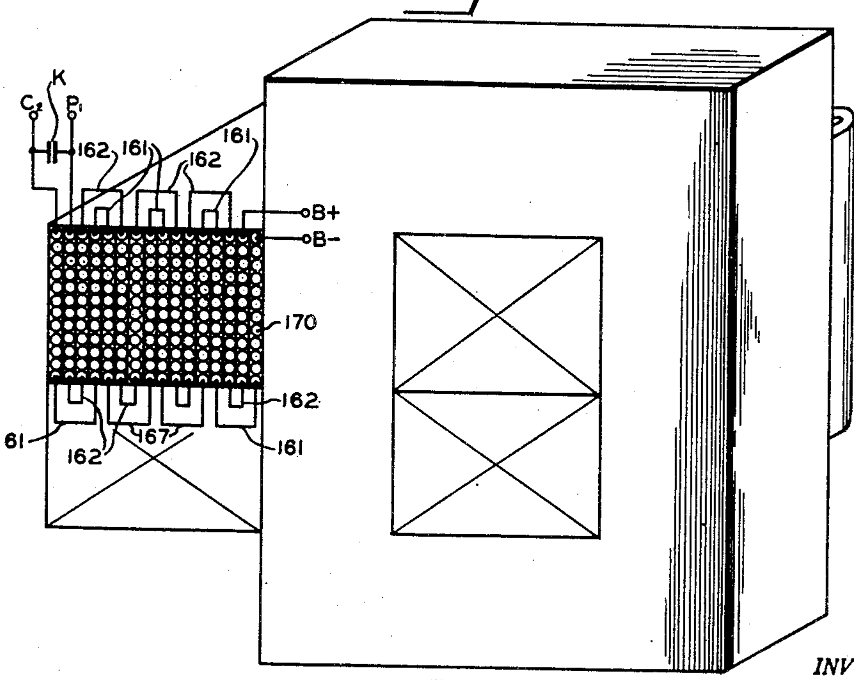

Fig. 10.

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UNITED STATES PATENT OFFICE

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WIDE BAND AMPLIFIER COUPLING CIRCUITS

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Application December 22, 1948, Serial No. 66,741

9 Claims. (Cl. 179—171)

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The present invention relates generally to improved audio and video frequency amplifiers, and to transformers utilizable therein, and more particularly to improved class B audio and video frequency electronic amplifiers which introduce extremely slight distortion over a wide band of frequencies, by utilizing output transformers of novel design, connected in novel relation to the electronic tubes of the amplifier.

The class B amplifier is a push-pull amplifier in which the tubes are biased approximately to cut-off. One of the tubes, in the normal system, amplifies the positive half cycles of the signal voltage while the other amplifies the negative half cycles, the output transformer combining the outputs of the two tubes, to reconstruct a replica of the signal voltage.

The frequency limits of the conventional audio or video amplifier depend largely upon the design of the output transformer, loss in amplification at low frequencies resulting from the low incremental inductance of the transformer primary, and falling off at high frequencies resulting from leakage inductance and the various distributed capacities of the transformer.

In order to obtain a good low frequency response the incremental primary inductance of the transformer must be high relative to the plate resistances of the tubes used. The primary winding of the transformer, then, should have a large number of turns. At the same time the resonant frequency of the leakage inductance and secondary capacitance must be beyond the highest frequency desired to be amplified, so that low leakage inductance and shunt capacity is essential, if the frequency response of the transformer is to be extended.

The above requirements are mutually conflicting, in various respects. The size of the core of a transformer, i. e., the total iron utilized, is limited by considerations of cost, space and weight requirements. This in turn fixes the total number of turns allotted to the primary and secondary windings. Decreasing core size and increasing total turns on the primary winding to retain high primary incremental inductance increases leakage inductance and shunt capacity, which in turn, reduces resonant frequency, and hence the high frequency response of the transformer. In practice, leakage inductance is decreased by interleaving primary and secondary windings, but this increases distributed capacity and so tends to neutralize the benefits obtained.

As a further consideration, high permeability cores must be used, to increase primary winding

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impedance. Such cores are adversely affected, in respect to the incremental inductance, by D. C. magnetization. Hence the latter must be avoided.

The effect of leakage inductance on class B push-pull amplifiers has been considered in the literature, and attention is directed particularly to an article by A. Pen-Tung Sah, in Proceedings of the I. R. E. for November, 1936. Sah points out particularly the deleterious effects of leakage inductance between primary windings of the output transformer of such an amplifier, first, in causing a decreased output, as frequency increases, and second, in introducing finite time constants into the circuit, thus causing transients which distort the output wave as one of the tubes changes from a conducting condition to a blocking condition, and vice-versa. The latter effect is the basis of great distortion at the higher audio frequencies.

It is a primary object of the present invention to provide improved push-pull amplifiers having negligible leakage reactance in their output transformers, and hence negligible transient effects during change-over of each tube of the amplifier from conducting to non-conducting condition.

It is an ancillary object of the invention to provide novel push-pull transformers having negligible leakage reactance.

It is a further object of the invention to provide a push-pull wide band transformer of relatively simple and economical construction, which eliminates leakage inductance between primary windings of the transformer.

It is another object of the invention to provide an improved push-pull transformer comprising bifilar primary windings, and futher to provide push-pull audio amplifiers capable of employing transformer having bifilar primary windings.

It is, further, an object of the invention to provide a push-pull transformer, having greater coupling between the secondary winding and the primary windings than is available in known designs, without increasing detrimental capacity effects, thereby to improve the frequency response and to enlarge the band width of such transformers when employed in amplifiers.

It is still another object of the invention to provide a push-pull transformer having radically reduced effective distributed capacity across the primary windings, and to provide a push-pull amplifier for effectively utilizing a transformer of this character.

It is a further object of the invention to provide a push-pull transformer of reduced distributed capacity and leakage inductance between primary ard secondary windings.

It is a further object of the present invention to provide a push-pull amplifier utilizing an output transformer having bifilar primary windings, the amplifier employing pentode, tetrode or beam power electronic tubes, wherein is provided means for maintaining the screen grid of each of the tubes at a fixed potential with respect to the associated cathode during operation of the tubes in the amplifier.

It is still another object of the invention to provide a push-pull amplifier arrangement capable of effectively utilizing a transformer having substantially zero leakage inductance between its primary windings, and which requires but a single anode voltage source for all the tubes of the amplifier.

It is a further object of the invention to provide novel push-pull transformer arrangements which are not bifilarly wound but which have many of the properties of bifilarly wound transformers, and particularly low or negligible leakage inductance between primary windings.

It is still another object of the invention to provide a modulator capable of supplying large amounts of undistorted power for modulating carrier frequency signals.

Briefly described, the various embodiments of the present invention hereinafter described in detail, and illustrated in the drawings, attain the objects of the invention by employing bifilar primary windings in the output transformers to reduce to a negligible value the leakage inductance between these windings. The effect of substantially eliminating leakage inductance between primary windings is radically to reduce transients during current cross-over from one to another of the tubes of a push-pull amplifier, these transients being particularly severe in class B operation. Leakage inductance between the primary windings and the secondary likewise contributes to these transient effects, but in reduced degree. Relating the primary windings in the manner stated inherently enables reduction of leakage inductance between primary windings and the secondary winding.

By proper arrangement and connection of the primary windings in the transformer the equivalent shunt capacity across the primary windings, due to the capacity between windings, which together with leakage reactance and the capacity of the secondary winding determine falling off of response at the higher audio frequencies and the high frequency cut-off point of the amplifier, may be similarly reduced, and the windings may be so related to the electronic tubes of the amplifier that but a single anode power supply is required, and that in certain of the embodiments conventional input circuits may be employed.

The conventional mode of reducing leakage inductance consists of sectionalizing primary and secondary windings and interleaving or interspersing these. This type of construction is expensive, and while it succeeds in reducing leakage inductance, results in increased capacities. The total capacity of the transformer windings may be reduced by avoiding the necessity for interleaving or pi-winding, in accordance with the present invention, in order to reduce leakage inductance. By avoiding the necessity for pi-winding, or interleaving, furthermore, the transformer of the present invention may be arranged more compactly than previously known transformers of the same performance, resulting in

reduction of iron requirements, and in a simplified, more economically fabricated core and winding structure.

In the conventional push-pull output transformer for class B amplifiers the primary windings of the transformer are connected in series between the plates of the electronic tubes of the amplifier. Accordingly, the primary windings being closely coupled, the total impedance of the primary windings is approximately four times the impedance of a single primary winding. In accordance with certain embodiments of the present invention the primary windings of the output transformer are not connected in series with each other between the amplifier tubes, but are connected effectively in parallel. Thereby a reduction in anode terminal to anode terminal impedance of (4), approximately, may be attained. Additionally, each coil, by reason of its bifilar relation to another coil, is for the same length of wire and length of coil of double the number of layers, resulting in a further decrease of shunt capacity. Reduction of anode to anode impedance of the windings, is, therefore, reflected in a corresponding decrease in anode to anode distributed capacity across the windings, and therefore in a radical extension upwards of the cut-off frequency of the amplifier, at its high end. Alternately, more turns may be employed in the primary windings, and the resultant increase of shunt capacity, due to increase in the number of turns, can be tolerated.

Audio amplifiers constructed in accordance with the present invention, and tested for distortion, have shown less than ½% distortion over the band 20 to 20,000 cycles, the conversion efficiency of the amplifier tubes remaining above 50% over the band, with an essentially flat response over the band of 20 to 200,000 cycles. Nevertheless, transformers constructed in accordance with the present invention inherently cost less to build than do transformers of the highest quality fabricated in accordance with prior art principles, and require less space and weigh less than the latter.

Further, no transformers currently available commercially or known to me are capable of attaining the wide frequency response and low wave form distortion attainable by the present system, regardless of their cost, weight or space.

The above and still further objects, advantages and features of the invention will become apparent upon consideration of the following detailed descriptions of various embodiments of the invention, especially when taken in conjunction with the accompanying drawings, wherein:

Figure 1 is a schematic circuit diagram of an embodiment of the invention wherein is employed a pair of bifilarly wound primary coils in an output transformer, one of the coils being connected in the cathode circuit of a vacuum tube of a push-pull amplifier, and the remaining coil connected in the anode circuit of the amplifier;

Figure 2 is a schematic circuit diagram of a further embodiment of the invention wherein is utilized a transformer having two bifilarly wound primary coils, each comprising two windings, each bifilarly wound coil having one of its windings connected in the cathode circuit and the other in the anode circuit of one of the vacuum tubes of the amplifier;

Figure 3 is a schematic circuit diagram illustrating a modification of the system illustrated in Figure 2 of the drawings, wherein the push-pull amplifier utilizes vacuum tubes having screen grids, each screen grid being maintained at a constant difference of potential with respect to its associated cathode during operation of the amplifier;

Figure 4 is a schematic circuit diagram of a modification of the system of Figure 2, wherein controllable degeneration is provided in the amplifier;

Figure 5 is a schematic circuit diagram of a variation of the system of Figure 1 of the drawings, arranged for balanced operation;

Figure 6 is a schematic circuit diagram of a variation of the embodiment illustrated in Figure 2 of the drawing, wherein the output transformer is an auto-transformer;

Figure 7 is a view, showing a transformer having bifilarly wound primary windings for use in push-pull amplifiers arranged in accordance with the invention; and,

Figures 8, 9 and 10 represent variations of the unity coupled transformer of Figure 7.

Referring now more particularly to the drawings and having reference particularly to Figure 1 thereof, there is illustrated a push-pull amplifier constructed in accordance with the principles of the present invention and utilizing an output transformer arranged in accordance with the invention.

The amplifier of Figure 1 is illustrated as employing a pair of triodes 1, 2 as amplifying electronic devices, the triodes 1 and 2 being provided respectively with grid leaks 3 and 4, which are connected between the control electrodes 5 and 6 of the triodes 1 and 2, respectively, the midpoint of the grid leak resistors 3 and 4 being grounded via a bias source 7. Driving potential is applied to the control electrodes 5 and 6 from sources conventionally illustrated as generators 8, 9, which may be presumed to provide potentials of opposite phases with respect to ground, and of suitable relative magnitudes, the potentials provided by the sources 8, 9 being applied to the control electrodes 5, 6 via coupling condensers 10 and 11 respectively, the resistors 12 and 13 representing the internal resistances of sources 8 and 9, respectively. The bias established by the bias source 7 may be such as to cause operation of the triodes 1 and 2 to be either as class A, class AB or class B amplifiers, the significance of the classification being well understood in the art, and defined by the Institute of Radio Engineers in its official definitions. While the circuits and structures of the present application have wide utility in amplifiers operating in accordance with any one of the above mentioned classifications, the invention has primary application to class B amplifiers, and will be described accordingly as utilized in amplifiers of this class, without intending thereby to limit the scope of the invention. For the purpose stated, the bias source 7 will be established to have a value such as to cut off the plate current of the triodes 1 and 2, in the absence of signal voltage applied to the grids thereof.

The input circuits of the triodes 1 and 2 will, accordingly, be seen to be completely conventional and to form essentially no part of the present invention.

A source of anode voltage 14 is provided, conventionally illustrated as a battery to simplify the drawings. The negative terminal of source 14 is grounded via the lead 15, and the positive terminal of source 14 is connected directly via the lead 16 to the anode 17 of the triode 1, the primary winding 18 of output transforcer T being connected in the cathode lead of the triode 1, intermediate the cathode 19 thereof and the negative terminal of the potential source 14. The cathode 20 of the triode 2 is connected directly to ground and a further primary winding 21 of the output transformer T is connected between the positive terminal of the potential source 14 and the anode 22 of the triode 2.

The primary windings 18 and 21 are wound in bifilar manner, or equivalently, as indicated in the schematic circuit diagram, the wires forming one of the windings being immediately adjacent the wires forming the other of the windings so that substantially zero leakage inductance exists as between the windings 18 and 21.

If it be assumed that a sine wave of potential is applied to the control electrodes 5, 6 by the sources 8, 9, the positive half of the sine wave deriving from source 8 effecting current transfer through the triode 1, and the positive half of the sine wave deriving from source 9 effecting current transfer through the triode 2, it will be apparent that while the positive half of the first mentioned sine wave is applied to the control electrode 5 that the triode 2 is cut off and that current flow through the primary winding 18 takes place in the direction of the arrow 23. On the other hand, while the positive half of the second mentioned sine wave is applied to the control electrode 6 of the triode 2, the triode 1 is cut off and current flow through the primary winding 21 takes place in the direction of the dotted arrow 24. Accordingly, with respect to the flux produced in the core 25 of the transformer T, current flow in the windings 18 and 21 is in opposite directions, so that an alternating magnetic flux is set up in the core 25, and an alternating voltage induced in the secondary winding 26 of the transformer T, for application to the load circuit conventionally illustrated as a resistance 27.

By virtue of the close coupling existing between the primary windings 18 and 21, the close coupling being brought about by the manner of winding the primary windings 18 and 21, substantially no leakage reactance will exist between these primary windings, and, accordingly, as explained in the article by Sah, cited hereinbefore, no transient effects will exist during change over of current carrying function from the triode 1 to the triode 2, and vice-versa. At the same time, the direction of the voltages E existing across both the windings 18 and 21 are always in identical direction, despite the fact that current flow in the two windings is in opposite sense because of the fact that the windings conduct in alternation and are closely coupled.

If we assume that the triode 2 is cut off, and the triode 1 conducting, for example, the winding 18 induces in the winding 21 a voltage congruent with its own voltage, and in the same sense in the two windings, the voltage in winding 21, however, being incapable of causing current flow in triode 2 because the input voltage applied to grid 6 is now negative in phase and of sufficient amplitude with respect to the voltage applied to the anode 22 of triode 2 by winding 21, to prevent such current flow. Precisely the same argument may be presented when triode 2 is conducting and triode 1 cut off.

Furthermore, the terminals 28 and 29 of the primary windings 18 and 21 are directly connected together via the potential source 14, which may be assumed to have zero impedance, and the total number of turns contained in the windings 18 and 21 and are precisely equal. Accordingly, no A. C. potential difference exists between any two adjacent points of the windings 18 and 21, so that but slight or zero capacitive currents flow between adjacent turns of the primary windings 18 and 21. Such currents as do flow tend to maintain the potentials of adjacent points of the two primary windings 18 and 21 identical, and accordingly contribute to the proper functioning of the system.

A condenser C may, if desired, be connected directly from cathode 19 to anode 22 without altering the operation of the system essentially, but to assure the equipotential relation between adjacent turns, particularly at the higher frequencies, where some leakage reactance might conceivably be present due to imperfections of the winding spacings.

It will be noted, upon close analysis, that, the triode 1 being cathode loaded and the triode 2 anode loaded, the former is subject to degeneration and the latter is not so subject. The gains of the triodes 1 and 2 are not equal, for that reason, and the input signals must be compensated accordingly. This feature of the system of Figure 1 detracts from its utility, in some degree.

Reference is now made to Figure 2 of the drawings, wherein is disclosed a variation of the specific embodiment of my invention illustrated in Figure 1 of the drawings, employing triode vacuum tubes 1 and 2, and having signal input circuits duplicating those disclosed in Figure 1, and described in connection with the description of the circuit connections and operation of the embodiment of my invention there illustrated, except that the signal sources 8*a* and 9*a* provide signals of identical magnitude.

Whereas in the embodiment of my invention illustrated in Figure 1 of the drawings a single primary winding is connected in the cathode lead of the triode 1, and a single primary winding connected in the anode lead of the triode 2, in the system of Figure 2 a more completely balanced arrangement is provided, wherein the primary circuit of the transformer T comprises four windings, one each in the cathode circuits of the triodes 1 and 2, and one each in the anode circuits of the triodes 1 and 2. The negative terminal of the anode supply 14 is again grounded, the positive terminal of one winding 30 being connected via the lead 31 to the anode 22 of the triode 2, and a second winding 33, in series with winding 30, being connected via the lead 34 to the anode 17 of the triode 1. Accordingly, the windings 30 and 33 are connected in push-pull relation to the triodes 1 and 2, and pass currents in alternation if the triodes 1 and 2 are biased for class B operation.

A further winding, 35, is connected in the cathode lead of the triode 1, and a winding 36, in series with winding 35, similarly connected in the cathode lead of the triode 2. Accordingly, current flow in the winding 35 takes place in phase with current flow in the winding 33, these current flows being additive in respect to flux production in the core of transformer T. Likewise current flow in the cathode winding 36 is in phase with current flow in the winding 30, and flux production responsive to the current flow in the windings 30 and 36 is cophasal in the core of the transformer T. Furthermore, the magnitudes of the currents flowing in the windings 33 and 35 are identical and the magnitudes of the currents flowing in the windings 30 and 36 are identical, and all the windings 30, 33, 35 and 36 are provided with the same number of turns. The terminals 37 and 38 of the windings 33 and 36 are connected together over the extremely low impedance provided by the potential source 14 and, accordingly, may be assumed to be at the same A. C. potential. The phase of the voltages across the windings 33 and 36 are identical, for the reasons provided in the explanation of the system of Figure 1, so that voltage correspondence extends along the lengths of the wires forming the windings 35, 36 to the remote terminals thereof. Due to the fact that voltage correspondence exists between every two adjacent points of the windings 33 and 36, only slight or zero interwinding current flow takes place by reason of capacities existing between the windings. Such current flow as does take place due to capacitive coupling is, moreover, beneficial rather than detrimental because it tends further to eliminate voltage differences between adjacent points of the windings 33, 36.

The argument presented in the previous paragraph may obviously be duplicated in respect to windings 30 and 35.

Further, the windings 30 and 35 are wound in bifilar or equivalent fashion, as are the windings 33 and 36, so that substantially no leakage inductance exists among the winding pairs 30, 33 and 35, 36.

Since substantially no leakage inductance exists between primary windings, the effect of transients due to leakage inductance, which have been described in the article by Sah, are completely eliminated in amplifiers constructed in accordance with the arrangement of Figure 2 of the drawings. Likewise because interwinding capacity currents are radically reduced, as well as because leakage inductance has been substantially eliminated, and for other reasons above provided, the high frequency resonant point of the transformers is raised by a matter of octaves over the resonant frequency of transformers capable of being constructed at equivalent cost in accordance with prior art principles. The radical reduction in shunt capacities and leakage inductance, furthermore, eliminates the normally expected reduction of response at the higher frequencies, so that the amplifier, taken as a whole, provides an extremely flat response over a very wide band of frequencies.

Actual examples of amplifiers comprising the invention illustrated in Figure 3 of the drawings have been constructed and found to produce a flat response curve over the band 20–200,000 cycles, having less than one-half percent distortion, over the range of frequencies 20 cycles to 20,000 cycles, inclusive, the conversion efficiency of the amplifier tubes remaining above 50% over this band, and the total amount of copper and iron utilized being equal to or less than is employed in high grade transformers of comparable price presently commercially available, the performance of the latter being far inferior.

The embodiment of my invention illustrated in Figure 3 of the darwings is substantially similar to that illustrated in Figure 2 of the drawings, except that the triodes 1—2 are replaced by pentodes 40—41, the pentodes being connected in a novel manner to assure high power conversion efficiency.

It will be realized that both the amount and the character of the potential difference between the cathode and the screen grid of a pentode, or a tetrode, are parameters which determine in large part the power conversion efficiency of the tube. Since the cathode potentials of cathode loaded pentode or tetrode tubes vary with respect to ground, it follows that if the screen potentials are fixed with respect to ground the cathode to screen potentials will vary, and, in general, the power conversion efficiency of the tubes will be found to be reduced.

In order to preserve the power conversion efficiency of pentodes and tetrodes when they are connected in cathode loaded circuits, it is usual to connect a condenser between the cathode and the screen grid, and to connect the screen grid to positive anode potential through a resistance. The object of circuit arrangements of this character is the maintenance of approximately constant potential of suitable value between the cathode and the screen grid. The total potential difference between the cathode and the screen grid approximates the potential difference between the positive and negative terminals of the power supply for the tube, less the potential drop due to the current flow in the screen dropping resistance and the drop due to D. C. resistance of the cathode load impedance. It accordingly follows that the size of the screen grid dropping resistance varies in inverse proportion to the potential difference between the screen grid and the cathode, as the resistance is varied. However, the minimum size of the screen grid dropping resistance is limited by the amount of loading imposed on the output circuit due to this resistance, so that an ideal solution cannot be realized, and maximum power conversion from pentode and tetrode tubes in cathode loaded circuits likewise cannot be obtained.

The circuit illustrated in Figure 3 of the drawing provides a solution to the problem of attaining maximum power conversion from pentode and tetrode tubes in cathode loaded push-pull amplifier circuits, arranged in accordance with the present invention, the solution consisting in connecting the screen grid **42** of one pentode **40** directly to the anode **43** of the other pentode **41**, and the screen grid **44** of the other pentode **41** directly to the anode **45** of the first pentode **40**. The connection of the screen grid **42** to the anode **43** implies connection of the screen grid **42** to the terminal **46** of the output transformer winding **30**, which, as has been explained, in connection with the embodiment of my invention illustrated in Figure 2 of the drawings, is maintained at the same A. C. potential as is the point **37** of the winding **35**. Since the terminal **37** is always at the cathode potential of the pentode **40**, likewise the terminal **46** of the winding **30** is maintained at the same A. C. potential as is the cathode of the pentode **40**, the D. C. potential existing between the two points being, however, that provided by the potential source **14**. Accordingly, as the cathode of the pentode **40** varies in potential, due to the presence in the cathode circuit of the current carrying winding **36**, the potential of the screen grid **42** varies in precisely similar manner. The difference in potential is thus maintained constant, thereby maintaining maximum power conversion from the pentode.

A precisely similar explanation may be provided in connection with the pentode **41**, this explanation, however, being sufficiently obvious.

It will be further realized that while I have disclosed tubes **40** and **41** as pentodes, that precisely the same principles and mode of operation and circuit connections may be employed in conjunction with the use of tetrodes, including beam power tubes, in the circuit of Figure 3.

Reference is now made to Figure 4 of the drawings, which illustrates basically a system of the same character as that illustrated in Figure 2 of the drawings, there being added to the latter, however, controllable degenerative feed-back, still further to reduce the distortion of the amplifier, or in the alternative to necessitate reduced driving signal, as compared with the embodiments of Figures 2 and 3. In the system of Figure 4 of the drawings, controllable degenerative feed-back is derived by connecting across the primary windings **35** and **36**, which are connected in the cathode leads of the triodes **1** and **2**, a resistor **50**, the latter then having developed across itself a voltage which is a replica of the output voltage available at the output of the transformer T. A pair of variable taps **51** and **52** are provided, taps **51** and **52** being located generally at points equidistantly located with respect to cathodes **20** and **19**, respectively. Accordingly, by varying the positions of the taps **51** and **52** the total feed-back voltage to each of triodes **1** and **2** may be varied. The voltage deriving from the tap **51** is applied to control electrode **6**, via a coupling condenser **53**, which is connected to one terminal of the secondary winding **56** of an input transformer S, which is supplied with exciting voltage via a primary winding **57** excited from the source of signal voltage A in conventional fashion. The remaining terminal of secondary winding **56** is connected to the control electrode **6** of the triode **2**. While the control electrode **6** is being raised in potential and the tube **2** is conducting, the potential of the tap **51** decreases in potential due to current flow in resistor **50** in the direction of the arrow I, the cathode **20** of the triode **2** being then at higher potential than is the cathode **19** of the triode **1**. In a similar manner, the tap **52** introduces a degenerative voltage into the grid of the triode **1** via a coupling condenser **53***a* which is connected in series with one terminal of the secondary winding **58** of the transformer S, the other terminal of winding **58** being connected to the control electrode **5** of the triode **1**. Grid leaks for triodes **1** and **2** are provided by resistors **59** and **54**, respectively connected in series with bias source **55**.

It will be clear, then, that, by moving tap **51** to cathode **19**, and tap **52** to cathode **20**, zero degeneration will be introduced into the system, and that degenerative voltages having values as great as twice those normally available in the system of Figure 2 may be made available by establishing tap **51** at cathode **19**, and tap **52** at cathode **20**.

Reference is now made to Figure 5 of the drawings wherein is illustrated a variation of the system of Figure 1 of the drawings. Specifically, in the system of Figure 1, a primary winding **18** of a transformer T is connected in series with a cathode circuit of a first triode **1** and a further primary winding **21**, which is wound in bifilar relation to the primary winding **18**, is connected in series with the anode circuit of a further triode **2**, so that effectively the triode **1** is cathode loaded, while the triode **2** is plate loaded.

In the system of Figure 5 of the drawings the tube **1** is cathode loaded by means of the primary winding **18** of transformer T. Input signal from the secondary **60** of an input transformer S is applied between the control electrode **5** of the tube **1** and the terminal **67** of winding **18** via leads **65** and **66**. However, the tube **2** is driven in a different manner in Figure 5 than is the triode **2** in Figure 1, the tube **2** being effectively cathode loaded in the system of Figure 5. To this end the primary winding 21 is connected in the anode circuit of the tube 2, in a similar manner to the connecions previously described in conjunction with Figure 1 of the drawings. A further signal is applied in opposite phase to the first mentioned input signal via a winding 62 connected between the anode 22 of the tube 2 and the controle electrode 6 of the tube 2 via the usual blocking condenser C.

Accordingly, the input circuit of tube 1 sees two alternative voltages, one originating in the primary winding 63 and which is inductively transferred to the secondary winding 60, the second constituting a degenerative feed-back voltage deriving from the primary winding 18 of the output transformer T by virtue of the connection of the terminal 64 of the secondary winding 60 via the lead 65, 66 to the negative terminal 67 of the primary winding 18.

The input circuit of tube 2 sees two alternating voltages, one originating in the primary winding 63, which is inductively transferred to the secondary winding 62, the second constituting a degenerative feed-back voltage, deriving from the primary winding 21 of output transformer T, and degenerative by virtue of the fact that winding 21 is effectively in the cathode circuit of tube 2, varying the potential of cathode 20 with respect to that of anode 22, in one phase, while the potential of control electrode 6 is being varied in the same phase with respect to anode 22 by the voltage in secondary 62. Looked at in another way, the input voltage for tube 2 consists of the voltages of windings 21 and 62 in series. So, when the positive half cycle of voltage in winding 62 is in the direction of the arrow E, the potential of the control electrode 6 with respect to cathode 20, assuming the latter fixed, increases positively. This results in an increase of plate current, which increases the voltage across coil 21, resulting in a voltage rise across winding 21 in the direction of arrow E'. It will be obvious that, as seen from the grid-cathode circuit of tube 2, voltages E and E' are oppositely directed and hence that voltage E' is degenerative.

Additionally, if a screen grid 67 is provided in tube 1, this may be connected directly to anode 22 of tube 2, and will be maintained at a constant potential with respect to cathode 19 of tube 1 equal to the voltage of source 14, because the same A.-C. voltages exist at all times on anode 22 and on cathode 19. If desired a capacitor, C, may be connected from cathode 19 to anode 22.

Similarly, a screen grid 68, provided in tube 2, may be connected directly to the positive terminal of source 14, and will be maintained at an A.-C. voltage difference from the potential of cathode 20 equal to the voltage of source 14, since no impedance exists between screen grid 68 and cathode 20.

It will be realized that the tubes 1 and 2 in Figure 5 of the drawings may then be triodes, tetrodes, pentodes, beam power tubes, or the like, as desired, and further that in the various embodiments and examples of my invention, illustrated and described herein, the specific character of the electronic amplifier tubes employed may be selected at will from among the various types available, i. e., triodes, tetrodes, pentrodes, beam power tubes and the like.

The system of Figure 6 represents a simple variation of the system of Figure 2, demonstrating that, if desired, the bifilar primary windings 35, 36 may be coupled directly to a load, the transformer T acting as an auto-transformer.

I have disclosed a variety of push-pull amplifier systems, employing each a bifilarly wound transformer, and have illustrated in the schematic circuit diagrams, Figures 1–6, conventionally, bifilarly wound transformers. I have, however, recited that transformer primary windings equivalent to bifilar windings may be employed.

Reference is accordingly made to Figures 7–10 inclusive, of the drawings, wherein is illustrated a plurality of different transformer winding constructions which may be employed in the circuits of Figures 1–6, inclusive, Figure 7 illustrating a transformer having four primary windings, bifilarly wound, and associated with a common secondary winding, Figure 8 illustrating a possible substitute for the system of Figure 7, employing superposed coils in place of bifilarly wound coils, the transformer of Figure 8 being in some respects equivalent to the transformer of Figure 7, when the windings are properly connected in a push-pull amplifier arranged in accordance with the invention. Figures 9 and 10 illustrate variants of the transformer of Figure 7 wherein separate layers of a single coil are incorporated by suitable interlayer connections in different primary windings of a push-pull transformer, providing a true approximate equivalent for a bifilarly wound transformer.

Referring now more specifically to Figure 7 of the drawings, there is illustrated a core 100 of conventional structure having wound thereon a coil 101 formed of a plurality of bifilarly wound layers 102, the winding commencing at point 103 and terminating at point 104. Leads 105, 106 are brought out from the commencement point 103 of the bifilar winding, to which may be connected B+ and B— terminals of a voltage supply, when the transformer is connected in an amplifier circuit. Similarly from the end of the winding, at point 104, are brought out two terminals 107, 108, intended for connection, respectively, to the plate or anode P1 of one amplifier tube of a push-pull amplifier, and the cathode C2 of the remaining tube.

A duplicate coil 110 is wound on the same core beside the coil 107, having terminals 111 and 112 for connection respectively to B+ and B— terminals of the voltage supply, and terminals 113, 114 for connection respectively to the cathode C1 of the one tube and the anode P2 of the remaining tube.

It will be noted that the respective windings are wound in opposite winding senses with respect to the core 100, for reasons explained hereinabove, and briefly because the coils 101 and 110 are intended to produce flux in push-pull, or alternately in opposite directions in the core 100.

Secondary windings 115, 116 are superposed on the primary coils 101 and 110, respectively, and are shown connected in series by a lead 117, it being understood that parallel connection is equally feasible.

In the broadly or approximately equivalent system of Figure 8, bifilar windings are dispensed with, and four primary windings are provided, numbered 120, 121, 122 and 123. The superposed windings 120 and 121 are wound in mutually identical sense, and the superposed windings 122 and 123 in identical sense, the latter two oppositely to the first mentioned two windings, and the winding pairs are arranged adjacently on the core. The initial point 124 of winding 120 may be connected to terminal B— and the terminating point 125 of winding 121 to terminal B+, of a plate voltage supply source, by appropriate terminals provided, and the terminal points 124 and 125 being thus joined by a path of negligible A.-C. impedance remain at identical A.-C. potential. The terminal point 126 of winding 120 and the initial point 127 of winding 121 are arranged to be in close juxtaposition, and are joined by a condenser K1, which serves to maintain the points 126 and 127 at identical A.-C. potentials.

The terminal point 126 may be connected to cathode C2 and the terminal 127 to anode P1.

The coil 122 may be similarly arranged, terminal 128 being connected to B—, terminal 129 of coil 123 to B+, and terminals 130 and 131 joined by a condenser K2, so that the terminals of pair 128, 129 and the terminals of pair 130, 131 are at identical A.-C. potentials. Terminal 130 may be connected to cathode C1 and terminal 131 to anode P2, of the tubes of the amplifier employing the transformer. The secondary winding 132 may be arranged as in the embodiment of Figure 7 of the drawings.

It will be realized that leakage inductance, in the case of the embodiment of my invention illustrated in Figure 8, will be greater than in the case of the embodiment of Figure 7. However, the transformer of Figure 8 may conceivably be more economically constructed than the transformer of Figure 7, and may prove desirable for that reason, despite its relatively poorer performance.

In Figure 9 of the drawings is illustrated a further modification of the system of Figure 7, wherein the effect of a bifilar coil is attained by winding the respective primary windings which are desired to be unity coupled, in successive layers, and joining the layers thereafter by means of suitable leads. Having particular reference to a transformer suitable for use in the amplifier system of Figure 2, for example, the winding 29 may comprise the winding layers 141, 142, 143, 144, 145, 146, etc., and the winding 30 the alternate layers 147, 148, 149, 150, 151 . . . The terminal point of layer 141 may be connected to B— and its other end point joined by lead 150 to an adjacent end point of layer 142, the layers 141 and 142 being wound in the same direction and current in each turn of both layers 141 and 142 flowing in the same sense, to produce mutually additive flux in the core. The process of layer interconnection is continued to the end of the winding, the winding layers 141, 142, 143 . . . being thus connected in series. The alternate layers, 147, 148, 149 . . . are likewise connected in mutual series relation by leads 161, and a secondary winding 163 may be superposed on the primary windings, in conventional fashion. The terminal points of the outermost pair of adjacent winding layers may then be brought out to anode P1 and cathode C2, respectively.

A similar pair of primary windings, 164 and 165 may be provided on the core, adjacent to the primary windings 29 and 30, for connection to the anode P2 and the cathode C1, and with the windings 29 and 30 associated a further secondary winding 164, connected in series with secondary winding 163, it being understood that parallel connection is equally feasible.

It will be realized, since the windings are adjacent in alternate layers, and since the starting points of initial layers 141 and 147 are adjacent and interconnected by a path of low impedance provided by the voltage source B+ and B—, that the potentials of adjacent turns of each pair of layers is ideally at identical A.-C. potential. To compensate for any departures from ideal conditions, brought about by winding irregularities and the like, I may interconnect the ends of the windings by means of a large condenser K, which establishes the ends of the windings at identical A.-C. potential.

Figure 10 illustrates a winding sequence which approaches that of the sequence provided in the embodiment of Figure 9 of the drawings, the winding being laid in successive layers, 170 which are left mutually unconnected when the coil is wound. The first, fourth, fifth, eighth, ninth, twelfth . . . layers are connected in series by leads 161 to provide one winding; the second, third, sixth, seventh, tenth, eleventh . . . layers are connected in series by leads 162 to provide the other winding. The initial points of the first and second layer may be connected respectively to the B+ and B— terminals of a voltage supply, and the two outermost windings (the eleventh and twelfth layers of a twelve layer winding, for example), connected to the cathode, C2, of one vacuum tube and the anode, P1, of a further vacuum tube of a push-pull amplifier arranged in accordance with the invention. The latter two terminals may be connected across a condenser K to assure that the same A.-C. potential exists at these terminals, as in the transformer arrangements of Figures 8 and 9, inclusive. The upper windings may be duplicated to provide two pairs of bifilarly wound equivalents.

It will further be realized, while the transformers illustrated in Figures 7, 9 and 10 approach relatively closely to the ideal, or bifilarly wound transformer, that the embodiment of Figure 8 is at best a very rough approximation, and, while operative, operates but imperfectly in circuits arranged in accordance with the invention, and is not recommended except in cases where other considerations than excellance of performance are primary.

It will further be realized that further variants of the transformers illustrated in Figures 7, 9 and 10 may be resorted to without departing from the true scope and spirit of the invention, which requires the provision of unity coupled transformers, for best performance, and which may employ any type of unity coupled transformers having the requisite windings, and which are known or which may become known to the art.

Consideration of the system of Figures 2, 3, 4 and 6 of the drawings will render evident that each of the tubes of the amplifiers or modulators disclosed is operated with negative feedback, since in each case a primary winding of an output transformer is connected in a cathode lead of a tube and the grid-cathode or input circuit is connected across the winding. Each of the tubes is, however, also plate loaded, so that part of the output of each tube derives from its plate circuit, and part from the cathode circuit. Thereby, I provide a push-pull amplifier which possesses the advantages of both a plate loaded and a cathode loaded system, simultaneously, in addition to the other advantages previously disclosed, a feature which has not previously been attainable in push-pull amplifiers useful for wide band amplification of audio or video signals, or the like, to my knowledge.

While I have described various modifications of amplifiers, or modulators, arranged to employ to advantage output transformers having bifilarly wound primary windings, further modifications may be devised, and re-arrangements and modifications of the modifications illustrated and described, resorted to, without departing from the true spirit and scope of the inventions, as defined in the appended claims.

In particular it will be realized that the various embodiments of my invention herein disclosed have particular application, though not exclusive application, to class AB and class B power amplifiers, and their variants, and hence to utilization as modulators in various systems of modulation, and particularly to class B plate modulators.

What I claim and desire to secure by Letters Patent of the United States is:

1. A push-pull wide band audio frequency amplifier, comprising, a first electronic amplifier tube having a first anode, cathode and control electrode, a second electronic amplifier tube having a second anode, cathode and control electrode, a source of anode voltage having a positive and a negative terminal, a magnetic core, first and second primary output transformer windings of substantially equal inductance and having each a high impedance at said audio frequencies, arranged in bifilar relation about said core, means for connecting said first winding between said negative terminal and said first cathode, means for connecting said second winding between said positive terminal and said second anode, third and fourth primary output windings of substantially equal inductance and having each a high impedance at said audio frequencies arranged in bifilar relation about said core, means connecting said third winding between said negative terminal and said second cathode, means for connecting said fourth winding between said positive terminal and said first anode, a secondary winding coupled substantially equally to said first, second, third and fourth windings, and a push-pull input circuit for said first and second electronic amplifier tubes, responsive to a wide band audio source for driving said control electrodes with oppositely phased wide band audio voltages.

2. The combination in accordance with claim 1 which includes means for biasing said amplifier tubes for class B operation.

3. The combination in accordance with claim 1 wherein said first amplifier tube comprises a first screen grid, and wherein said second amplifier tube comprises a second screen grid, means for connecting said first screen grid directly to said second anode and means for connecting said second screen grid directly to said first anode.

4. A push-pull wide band audio frequency amplifier, comprising, a first electronic amplifier tube having a first anode, cathode and control electrode, a second electronic amplifier tube having a second anode, cathode and control electrode, a source of anode potential having a negative and a positive terminal, an output transformer having a magnetic core, multiturn primary windings of substantially equal inductance and having high impedance at audio frequencies linking said core and coupled to said first and second tubes, said primary windings comprising at least two closely coupled windings wound in identical winding sense, means for connecting one of said windings between said negative terminal and said first cathode, means for connecting the other of said windings between said positive terminal and said second anode, said primary windings comprising at least two further closely coupled multiturn windings of substantially equal inductance and having high impedance at audio frequencies linking said core and wound in identical winding sense, opposite to said first mentioned winding sense, means for connecting one of said further windings between said positive terminal and said first anode, means for connecting the other of said further windings between said negative terminal and said second cathode, and a push-pull wide band input circuit for applying a wide band of audio frequencies to said control electrodes in push-pull relation, and means for biasing said electronic amplifier tubes for anode current flow in at least one of said tubes at all times in response to said signals.

5. The combination in accordance with claim 4 wherein said first and second electronic amplifier tubes have a first and a second screen grid, respectively, and wherein is provided means for maintaining constant potential between said first screen grid and said first cathode and between said second screen grid and said second cathode, during operation of said amplifier.

6. The combination in accordance with claim 4 wherein said means for maintaining constant potential between said first screen grid and said first cathode comprises a direct current connection between said first screen grid and said second anode, and wherein said means for maintaining constant potential between said second screen grid and said second cathode comprises a direct current connection between said second screen grid and said first anode.

7. A wide band amplifier, comprising, a first amplifier tube having a first cathode circuit and a first anode circuit, a second amplifier tube having a second cathode circuit and a second anode circuit, an output transformer having a magnetic core, a first pair of unity coupled primary windings and a second pair of unity coupled primary windings, both linking said core, means for connecting one of said first pair of windings in said first anode circuit and the other of said first pair of windings in said second cathode circuit, means for connecting one of said second pair of primary windings in said second anode circuit and the other of said second pair of primary windings in said first cathode circuit, a load circuit coupled substantially equally to all said primary windings, means for biasing said amplifier tubes to provide current flow in at least one of said tubes in response to any finite signal, and a wide band input circuit connected in push-pull relation to said control electrodes for applying said wide band of signals thereto.

8. An amplifier for amplifying a wide band of signals with essentially flat response, comprising, a first electronic amplifier tube having a first anode, cathode and control electrode, a second electronic amplifier tube having a second anode, cathode and control electrode, a source of anode voltage having a positive and a negative terminal, a magnetic core, first and second primary output windings arranged in unity coupled relation about said core, each of said windings having an impedance at the low end of said band which is of the same order of magnitude as the internal resistance of one of said tubes, means for connecting said first winding between said negative terminal and said first cathode, means for connecting said second winding between said positive terminal and said second anode, third and fourth primary output windings arranged in unity coupled relation about said core, said third and fourth primary output windings each substantially duplicating an impedance one of said

first and second primary windings, means connecting said third winding between said negative terminal and said second cathode, means for connecting said fourth winding between said positive terminal and said first anode, an untuned load circuit coupled to said first, second, third and fourth windings equally, an input circuit coupled in push-pull relation to said first and second control electrodes for applying to said control electrodes in push-pull relation said wide band of signals, and means for biasing said amplifier tubes for operation with anode current flowing in at least one of said amplifier tubes at all times in response to said signals.

9. The combination in accordance with claim 8 wherein each of said first and second amplifier tubes comprises a further control electrode,

means for connecting said further control electrode of said first amplifier tube to said second anode over a path of negligible impedance, means for connecting said further control electrode of said second amplifier tube to said first anode over a path of negligible impedance.

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