Oct. 31, 1944. L. WALSH 2,361,889

AUTOMATIC BIAS CONTROL

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Fig. 1

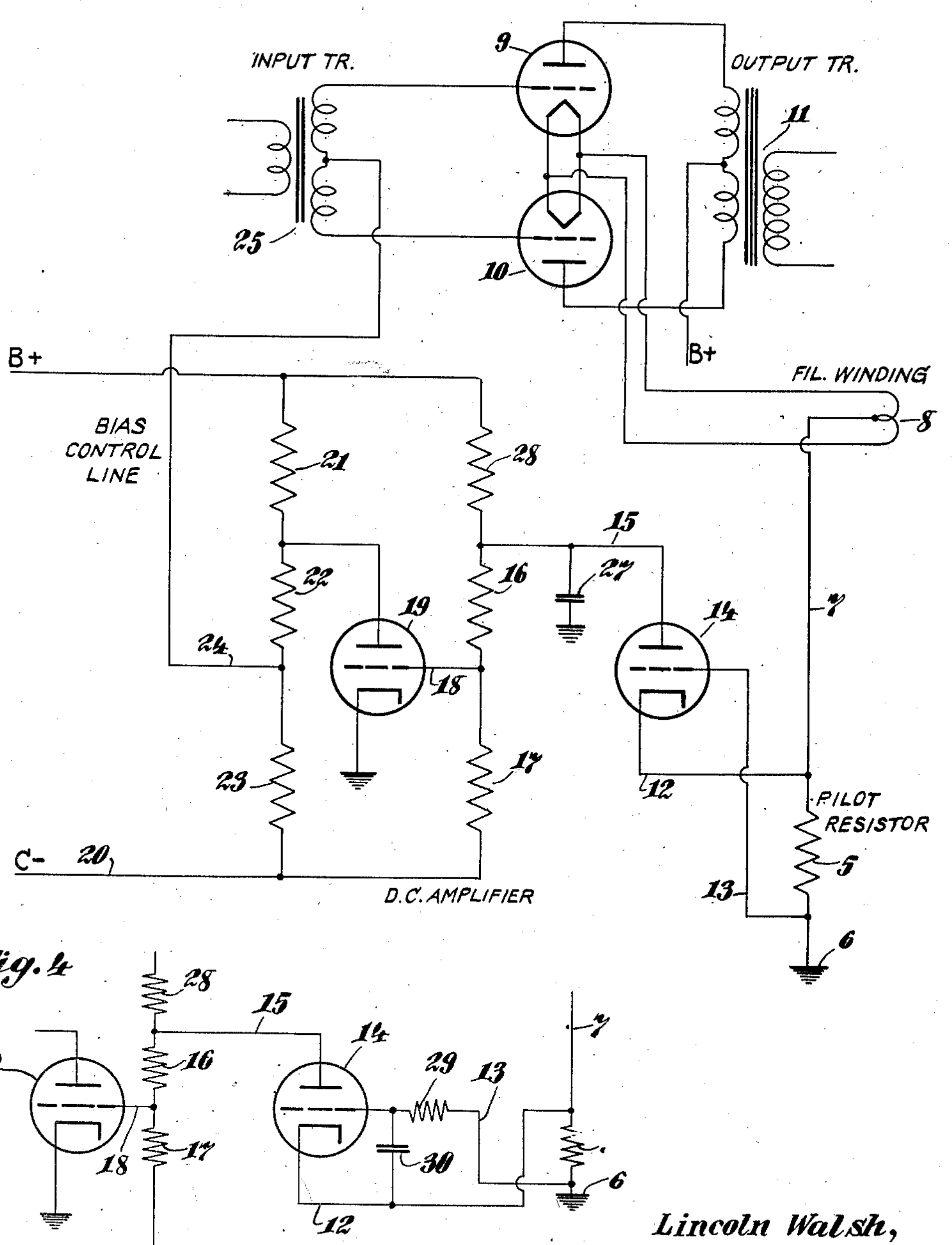
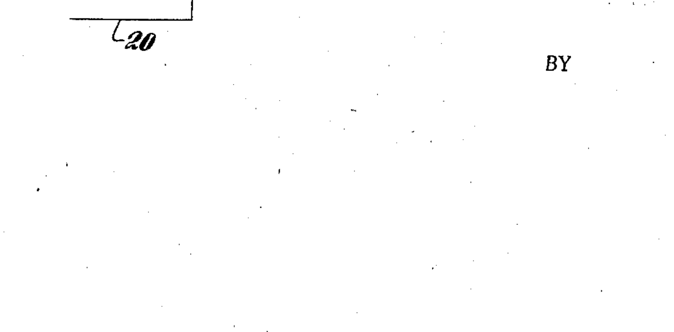


Fig. 4



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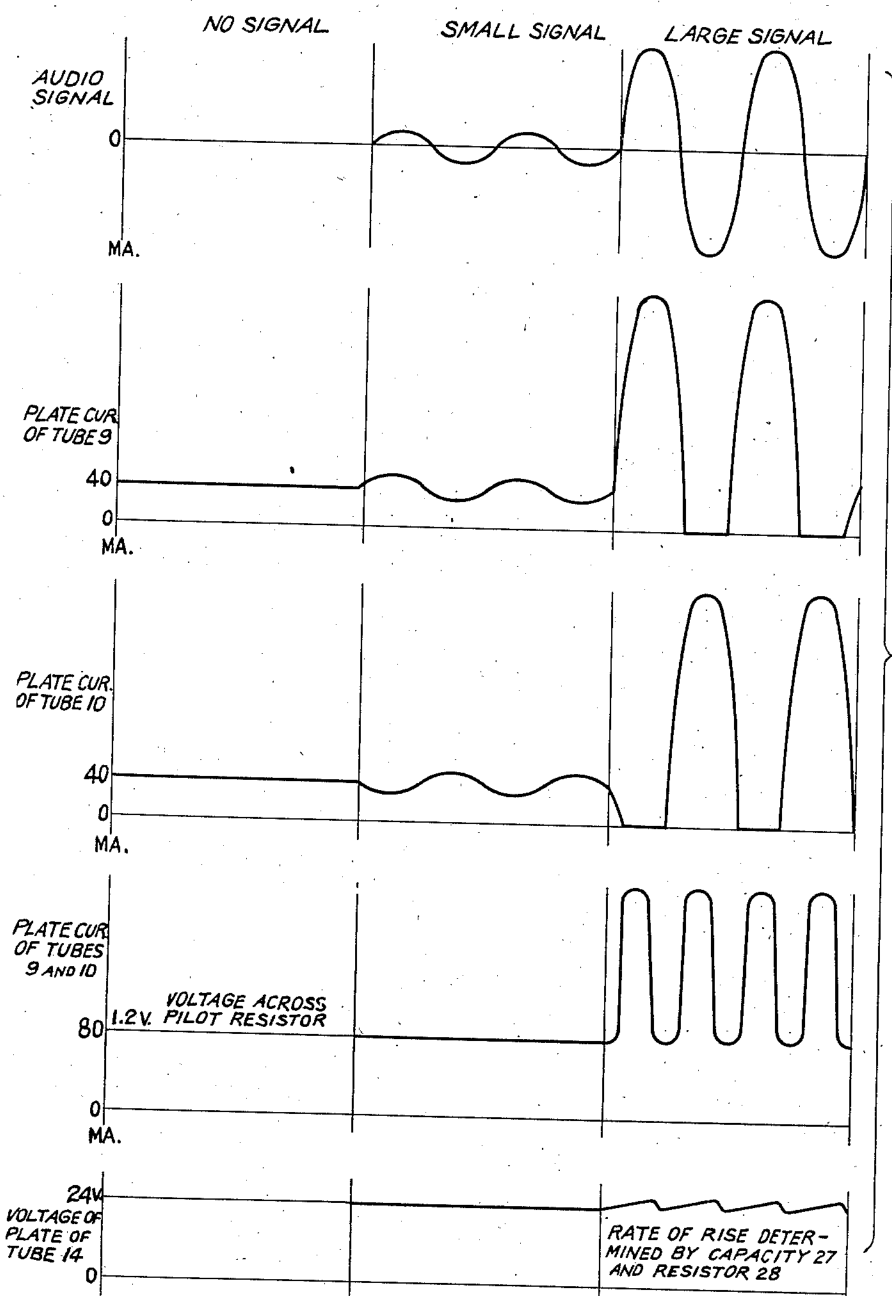

Fig. 2

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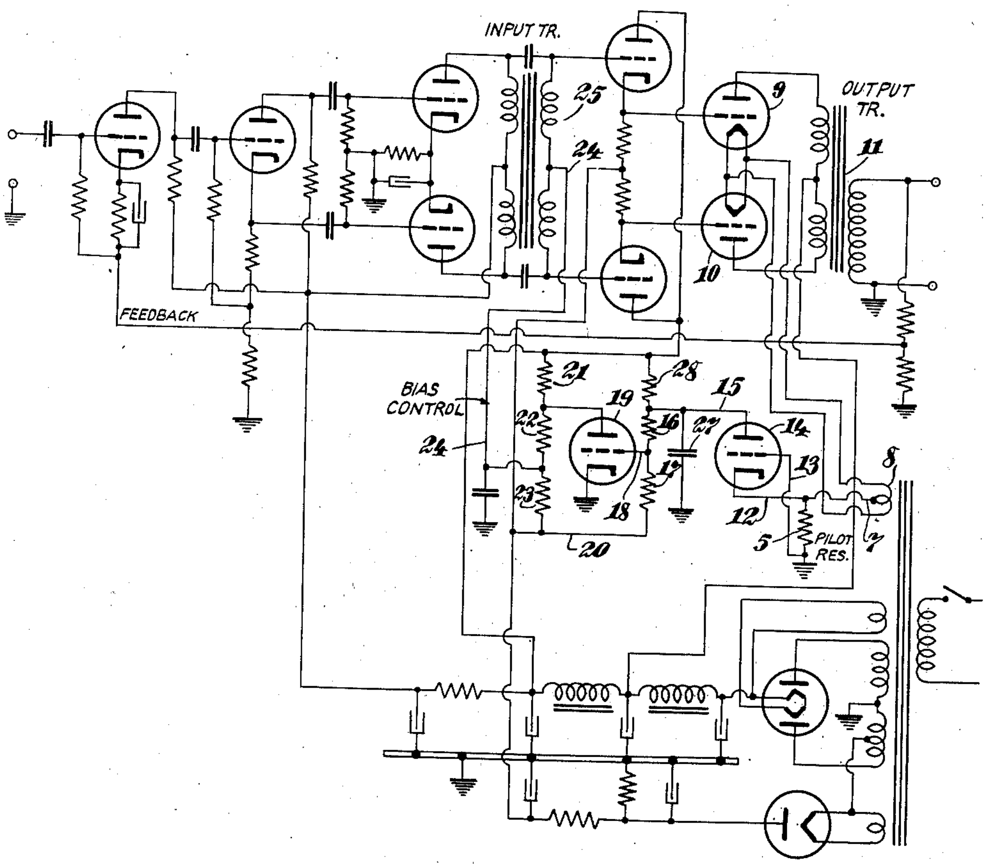
Fig. 3



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AUTOMATIC BIAS CONTROL

Lincoln Walsh, Elizabeth, N. J.

Application November 11, 1941, Serial No. 418,633

8 Claims. (Cl. 179—171)

The invention here disclosed relates to control of the grid bias in vacuum tube amplifiers.

Special objects of the invention are to enable attainment of maximum power output, with a minimum of distortion, to hold the power requirements of the amplifier to a minimum and to maintain the plate current of the amplifier at a value which will not impair the life of the tubes.

Other important objects of the invention are to provide an amplifier so free of critical features that it may be readily manufactured from component parts having normal variations and be utilized generally without requiring any special or technical supervision, and which will be capable of delivering the highest power output of which the tubes are capable.

In line with the last stated objects, it is a purpose of the invention to provide an amplifier, which will combine the high performance characteristics of the fixed bias type of amplifier, with the freedom from criticalness of the self-bias form of amplifier and thus to obtain an amplifier of high performance and high efficiency characteristics that can be easily built and maintained in good operating condition.

A further special object of the invention is to improve the efficiency and operating characteristics of push-pull audio frequency amplifiers, particularly in the last or output stage.

Other objects and advantages of the invention will appear as the specification proceeds.

The drawings accompanying and forming part of the specification illustrate features and certain of the preferred embodiments of the invention. The actual physical form of the invention however, may be modified and changed as regards the present illustrations, as will be clear from the description following and the claims attached, broadly covering the invention.

Fig. 1 is a circuit diagram illustrating the invention in fundamental form.

Fig. 2 is a composite diagram illustrating the time-amplitude relations.

Fig. 3 is a more complete circuit diagram of an amplifier embodying the basic control feature of Fig. 1.

Fig. 4 is a view similar to Fig. 1, illustrating a modification.

As shown particularly in Fig. 1, the basic or fundamental feature of the invention consists in applying to the grid circuit of a vacuum tube amplifier a voltage which is a function of the plate current of the amplifier, to thereby cause the plate current, under varying conditions to seek that value which will give the best results.

This is accomplished, in the case of a push-pull amplifier, such as illustrated, by transmitting the plate current through a "pilot" resistor of small value to ground and utilizing the voltage appearing across this pilot resistor as a control by passing it through a D. C. amplifier and taking the output of such amplifier to directly govern the voltage applied to the grid bias circuit of the push-pull amplifier.

In the illustration, the pilot resistor is indicated at 5, grounded at one side at 6, and connected at the other side at 7, with the midpoint of the filament winding 8, supplying current to the filaments of the push-pull amplifier tubes 9, 10, so that plate current of tubes 9 and 10 flows through the pilot resistor.

The plates of the amplifier tubes are shown supplied through the primaries of the output transformer 11.

For purposes of illustration, some values will be given that have been found suitable in an amplifier embodying this invention, employing a pair of 2A3 tubes in push-pull for audio frequencies. It may be considered that the power supply delivers a voltage of about 350 volts to the plates of tubes 9 and 10, and that a plate current of approximately 80 milliamperes may flow through the pilot resistor and that the latter can have a resistance of about 15 ohms, thus to produce a voltage of about 1.2 volts across its terminals. By connections 12, 13, this control voltage is impressed between the cathode and grid of the D. C. amplifier tube 14.

The resistor network through which the plate current of tube 14 is fed is of high resistance, so the voltage at the plate of tube 14 is approximately the grid voltage multiplied by the mu of the tube, which in the case supposed may be 1.2 v.×20=24 volts (for type 6J5G). This voltage is impressed by conductor 15, on a voltage divider made up of resistors 16, 17, and which through connection 18, impresses on the grid of tube 19, a voltage intermediate between the variable positive voltage of the plate of tube 14 and the fixed negative voltage derived from the power supply at 20, and which may be on the order of —200 v.

In this manner, the grid of tube 19, is maintained at a negative voltage, which is desirable and yet is coupled directly to the plate of the preceding tube, which is at a positive voltage.

The tube 19 and the resistor network 21, 22, 23, form a similar D. C. amplifier stage, and the output here which may be about 90 volts negative in the illustration, is conducted by a control line 24, to the midpoint of the grid potential windings of the input transformer 25, and is the bias voltage.

This particular form of D. C. amplifier has the unique advantage that the output can be at a potential which is negative relative to the input.

In operation, when the static or no-signal plate current of the output tubes 9 and 10, increases for any cause, the voltage across the pilot resistor 5, increases, causing the cathode of tube 14, through connection 12, to become more positive. The grid of tube 14, is at ground potential through connection 13, and this causes the grid to become more negative relative to the cathode and the plate current to decrease, resulting in the plate of tube 14, becoming more positive. The grid of tube 19, being at a potential intermediate between the variable plate potential of tube 14, and the fixed negative potential of the negative line 24, said grid therefore follows the plate of tube 14, by becoming more positive. This in turn causes the plate of tube 19 to become more negative. As the grid bias line 24, is at an intermediate potential differing from that of the variable plate of tube 19, as determined by the voltage divider made up of resistors 22 and 23, the grid bias line becomes more negative. As the bias on the grids of the push-pull amplifier tubes 9 and 10 is made more negative by the control line 24, the plate current of these tubes is reduced to a value at which the system finds equilibrium.

When a signal is impressed on the amplifier, the plate currents vary as shown in Fig. 2. The currents in the two tubes of a push-pull amplifier rise and fall in opposition or 180° out of phase, in accordance with the well known facts of push-pull operation. For signals of any amplitude the positive change in current is greater than the negative, and the average current is increased by an increment which is approximately proportional to the square of the input voltage. For small signals, as shown in Fig. 2, the change in the average plate current is negligible. For large signals, the total current increases twice per signal cycle, and for very large signals, each tube alternately goes completely to cutoff, and the current flows through only one tube during parts of the signal cycle. But for two short periods during the signal cycle when the signal voltage is crossing the zero axis, the plate current of each tube is very close to its zero signal value, and the sum of the plate currents is very close to that value when there is no signal impressed on the amplifier. This is strictly true only when the load is non-inductive, but in practice when the amplifier is feeding a loudspeaker for example, conditions are substantially as stated.

For best operation it is desirable that the instantaneous minimum of the sum of the plate currents be held substantially constant at the zero signal value.

This invention, among its other features, is therefore designed to utilize this instantaneous minimum of plate currents as the control factor in setting the grid bias, and to be substantially unaffected by changes in the average current due to increases in the plate currents which occur during the signal cycle.

When a small signal is impressed, as previously stated, the average current through the tubes and therefore through the pilot resistor does not change.

When a large signal is impressed, the total plate currents rise as shown in the fourth curve of Fig. 2, increasing the negative voltage on the grid of tube 14 relative to its cathode, and the plate voltage tends to rise. But this tube plate is shunted by condenser 27, and is fed through the resistance 28, which is of very high value, of the order of 1 megohm. So as grid of tube 14 becomes more negative, the voltage of its plate cannot change instantaneously but rises slowly at a rate determined by condenser 27 and resistor 28. Until the plate voltage reaches a value approximately mu times the grid-cathode bias, no plate current flows, and the current flowing through resistor 28, flows into the condenser, increasing its voltage. The time constant of the condenser 27, and resistor 28, is quite long relative to any signal cycle, and so, before the voltage builds up appreciably, the signal approaches the zero axis, the plate current of tubes 9 and 10 drops to its zero signal value, and the grid bias on the tube 14 drops to its zero signal value. The plate of tube 14 again conducts and discharges condenser 27, down to its original voltage corresponding to zero signal as shown in last curve of Fig. 2, showing the sawtooth wave form of voltage at plate of tube 14. As the voltage of condenser 27, has too short an interval to build up its voltage appreciably, its average voltage remains substantially at the value for zero signal, and does not change appreciably when the signal increases from zero to a very large value. The voltage on plate of tube 14 impressed on the voltage divider formed by resistances 16, 17, results in a voltage being impressed on grid of tube 19, which varies proportionally to the plate voltage of tube 14, but negative relative thereto, so that the grid voltage of tube 19 is negative. As a result, the plate voltage of tube 19, varies with that of tube 14, but in opposite sense, and in larger amount, due to the amplification of tube 19. Similarly, the plate voltage of tube 19 impressed on the voltage divider formed by resistances 22 and 23, results in a voltage on conductor 24 feeding bias to the amplifier tubes 9, 10, which varies proportionately with the voltage on plate of tube 14, but negative relatively thereto. The bias voltage delivered by conductor 24 is therefore directly controlled by the instantaneous minimum of total plate current of tubes 9 and 10, which is the desired condition for maximum power output, minimum distortion, and highest efficiency.

By proper choice of elements in the control circuits, the following desirable results can be obtained:

1. Under static or no load conditions, the total plate current of the two push-pull amplifier tubes is maintained close to the desired value, despite manufacturing variations in tubes, resistors and other components. This desired value of plate current is determined by consideration of the maximum power dissipation of the push-pull amplifier tubes consistent with good life, of the distortion, of the drain on the power supply system and similar factors.

2. Under dynamic or conditions of load up to maximum undistorted output, the plate current rises substantially but the grid bias voltage remains substantially at its no load value, resulting in the highest power output possible, minimum distortion and maximum efficiency.

These conditions are illustrated generally in the five graphs shown in Fig. 2.

The grid bias of the push-pull amplifier is a continuous function of the plate current and operates to maintain the plate current at the desired value under no load conditions, but when conditions change toward full load, the plate current increases to a value much greater than its no load value, without however causing any substantial corresponding change in the grid bias voltage.

In the present invention, the advantages of both self-bias and fixed bias forms of amplifiers are combined, it being well adapted to mass production, because of freedom from critical values and it having the high performance characteristics heretofore only attained but with attendant critical limitations, in fixed bias amplifiers.

If the bias control system is modified as indicated in Fig. 4, by omitting condenser 27, and adding a resistor 29, in series with grid of tube 14, and a condenser 30, in shunt with said grid, the fluctuating component of the voltage in pilot resistor 5 is filtered out and the system, instead of responding to the instantaneous minimum of total plate current, responds instead to the average current, and holds the average plate current substantially at a value for which the system is set. This condition may be desirable for certain applications.

In Fig. 3, the invention is shown incorporated in a complete amplifier circuit, with reference characters applied corresponding to those in Fig. 1 and while here also is shown applied to the push-pull circuits of the final stage, it will be realized that the invention is equally applicable in some or all of its phases to other types of amplifiers, such as single-sided amplifiers. It will be understood also that while shown in connection with audio frequency amplifiers, the invention is applicable as well to amplifiers of any frequency and to other electronic systems, such as oscillators, harmonic generators, modulators, etc.

What is claimed is:

1. A vacuum tube amplifier, comprising grid and plate circuits, and means connected with said grid and plate circuits for supplying automatically a grid bias voltage which is a function of the plate current at zero signal and substantially independent of variations in the plate current due to signals.

2. A vacuum tube amplifier, comprising grid and plate circuits, and means connected with said grid and plate circuits for automatically controlling the grid bias to maintain the plate current at any desired value by offsetting changes in the static conditions but substantially without offsetting variations in plate current due to variations in signal or load values.

3. A push-pull vacuum-tube amplifier comprising tubes having grid and plate circuits, means connected with said grid and plate circuits for maintaining between the respective grids and cathodes of the tubes, a voltage which is a function of the lowest value of the sum of the plate currents reached during a signal cycle.

4. A push-pull vacuum tube amplifier comprising tubes having grid and plate circuits, means connected with said grid and plate circuits by which the grid bias is controlled by the plate current of the tubes in such manner that the instantaneous minimum of plate current remains substantially constant, regardless of the average value of plate current.

5. In a vacuum tube amplifier, a resistor through which flows the plate current of one or more of the vacuum tubes, producing a voltage across the terminals of said resistor, a two-stage resistance-coupled direct current amplifier into which said voltage is fed, a capacitor connected across the plate and cathode of the first stage of said D. C. amplifier, the output of said D. C. amplifier controlling the voltage fed to the bias circuit of the first named amplifier.

6. An electronic system comprising grid and plate circuits and, electronic means connected with said circuits and controlled by current in the plate circuit to control the voltage in the grid circuit to a value which will maintain the plate current at the desired value in the absence of a signal and for maintaining substantially the same voltage in the grid circuit when the plate current rises as a result of an impressed signal.

7. In a vacuum tube amplifier, a resistor through which flows the plate current of one or more of the vacuum tubes, producing a voltage across the terminals of said resistor, a two-stage resistance-coupled direct current amplifier into which said voltage is fed, the output of said D. C. amplifier controlling the voltage fed to the bias circuit of the first named amplifier.

8. In a vacuum tube amplifier, the method of improving performance, which comprises feeding the plate current through a resistor and utilizing the voltage produced across the resistor as a control for the D. C. plate current by applying said produced voltage through a delay circuit at the input of a D. C. amplifier and applying the output of said D. C. amplifier to directly control the grid bias voltage of the said first mentioned amplifier.

LINCOLN WALSH.