March 4, 1941. R. J. ROCKWELL 2,233,961

AMPLIFYING SYSTEM AND PROCESS

Filed July 18, 1939 2 Sheets-Sheet 1

Fig. 1.

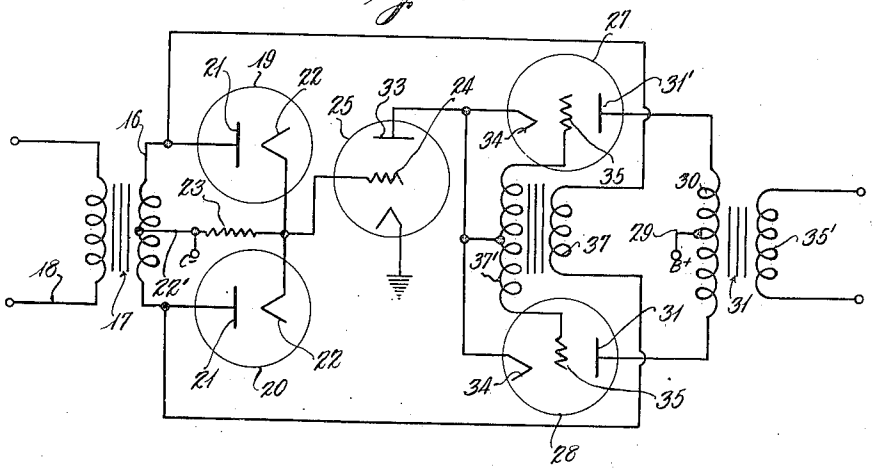
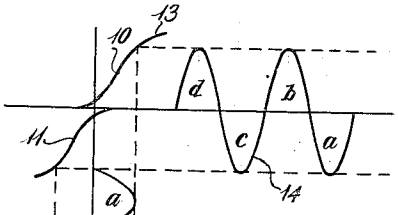
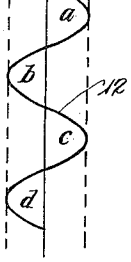


Fig. 2.





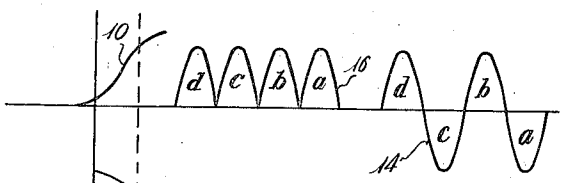
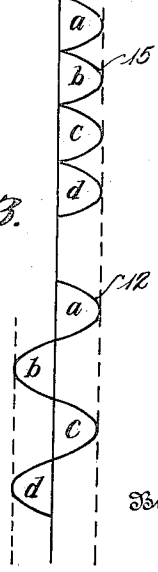


Fig. 3.



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March 4, 1941. R. J. ROCKWELL 2,233,961

AMPLIFYING SYSTEM AND PROCESS

Filed July 18, 1939 2 Sheets-Sheet 2

Fig. 4.

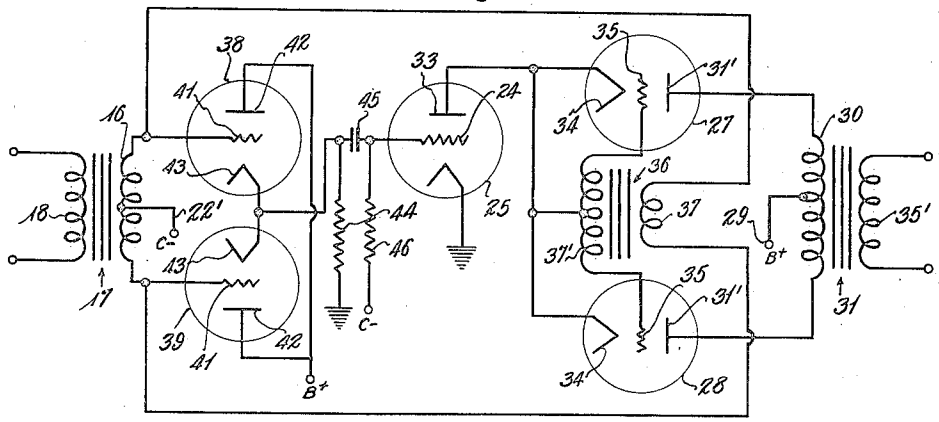
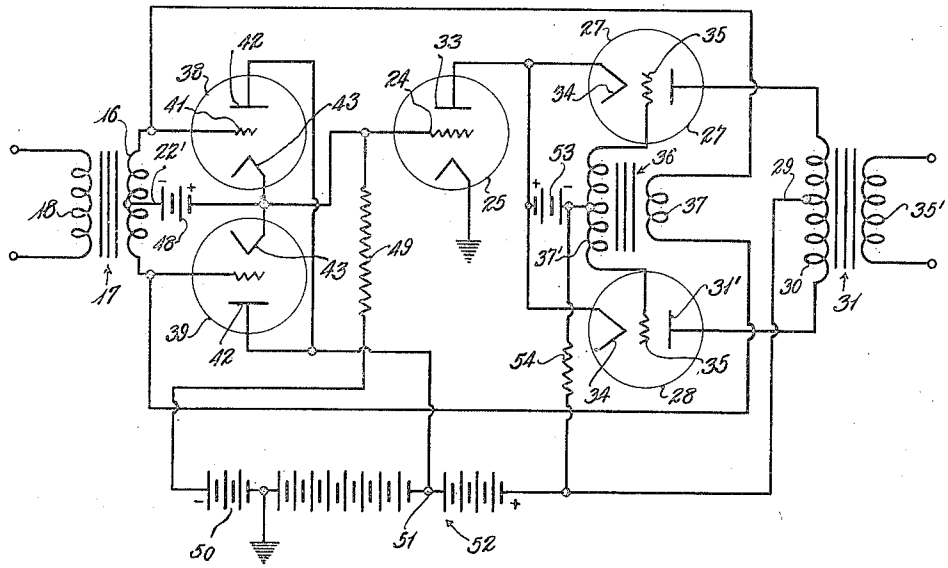


Fig. 5.



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Patented Mar. 4, 1941 2,233,961

UNITED STATES PATENT OFFICE

2,233,961

AMPLIFYING SYSTEM AND PROCESS

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Application July 18, 1939, Serial No. 285,180

15 Claims. (Cl. 179—171)

This invention relates to an amplifier system, and process of amplification, and more particularly to an amplifying system in which one amplifying tube is capable of performing work heretofore requiring two tubes of the same type. The invention is particularly applicable to high powered class B amplifying systems, but may be employed for other purposes.

In many modern high powered transmitting stations, class B audio frequency amplifier tubes are employed as plate circuit modulators for the output tubes of the radio frequency amplifying system. For example, in a 500 k. w. transmitter, eight 100 k. w. audio amplifier tubes operating as class B push-pull amplifiers may be employed as modulators for twelve 100 k. w. radio frequency amplifier tubes. Each 100 k. w. tube costs in the neighborhood of $1650 and furthermore requires approximately 7.5 k. w. tube for filament excitation.

In accordance with the present invention, eight 100 k. w. audio amplifier tubes may be replaced by four similar tubes, not only saving the initial cost of the tubes but providing a material saving in power requirements.

Such modulator tubes are ordinarily operated as class B amplifiers with one-half of the tubes in push-pull with the other half. Only one tube of a pair is utilized at a time, as each tube operates during one-half cycle. That is to say, the grid of one tube is driven in a positive direction while the other tube is driven in a negative direction and since the tubes are operated with a negative bias substantially equal to cut off, the plate current in one tube is zero during each half cycle. The load, therefore, shifts from one tube to the other, depending upon which grid is driven in a positive direction.

In accordance with the present invention, the alternate half wave impulses of the voltage or signal usually applied to the grid of one of a pair of amplifier tubes are transferred or folded over to the other side of the axis of the wave so that both half cycles are on the same side of the axis and are applied to the grid of the same amplifier tube. After amplification, the alternate half cycles are then restored to the opposite side of the axis so that the resulting wave form is the same as that produced from two amplifier tubes operating in push-pull. That is, the same amplifier tube is employed for both halves of the wave. The cost and size of amplifier tubes operating as class B amplifiers are primarily determined by the peak emission conditions rather than heat radiating conditions. That is to say, the capacity of the tube is determined by the maximum usable emission of electrons from the filament rather than the power losses in the tube. The maximum electron emission in a given tube is not increased when one tube replaces a pair of tubes in accordance with the present invention and one tube can perform the work ordinarily requiring two tubes.

It is therefore an object of the present invention to provide an amplifying system and process in which both halves of the wave to be amplified are applied to the grid of a single amplifier tube so that the tube does the work of two tubes operating in push-pull.

Another object of the invention is to provide a system and method of amplifying in which successive half cycles of the wave to be amplified are transferred to the same side of the axis so that both half waves appear on the same side of the axis during amplification.

Another object of the invention is to provide a system of amplification in which the wave to be amplified is rectified and then applied to the grid of a class B amplifier tube so that one tube performs the work of two tubes.

A further object of the invention is to provide a system and process of amplification in which the half cycles of the wave to be amplified are positioned upon the same side of the axis, the resulting wave amplified, and alternate half cycles restored to the opposite side of the axis.

Other objects and advantages of the invention will appear in the following description of preferred embodiments thereof shown in the attached drawings, of which:

Figure 1 is a schematic diagram of a circuit in accordance with the present invention;

Figure 2 is a diagram illustrating the operation of the conventional class B amplifier;

Figure 3 is a similar view illustrating the operation of an amplifier in accordance with the present invention;

Figure 4 is a view similar to Figure 1 showing a modified amplifying system; and

Figure 5 is another view similar to Figure 1, showing a further modified amplifying system.

Referring to Figure 2, this figure is a conventional representation of the operation of a class B push-pull amplifier. The curve 10 represents the dynamic grid voltage plate current characteristic of one of the tubes and the curve 11 represents the similar characteristic of the other tube. The tubes are operated at a negative bias substantially equal to cut off so that alternate

half cycles *a* and *c* of the impressed voltage represented by the curve 12 causes current to flow in one tube and the other alternate half cycles *b* and *d* cause current to flow in the other tube. The curves 10 and 11 together produce a substantially straight line characteristic provided the tubes are operated below the knee 13 of the curves 10 and 11 representing the maximum usable electron emission of the tubes. That is to say, the capacity of the tube is determined by the peak emission characteristics of the tube. The curve 14 represents the current in the output circuit of a conventional class B push-pull amplifier.

As illustrated in Figure 3, the impressed voltage represented by the curve 12 is in accordance with the present invention first rectified, or subjected to a frequency doubling operation, so that the half cycles of the signal are all on the same side of the axis as illustrated by the curve 15. This signal is then applied to a single amplifier tube operated with a negative bias substantially equal to cut off, the dynamic characteristic of which is represented by the curve 10. The plate current is represented by the curve 16 and the positions corresponding to alternate half cycles of the original signal are then restored to the opposite side of the axis to produce a signal represented by the curve 14 which is the same as the curve 14 of Figure 2.

In the circuit shown in Figure 1, the voltage represented by the curve 12 of Figures 2 and 3 is obtained from a center tapped secondary 16 of an input transformer 17 provided with a primary 18 connected to a source of voltage (not shown). Rectifying tubes 19 and 20 have their plates 21 connected to opposite terminals of the secondary 16 and their cathodes 22 connected together and to the center tap 22' of the secondary 16 through a resistor 23. It will be apparent that the tubes 19 and 20 are connected to form a full wave rectifier circuit and that the voltage across resistor 23 is of the form represented by the curve 15 of Figure 3. This voltage is impressed upon the grid 24 of a main amplifier tube 25, preferably by connecting the grid 24 directly to the cathodes 22 of the tubes 19 and 20.

The sources of the filament, plate and bias potentials are not shown in Figure 1 to avoid complicating the diagram. Bias potential is furnished to the grid 24 of the tube 25 from a source of grid potential (not shown) through the center tap 22' of the transformer secondary 16 and the grid circuit is completed to ground through the source of bias potential. The plate circuit for the tube 25 is completed through grid controlled rectifier tubes 27 and 28; the center tap 29 of the primary 30 of an output transformer 31 connected across the plates 31' of the tubes 27 and 28; and the source of plate potential (not shown) having its negative terminal connected to ground and its positive terminal connected to the center tap 29. The plate 33 of the amplifier tube 25 is connected to the cathodes 34 of the grid controlled rectifier or restoring tubes 27 and 28 and the plate current of the tube 25 has a wave form similar to that of the curve 16 of Figure 3.

The tubes 27 and 28 are employed to shift alternate half cycles of this current to the opposite side of the axis in the primary 30 of the output transformer 31. It will be noted that the plate current represented by the curve 16 is zero at the end of each half cycle. Voltages obtained from the circuit prior to the rectifier tubes 19 and 20 can be impressed upon the grids 35 of the tubes 27 and 28 so that current flows in each tube during alternate half cycles. This voltage may be obtained from the terminals of the secondary 16 of the input transformer 17 and may be applied to the grids 35 through a transformer 36 having a primary 37 connected across the secondary 18 of the transformer 17 and a secondary 37' having its opposite terminals connected to the grids 35 of the tubes 27 and 28 and a center tap connected to the cathodes 34 of the tubes 27 and 28. It will be appreciated that the secondary 37' of the transformer 36 may be a tertiary winding upon the transformer 17 is sufficiently insulated from the other windings of the transformer 17. The grid 35 of one tube 27 will be positive, while the grid 35 of the tube 28 is negative, and by employing tubes, preferably of the gas-filled type in which a negative grid prevents current flow from starting when voltage is applied to the tube, alternate half cycles may be caused to flow alternately through the tubes 27 and 28, such that the wave form of the current in the secondary 35' of the transformer 31 is of the character represented by the curve 14 of Figures 2 and 3.

The rectifier tubes 19 and 20, as well as restoring tubes 27 and 28, may be of relatively small size as compared to the amplifier tube 25, so that the cost of an initial installation is lessened and less power required to produce a given amount of amplification. Thus, the current flowing through the tubes 19 and 20 may be small as compared to the plate current of the tube 25, as the function of the tubes 19 and 20 is to rectify the voltage applied to the grid 24 of the amplifier tube 25. These tubes need only be of sufficient size that sufficient current is carried thereby to produce a drop across the resistor 23 to excite the grid 24 and still enable a low enough value of resistance in the resistor 23 to be used to enable grid current to flow therethrough if the grid 24 of the tube 25 swings positive with respect to the cathode. It is entirely possible to employ gas-filled tubes for the rectifier tubes 19 and 20 in order that comparatively large amounts of power may be handled by relatively small tubes. Also, the tubes 27 and 28 are preferably gas-filled tubes which can handle relatively high currents with low voltage drop thereacross. If the amplifier tube 25 is operated at a negative bias equal to cut off, the plate current thereof drops to zero at the end of each half cycle of the curve 16 of Figure 3, so that the arc in one of the gas-filled tubes is extinguished and the grid thereof is capable of preventing striking of the arm when a negative potential is placed thereon from transformer secondary 37'. Thus, four relatively small tubes representing a very small fraction of the initial cost of a large amplifying tube and requiring materially less power for operation can be employed in a manner to eliminate one large amplifier tube.

The amplifying system of Figure 4 is essentially similar to the amplifying system of Figure 1, and the same reference characters have been applied to similar elements. Instead of employing two electrode rectifier tubes for exciting the grid 24 of the amplifying tube 25, amplifier tubes 38 and 39 operated as class B amplifiers may be employed to excite the grid 24. A source of bias potential (not shown) for the tubes 38 and 39 may be connected between the center tap 22' of the secondary 16 of the transformer 17 and the cathodes 43 so as to bias the tubes 38 and 39

substantially to cut off. The grids 41 of these tubes may be connected to opposite terminals of the secondary 16 of the transformer 17 and the plates 42 may be connected together and to the positive terminal of a plate potential source (not shown) having its negative terminal connected to ground. The cathodes 43 of the tube 38 and 39 may be connected to ground through a load resistor 44. If the tubes 38 and 39 are operated class B, the voltage appearing across the resistor 44 is similar to that represented by the curve 15 of Figure 3. This voltage may be applied to the grid 24 of the amplifying tube 25 through a coupling condenser 45, and grid potential can be applied to the grid 24 through a resistor 46. Sufficient negative grid potential should be applied to the grid 24 to bring the plate current of the tube 25 to zero value at the end of each half cycle. The plate current of the tube 25 will then be similar to the curve 16 of Figure 3. The remainder of the circuit for restoring alternate half cycles of the opposite side of the axis to produce a current wave form similar to the curve 14 of Figure 3 may be entirely similar to that of Figure 1, and need not be further described.

The tubes 38 and 39 for exciting the grid of the amplifying tube 25 are essentially voltage amplifiers and can carry a relatively low plate current as compared to the tube 25 and may therefore be of relatively small size. The particular coupling arrangement between the tubes 38 and 39 and the grid 24 of the tube 25 has the disadvantage that the input to the tube 25 is of relatively high impedance, so that the grid 24 of the tube 25 must not be driven to any considerable extent positive if distortion is to be minimized in the amplifying system.

As shown in Figure 5, it is possible to directly connect the grid 24 of the amplifier tube 25 to the cathodes of the tubes 38 and 39 so that the input to the grid 24 of the tube 25 can be made of relatively low impedance and the grid 24 can be driven positive. A source of bias potential 48 is shown as being connected between the center tap 22' of the transformer secondary 16 and the cathodes 43 of the tubes 38 and 39 so as to bias the tubes 38 and 39 substantially to cut off. The cathodes 43 are also connected to ground through a resistor 49 and a source 50 of bias potential for the grid 24 of the tube 25. Plates 42 of the tubes 38 and 39 may be connected to an intermediate point 51 of a source 52 of plate potential in order to secure proper plate voltage for the tubes 38 and 39. The cathode current for the tubes 38 and 39 flows through the resistor 49 and the potential source 50 so that the source 50 must be of sufficiently low impedance to carry this cathode current. The voltage applied to the grid 24 of the tube 25 is of the wave form represented by the curve 16 of Figure 3 superimposed upon a direct current voltage, which latter voltage is just sufficient to render the plate current of the tube 25 zero except when the grid 24 is driven in a positive direction. By employing tubes 38 and 39 capable of developing a considerable amount of power, the resistor 49 may be of sufficiently low impedance that the grid 24 in the tube 25 may be driven substantially positive without causing major distortion in the amplifying system.

The remainder of the circuit for restoring alternate half cycles of the plate current of the tube 25 to the opposite side of the axis may be essentially similar to that shown in Figures 1 and 4 and employ grid controlled rectifying tubes 27 and 28. In many instances it may be desirable to apply a slight negative bias potential to the grids 35 of the tubes 27 and 28 in order to insure that these grids are slightly negative at the start of each half cycle so that only the tube having its grid driven in a positive direction will permit current flow therethrough. This may be accomplished by connecting an insulated source 53 of bias potential between cathodes 34 of the tubes 27 and 28 and the center tap of the secondary 37' of the transformer 36. It is also desirable to connect a resistor between the cathodes and plates of the rectifier tubes 27 and 28 in order to reduce the peak inverse voltage thereacross. This may be accomplished by connecting a resistor 54 to the center tap 29 of the primary 30 of the transformer 31 and to the cathodes 34 through the potential source 53. This connection also provides for maintaining plates of the tubes 27 and 28 at a slight negative potential with respect to the cathodes at the end of each half cycle so as to insure extinguishing the arc in the tube operating on the previous half cycle so that the load can be transferred to the other tube. The sources of bias and plate potential have been shown as batteries, but any other suitable sources of direct current may be employed.

The invention has particular utility in connection with class B amplifying systems, but it is evident that it is also directly applicable to any amplifying system in which the plate current of the amplifier tube is zero at the end of each half cycle, for example class C amplifying systems. Also, by applying a proper bias to the restoring tubes 27 and 28 in a manner similar to that shown in Figure 5 so that the plates or grids of the tubes 27 and 28 are at zero potential or even slightly negative with respect to the cathodes at the end of each half cycle, the amplifier tube 25 may be operated class AB or even class A and the wave form restored so that successive half cycles are on opposite sides of the axis as illustrated by the curves 14 of Figures 2 and 3.

While I have disclosed the preferred embodiments of my invention, it is understood that the details thereof may be varied within the scope of the following claims.

I claim:

1. A system for amplifying an alternating current wave, which comprises, means for transferring alternate half cycles of said wave to the other side of the axis of the wave so that all of the half cycles are positioned on the same side of said axis, means for amplifying the resulting wave, and means for restoring the amplified wave to a form similar to the original wave.

2. A system for amplifying an alternating current wave, which comprises, means for transferring alternate half cycles of said wave to the other side of the axis of the wave so that all of the half cycles are positioned on the same side of said axis, means for amplifying the resulting wave, and means for restoring the portions of the amplified wave corresponding to alternate half cycles of the original wave to the opposite side of the axis to produce an amplified wave having a form similar to the original wave.

3. A system for amplifying an alternating current wave, which comprises, full wave rectifying means for rectifying said wave so that the half cycles of the original wave are positioned on the same side of the axis of the wave, an amplifying

tube including a grid, plate and cathode, means for impressing said rectified wave on the grid of said amplifying tube to produce a plate current through said tube having a wave form similar to said rectified wave, and means for inverting portions of said plate current corresponding to alternate half cycles of the original wave to produce a current having a wave shape similar to the shape of the original wave.

4. A system for amplifying an alternating current wave, which comprises, means for transferring alternate half cycles of said wave to the same side of the axis of the wave as the other half cycles so that all said half cycles are positioned on the same side of said axis, amplifying means for amplifying the resulting wave, a pair of grid controlled tubes each connected to said amplifying means in series therewith, and means for applying voltages to the grids of said tubes to provide for current flow alternately through said tubes during time intervals corresponding to half cycles of the original wave, said tubes being connected to combine said current flow so that a current having a final wave shape similar to that of the original wave is produced.

5. A system for amplifying an alternating current wave, which comprises full wave rectifying means to rectify said wave, amplifying means for amplifying said rectified wave, a pair of grid controlled tubes each connected to said amplifying means in series therewith, means for applying voltages to the grids of said tubes to provide for the flow of current from said amplifying means alternately through said tubes during time intervals corresponding to half cycles of said original wave, an output transformer provided with a secondary winding and a primary winding having a center tap, a source of potential connected between said amplifying means and said center tap, the plates of said tubes being connected to opposite terminals of said primary winding so that said current flows alternately in opposite directions in said primary winding to produce an output current in said secondary winding having a wave shape similar to that of the original wave.

6. A system for amplifying an alternating current wave, which comprises, full wave rectifying means for rectifying said wave, an amplifier tube having a grid, plate and cathode, and connected to operate as a class B amplifier, means for applying said rectified wave to the grid of said tube whereby the plate current of said tube is zero at the end of each half cycle of the original wave, a pair of gas filled grid controlled tubes each provided with a cathode and plate and each having its cathode and plate connected in series with the plate and cathode of said amplifier tube, means for applying a voltage having a wave shape similar to the original wave to the grid of one of said gas filled tubes and a similar voltage in phase opposition to the grid of the other gas filled tube whereby current flows through one of said gas filled tubes for alternate half cycles of the original wave and through the other gas filled tube for the other half cycles of the original wave, and means for combining the currents through said gas filled tubes to produce a wave form similar to said original wave.

7. A system for amplifying an audio frequency signal, which comprises, a pair of relatively small amplifier tubes arranged in a circuit for push-pull operation and having a common cathode circuit with an impedance therein, said tubes having a grid bias so that substantially no current flows therethrough when no signal is impressed thereon whereby a voltage is produced across said impedance in which all half cycles of the signal are on the same side of the axis of the original signal, a relatively large amplifier tube, means for impressing said voltage upon the grid of said relatively large tube, said relatively large tube having a grid bias so that substantially no current flows therethrough when no voltage is applied to the grid thereof, a pair of relatively small grid controlled gas-filled restoring tubes each connected to said relatively large amplifier tube in series therewith, said restoring tubes being of the type in which a negative grid prevents starting of current flow and a positive grid permits current flow, means for applying voltage similar to the original signal but in phase opposition to the grids of said restoring tubes, and means for combining the currents through said restoring tubes to produce an amplified signal having a wave shape similar to the wave shape of the original signal.

8. A system for amplifying a signal, which comprises, a pair of relatively small rectifier tubes connected for full wave rectification of said signal, a relatively large amplifier tube, means for impressing the rectified signal upon said amplifier tube to produce an amplified rectified signal, and means including a pair of relatively small grid controlled tubes for restoring said amplified rectified signal to substantially the wave shape of the original signal.

9. A system for amplifying an alternating current signal, which comprises, means including a pair of relatively small tubes for producing full wave rectification of said signal, means including a relatively large amplifier tube for amplifying said rectified signal, and means including a pair of relatively small grid controlled tubes for restoring said amplified rectified signal to substantially the wave shape of the original signal.

10. A system for amplifying an alternating current signal, which comprises, means including a pair of relatively small tubes for producing full wave rectification of said signal, means including a relatively large amplifier tube for amplifying said rectified signal, and means including a pair of relatively small grid controlled tubes and connections for impressing voltages derived from said signal prior to rectification upon the grids of said last mentioned tubes for restoring said amplified rectified signal to substantially the wave shape of the original signal.

11. A system for amplifying an alternating current signal, which comprises, means including a pair of tubes for producing full wave rectification of said signal, means including an amplifier tube for amplifying said rectified signal, and means including a pair of grid controlled tubes and connections for impressing voltages derived from said signal prior to rectification upon the grids of said last mentioned tubes for restoring said amplified rectified signal to substantially the wave shape of the original signal.

12. The method of amplifying an alternating current wave, which comprises, transferring alternate half cycles of said wave to the other side of the axis thereof so that all of the half cycles of the wave are positioned on the same side of said axis, amplifying the resulting wave, and thereafter restoring alternate portions of the amplified wave corresponding to alternate half cycles of the original wave to the opposite side of the axis to produce an amplified wave having a wave shape similar to the original wave.

13. The method of amplifying a signal, which comprises, rectifying said signal to produce a full

wave rectified signal, amplifying said full wave rectified signal, and thereafter restoring the amplified full wave rectified signal to substantially the same wave shape as the original signal in response to voltages derived from the original signal.

14. The method of amplifying a signal, which comprises, rectifying the signal to produce a full wave rectified signal, amplifying said full wave rectified signal by a single channel amplifier, and thereafter restoring the amplified signal to substantially the same wave shape as the original signal.

15. A system for amplifying an alternating current signal, which comprises, means for transferring alternate half cycles of said signal to the other side of the axis of the signal wave so that all of the half cycles are positioned on the same side of said axis, means for amplifying the resulting signal, and means responsive to voltages derived from the original signal and having substantially the same wave form as said original signal for restoring the amplified signal to a form similar to the original signal.

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