

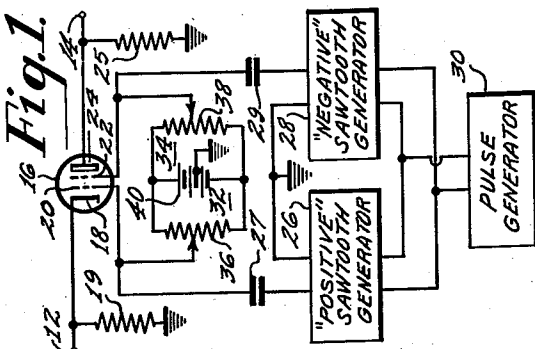
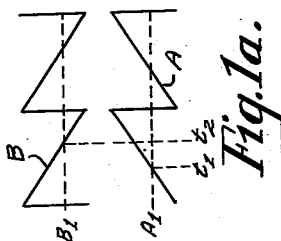
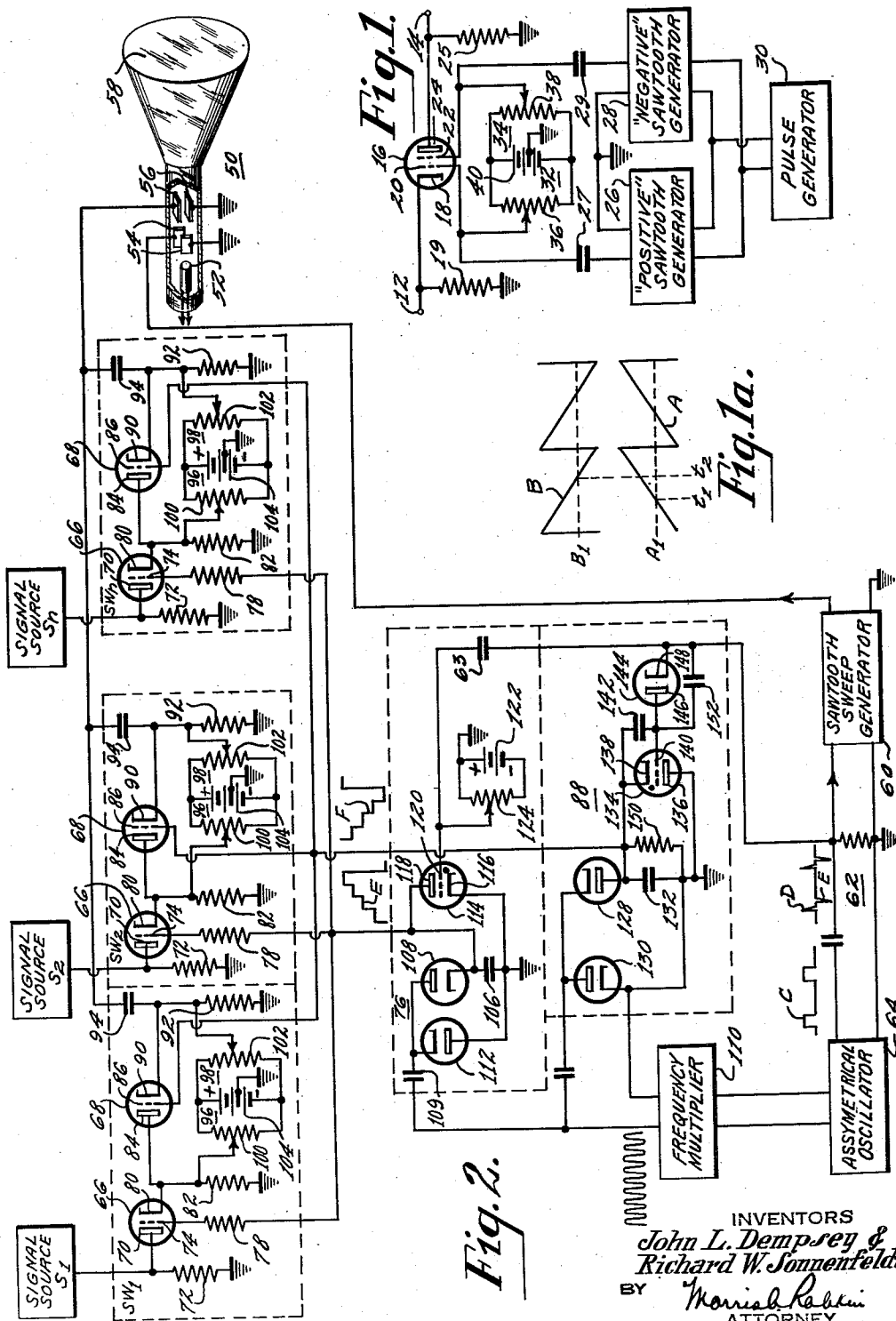
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ELECTRONIC SWITCH

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ELECTRONIC SWITCH

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1

This invention relates to improvements in electrical switches, and particularly to an improved switch of the type commonly designated "electronic," as distinguished from mechanical switches.

In an electronic switch, as that term is used herein, electron tubes are utilized to provide very high speed switching or commutating action. In conventional electronic switches, a square wave or the like may be applied to the control grid of an electron tube to turn the tube off and on rapidly while a signal voltage is being applied continuously to another grid in the tube. Where a commutating action is required, several such tubes may be turned on and off by a plurality of square wave generators operating in sequence (see, e. g., U. S. Patent 2,426,454—Johnson).

While switch systems of the foregoing type have many useful characteristics, they are not entirely satisfactory in all respects. In general, with a single electronic switch unit, any change in the rate of switching or in the duration of the switching interval requires a change in the switching voltage waveform. Where a plurality of such switch units are arranged as an electronic commutator, changes in the order or rate of switching, or in the switch intervals, require extensive changes in the switching voltage waveform or in the number of switch waveform generators required.

Assume, for example, that one wishes to display a plurality of different signals sequentially on a cathode ray oscilloscope. In such case, the cathode ray tube deflection system can be connected to the various signal sources through an electronic switch system of the type just described. However, if one wishes to change the display time allotted to each waveform, or to make other changes in the display, substantial changes must be made in the switching system.

It is, accordingly, a general object of the present invention to provide an improved electronic switch which is adaptable to a wide variety of switching problems.

A more specific object of the invention is to provide an electronic switch which is simple to adjust, has a minimum number of elements, yet is extremely accurate and dependable in operation.

A further object of the invention is to provide an improved electronic commutator for signal separation or signal combining purposes.

In accordance with the invention, certain of the foregoing objects and advantages of the invention are attained by utilizing two varying

2

control voltages to operate an electronic switch. The control voltages are arranged to vary simultaneously, and each control voltage acts upon a separate control element in the switch. With this arrangement, one of the control voltages can be utilized to "open" the switch at a predetermined time. At a predetermined later time, the other control voltage can be utilized to "close" the switch. As will be shown, it is a simple matter to vary the operating characteristics of the switch simply by adjusting unidirectional voltages applied to the switch electrodes, but without changing the basic switch control waveforms.

In accordance with a preferred embodiment of the invention, control voltages of "staircase" waveform are utilized. A further feature of the invention resides in the provision of an improved "negative" staircase voltage wave generator particularly suitable for use in a switching system of the type contemplated by the present invention.

A more complete understanding of the invention can be had from the following description of illustrative embodiments thereof, when considered in connection with the accompanying drawing, wherein:

Figure 1 is a schematic diagram of an electron switch arranged in accordance with the invention,

Figure 1a shows certain of the voltage waveforms utilized in the switch of Figure 1, and

Figure 2 is a schematic diagram of an electronic commutator arranged in accordance with the invention and including individual switch sections embodying a modified form of the switch shown in Figure 1.

Referring particularly to Fig. 1 of the drawing, there is shown one form of electronic switch illustrative of the invention. The switch of Fig. 1 is connected between an input terminal 12 and an output terminal 14 to open and close the circuit between the terminals 12, 14. As will be shown hereinafter, either the terminal 12 or the terminal 14 can be connected in common with other input and output terminals to provide a commutator arrangement either for signal combining purposes or for signal separation.

The switch of Fig. 1 comprises an electron tube 16 having a cathode 18, first and second control electrodes or grids 20, 22, and an anode 24. The cathode 18 is connected to the input terminal 12, while the anode 24 is connected to the output terminal 14. The cathode 18 and the anode 24 are connected to ground through relatively large resistors, 19 and 25, respectively.

In a case where the signal to be passed through the switch 10 is of negative polarity, such signal would be applied to the terminal 12 and taken off at the terminal 14. If a positive polarity signal is involved, the designations "input" and "output" for the terminals 12, 14 would be reversed; the terminal 14 then serving as the input terminal and the terminal 12 as the output terminal. In either event, it will be understood that a signal could be transferred from one to the other of the terminals 12, 14 at any given time only if the voltages on both of the control electrodes 20, 22 were such as to allow the tube 16 to conduct current at that time. In other words, the control electrode voltages will determine the tube conductivity in the usual manner characteristic of electron tube operation. However, in the absence of a signal, no current will flow in the tube 16, since the "anode voltage" for the tube 16 is provided by the signal itself.

In accordance with the invention, the control electrodes 20 and 22 each are connected to separate varying voltage sources, shown as "sawtooth" wave generators 26, 28, through coupling capacitors 27, 29. One of the generators, 26, is adapted to provide a "positive" sawtooth voltage; i. e. a voltage wave that increases steadily from a minimum to a maximum value, and then drops abruptly back to a minimum value at the end of the cycle. This is shown by the waveform A in the drawing. The other generator, 28, is adapted to provide a "negative" sawtooth voltage; i. e. a wave B having the same shape as the positive wave A, but inverted in polarity. The two generators 26, 28 are connected to operate synchronously in response to pulses from an oscillator or pulse generator 30. No details are given for the generators 26-30 since such generators are well known in the art (see e. g. pgs. 511-515 of Terman—"Radio Engineers' Handbook," first edition, McGraw-Hill Inc.).

In the switch system of Fig. 1, as thus far described, it is evident that the sawtooth voltages A, B, will tend to vary the conductivity of the tube 16 in opposite directions simultaneously. Of course, the exact effect of each sawtooth voltage will depend on the absolute value thereof with respect to the cathode voltage. In other words, due to the coupling capacitors 27, 29, the instantaneous absolute values of the voltages A, B at the grids 20, 22 will depend on the direct current circuits connected to the grids 20, 22. In order to adjust the absolute values of the voltages A, B to vary the operating conditions, the grids 20, 22 are connected to separately adjustable unidirectional voltage sources, 32, 34. For simplicity, the voltage sources 32, 34 are shown as a pair of potentiometers 36, 38 connected in parallel with a common battery 40. Thus, the voltage at either grid, 20 or 22, at any instant will depend on the setting of the associated potentiometer, 36 or 38, as well as on the value of the varying voltage, A or B, applied to the grid at that instant.

For a typical case, assume that the potentiometer 36 is set so that the grid 20 will allow the tube 16 to conduct when the voltage A is above the level A_1 in the drawing. Assume also that the potentiometer 38 is set so that the grid 22 will permit conduction in the tube 16 until the voltage B is below the level B_1 . When the voltage A rises to the cut-off level A_1 , at the time t_1 , the voltage B will be above cut-off. Therefore, the tube 16 will be able to pass a signal from cathode to anode until the time t_2 when the

voltage B drops to the level B_1 . This particular combination of potentiometer settings will give a switching interval of duration t_1-t_2 , occurring at the predetermined time t_1 in each sawtooth cycle. To change the duration of the switching interval, or to change the time of switching in the sawtooth cycles, it is a simple matter to adjust either or both of the potentiometers 36, 38 to attain the desired result. It is especially important to note that these changes in switching interval and time of switching can be made without making any change in the basic switching waveform. Moreover, it should be noted that the circuit is adaptable to a wide variety of variable interval automatic switching operations simply through the provision of automatically variable unidirectional voltage sources, such as carbon-pile resistors, heat actuated resistors, bridge-circuits, and the like. It should also be noted that the invention is not limited to the use of sawtooth waveshape control voltages. Sinewave and other generally sloping waveform switch-control waveforms can be used in a manner similar to that already described, all within the scope of the invention. Of course, a square wave switching voltage would not be suitable since it would not permit switch interval adjustment by bias voltage variations.

It was previously noted that the "anode" voltage for the tube 16 consists of the signal voltage to be transferred between the terminals 12, 14. Of course, where the signal to be transferred is not strong enough to carry through the tube 16 without amplification, conventional anode voltage can be applied to the tube. The signal then can be applied to an additional grid electrode in the tube to obtain signal amplification in addition to switching action. However, if the tube 16 is operated with conventional anode voltage, the output signal will contain a unidirectional voltage component which usually must be removed before the signal finally is used. In removing this unidirectional component, it is extremely difficult to avoid distorting the signal. Therefore, the arrangement shown is deemed preferable wherever sufficient signal voltage is available.

While the switch shown in Fig. 1 has the advantages already noted, it is subject to certain limitations. In the great majority of electron tubes having two control electrodes, these two electrodes do not have an exactly equal effect on the tube current. This makes it necessary, in some instances, to provide a rather large varying voltage to the control electrode which has the least effect on tube conductivity. Also, where a single tube is used, as in the switch of Figure 1, both the varying switching voltage and the unidirectional adjusting voltage must be applied to the same electrodes, or to additional control electrodes. Either of these arrangements may be undesirable.

In Fig. 2, there is shown an electronic commutator arranged in accordance with the invention, and including a modified form of switch which avoids the foregoing problems. Also, the system of Fig. 2 includes a novel circuit for generating one of the switching voltage waveforms.

To illustrate one use of an electronic commutator embodying the principles of the invention, the system of Fig. 2 comprises an arrangement for displaying on a cathode ray tube 50 samples of the signals from a plurality of signal sources S_1-S_n . While only three signal sources S_1, S_2, S_n , with accompanying switch units SW_1, SW_2 ,

SW_n , are shown, it will be understood that a much larger number of signals could be accommodated in this way.

The cathode ray tube 50 is provided with the usual electron gun 52, sets of horizontal and vertical deflection plates 54, 56, and a fluorescent screen 58. For simplicity, other details of cathode ray tube structure have been omitted. The vertical deflection plates 56 are connected to the signal sources S_1 — S_n through the switch units SW_1 — SW_n . The horizontal deflection plates 54 are connected to a conventional sawtooth sweep voltage generator 60.

An oscillator 64 is provided to generate a voltage of asymmetrical waveform for timing the various operations of the system, and the sweep generator 60 is connected through a differentiating network 62 to the oscillator 64. The oscillator 64 can be of any conventional type, such as a so-called blocking oscillator, a multivibrator, or the like, details of which are given in the above mentioned Handbook, pgs. 511-516. Assuming that the oscillator 64 is adapted to provide a voltage of rectangular pulse waveform C, the differentiator output voltage will consist of positive and negative pulses D, E. Assuming also that the sweep voltage generator 60 will be triggered by the positive pulses D, the cathode ray beam in the tube 50 will make one horizontal sweep for each output pulse C from the oscillator 64.

It is intended that a sample of the signal from each of the sources S_1 — S_n be displayed on the tube screen 58 during succeeding portion of each horizontal sweep. This can be accomplished by sequentially connecting the sources S_1 — S_n to the vertical deflection plates 56 through the switch units SW_1 — SW_n .

Each of the switch units SW_1 — SW_n comprises a pair of serially connected electron tubes 66, 68. Since these switch units are substantially identical, only the first unit SW_1 will be described in detail.

In the switch unit SW_1 , one of the tubes, 66, has an anode electrode 70 which is connected to ground through a relatively large resistor 72 and also to the associated signal source S_1 . The same tube 66 has a control electrode 74 connected to a source 76 of "staircase" waveshape voltage (described in detail hereinafter) through a current limiting resistor 78. The cathode electrode 80 of the tube 66 is connected to ground through a relatively large resistor 82.

The other tube 68 has an anode electrode 84 connected to the preceding tube cathode 80, a control electrode 86 connected to a second source of "staircase" waveshape voltage 88 (also described hereinafter), and a cathode electrode 90 connected to ground through a relatively large resistor 92. The cathode 90 also is connected to the cathode ray tube vertical deflecting electrodes 56 through a coupling capacitor 94.

The cathodes 80, 90 are connected to separate sources 96, 98 of variable unidirectional voltage. The voltage sources 96, 98 are shown as a pair of potentiometers 100, 102 connected in parallel with a battery 104. The potentiometers 100, 102 and the battery 104 provide means for adjusting the voltage level required at the control electrodes 74, 86 to allow conduction through the tubes 66, 68, similar to the function of the voltage sources 32, 34 in the switch of Fig. 1. However, it is to be noted that the arrangement of the switches SW_1 — SW_n in Fig. 2 avoids common connection of the switching voltage sources 76, 88 and the adjusting voltage sources 96, 98, and

without requiring additional control elements in the switch. Of course, the voltages selected at the potentiometers 100, 102 should not be more positive than the minimum value of signal voltage expected from the signal source S_1 .

The switching voltages for the switches SW_1 — SW_n are of staircase waveshape, as shown at E, F, each increasing in discrete steps, but in opposite directions, from a minimum to a maximum value and then returning abruptly to the minimum value. While switching voltages of staircase waveshape do not provide continuous control of the switch action as would sawtooth or similar voltages, they do permit more exact control of the switches, as will be pointed out hereinafter.

One of the staircase switch voltage generators, 76, is of conventional design, and comprises a storage capacitor 106 connected to be charged by positive pulses received through a coupling diode 108 and a capacitor 109. The source of charging pulses comprises a frequency multiplier network 110, connected to provide a pulsating voltage at a multiple of the frequency of the oscillator 64. The multiplier 110 may be any one of a number of well known circuits, such as a class C amplifier having a high Q resonant output circuit tuned to a harmonic of the frequency of the oscillator 64 (see e. g. the above-mentioned Handbook, pgs. 458-462). Assuming that multiplier 110 is a circuit of the type just mentioned, the output thereof will comprise a pulsating voltage containing a predetermined number of positive and negative half cycles for each oscillator output pulse. Each positive half cycle from the multiplier will cause current to flow through the diode 108 to place an increment of positive charge on the capacitor 106. Each negative half cycle from the multiplier 110 will be shunted around the storage capacitor 106 by a second diode 112 connected in parallel with the series path through the diode 108 and the storage capacitor 106. Thus, the voltage on the storage capacitor 106 will continually increase in stepwise fashion.

At the end of a predetermined number of "steps," it is necessary to discharge the capacitor 106 to begin a new cycle of the staircase wave. To this end, a gas-filled tube 114 is connected in parallel with the storage capacitor 106. The gas tube cathode 116 is connected to one capacitor terminal, and the anode 118 is connected to the other capacitor terminal. The control grid 120 of the gas tube is connected to receive pulses from the differentiator 62 through a capacitor 63. The gas tube 114 is of conventional "grid-start plate-stop" type, wherein initiation of conduction, or firing, is controlled by the grid 120, while conduction is interrupted by a decrease in anode voltage.

The gas tube control grid 120 is connected to an adjustable negative voltage source, shown as a battery 122 and potentiometer 124. As the voltage increases on the capacitor 106, the gas tube anode voltage also will increase, but the gas tube will not conduct current to discharge the capacitor due to the bias voltage from the potentiometer 124. However, when a positive voltage impulse is applied to the control grid 120 from the differentiator 62, the gas tube 114 will fire. Therefore, at the end of each horizontal sweep of the cathode ray beam, the gas tube 114 will fire and the storage capacitor 106 will discharge through the gas tube. The resultant drop in gas tube anode voltage will cause the gas tube to stop

conducting, allowing a new cycle of stepcharging of the capacitor 106 to begin.

The other step voltage generator 88 is similar in some respects to the positive staircase generator 76. However, as a negative-going staircase wave is required from the generator 88, a pair of diodes 128, 130 are connected to a storage capacitor 132 in opposite polarity to the diodes 108, 112 of the positive staircase generator. That is, positive half cycles of voltage from the multiplier 110 will be shunted around the capacitor 132 by the parallel-connected diode 130, while negative half cycles will place a negative charge on the capacitor 132 through the series-connected diode 128. Accordingly, the voltage on the capacitor 132 will increase stepwise in a negative direction while the voltage on the capacitor 106 is increasing stepwise in a positive direction. A gas tube 134 is connected in parallel with the storage capacitor 132, with the gas tube anode 136 being connected to the grounded terminal of the capacitor 132 and the cathode 138 being connected to the other terminal of the capacitor 132.

It can be seen that the problem of discharging the storage capacitor 132 in the negative staircase generator is somewhat different than that of discharging the storage capacitor 106 in the positive staircase generator 76. In the latter case, the cathode 116 of the gas tube 114 is grounded, so there is no change in the grid-to-cathode voltage during charging of the storage capacitor 106. Of course, it will be understood that the grid-to-cathode voltage is of critical importance as regards firing of the gas tube. In the negative staircase generator 88, the gas tube cathode 138 becomes increasingly negative during the stepwave, so that the grid voltage also must become more negative as the cathode voltage increases. Otherwise, the tube would fire on the first or second step of the negative staircase.

In accordance with the invention, this difficulty is avoided by coupling the grid 140 to the cathode 138 through a capacitor 142. Means are provided for placing a negative grid-to-cathode voltage on the capacitor 142 shortly after each stepcharging cycle begins. The terminal of the capacitor 142 at the gas tube grid 140 is connected to the differentiator 62 through a diode 144. The diode anode 146 is connected to the capacitor 142, and the diode cathode 148 is connected to the differentiator 62. The other terminal of the capacitor 142 is connected to ground through a resistor 150 to complete a charging current path through the capacitor 142, the differentiator 62, and the diode 148. A coupling capacitor 152 is shunted across the diode 144.

With the arrangement just described, each negative output pulse E from the differentiator 62 will cause current to flow through the diode 144, placing a negative voltage on the capacitor 142. As long as the gas tube 134 is non-conductive, the grid-to-cathode impedance will be high and the voltage on the capacitor 142 will not change appreciably. Accordingly, as the gas tube cathode voltage becomes more negative, the grid 140 will stay more negative than the cathode 138, preventing firing of the tube 134. Subsequently, when a positive pulse D is generated at the differentiator 62, the tube 134 will fire. At that time, the step-charge storage capacitor 132 will discharge through the low impedance anode-cathode space in the tube 134. The voltage on the capacitor 142 will reverse polarity temporarily while the positive pulse D is being gener-

ated at the differentiator 62. Whether or not a positive charge will remain on the capacitor 142 at the end of the positive pulse D will depend on the internal impedance of the oscillator 64. In any event, when the next negative impulse E is generated at the differentiator 62, a negative charge will be left on the capacitor 142 as previously described.

Considering, next, the sequential action of the switch units SW₁—SW_n, it will be noted that each switch unit receives the same positive and negative staircase voltages, E, F, from the generators 76, 88. The potentiometers 100, 102 in the various switch units SW₁—SW_n each are adjusted so that the tubes 66, 68 controlled thereby will become conductive or non-conductive on selected steps of the staircase voltages. In a simple case, it can be assumed that the tube 66 in the first switch unit SW₁ will be turned on by the first step in the positive staircase E, and that the tube 68 therein will be cut off by the second step in the negative staircase F; that the second switch unit SW₂ is adjusted so that its first tube 66 will conduct on the second step in the positive staircase E and its second tube 68 will cut-off on the third step in the negative staircase F; and that the third switch unit SW_n is adjusted to "close" and "open" on the third and fourth steps of the positive and negative staircase. It is apparent that such adjustment will provide the desired sequential action. Any desired change in the switching sequence can be obtained simply by suitable adjustment of the various bias voltages in the switch units SW₁—SW_n.

As previously stated, staircase waveshape switching voltages provide most precise switch action, although they do not provide the continuous range of adjustment obtainable with smoothly varying switch voltages. The abrupt changes from step to step in the staircase voltages insure that the switch tubes will turn on and off exactly on the vertical section of the selected steps, whereas with smoothly varying switch voltages, the transition from conduction to cut-off and vice versa may vary by a small amount from one switching cycle to the next. The waveshape selected for the switching voltages in any given system will, of course, depend on the characteristics of switch action desired.

Although switching voltages of equal frequency have been assumed in connection with the systems of both Fig. 1 and Fig. 2, the invention is not necessarily limited thereto. By utilizing switching voltages of different frequency, very complex switching sequences can be obtained.

It will be understood that various other changes could be made in the systems shown and described, all within the scope and spirit of the invention. By way of example only, it is noted that the frequency multiplier 110 of Fig. 2 could be eliminated by providing a frequency divider network between the oscillator 64 and the differentiator 62. In some instances, it may be desirable to have a blocking capacitor between the cathode 80 of the tube 66 and the anode 84 of the tube 68. Provision of such a capacitor would avoid interdependence between the biasing voltages used in any given switch unit. Accordingly, the foregoing is to be construed as illustrative, and not in a limiting sense.

What is claimed is:

1. In an electronic switch for opening and closing a circuit between an input terminal and an output terminal, in combination, electron tube means connected between said terminals and in-

cluding anode and cathode electrodes connected one to each of said terminals, first and second conductivity control electrodes in said tube means for controlling the conductivity of said tube means as a function of the voltage on each said control electrode, a first source of periodically varying voltage, a second source of voltage varying simultaneously with said first source voltage and in a direction opposite to the direction of variation of said first source voltage at any given instant, said voltage sources being connected one to each of said control electrodes to vary simultaneously and in opposite directions the effect of said control electrodes on the conductivity of said tube means, and means to adjust separately the voltage level required at each said control electrode to establish conductivity between said terminals through said tube means.

2. Apparatus as defined in claim 1 wherein said tube means comprises two serially connected tubes each having anode and cathode electrodes and each having one of said control electrodes.

3. Apparatus as defined in claim 1 wherein said first and said second voltage sources each comprise a staircase waveform voltage generator.

4. As defined in claim 1 wherein said adjusting means comprises first and second variable unidirectional voltage sources connected each to separate ones of said electrodes.

5. In an electronic commutator of the type comprising a plurality of switch units having one common terminal and wherein said switch units each comprises electron tube means having anode and cathode electrodes and two conductivity control electrodes for controlling the conductivity of said tube means as a function of the voltage on each said control electrode, the combination with said switch units of first and second sources of voltage varying simultaneously and in opposite directions, each said voltage source being connected to a separate one of said control electrodes in each said switch unit, and means to adjust separately the voltage level required at each said control electrode to establish conductivity in said tube means.

6. Apparatus as defined in claim 5 wherein said voltage sources each comprise a generator of staircase waveform voltage.

7. Apparatus as defined in claim 6 wherein one

of said generators comprises a first capacitor, a first source of pulsating voltage, a first diode electron tube connected in series with said first capacitor and said pulsating voltage source, a second diode electron tube connected in series with said pulsating voltage source but in polarity opposite to that of said first diode, said second diode being connected in parallel with the series combination of said capacitor and said first diode, a gas-filled electron tube connected in parallel with said first capacitor and having anode, cathode, and control grid electrodes, a second source of pulsating voltage of recurrence rate which is a submultiple of the recurrence rate of pulses from said first pulsating voltage source, said second pulse source being connected to said gas tube grid, and a second capacitor connected between said gas tube grid and cathode.

8. Apparatus as defined in claim 6 wherein one of said generators comprises a first capacitor having a pair of terminals, means to charge said capacitor in discrete steps of predetermined recurrence rate so that one of said capacitor terminals becomes increasingly negative relative to the other of said capacitor terminals, a gas-filled electron tube having an anode, a cathode, and a control grid, said gas tube cathode being connected to said one capacitor terminal and said gas tube anode being connected to said other capacitor terminal, a source connected to said gas tube grid of positive and negative voltage pulses of recurrence rate which is a submultiple of said predetermined rate, and a second capacitor connected between said gas tube grid and cathode for maintaining said gas tube grid negative with respect to said gas tube cathode during intervals between said positive pulses.

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