May 22, 1951 N. B. THARP 2,554,279

RADIO APPARATUS

Filed March 13, 1948 2 Sheets-Sheet 1

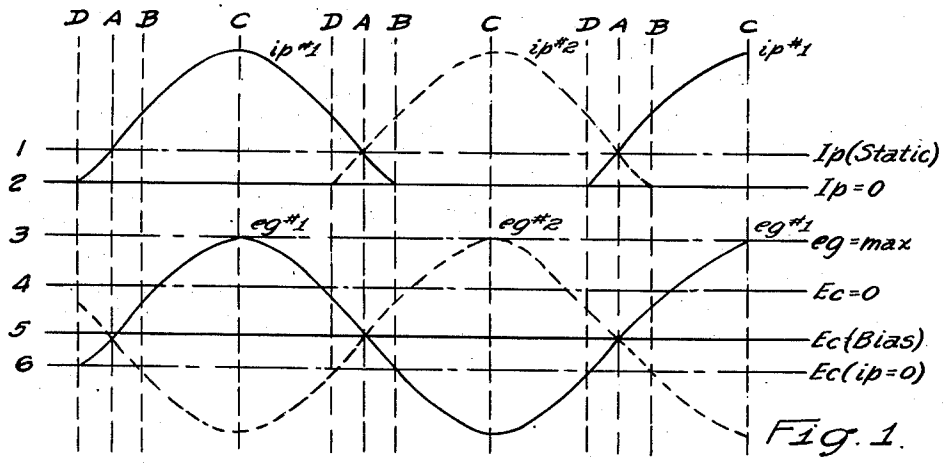


Fig. 1.

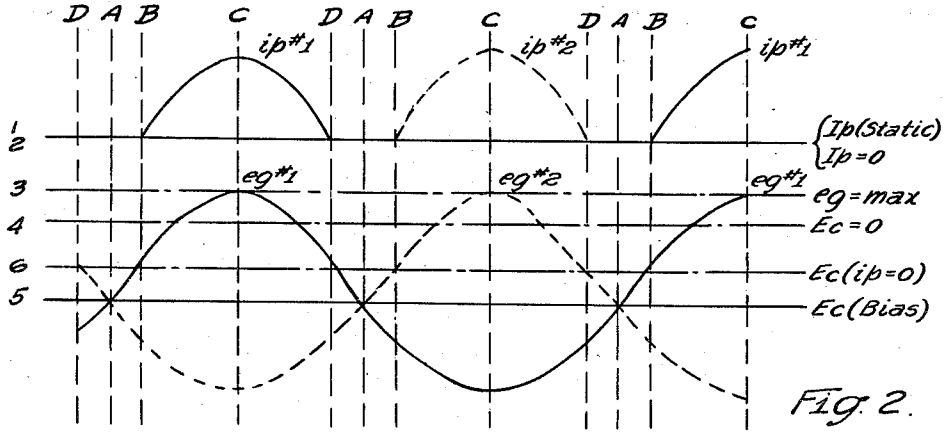


Fig. 2.

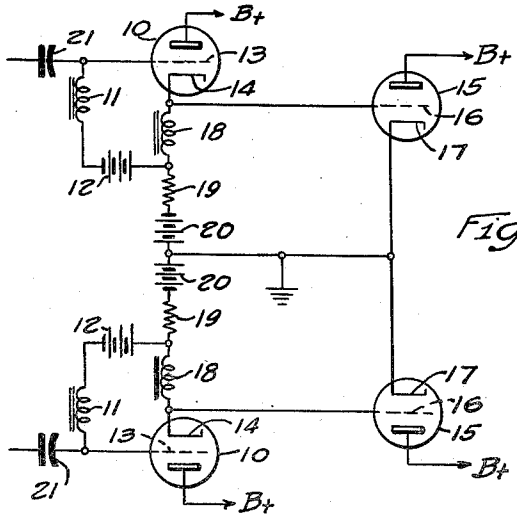


Fig. 3.

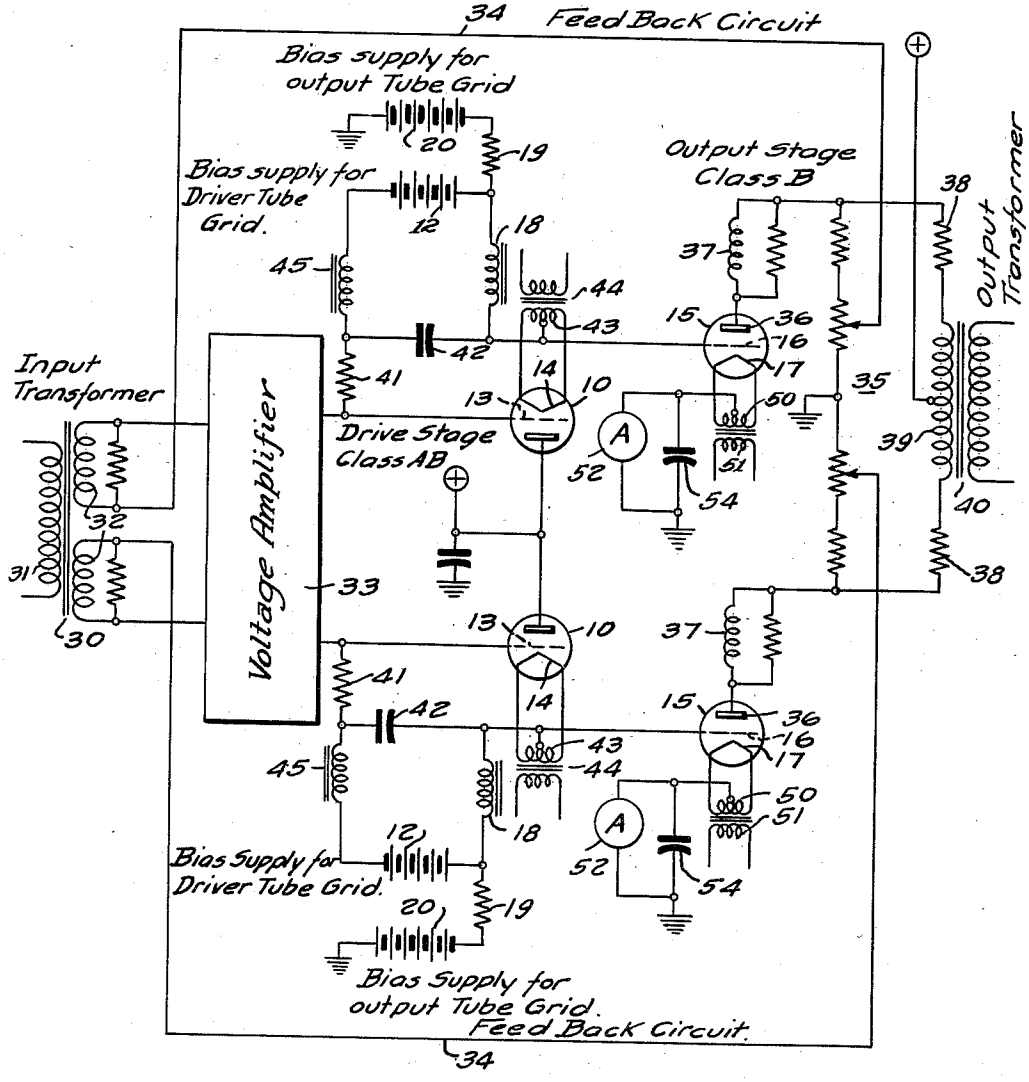
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Fig. 4.



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UNITED STATES PATENT OFFICE

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RADIO APPARATUS

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6 Claims. (Cl. 332—38)

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This invention relates to audio frequency, vacuum tube amplifiers, and relates more particularly to modulators for radio transmitters having class B output stages.

It is desirable to operate class B modulator tubes, as used in radio transmitters, with as low static plate currents as possible so that the power dissipated therein, under no and low modulation conditions, will be as small as possible. However, due to the characteristics of the tubes where they cut-off in plate current, considerable harmonic distortion results, and spurious oscillations are generated at high modulation levels, if the tubes are run at or too near cut-off, as often happens when their plate voltage supply source has poor voltage regulation.

This invention provides for varying the grid bias of a vacuum tube for maintaining the proper relationship between the amplitude of the grid bias and plate supply voltages at different signal levels when the plate supply voltage varies under load. For example, when the grids of class B output tubes are driven more positive on a large signal level increase on the grids of the driver tubes, the resulting plate current increase will cause the plate supply voltage to decrease when the voltage regulation is poor. Utilizing this invention, the grids of the driver tube are so biased that the same large signal level increase on the grids of the driver tubes, which causes the plate supply voltage to decrease, will cause the average direct current values of the cathode currents of the driver tubes to increase and flow through resistors across which voltages are developed, which voltages cause the effective grid bias voltages of the output tubes to become less negative, thus automatically compensating for the fall in plate voltage. Thus, at different, relatively high, signal levels, the grid bias voltages of the output tubes will be automatically adjusted so as to maintain the proper relationship between the grid and plate supply voltages.

An object of the invention is to prevent harmonic distortion in the output of a vacuum tube amplifier having a plate supply source with poor voltage regulation.

Another object of the invention is to prevent the generation of spurious oscillations in a vacuum tube amplifier having a plate voltage supply source with poor voltage regulation.

Another object of the invention is to maintain the proper relationship between the grid bias and plate supply voltages of a vacuum tube when the plate supply voltage varies under load.

Another object of the invention is to use the

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cathode current increase of a class AB driver tube caused by a large increase in signal level applied to the grid of the tube, to decrease the negative grid bias voltage of a following tube to which it is connected.

The invention will now be described with reference to the drawings, of which:

Fig. 1 is a graph illustrating the plate currents and grid voltages of a pair of properly operated class B output tubes using a plate voltage supply source having good voltage regulation;

Fig. 2 is a graph similar to Fig. 1 but illustrating the operating conditions when the plate voltage supply source has poor voltage regulation;

Fig. 3 is a simplified circuit schematic illustrating this invention, as embodied in a modulator having class B output tubes driven by class AB cathode follower tubes; and

Fig. 4 is a circuit schematic illustrating this invention embodied in a class B modulator of a radio transmitter.

Referring first to Fig. 1, the continuous line, sine wave curve marked *eg* #1 illustrates the grid voltage of one of the push-pull connected output tubes of a class B modulator; the continuous line, sine wave curve marked *ip* #1 illustrates the resulting plate current of the same tube; the dashed-line, sine wave curve marked *eg* #2 illustrates the grid voltage of the other output tube; and the dashed-line, sine wave curve marked *ip* #2 illustrates the resultant plate current of the other output tube. The horizontal line marked 2 is a line along which there is no plate current during the operating cycles; the horizontal line marked 1 is a line showing the static plate current when there is no modulation; the horizontal line marked 3 is the line of maximum grid voltage; the horizontal line marked 4 is the line of zero grid bias voltage; the horizontal line marked 5 is the line of normal grid bias voltage; and the horizontal line marked 6 is the line of cut-off grid bias voltage, the bias voltage where the plate current is zero. The vertical dashed lines marked D represent the start of each cycle; the vertical dashed lines marked A represent the times after the starts of the cycles where the plate current curves cross the static current lines; and the vertical dashed lines marked B represent time intervals following the crossing of the static current line by the plate current curves, the intervals D—A equalling the intervals A—B. The bias voltage line 5 of Fig. 1 is seen to run far enough above the cut-off bias voltage line 6 to permit sufficient static current I to flow so that there is a minimum of harmonic distortion. The

tubes draw plate current simultaneously during the intervals D—B.

Fig. 2 illustrates the operation of the same tubes when the plate voltage regulation is poor. The identification of the curves and of the horizontal and vertical lines of Fig. 2 is the same as that of Fig. 1, but it will be observed that the static plate current line 1, and the zero plate current line 2 in Fig. 2 coincide under conditions of maximum modulation. From this it can be observed that the cut-off bias voltage line 6 of Fig. 2, has been shifted above the bias voltage line 5. This represents the condition where, under modulation, the plate supply voltage falls so that the necessary voltage to cut off the flow of plate current is reduced. This causes, as illustrated by Fig. 2, the plate current of the tubes to be cut off during the intervals D—B, a substantial portion of each cycle. As is known, severe harmonic distortion is introduced into the output of such tubes when their plate currents are cut off, or even closely approach cut-off, during any part of the operating cycle.

Another serious disadvantage of having the plate currents of class B output tubes cut off during portions of their operating cycles is that when the plate current of one tube is cut off and the plate current of the other tube does not begin to rise for an instant after, the leakage reactance of the output transformer causes oscillations in the plate circuits, especially at high frequencies, which oscillations will be fed back into the grid circuits unless some provision is made to damp them out. This condition will also occur when non-linearity of plate current exists in the region where both tubes conduct simultaneously.

A feature of this invention is that the bias voltages of the grids of class B output tubes are varied automatically so that regardless of variations in the plate supply voltage resulting from poor regulation, as the plate current of one tube approaches zero, the plate current of the other tube will have started to rise, thus providing continuous flow of plate current which prevents the generation of spurious oscillations, and of harmonic distortion in the tube output circuits.

Another feature of this invention is that it enables the tubes of a class B modulator to be operated at relatively low static plate current levels when there is low or no modulation, resulting in high efficiency, and without distortion resulting from poor plate voltage supply regulation under high modulation operation.

In a class AB driver stage as used in this invention, the grids of the driver tubes are so biased that they operate class A at low signal levels, at which time the direct current values of their cathode currents remain substantially constant as in straight class A stages, and that they operate class AB_1 or AB_2 at high signal levels at which time the average direct current values of their cathode currents increase with increases in signal levels.

The invention now be described with reference to Fig. 3. The class AB driver tubes 10 have the conventional input circuits consisting of the load impedances 11 and the bias voltage supply sources 12 connected between the grids 13 and the cathodes 14. The grids 13 of the tubes 10 are adapted to be connected through the coupling condensers 21 to a suitable amplifier which is not illustrated. The tubes 10 are connected as cathode followers to the class B modulator tubes 15 through the connection of the cathodes 14 of the tubes 10 to the grids 16 of the tubes 15; through the connection of the cathodes 17 of the tubes 15 to ground; and through the connection of the cathodes 14 of the tubes 10 to ground through the series connections of the inductances 18, the resistors 19, and the bias voltage supply sources 20.

The plus sides of the bias voltage supply sources 20 are connected to ground, and their minus sides are connected in series with the resistors 19 and the inductances 18, to the cathodes 14 of the tubes 10.

The inductances 18 are designed to have low direct current resistance and to have high reactances to the frequencies being used. The signal voltages which are developed across the inductances 18 excite the grids 16 of the tubes 15 through the cathode follower connections. The tubes 15 obtain their negative grid bias voltages through the inductances 18 and the resistors 19, from the bias voltage supply sources 20.

The driver tubes 10 are biased to operate class AB so that on large signals, the average direct current, cathode currents passing through the resistors 19 will rise and fall with the modulation envelope. Thus, as the signal level increases in amplitude above the level where the tubes operate class A, the average direct current values of the respective cathode currents increase, and voltages are developed across the resistors 19, the polarities of which are such as to oppose the negative bias voltages supplied by the bias supply sources 20, and so make the effective biases on the grids of the tubes 15 less negative.

When the grids 16 of the tubes 15 are driven more positive on signal level increases, their plate currents will increase, and the voltage of the plate supply source will decrease if its voltage regulation is poor. The same signal level increase will, however, cause the grid biases of the tubes 15 to become less negative, and this will cause the operating points on their characteristic curves to shift so that the proper relations between plate currents and grid voltages for avoiding distortion are maintained.

It is seen, therefore, that this invention permits the modulator tubes to be set at a fairly low static current (near cut-off) for highly efficient operation during periods of zero or low modulation, and automatically decreases the negative grid bias of the tubes under conditions of high modulation and lower plate voltage, so as to prevent the tubes from operating in the approach to cut-off, or at cut-off, with resulting distortion and oscillations.

Fig. 4 illustrates the invention embodied in a class B modulator for a radio transmitter. The conventional input transformer 30 has a primary winding 31 adapted to be connected to a source of signal currents, and has the secondary winding 32 connected to the input of the conventional voltage amplifier 33, and through the conventional degenerative feed-back connections 34, to the conventional voltage dividing network 35 in the plate circuits of the tubes 15.

The plate 36 of the tubes 15 are connected through the conventional radio frequency chokes 37 to the network 35, and through the conventional resistors 38 to the ends of the primary winding 39 of the conventional output transformer 40.

The output of the voltage amplifier 33 is connected to the grids 13 of the tubes 10, which are connected through the grid resistors 41 and the capacitors 42 to the center points of the secondary windings 43 of the filament transformers

44, which supply heating currents to the cathodes 14 of the tubes 10.

The grids 13 of the tubes 10 are also connected through the resistors 41 and the inductances 45, to the negative sides of the bias voltage supply sources 12, the negative sides of the sources 12 being connected through the inductances 18 to the center points of the filament transformer windings 43. The grids 13 of the tubes 10 get their direct current, negative bias voltages through the resistors 41 and the inductances 45 from the bias supply sources 12, the alternating current components flowing through the capacitors 42.

The cathodes 17 of the tubes 15 are energized by the secondary windings 50 of the filament transformers 51, the center points of the windings 50 being connected through the conventional ammeters 52 to ground, the ammeters being shunted by the capacitors 54.

An increase in signal level reaching the grids of the driver tubes 10 through the input transformer 30 and the voltage amplifier 33, sufficient to cause the tubes to change from class A to class AB operation, causes increased average direct current, cathode current to flow through the inductances 18, the resistors 19, and the bias supply sources 20 to ground, the negative sides of the plate supply voltage sources, which are not illustrated, being grounded as is conventional. The grids of the output tubes 15 will be driven more positive by the driver tubes 10 upon the increases in signal level so that the tubes 15 will draw more plate current from their plate voltage supply source causing the plate voltages to drop, assuming the plate voltage supply source has poor voltage regulation. At the same time, the increased average direct current from the cathodes 14 through the resistors 19 causes voltage drops thereacross which decrease the negative bias voltages on the grids 16 of the tubes 15. This will cause the tubes 15 to draw sufficient plate currents under high modulation conditions, as described in the foregoing in connection with Fig. 3, for avoiding distortion.

By way of example, each driver tube 10 may be a WL 473 and each modulator tube 15 may be a WL 5671.

The plate voltage of the driver tubes 10 may be 3300 volts, direct current, and their bias supply sources 12 may supply biases of 250 volts, direct current. The cathode current of each driver tube when operating class A, may be 75 milliamperes, direct current. The cathode current of each driver tube when operating class AB_1 for providing, for example, 100 per cent modulation, may be 200 milliamperes, direct current. Each resistor 19 may have a resistance of 900 ohms. Each inductance 18 may have a value of 75 henries with a low direct current resistance.

Under static conditions, the plate voltage of the modulator tubes 15 may be 15,500 volts, direct current, and their bias supply sources 20 may provide voltages of 450 volts, direct current. The drop through each resistor 19 under static conditions would be approximately 67 volts, so that the biases supplied to the grids of the modulator tubes at such times would be approximately 382 volts.

At 100% modulation, when the average, direct current values of the cathode currents of each driver tube would increase to 200 milliamperes, the drop through each resistor would increase to 180 volts, resulting in the bias on the grid of each modulator tube being decreased to 270 volts. This will cause the modulator tubes to operate sufficiently above cut-off that no distortion can result.

Thus when the modulator tubes would normally operate with distortion due to poor plate voltage regulation, as illustrated by the operating curves of Fig. 2, this invention through automatically maintaining the proper relationship between the effective plate voltage and the grid bias voltage, of the modulator tubes, will cause them to operate properly as illustrated by the operating curves of Fig. 1.

It is understood that it is within the scope of my invention to operate the driver tubes class AB_2, if it is so desired. It also being understood by one skilled in the art that during class AB_2 operation the grids of the driver tubes draw current at higher signal levels.

I claim as my invention:

1. A signal amplifier comprising an output stage including a thermionic tube having a grid; a driver stage including a thermionic driver tube having a grid and a cathode connected to said output stage; means for biasing the grid of said driver tube so that it operates class A at low signal levels and operates class AB at high signal levels; a bias voltage supply source connected to said output tube grid so as to apply a negative bias voltage to same, and means for utilizing an increase in the direct current flowing through said cathode resulting from an increase in the strength of the signal on the grid of the driver tube sufficient to change same from class A to class AB operation, for providing a bias voltage which decreases the negative bias voltage from said source on said output tube grid.

2. A signal amplifier comprising an output stage including a thermionic output tube having a grid; a driver stage including a thermionic driver tube having a grid and a cathode, connected to said output stage; means for biasing the grid of said driver tube so that it operates class A at low signal levels and operates class AB at high signal levels; a bias voltage supply source connected to said output tube grid for applying a negative bias voltage to same, and mean including a resistor in series with said source and the output tube grid for utilizing an increase in the strength of the signal on said driver tube grid sufficient to change same from class A to class AB operation, for providing a bias voltage which decreases the negative bias voltage from said source on said output tube grid.

3. A signal amplifier comprising an output stage including a thermionic output tube having a grid and a cathode; a driver stage including a thermionic driver tube having a grid and a cathode; means for biasing the grid of said driver tube so that it operates class A at low signal levels and operates class AB at high signal levels; an inductance connected at one end to said driver tube cathode and to said output tube grid; a bias voltage supply source having its positive side connected to said output tube cathode, and a resistor connected to the negative terminal of said source and to the other end of said inductance, said inductance and said resistor having such values that the signal voltages developed across said inductance excite said output tube grid, and that an increase in the average, direct current, cathode current through said resistor resulting from an increase

in the signal level on said driver tube grid sufficient to change same from class A to class AB operation, causes a voltage drop across said resistor which decreases the negative bias supplied by said source to said output tube grid.

4. A modulator comprising a class B output stage including a thermionic output tube having a grid; a driver stage including a thermionic driver tube having a grid, connected to said output stage; means for biasing said driver tube grid so that it operates class A at low signal levels and operates class AB at high signal levels; means including a bias voltage supply source for maintaining a negative bias voltage upon said output tube grid when no modulating signals are applied to said driver tube grid, and mean effective when modulating signals having levels high enough to change said driver tube from class A to class AB operation, are applied to the grid thereof, for decreasing the negative bias supplied by said supply source to said output tube grid.

5. A modulator comprising a class B output stage including a thermionic tube having a grid; a driver stage including a thermionic driver tube having a grid and a cathode, connected to said output stage; means for biasing said driver tube grid so that it operates class A at low signals and operates class AB at high signal levels; means including a grid bias voltage supply source for maintaining a negative bias voltage upon said output tube grid during periods when no modulating signals are applied to said driver tube grid, and means including a resistor connected to said cathode and to said output tube grid and in series with said source, for utilizing an increase in the direct current flowing through said cathode resulting from a modulating signal on said driver tube grid having a level sufficient to change same from class A to class AB operation, for providing a bias voltage which decreases the negative bias from said source on said output tube grid.

6. A modulator comprising a class B output stage including a thermionic tube having a grid and a cathode, a driver stage including a thermionic tube having a grid, a cathode and a plate, a biasing source connected to said grid of said driver tube, said driver tube being biased at low modulation percentages so that said grid draws no current and plate current of said driver tube is continuous over a complete cycle, said driver tube being biased at higher modulation percentages so that said grid draws current and plate current of said driver tube is cut off over a portion of a cycle, and a connection for impressing signal voltage developed in the cathode circuit of said driver tube upon the grid of said output stage.

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