

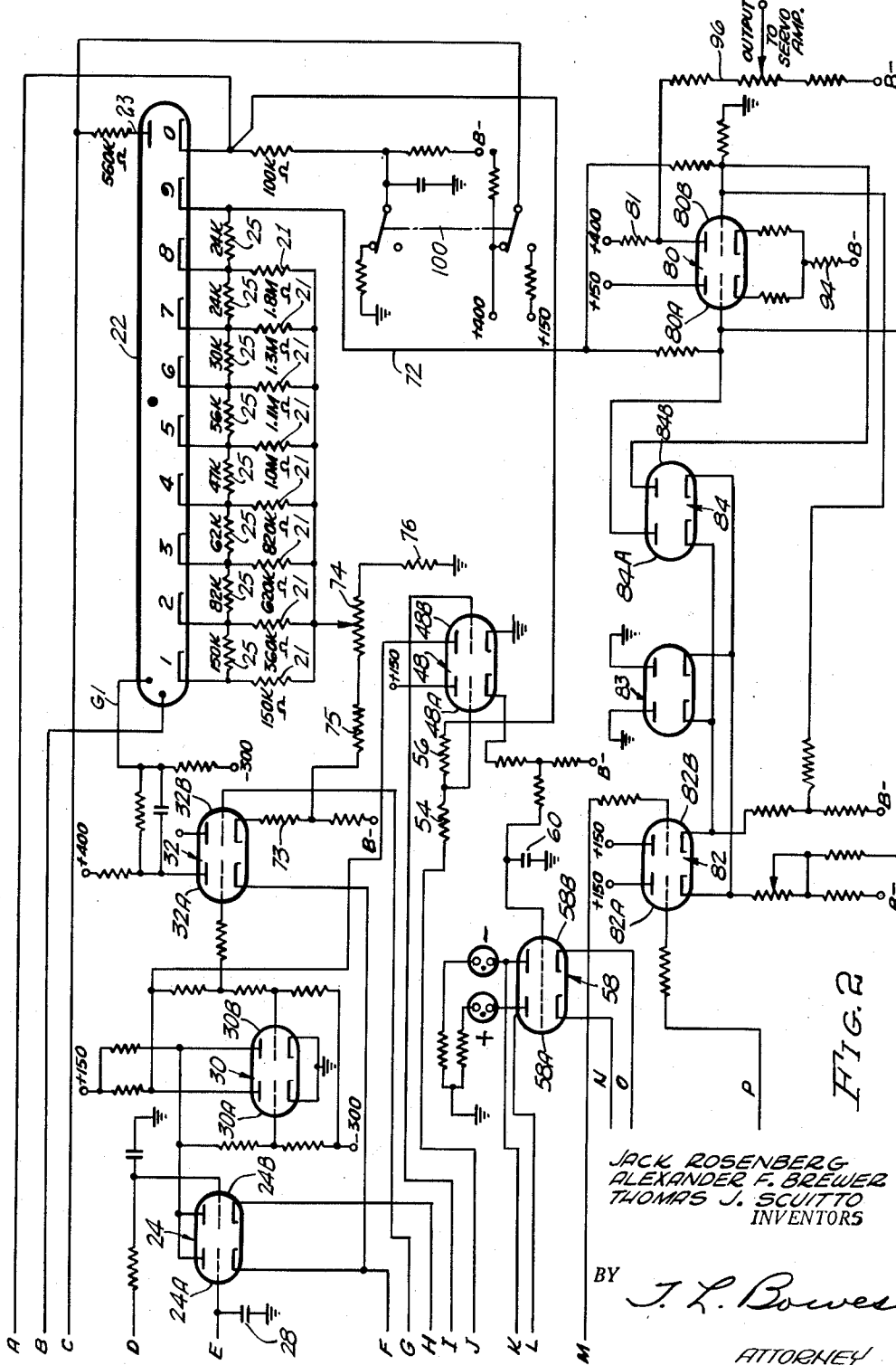
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REVERSIBLE DECADE COUNTER

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1

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REVERSIBLE DECADE COUNTER

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9 Claims. (Cl. 235-92)

This invention relates to electronic counting circuits and, more particularly, to an improved reversible decade counting circuit.

In an application by Jack Rosenberg et al. for an Automation System, Serial No. 544,478, filed November 2, 1955, now Patent No. 2,833,941, and assigned to a common assignee, there is described and claimed a system for providing an automatic control for machine tools. There is also described therein a novel and useful reversible decade counter and digital-to-analog converter. The present application is a division of the Jack Rosenberg et al. application and is directed to the novel, reversible decimal counter and digital-to-analog converter described therein.

The embodiment of the invention employs a glow-switching type of gas tube which is sold commercially by Sylvania Electric Products, Inc., and is known as type 6476. This tube is described in the Sylvania Engineering data service publication 6476. Briefly described, this tube has a common anode, about which are disposed 30 cathodes. Ten of these are called main cathodes; the remainder are called guide cathodes and are classed as first and second guide cathodes. Between each two main cathodes are a first and second guide cathode. The disposition can be considered as main cathode, first guide, second guide, main cathode, etc., around the circle of cathodes. The tube operates on the principle that the ionization, or starting voltage, of gas-filled tubes is lower if ions or electrons are already present in the anode-cathode gap. Under these conditions, a glow discharge can be made to move from one cathode to an adjacent one by means of a relatively small negative pulse on the new cathode, provided that electrons or ions are able to diffuse this new anode-cathode gap. With the series of cathodes about a common anode, a glow discharge can be made to move in succession along the cathode series by application of successive voltage pulses to each cathode. Thus, the first and second guide cathodes are employed to determine the direction of the glow discharge from main cathode to main cathode. With a glow present on a main cathode, first a negative pulse is applied to the adjacent first guide cathode, then a second negative pulse is applied to the adjacent second guide cathode, then, upon the termination of the second pulse, because the main cathodes are biased to a potential below the guides, the glow discharge will be transferred to the succeeding main cathode. If the first negative pulse is applied to the adjacent second guide cathode and the second negative pulse is applied to the first guide cathode, then upon termination of the second pulse to the first guide cathode the main glow will be transferred to a preceding main cathode.

Within a beam-switching tube all first guides are connected together and brought out to a first guide terminal. All second guides are connected together and brought out to a second guide terminal. The order of application of a first pulse and a second pulse respectively to the first and second guide output terminals determines whether

2

within a beam-switching tube the count advances or regresses.

While it can be readily seen that operation of a single stage decimal counter employing one of these gas-beam tubes is a simple affair, complications are presented when it is attempted to couple a plurality of these gas tubes to form a multi-stage reversible decade counter with a capacity to count hundreds, or thousands, or even greater. These complications arise because of the necessity for applying two pulses from a lower to a higher order decade to effectuate carryover when the lower decade count exceeds nine and also to effectuate a negative carryover (subtraction) when the lower order decade passes through the ten count to the nine count. By way of example, using a decimal and tens order decade tube, if a count of nine has occurred, the tens decade must be made to go from a zero to a one count or not, depending upon whether the next first and second pulses being applied have an order to add or subtract from the count of nine. Also, using another illustration, if the count of 20 has occurred, it must be known whether the units and tens decade are to be advanced to the count of 21 or to the count of 19, in accordance with the information contained in the incoming first and second pulses.

An object of the present invention is to provide a novel interstage coupling means between glow-switching gas tubes to provide a novel, reversible decade counter consisting of a plurality of decade stages.

Another object of the present invention is to provide a novel and useful reversible decade counter consisting of a plurality of decade stages.

Another problem is presented when the count in the reversible decade counter becomes negative. A way must then be found for effectuating a subtraction with positive input counts and an addition with negative input counts. This is further complicated by the fact that two pulses are required for advancing or regressing the count in the counter.

Accordingly, a further object of this invention is to provide a unique arrangement for sensing and storing the polarity of the count in the counter and controlling the sense of any input applied to the counter in accordance with the sign of the count in the counter.

Another object of the present invention is to provide a unique arrangement whereby a reversible decimal counter may be employed to provide a digital-to-analog conversion.

Yet another object of the present invention is the provision of a novel arrangement whereby the same circuit which indicates the sign of the count in the counter controls the digital-to-analog conversion arrangement in accordance therewith.

These and other objects of the present invention are achieved in a reversible decimal counter wherein each decade stage comprises a gas-beam-switching tube. Each decade has a first and second input guide terminal. In order to advance the count of a decade, a first and second pulse in sequence are respectively applied to the first and second guide input terminals. To reduce the count in a decade, a first and second pulse are respectively applied to the second and first guide in the decade. All the second guides of the plurality of decades are connected together. Accordingly, a second pulse is applied to the second guide of all the decades simultaneously.

An interstage coupling arrangement is provided between each two decades wherein, when the lower decade is in the nine count condition and a first and second pulse are respectively applied to the first and second guides of this decade, a pulse is applied to the first guide of the succeeding, or higher, decade before the pulse is applied to the second guide of the higher decade. In response to the lower decade being in the zero count condition

and a pulse being applied to the lower decade second guide before the application of a pulse to the first guide, a pulse will be applied to the first guide of the succeeding, or higher, decade after the application of a pulse to its second guide.

A memory is provided which, when the entire counter is at zero, senses the sign of the next count being entered into the counter. From this, it stores and indicates the sign of the count in the counter. Gating means are provided at the input of the counter which are controlled by the memory means to apply a first and second input pulse to the counter in a manner to add to or subtract from the count in the counter which is resolved by the information contained in the memory as to the sign of the counter count and the order of the application of the first and second pulses. Furthermore, a digital-to-analog conversion resistance ladder is provided for each decade, the output of which is applied to circuitry which is controlled responsive to the memory to provide an analog output indicative of the count and also having a polarity which is determined by the memory.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention itself, both as to its organization and method of operation, as well as additional objects and advantages thereof, will best be understood from the following description when read in connection with the accompanying drawings, in which:

Figures 1 and 2 comprise a circuit diagram of an embodiment of the invention.

As described previously, the invention herein employs a glow-switching type of gas tube which requires the application thereto of two pulses in order to advance or regress the count. Figures 1 and 2 show a circuit diagram of an embodiment of the invention employing two decades. This should not be construed as a limitation because from the description employing two decades it will become readily apparent how any number of decades required may be connected together and still be within the spirit and scope of this invention.

It should be noted that Figures 1 and 2 herein are identical to Figures 16A and 16B in the previously noted application to Rosenberg et al. In that application, the arrangement was employed as an error register, wherein pulses commanding motion and pulses responsive to motion commands having been executed are combined and applied to the counter so that the resultant count will be positive if the total number of command pulses exceeds the total number of response pulses. The output of the counter is converted to an analog voltage which controls subsequent apparatus to operate in a direction to provide pulses to reduce the count in the error register to zero.

The two figures of the drawing herein actually constitute a single circuit, and not two separate circuits. In order to identify the same leads which connect apparatus in one figure of the drawing with apparatus in the second figure of the drawing, the leads are brought out to the side of the drawing and have assigned letters thereto which correspond.

Input terminals 6 and 8, respectively also assigned letters G1 and G2, provide terminals to which a first and second pulse may be applied, either in that sequence or in a reverse sequence to be added or subtracted from the count in the counter. Terminal 6 is connected to the two cathodes of a double triode tube 10. One side of this double triode tube is referred to as 10A and the other side as 10B. Terminal 6 is also connected to Figure 2 of the drawings along a lead designated by the reference letter "O." Input terminal 8 is connected to two cathodes of a double triode tube 12, having each of its triodes respectively designated by 12A and 12B. Input terminal 8 is also connected to the apparatus in Figure 2 of the drawing by a lead having applied thereto the reference numeral "N." These latter connections will be described further subsequently.

Tubes 10A and 12B have their anodes connected together and brought up to be connected to the grid of tube 14B in a double triode tube 14. A clamping diode 15 and a biasing triode 17 are employed to establish the most positive signal level to which the grids of tubes 14A and 14B can be driven. This positive clamping arrangement is effectuated by connecting the grid of tube 17 to a voltage divider 23, connected across the operating potential supply. Tube 17, which is connected as a cathode follower, is thus biased to be in a conducting condition. Its cathode thus is maintained positive and is coupled to the diodes 15A and 15B of double diode 15. The cathode of diode 15B is connected to the grid of tube 14B; the cathode of diode 15A is connected to the grid of tube 14A. Under quiescent operating conditions, the value of the positive bias applied to the grids of tubes 14A and 14B by means of the voltage dividers to which these grids are connected has a sufficient amplitude so that no conduction occurs through diodes 15A and 15B. Upon the application of a negative-going signal to either of the grids of tubes 14A or 14B, which lowers the potential of either of these grids to the point where the diode 15A or diode 15B begins to conduct, the grid will be effectively clamped to the potential of the cathode of tube 17 and will go no further negative. Tube 14B is a cathode follower and has output from its cathode coupled to the cathode of tube 16B in double triode tube 16. In response to input, tube 16B provides an output pulse which is applied to the guide 1 input terminal of a decade glow-switching gas tube 18. This terminal is also labeled G1. Tubes 10B and 12A have their anodes connected together and brought up to the side 16A of the double triode 16. Side 16A is also cathode-follower connected, and output from its cathode is applied to all the guide 2 terminals of all the gas tube decades 18, 22 employed in the gas tube counter. The guide 2 output terminals of all the decades are connected together over lead B.

It should be noted that the control grids of tubes 10A, 10B and 12A, 12B are direct-coupled through resistors to the control grids of a flip-flop circuit 20. The flip-flop circuit 20 includes two tubes, respectively designated as 20A and 20B. The potential of the control grids of tube 20A establishes the potential at the control grids of tubes 10B and 12B. The potential at control grid of tube 20B establishes the potential at the control grids of tubes 10A and 12A. Thus, the state of the flip-flop will determine which sides of the double triode tubes 10 and 12 can become conductive when an input pulse is applied to the cathodes of those tubes from the first and second input terminals 6 and 8.

Flip-flop 20 is the well-known two-tube type of flip-flop circuit having two stable states with the anode of one of the tubes connected to the grid of the other and the anode of the other of the tubes connected to the grid of the one. It may be driven from one to the other of its stable states by the application thereto of pulses. Flip-flop 20 serves as a memory to store the sign of the count which is held in the decade counter. The manner of its being driven will be described subsequently.

For the purposes of explaining the operation of the input gating means, including double triodes 10 and 12 in response to the sign-storing flip-flop 20, let it be assumed that flip-flop 20 is in a stable condition wherein triode 20A is conducting. When this occurs, there is a positive signal on its grid which is applied thereto from the plate of tube 20B. This positive grid signal is also applied to the grid of tubes 12B and 10B. Assume that a negative signal is applied first to input terminal 6 and then to terminal 8. This will enable tube 10B to conduct first, followed by tube 12B. The output of tube 10B is applied to tube 16A. The output from the cathode of tube 16A is applied to guide 2. The output of tube 12B is applied to tube 14B. The output of tube 14B is applied to tube 16B, the output from which is applied to guide 1. The

counter is thus made to subtract, since the guide 2 pulse precedes the guide 1 pulse.

Assuming the same state of the flip-flop 20, the application of a pulse to input terminal 8 before the application of a pulse to input terminal 6 will cause tube 12B to become conductive before tube 10B. Therefore, a guide 1 pulse will be received at the counter before the guide 2 pulse.

It is thus seen that when flip-flop 20 is in a stable condition with its tube 20A conducting, the order of application of a first and second pulse applied to the input terminals is reversed when they are applied to the counter tubes.

Assume now that flip-flop 20 is in condition with the tube 20B conducting and tube 20A not conducting. Tubes 10A and 12A are enabled, so that when a first and second pulse are applied to input terminals 6 and 8, these tubes will do the conducting. Thus, the application of input pulses to terminal 6 first and then terminal 8 results in first tube 10A becoming conductive and then tube 12A. Tube 10A drives tube 14B, the output of which is applied to guide 1 through tube 16B. Tube 12A drives tube 16A, the output of which is applied to guide 2. Assuming the same stable condition on the part of flip-flop 20, then the application of a pulse first to input terminal 8, followed by the application of a pulse to input terminal 6, will result in a pulse being first applied to the guide 2 terminal, followed by a pulse being applied to the guide 1 terminal.

Thus, with the flip-flop 20 in its second stable condition, or the one just described, guide 1 and guide 2 of the counter tubes will receive pulses in the order of application respectively to input terminals 6 and 8, or respectively G1 and G2. If flip-flop 20 is in its other stable state, then guide 1 and guide 2 of the counter tubes will receive pulses, the order of which is in reverse to the order of their application respectively to input terminals G1 and G2.

The gas tubes 18, 22 have their ten main cathodes numbered from 0 to 9. Their guide cathodes are not shown to maintain clarity in the drawings. Tube 18 has a single anode 19, and tube 22 has a single anode 23. As shown in the drawing, in each counter tube a resistor 21 is inserted in series with each of the cathodes which are numbered from 1 through 0. When an arc exists between an anode and a particular cathode, the current being drawn causes a voltage of approximately +35 volts to exist at the cathode. By connecting separate resistors 25 between the cathodes and tapping off at one end of the resistive ladder thus created, a voltage may be obtained which is the analog of the count in the counter. To explain this, assume, for example, that an arc exists at cathode 2. At a tapoff point on the cathode 8 there will be a lower value of voltage than if an arc existed at cathode 7. The reason, obviously, is because there is more resistance between cathode 2 and the tapoff point at cathode 8 than there is between cathode 7 and the tapoff point.

The values for the resistors in the resistance ladder, as well as for the cathode resistors to provide fairly discrete steps of the analog voltage are shown in the drawing. These are not to be construed as a limitation, since other values may be employed which may function equally well. However, these values were used in an embodiment of the invention which was built and operated satisfactorily. Cathode 8 and cathode 9 are respectively coupled to a common point on lead G through a resistor 27 and through a diode 29. The operation of the digital-to-analog converter will be described in further detail subsequently herein.

The circuitry to be described next is that for the inter-coupling arrangement between the decades. This inter-coupling arrangement may be employed between successive decade stages. The output from cathode 9 of the lower decade stage 18 is connected over lead E to the grid of tube 24A. Between the tube grid and ground

there is connected a condenser 28. This condenser is employed to maintain the voltage provided by the cathode 9 output for an interval required to insure the operation of the subsequent circuitry, since the transition of the nine-count stage can be too rapid. The anode of tube 24A is connected to the anode of a flip-flop tube 30B. Flip-flop 30 is the same type as flip-flop 20. Tube 24A is coupled to flip-flop 30B as a plate follower. In other words, when tube 24A is rendered conductive by receiving a signal both on its grid and on its cathode, it pulls current through the anode load of tube 30B, whereby tube 30B may be made to become conductive. This causes the tube 30A to become nonconductive, and its anode then becomes positive. This positive output is applied to the grid of tube 32A. However, tube 32A cannot become conductive until such time as a signal is applied to its cathode as well as its grid. This required cathode signal for both tubes 24A and 32A is received over lead F from the cathode of tube 14B. Tube 32A output is applied to the guide 1 terminal of the succeeding counter stage 22. An "add 1" input applied to counter tube 18 when it is in its ninth count condition requires a carryover to counter tube 32, since it is necessary for tube 18 to go to its zero count condition and tube 22 to go to its one count condition, representative of the number 10. To switch tube 22 from its zero to its one count condition, it is necessary to apply a pulse to its guide 1 terminal, followed by a pulse to its guide 2 terminal. To enable the addition of a count into tube 18, it is necessary for it to receive a guide 1 pulse followed by a guide 2 pulse. Thus, if the first pulse being applied to tube 18 is received from tube 14B, this first pulse is also applied over lead F to enable tubes 24A and 32A to conduct to provide the guide 1 pulse to the succeeding count stage. The following pulse is applied to all guide 2 terminals simultaneously. Thus, the succeeding decade is made to add a count.

When a count is to be subtracted, the pulse destined for the guide 2 terminal of the counters occurs first, then a guide 1 pulse. This removes the glow from main cathode 9 to a guide cathode. Thus, at the time a signal is received over lead F no signal is being received from main cathode 9, and the charge on condenser 28 has leaked off. For the situation where a first guide terminal pulse occurs first (carryover required), the conduction of tube 24A occurs either while the glow is still at main cathode nine or so shortly after it has been transferred from main cathode nine to the adjacent guide 1 that the voltage on the grid of tube 24A is still maintained by condenser 28.

For resetting flip-flop 30 after it has been operated, another plate follower tube 48B is employed. This tube has its anode coupled to the anode of tube 30A, and thus when tube 48B conducts it causes tube 30A to conduct, which is the standby or reset state of flip-flop 30. Tube 48B is controlled to be conductive except during the interval when first and second pulses are present. This is arranged by connecting the grid of tube 48B over lead I to the anodes of a double diode 40. The anodes are connected through a resistor 46 to a source of positive potential. One cathode 44 is coupled through resistors to the anodes of tubes 10B and 12A. The other cathode 42 is coupled through resistors to the anodes of tubes 10A and 12B. A first and a second pulse received from these gating tubes causes current to be drawn through these diodes as long as these pulses last. They are made to have some small overlap time, and therefore current is drawn through the resistor 46 during the first and second pulse interval. This causes a more negative potential to exist at the double diode anodes, which is applied over lead I to the grid of tube 48B, cutting off its conduction. Thus, at the termination of the first and second pulses the double diode 40 no longer conducts and tube 48B can reset the flip-flop 30.

The interdecade stage coupling circuit also performs the function of subtracting a count from the succeeding decade when the preceding decade goes from a zero to a nine condition. Regarding Figure 1, it will be seen that the zero main cathode is coupled to the grid of tube 24B. Tube 24B has its anode coupled to the anode of tube 24A, which is also connected to the anode of tube 30B of the flip-flop. Thus, when the zero count condition occurs, a positive signal is applied to the grid of tube 24B. It, however, cannot conduct until it receives a negative signal upon its cathode. This is received over the lead labeled "H," which is coupled to the cathode-follower tube 14A. The control grid of tube 14A is coupled to the control grid of tube 16A, the output of which is applied to the guide 2 terminals of all the decades. Thus, upon the appearance of a guide 2 pulse preceding a guide 1 pulse subsequent to the decade 18 reaching its zero count condition, tube 24B is rendered conductive, driving the flip-flop 30. The second guide pulse which has initiated the operation of the flip-flop 30 has been applied to the decade 22 prior to the application thereto of a first pulse from the tube 32A, since the flip-flop acts to provide the necessary delay. Therefore, when the decade 18 is in its zero count condition and a count is to be subtracted, the interstage coupling circuitry subtracts a count from the subsequent decade 22. After the termination of the first guide pulse, the flip-flop 30 is reset by tube 48B in the manner described previously.

Next there will be described the arrangement whereby the flip-flop 20 is enabled to store an indication of the sign of the number of the counter. Tube 48A has its grid connected between two resistors 54 and 56. Resistor 54 is connected over lead J to the zero cathode in decade 18. Resistor 56 is connected to the zero cathode in decade 22. Tube 48A is biased so that it will become conductive only when the glow exists in decades 18 and 22 at both zero cathodes. Tube 48A is connected as a cathode follower, and when it becomes conductive, its output is applied to the grids of tubes 58A and 58B. Because of the possibility of a rapid transition of the zero count, a condenser 60 maintains for a time the voltage from the cathode of tube 48A applied to the grid of tube 58B. The anodes of tubes 58A and 58B are connected through neon indicator tubes through separate resistors to ground. The anode of tube 58B is also connected over lead K to the anode of tube 20B in flip-flop 20 and the anode of tube 58A is connected over the lead L to the anode of tube 20A in flip-flop 20. It is thus seen that tubes 58A and 58B are plate-follower connected to tubes 20A and 20B, respectively. However, neither tube 58A nor tube 58B is able to conduct unless a negative signal is applied to its cathode. The cathode of tube 58A is connected over lead N to input terminal 8 (G2) and the cathode of tube 58B is connected over lead O to input terminal 6 (G1).

The operation of this system therefore is as follows: when all decade stages in the counter are at their zero count condition, then tube 48A is enabled to conduct. It applies an output from its cathode to the grids of tubes 58A and 58B. Neither of these tubes, however, can conduct unless a negative pulse is applied to their cathodes. These negative pulses consist of the first and second guide pulses which are being applied to the counter. If it is desired that the counter advance its count as previously described, a first guide pulse is received at G1, followed by a second guide pulse at G2. The first guide pulse on input terminal 6 is applied over lead "O" to the cathode of tube 58B. This causes tube 20B in flip-flop 20 to become conductive, thus storing the fact that the counter has a positive count. Tubes 10A and 12A in the input-gating arrangement are enabled, whereby the first guide pulse is applied to the first guide input terminal from tube 16B and the second guide pulse which occurs subsequently is applied to the second guide input terminal of the decades. By the time the second guide pulse arrives, the first guide pulse has been applied to the glow-switching tube 18 and

the glow is shifted from the zero cathode to the first guide cathode adjacent thereto. Therefore, tube 48A is no longer conductive and there is no longer a signal being applied to the grid of tubes 58A and 58B. Tube 58A will therefore not be rendered conductive by the succeeding second guide pulse.

Assume now that all the decades are in their zero count condition and a positive pulse is being applied to the control grid of tubes 58A and 58B. At this time it is desired to apply a negative count to the counter. Therefore, a second guide pulse is first applied to terminal 8 and a first guide pulse is subsequently applied to terminal 6. At the time the second guide pulse arrives, it is applied over lead N to the cathode of tube 58A, enabling it to become conductive. As a result, tube 20A is made conductive by the plate follower action of tube 58A. Tubes 10B and 12B are enabled by flip-flop 20. The pulse on terminal G2 is therefore applied through tubes 12B, 14B and 16B to the first guide input terminal of decade 18. The pulse on terminal G1 arriving subsequently is applied through tube 10B and tube 16A to the second guide input terminal of the decades. Thus, when flip-flop 20 indicates that the count is negative, any subsequent negative count inputs increase the count in the counter and any subsequent positive count inputs decrease the count in the counter. Thus, the effect of the sign flip-flop 20, when it indicates a negative count, is to reverse the order of the pulses which are applied to input terminals 6 and 8.

It is thus seen that tube 48A functions to sense when the decades are in their zero count condition. Tubes 58A and 58B function to determine by the order of the first and second guide input pulses thereafter applied whether or not the sign of the count is positive or negative, and with this information flip-flop 20 is set to store the proper indication. Flip-flop 20 controls the input gating means so that first and second guide pulses are applied in the proper sense to the decade counter in accordance with the sign of the count in those counters. Similarly, flip-flop 30 and its associated gating circuitry serves the purpose of applying a first guide pulse, either before or after the second guide pulse, to the succeeding decade in accordance with whether or not the count in the preceding decade is advancing from nine or regressing from zero.

The circuitry to be described is that for the digital-to-analog conversion of the counts in the decade counter. It will be noted that a plurality of resistors 25 are connected in a ladder between the cathode-load resistors of the respective decade tubes 18 and 22. The values provided for these resistors are selected for a suitably operating digital-to-analog conversion and are not to be considered as the only ones possible. These were the ones which were employed in an operative embodiment of the invention. In decade 18 the connection between the eighth and ninth main cathodes includes two resistors and a diode 29. The reason for the use of this diode is to isolate the main cathodes preceding the ninth from the grid of tube 24A. The cathode of the diode 29 is connected over a lead G to the control grid of a tube 32B. Tube 32B has resistors 73, 75, 76 and a potentiometer 74 connected in series between ground and its cathode. The movable arm of the potentiometer 74 is connected to all the cathode load resistors 21 of the main cathodes of the decade 22. As previously noted, tube 22 also has a resistance ladder formed by connecting a resistor 25 between each two main cathodes. The end of this resistance ladder on main cathode 9 is connected to the grid of a tube 80A and to the grid of another tube 80B. Only the anode of tube 80B has a load resistor 81, both cathodes of tubes 80A and 80B have cathode load resistors which are coupled to a common cathode load resistor 94 and to a negative bias source. Output from these two tubes is derived from the anode of tube 80B.

When a count has been entered into the decades, the count condition of decade 18 will be manifested by a

voltage on lead G, which is an analog representation of that count. This occurs since, as previously described, the resistance ladder which is employed will have a voltage on the order of 35 volts applied thereto at any one of nine contact points, as determined by the location of the glow at any one of the nine cathodes. A tapoff is made at the ninth cathode end of the ladder. Therefore, the amplitude of the tapoff voltage increases as the count approaches nine. This analog voltage is applied to the grid of the tube 32B, to render it conductive to a degree determined by the amplitude of the input to its grid. The voltage across the potentiometer 74 is determined by the signal which is applied to the grid of the tube 32B. Decade 22 draws the glow current required for itself through potentiometer 74. The potential at the potentiometer 74 is established by the conductive condition of tube 32B. Therefore, the voltage which is applied by lead 74 to the grids of tubes 80A and 80B is the sum of the voltage derived from the decade 18 resistance ladder, plus that from the decade 22 resistance ladder. Tube 32 serves to raise the voltage due to the count in decade 22 by the amplitude of the voltage due to the count in decade 18.

Referring now to Figure 1, it will be seen that output from the memory flip-flop 20 is applied along leads M and P to the respective grids of two tubes 82A, 82B. These two tubes are cathode followers and have their outputs respectively applied through two diodes 84B and 84A to the respective grids of tubes 80B and 80A. The signals derived from the cathodes of tubes 82A and 82B are only positive ones, since negative signals are clamped to ground by the double diode clamp 83 connecting these leads to ground. Since the output of the flip-flop 20 will consist of both a negative and a positive signal, the cathodes of one of the two tubes 82 will be positive and the other cathode will be negative. The positive cathode will block the conduction of its corresponding diode 84A or 84B and the negative cathode will enable conduction of the corresponding cathode to ground. In this manner, one of the grids of the tubes 80A and 80B will be connected to ground by the one of the cathodes 82A, 82B which is negative. The other of the grids of the tubes 80A, 80B will be able to respond to the positive signal received from the lead 72.

Assume for illustrating this operation that the flip-flop 20 has tube 20A conducting and tube 20B not conducting, a positive signal is applied along lead P to the grid of tube 82A and a negative signal is applied along lead M to the grid of tube 82B. The cathode of tube 82A goes positive and will therefore block conduction through diode 84B. The cathode of tube 82B goes negative and therefore conduction of tube 84A is enabled and the clamping diode then places the cathode of tube 84A at ground. Accordingly, the signal received from lead 72 will be applied to the grid of tube 80B, since, effectively, the grid of tube 80A is connected to ground.

As a result of the tube 80B being enabled to conduct, an output is derived from its anode which varies in a negative direction in response to an increase in the analog signal applied to its grid. This is as it should be, since when the side 20A of flip-flop 20 is conductive, this is indicative of the fact that a negative count is in the counter. When side 20B of the flip-flop is conducting, indicative of the fact that a positive count is in the counter, then tube 82B receives a positive signal, cutting off diode 84A and enabling grid 80A to follow the signal being applied to it from lead 72. The common cathode coupling resistor 94 applies the signal which is being applied to the grid of tube 80A to tube 80B. Its output follows the signal, and a positive-going voltage is derived at the output potentiometer 96, which is the analog of the positive digital count in the counter. Therefore, the polarity of the output analog voltage is controlled by the sign of the count in the counter which is stored in the flip-flop 20.

The double-pole, double-throw relay 100 serves the function of enabling a resetting of the counter to the zero count condition. It does this by opening the cathode connection to ground of the zero cathode of the decade 22, which is also connected to the zero cathode through a coupling resistor of decade 18. The plates of the various decades are then connected to the +150 volt source, instead of the 400 volt source. With this arrangement, the decade gas tubes have their zero cathodes connected to B— and, therefore, the glows will be switched to the zero cathodes.

To summarize the operation of the decade counter, a first and second pulse are applied to the G1 and G2 input terminals. The order of the first and second pulse applied to these input terminals indicates whether or not the count should be added to the count in the counter or is subtracted from the count in the counter. A memory circuit, which is the flip-flop 20, serves the function of storing the sign of the count in the counter so that gating means, consisting of the tubes 10 and 12, may be enabled in a manner to enable the proper addition or subtraction of the count by controlling the interconnection between the G1 terminal to the first guide input terminal in the gas tube decade counters and the G2 terminal to the second guide input terminal in the gas tube decade counters. An interstage coupling arrangement is provided whereby between each two decades there is provided a flip-flop circuit which, when a preceding decade has the proper count, is set in a condition to apply a first guide pulse to the subsequent decade before or after a second guide pulse if the next count to the preceding decade warrants this operation. If not, then the interstage flip-flop is reset. Means are also provided in the form of resistance ladders connected between main cathodes of each decade whereby a digital-to-analog conversion of the count is enabled. The analog voltages of the various decades are in effect added by means of a cathode follower, and the resultant analog voltage is either presented at an output terminal in a positive- or negative-going direction in accordance with the sense of the count in the counter. The memory flip-flop establishes the polarity sense of the analog voltage.

Accordingly, there has been described and shown herein a novel, useful, reversible decade counter and digital-to-analog converter.

We claim:

1. A reversible decade counter having a plurality of decade stages each of which includes a gas flow-switching tube of the type having a first and a second guide terminal the advance or regression of a count being obtained by the order of application of a first and second pulse respectively to said first and second guide terminals, means for applying a first and second pulse to a first of said plurality of decades, means for coupling all the second guide terminals of all decades together, interstage coupling means between decades each including means for applying a first pulse to the first guide terminal of a succeeding decade prior to a second pulse to the second guide terminal of said succeeding decade responsive to a preceding decade being in its ninth count condition and the application thereto of a first pulse followed by a second pulse, and means for applying a first pulse to the first guide terminal of said succeeding decade subsequent to a second pulse to the second guide terminal of said succeeding decade responsive to said preceding decade being in its zero count condition and the application thereto of a second pulse followed by a first pulse.

2. A reversible decade counter having a plurality of decade stages each of which includes a gas glow-switching tube of the type having a first and a second guide terminal, the advance or regression of a count being obtained by the order of application of a first and second pulse respectively to said first and second guide terminals, means for applying first and second pulses to a

11

first decade, means for coupling all said second guide terminals together, a coupling arrangement between decades including a flip-flop circuit having a first and second stable state, a first means for driving said flip-flop from its first to its second stable state responsive to said first decade being in its ninth count condition and the application thereto of a first pulse preceding a second pulse, a second means for driving said flip-flop from its first to its second stable state responsive to said first decade being in its zero condition and the application thereto of a second pulse preceding a first pulse, means to apply output from said flip-flop in its second stable state to the first guide terminal of a decade succeeding said first decade, and means responsive to the application of a first pulse or a second pulse to said first decade to reset said flip-flop.

3. A reversible decade counter having a plurality of decade stages each of which includes a gas glow-switching tube of the type having a first and second guide terminal, the advance or regression of a count being obtained by the order of application of a first and second pulse respectively to said first and second guide terminals, first and second pulse input terminals, means for coupling the second guide terminals of all decades together, interstage coupling means between decades each including means for applying a first pulse to the first guide terminal of a succeeding decade prior to a second pulse to the second guide terminal responsive to the preceding decade being in its ninth count condition and the application to said preceding decade of a first pulse followed by a second pulse, and means for applying a first pulse to the first guide terminal of a succeeding decade subsequent to a second pulse to the second guide terminal responsive to the preceding decade being in its zero count condition and the application to said preceding decade of a second pulse followed by a first pulse, means for storing the sign of the count in said counter responsive to all said decades being in their zero count condition and the order of application of a first and a second pulse to said first and second pulse input terminals, and means responsive to the sign of the count in said means to store to establish the order of the application of first and second pulses from said first and second pulse input terminals to said first decade.

4. A reversible decade counter having a plurality of decade stages each of which includes a gas glow-switching tube of the type having a first and second guide terminal, the advance or regression of a count being obtained by the order of application of a first and second pulse respectively to said first and second guide terminals, first and second pulse input terminals, means for coupling the second guide terminals of all decades together, interstage coupling means between decades each including a first flip-flop circuit having a first and second stable state, a first means for driving said flip-flop from its first to its second stable state responsive to a preceding decade being in its ninth count condition and the application thereto of a first pulse preceding a second pulse, a second means for driving said flip-flop from its first to its second stable state responsive to a preceding decade being in its zero count condition and the application thereto of a second pulse followed by a first pulse, means to apply output from said flip-flop in its second stable state to the first guide terminal of a said succeeding decade, and means responsive to the application of a first or second pulse to said first decade to reset said flip-flop, a second flip-flop circuit having a first and second stable state, means responsive to all said decades being in their zero count condition and to the application to said first decade of a first pulse followed by a second pulse to drive said second flip-flop to a first stable state and to the application to said first decade of a first pulse followed by a second pulse to drive said second flip-flop to a second stable state, and means responsive to the stable state of said second flip-flop to

12

establish the order of the application of first and second pulses from said first and second pulse input terminals to said first decade.

5. A reversible counter as recited in claim 4 wherein said means to drive said second flip-flop responsive to all said decades being in their zero count condition and to the order of application of first and second pulses includes a first cathode follower tube, means coupling said cathode follower tube to all the decades when in their zero count condition, a first and second plate follower tube each having an anode, cathode, and control grid, means to apply said cathode follower tube output to the control grids of said first and second plate followers, means coupling said first pulse input terminal to said first plate follower cathode, means coupling said second pulse input terminal to said second plate follower cathode, and means coupling said first and second plate follower anodes to said second flip-flop circuit to drive it to its first or second stable condition responsive to whichever of said first and second plate follower tubes is rendered conductive.

6. A reversible decade counter as recited in claim 4 wherein said means responsive to the stable state of said second flip-flop to establish the order of the application of said first and second pulses from said first and second input terminals to said first decade includes first, second, third, and fourth coincidence gates each requiring a coincidence of their inputs to provide an output, means for applying the output of said first and third gate to the first guide terminal of said first decade, means for applying the output of said second and fourth gate to the second guide terminal of said first decade, means to apply output from said second flip-flop in its first stable state to said first and third gates, means to apply output from said second flip-flop in its second stable state to said second and fourth gates, means to couple said first input terminal to said first and second gate, and means to couple said second input terminal to said third and fourth gates.

7. A reversible counter as recited in claim 4 wherein each decade stage includes an anode and ten main cathodes, a separate load resistor in series with each of said cathodes, a plurality of resistors, means for coupling a different one of said resistors between adjacent ones of nine of said main cathodes to form a resistance ladder, means for combining the voltages existing across the resistance ladders of all said decades in said counter, and means responsive to the stable state of said second flip-flop and to the output of said means for combining to provide an output having an amplitude and polarity which is an analog representation of the count in said counter.

8. A reversible decade counter having a plurality of decade stages each of which includes a gas glow-switching tube of the type having ten main cathodes, and a first and second guide input terminal, the advance or regression of a count being obtained by the order of application of a first and a second pulse respectively to said first and second guide terminals, means for applying first and second pulses to a first of said plurality of decades, means for coupling all the second guide terminals together, interstage coupling means between each decade for advancing the count of a succeeding decade responsive to a preceding decade being in its ninth count condition and the application thereto of a first pulse before a second pulse and for regressing the count in said succeeding decade responsive to said preceding decade being in its zero count condition and the application thereto of a second pulse before a first pulse, means to establish the sign of the count in said counter, a plurality of cathode load resistors, a different one of which is in series with a different main cathode in each gas tube, a plurality of coupling resistors for each gas tube, means for connecting a different one of said coupling resistors between two adjacent ones of nine

13

of said cathodes to form a resistance ladder, means for combining the outputs of the resistance ladders of all the gas tubes in said counter, and means responsive to the combined resistance ladder outputs and to the sign of the count established in said counter to provide an output which is an analog representation of the count in said counter.

9. A reversible decade counter as recited in claim 8 wherein said means responsive to the combined resistance ladder outputs and to the sign of the count established in said counter to provide an output which is an analog representation of the count in said counter includes a first and a second tube each having an anode, cathode, and control grid, a load resistor connected to the anode of said first tube, a common cathode load resistor coupled to both tube cathodes, a source of nega-

14

tive potential, an output resistor connected between said first tube anode and said source of negative potential, an output terminal connected to said output resistor, means to apply the output of said means for combining to the grids of said first and second tubes, and means responsive to said means to establish the sign of the count establishing a positive sign to clamp the first tube grid and establishing a negative sign to clamp the second tube grid.

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