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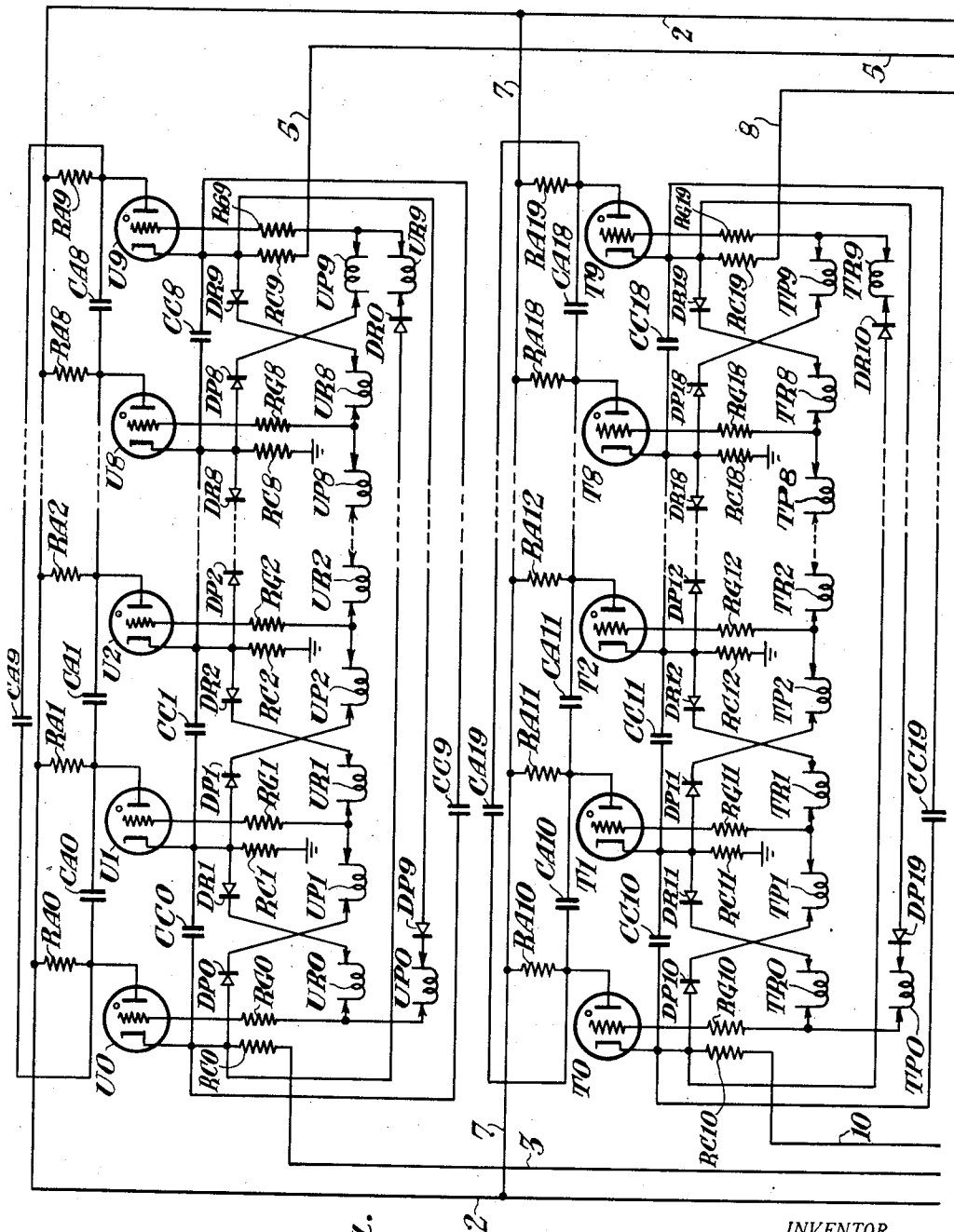
D. POUZET

2,902,216

REVERSIBLE COUNTING APPARATUS

Filed April 24, 1956

3 Sheets-Sheet 1



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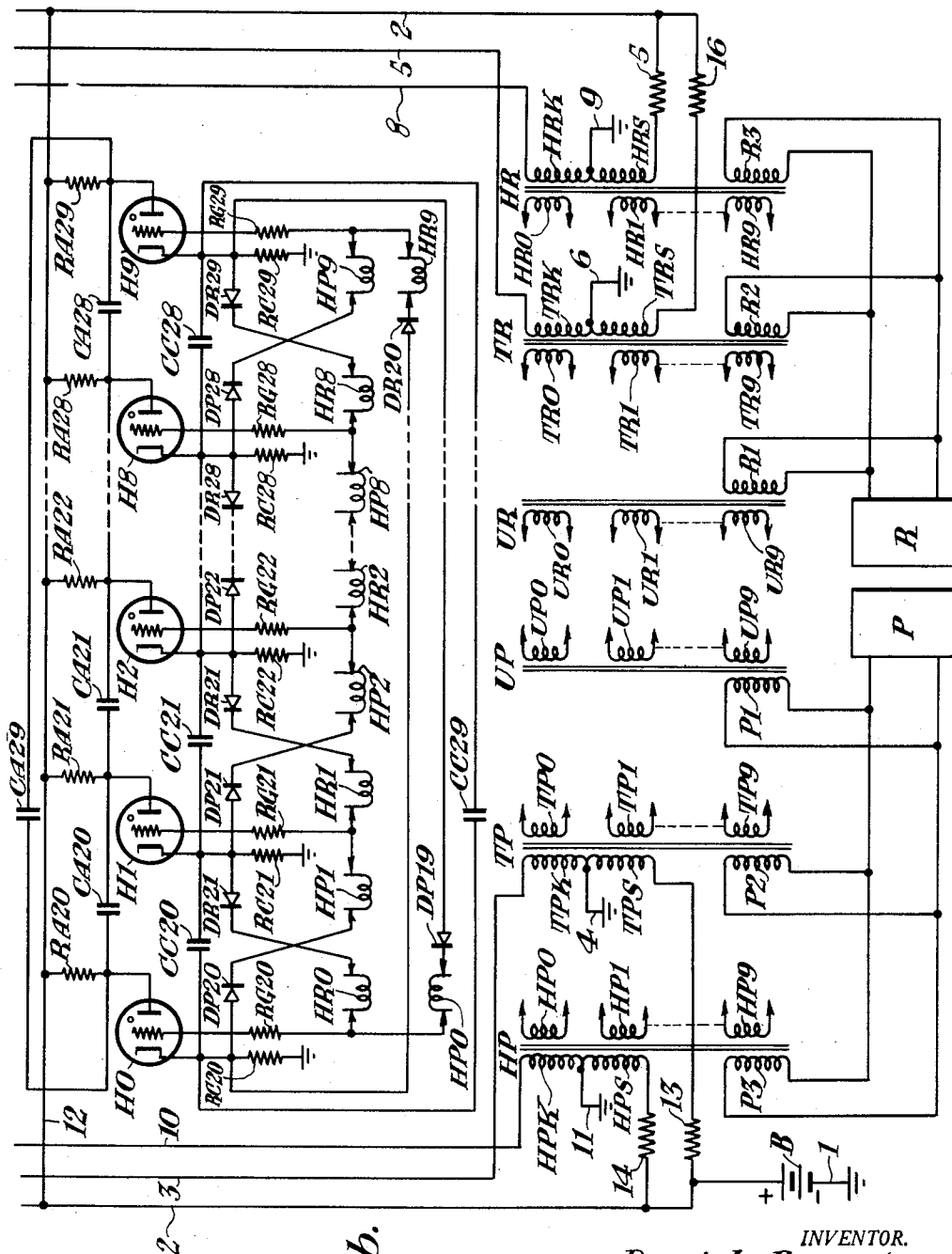
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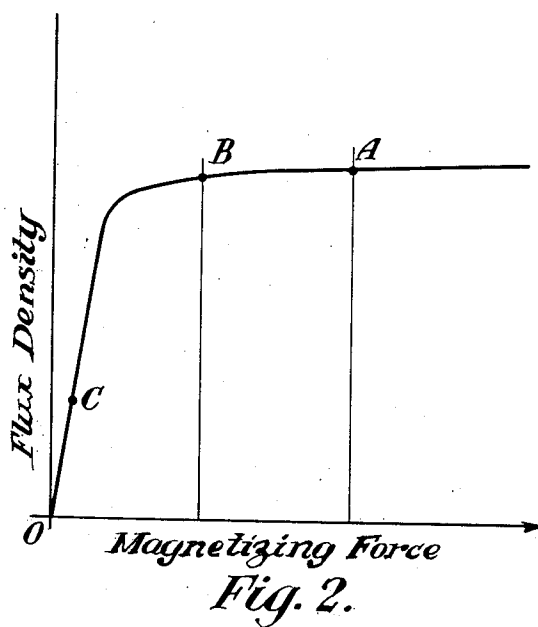
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REVERSIBLE COUNTING APPARATUS

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Claims priority, application France April 26, 1955

10 Claims. (Cl. 235—92)

This invention relates to counting apparatus and particularly to an improved reversible electronic counting chain adapted to indicate the accumulated algebraic sum of add and subtract pulses received over separate input transformers.

In telecommunication, remote control, computing and signaling, the problem frequently arises of counting or registering serial impulses, and in many cases it is required to register or indicate the accumulated algebraic total of signed impulses. Counting devices are known which have been used for various purposes in these fields, but such devices have generally included relays, movable parts, or rotating or step-by-step commutators, which present certain complications and difficulties in installation and operation. Accordingly, it is an object of the present invention to provide a reversible counting device which is fully electronic and incorporates no moving parts.

It is a further object of my invention to provide a reversible electronic counting apparatus which utilizes a minimum number of electronic tubes.

It is a further object of my invention to provide a reversible electronic counting apparatus comprising a plurality of counting chains corresponding to successive orders of magnitude and improved pulsing means for applying adding or subtracting counting impulses to such chains in such a manner that the counting chain for a given order of magnitude will complete a cycle of operation for each step of operation of the next higher order counting chain.

Other objects and further advantages of my invention will become apparent to those skilled in the art as the description proceeds.

In carrying out the above and other objects of my invention, according to one embodiment of my invention I provide an arrangement for counting in a given number system comprising a number of electronic tubes for each order of magnitude to be considered corresponding to the number of signs of the numerical system in question for each order of magnitude (10 for a decimal system, 2 for a binary system, 3 for a ternary system, etc.), two charging resistances in series, one in the circuit of the anode of each tube, the other in the circuit of the cathode, and means for supplying the assembly of the tubes from a source of direct current in series with the charging resistances. I further provide means for cutting off preceding or succeeding tubes upon the energization of a given tube, comprising anode capacitors located between anodes of the consecutive tubes and cathode capacitors located between cathodes of the consecutive tubes.

According to another feature of my invention, each of the tubes in a counting chain includes a control circuit comprising preparing elements for applying to each grid circuit a potential forming an essential part of the amplitude necessary for firing the tube, and pulsing elements for applying to each grid circuit successively an impulse controlling the progression or the retrogression of the counting chain. A further feature of one form of my

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invention is that the previously described preparing elements in the grid circuits of each tube comprise components of asymmetric or unidirectional conductivity connected in an opposite manner with respect to each other in each of the connections between cathodes and grids of the successive tubes.

In a particular embodiment of my invention, the pulsing elements connected in each grid circuit are made up of windings mounted in series with the connections between the cathodes and grids of the tubes whereby these windings form independent secondaries of an impulse transformer fed by a generator of progressive or retrogressive impulses.

According to a further feature of one embodiment of my invention, for each order of magnitude higher than the first a magnetic circuit is provided which comprises a primary winding on a saturable core fed in a permanent manner and bringing the point of operation of the circuit to rest in saturation, a secondary winding fed in a similar manner as the primary of the previously mentioned impulse transformer, a third winding in series in the anodic or cathodic circuit of the first or last tube of the series of tubes corresponding to the order of magnitude under consideration, and finally a series of receiver windings connected to the tubes of the order of magnitude under consideration in the same manner as the secondaries of the before-mentioned impulse transformer are connected to the tubes corresponding to the first order of magnitude.

A further feature of one embodiment of my invention comprises the provision of two impulse transformers for the first order of magnitude, one corresponding to the impulses in the progressive direction and the other to the impulses in the retrogressive direction, and furthermore, for each order of magnitude higher than the first, two magnetic circuits as defined above, one for the progressive operation of the meter and the other for the retrogressive operation.

I shall first describe one embodiment of my invention, and shall then point out the novel features thereof in claims.

Figures 1a and 1b, when arranged horizontally with Fig. 1a at the top, comprise a wiring diagram of one embodiment of my invention.

Fig. 2 is a graph showing the operation of the circuit of Figures 1a and 1b.

Referring to Figures 1a and 1b, a three decade reversible counter for use in the decimal number system is shown. Ten electronic tubes are provided for each decade. As shown, these tubes may be cold cathode thyatrons, but it will be apparent to those skilled in the art that other electron discharge devices could be employed without departing from the broader aspects of my invention.

The tubes employed for each decade are arranged to form a continuous reversible counting ring. For the units decade, tubes U0 through U9 are provided. Since the circuits for tubes U3 through U7 would merely repeat the circuits for the tubes shown, they have been omitted for the sake of simplicity and clarity. The tens decade of the counter comprises tubes T0 through T9, and the hundreds decade comprises tubes H0 through H9. Each of the counting chains thus formed is adapted to be energized in a progressive or retrogressive direction by impulses in a manner to be described.

A source of adding, of progressive, impulses is shown schematically at P. Since the details of this source form no part of my present invention, they are not shown. However, it is obvious that any suitable means for providing a pulse of voltage for each event to be added, such as a pulsing transformer or a manually operable key, could be employed for this purpose. Similarly, a source R of retrogressive or subtractive impulses is

shown in block form. These impulses are transmitted to the various orders of the counting apparatus through transformers UP, UR, TP, TR, HP, and HR, through circuits to be described.

Referring now to the first decade counting chain comprising tubes U0 through U9, it will be apparent that each of the tubes is supplied from a source comprising a suitable battery B through a circuit comprising a pair of charging resistances RA_i and RC_i in series, where *i* represents the number of the tube. In particular, a circuit extends from a suitable grounding point 1 through battery B and over positive bus or lead 2 through anode resistance RA0, from the plate to the cathode of tube U0, through cathode resistance RC0 of tube U0, over lead 3, through winding TPK on saturable transformer TP, to be described and back to ground at 4. The circuit for tube U1 extends from positive lead 2 through anode resistance RA1, between the plate and cathode of tube U1, through resistance RC1 to ground. Similarly, the circuit of tubes U2 through U8 include anode resistances RA2 through RA8 and cathode resistances RC2 through RA8 connected between lead 2 and ground. Since these circuits are repetitive, it is believed unnecessary to describe each one in detail. The circuit of tube U9 extends from positive lead 2 through anode resistance RA9, between the plate and cathode of tube U9, through resistance RC9, over lead 5, and through winding TRK of saturable transformer TR, to be described, to ground at 6.

Each of the successive tubes U0 through U9 has its plate or anode connected to the plate of the preceding and succeeding tubes in the counting ring by capacitors CA_i, where *i* represents the number of the stage. In particular, the plate of tube U0 is connected to the plate of tube U1 through capacitor CA0 and the plate of tube U0 is also connected to the plate of the preceding tube, in this case U9 at the end of the chain, through capacitor CA9. The plate capacitances for the remaining tubes are identical with those just described and will not be further considered in detail. Further, the cathodes of each of the tubes in the chain are connected to preceding and succeeding cathodes through cathode capacitances CC_i, where *i* is the number of the tube. For example, the cathode of tube U0 is connected to the cathodes of tubes U1 and U9 through capacitors CC0 and CC9, respectively. Since the other capacitors CC_i are similarly connected, they will not be further described.

Each of the cathodes in the tubes of the counting ring are connected to the grids of succeeding tubes through rectifiers DP_i, where *i* is the number of the tube. For example, tube U0 has its cathode connected to the grid of tube U1 through rectifier DP0, the terminals of secondary winding UP1 of transformer UP, to be described, and a grid resistor RG1. Similarly, the cathode of tube U1 is connected to the grid of tube U2 by connections including rectifier DP1, the winding of secondary UP2 on transformer UP, to be described, and grid resistance RG2. The cathode of tube U2 is connected to the grid of the succeeding tube, not shown, by a similar circuit including rectifier DP2. The remaining connections are the same as those just described, and it is believed unnecessary to describe them in further detail except to point out that the cathode of tube U9 is connected to the grid of tube U0 at the beginning of the chain by a circuit including rectifier DP9, the secondary winding UP0 of transformer UP, to be described, and grid resistance RG0.

The cathodes of each of the tubes in the counting ring are also connected to the grids of preceding tubes in the chain by connections which will now be described. Beginning with tube U2, the cathode of this tube is connected to the grid of tube U1 through rectifier DR2, the secondary winding UR1 of transformer UR, to be described, and grid resistance RG1. The cathode of tube U1 is connected to the grid of tube U0 through rectifier DR1, secondary winding UR0 on transformer

UR, and grid resistance RG0. The cathode of tube U0 is connected to the grid of tube U9 through rectifier DR0, secondary winding UR9 on transformer UR, and grid resistance RG9. The remaining tubes are similarly connected and these connections need not be further described.

The tens and hundreds decade counting chains are connected exactly as just described for the units decade except for certain differences in the initial and final tube circuits, as will now be described. First tube T0 in the tens decade counter has an operating circuit extending from positive bus 2 over lead 7, through anode resistance RA10, through tube T0, through cathode resistance RC10, over lead 10, and through winding HPK on saturable transformer HP, to be described, to ground at 11. A circuit for tube T9 extends from positive bus 2 over lead 7 through anode resistance RA19 and tube T9, through cathode resistor RC19, over lead 8, and through winding HRK on saturable transformer HR, to be described, to ground at 9. Similarly, tubes T1 through T8 are connected between positive bus 2 and ground by circuits including their anode resistances RA11 through RA18 and their cathode resistances RC11 through RC13.

Each of the cathodes of the tubes of the tens decade counter are connected to the grids of succeeding tubes by circuits including a rectifier, a secondary winding of an input transformer, and a grid resistance. For example, the cathode of tube T0 is connected to the grid of tube T1 by a circuit including rectifier DP10, winding TP1 of transformer TP, and resistance RG11 to the grid of T1. The cathode of tube T9 is connected to the grid of tube T0 by a circuit including rectifier DP19, winding TP0 of transformer TP and grid resistance RG10 to the grid of T0. The cathodes of the remaining tubes T1 through T8 are connected to their succeeding tubes by T2 through T9 by circuits including their associated rectifiers DP11 through DP13 and windings TP2 through TP8 on transformer TP, to be described.

The cathodes of each of the tubes of the tens decade counting chain are likewise connected to the grids of preceding tubes by connections including a rectifier, a winding of one of the input transformers, and a grid resistance. For example, the cathode of tube T0 is connected to the grid of tube T9 by a circuit including rectifier DR10, winding TR9 of transformer TR and grid resistance RG19. The cathode of tube T9 is connected to the grid of tube T8 by a circuit including rectifier DR19, winding TR8 of transformer TR, and grid resistance RG18. The cathodes of the remaining tubes T3 through T1 are similarly connected to their preceding tubes T7 through T0 by connections including their associated rectifiers DR18 through DR11, windings TR7 through TR0 of transformer TR, and grid resistances RG17 through RG10.

The anodes of tubes T0 through T9 are interconnected by the anode capacitors CA10 through CA19, as shown. The cathodes of tubes T0 through T9 are also interconnected by capacitors CC10 through CC19, as shown.

The charging circuits for tubes H0 through H9 of the hundreds decade counting chain extend from positive bus 2, over lead 12, through the anode resistances of the tubes, from plate to cathode of each tube, and through the cathode resistances to ground. For example, the charging circuit for tube H0 extends from the positive terminal of battery B over bus 2 and lead 12, through anode resistance RA20, from the plate to the cathode of tube H0, and through cathode resistor RC20 to ground and to the negative terminal of battery B. Similar parallel circuits extend from lead 12 through anode resistances RA21 through RA29, tubes H1 through H9, and cathode resistances RC21 through RC29 to ground.

The anodes of the succeeding tubes H0 through H9 in the hundreds decade are interconnected by capacitors CA20 through CA29, as shown. Similarly, the cathodes

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of tubes H0 through H9 are interconnected by capacitors CC20 through CC29, as shown.

The cathodes of the tubes H0 through H9 are connected to the grids of succeeding tubes in the ring by connections including a rectifier, a winding of a saturable transformer HP, to be described, and grid resistances RG20 through RG29. For example, the cathode of tube H0 is connected to the grid of tube H1 over a circuit including rectifier DP20, winding HP1 of saturable transformer HP and grid resistance RG21. The cathode of tube H9 is connected to the grid of tube H0 over a circuit including rectifier DP19, winding HP0 of saturable transformer HP, and grid resistance RG20. The remaining tubes have identical connections which need not be further described in detail.

The cathodes of each of tubes H0 through H9 are likewise connected to the grids of preceding tubes in the ring by connections including a rectifier, a secondary winding of saturable transformer HR, and the grid resistance previously described. For example, the cathode of tube H9 is connected to the grid of tube H8 by a circuit including rectifier DR29, winding HR8 of transformer HR, and grid resistance RG28. Similarly, the cathode of tube H0 is connected to the grid of tube H9 over a circuit including rectifier DR20, winding HR9 of transformer HR, and resistance RG29. The remaining circuits for the other tubes are identical and will not be further described.

As previously described, source P comprises the source of progressive or adding pulses which serve to sequentially actuate the counting tubes of the counting chain for the various orders previously described. Source P has an output circuit including in parallel primary windings P1, P2 and P3 on transformers UP, TP and HP, respectively.

Transformer UP may be of conventional construction, comprising primary winding P1, a conventional core, shown schematically, and a plurality of secondary windings UP0 through UP9. These secondary windings are connected in the circuits of tubes U0 through U9, respectively, as indicated by showing the symbols for the windings at both the tube and transformer location. This convention was adopted to avoid showing the leads from the windings to the grid circuits of the tubes, since to show them would unnecessarily complicate the drawings. It will be apparent that upon the appearance of a pulse at the output of source P, winding P1 of transformer UP is energized by a voltage which will induce a voltage in secondaries UP0 through UP9, and apply impulses to the grid circuits of tubes U0 through U9.

Transformer TP is a conventional saturable transformer and includes, in addition to primary winding P2 and secondary windings TP0 through TP9, a saturating winding TPS and a desaturating winding TPK, for a purpose to be described.

Saturating winding TPS is energized by a circuit extending from ground at 1, through battery B, and through resistance 13 and the winding TPS to ground at 4. The number of turns on winding TPS is so selected that the core of transformer TP is saturated and, with reference to the magnetization curve of Fig. 2, will be sufficiently beyond the saturation point so that the flux will substantially correspond to point A on the curve. This value is so chosen that a pulse appearing across primary winding P2 of transformer TP will only suffice to bring the operating point of the core back to point B on Fig. 2, and no substantial change in flux density will occur. Accordingly, there will be no output on secondaries TP0 through TP9 in the presence of a pulse across P2 alone.

Additional winding TPK is provided to aid pulses appearing across primary P2 under certain conditions, to be described, so that the cumulative effect of windings TPK and P2 will bring the operating point of the core back to point C in Fig. 2, and the corresponding change in flux density in the core will induce an output voltage across secondaries TP0 through TP9, which will be trans-

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mitted to the grid circuits of tubes T0 through T9 by the connections shown.

Transformer HP is a saturable transformer substantially identical with transformer TP, just described. This transformer comprises a saturable core and a primary winding P3, a plurality of secondary windings HP0 through HP9 connected in the grid circuits of tubes H1 through H9 as schematically shown, a saturating winding HPS, and an additional winding HPK.

Winding HPS is energized by a D.C. voltage over a circuit extending from ground at 1 through battery B, resistor 14, and the winding of HPS to ground at 11. The number of turns on the winding of HPS is selected to produce a magnetomotive force sufficient to bring the core to a saturated value such as A in Fig. 2 as previously described in connection with transformer TP.

Winding HPK, acting under conditions to be described, at times aids winding P3 to overcome the effect of winding HPS and bring the operating point of the core back to point C in Fig. 2, as described in connection with transformer TP, to permit an output pulse to appear across secondary windings HP0 through HP9.

Source R of retrogressive or subtractive impulses for sequential operation of the counter tubes has parallel output circuits connected to primary windings R1, R2 and R3 on transformers UR, TR and HR.

Transformer UR is a conventional transformer identical in construction to transformer UP, previously described, and has a primary winding R1 and a plurality of secondary windings UR0 through UR9 connected, as indicated by the convention previously described, to the grid circuits of tubes U0 through U9. The leads connecting these windings to their respective grid circuits have not been shown, since to do so would unnecessarily complicate the circuit.

Transformers TR and HR comprise conventional saturable transformers identical with transformers HP and TP, previously described. These transformers have primary windings R2 and R3 and secondary windings TR9 and HR0 through HR9, respectively. Each of the transformers TR and HR also has a saturating winding TRS and HRS, respectively, transformer TRS being energized by a D.C. voltage over a circuit extending from ground at 1, through battery B, over lead 2, through resistor 16, and through the winding of TRS to ground at 6. Winding HRS is energized by a D.C. voltage over a circuit extending from ground at 1, through battery B, over lead 2, through resistance 15, and through winding HRS to ground at 9. Additional windings TRK and HRK co-operate at times to be described with primary windings R2 and R3 to desaturate the core and produce output windings across secondary windings TR0 through TR9 and HR0 through HR9, respectively.

The operation of this embodiment of my invention will now be described. For this purpose, assume that tubes U0, T0 and H0 are conducting, which is the zero-indicating condition of the apparatus.

Considering first the units decade chain, it will be apparent that the cathode of tube U0 will be above ground potential due to the drop through cathode resistor RC0. Accordingly, a positive voltage is transmitted through rectifier DP0, winding UP1, and grid resistor RG1 to the grid of tube U1, and a similar voltage is transmitted to the grid of tube U9 through rectifier DR0, winding UR9, and resistance RG9. Cathode resistances RCi, where i is the number of the stage, are so selected that this voltage is insufficient to cause tubes U1 and U9 to fire, but the voltage thus supplied to the grids of U1 and U9 is a substantial part of the voltage necessary for firing. Accordingly, any additional voltage applied to the grids of either U1 or U9 will cause these tubes to conduct.

Now, assume that a progressive impulse is transmitted from source P and appears across primary winding P1 of transformer UP. This voltage impulse will induce an impulse in secondary windings UP0 through UP9. Con-

sidering secondary winding UP₁, the half cycle or half cycles of this impulse which are effective act in the direction indicated by the arrowhead of the rectifier symbol DP₀. If opposite half cycles occur, they will be ineffective because blocked by rectifier DP₀ and opposed by the cathode voltage of U₀. The effective pulse in the direction of the arrowhead of the rectifier symbol DP₀ will add to the cathode voltage of U₀ appearing through rectifier DP₀ and the cumulative voltage applied to the grid of U₁ through resistor RG₁ will be sufficient to fire tube U₁.

Before considering the events occurring upon the conduction of tube U₁, the action of the remaining primary windings UP₀ and UP₂ through UP₉ will be considered. It will be seen that the impulse appearing across transformer secondary UP₉ in the direction of the arrowhead of rectifier symbol DP₈ is applied to the grid of U₉ in parallel with the preparing voltage from the cathode of U₀ which is supplied through rectifier DR₀ and winding UR₉. Accordingly, this voltage will not substantially increase the voltage of tube U₉ and this tube will not be fired. Of the remaining tubes, U₀ is already conducting and tubes U₂ through U₈ will not be rendered conducting since the impulses appearing across windings UP₂ and UP₈ will be insufficient, in the absence of a preparing voltage from the cathode of an adjacent conducting tube, to render these tubes conducting. Accordingly, only tube U₁ will be rendered conducting.

Upon the conduction of tube U₁, the simultaneous lowering of the anode voltage due to the drop across resistor RA₁ and the raising of the cathode voltage due to the voltage drop across cathode resistor RC₁ will be transmitted to the plate and cathode, respectively, of tube U₀ through capacitor CA₀ and CC₀. The simultaneous lowering of the plate potential of U₀ and raising of its cathode potential will be effective to cut off tube U₀ and it will be deenergized. Capacitors CA₁ and CC₁ similarly transmit impulses to the plate and cathode, respectively, of tube U₂, but these impulses have no effect since tube U₂ is already deenergized.

Due to the rise in cathode potential of tube U₁, a positive preparing voltage is applied to the grid of tube U₀ over a circuit including rectifier DR₁, winding UR₀ of transformer UR and grid resistor RG₀. A similar preparing voltage is applied to the grid of tube U₂ from the cathode of U₁ over a circuit including rectifier DP₁, winding UP₂ of transformer UP and grid resistor RG₂. U₂ is therefore prepared for conduction upon the receipt of the next progressive pulse, whereas U₀ is prepared for conduction upon the receipt of the next retrogressive or subtractive pulse.

The effect of the first progressive pulse on transformers TP and HP will be next considered. Windings TP₈ and HP₈ on these units maintain the flux densities in their respective cores in the saturation region as indicated by point A in Fig. 2. The progressive pulse applied to primary windings P₂ and P₃ on these transformers is sufficient to bring the flux density back to point B in Fig. 2, but is insufficient to cause any substantial change in flux in the core. Winding TPK on transformer TP is subject to a pulse of voltage as tube U₀ ceases to conduct due to the counting action in the units decade as previously described. However, this pulse will be out of phase with the input pulse on winding P₂ and hence does not effect a desaturation of the core of transformer TP. Accordingly, there is no output on the secondary windings TP₀ through TP₉ of transformer TP and no change takes place in the tens decade counting chain. Since there is no change in the conducting states of tubes T₀ through T₉ in a tens decade counting chain, there will be no effect on winding HPK of transformer HP and there will therefore obviously be no output across secondary windings HP₀ through HP₉. Accordingly, no change takes place in the hundreds decade counting chain.

Next, assume that tube U₁ is conducting as previously described and a regressive or subtractive impulse is received from input pulse source R. This pulse input will be applied in parallel across primary windings R₁, R₂ and R₃ of transformers UR, TR and HR, respectively. Since tube U₁ is conducting, the grids of tubes U₀ and U₂ are prepared for causing these tubes to conduct upon the receipt of a suitable additional pulse. The preparing circuit for the grid of tube U₀ extends from the cathode of U₁ through rectifier DR₁ and the winding of secondary UR₀ of transformer UR as previously described. Accordingly, the impulse induced in secondary winding UR₀ by primary winding R₁ is applied in series with the preparing voltage from the cathode of U₁ and tube U₀ is caused to conduct. The pulse appearing across secondary winding UR₂ will be ineffective to render tube U₂ conducting because this pulse acts in parallel with the preparing voltage, which is supplied by a circuit extending from the cathode of tube U₁ through rectifier DP₁ and winding UP₂ on transformer UP, which is deenergized at this time. The remaining tubes will be unaffected by pulses appearing across the UR secondaries because their grids are not prepared.

As tube U₀ goes into conduction, the change in current through its charging circuit causes a pulse to appear across winding TPK of transformer TP which is sufficient to bring the flux density in its core back to point B in Fig. 2. However, due to the absence of a progressive pulse across primary P₂ at this time, there is no output across transformer TP.

The drop in plate voltage and rise in cathode voltage attendant upon the conduction of tube U₀ are transmitted through plate capacitors CA₀ and CA₉ and cathode capacitors CC₀ and CC₉ to the plates and cathodes of tubes U₉ and U₁, respectively. Since tube U₉ remains non-conducting, this pulse has no effect on its operation. However, the drop in plate voltage and rise in cathode voltage imposed on tube U₁ causes this tube to cease conduction. The input pulse appearing across windings R₂ and R₃ of transformers TR and HR will be effective to return the flux densities of the cores of these transformers to point B in Fig. 2, but since there is no change in states of tubes U₉ and T₉, no impulses appear across windings TRK and HRK, respectively, and therefore there is no output across the secondaries of transformers TR and HR. No change, therefore, takes place in the tens and hundreds decade. The apparatus is accordingly returned to its initial state.

Next, assume that tube U₉ in the units decade is conducting and that tubes T₀ and H₀ in the tens and hundreds decades are conducting, indicating 9. Now, assume that a progressive pulse is received from source P and appears across primary windings P₁, P₂ and P₃. Since tube U₉ is conducting, tubes U₈ and U₀ are prepared for conduction by the voltage applied from the cathode of tube U₉ through the circuits previously traced to the grids of tubes U₈ and U₀. Due to the input pulse across P₁, an output pulse appears across secondaries UP₀ through UP₉ in transformer UP. It will be apparent from the preceding discussion that the pulse appearing across UP₈ will be in parallel to the preparing voltage to the grid of U₈ supplied through rectifier DR₉ and the winding UR₈ of deenergized transformer UR. Accordingly, tube U₈ will remain non-conducting. However, the impulse supplied to the grid of tube U₀ through primary winding UP₀ will act in series with the preparing voltage supplied from the cathode of tube U₉ through rectifier DP₉. Accordingly, tube U₀ will begin conduction.

The consequent rise in cathode potential on U₀ will result in a change of current through winding TPK on transformer TP. Since this pulse is in a sense to aid the pulse appearing across primary winding P₂, and since it appears substantially simultaneously with the input pulse

due to the rapid change in state of tubes U9 and U0, the flux density in transformer TP is brought back to point C in Fig. 2 and the consequent change in flux density causes an output pulse to appear across secondary windings TP0 through TP9. Since tube T0 is conducting, the tubes T1 and T9 are prepared for conduction by the circuits previously described. The impulse appearing across winding TP1 will accordingly be effective to aid the preparing voltage supplied from the cathode of T0 through rectifier DP10 to cause conduction in tube T1. T1 will accordingly begin to conduct and will cut off tube T0 by the action of its plate and cathode coupling capacitances CA10 and CC10.

At the cessation of conduction in tube T0, a change in voltage appears across winding HPK of transformer HP which is opposite to the phase of the residue of the pulse on P3. Accordingly, no output will appear across secondaries HP0 through HP9. The apparatus will accordingly be in equilibrium with tube T1 conducting and tubes U0 and H0 conducting, indicating 10.

Next, assume that a regressive or subtractive pulse is received from source R with tubes U0, T1 and H0 conducting. From the preceding discussion, it will be apparent that in the units decade counting chain tubes U1 and U9 will be prepared, in the tens decade tubes T0 and T2 will be prepared, and in the hundreds decade tubes H1 and H9 will be prepared. Tube T0 is prepared over a circuit extending from the cathode of tube T1 through rectifier DR11 and secondary winding TR0 of transformer TR. Accordingly, an input pulse appearing across TR0 in series with rectifier DR11 will cause tube T0 to become conducting and cut off T1. Tube U9 is prepared by a circuit extending from the cathode of tube U0 over rectifier DR0 and through winding UR9 on transformer UR. Since the regressive pulse appearing across R1 is applied directly to the secondary windings of UR, a pulse appears across UR9 adding to the preparing voltage and tube U9 becomes conducting, cutting off U0. As U9 becomes conducting, a pulse appears across TRK due to the circuit extending from the cathode of U9 through resistance RC9, and lead 5 through the winding of TRK to ground at 6. This pulse aids the pulse appearing across R2 from source R and there is therefore an output pulse across the secondary windings TR0 through TR9. The pulse appearing across TR0 adds to the preparing voltage from the cathode of T1 to fire T0 and cut off T1 by the circuit action previously described. This pulse has no effect on either of prepared tubes H1 and H9 in the hundreds decade chain, since the pulse which appears across transformer R3 is not applied to the secondaries HR0 through HR9 because winding HRK remains deenergized.

As an example, a transition from 100 to 99 will be described. Assume that tube U0 in the units decade, T0 in the tens decade, and H1 in the hundreds decades are conducting indicating 100. To indicate 99, tubes H0, T9, and U9 must be rendered conductive and tubes H1, T0, and U0 must be cut off.

From the preceding discussion, it will be apparent that in the units decade counting chain tubes U1 and U9, in the tens decade counting chain tubes T1 and T9, and in the hundreds decade tubes H0 and H2 will be prepared. Tube H0 is prepared over a circuit extending from the cathode of tube H1 through rectifier DR21 and secondary winding HR0 of transformer HR. Tube T9 is prepared over a circuit extending from the cathode of tube T0 through rectifier DR10 and through winding TR9 on transformer TR. Likewise tube U9 is prepared over a circuit extending from the cathode of tube U0 through rectifier DR0 and through winding UR9 on transformer UR.

Assume that a regressive pulse is received from source R.

Since the regressive pulse from source R appearing across transformer primaries R1, R2 and R3 is applied directly to the secondary windings of UR a pulse appears

across UR9. The pulse across UR9 adds to the preparing voltage, and tube U9 becomes conductive, cutting off U0.

The pulse appearing across secondary winding UR1 will be ineffective to render tube U1 conducting because this pulse acts in parallel with the preparing voltage for tube U1 which is supplied over the circuit extending from the cathode of tube U0 through rectifier DP0 and winding UP1 on transformer UP, which transformer is not energized at this time.

As tube U9 becomes conductive a pulse appears across TRK due to the circuits extending from the cathode of tube U9 through resistance RC9, and lead 5 through the winding of TRK to ground at 6. This pulse appearing across TRK aids the pulse appearing across primary R2 from source R and there is, therefore, an output pulse across secondary windings TR0 through TR9. Since T9 is prepared over the circuit described above, the pulse appearing across TR9 causes T9 to become conductive, cutting off T0. Likewise, as tube T9 becomes conductive a pulse appears across HRK by way of the circuits extending from the cathode to tube T9 through resistance RC19 and lead 8 through the winding of HRK to ground at 9. This pulse appearing across HRK aids the pulse appearing across primary R3 from source R and there is, therefore, an output pulse across secondary windings HR0 through HR9. Since H0 is prepared over the circuit described above, the pulse appearing across HR0 causes H0 to become conductive, cutting off H1.

The pulses appearing across secondary winding HR2 will be ineffective to render tube H2 conducting because this pulse acts in parallel with the preparing voltage which is supplied by the circuit extending from the cathode of tube H1 through rectifier DP21 and winding HP2 on transformer HP, which transformer is not energized at this time.

Likewise, the pulses appearing across secondary winding TR1 will be ineffective to render tube T1 conductive.

It is believed that the specific examples of operation just described will be sufficient to indicate to those skilled in the art the operation of the disclosed apparatus under any other operating condition. Obviously, in infinite variety of input conditions could occur, but in each case the application of a progressive or regressive pulse causes the tubes which are ahead of or behind the previously conducting tube in the chain, respectively, to be energized and to cut off the previously conducting tube. Further, as each order chain completes a counting cycle by firing its tube 0 and cutting off its tube 9, the next higher order decade input transformer is activated to permit the transmission of a pulse to a tube in that chain. Also as each regressive cycle is begun in a given chain by cutting off its tube 0 and firing its tube 9, the pulse transformer for the next higher order chain is prepared for the reception of a regressive pulse to step back one counting unit. As examples of each of these events have been given, it is believed unnecessary to further describe the operation of the circuit.

Although I have shown an embodiment of my invention based on the decimal numbering system and showing three counting decades, it will be apparent to those skilled in the art that any numbering system could be used as a basis for an embodiment of my invention, in which case the number of tubes in each order counting chain would equal the number of signs for each order in that numbering system, and that any numbering system, and that any number of orders could be provided depending upon the range over which it was desired to count. Further, while I have shown only one embodiment of my invention in detail, other changes and modifications will be apparent to those skilled in the art upon reading this description, and I accordingly do not wish to be limited to the details shown, but only by the scope of the following claims.

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Having thus described my invention, what I claim is:

1. A reversible counting chain, comprising, in combination, first and second order counting rings comprising a first and second plurality of electron discharge devices, each device having an anode, a cathode and a control electrode, successive anodes of the devices of said rings being capacitively coupled, successive cathodes of the devices of said rings being capacitively coupled, whereby upon conduction of a given device preceding and succeeding adjacent devices which may be conducting are cut off, unidirectionally conducting means connecting each of said cathodes to the control electrodes of the preceding and succeeding devices in its ring, whereby upon conduction of a given device, a priming voltage is transmitted to the control electrodes of preceding and succeeding devices, a first transformer for each ring having a secondary winding for each device of the ring and a primary winding adapted to be energized by a counting voltage pulse, each of said secondary windings being connected in series with corresponding ones of said unidirectional conducting means between the control electrode of a device and the cathode of the preceding device, whereby upon receipt of a counting voltage pulse during the conduction of a given device the control electrode of the succeeding device receives said priming voltage in series with said pulse and said succeeding device is caused to conduct, a second transformer for each ring having a secondary winding for each device and a primary winding adapted to be energized by a subtracting voltage pulse, each of said secondary windings being connected in series with corresponding ones of said unidirectional conducting means between the control electrode of a device and the cathode of the succeeding device, whereby upon receipt of a subtracting voltage pulse during the conduction of a given device the control electrode of the preceding device receives said priming voltage in series with said subtracting pulse and said preceding device is caused to conduct, said first and second transformers for said second ring having saturable cores, first additional windings on said saturable cores adapted to be energized by a voltage sufficient to saturate said cores regardless of the presence of a voltage pulse on said primary windings, second additional windings on said saturable cores, means coupling the cathodes of first and second adjacent devices in said first ring to said first and second transformers of said second ring, respectively, so that upon receipt of a counting pulse causing conduction of said first device a pulse is applied to said second additional winding on said core of said first transformer of said second ring of a value sufficient, in the presence of said counting pulse, to desaturate said core and produce an output pulse on said secondary windings, and so that upon receipt of a subtracting pulse causing conduction of said second device a pulse is applied to said second additional winding on said core of said second transformer of said second ring of a value sufficient, in the presence of said subtracting pulse, to desaturate said last mentioned core and produce an output pulse on its secondary windings, whereby said first ring will complete one cycle of operation for each step of operation of said second ring.

2. A reversible counting chain, comprising, in combination, a plurality of counting devices arranged in an order of precedence from a first to a last device, each device having a control circuit and a load circuit, said load circuit having an energized or a non-energized state in accordance with the state of said control circuit, means coupling the load circuit of each device to the load circuits of preceding and succeeding devices, including couplings between the load circuits of said first and last devices, said couplings being effective upon the energization of a given load circuit to deenergize a preceding or succeeding load circuit which may be energized, non-linear coupling means connecting the load circuit of each device to the control circuit of preceding and succeeding devices, including couplings between the load and control circuits of said first and last devices, said non-linear

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coupling means being effective in the energized state of a device to prepare the control circuits of preceding and succeeding devices for changing the state of the load circuits of said last mentioned devices upon the receipt of a counting pulse, means for applying progressive counting pulses simultaneously to the control circuits of said devices in series with the non-linear coupling means between the load circuits of said devices and the preceding control circuits, and means for applying retrogressive counting pulses simultaneously to the control circuits of said devices in series with the non-linear coupling means between the load circuits of said devices and the succeeding control circuits.

3. In a reversible counting device, in combination, a first counting chain comprising a plurality of devices including a first and last device, said devices being sequentially operable in a first sense in response to progressive counting pulses applied thereto and sequentially operable in a reverse sense in response to retrogressive counting pulses applied thereto, means for applying progressive counting pulses to said devices, means for applying retrogressive pulses to said devices, a second counting chain comprising a plurality of devices sequentially operable in a first sense in response to progressive counting pulses applied thereto and sequentially operable in a reverse sense in response to retrogressive counting pulses applied thereto, first transformer means responsive to operation of said first device by a progressive pulse for applying said pulse to said second chain, and second transformer means responsive to operation of said last device by a retrogressive pulse for applying said retrogressive pulse to said second chain.

4. Reversible counting apparatus for counting over a predetermined number of orders of magnitude in a selected number system, said apparatus having for each order of magnitude a counting ring of electron discharge devices equal in number to the number of signs for each order in said number system, said devices having anodes, cathodes, and control electrodes, capacitive connections between adjacent anodes and between adjacent cathodes of said devices, first non-linear impedance means and a first coil connected in series between each cathode and the control electrode of the preceding discharge device, second non-linear impedance means and a second coil connected in series between each cathode and the control electrode of the succeeding discharge device, first means for applying voltage pulses in parallel to said first coils, second means for applying voltage pulses in parallel to said second coils, blocking means for each order of magnitude higher than the first for rendering said first and second pulse applying means ineffective, means responsive to conduction of the last device in a given order ring for overcoming the effect of said blocking means on said first pulse applying means in the succeeding order ring, and means responsive to conduction of the first device in a given order ring for overcoming the effect of said blocking means on said said second pulse applying means in the succeeding order ring, whereby each order ring completes a cycle of operation for each step of operation of the succeeding order ring.

5. In a counting device for reversibly counting over a predetermined number of orders of magnitude in a number system having a predetermined number of signs for each order of magnitude, a number of electron tubes for each order equal to said number of signs, each tube having an anode circuit, a cathode circuit, and a grid circuit, a source of direct voltage, two series charge resistances for each tube, one in the anode circuit and one in the cathode circuit, said anode and cathode circuits being connected to opposed terminals of said source whereby all of the tubes are fed from said source, anode capacitors located between anodes of consecutive tubes, cathode capacitors located between cathodes of consecutive tubes, preparation elements for applying to each grid circuit a potential forming an essential part of the

amplitude necessary to start each tube, and pulsing elements for applying an impulse to said grid circuits, the impulses from said pulsing elements co-operating with the potential applied to said grid circuits to successively control the progression or retrogression of the device.

6. A device as recited in claim 5, in which the preparation elements comprise members of asymmetric conductivity connected in an opposite way with respect to each other in each of the connections between cathodes and grids of successive tubes.

7. A device as recited in claim 5, in which the pulsing elements comprise windings connected in series with the connections between cathodes and grids, and in which these windings form independent secondaries of impulse transformer means fed by means for generating progressive or retrogressive impulses.

8. A device as recited in claim 5, further comprising a pair of magnetic circuits for each order of magnitude higher than the first, said circuit comprising a first winding fed in a permanent manner and bringing the point of operation of said circuit to rest in saturation, a second winding for each circuit, one of said second windings fed by a generator of progressive impulses and the order of said second windings fed by a generator of retrogressive impulses, a third winding in one of said circuits in series in the cathode circuit of the first tube of the series of tubes corresponding to the order of the magnitude under consideration, and a third winding in the other of said circuits in series in the cathode circuit of the last tube of the series of tubes corresponding to the order of magnitude under consideration, said previously recited pulsing elements for orders of magnitude higher than the first comprising a series of independent secondary windings in said magnetic circuits.

9. In a driving circuit for a reversible counting device having a plurality of reversible counting chains representing successive orders of magnitude in a predetermined number system, in combination, first and second transformers for sequentially actuating the first order chain, said transformers having a primary winding and output winding means, first pulsing means for applying progressive impulses to the primary winding of said first transformer, second pulsing means for applying retrogressive impulses to the primary winding of said second transformer, means connecting the output winding means of said first transformer to sequentially actuate said first order chain in a progressive sense, means connecting the output winding means of said second transformer to sequentially actuate said first order chain in a retrogressive sense, first and second magnetic circuit means for each order higher than the first for sequentially actuating the higher order chains, said circuits comprising a saturable core having a primary winding and output winding means, a first additional winding on each core adapted to be energized by a voltage exceeding by a predetermined amount the voltage necessary to saturate said core, a

second additional winding on the core of said first magnetic circuit responsive to completion of a progressive cycle of operation of the next lower order chain for applying a voltage sufficient to nullify part of said predetermined amount of voltage, a second additional winding on the core of said second magnetic circuit responsive to the beginning of a retrogressive cycle of operation of the next lower order chain for applying a voltage sufficient to nullify part of said predetermined amount, said primary windings for said first magnetic circuits being connected in parallel to said first pulsing means, said primary windings for said second magnetic circuits being connected in parallel to said second pulsing means, said primary windings being effective when pulsed to apply a voltage to said cores sufficient in the presence of a voltage from said second additional windings to desaturate said cores and apply impulses to said output winding means, said output winding means for said first magnetic circuits being connected to corresponding higher order chains for progressive sequential operation thereof, and said output winding means for said second magnetic circuits being connected to corresponding higher order chains for retrogressive operation thereof.

10. Apparatus of the class described, comprising, in combination, first and second impulse generators for supplying progressive and retrogressive counting impulses, respectively, a plurality of sequentially operable counting chains arranged to correspond to successive orders of magnitude, pulse transmitting means for each chain for applying impulses from said first and second impulse generators to said chains to effect sequential operation thereof in a progressive or retrogressive sense in accordance with energization of the first or second generator, transformer means for each pulse transmitting means but those corresponding to the first order chain for blocking the transmission of impulses, transformer means connected to each chain and responsive to completion of a progressive cycle of operation for rendering said blocking means for the next higher order chain ineffective to block a progressive impulse, and transformer means connected to each chain and responsive to the beginning of a retrogressive cycle of operation for rendering said blocking means for the next higher order chain ineffective to block a retrogressive impulse.

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