

Dec. 29, 1942.

J. M. HOLLYWOOD

2,306,386

ELECTRONIC APPARATUS

Filed April 30, 1941

2 Sheets-Sheet 1

Fig. 1.

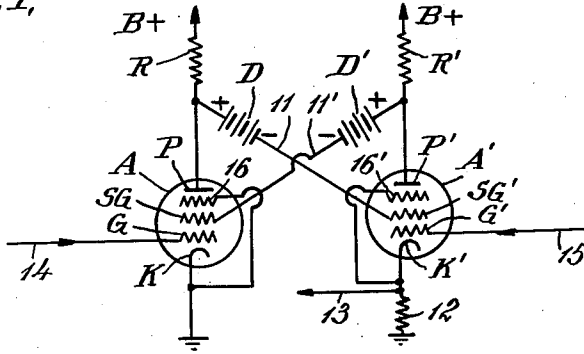
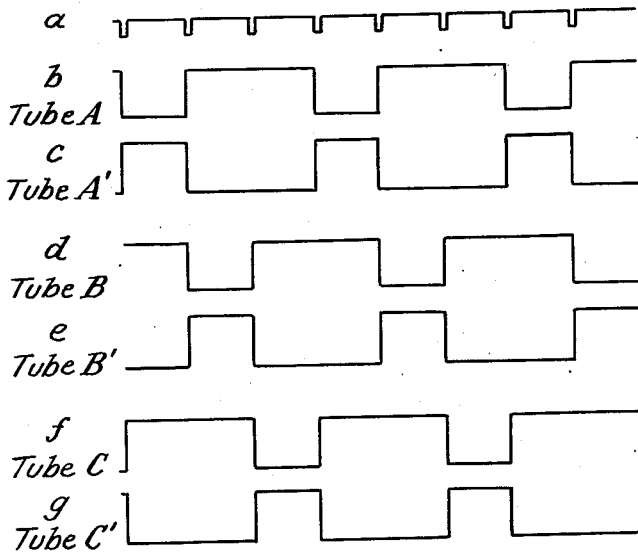


Fig. 3.



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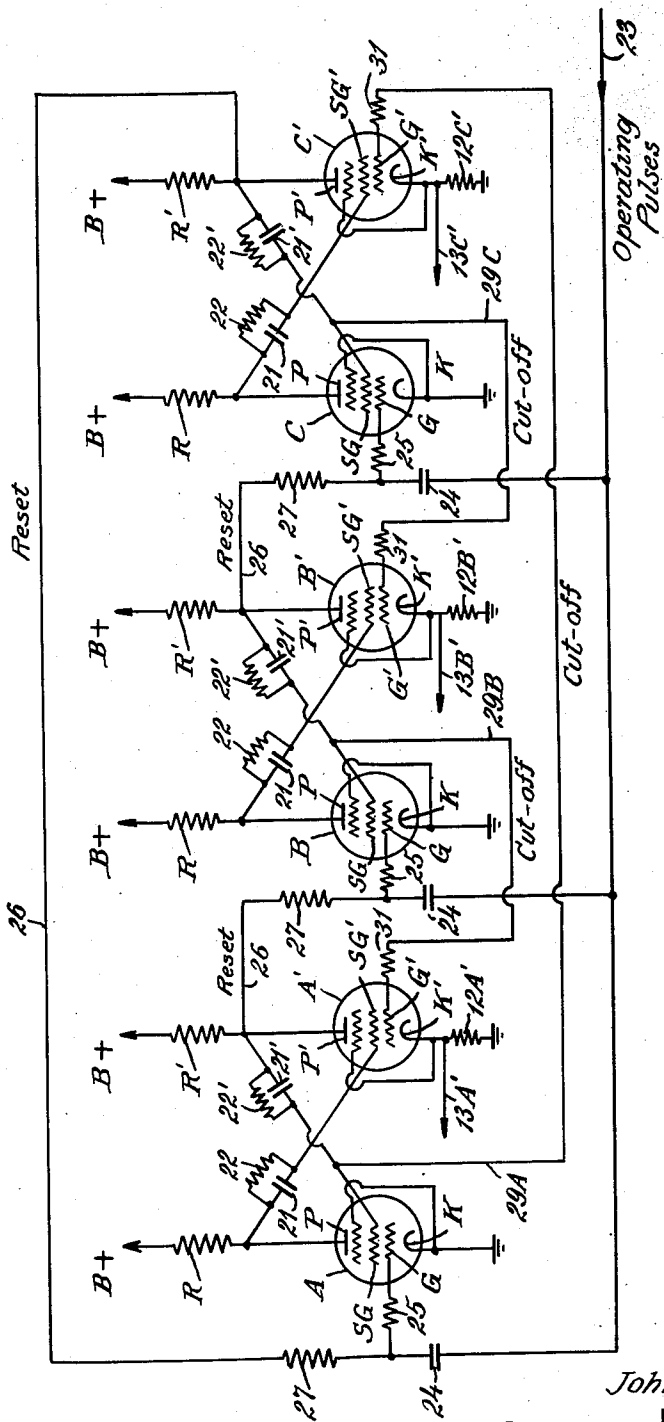
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2 Sheets-Sheet 2

Fig. 2,



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ELECTRONIC APPARATUS

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Application April 30, 1941, Serial No. 391,169

18 Claims. (Cl. 178—5.4)

This invention relates broadly to the field of electronic switching circuits. The invention particularly contemplates an electronic switching circuit of the so-called "ring type," but in certain respects the invention is of broader application. The invention is particularly important in the field of color television, being especially adapted for use in changing the balance between different color components of a color television signal. However, the invention may be applied to other fields of use.

The term "electronic switching" may be applied to the making of circuits operative or inoperative, or the changing from one condition of operation to another, by means of an electronic device. The switching may be effected, for example, by a change in polarity or magnitude, or both, of a voltage or current.

There have heretofore been proposed a number of electronic switching circuits, including those of the ring type, employing gas-filled triodes of the so-called "Thyratron" type. The switching is effected by impressing suitable control pulses on the circuit. In the case of a ring circuit, the control pulses cause the tubes to be "fired" successively around the ring. Such circuits, while satisfactory for many purposes, are subject to some eccentricities of operation due to the presence of the gas, and the abruptness of the switching is limited by the time of ionization and deionization of the gas in the tubes as well as by the circuit constants required.

A primary object of the present invention is to provide circuits employing vacuum tubes, rather than gas-filled tubes, which are therefore free from the eccentricities of gaseous discharge tubes and faster in operation. Furthermore, the invention provides circuits in which the electronic switching can be readily controlled and involves a minimum of interaction on the control voltages.

In accordance with the invention, one or more pairs of electronic vacuum tubes are employed, each tube having a plurality of control electrodes. The anode circuit of each tube is interconnected with a control electrode of the other tube of the pair so that anode current exceeding a given value in one tube restricts anode current in the other tube below a lower limiting value. Preferably the anode current of the tubes is switched between substantially cut-off and a relatively large value. Control voltages are impressed on the other control electrodes of the tubes of a pair in order to switch current flow from one tube to the other. The use of two control electrodes in each tube of a pair facilitates the ready and

precise control of the switching and enables the switching to be performed with a minimum of interaction on the control voltages.

For convenience of description hereinafter, when anode current is flowing in the second tube of a pair, that pair will be considered to be in an "actuated" state, whereas current is flowing in the first tube of a pair, that pair will be considered to be in an "unactuated" state. These terms will be understood to be employed for convenience in description, only, since output voltages or currents may be derived from the circuits of either or both tubes of a pair, as the use dictates.

The ring switching circuit, in accordance with the invention, comprises three or more pairs of vacuum tubes interconnected so that current is switched in the pairs of tubes successively around the ring. Provision is made whereby switching of current in one pair of tubes to an actuated state automatically reswitches the current in the preceding pair to an unactuated state and resets the succeeding pair of tubes so that the next control pulse can switch current in that succeeding pair to an actuated state.

The specific ring circuit described hereinafter is particularly adapted for use in the color mixer described in the application of Peter C. Guldmark, Ser. No. 357,082, filed September 17, 1940. In that application a color television signal is passed into three channels and blanking waves are applied to the channels to blank out all but the red signal in one channel, all but the green signal in a second channel, and all but the blue signal in the third channel. In order to properly synchronize and phase the blanking waves with the color television signals, the control pulses for the ring circuit are derived from the television signal. For example, the field synchronizing pulses or the peaks of the vertical sawtooth waves may be employed.

The invention will be more fully understood by reference to the specific embodiments illustrated in the drawings and the following description thereof. In the drawings:

Fig. 1 is a circuit diagram of a pair of vacuum tubes interconnected in accordance with the invention;

Fig. 2 is a circuit diagram illustrating a ring connection of three pairs of tubes; and

Fig. 3 is a diagram showing the manner in which a train of operating pulses causes current to change in the various tubes.

Referring to Fig. 1, a pair of vacuum tubes A and A' are employed having cathodes K and

K', anodes P and P', and a plurality of control electrodes G, SG and G', SG'. The tubes specifically illustrated are pentodes, for example, of the 6C6 type, and both the screen and control grids are employed as control grids. It will of course be understood that other types of tubes may be employed if desired. The anode will ordinarily be the plate of the tube, and the control electrodes will be in the form of grids. Also, the cathodes will usually be thermionic and heated by a suitable current source (not shown). The cathode K of tube A is grounded, and the cathode K' of tube A' is connected to ground through an output impedance, here shown as a resistance 12. Preferably 12 has a low resistance relative to that of R'. The suppressor grids 16 and 16' are connected to the respective cathodes, in the usual manner.

The anode-cathode circuit of each tube includes an impedance, here shown as resistance R (R'), connected between the respective anode and the anode voltage (B+) supply. The anode-cathode circuit is completed in the usual manner by connecting the negative side of the B+ supply to ground. The anode voltage may be obtained in any convenient manner, such as from batteries or the more usual rectifier supply. Between the anode-cathode circuit of each tube and a first control electrode of the other tube is an interconnection 11 (11'). This interconnection is connected to the anode-cathode circuit at a point of the anode impedance which is remote from the cathode so that the voltage drop through at least a portion of the impedance is impressed on the control electrode of the other tube when anode current flows through the impedance. As specifically illustrated, each interconnection is directly from the anode of one tube to the control grid SG of the other tube, and includes a source of biasing voltage D (D') for biasing each control electrode below the potential of the corresponding anode of the other tube.

With the interconnections as shown, it will be seen that when no anode current is flowing in one tube, say, tube A, there will be no substantial voltage drop across resistance R and the algebraic sum of the anode voltage source B and the additional biasing source D will be impressed upon the grid SG' of tube A'. If the voltage of D is small compared with that of B, for example, 45 volts against 150 volts, the potential of the grid SG' will be highly positive with respect to the cathode K' and will exert little if any limiting action on the flow of current in tube A'. When current flows in tube A, however, the voltage drop across resistance R reduces the potential on grid SG'. By selecting a suitable value of R, in conjunction with the other circuit constants, the potential on SG' will be altered to completely cut off current in tube A'.

For specific example, with the battery voltages just given, 6C6 tubes, and anode resistances R, R' of, say, 100,000 ohms, the anode current in tube A is such that the voltage drop across the tube is relatively low, say, 10 or 20 volts, and the voltage drop across resistance R will be relatively large, say, 140 or 130 volts. Thus the bias on SG' will be made negative, say 35, or 25 volts negative to the cathode K'. Under these conditions when anode current flows in one tube, it completely cuts off current in the other tube.

To obtain this operation the potential of the second control electrode in the tube passing current, for example, G in tube A, must be sufficiently

above cut-off to allow the required amount of anode current to flow to produce the desired voltage drop in resistance R.

It will be understood that the particular tubes, voltages, values of resistance, etc., given above are for specific example only, and the invention is not limited thereto. The selection of tubes, voltages and circuit constants may vary widely depending on the use contemplated, and will be clear to those skilled in the art from the description given herein.

Broadly, each interconnection is made to a point of the anode-cathode circuit of one tube such that increase in anode current decreases the potential impressed on the control electrode of the other tube. The voltage and polarity of the additional bias source is then selected in view of the change in potential and other voltages between control electrode and cathode so that the change in potential due to current in one tube operates the other tube between cut-off and a relatively large current.

Considering now the switching of current from one tube to the other, assume that both grids G and G' are biased considerably above cut-off and that tube A is passing anode current, thus impressing a potential on control grid SG' to prevent current flow in tube A'. If, now, a negative pulse is applied to grid G of sufficient magnitude to substantially cut off anode current in tube A, the voltage drop in resistance R will become very small and the potential of grid SG' of tube A' will be changed from beyond cut-off to a relatively large positive value, since the B+ voltage exceeds that of D. Current will thereupon flow in tube A'. If grid G' is sufficiently above cut-off, sufficient anode current will flow in tube A' to cause the voltage drop in resistance R' to bias the control grid SG of tube A beyond cut-off. That is, anode current in tube A' exceeding a limiting value will bias grid SG of tube A beyond cut-off. (It will be understood that the term biasing "beyond" cut-off includes "to" cut-off. Ordinarily a negative potential somewhat greater than that just sufficient to cut off anode current will be employed to insure reliability of operation.) Thereafter, even though the negative pulse be removed from grid G and the grid returned to its initial value above cut-off, tube A will be prevented from passing current by the voltage on SG. On the other hand, current will continue to flow in tube A' until a negative pulse is applied to grid G' of sufficient magnitude to substantially cut off current therein, whereupon the voltage drop in R' will become very small and the voltage on grid SG of tube A will rise to a large positive value. If grid G is sufficiently above cut-off, the anode current in tube A will produce a sufficient voltage drop in R to bias grid SG' in tube A' beyond cut-off, thus preventing current flow in A' even though the negative pulse on G' is removed.

Although the above operation is that preferred, particularly for the application to color mixing above referred to, wherein abrupt changes in current are desired, the circuit constants may be selected to produce a change between two different current values. For example, instead of changing the current in each tube between substantially cut-off and a relatively high value substantially unaffected by control potentials on the two grids, the current in the tubes may be changed between a lower value and an upper value. The desired lower value may be obtained by adjusting the voltages of the B and

D batteries and the value of the plate impedance so that the potential on, say, SG' when current is flowing in tube A does not completely cut off current in tube A' but limits it below a lower limiting value. The maximum current flowing may be limited by appropriately selecting the voltages and anode impedance or by applying suitable potentials to other control electrodes in the tubes. In the present specification and claims the term "upper limiting value" of the anode current in either tube means the value which will restrict anode current in the other tube at a given lower limiting value. Normally, current in excess of the upper limiting value in one tube will bias the control electrode of the other tube below the lower limiting value.

In the foregoing description of the operation, current is always flowing in one or the other of the tubes of the pair. This type of operation is advantageous, particularly in connection with the ring circuit hereinafter described. However, for other uses it may be desirable at intervals to cut off or restrict current in both tubes simultaneously. This may be done by impressing suitable voltages simultaneously on both control grids G and G', or on other control electrodes provided in the tubes. Further uses and adaptations of the circuit of Fig. 1 will be apparent to those skilled in the art in view of the foregoing description.

In Fig. 1 the anode-cathode circuit of tube A' contains a load impedance 12 and an output circuit connection 13. From the foregoing explanation it will be understood that the current flowing in resistance 12 will change abruptly between cut off and a relatively high value, or between lower and upper limits, in accordance with the control pulses impressed upon grids G and G' through input circuit connections 14 and 15. Output connections may of course be taken from any other desired portion of the circuit where the shape of the current or voltage wave is that desired.

It is considered advantageous to connect the cross-connections to the screen grids of the tubes and apply the external operating pulses to the control grids thereof. However, the grids may be reversed if desired. It will be understood that in the specification and claims the terms "first" and "second" control electrodes are used for purposes of differentiation only, and do not refer to the order in which the grids are spaced from the cathode.

Fig. 2 illustrates a ring connection of pairs of tubes particularly adapted to yield the waves shown in Fig. 3, when controlled by a train of uniformly spaced pulses. Fig. 2 employs three pairs of tubes A-A', B-B', C-C'. The tubes of each pair are interconnected in the manner shown in Fig. 1. However, batteries D and D' of Fig. 1 are replaced by respective combinations of a condenser 21, 21' and a parallel resistor 22, 22'. The values of these resistors and condensers should be selected with respect to the screen grid current and the frequency of operation to provide a bias equivalent to batteries D, D', as will be understood by those in the art. Batteries may of course be employed, particularly with a train of control pulses of low frequency.

The train of operating pulses from the input 23 is applied simultaneously to the control grids G of one tube of each pair, called the first tube for convenience of description. As specifically illustrated, the pulses are applied to the grids G of tubes A, B and C through respective con-

densers 24 and resistances 25. For the specific operation here contemplated, it is desired that an output voltage be generated by only one pair of tubes at a time. (See Figs. 3c, 3e and 3g.) Therefore interconnections are provided so that only one pair of tubes is in condition for current to be "switched" from an unactuated to an actuated state by a control pulse at any given time, and the switching of current in this pair will cause the reswitch of current in the previous pair, thereby cutting off the output voltage generated by the previous pair.

To yield this operation "resetting" interconnections are provided from each pair of tubes to a control electrode of a tube of the following pair adapted to bias the control grid to an upper level above cutoff when the first pair is in an unactuated state, and to a lower level above cutoff when the first pair is in an actuated state. The levels are selected with respect to the operating pulses so that a pulse cannot cut off a tube at the upper level, hence preventing the switching of current in that pair, but can cut off current in a tube at the lower level, hence allowing current to be switched in that pair.

As specifically illustrated, the resetting connections 26 include resistances 27 connected, respectively, between the anode circuits of the second tubes of the pairs A', B', C', and the grid resistances 25 of the first tubes of the following pairs B, C, A. ("Following" pairs are the next pairs around the ring from left to right, tube A being considered to "follow" tube C'.)

The point at which the resetting interconnection is connected to the anode circuit is selected so that when no current is flowing in the anode circuit of any one of tubes A', B', C', a sufficient positive bias above cutoff will be applied to the grid G of the following tube to over-balance a negative operating pulse from the input circuit 23 and thus prevent the following tube A, B or C, as the case may be, from being cut off by the operating pulse. This thereby prevents the corresponding paired tubes A', B' or C' from developing an output voltage. On the other hand, the point of connection to the anode circuit is such that when current is flowing in the anode circuit the bias above cutoff on the grid G of the following tube is reduced to a value such that a negative operating pulse can cut off current in that tube, thereby switching current to the other paired tube and developing an output voltage.

In the specific embodiment of Fig. 2, the resetting interconnections 26 are connected directly to the anodes of tubes A', B', C', respectively. Thus when any of tubes A', B', C' is not passing current, the high positive voltage of the B+ supply is impressed on the grid G of the following tube and is sufficient to far overbalance an operating pulse. On the other hand, when a second tube, say B', is passing current, the voltage drop in its corresponding anode resistance R' will reduce the positive bias on the grid G of the following tube C to a lower value above cutoff, thereby "resetting" tube C and permitting the next starting pulse to cut off current therein. The next pulse will then cause current to flow in C' to create an output potential at 13C'.

Condensers 24 associated with the resetting interconnections introduce a small time lag in resetting, if the input circuit 23 is of low impedance compared to resistor 27, so that a single operating pulse will not switch current in each pair of tubes in quick succession. If the input circuit is of high impedance, other suitable means for intro-

ducting time lag may be employed, as will be understood by those in the art from the disclosure given herein. The resetting should of course take place before the next starting pulse arrives. In this manner, only one pair of tubes at a time is in condition to be actuated by a starting pulse, and the particular pair is the one following the pair which is already actuated and producing an output voltage.

"Cut-off" interconnections are also provided between each pair of tubes and the preceding pair so that when one pair is "actuated" by an operating pulse, current in the preceding pair will be switched to the unactuated state. To accomplish this result, the cut-off interconnections may be connected between the anode circuit of the second tube of a pair and a second control electrode of the second tube of the preceding pair, designed so that current flow in one second tube cuts off flow in the preceding second tube. In the specific embodiment of Fig. 2, the control grids G' of tubes A' , B' , C' are connected through resistances 31 to the control grids SG of the following tubes B , C , A , respectively, the grids SG being in turn connected to the anode circuits of the paired tubes B' , C' , A' .

Thus, cut-off interconnection $29B$ is connected to the anode circuit of tube B' through the condenser-resistor biasing source $21'$, $22'$, and to the grid G' of tube A' through resistance 31 . When no current is flowing in the anode circuit of tube B' the control electrode SG of tube B will be at an elevated potential and this same potential will be applied through resistance 31 to control electrode G' of tube A' . In this condition, tube A' is allowed to pass current under the control of its control electrode SG' . However, when anode current is flowing in tube B' , the voltage drop in its plate impedance R' not only impresses a negative potential on grid SG of tube B but also impresses a negative potential on grid G' of tube A' . Thus, flow of current in tube B' cuts off current in tube A' , as well as in tube B .

To summarize the operation of the specific circuit of Fig. 2, assume that the pair of tubes B , B' is in the actuated state (B cut off and B' passing current) and that the other pairs are in the unactuated state. Grid SG in tube B will be at cutoff, and so will grid G' of tube A' because of cut-off interconnection $29B$. Current in B' will also have reset the succeeding pair of tubes C , C' by reducing the potential on grid G of tube C to its lower level above cutoff. An output voltage will appear at $13B'$.

When the next operating pulse comes along it will cut off current in tube C by reducing the potential on its grid G from the lower level above cutoff to a value beyond cutoff. This will cause full current to flow in tube C' , thus creating an output voltage at $13C'$. At the same time, the flow of current in C' will cut off current in tube B' through cutoff interconnection $29C$, thus cutting off output voltage in $13B'$. Current in C' will also reduce the potential on grid SG of tube C to beyond cutoff, thus preventing tube C from passing current after the operating pulse has passed. In addition, current in tube C' will reset the pair of tubes A , A' by reducing the bias on grid G of tube A from the upper to the lower value above cutoff. In the meantime, the cutting off of current in tube B' will have changed the potential on grid G of the tube C to its upper value above cutoff (through reset connection 26), thereby preventing the next operating pulse from cutting off current in tube C . This condi-

tion will obtain until the next operating pulse comes along.

The next operating pulse will switch current in the pair of tubes A , A' by cutting off current in tube A and thereby allowing full current to flow in A' ; thus placing tubes A , A' in the actuated state. The actuation of tubes A , A' will in turn reswitch tubes C , C' to the unactuated state, in the manner just described for the preceding pulse, and will reset the pair of tubes B , B' so that the next pulse will actuate B , B' .

As a result of the operation just described, if starting pulses of brief duration recur at, say 120 pulses per second, output signals will be successively generated at the terminals $13A'$, $13B'$ and $13C'$ at intervals of $\frac{1}{120}$ second, and each output signal will have a substantially constant value for substantially $\frac{1}{120}$ second. This is illustrated in Fig. 3, where the train of operating pulses is shown at $3(a)$. The waves shown at (c) , (e) and (g) represent the anode current flowing in tubes A' , B' and C' , and the corresponding output voltages will have similar shape. The output pulses are very nearly rectangular and just barely overlap each other. Fig. 3 also shows the corresponding currents of tubes A , B and C . It will be noted that when current is flowing in one tube of a pair it is cut off in the other paired tube.

In the color television system for changing the relative magnitudes of the different colors in a video signal, described hereinbefore, the output waves from terminals $13A'$, $13B'$, $13C'$ may be connected to the three channels for blanking out all but the desired color in each channel. The precise control of the circuit of Fig. 2 by synchronizing pulses correlated with the color video signal, and the sharpness of the generated rectangular waves, results in very satisfactory blanking.

Any number of pairs of tubes, more than three, may be employed in the ring connection of Fig. 2. Output voltages or currents may be taken from any convenient point where the shape of the wave is that desired. In particular, instead of taking an output voltage from output impedances $12A'$, $12B'$, $12C'$, as shown, waves of similar shape but opposite polarity, may be taken from the grids SG of tubes A , B and C . Slight imperfections in the waves may dictate which should be employed.

It may be desired in a ring of " n " pairs of tubes to modulate the operating pulses so that every n^{th} pulse is distinguished in some way from the others, and to have the output from a particular pair of tubes always follow one of these distinctive pulses. This operation may be achieved by having a different resetting voltage applied to this particular pair of tubes, so that the resetting is insufficient for any other pulse to actuate this pair, but sufficient for one of the distinctive pulses to actuate this pair.

As a specific example, it may be desired in the arrangement of Fig. 2 to have every third operating pulse larger than the others, and to have the output $13A'$ always follow the larger operating pulses. To yield this operation, the resetting voltage applied through connection 26 to the associated pair of tubes A , A' can be taken from an intermediate point of the resistance R' which forms the anode resistance for tube C' . If this point is properly chosen, when the pair of tubes C , C' is actuated, the resetting voltage will be at such a level that only a distinctive pulse will bias the grid G of tube A beyond cut-off and

actuate the pair of tubes A, A'. If the ring should be out of step at the start of operation, the pair of tubes A, A' will remain unactuated until one of the larger pulses is applied, and the operation from that time on will be in step.

For some applications it may be desired to use a chain connection of pairs of tubes, instead of a ring connection. This may be effected by omitting the resetting and cut-off interconnection between the first and last pairs. Also, the cut-off interconnections between pairs may be omitted if desired.

The modification described in connection with Fig. 1 in which current in either tube changes between lower and upper limits, rather than between cut-off and a large value, may be employed in a ring circuit of the type shown in Fig. 2, if desired.

With respect to the specific embodiments described herein, it will be understood that the circuit elements included in the cross connections between the tubes of a pair, in the cut-off interconnections and in the resetting interconnections, and the points between which they are connected, may be changed in many respects by those skilled in the art within the spirit and scope of the invention.

In particular, in the specific embodiment described the resetting and cut-off interconnections are connected between the anode-cathode circuit of the second tubes of a pair and the proper control electrodes. However, the interconnections may be made to other suitable points in the connected pairs of tubes if desired. For example, a cathode resistor for the first tube and sensitive grid control for the second tube made be employed for cutoff, with more or less success. Moreover, although symmetrical interconnections in each pair of tubes and similarity between pairs of tubes are advantageous, unsymmetrical interconnections and dissimilar pairs may be employed if desired.

In other respects, also, it will be understood that the present invention is not limited to the mere details of design, construction and arrangement of the elements disclosed, since many modifications may be made by those skilled in the art without departing from the spirit and scope of the invention.

The invention may be employed with advantage for a number of purposes in addition to those mentioned hereinbefore. In particular, it is useful in connection with frequency division where the frequency of the output of one pair of tubes is a sub-multiple of the incoming operating pulses, and in pulse distributing circuits in general.

I claim:

1. In an electronic switching circuit, the combination which comprises a pair of electronic vacuum tubes each having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each tube and a first control electrode of the other tube for restricting anode current in either tube below a lower limiting value when current in the other tube exceeds an upper limiting value, and circuit connections for each tube for receiving operating pulses and applying the pulses to a second control electrode of the respective tube to change the potential thereof between a potential sufficient to restrict anode current below said lower limiting value and a potential sufficient to allow anode current exceeding said upper limiting value to flow.

2. In an electronic switching circuit, the combination which comprises a pair of electronic vacuum tubes each having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including an impedance and a source of anode voltage, interconnections between a first control electrode of each tube and a point of the anode-cathode circuit of the other tube selected so that increase of anode current in either tube decreases the potential impressed on the first control electrode of the other tube, said interconnections and impedances being selected so that anode current in either tube exceeding an upper limiting value yields and maintains a potential for the first control electrode of the other tube sufficient to restrict anode current therein below a lower limiting value, the bias on the first control electrode of either tube when anode current in the other tube is below said lower limiting value being sufficiently above cut-off to allow anode current exceeding said upper limiting value to flow, means for biasing a second control electrode of each tube to allow anode current exceeding said upper limiting value to flow therein, and circuit connections for each tube for receiving operating pulses and applying the pulses to said second control electrode of the respective tube to restrict the anode circuit therein below said lower limiting value.

3. In an electronic switching circuit, the combination which comprises a pair of electronic vacuum tubes each having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each tube and a first control electrode of the other tube for substantially cutting off anode current in either tube when anode current in the other tube exceeds a limiting value, and circuit connections for each tube for receiving operating pulses and applying the pulses to a second control electrode of the respective tube to change the potential thereof between substantially cut-off and a value sufficient to allow anode current exceeding said limiting value to flow.

4. In an electronic switching circuit, the combination which comprises a pair of electronic vacuum tubes each having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each tube and a first control electrode of the other tube designed so that anode current exceeding a limiting value in either tube yields and maintains a potential for the control electrode of the other tube sufficient to substantially cut off anode current therein, means for biasing the first control electrode of each tube to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other tube, and circuit connections for each tube for receiving operating pulses and utilizing said pulses to change the potential on a second control electrode in the respective tube between substantially cut-off and a value sufficient to allow anode current exceeding said limiting value to flow.

5. In an electronic switching circuit, the combination which comprises a pair of electronic vacuum tubes each having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including an impedance and a source of anode voltage, interconnections between a first control electrode of each tube and a point of the anode-cathode circuit of the other

tube selected so that increase of anode current in either tube decreases the potential impressed on the first control electrode of the other tube, said interconnections and impedances being designed so that anode current exceeding a limiting value in either tube yields and maintains a potential for the first control electrode of the other tube sufficient to substantially cut off anode current therein, means for biasing the first control electrode of each tube to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other tube, means for biasing a second control electrode of each tube sufficiently above cut-off to allow anode current exceeding said limiting value to flow therein, and circuit connections for each tube for receiving operating pulses and applying the pulses to said second control electrode of the respective tube to substantially cut off anode current therein.

6. In an electronic switching circuit, the combination which comprises a pair of electronic vacuum tubes each having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including an impedance and a source of anode voltage, interconnections between a first control electrode of each tube and a point of the impedance of the other tube remote from the corresponding cathode, said interconnections and impedances being designed so that anode current exceeding a limiting value in either tube yields and maintains a potential for the first control electrode of the other tube sufficient to substantially cut off anode current therein, means for biasing the first control electrode of each tube to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other tube, means for biasing a second control electrode of each tube sufficiently above cut-off to allow anode current exceeding said limiting value to flow therein, and circuit connections for each tube for receiving negative operating pulses and applying the pulses to said second control electrode of the respective tube to substantially cut off anode current therein.

7. In an electronic switching circuit, the combination which comprises a pair of electronic vacuum tubes each having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including an impedance and a source of substantially constant anode voltage in series, interconnections between a first control electrode of each tube and a point of the impedance of the other tube remote from the corresponding cathode, a source of biasing voltage in each of said interconnections, said sources of voltage and impedances being designed so that anode current exceeding a limiting value in either tube yields and maintains a potential for the first control electrode of the other tube sufficient to substantially cut off anode current therein, the bias on the first control electrode of either tube being sufficiently above cut-off to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other tube, means for biasing a second control electrode of each tube sufficiently above cut-off to allow anode current exceeding said limiting value to flow therein, and circuit connections for each tube for receiving operating pulses and applying the pulses to said second control electrode of the respective tube to substantially cut off anode current therein.

8. In an electronic switching circuit, the com-

5 combination which comprises a pair of electronic vacuum tubes each having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including a source of substantially constant anode voltage and a resistance connected in circuit between the corresponding anode and said voltage source, interconnections between a first control electrode of each tube and a point of the resistance of the other tube remote from the corresponding anode voltage source, a source of biasing voltage in each of said interconnections for biasing each first control electrode below the potential of said remote point of the respective resistance, said sources of voltage and resistances being selected so that anode current exceeding a limiting value in either tube yields and maintains a potential for the first control electrode of the other tube sufficient to substantially cut off anode current therein, the bias on the first control electrode of either tube being sufficiently above cut-off to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other tube, means for biasing a second control electrode of each tube sufficiently above cut-off to allow anode current exceeding said limiting value to flow therein, and circuit connections for each tube for receiving negative operating pulses and applying the pulses to said second control electrode of the respective tube to substantially cut off anode current therein.

9. An electronic switching circuit which comprises a plurality of pairs of electronic vacuum tubes, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each paired tube and a first control electrode of the other paired tube for restricting anode current in either tube below a lower limiting value when anode current in the other tube exceeds an upper limiting value, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, means for biasing the second control electrode of a first tube of at least one pair to an upper potential level, and a re-setting interconnection from another connected pair of tubes to the second control electrode of the first tube of said one pair for changing the bias thereon to a lower potential level when anode current exceeding said upper limiting value flows in the second tube of said other pair, said potential levels being correlated with said operating pulses so that a pulse restricts anode current below said lower limiting value in a first tube biased to said lower potential level but not in a first tube biased to said upper potential level.

10. An electronic switching circuit which comprises three or more pairs of electronic vacuum tubes forming a ring, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each paired tube and a first control electrode of the other paired tube for restricting anode current in either tube below a lower limiting value when anode current in the other tube exceeds an upper limiting value, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, means for biasing the second control electrodes of said

first tubes to an upper potential level, re-setting interconnections from each connected pair of tubes to the second control electrode of the first tube of the succeeding pair for changing the bias thereon to a lower potential level when anode current exceeding said upper limiting value flows in a second tube of a pair, said potential levels being correlated with said operating pulses so that a pulse restricts anode current below said lower limiting value in a first tube biased to said lower potential level but not in a first tube biased to said upper potential level, and interconnections from each connected pair of tubes to a second control electrode of the second tube of the preceding pair for restricting anode current therein below said lower limiting value when anode current exceeding said upper limiting value flows in a second tube of a pair.

11. An electronic switching circuit which comprises three or more pairs of electronic vacuum tubes forming a ring, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including an impedance and a source of anode voltage, interconnections between a first control electrode of each paired tube and a point of the anode-cathode circuit of the other paired tube selected so that increase of anode current in either tube decreases the potential impressed on the first control electrode of the other tube, said interconnections and impedances being selected so that anode current in either paired tube exceeding an upper limiting value yields and maintains a potential for the first control electrode of the other paired tube sufficient to restrict anode current therein below a lower limiting value, the bias on the first control electrode of either paired tube when anode current in the other paired tube is below said lower limiting value being sufficiently above cut-off to allow anode current exceeding said upper limiting value to flow, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, means for biasing the second control electrodes of said first tubes to an upper potential level, re-setting interconnections from the anode circuit of the second tube of each pair to the second control electrode of the first tube of the succeeding pair for changing the bias thereon to a lower potential level when anode current exceeding said upper limiting value flows in a second tube of a pair, said potential levels being correlated with said operating pulses so that a pulse restricts anode current below said lower limiting value in a first tube biased to said lower potential level but not in a first tube biased to said upper potential level, and interconnections from the anode circuit of the second tube of each pair to a second control electrode of the second tube of the preceding pair for restricting anode current therein below said lower limiting value when anode current exceeding said upper limiting value flows in a second tube of a pair.

12. An electronic switching circuit which comprises a plurality of pairs of electronic vacuum tubes, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including an impedance and a source of anode voltage, interconnections between a first control electrode of each paired tube and a point of the anode-cathode circuit of the other paired tube selected so that increase of anode current in either tube decreases the potential impressed on the first con-

trol electrode of the other tube, said interconnections and impedances being designed so that anode current exceeding a limiting value in either paired tube yields and maintains a potential for the first control electrode of the other paired tube sufficient to substantially cut off anode current therein, means for biasing the first control electrode of each paired tube to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other paired tube, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, means for biasing the second control electrode of a first tube of at least one pair to an upper potential level, and a re-setting interconnection from the anode circuit of the second tube of another pair to the second control electrode of the first tube of said one pair for changing the bias thereon to a lower potential level when anode current exceeding said limiting value flows in the second tube of said other pair, said potential levels being correlated with said operating pulses so that a pulse substantially cuts off current in a first tube biased to said lower potential level but not in a first tube biased to said upper potential level.

13. An electronic switching circuit which comprises three or more pairs of electronic vacuum tubes forming a ring, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each paired tube and a first control electrode of the other paired tube for substantially cutting off anode current in either tube when anode current in the other tube exceeds a limiting value, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, means for biasing the second control electrodes of said first tubes to an upper level above cut-off, resetting interconnections from each connected pair of tubes to the second control electrode of the first tube of the succeeding pair to bias the electrode to a lower level above cut-off when anode current flows in a second tube of a pair, said levels being correlated with said operating pulses so that a pulse substantially cuts off current in a first tube biased to said lower level but not in a first tube biased to said upper level, and cut-off interconnections from each connected pair of tubes to a second control electrode of the second tube of the preceding pair to substantially cut off anode current therein when anode current flows in a second tube of a pair.

14. An electronic switching circuit which comprises three or more pairs of electronic vacuum tubes forming a ring, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each paired tube and a first control electrode of the other paired tube designed so that anode current exceeding a limiting value in either tube yields and maintains a potential for the control electrode of the other tube sufficient to substantially cut off anode current therein, the first control electrode of each tube being biased to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other paired tube, circuit connections for receiving a train of operating

pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, means for biasing the second control electrodes of said first tubes to an upper potential level above cut-off, re-setting interconnections from each connected pair of tubes to the second control electrode of the first tube of the succeeding pair to bias the electrode to a lower potential level above cut-off when anode current exceeding said limiting value flows in a second tube of a pair, said potential levels being correlated with said operating pulses so that a pulse substantially cuts off current in a first tube biased to said lower level but not in a first tube biased to said upper level, time delay means associated with said re-setting interconnections for delaying a change from upper to lower potential levels, and cut-off interconnections from each connected pair of tubes to a second control electrode of the second tube of the preceding pair to substantially cut off anode current therein when anode current exceeding said limiting value flows in a second tube of a pair.

15. An electronic switching circuit which comprises three or more pairs of electronic vacuum tubes forming a ring, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including an impedance and a source of anode voltage, interconnections between a first control electrode of each paired tube and a point of the anode-cathode circuit of the other paired tubes selected so that increase of anode current in either tube decreases the potential impressed on the first control electrode of the other tube, said interconnections and impedances being designed so that anode current exceeding a limiting value in either paired tube yields and maintains a potential for the first control electrode of the other paired tube sufficient to substantially cut off anode current therein, the first control electrode of each tube being biased to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other paired tube, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, means for biasing the second control electrodes of said first tubes to an upper potential level above cut-off, re-setting interconnections between the anode circuit of the second tube of each pair and the second control electrode of the first tube of the succeeding pair to bias the electrode to a lower potential level above cut-off when anode current exceeding said limiting value flows in a second tube of a pair, said potential levels being correlated with said operating pulses so that a pulse substantially cuts off current in a first tube biased to said lower level but not in a first tube biased to said upper level, and cut-off interconnections between the anode circuit of the second tube of each pair and a second control electrode of the second tube of the preceding pair for cutting off anode current therein when anode current exceeding said limiting value flows in a second tube of a pair.

16. An electronic switching circuit which comprises three or more pairs of electronic vacuum tubes forming a ring, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube including a resistance and a source of substantially constant anode voltage in series, interconnections between a first control electrode of each

paired tube and a point of the resistance of the other paired tube remote from the corresponding cathode, a source of biasing voltage in each of said interconnections, said sources of voltage and resistances being selected so that anode current exceeding a limiting value in either paired tube yields and maintains a potential for the first control electrode of the other paired tube sufficient to substantially cut off anode current therein, the bias on the first control electrode of either paired tube being sufficiently above cut-off to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other paired tube, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, re-setting interconnections from a point of the resistance of the second tube of each pair remote from the cathode thereof to the second control electrode of the first tube of the succeeding pair for biasing said electrode to an upper potential level above cut-off when anode current is not flowing in said second tube and to a lower potential level above cut-off when anode current is flowing therein, said potential levels being correlated with said operating pulses so that a pulse cuts off current in a first tube biased to said lower level but not in a first tube biased to said upper level, time delay means associated with the re-setting interconnections for delaying a change from upper to lower levels, and cut-off interconnections from a point of the resistance of the second tube of each pair remote from the cathode thereof to a second control electrode of the second tube of the preceding pair for biasing said electrode above cut-off when anode current is not flowing in said resistance and beyond cut-off when anode current is flowing therein.

17. An electronic switching circuit which comprises three or more pairs of electronic vacuum tubes forming a ring, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each paired tube and a first control electrode of the other paired tube for restricting anode current in either tube below a lower limiting value when anode current in the other tube exceeds an upper limiting value, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, selected operating pulses differing from the remainder, means for biasing the second control electrodes of said first tubes to an upper potential level, re-setting interconnections from each connected pair of tubes to the second control electrode of the first tube of the succeeding pair for changing the bias thereon to a lower potential level when anode current exceeding said upper limiting value flows in a second tube of a pair, said potential levels being correlated with said operating pulses so that a pulse restricts anode current below said lower limiting value in a first tube biased to said lower potential level but not in a first tube biased to said upper potential level, the re-setting interconnection to the first tube of one pair differing from the re-setting interconnection to other first tubes so that only said selected different operating pulses restrict anode current below said lower limiting value in the first tube of said one pair, and interconnections from each connected pair of tubes to a second control electrode of the second tube of the preceding pair for restricting anode current

therein below said lower limiting value when anode current exceeding said upper limiting value flows in a second tube of a pair.

18. An electronic switching circuit which comprises three or more pairs of electronic vacuum tubes forming a ring, each of said tubes having an anode, cathode and a plurality of control electrodes, an anode-cathode circuit for each tube, interconnections between the anode-cathode circuit of each paired tube and a first control electrode of the other paired tube designed so that anode current exceeding a limiting value in either tube yields and maintains a potential for the control electrode of the other tube sufficient to substantially cut off anode current therein, the first control electrode of each tube being biased to allow anode current exceeding said limiting value to flow therein when anode current is substantially cut off in the other paired tube, circuit connections for receiving a train of operating pulses and applying the pulses simultaneously to a second control electrode of a first tube of each pair, selected operating pulses having a magnitude greater than the remainder, means for biasing the second control electrodes of said first tubes to an upper potential level above cut-off, re-setting

interconnections between the anode circuit of the second tube of each pair and the second control electrode of the first tube of the succeeding pair to bias the electrode to a lower potential level above cut-off when anode current exceeding said limiting value flows in a second tube of a pair, said potential levels being correlated with said operating pulses so that a pulse substantially cuts off current in a first tube biased to said lower level but not in a first tube biased to said upper level, the lower potential level yielded by the re-setting interconnection to the first tube of one pair exceeding the lower level of other first tubes so that only an operating pulse of said greater magnitude substantially cuts off current in the first tube of said one pair, time delay means associated with said re-setting interconnections for delaying a change from upper to lower potential levels, and cut-off interconnections from each connected pair of tubes to a second control electrode of the second tube of the preceding pair to substantially cut off anode current therein when anode current exceeding said limiting value flows in a second tube of a pair.

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