

July 16, 1940.

E. B. FERRELL

2,207,976

AMPLIFIER CIRCUIT

Filed Aug. 6, 1937

3 Sheets-Sheet 1

FIG. 1

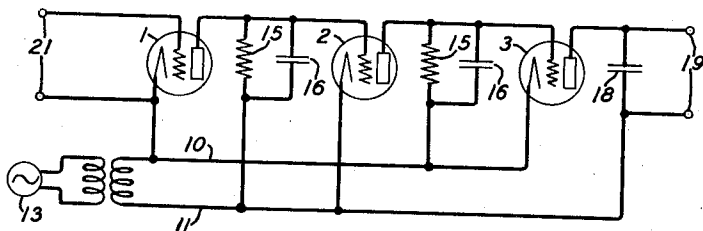


FIG. 2

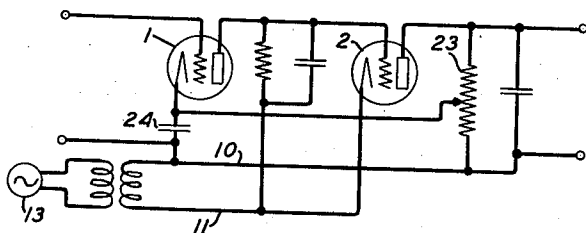


FIG. 3

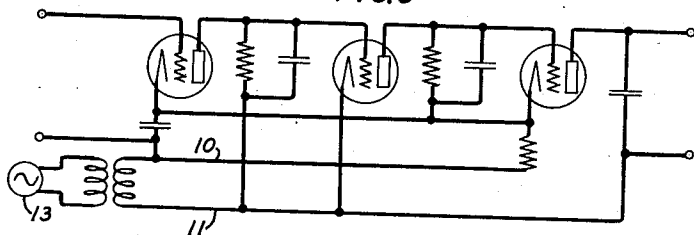
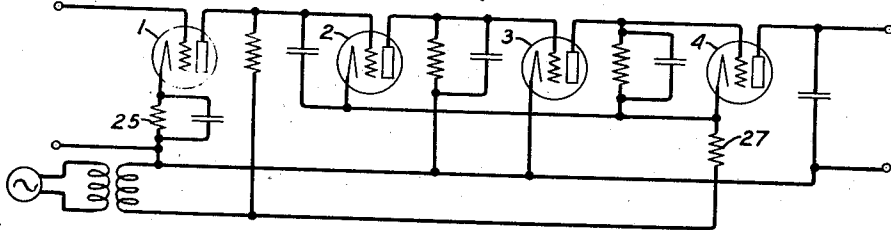


FIG. 4



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FIG. 5

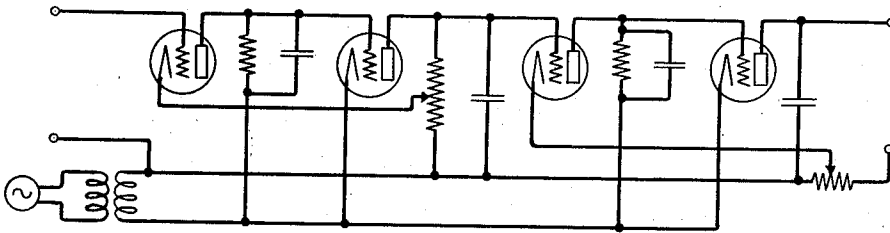


FIG. 6

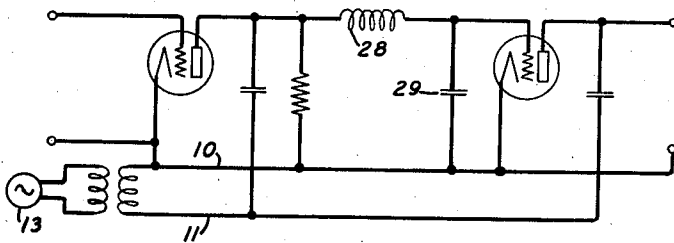


FIG. 7

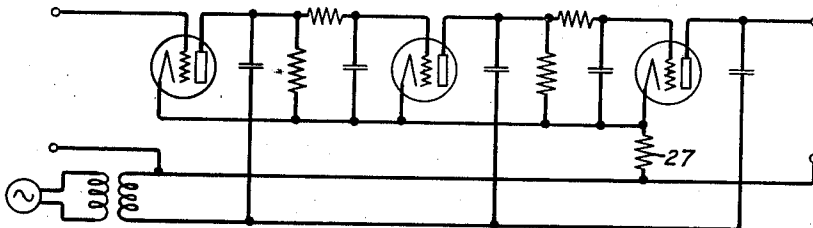
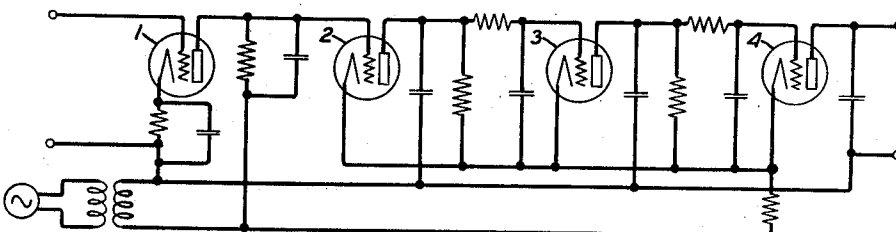


FIG. 8



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FIG. 9

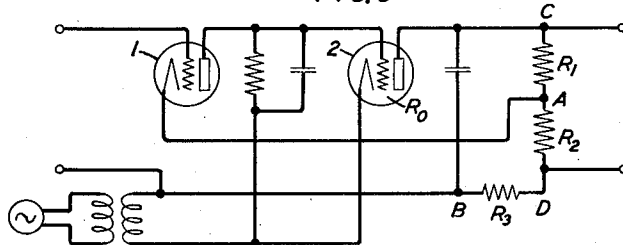


FIG. 10

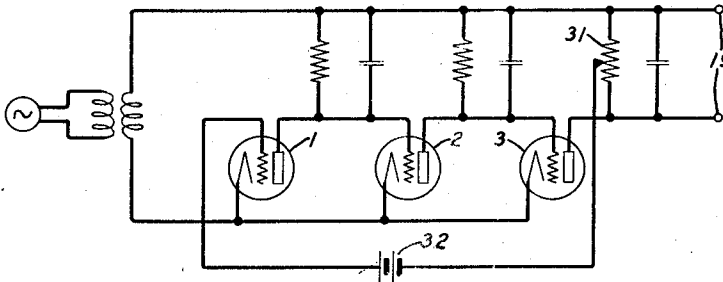
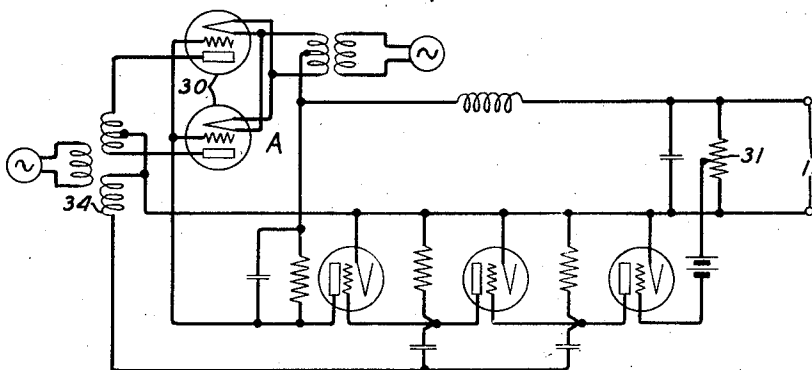


FIG. 11



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AMPLIFIER CIRCUIT

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Application August 6, 1937, Serial No. 157,693

5 Claims. (Cl. 179—171)

This invention relates to amplifier circuits and more particularly to circuits making use of vacuum tube amplifiers for which the basic supply of power is an alternating current source. Still more particularly it relates to an amplifier circuit in which alternating current voltage is supplied directly to the plate circuits of tubes without the intermediate step of rectification.

In some cases I arrange the circuits so that alternate tubes have their anodes connected to one side of the alternating current power line and the other tubes have their anodes connected to the other side of the power line. In other cases I find it convenient to connect all the tubes in such manner that the anodes are connected to the same side of the alternating current power source. In both cases the intermittent supply of power to the tube gives substantially the same effect as is accomplished in a conventional direct current amplifier by a plurality of separate batteries or by batteries of opposed polarity.

The invention will be better understood by reference to the following specification and the accompanying drawings, in which

Fig. 1 represents the basic principles of my circuit with the tubes connected in the alternate arrangement;

Figs. 2 to 5 are various modifications of the circuit of Fig. 1, all embodying feedback circuit connections in a manner to be hereinafter described;

Fig. 6 shows an arrangement in which the anodes of the tubes are connected to the same side of the power line;

Fig. 7 is a modification of Fig. 6 incorporating feedback connections;

Fig. 8 is a circuit which includes both the arrangement of alternate connection and the arrangement of tubes connected to one side of the power line;

Fig. 9 is a circuit similar to Fig. 2, but with a modified form of feedback connection; and

Figs. 10 and 11 show certain applications of the previous circuits to control purposes.

Referring more particularly to Fig. 1, there is shown a circuit of three amplifier tubes 1, 2 and 3 connected in cascade or tandem formation. A power line 10—11 supplied from an alternating current source 13 is provided with connections from the cathodes of the odd-numbered tubes to one side 10 of the alternating current power line, the alternate tube 2 having its cathode connected to the other side 11 of the power line. The anodes of the tubes 1 and 3 are connected to the one side 11 of the power line through suit-

able external impedances and the tube 2 is similarly connected to the side 10 of the power line. The output circuit of all but the last tube is here shown as consisting of a resistance element 15 in parallel with a condenser 16 and this external impedance constitutes also the interstage coupling from one tube to the next tube. The output of the last tube is shown as a condenser 18 connected to any desirable load circuit 19.

On those half-cycles which carry the conductor 11 positive, the first tube conducts and as a rectifier builds up a voltage across its external plate resistance 15. The impedance of this tube as a rectifier, and hence the voltage across its load resistance 15, depends upon the potential of its grid and the more positive is the grid with respect to its cathode, the greater is the voltage across the load resistance. The potential of the grid is controlled by any suitable signal impressed on the input circuit 21.

It will be noted that the voltage across the resistance 15 of the first tube is negative with respect to the conductor 11. Hence, according to the connections shown, the grid of the second tube is biased negative with respect to its own cathode and this negative bias is made more negative when the first grid is made more positive with respect to the first cathode. The time constant of the impedance 15—16 is made sufficiently high to permit the signal output from the tube 1 to be impressed on the succeeding tube 2 at a time when the latter has positive potential on its anode.

When the conductor 10 takes on a positive value, the tube 2 begins to conduct and the current which flows is determined in part by the potential of its grid, which in turn is controlled by the potential difference across the interstage coupling between tubes 1 and 2 and this potential in turn is controlled by the signal voltage at the input 21.

In precisely the same way the tube 3 is rendered conducting at the same time as the tube 1, during which time the tube 2 is not conducting. The current, however, which flowed through the tube 2 has permitted the building up of a charge in the interstage coupling between 2 and 3, which charge maintains a potential on the grid of tube 3 in spite of the fact that the tube 2 has become non-conductive. Obviously, the number of tubes which are connected in cascade formation may be increased to such extent as is desired and in the output of the last tube there is connected a suitable load circuit 19, supply for which is maintained by the condenser 18.

It will be noted that the instantaneous value of the potential of the anode of such a tube as tube 1 is given by the expression

$$(E \cos pt - e_p - \mu e_c)$$

where E is the peak value of the voltage across the power line,

e_p is the numerical value of the direct current voltage across the plate resistance 15, and

e_c is the numerical value of the negative direct current voltage supplied to the grid.

It is apparent that the tube 1 cannot conduct current unless this quantity has a positive value.

As stated above, the interstage coupling circuit 15-16 has a time constant sufficiently high so that its potential difference carries over from one cycle to the next of the alternating current supply. This means that the amplifier will not follow variations of the input voltage at a rate as high as that of the alternating current source and the circuit is therefore more peculiarly adapted for amplifying signal frequencies of lower value than the frequency of the alternating current source. Thus, if the source should be of the usual 60-cycle frequency, the circuit is especially adapted for what is commonly called a direct current amplifier or for the amplification of signals, the essential frequencies of which are lower than the 60-cycle frequency of the power line. If it is desired to amplify a band of frequencies extending from 0 to f , inclusive, a source of supply should be used having a frequency higher than f .

In general, undesirable modulation products involving combinations of the power frequency and the signal frequency will be formed. Some of these will be of frequency lower than the power supply. Hence, it may be desirable and in some cases necessary to space the power frequency well above the signal frequency. For example, if it is desired to amplify direct current and all frequencies up to 10 kilocycles, one may use a power supply at 50 or 100 kilocycles. In this case also it will be desirable that the interstage coupling circuits shall take on definite filter characteristics, which for the example cited might be arranged to cut off at 12 or 15 kilocycles, suppressing frequencies above the cut-off value. Such filters may be used to replace any or all of the interstage couplings and may, if desired, also be used in the output circuit.

It will be recognized that this amplifier in the simple form of Fig. 1 would be likely to give rise to considerable distortion and be subject to the objections of instability with supply of voltage variations, tube aging, etc. For this reason I find it advantageous to supply a negative feedback which has the property of increasing stability and decreasing distortion occurring in the circuit. Such a feedback connection may be introduced in a variety of ways. Thus, referring to Fig. 2, it will be noted that there are two tubes 1 and 2 connected in reverse manner to the main supply, having an interstage coupling and an output circuit similar to that of Fig. 1. Across the output circuit of the tube 2, however, is shown the resistance 23, serving as a potentiometer, from one point of which there is a connection to the cathode of tube 1. The feedback connection comprises, then, a portion of the resistance 23 and also the condenser 24, the two elements constituting a circuit with a time constant comparable to that of the circuit 15-16. If in the circuit of Fig. 2 the first grid is driven

positive, the first tube draws more current. The first plate, therefore, carries the second grid more negative with respect to the second cathode and the second tube then draws less current, and the second plate now becomes less negative with respect to its power line. This is a movement in the positive direction and if a part of this is applied to the first cathode as shown, it decreases the effect of the initially assumed positive drive on the first grid. The feedback is, therefore, a negative feedback.

Fig. 3 shows a similar arrangement using three stages. It is also possible to use four stages with the feedback voltage taken from the plate of the fourth tube in the manner shown in Fig. 2.

It will be noted that the feedback of Fig. 2 is a voltage feedback, but this feedback voltage may be developed across a small resistance in series with the plate and thus made a current feedback as illustrated in Fig. 3. Still other forms of feedback connections may be used, as will be pointed out hereinafter.

The arrangement of Fig. 2 is particularly desirable in that it may take a voltage which is negative from one of the power supply wires, which may be grounded, for example, and delivers finally a voltage which is negative from the same reference point. In this way it would be observed that one may have a circuit with an output which has one side common to the input. Also, this feature of an output with one side common to the input may be obtained with greater amplification by the arrangement of Fig. 4. Here the first tube 1 has a large resistance 25 in series with the cathode. It is, therefore, highly degenerative and has a low but quite constant gain. It serves principally as a phase inverter, but it will be noted that one side of the input circuit is common with one side of the output circuit. Also, this Fig. 4 involves two feedback amplifiers, one containing a single stage comprising the tube 1 and the other containing three stages comprising the tubes 2, 3 and 4, the feedback in this case being accomplished through the resistance 27.

As a variation of the feedback connection, Fig. 5 shows a total of four stages made up of two two-stage feedback amplifiers in cascade, and it becomes apparent now that a great variety of combinations of one, two, or more stages of feedback amplifiers could be made.

While the invention has thus far been described as one in which alternate cathodes are tied to opposite sides of the power supply line, this is not necessary. Thus, Fig. 6 shows an amplifier in which all the cathodes are tied together. The action of the circuit will be obvious from the description which has been given heretofore. The connections of Fig. 6 cause all tubes to draw current on the same half-cycle. This will not ordinarily cause undue loading of the power line on the one side alone, for it will be understood that in all of the circuits the current of the last tube is ordinarily much larger than that of the others.

In this circuit of Fig. 6, as well as in the others of this application, there will be occasions when the frequencies due to the primary alternating current source will be troublesome. These will to a large extent be suppressed by the circuits 15, 16 but in case the residual variations are still troublesome they may be suppressed by means of wave filters introduced at one point or another in the line in the circuit. Thus, in Fig. 6, there is shown one section of a low-pass filter compris-

ing the inductance 28 and the capacity 29. Obviously more elaborate filters may be introduced at this or other points as one may desire.

Fig. 7 is a modification of the circuit of Fig. 6, there being shown here three stages of amplification, with the cathodes all connected to one side of the power line and with a negative feedback introduced by the resistance 27. It will also be noted in this case that the output circuit has one side common to the input circuit.

Fig. 8 shows a combination of these two arrangements. Thus, the cathode of the first tube is connected to one side of the power line and the cathodes of all the other tubes are connected in parallel to the other side of the power line. The first tube acts virtually as a phase inverter, in a manner analogous to that of tube 1 in Fig. 4. The interstage coupling arrangement from tube 1 to tube 2 is similar to that of Fig. 1, and the interstage couplings between tubes 2-3 and tubes 3-4 are the same as that shown for Figs. 6 or 7.

Fig. 9 illustrates an extension of the arrangements for providing feedback connection, the one here shown being that commonly known as the bridge type of feedback. In Fig. 9, R_0 represents the internal impedance of the last tube. The resistances R_0 , R_1 , R_2 and R_3 form a balanced bridge with the points AB conjugate to the points CD. Under these circumstances, the voltage between A and B is dependent upon the apparent generator voltage in the last tube and is fed back to the grid of the first tube, but this voltage between A and B is independent of changes occurring in the load circuit, all in the manner which is well known in the art.

An amplifier of the type described above is particularly applicable to control circuits such as those for automatic volume control, rectifier output regulation, battery charging, alarm signal operation, etc. In the automatic volume control circuit as applied to many radio receiving sets the negative bias applied to various tubes should be proportional to, but many times as large as the negative voltage developed at the detector, and the circuits described above are peculiarly well adapted to supply this. In the regulation of rectifiers or generators some standard voltage may be used as a reference. The direct current amplifier of my invention would be used to drive the grids of the rectifier tubes or the field of the generators so that the rectifier or generator output current is proportional to the difference between the terminal voltage and the reference voltage. An illustration of this is given in Fig. 10 in which the group of amplifiers 1, 2 and 3 are arranged in tandem in substantially the manner indicated in Figs. 6 and 7. The tube or tubes serve as a rectifier to deliver direct current power at the terminals 19 from the alternating current power supply. Across the direct current power line is bridged a volt coil 31, and a feedback connection from a suitable point thereon goes to the grid of tube 1. In this feedback grid circuit there is also included a reference voltage from a source 32. If the voltage amplification in this circuit after feedback is, say, 100, and if we use as the input or reference voltage 32 a 1.5 volt dry cell, then the output across the terminals 19 is 150 volts and in so far as the negative feedback has made the amplification ratio independent of time, load, supply voltage, etc., this output voltage will also be independent of those variables. It will be observed that the source of reference voltage 32 need not deliver any appre-

ciable current and may, therefore, consist of small cells designed for long shelf life. For more precise regulation some of the well-known standard voltage cells can be used.

Still another particular illustration of the application of my invention is shown in Fig. 11 in which the upper part A of the figure represents a conventional rectifier supplying direct current power to the terminals 19. The rectifier tubes 30 have grid control. Due to variations in the load or in the alternating current supply the voltage across the terminals 19 will in general, be subject to fluctuations. To protect against this, there is provided as shown in the lower part of Fig. 11 a direct current amplifier feeding part of its output back to the grids of the rectifier tubes in the portion A. Any variations in the voltage across the terminals 19 are effective, through the volt coil 31, to operate on the grid of the first in the train of direct current amplifier tubes. The particular circuit of Fig. 11 is applicable to high vacuum rectifying tubes, each tube comprising three elements, one of which is a control grid, such as are well-known in the art. It is, however, evident that any type of rectifier tube may be used so long as these rectifier tubes are subject to control. Thus, they may be replaced by gaseous rectifiers of the hot cathode or ignitron type, if these are at the same time provided with suitable alternating current excitation of the grids. In this Fig. 11 a separate secondary winding 34 is shown as providing power for the plate circuits of the direct current amplifier. This, however, is a matter of convenience and the necessary alternating current voltage could be obtained by tapping from the main high voltage winding.

A division of this application, directed particularly to the subject-matter of Figs. 10 and 11, was filed March 13, 1940, as application Serial No. 323,689, for Amplifier circuits.

While this invention has been described in terms of three-electrode tubes, this is for the sake of simplicity. It is understood that any or all of these tubes may be replaced by tubes of other types such as screen grid tubes or pentodes. The substitution of these will be obvious to those skilled in the art.

What is claimed is:

1. An amplifier circuit comprising a plurality of electron discharge devices in tandem, an alternating current power source connected to the cathodes and anodes of said devices such that alternate devices operate on alternate half cycles of said supply, a negative feedback circuit for the initial discharge device, and a negative feedback circuit for the succeeding devices, said latter feedback circuit including an impedance common to the cathode-anode circuits of each of said succeeding devices.

2. An amplifier circuit comprising a plurality of electron discharge devices in tandem, an alternating current power source connected to the cathodes and anodes of said devices such that alternate devices operate on alternate half cycles of said supply, a negative feedback circuit for the initial discharge device, and a negative feedback circuit for the succeeding devices, said latter feedback circuit including an impedance common to the cathode-anode circuits of each of said succeeding devices, one side of the input circuit of the amplifier being common with one side of the output circuit of the amplifier.

3. An amplifier circuit comprising a plurality of electron discharge devices in tandem, an al-

ternating current power source connected to the cathodes and anodes of said devices, a negative feedback circuit for the initial discharge device, and a negative feedback circuit for the succeeding devices, said latter feedback circuit including an impedance common to the cathode-anode circuits of said succeeding devices.

4. An amplifier circuit comprising a plurality of electron discharge devices in tandem, an alternating current power source connected to the cathodes and anodes of said devices, a negative feedback circuit for the initial discharge device, and a negative feedback circuit for the succeeding devices, said latter feedback circuit includ-

ing an impedance common to the cathode-anode circuits of each of said succeeding devices, one side of the input circuit of the amplifier being common with one side of the output circuit of the amplifier.

5. An amplifier circuit comprising a plurality of electron discharge devices in tandem, an alternating current power source connected to the cathodes and anodes of said devices, and a negative feedback connection for said devices comprising an impedance common to the cathode-anode circuits of said devices.

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