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SELF-BALANCING AMPLIFIER

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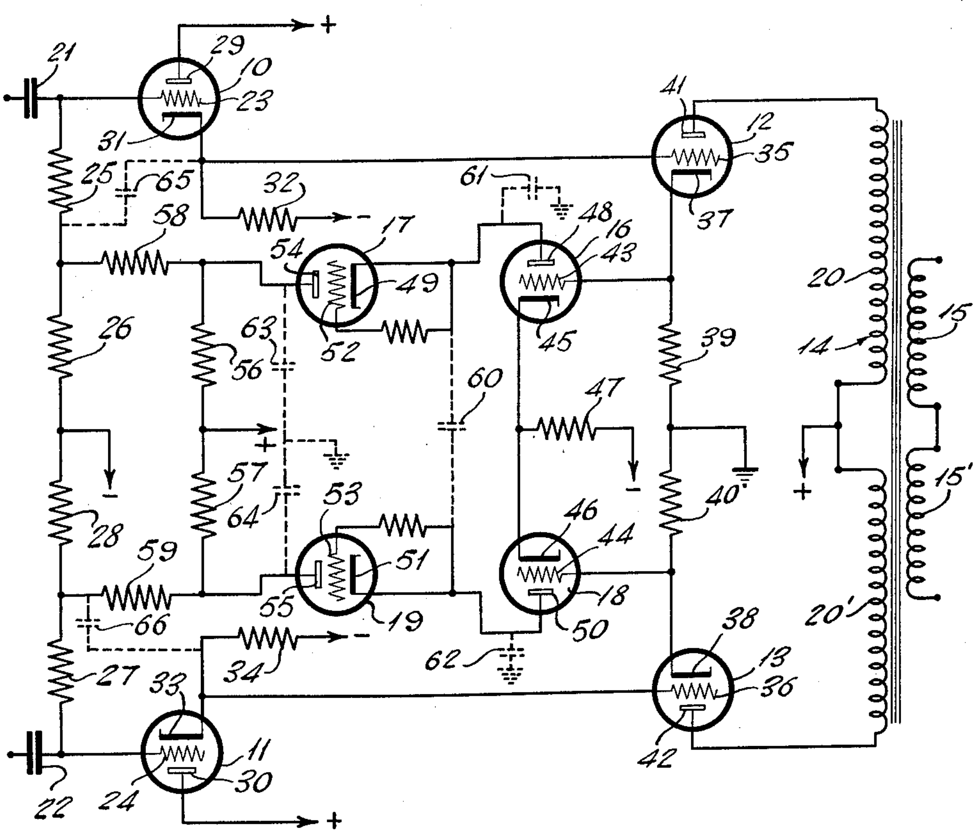

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SELF-BALANCING AMPLIFIER

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This invention relates to electronic amplifying systems and more specifically concerns an improved method and circuit for driving two or more vacuum tubes in push-pull wherein the driven tubes are maintained in a statically balanced condition and the class of operation may be modified in accordance with the signal level impressed on the tubes.

While this improved system is generally useful in all types of amplifying equipment it is particularly important in audio amplifiers for driving a push-pull output stage having transformer coupling in the output circuit. It is well recognized that electronic vacuum tubes of any given type vary in operating characteristics one from the others and in addition are further subject to changes during their life. Differences in the characteristics of tubes operated in push-pull result in differences in their plate currents which when fed through oppositely phased balanced windings of an output transformer will produce a D.C. saturating field in the transformer proportional to the difference between them that adversely affects the operation of the amplifier.

Transformer saturation is normally overcome by the use of adjustable resistors in the output stage to independently vary the grid bias on each tube and thus enable equalization of the plate currents. This procedure obviously does not take into consideration changes in tube characteristics with age and therefore in order to be assured of high fidelity response at all times it is essential that the plate currents in the output tubes be frequently checked and readjusted. While this can be accomplished by one skilled in the art it is not at all satisfactory for commercial equipment intended for use by the laymen. Accordingly it is one object of the invention to provide means for automatically balancing the output tubes of an amplifier to maintain their static plate currents substantially equal at all times. In this way transformer saturation is held at a minimum and a balanced dynamic signal is produced.

Another object of the invention is a self-balancing driving and output circuit for a push-pull amplifier that is characterized by its simplicity, dependability and relatively low cost. While additional amplifying and rectifying elements are used to attain this self-balancing feature the circuit eliminates expensive and critical components and may be quickly and easily adjusted for the desired operation.

A still further object of the invention resides in the provision of a self-balancing output stage for amplifiers together with a push-pull driving stage therefor wherein the self-balancing circuit will provide in addition to excellent static balancing of the output tubes an automatic bias control for the output tubes so that maximum power output can be attained at all power levels. With this arrangement as the input signal to the driving stage is increased the bias on the output tubes is automatically increased to shift the class of operation of the output tubes, for example, from class A to class AB1, AB2, etc.

The above and other objects of the invention will be-

come more apparent with reference to the following description and accompanying drawings forming part of this application and illustrating one embodiment of an amplifier in accordance with the invention.

Briefly, the amplifier illustrated in the drawings comprises a pair of driver tubes **10** and **11** connected as cathode followers and adapted to be operated in push-pull. The cathode of tube **10** is directly coupled to the grid of one output tube **12** while the cathode of the tube **11** is directly coupled to the grid of the output tube **13**. The plate circuit of the output tubes **12** and **13** includes a push-pull transformer **14** adapted to feed a load connected to the secondary windings **15** and **15'**. The automatic balancing features includes a triode **16** and tube **17** connected between the output tube **12** and the cathode follower driver **10** and a second triode **18** and tube **19** interconnecting the cathode of the output tube **13** with the grid of the cathode driver follower **11**. By proper selection of the components interconnecting the several tubes the plate currents of tubes **12** and **13** which are drawn through the primary windings **20** and **20'** of the transformer winding **14** can be maintained in good static balance. This is accomplished through direct coupling of the components so that the D.C. voltage applied to the grids of the output tubes can be controlled by means of the feed back system. Furthermore the values of the various resistors and the characteristics of the tubes in the feed back circuit can be selected so that in addition to static balance, automatic bias control can be effected to gradually increase the negative bias applied to the grids of the ouput tubes as the signal applied to the tubes **10** and **11** is increased.

More specifically a push-pull input signal is applied to the tubes **10** and **11'** through blocking condensers **21** and **22**, respectively, connected to the grids **23** and **24** of the tubes **10** and **11**. The grid return circuit for the grid **23** of tube **10** includes series connected resistors **25** and **26** and a source of negative potential. The grid **24** of tube **11** is similarly connected to a source of negative potential through series connected resistors **27** and **28**. The plates **29** and **30** of tubes **10** and **11** are connected directly to a source of positive potential while the cathode **31** of tube **10** is connected to a negative supply through the cathode resistor **32**. The cathode **33** of tube **11** is connected to a source of negative voltage through its cathode resistor **34**.

The output signal from the cathode follower driver **10** is attained from the cathode **31** and fed directly to the grid **35** of the output tube **12**. Similarly the cathode **33** of the driver tube **11** is connected to the grid **36** of the output tube **13**. Cathodes **37** and **38** of the tubes **12** and **13** are connected to ground through relative low value sampling resistors **39** and **40**, respectively, that may be of the order of five ohms depending upon the magnitude of the plate currents in the output tubes. The plates of the output tubes **41** and **42** are fed through the reversely phased primary windings **20** and **20'** of the output transformer **14** which are in turn connected to a source of positive potential. It will be observed thus far that by properly biasing the tubes **10**, **11**, **12** and **13** that they will perform a normal amplifying function. For instance, the positive and negative supply voltages applied to the cathode driver follower **10** must be proportioned so that the cathode **31** of that tube is at a negative potential of the order required for the desired type of operation to be obtained from the output tube **12**. In this connection the value of resistor **39** may need to be taken into consideration as it will have some effect on the potential of the cathode **37** since the bias or negative voltage applied to the grid is measured with respect to the cathode of the tube. The same requirements apply to the other half of this balanced amplifier involving tubes **11** and **13**.

Referring now to the self-balancing feedback circuits involving tubes **16** through **19**, the grid **43** of the tube **16** is directly coupled to the cathode **37** of the tube **12** while the grid **44** of the tube **18** is connected directly to the cathode **38** of the tube **13**. The cathodes **45** and **46** of the tubes **16** and **18** are coupled together and connected to a negative supply voltage through a common cathode resistor **47**. The plate **48** of the tube **16** is connected to the cathode **49** of the tube **17** while the plate **50** of the tube **18** is connected to the cathode **51** of tube **19**. The tubes **17** and **19** are connected as cascode D.C. amplifiers with the grids **52** and **53**, respectively, being connected through suitable resistors to the cathodes **49** and **51**. If desired these grids **52** and **53** may be returned directly to a source of positive potential.

The plates or anodes **54** and **55** of the tubes **17** and **19** are connected through plate resistors **56** and **57**, respectively, to a source of positive potential. In addition the plate **54** of tube **17** is connected through resistor **58** through the junction of grid resistors **25** and **26** of tube **10** and the plate **55** of tube **19** is connected through a resistor **59** to the junction of resistors **27** and **28** in the grid circuit of tube **11**.

Considering the upper half of the feed back circuit involving tubes **16** and **17**, the tube **17** functions in cooperation with the triode **16** to provide added gain in the feedback circuit without encountering phase reversal. The gain of tube **16** is approximately

$$\frac{uR_L}{R_L-R_P}$$

where u is the amplification factor, R_L is the load impedance on the tube, and R_P is the internal plate resistance of the tube.

The gain of the feedback circuit with the cascode amplifier tube **17** in the plate circuit of tube **16** is

$$\frac{u^2R_L}{R_L+R_P}$$

While the filament circuits have been omitted from this figure for simplicity the tubes are of course provided with suitable filaments for heating the cathodes in accordance with conventional practice. While the tubes **12** and **13** are illustrated as indirectly heated tubes they may of course be filament type tubes with separate voltage supplies for each tube. In addition two or more output tubes **12** and **13** may be employed in cases requiring additional power output.

With the circuit as described above, and with no input applied to the grids of the driver tubes **10** and **11**, the current through the cathode resistors **32** and **34** will determine the bias on the grids of the output tubes **12** and **13**. The current in the plate circuits of these output tubes will be a function of this bias voltage and the potential of the cathodes **37** and **38** of the output tubes. Now assuming that the output tubes **12** and **13** are unbalanced with the tube **12** drawing more current than tube **13**. This will cause the cathode **37** to assume a positive potential higher than that of the cathode **38**. Since the plate current of tube **16** varies with the potential of cathode **37** it will draw more plate current through the tube **17** and plate resistor **56**. The reduction of the potential at the plate **54** of tube **17** decreases the current through grid resistor **26** with the result that the grid **23** of tube **10** becomes more negative. The current through the cathode resistor **32** of tube **10** is thereby decreased, the cathode **31** of tube **10** and grid **35** of tube **12** become more negative and the plate current of tube **12** is decreased.

Simultaneously with the foregoing action the plate current of the output tube **13** is increased through the action of the common cathode resistor **47** for the tubes **16** and **18**. Thus under a condition where the tube **16** draws more current both cathodes **45** and **46** become more positive

and effectively increases the negative bias on grid **44** of the tube **18** so that the grid **36** of output tube **13** will become more positive and cause the tube **13** to draw more plate current. In this way automatic static balance is attained.

In certain cases it may be necessary to prevent undesirable degeneration or feedback of the signal voltage through the feedback circuits and in addition prevent the balancing procedure from functioning too rapidly. To increase the time constant of the circuit a condenser **60** may be connected between the plates **48** and **50** of tubes **16** and **18** as illustrated in dotted outline. This condenser will also serve to prevent degeneration and its action may be supplemented by condensers **61**, **62**, **63** and **64** connected from the plates of tubes **16** to **19** to ground, respectively. Increased input impedance to the tubes **10** and **11** can be attained by the utilization of condensers **65** and **66** connected between the cathode and grid circuits of those tubes.

As previously pointed out, the feedback circuits of this amplifier can be operated to modify the class of operation of the output tubes **12** and **13**. In this case the circuit elements would be adjusted so that the feedback signal from the cathodes of the output tubes to the grids of the driver tubes would vary so that the grids of the output tubes would become more and more negative as the signal is increased and thus maintain output tube operation at all times along the straight portion of the grid voltage plate current curve.

It is significant to note that with the condensers **60** to **66** omitted, the time constant of the feedback circuit is very small and only static balancing is obtained. With the condensers as described above dynamic control of the bias of the output tubes is obtained since the long time constant will sustain the feedback voltages. Furthermore the required D.C. component amplified by the feedback circuit to attain a change in bias results from the rectification produced by the output tubes themselves since in push-pull operation the plate current variations of each tube are not symmetrical about a central value and therefore the differences between the positive and negative changes in plate current results in a D.C. component proportional to the asymmetrical nature of these variations.

While only one embodiment of the invention has been illustrated and described it is apparent that modifications, alterations and changes may be made without departing from the true scope and spirit thereof.

What is claimed is:

1. In an amplifier having a pair of driver tubes each directly coupled with one of a pair of output tubes connected in pushpull for the transmission of direct current and alternating current signals, said output tubes each having a control electrode and means for biasing said electrode, feedback means including at least two direct current amplifiers each connected with one of said driver tubes and responsive to the biasing means of the associated output tube to modify the operating characteristics of the last said driver tube and control the bias on the control electrode of the output tube coupled to the last said driver tube and a biasing impedance in circuit with both of said direct current amplifiers so that an increase in a signal produced by one direct current amplifier will result in a decrease in the corresponding signal produced by the other amplifiers.

2. An amplifier comprising a pair of amplifying devices each connected as a cathode follower and having at least three electrodes including a control electrode, at least two output amplifying devices connected in push pull and each having at least three electrodes including a control electrode, individual means self-biasing each of said output devices, direct coupling between each cathode follower amplifier and the control electrode of one of said output tubes, at least two direct current amplifying devices each having a control electrode connected with one of said self-biasing means, a biasing impedance common

to both of the last said devices for biasing the control electrodes thereof, and connections between each of said cathode follower amplifiers and one of said direct current amplifiers to modify the operation of said cathode follower amplifying devices and the bias on said control electrodes of said output devices in accordance with changes in the self-bias of each of said output devices.

3. An amplifier comprising at least two cathode follower connected driver tubes each having a plate, cathode and control grid adapted to be operated in push-pull, an output stage having at least two tubes each including a plate, cathode and control electrode connected for push-pull operation, direct current coupling between the cathodes of each of said driver tubes and control electrodes of said output tubes, a direct current amplifier interconnecting the cathode of each output tube with the grid of its associated driver tube and electrical means interconnecting the last said direct current amplifiers to produce an increased signal in one amplifier when the signal in the other is decreased, whereby a change in cathode current of one output tube in one direction will function through its associated direct current amplifier and driver tube to effect a change in potential of its grid and thereby change its cathode current in the other direction and simultaneously reflect corresponding changes of reverse direction in the direct current amplifier and driver tube associated with the other output tube and cathode current of the last said output tube.

4. An amplifier according to claim 3 wherein each direct current amplifier includes at least one amplifying device having a plate, grid and cathode and a rectifier interconnected therewith and said electrical means comprises an impedance to common to the cathodes of both direct current amplifying devices.

5. An amplifier comprising a pair of vacuum tubes each connected as a cathode follower and having a cathode, plate and at least one grid, at least two output tubes each having a cathode, plate and at least one grid, means coupling the plates of the output tubes in push-pull, separate impedance in circuit with each output tube cathode, a direct connection between the cathode of each cathode follower and the grid of one of said output tubes, at least two direct current amplifier tubes each having a plate, cathode and at least one grid, a connection between the grid of each direct current amplifier and the cathode of one of said output tubes, an impedance in series with the cathodes of both direct current amplifiers, at least two cascode amplifiers each in series with the plate of one of said direct current amplifiers and impedance means coupling each cascode amplifier to the grid of one of said cathode followers, whereby an increase in the cathode potential of one output tube will change the cathode potential of the associated cathode follower and the grid of the last said output tube to reduce cathode potential thereof and at the same time produce a reverse reaction in the other output tube to cause its cathode potential to decrease.

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