March 20, 1956 W. D. HOUGHTON 2,739,234

STEP WAVE GENERATORS

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Fig. 1a.

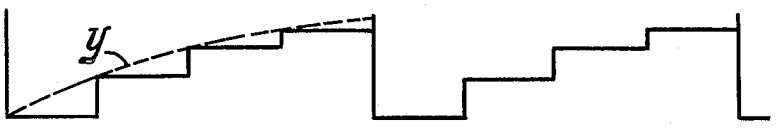


Fig. 1b.



Fig. 1c.

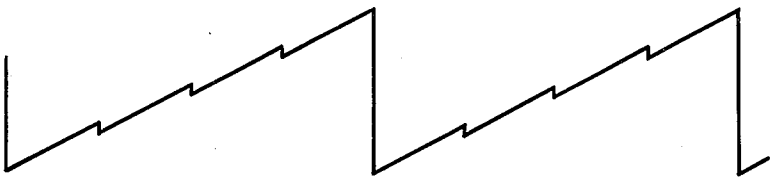


Fig. 1d.

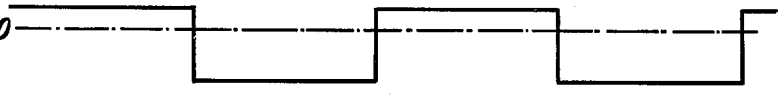


Fig. 1e.



Fig. 1f.

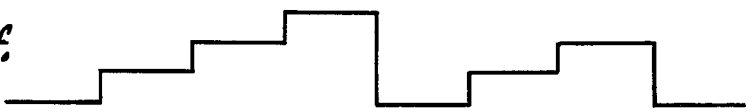
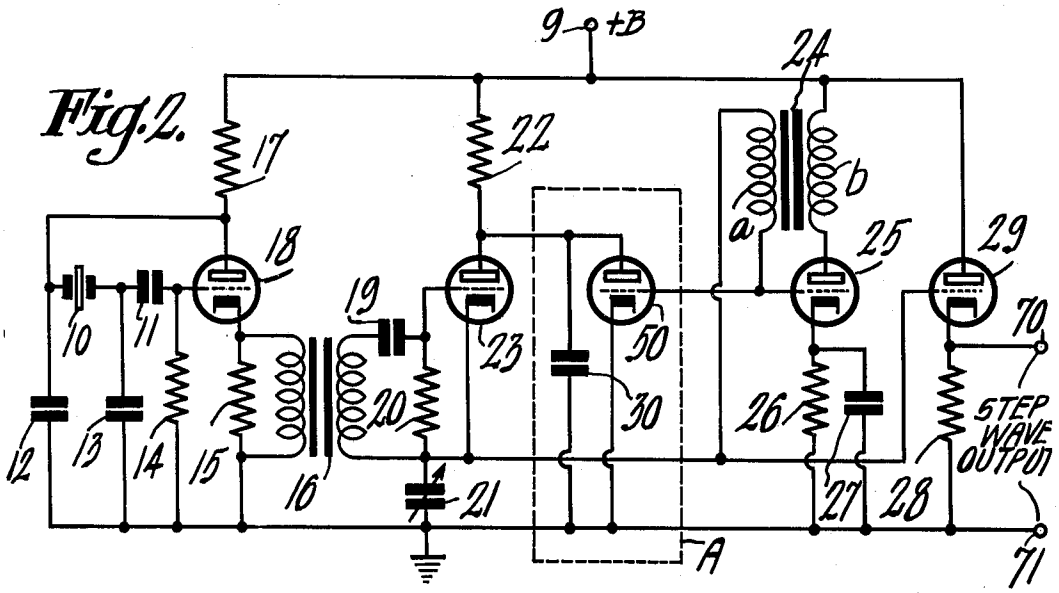


Fig. 2.



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Fig. 3.

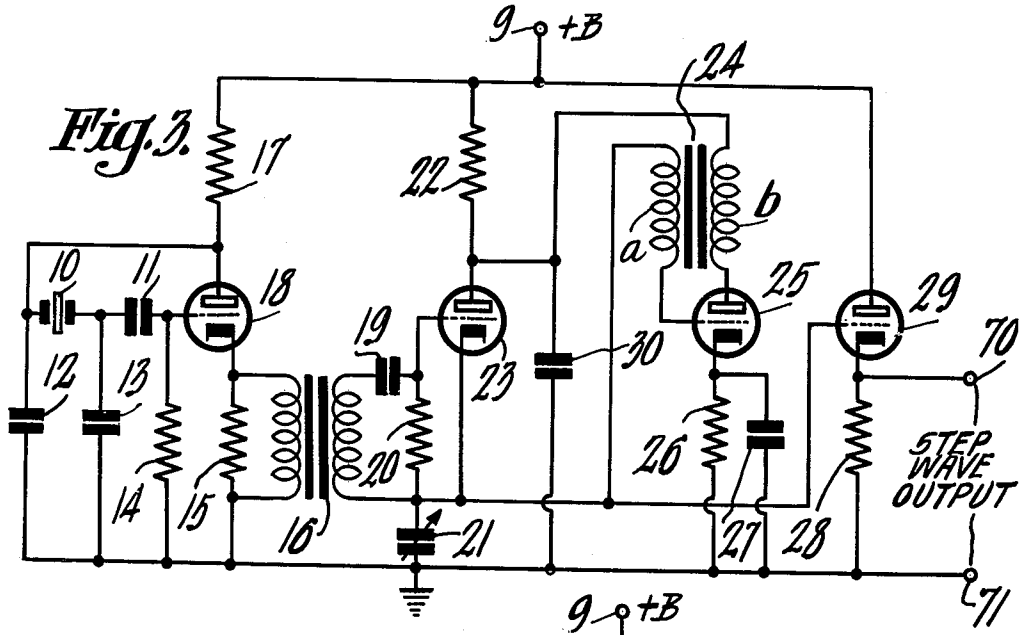
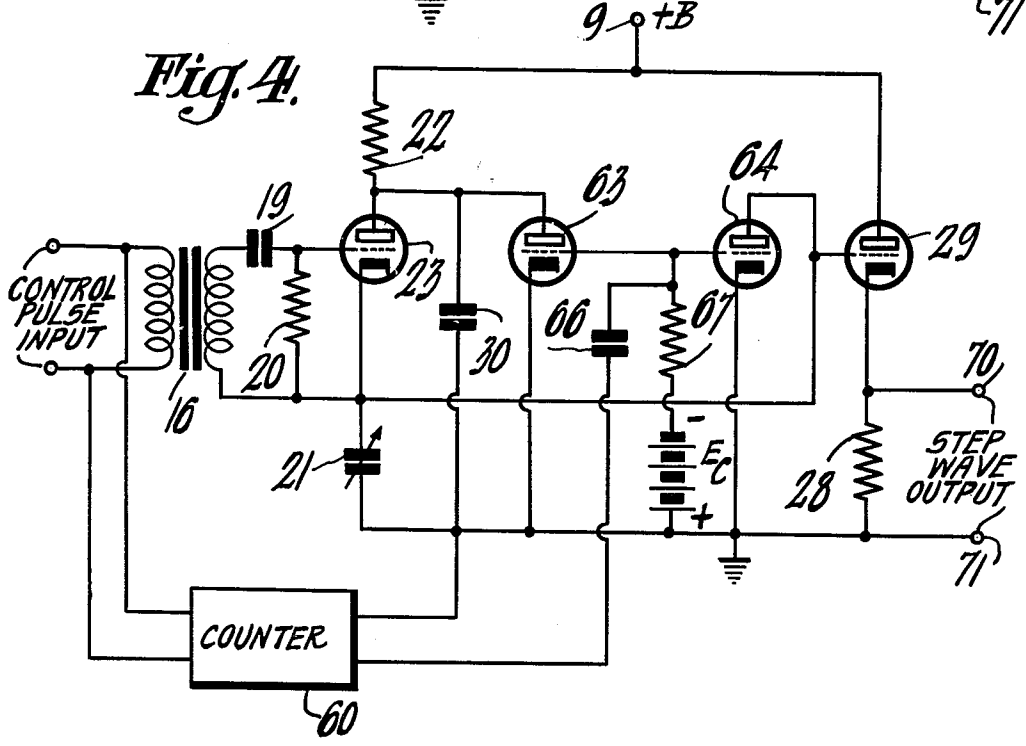


Fig. 4.



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Fig. 5

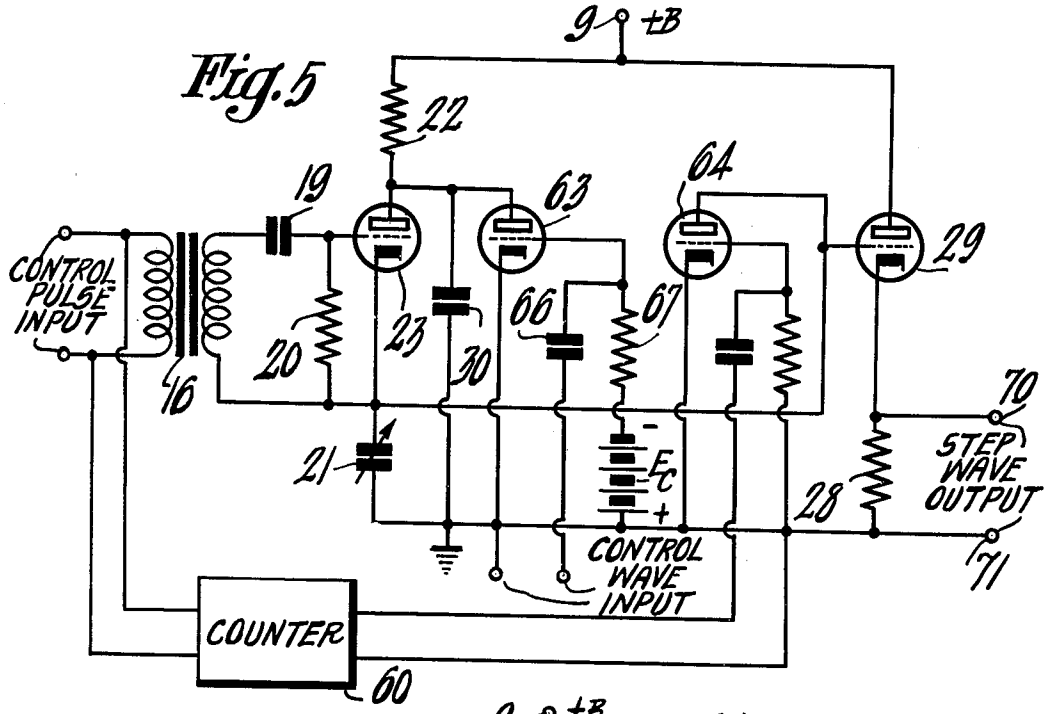
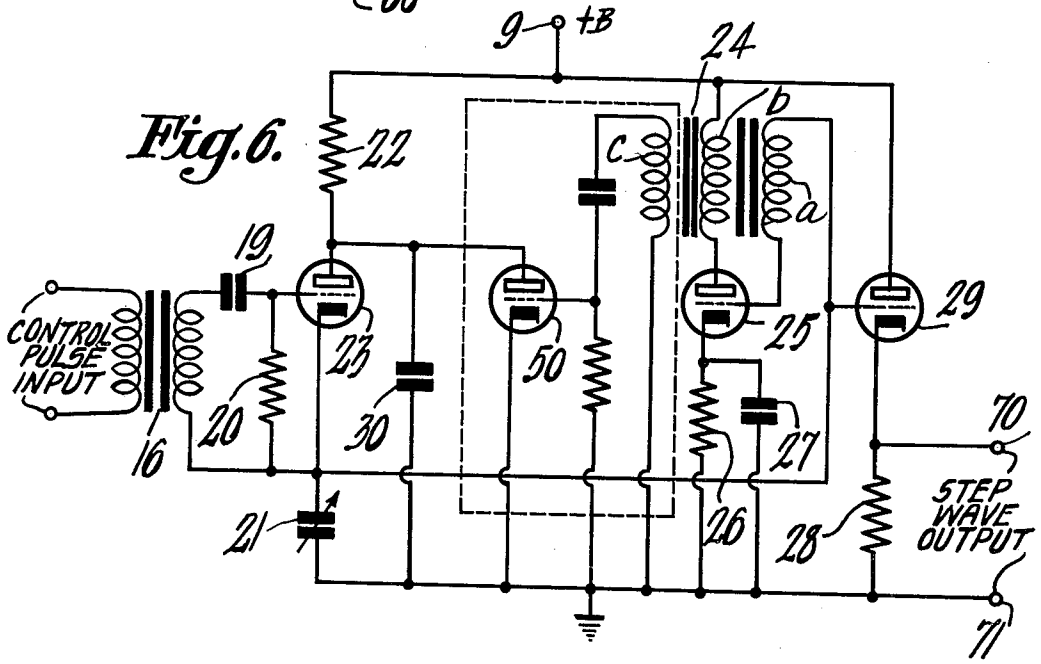


Fig. 6.



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STEP WAVE GENERATORS

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Application February 27, 1951, Serial No. 212,909

The terminal fifteen years of the term of the patent to be granted has been disclaimed

16 Claims. (Cl. 250—27)

This invention relates to step voltage wave generators.

A step voltage wave may be defined as a wave produced by adding in time sequence incremental voltages and maintaining the resultant voltage between the times of such addition. After the addition of a predetermined number of such increments, the voltage rapidly decreases to a low value whence the process is repeated. The wave thus consists of a series of cycles of changing voltage in which each cycle, when plotted with time as abscissa and amplitude as ordinate has the shape of the profile of a set of steps. Since some finite time is required to add the incremental voltages, the risers which connect the steps are not exactly perpendicular. However, the riser time is made quite small relative to the time between additions.

Step wave generators find many applications in present day electronic apparatus. By way of example, by means of differently biased amplifiers arranged to become sequentially operative with the application of different voltages applied to their inputs, a step voltage wave may be used to switch "on" and "off" the amplifiers in a desired sequence. Such an arrangement is known as an electronic switching or commutating device which finds utility in multiplex communications systems.

In order to add and store the incremental voltage changes or steps, it is common practice to use a condenser as a storage element. However, the voltage charge which is induced in a condenser by voltage changes of equal amplitude and time duration is not linear. That is, in the discharged state of the condenser, the application of a particular voltage for a given time period will result in a voltage increase which is greater than that resulting from the application of the same amplitude voltage for the same period at a time when the condenser is more fully charged. In other words, due to the exponential charging rate of a condenser, the application of equal amplitudes of voltage for equal times results in gradually decreasing voltage changes in the stored voltage.

Accordingly, it is an object of this invention to provide a novel method of and means for generating a step voltage wave having equal incremental increases between steps constituting the step voltage wave.

Another object of the invention is to provide an improved step voltage wave generator in which the individual voltage changes of the generated wave have a predetermined amplitude range.

Still another object of the invention is the provision of a novel generator of step voltage waves the steps of which do not follow the charging rate of a storage device such as a condenser.

In accordance with the invention, the above and other objects are achieved by the provision of means for charging a storage condenser through a vacuum tube and varying the effective impedance of the charging tube in accordance with the degree of charge of the storage condenser. The variation in effective impedance is obtained by means of a compensating condenser connected in the anode circuit of the charging tube. The compensating condenser is charged during the step wave cycle and effectively increases the anode potential of the charging tube and hence its effective impedance. The storage condenser and compensating condenser are simultaneously discharged at the end of the step wave cycle.

The invention will be clear by reference to the following detailed description taken in conjunction with the accompanying drawings in which:

Figs. 1*a* through 1*f* illustrate the principles of the invention;

Fig. 2 represents schematically an embodiment of the invention;

Fig. 3 represents schematically a modification of the circuit arrangement of Fig. 2;

Fig. 4 represents schematically a modified form of the invention;

Fig. 5 represents schematically a modification of the arrangement shown in Fig. 4; and

Fig. 6 represents schematically still another modification of the circuit arrangement of Fig. 2.

Referring to Fig. 1*a* there is shown an assumed curve, in solid lines, representing two cycles of a step voltage wave such as would be produced by charging a condenser with equal time duration pulses of equal amplitude voltages and discharging the stored voltage after a predetermined number of pulses. For purposes of simplicity, only three steps have been illustrated. It is to be understood that the principles of the invention are applicable to similar arrangements producing any desired number of steps. It will be noted, that the voltage risers of the steps are not uniform but decrease with increase in stored voltage as indicated by the dotted line "*y*." The dotted line "*y*," as explained above, corresponds to the exponential charging rate of the storage condenser.

In Fig. 1*b* there is shown an idealized curve, in solid lines, representing two cycles of a step voltage wave the risers of the steps of which are equal in amplitude, as indicated by the dotted line "*x*." The hatched portions under the last two steps indicate the additional charge necessary to arrive at the linear increase in stored voltage.

From an inspection of Fig. 1*a* it will be clear that in the absence of extremely sensitive apparatus, the voltage change in the last step is so small as to make its use impractical. Thus, although a three step wave has been generated, its practical use is limited to two steps. However, by providing the equal riser step voltage wave of Fig. 1*b* all steps may be used.

Referring now to Fig. 2, there is shown an embodiment of the invention applied to a common type of step wave generator. In order to simplify the description of the invention, that portion of the circuitry of Fig. 2 which has been added in accordance with the invention is enclosed within the dotted box 23*a*.

In this figure, the pulse generator consists of a crystal controlled oscillator comprising a vacuum tube 18 provided with a crystal 10, tuning condensers 12 and 13, a grid blocking condenser 11, a grid leak 14, and an anode resistor 17 as shown. A transformer 16 is coupled between the cathode of the tube 18 and ground, and across the cathode resistor 15. The tube 18 conducts on each positive peak of the sine wave developed across its grid and, hence, pulses of anode current flow therethrough. Any type of pulse generator may be used, the particular arrangement shown being merely for the purpose of illustration.

The pulses of anode current result in pulses of voltage being developed across the primary winding of the transformer 16. The windings on the transformer 16 are so

poled that a positive pulse is developed across the resistor **20** connected between the grid and cathode of a vacuum tube **23**. Each pulse developed across the resistor **20** is made sufficient in amplitude to drive the tube **23** to a positive grid-to-cathode potential causing electron current to flow in the grid circuit of tube **23** and hence store a charge in condenser **19**. After the pulse across the resistor **20** has ceased, the charge stored in condenser **19** leaks off through resistor **20** and develops a bias thereacross sufficient to maintain the tube **23** below cut off for the time interval between applied pulses.

Disregarding for the moment, the effect of the elements within the dotted box **23***a* it will be seen that each time the tube **23** conducts, current flows into condenser **21** storing a charge therein. Since there is no resistance across condenser **21**, the charge stored by each pulse is added to the charges stored by the preceding pulses. This results in steps of voltage as shown in Fig. 1*a* being developed across condenser **21** and also between the grid of a vacuum tube **25** and ground. The tube **25** is normally biased below cut off due to bias developed across its cathode resistor **26**. When the voltage on the grid of tube **25** exceeds the bias on its cathode, anode current starts to flow in the anode winding B of transformer **24**. The windings *a* and *b* of transformer **24** are so poled that an increase in current in winding *b* causes an increase in voltage on the grid of tube **25**. The increased grid voltage further increases the anode current which in turn further increases the grid voltage. This action continues until the grid of tube **25** draws grid current. The grid current from tube **25** then discharges condenser **21**. When grid current starts to flow in the grid of tube **25**, the anode current ceases to increase which results in a decrease in grid voltage. The decrease in grid voltage causes a reduction in anode current. This action continues until tube **25** cuts off. During the time when tube **25** conducts, a charge is stored in condenser **27**, and when tube **25** cuts off the charge stored in condenser **27** leaks off through resistor **26**. Resistor **26** is chosen to be of such a value that a direct current voltage of the desired magnitude is developed thereacross. The magnitude of the bias voltage developed across resistor **26** is made slightly greater than the peak to peak amplitude of the step voltage wave developed across the condenser **21**.

Tube **29** is a cathode follower which faithfully passes a waveform representative of the step wave voltage developed across condenser **21**, for utilization at output terminals **70** and **71**.

It will now be seen that without compensation the impedance of tube **23** increases as the amplitude of the step voltage across condenser **21** increases due to the fact that each time the voltage across the condenser **21** is increased the effective anode potential of tube **23** is decreased by an amount representative of the charge stored in condenser **21**. This results in a further non-linearity between the lower and upper voltage risers of the step wave.

Considering now the effect of the addition of the vacuum tube **50** and the condenser **30** to the circuit so far described, it will be seen that each time the voltage on the grid of tube **25** rises to a point where tube **25** conducts, tube **50** will also conduct since their grids are connected in an electrically parallel manner as shown. The grid current from tube **25** causes condenser **21** to be discharged as previously described. When tube **50** conducts it causes condenser **30** to be discharged. During the cut off time of tubes **25** and **50**, condenser **30** charges linearly through resistor **22** with a resulting wave form as shown in Fig. 1*c*. The small irregularities in the wave form of Fig. 1*c* are slight discharges of condenser **30** due to tube **23** becoming conducting at the pulse time.

It will be seen that as the voltage across condenser **21** increases, the voltage applied to the anode of tube **23** also increases due to the charge stored in condenser **30**. As a result, the charge stored in condenser **21** due to tube **23** being made conducting may be made practically

constant and therefore all risers in the step voltage wave will be of practically equal amplitude.

By properly proportioning the values of resistor **22** and condenser **30**, over-compensation may be achieved. That is, the upper risers may be made larger than the lower risers. In addition the parameters of resistor **22** and condenser **30** may be designed to cause larger risers in the center than at the upper or lower ends. As an example of one arrangement which has proved satisfactory to give equal risers with 280 volts applied to the positive terminal **9**, the components were given the following values:

Resistor **22**	ohms	100,000
Resistor **20**	megohm	1
Condenser **19**	mf	.01
Condenser **21**	mmf	330
Condenser **30**	mf	.001

In Fig. 3 there is shown a modification of the arrangement of Fig. 2 in which the positive potential end of the winding B of transformer **24** is returned to the anode of tube **23** and also to the junction between resistor **22** and condenser **30**. This arrangement makes possible the elimination of the tube **50**. In this case the anode current of the tube **25** is used to discharge the condenser **30** so that it may perform its compensating action. The remainder of the circuitry acts as described for the arrangement shown in Fig. 2.

In Fig. 4 there is shown an arrangement providing a compensated step voltage wave in which the discharge of the storage capacitor **21** and the compensating condenser **30** is obtained by an external control pulse. In that figure, a step voltage wave is developed across the condenser **21** as described in connection with the arrangement shown in Fig. 2. It will be noted that the input control pulses are also supplied to an electronic counter circuit indicated by the box **60**. The counter circuit may be of any suitable type. One common type of counter is the usual step wave generator since, after a predetermined number of input pulses an output pulse is generated. Thus an arrangement such as shown in Fig. 2 where the input pulses are derived from the input to the circuit arrangement of Fig. 3 instead of the oscillator may be used. Since only the output pulse is required, the circuit need not be compensated. However, in accordance with the invention, the compensating condenser **30** and the tube **50** may be made common to all the step wave generators and all may be thus compensated. After a predetermined number of input pulses, the counter **60** produces a pulse. This pulse is coupled to the grids of the normally non-conducting vacuum tubes **63** and **64**, and causes them to become conducting. Tubes **63** and **64** are normally biased to cut off by means of a suitable bias source E_c. The tube **64** discharges the storage condenser **21** and thus completes a cycle of step wave generation. Tube **63** discharges condenser **30**. The operation of the remainder of the circuit is the same as described in connection with the circuit arrangement of Fig. 2.

The arrangement illustrated in Fig. 5 is similar to that shown in Fig. 4 with the exception that separate inputs are provided for the discharge tubes **63** and **64**. The input to tube **63** is in the form of a square wave pulse which is synchronous with the step wave. The square wave pulse may be derived from any suitable source such, by way of example, as the simple multivibrators or relaxation oscillators described by Eugene R. Shenk in the January, February and March 1944 issues of the publication "Electronics."

When a square wave pulse such as illustrated in Fig. 1*d* is applied to the input of tube **63** it will be conducting for one-half of the step wave cycle and non-conducting for the remainder of the cycle. During its conducting time the compensating condenser **30** will remain discharged and hence no compensation will be provided. During its non-conducting time the condenser **30** will charge at a constant rate and compensation will be pro-

vided in the manner already described. The charge cycle of condenser 30 under these conditions is illustrated in Fig. 1*e*. The resulting step wave is illustrated in Fig. 1*f*. It will be seen that over-compensation is provided for the later steps.

It will be clear, that, by providing a suitably shaped input wave to control the on-off operating times of tube 63, a desired amount of compensation may be provided over the entire step wave cycle.

The arrangement shown in Fig. 6 is similar to that shown in Fig. 2 with the exception of certain changes in the transformer 24 and its connections. Each time tube 25 conducts as described above, a positive pulse is developed across the winding C of the transformer 24. The positive pulses thus developed are applied to the grid of tube 50 and condenser 30 discharges in a manner already described. The voltage stored in condenser 21 is applied to the grid of tube 25 through winding A of transformer 24. The discharge of storage condenser 21 is effected by tube 25 in a manner already described.

What I claim is:

1. A wave generator comprising in combination an electron device having a cathode electrode and an anode electrode, a storage device connected between said cathode and a point of fixed reference potential, means for applying a charging potential between said anode and said point of fixed reference potential in the form of equal amplitude and time duration pulses, a second storage device connected between said anode and said point of fixed reference potential, a second electron device connected in parallel with said second storage device, a third electron device connected to said first mentioned storage device and controlled thereby, and means whereby said second and third electron devices are made conducting after a predetermined number of said pulses.

2. A wave generator according to claim 1 including means to render said second and third electron devices simultaneously and momentarily conducting at the end of each wave cycle.

3. A wave generator according to claim 1 including means whereby the conduction times of said second and third electron devices may be independently controlled.

4. A wave generator comprising in combination an electron device having a cathode, a grid, and an anode, a resistance connected between said grid and said cathode, a resistance connected between said anode and a potential supply source terminal, a storage device connected between said cathode and a point of fixed reference potential, means coupled to said electron device for applying control pulses to said grid whereby said electron device is conducting only during the duration of said pulses, a second electron device having a grid electrode and an anode, means coupling said storage device and said grid electrode for discharging said storage device through said grid electrode, a second storage device connected between said anode of said first mentioned electron device and said point of fixed reference potential, means coupling said second storage device and said anode of said second electron device for discharging said second storage device through anode of said second electron device, and means coupled to said second electron device for controlling the conduction time of said second electron device whereby said storage devices are discharged only after the occurrence of a predetermined number of said pulses.

5. A wave generator comprising in combination, a first vacuum tube having a cathode, a control grid and an anode, a first storage condenser connected between said cathode and ground, a resistance connected between said grid and said cathode, a resistance connected between said anode and a potential supply source terminal, means coupled to said grid for applying control pulses thereto whereby said tube is conducting only during the duration of said pulses, a second storage device connected between said anode and ground, and means coupled to said storage device for cyclically discharging said storage devices.

6. A wave generator according to claim 5 wherein said last mentioned means includes a second vacuum tube having a cathode, an anode and a control grid, said anode of said second tube being coupled to said anode of said first tube, said cathode of said second tube being connected to ground, and means for supplying control potential pulses to said control grid of said second tube to control its conduction time and hence the discharge of said second storage device.

7. A wave generator according to claim 6 including means to couple the control grid of said second tube to said first storage device whereby said first storage device is discharged by means of grid current flow during said conduction time.

8. A wave generator according to claim 6 including a third vacuum tube coupled to said first storage device to discharge said first storage device.

9. A wave generator according to claim 6 including means coupled to said second and third tubes to apply the same source of potential pulses to both said second and said third tubes to control the time of conduction of both said second and said third tubes.

10. A wave generator according to claim 6 including means coupled between said first storage device and said second and third tubes to apply the potential stored in said first storage device to the control electrodes of said second and third tubes to control the conduction time of both said second and said third tubes.

11. A wave generator according to claim 8 including a separate source of control pulses coupled to said second and third tubes to simultaneously control their times of conduction.

12. A circuit arrangement for cumulating a charge on a storage device in substantially equal increments, including an electron discharge device having at least a cathode electrode and an anode electrode defining a space charge path connected in series circuit with said storage device, a further storage device connected across said series circuit, and an electron discharge structure having at least an anode and a cathode defining a space charge path connected across said further storage device and having a grid coupled to the junction between said electron discharge device and the first said storage device.

13. A circuit arrangement for cumulating a charge on a storage device in equal increments, including an electron discharge device having at least a cathode electrode and an anode electrode, said charge storage device being connected between the cathode electrode of said electron discharge device and a point of fixed reference potential, means to apply recurrent charging potentials of substantially constant amplitude to said electron discharge device whereby said storage device is charged in successively decreasing increments, a further storage device coupled in circuit between said anode electrode and said point of fixed reference potential, an electron discharge structure having at least an anode connected to said anode electrode, a cathode coupled to said point of fixed reference potential and a control grid, and means coupling said control grid to said cathode electrode of said electron discharge device, thereby to vary the effective impedance of said electron discharge device to compensate at least in part for the decreasing increment of the charge stored in the first said storage device.

14. A circuit arrangement for cumulating a charge on a storage device in substantially equal increments, including an electron discharge device having at least a cathode electrode, a control electrode, and an anode electrode defining a space charge path connected in series circuit with said storage device, a resistance connected between said control electrode and said cathode electrode, a resistance connected between said anode electrode and a potential supply source terminal, means coupled to said control electrode for applying control pulses thereto whereby said electron discharge device is conducting only during the duration of said pulses, a fur-

ther storage device connected across said series circuit, an electron discharge structure having at least a grid, an anode and a cathode defining a space charge path connected across said further storage device, and a normally blocked electron discharge tube circuit coupled between said grid and the junction between said electron discharge device and said first storage device.

15. A circuit arrangement for cumulating a charge on a capacitor in equal increments, including an electron discharge device having at least a cathode electrode, a grid electrode and an anode electrode, said capacitor being connected between the cathode electrode of said electron discharge device and a point of fixed reference potential, a resistance connected between said anode electrode and a potential supply source terminal, a resistance connected between said grid and cathode electrodes, means coupled to said grid electrode to apply recurrent charging potentials of substantially constant amplitude thereto whereby said electron discharge device is conducting only during the duration of said recurrent potentials so that said capacitor is charged in successively decreasing increments, a further capacitor coupled in circuit between said anode electrode and said point of fixed reference potential, an electron discharge structure having at least an anode connected to said anode electrode, a cathode coupled to said point of fixed reference potential and a control grid, and a normally blocked electron discharge tube circuit coupling said control grid to said

cathode electrode of said electron discharge device, thereby to vary the effective impedance of said electron discharge device to compensate at least in part for the decreasing increment of the charge stored in the first said storage device.

16. A wave generator according to claim 6, including a third vacuum tube coupled to said first storage device to discharge said first storage device, the time of conduction of said third tube being controlled in response to the potential stored in said first storage device, and connections between said second and third tubes to control the conduction time of said second tube in response to the application thereto of pulses developed by said third tube.

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