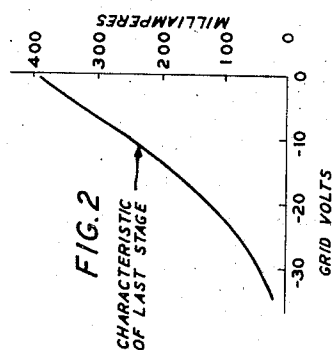
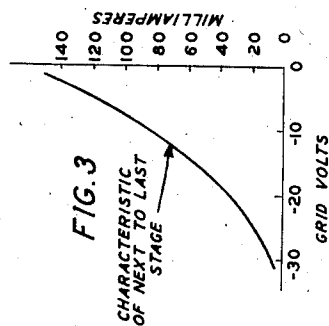
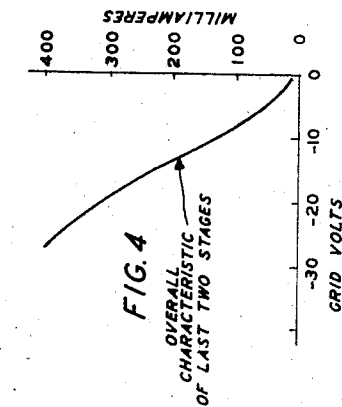
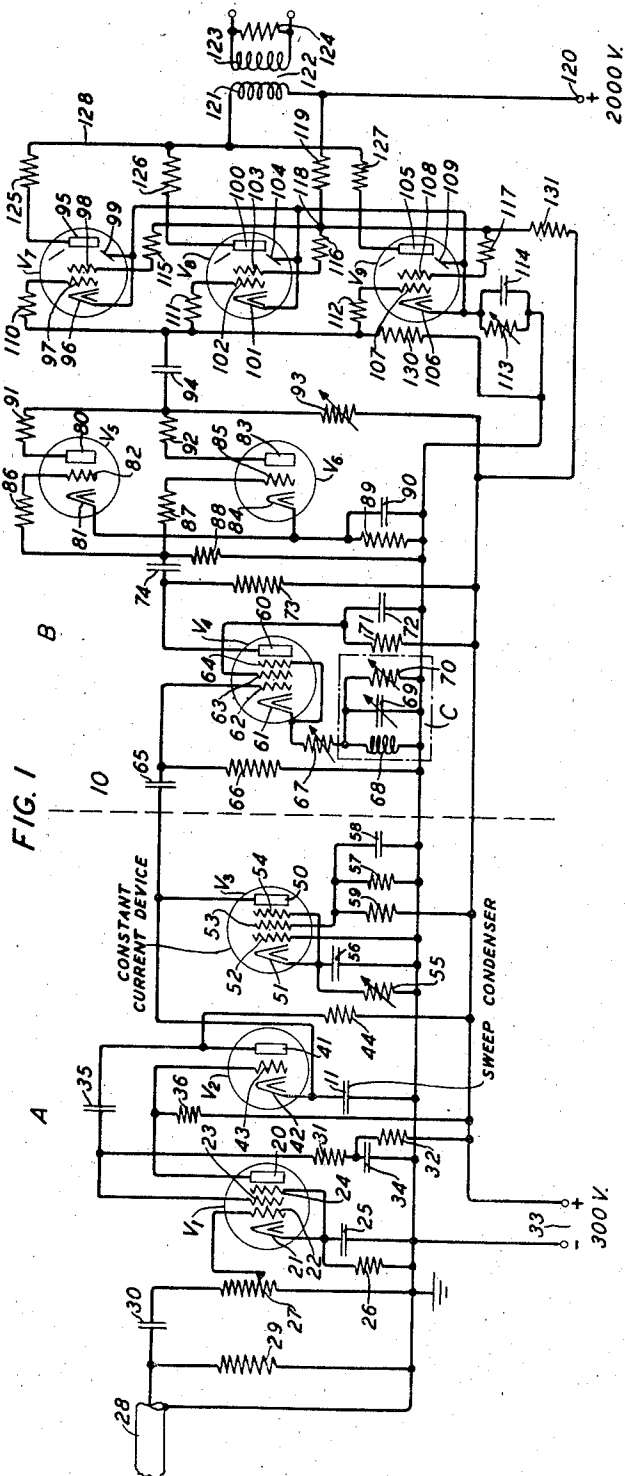


June 29, 1943.

B. M. OLIVER
ELECTRIC CIRCUIT
Filed Sept. 11, 1941

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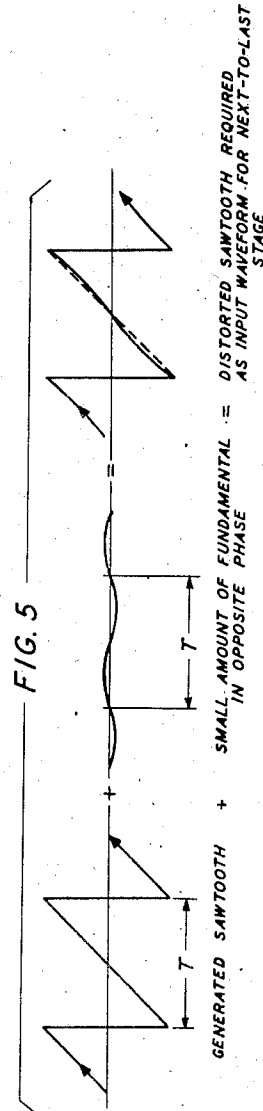
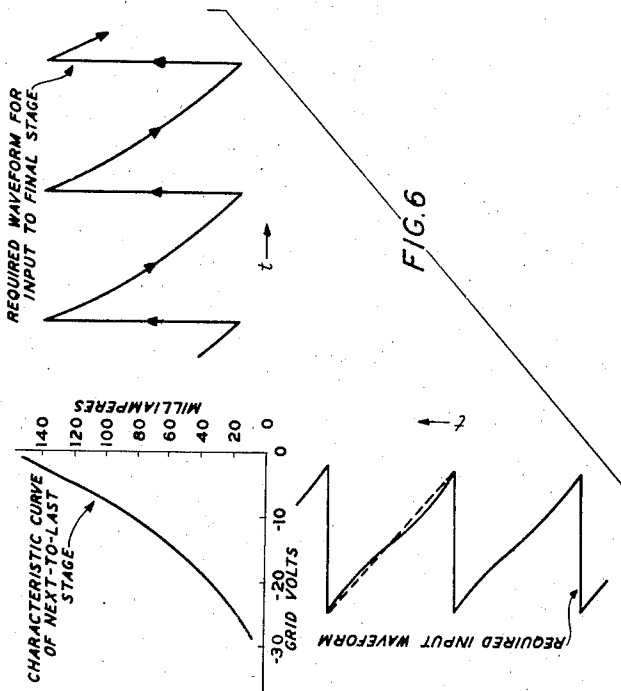
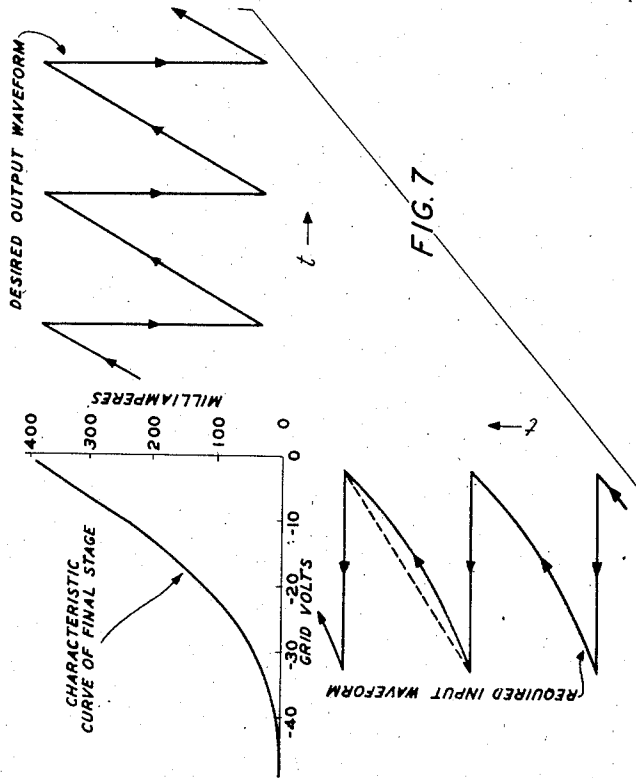
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,322,875

ELECTRIC CIRCUIT

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21 Claims. (Cl. 179-171)

This invention relates to electric circuits and more specifically to circuits containing amplifier stages and to methods of and means for correcting for distortions therein.

It is an object of this invention to provide novel methods of and means for correcting for distortions in an amplifying or repeating circuit.

It is another object of this invention to provide a novel sweep circuit containing an amplifier in which distortions introduced by the amplifier are compensated.

In the operation of a cathode ray tube suitable for television, the sweep circuit used is frequently of the type in which one or more condensers are charged and discharged in such a manner that a saw-toothed wave form of current or voltage is produced, which wave form may be applied between a pair of electrostatic deflecting plates within the tube or through electromagnetic deflecting coils associated with the cathode ray tube. It has often been found in practice that it is desirable to amplify the saw-toothed waves before applying them to the deflecting means. The design of an amplifier suitable for passing a saw-toothed wave introduces many problems due to the relatively wide band of frequencies of which a wave of this type is comprised. Moreover, when the sweep circuit is associated with an electron camera tube of the dissector type, that is, a tube in which a beam of electrons of relatively large cross-sectional area must be deflected at a line scanning frequency of over 13 kilocycles (where 441 line scanning is used), a relatively large current for deflection is required. The desired amplifier must thus be capable of passing a wide band of frequencies with minimum distortion and at the same time to deliver to the output circuit (the deflection coils or a transformer feeding them) a large current. The quality of a television image is greatly affected by even small departures from linearity in the saw-toothed deflecting waves so that substantial elimination of distortion in that portion of the amplified deflecting waves which effects the scanning movements of the cathode beam is highly desirable.

There is of course an advantage in confining the working range of an amplifier to the straightest portion of its input-voltage output-current characteristic, but when large output is desired it may be expedient to permit the working range to be extended in the final or power stage, so that distortion is introduced by the curvature of the characteristic beyond its relatively straight portion, if compensation for this distortion can be effected. This problem of com-

pensating for this distortion was confronted in the design of an amplifier to meet the above-mentioned requirements for amplifying a saw-toothed current wave.

In accordance with the invention, a sweep circuit is provided in which distortions in the output wave produced by large swings in amplitude in the output stage of the amplifier are largely compensated by balancing the effect of the curvature of the characteristic of the final stage against that of the preceding or driving stage by loading the driving stage so that the working range likewise extends beyond the straighter portion of its input-voltage output-current characteristic. In the arrangement chosen to illustrate the invention the necessary loading of the driving stage is accomplished by making the output or anode resistance small, utilizing the potential difference across this resistance as the input to the final stage, and using an input amplitude for the driving stage sufficiently large to give the required input voltage for the final stage. There still exists after this compensation a slight residual distortion (S curvature) which, in the illustrative arrangement hereinafter described, is substantially compensated by introducing into the input of a stage prior to the driver stage and in reverse phase to the signal component of fundamental frequency, some of the fundamental frequency which, for a saw-tooth wave used for line scanning deflection in a 441-line television transmitter tube, is about 13 kilocycles. The method of obtaining sweep linearity in accordance with the present invention is particularly useful when the design of the transformer feeding the sweep coils or any other factor makes the use of a push-pull output stage undesirable.

It will be noted that the introduction of a wave of fundamental frequency and of small amplitude, relative to that of this component of the saw-toothed wave, into the input of the earlier amplifier stage in phase opposition to that of the component of fundamental frequency of the signal, reduces the amplitude of the component of fundamental frequency of the signal. The same result may therefore be obtained by any means which reduces the amplitude of the fundamental frequency component of the saw-toothed signal wave by the proper amount. It is preferred to effect this reduction before the signal wave has been amplified to a large value, in which case the reduction results in a predistortion of the signal wave.

The invention will be more readily understood by referring to the following description taken in

connection with the accompanying drawings forming a part thereof in which:

Fig. 1 is a diagram of a sweep circuit in accordance with this invention; and

Figs. 2 to 7, inclusive, are graphical representations to aid in understanding the invention.

Referring more specifically to the drawings, Fig. 1 shows an embodiment of the invention to illustrate, by way of example, the principles thereof. In the arrangement shown in this figure there is provided a sweep circuit 10 which may be considered, for convenience, as divided into a sweep generator A and an amplifier B. The sweep generator A comprises a sweep condenser 11, two tubes V_1 and V_2 comprising a two-tube synchronized "multivibrator" arrangement to steepen the wave front, and a constant current device V_3 . The amplifier B preferably comprises three stages, the first stage consisting of the tube V_4 , the second stage of two tubes V_5 and V_6 in parallel, and the third stage consisting of three tubes V_7 , V_8 and V_9 in parallel.

With reference to the sweep generator A, the sweep condenser 11 is charged relatively quickly by means of the multivibrator (the tubes V_1 and V_2) and discharged relatively slowly and substantially linearly with respect to time by means of the constant current device V_3 .

The tube V_1 preferably comprises an anode 20, a cathode 21, a control grid 22, a screen grid 23, and a suppressor grid 24. Self-bias for the control grid 22 is supplied by means of the condenser 25 and the resistance 26 connected thereacross, a grid resistor 27 being also connected in circuit between the cathode 21 and the control grid 22. Synchronizing signals of, for example, line scanning frequency, are applied between the control grid 22 and the cathode 21 from an input circuit 28 by means of a coupling resistor 29 and a coupling condenser 30. The suppressor grid 24 is connected to the cathode in accordance with well-known practice. The screen grid 23 is connected through resistances 31 and 32 to the positive terminal of a source 33, a condenser 34 being connected from the junction of the resistance 31 and the resistance 32 to ground to provide a low impedance path for alternating current. The screen grid 23 is also connected through a coupling condenser 35 to the anode 41 of the tube V_2 which preferably comprises the anode 41, a cathode 42, and a control grid 43. The anode 20 of the tube V_1 is connected through an anode resistor 36 and the high potential source 33 to ground and is also connected directly to the grid 43 of the tube V_2 . The cathode 42 of the tube V_2 is connected through the sweep condenser 11 to ground and is connected directly to the anode 50 of tube V_3 . The anode 41 of the tube V_2 is connected through an anode resistor 44 and the high potential source 33 to ground.

The constant current device V_3 preferably comprises an anode 50, a cathode 51, a control grid 52, a screen grid 53, and a suppressor grid 54. Bias for the cathode 51 is supplied by means of the resistor 55 and the condenser 56 which are connected between the cathode 51 and ground, the control grid 52 being also connected to ground. The suppressor grid 54 is directly connected to the cathode 51 while the screen grid 53 is connected to ground through a resistance 57 and a condenser 58 connected thereacross, and is connected through a resistor 59 and high potential source 33 to ground. Thus the anode-cathode path of the tube V_3 is connected in circuit with the sweep condenser 11 and as the pentode

tube is inherently a constant current device over a large portion of its characteristic, the sweep condenser 11 discharges substantially linearly and slowly through the device V_3 , it being charged periodically and relatively quickly by the multivibrator arrangement V_1 and V_2 , as will be pointed out more fully below.

The cathode 42 of the tube V_2 is connected by means of the well-known "cathode follower" connection to the control grid 62 of the tube V_4 through a coupling condenser 65, a coupling resistor 66 being also included in the input circuit of this tube. The tube V_4 preferably comprises an anode 60, a cathode 61, the control grid 62, a screen grid 63, and a suppressor grid 64. The cathode 61 is connected through a resistance 67 and a tuned circuit C to ground. The tuned circuit C preferably comprises an inductance 68, a condenser 69, and a variable resistor 70. This circuit C is tuned to be antiresonant at the fundamental frequency, which is about 13 kilocycles in a preferred operating arrangement. The screen grid 63 is connected through a resistor 71 and source 33 to ground while a low impedance path to ground for alternating current is provided by means of the condenser 72. The suppressor grid 64 is preferably connected to the cathode 61. The anode 60 is connected through an anode resistor 73 and the high potential source 33 to ground and is connected through a coupling condenser 74 to the second stage of the amplifier comprising the two tubes V_5 and V_6 connected in parallel.

The tube V_5 preferably comprises an anode 80, a cathode 81 and a control grid 82 while the tube V_6 preferably comprises an anode 83, a cathode 84 and a control grid 85. Input resistors 86 and 87 are provided between the coupling condenser 74 and the control grids 82 and 85, respectively. A common input resistor 88 is connected from the common terminal of the two resistors 86 and 87 to ground while self-bias for the cathodes 81 and 84 is obtained by means of the resistor 89 having the condenser 90 connected thereacross.

The anodes 80 and 83 are connected through output resistors 91, 92 and a common resistor 93 to the positive terminal of the 300-volt power supply 33, the negative terminal of which is connected to ground, these resistors being of excessively low resistance for a reason which will appear more fully hereinafter.

The output circuit of the tubes V_5 and V_6 is connected to the input circuit of the third amplifying stage comprising tubes V_7 , V_8 and V_9 by means of coupling condenser 94. The tube V_7 comprises an anode 95, a cathode 96, a control grid 97, a screen grid 98 and a beam forming plate 99. The tube V_8 comprises an anode 100, a cathode 101, a control grid 102, a screen grid 103 and a beam forming plate 104, while the tube V_9 comprises an anode 105, a cathode 106, a control grid 107, a screen grid 108 and a beam forming plate 109. Grid resistors 110, 111 and 112 are provided for the control grids 97, 102 and 107, respectively, these resistors having a common terminal which is connected to the coupling condenser 94. The cathodes 96, 101 and 106 are connected together and the common terminal is connected through the resistor 113 and the condenser 114 connected thereacross to ground. The beam forming plates 99, 104 and 109 are connected to the respective cathodes. The screen grids 98, 103 and 108 are connected through resistors 115, 116 and 117, respectively, to a common terminal 118 which is connected

to the source 33 through the resistor 131, and through a resistor 119 to the positive terminal 120 of a high potential source which may be of the order of 2,000 volts. The resistor 131 and resistor 119 are portions of a potentiometer resistor between ground and a point having a potential of +2000 volts, this difference of potential being obtained by any suitable direct current power supply. This resistor 119 is also connected to one terminal of the primary winding 121 of the transformer 122, the secondary winding 123 of which is connected to sweep coils associated with a cathode ray tube. Preferably a resistor 124 shunts the winding 123. The anodes 95, 100 and 105 are connected through resistors 125, 126 and 127, respectively, to a common terminal 128 which is connected through the primary winding 121 to the positive terminal 120 of the source of high potential.

Due to the large current swings in the last stage of the amplifier, the output is not linear. However, this non-linearity can in large part be corrected by balancing the curvature of the second stage V_5 and V_6 against the curvature produced by the third stage V_7 , V_8 and V_9 . One way of doing this is by using unusually low load resistances 91, 92 and 93 in the plate circuits of the second stage so that to obtain the same output voltage it is necessary to drive the tubes of this stage over a larger portion of their characteristic. While this predistortion or compensation largely corrects for the distortion which would otherwise be present in the output of the third stage, there still remains a slight S-shaped curvature in the over-all characteristic. The nature of the saw-toothed wave is such that when it is amplified by an amplifier having this S-shaped characteristic the resulting distortion of the wave substantially takes the form of an S-shaped departure from linearity in the slowly varying portion of the wave. The rapidly varying portion of each wave constitutes only a small part of the wave in point of time. This S distortion is removed, in the embodiment of the invention here described, by introducing some of the fundamental frequency into the input of amplifier tube V_4 in opposite phase to the fundamental frequency component of the signal wave by means of the antiresonant local feedback impedance C in the cathode lead of the first stage, which reduces the gain at 13 kilocycles (the frequency of the sweep circuit).

The operation of the circuit shown in Fig. 1 is as follows: Negative pulses from the synchronizing generator, not shown, and supplied over the input line 28, are first amplified by the tube V_1 which may be a type 310-A pentode tube. Resulting positive pulses on the anode 20 of the tube are applied to the grid 43 of tube V_2 which may be a type 262-B triode which thereby periodically and quickly charges the sweep condenser 11 in its cathode lead. In order to shorten the charge time, a feedback voltage consisting of negative pulses is developed in the plate circuit of the tube V_2 and applied to the screen grid 23 of the tube V_1 . This regenerative action steepens the wave front of the pulse on the grid of the tube V_2 and thus shortens the charging time of the condenser in its cathode lead. The feedback is applied to the screen grid rather than to the control grid in order to prevent pulses from the tube V_2 from reaching the pulsing generator. The sweep condenser 11 is also connected to the plate of the tube V_3 which may be a 310-A pentode tube, which tube is adjusted

to draw a constant plate current determined by the cathode bias resistor setting and which thus discharges the condenser at a constant rate. As a result a linear saw-tooth voltage is developed across the condenser 11, the amplitude of which is controlled by the rate of charging and the frequency of which is controlled by the frequency of the incoming pulses over the cable 28.

The saw-tooth voltage developed across the sweep condenser 11 is fed into the three-stage amplifier B which drives the sweep coils through the transformer 122. The first stage of this amplifier consists of the single tube V_4 which may be a type 336 pentode tube. The output of this stage drives the two tubes V_5 and V_6 in parallel which may be 271-A triode tubes and they in turn drive the three parallel output tubes V_7 , V_8 and V_9 which may be 813 output tubes. The large amount of power in the output is necessitated by the high frequency of the sweep (due to the fact that this sweep is particularly adapted for use with a 441-line dissector film scanner which would necessitate a sweep frequency of over 13 kilocycles. This power is also required because a considerable flux density must be established over a large space in the dissector tube. As pointed out above, in order to correct for the non-linearity of the output tubes V_7 , V_8 and V_9 , certain predistorting characteristics are included in the first two stages of the amplifier B. By using excessively low load resistances 91, 92 and 93 in the plate circuits of the 271-A driver stage, so that it is also necessary to drive this stage over a considerable portion of its characteristic to obtain the same output voltage, an opposite curvature in the input wave form introduced on the grids of the three output tubes V_7 , V_8 and V_9 is obtained. This predistortion largely corrects for the distortion which would otherwise be present in the output. However, there still remains a slight S-shaped distortion which, in the embodiment of the invention being described, is substantially removed by introducing some of the fundamental frequency in opposite phase to the component of fundamental frequency in the signal by means of the antiresonant local feedback impedance C in the cathode lead of tube V_4 , which reduces the gain at 13 kilocycles. This method of obtaining sweep linearity has proven quite satisfactory and has produced a large-amplitude, substantially linear saw-toothed current wave in the coils of the dissector tube. The output wave may be fed through sweep coils of the type disclosed in Patent 2,278,478, issued April 7, 1942 to B. M. Oliver.

The manner in which distortions are removed in the amplifier is graphically shown in Figs. 2 to 7, inclusive. Fig. 2 shows the characteristic curve of the third (last) stage alone; Fig. 3 shows the characteristic curve of the second (next-to-the-last) stage alone; and Fig. 4 shows the combined or over-all characteristic of the last two stages. It should be noted that the curve in Fig. 4 has a slight S-curvature which is compensated by the feedback in the first stage. Fig. 5 shows the manner in which the fundamental frequency wave predistorts the generated saw-toothed wave, which distorted wave, as shown in Fig. 6, is applied as an input to the next-to-the-last stage to obtain an output wave which, as shown in Fig. 7, is applied as an input to the last stage to obtain a desired output wave which is a linear saw-tooth.

In a circuit constructed and operated in ac-

cordance with this invention the following values of circuit constants were used: Resistor 29, 75 ohms; resistor 27, 2,000 ohms; resistor 26, 1,000 ohms; resistor 31, 10,000 ohms; resistor 32, 0.2 megohm; resistor 35, 25,000 ohms; resistor 44, 3,000 ohms; resistor 55, 50,000 ohms; resistor 57, 50,000 ohms; resistor 59, 0.1 megohm; resistor 66, 1 megohm; resistor 67, 20,000 ohms; resistor 70, 2,500 ohms; resistor 71, 0.2 megohm; resistor 73, 10,000 ohms; resistors 86 and 87, 100 ohms apiece; resistor 88, 25,000 ohms; resistors 91 and 92, 50 ohms apiece; resistor 93, 400 ohms; resistors 110, 111 and 112, 50 ohms apiece; resistor 130, 5,000 ohms; resistors 115, 116 and 117, 100 ohms apiece; resistors 125, 126 and 127, 125 ohms apiece; resistor 113, 400 ohms; condenser 30, 0.001 microfarad; condenser 25, 25 microfarads; condenser 34, 1 microfarad; condenser 35, 0.001 microfarad; sweep condenser 11, 0.0005 microfarad; condenser 56, 1 microfarad; condenser 58, 1 microfarad; condenser 65, 0.001 microfarad; condenser 69, 0.03 microfarad; condenser 72, 1 microfarad; condenser 74, 0.09 microfarad; condenser 90, 25 microfarads; condenser 94, 0.5 microfarad; condenser 114, 50 microfarads; and the inductance 68, 10 millihenries. Obviously, however, the invention is not limited to a circuit having these values, they being given merely by way of example of an operative circuit.

Various modifications may be made in the embodiment described herein without departing from the spirit of the invention, the scope of which is indicated in the appended claims. For example, the tubes in the driver stage may be of low current capacity, thus not requiring a low output resistance, to produce the required predistorting. Also, as above stated, the reduction in amplitude of the fundamental frequency component may be effected elsewhere than in the position chosen herein for purposes of illustration and by other well-known means for obtaining a reduction of one frequency component relative to others or amplification of said other frequency components relative to said one.

What is claimed is:

1. A multistage amplifier comprising means in an early stage for producing a distortion of a wave which is substantially complementary to that produced in a later stage in said amplifier, and means for correcting for the residual distortion resulting from the imperfect matching of said two distortions, said means comprising means for effectively introducing a wave of fundamental frequency in the input circuit of one of the stages of said amplifier.

2. A multistage amplifier comprising means in the next-to-the-last stage for producing a distortion of a wave which is substantially complementary to that produced in the last stage of said amplifier, and means for correcting for the residual distortion resulting from the imperfect matching of said two distortions, said means comprising means for effectively introducing a wave of fundamental frequency in the input circuit of a stage of said amplifier preceding the next-to-the-last stage.

3. A multistage repeating device for sawtooth waves comprising means in a stage preceding the last one for producing a distortion of a wave which is substantially complementary to that produced in the last stage of said device, and means for correcting for the residual distortion resulting from the imperfect matching of said two characteristics, said means comprising means for effectively introducing a wave of fundamental

frequency in the input circuit of one of the stages of said amplifier.

4. The combination of claim 3 in which said means in said stage preceding the last one comprises a relatively low output impedance.

5. The combination of elements as in claim 3 in which said means for introducing a wave of fundamental frequency comprises a tuned circuit in both the input and output circuits of one of the stages of said amplifier.

6. The method of eliminating distortion of a signal wave in an amplifier in which, due to the wide range of amplitude values, distortion is introduced in the output stage, comprising the steps of predistorting the wave in the next-to-the-last stage so that the final distortion is at least substantially compensated, and also applying another predistortion for compensating for imperfect compensation due to said first predistortion.

7. The method of eliminating distortion of a signal in an amplifier in which, due to the wide range of amplitude values, distortion is introduced in the output stage, comprising the steps of predistorting the signal in the next-to-the-last stage so that the final distortion is at least substantially compensated, and correcting for the residual distortion resulting from the imperfect matching of said two distortions produced by said two stages by effectively introducing a wave of fundamental frequency in the input circuit of one of the stages of said amplifier.

8. The method of claim 7 in which said wave of fundamental frequency is effectively introduced in a stage preceding the next-to-the-last stage.

9. The method of compensating for an S-shaped distortion in the slowly varying portion of a saw-tooth wave which comprises the step of effectively combining a second wave of the fundamental frequency of said saw-tooth wave with said saw-tooth wave.

10. The method of claim 9 in which said second wave is a sine wave of relatively low amplitude in comparison with the peak amplitude of said saw-tooth wave.

11. A circuit for amplifying saw-tooth waves suitable for causing deflection of the beam in a cathode ray tube comprising amplifying means which introduces distortions into said wave, which distortions take the form of an S-shaped variation from linearity in the slowly varying portion of said wave, and means for effectively introducing a wave of the frequency of said saw-tooth wave into said circuit to compensate for said S-shaped distortion.

12. A circuit as in claim 11 in which said amplifying means comprises an output stage and a next-to-the-last stage both of which produce compensating distortions which are imperfectly matched.

13. The combination with a device for repeating signal waves having a voltage-input current-output characteristic comprising a substantially symmetrical S-shaped portion, of means for impressing an alternating non-sinusoidal signal voltage wave upon the input of said device so that the positive and negative portions of said wave respectively fall wholly on the two sides of the center of symmetry of said S portion of the characteristic, and additional means for reducing the amplitude of the fundamental frequency component of said signal wave, before or after being repeated by said device, relatively to the other component or components of said wave to compensate in part at least for the distortion introduced by said device into the repeated wave.

14. The combination of claim 13 in which said repeating device comprises an even number of amplifiers connected in tandem.

15. A circuit for amplifying a signal wave comprising an output stage and a driver stage, said output stage comprising a plurality of tubes in parallel and said driver stage comprising a plurality of tubes in parallel but having a lesser number of tubes than said output stage, means for applying an alternating current wave to said driver stage in such a manner that the range of amplitude of said wave covers a portion of the grid-volts vs. plate-current characteristic of said driver stage which is curved in one direction only, means for applying the output wave from said driver stage to said output stage in such a manner that the range of amplitude of said last-mentioned wave covers a portion of the grid-volts vs. plate-current characteristic curve of said output stage which occupies a similar position on said curve as the operating portion of the characteristic curve of said driver stage corresponding to the range of amplitudes of the wave applied to said driver stage, whereby the distortion produced in said driver stage due to the curvature of its characteristic is in some measure compensated by the distortion produced in said output stage due to the curvature of its characteristic but there remains, in the absence of other compensating means, a residual distortion having a frequency equal to the fundamental frequency of said alternating current wave, and means for effectively introducing a compensating distortion of the fundamental frequency into said amplifier to produce a wave in the output of said output stage which is a substantially undistorted counterpart of said signal wave.

16. The combination of elements as in claim 15 in which said last-mentioned compensating distortion is effectively introduced into said signal wave by means of a negative feedback circuit in a stage prior to said driver stage, said feedback circuit being antiresonant at said fundamental frequency.

17. A circuit for amplifying saw-tooth waves having a slowly varying portion occupying most of the cycle suitable for causing deflection of the beam in a cathode ray tube comprising amplifying means which in the absence of compensating means introduces distortions into said wave, which distortions take the form of an S-shaped variation from linearity in the slowly varying portion of said wave, and means for compensating for said S-shaped distortions, said last-mentioned means comprising means for reducing the amplitude of the fundamental frequency of said saw-tooth wave relative to that of other frequencies in said wave.

18. The combination with a wave transducing means having an input-output characteristic each of two adjacent portions of which has a cur-

vature substantially reverse to that of the other, of means for impressing an alternating non-sinusoidal wave upon the input of said transducing means so that the positive and negative portions of said wave respectively fall substantially wholly upon said two portions of the characteristic, and means comprising wave selecting means selective of the fundamental frequency of said wave to change the amplitude of the fundamental frequency component of said wave relative to the other components thereof to compensate in part at least for the distortion introduced by the curvature of said characteristic.

19. The combination of claim 18 in which said transducing means comprises an even number of repeater stages in tandem.

20. The combination with two wave repeating elements in tandem each having an input-output characteristic having a portion which is curved, of means for impressing a non-sinusoidal wave upon the input of the first of said elements so as to cause it to repeat said wave while working upon said curved portion at least of its said characteristic, coupling means between said elements to impress the repeated wave upon said second element so as to cause it to repeat said wave while working upon its said curved portion at least of its said characteristic, said two characteristics acting in a complementary manner to produce an over-all characteristic of generally S-shape and of relatively great curvatures, and means comprising wave selecting means selective of one at least of the frequency components of said non-sinusoidal wave to change the amplitude of the component of said wave of which said selecting means is selective relative to other components thereof to compensate for distortion introduced by said over-all characteristic.

21. The combination with two wave repeating elements in tandem each having an input-output characteristic having a portion which is curved, of means for impressing a saw-tooth wave upon the input of the first of said elements so as to cause it to repeat said wave while working upon said curved portion at least of its said characteristic, coupling means between said elements to impress the repeated wave upon said second element so as to cause it to repeat said wave while working upon its said curved portion at least of its said characteristics, said two characteristics acting in a complementary manner to produce an over-all characteristic having an S-shape of relatively great curvatures, and means comprising wave selecting means selective of the fundamental frequency of said wave to change the amplitude of the fundamental frequency component of said wave relative to the other components thereof to compensate for distortion introduced by the curvatures of said S-shaped characteristic.

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