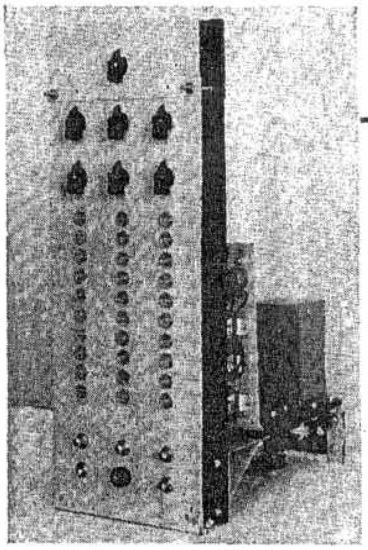

Complete three-decade counter comprising circuit of Fig. 4

Neon Diode

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DEVELOPMENT of the circuit to be described was prompted by the need for a simple and inexpensive counting device to replace the usual type of revolution counter which is subject to severe wear, particularly when it is frequently and rapidly reset to zero.

The high counting speed available in the relatively expensive flip-flop or ring counter using high-vacuum tubes is not required, and this feature makes possible the use of 0.04-watt or 0.25-watt neon glow-discharge tubes as the basic elements of the counter since de-ionization times of the order of several hundred microseconds can be tolerated. The counter uses glow-discharge diodes in conjunction with germanium crystal diodes, and employs capacitance coupling between stages. It thus offers a considerable advantage over an earlier circuit using glow-discharge tubes and employing transformer coupling between stages[1].

The circuit is capable of counting up to 30,000 impulses per minute. This rate is considerably in excess of that of any existing mechanical revolution counter or electromagnetic impulse register. Among the advantages of this circuit are essential simplicity, low cost, and small power consumption. The glow-discharge tubes serve not only as the basic elements of the counter, but inherently provide a visible indication of the count.

The circuit is basically a ring circuit, and while decades or rings-of-10 are discussed here, any even number of stages may be included in a ring. Any number of decades may be connected in tandem to make a counter which is capable of recording a total of 9, 99, 999, and so on, counts. Any such composite counter can be instantaneously reset to zero, presetting circuits can be added to set the counter to any required number before actual counting begins, and simple predetermining circuits can be added to detect the accumulation of any given number of counts within the range of the counter.

Principles of Operation

The basic circuit of an addition counter appears in Fig. 1. Each stage consists of a glow-discharge diode T, a crystal diode X, and a resistor R in series.

Suppose that each of the glow tubes ignites at a voltage v_i and operates at a lower voltage v_o. Suppose further that tube T_0 in Fig. 1 is conducting at time t_0 in Fig. 2. Current flows from the source of supply voltage through R_b, through X_0 in the forward direction, through T_0 and R_0 to the ground bus. The values of R_b, R_0 and supply voltage are so chosen that the potential of point b_1 is maintained less than the striking voltage of the glow tubes so that there is no tendency for any other tube to strike. Capacitor C_1 is charged as shown in Fig. 1 to the voltage appearing across R_0. Since S_t is normally open, C_t is charged as shown to the difference between the potential of the positive bus b_1 and the potential of the point p in the voltage divider R_x and R_y.

If switch S_t is closed the potential of p becomes zero instantaneously and the potential of the bus b_1 is depressed by an amount equal to the original potential of point p. This drop in the bus voltage is shown at time t_1 in Fig. 2, curve b_1. The bus voltage is made to drop below the operating voltage of T_0 with the

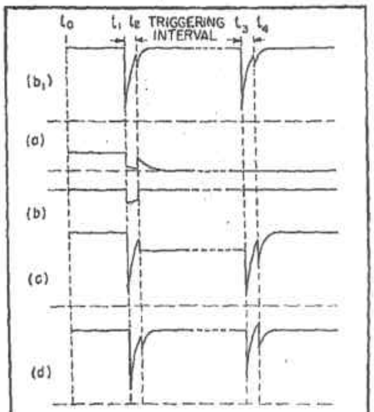


FIG. 2—Waveform of voltages at lettered points in Fig. 1

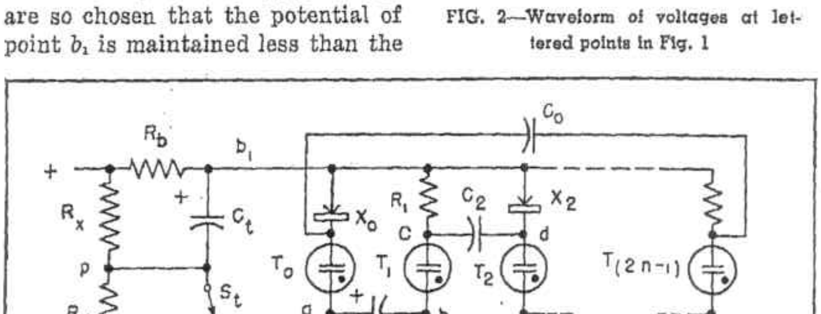


FIG. 1—Basic circuit of addition counter

Ring Counter

Relatively slow speeds up to 30,000 impulses per minute can be counted in ring circuits using neon tubes and germanium diodes. The counter can be reset instantaneously, presetting and predetermining circuits can be added and the counting action can be reversed to permit subtraction

result that T_0 is extinguished Then while S_t remains closed, capacitor C_t charges through R_b and the potential of b_1 increases exponentially toward the value of the supply voltage.

The time constant R_bC_t is made sufficiently long that the potential across T_0 remains below the operating voltage of the tube for an interval which allows its complete deionization. Meanwhile no one of the glow tubes is conducting and the discharge current of capacitor C_1 flows through R_0 and through X_1 in the inverse direction.

Voltage Distribution

Since the value of R_0 can be made much smaller than the inverse resistance of X_1, a large proportion of the voltage across C_1 appears across X_1. The resulting voltage wave forms at points a and b are given in the corresponding lines of Fig. 2. Thus while C_t is charging and the potential of the upper electrode of each glow tube is becoming more positive with respect to ground, the potential of the lower electrode of T_1 assumes a negative potential with respect to ground, and hence a greater voltage appears across T_1 than across any other tube.

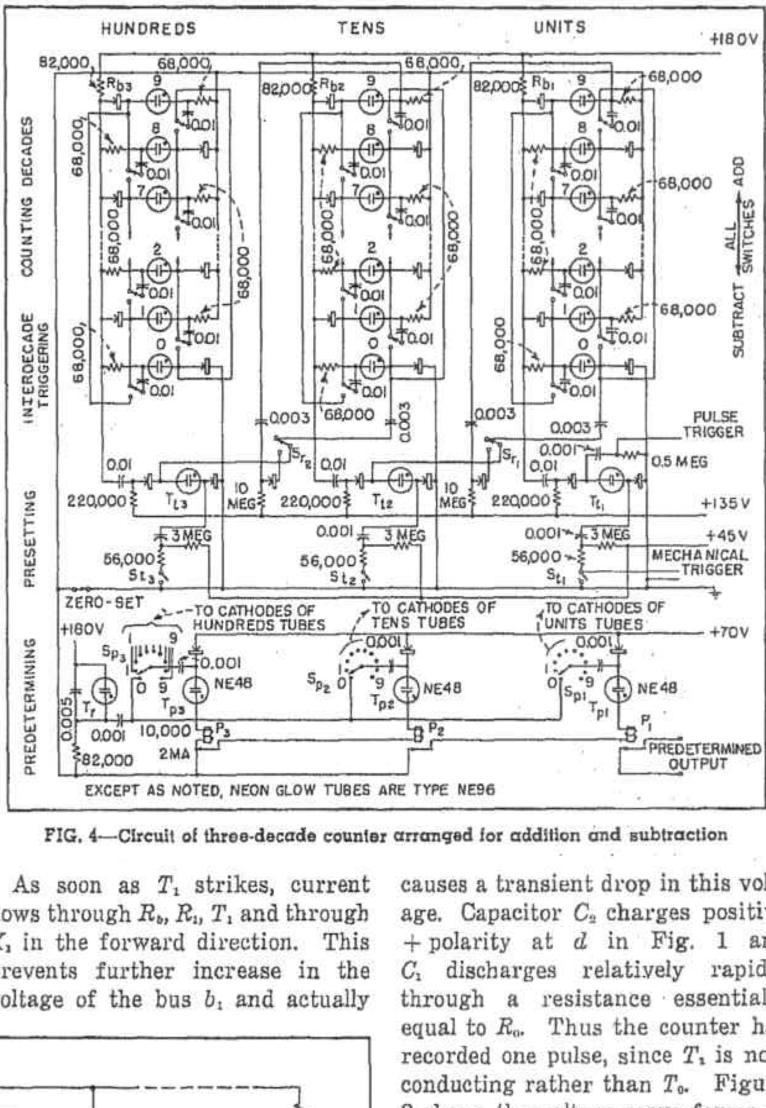


FIG. 4—Circuit of three-decade counter arranged for addition and subtraction

As soon as T_1 strikes, current flows through R_b, R_1, T_1 and through X_1 in the forward direction. This prevents further increase in the voltage of the bus b_1 and actually causes a transient drop in this voltage. Capacitor C_2 charges positive + polarity at d in Fig. 1 and C_1 discharges relatively rapidly through a resistance essentially equal to R_0. Thus the counter has recorded one pulse, since T_1 is now conducting rather than T_0. Figure 2 shows the voltage wave forms at significant points in the circuit. After switch S_t is opened, the potential of point p returns to its normal value.

Succeeding Cycles

If switch S_t is closed again after the normal potential has been restored at point p, the bus voltage is again depressed, as at time t_3 in

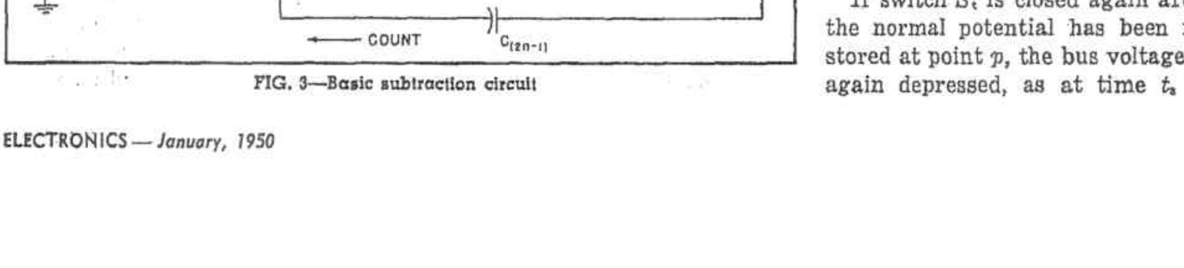


FIG. 3—Basic subtraction circuit

Fig. 2, and causes T_1 to be extinguished. Capacitor C_2 then discharges through X_2 in the inverse direction and through R_1. Hence as C_t charges again the positive potential of point d with respect to ground exceeds that of bus b_1, and the potential across T_2 exceeds that across any other tube. Hence T_2 strikes as shown at time t_4, and the counter has recorded two counts.

Each subsequent operation of the switch S_t advances the count one stage until tube T_{2n-1} becomes conducting. The next operation of the switch causes the ignition of T_0 again through the capacitor C_0 which closes the ring-of-$2n$. Value n may be any integer greater than unity, and if $n = 5$ the counter forms a decade or ring-of-ten.

The operation of the circuit depends essentially on two inherent characteristics of the circuit elements. The first of these is the difference between the striking and operating voltages of the glow tubes which insures that whenever any one of the tubes is conducting the potential across all of the others is maintained lower than the striking potential. Thus no more than one tube is conducting at one time and the count is unambiguous.

The second inherent feature of importance is the significant difference between the forward and backward resistance of the crystal diodes which allows each coupling capacitor to charge quickly whenever its corresponding tube is conducting, but which allows that capacitor to discharge only very slowly after its tube is extinguished.

Subtraction

An attractive feature is the essentially simple rearrangement of the coupling capacitors which will cause the circuit to subtract rather than add. Figure 3 shows the coupling capacitors rearranged and connected between the upper electrodes of T_0 and T_1, between the lower electrodes of T_1 and T_2, and so forth. Suppose that T_2 is originally conducting. Then when switch S_t is operated T_2 is extinguished, the lower electrode of T_1 becomes negative with respect to ground and T_1 strikes. Hence the count proceeds from right to left in the diagram and the circuit subtracts.

Figure 4 shows a complete circuit diagram of a three-decade counter in which a switch is used in each stage of each decade to alter the connection of the coupling capacitors. This switch may be either a gang of wafer switches with leads connecting it to the electrodes of the tubes, or preferably a long sliding switch which parallels each row of tubes to reduce the length of the connecting leads. In order that the circuit hold its count during transitions between addition and subtraction it is imperative that the fixed connection of each coupling capacitor be made at the resistor of one of the stages. This precaution insures that neither of the tubes adjacent to the one which is conducting before the switch is operated will be ignited by the operation of the switch.

Trigger Circuits

In addition to the trigger circuit shown in Fig. 1 and 3, the circuits of Fig. 5 may be used. That of Fig. 5A requires fewer components but must have a double-pole switch. This switch is normally closed on the upper contact and the charge on the capacitor C_t is then zero. If the switch is suddenly closed on the lower contact, the potential of the bus b_1 is depressed to zero and thereafter increases exponentially as C_t charges through R_b. The voltage waveform at b_1 is therefore essentially the same as shown in Fig. 2 except for the magnitude of the original depression. The triggering switch S_t in either this circuit or the one described previously may be actuated by a rotating shaft or by the motion of any mechanical member whose movements are to be counted.

For operation of the counter at speeds higher than those obtainable with moving contacts, such as in recording impulses from a photoelectric cell, the triggering circuit of Fig. 1 can be adapted to the use of a glow tube as shown in Fig. 5B. Switch S_t is replaced by a glow tube T_t. The potential across this tube is maintained normally a few volts less than its striking potential through the resistor R_z connected to an appropriate tap on the voltage divider R_x and R_y. Either positive voltage pulses injected at a or negative voltage pulses injected at b will cause tube T_t to strike. The potential of b_1 is thus depressed an amount equal to the difference between the original voltage at point p and the operating voltage of T_t, and thereafter increases exponentially as shown in Fig. 2 during a triggering interval.

The succeeding depression of the potential of b_1 which results upon the striking of the primed tube in the associated ring, such as is shown at t_2 or t_4 in Fig. 2 (b_1), is sufficient to extinguish T_t so that it is ready to respond to the next triggering impulse as soon as the normal potential at point p is restored. The crystal diodes X_{ta} and X_{tb} are employed respectively to increase and to provide the impedance across which the triggering voltage is developed. Two glow tubes may be used in series if desired to increase the initial depression of the bus voltage.

For counting speeds greater than about 150 cps glow tube T_t should be replaced by a thyratron such as a 2D21, which may be ignited by any convenient positive signal on its control grid, and which will be extinguished in the same manner as the glow tube. The time constant R_bC_t may have to be adjusted in

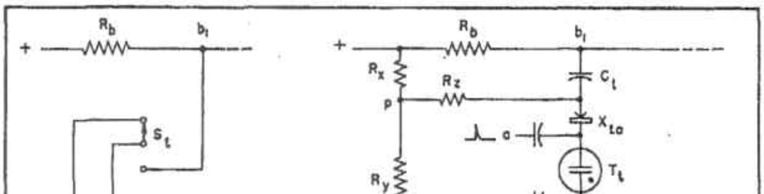


FIG. 5—Alternative trigger circuits

each of the possible trigger circuits to accommodate the particular value of the initial depression of the bus voltage. This initial depression is much less in the circuit of Fig. 5B than in that of Fig. 5A, and a longer time constant may be necessary to allow deionization of the conducting tube in the associated ring.

Complete Counter

The three-decade counter of Fig. 4 can be preset to any required number before input signals are applied, and can produce an output signal after the counter has reached any given number up to 999.

All the add-subtract switches within the three decades and the two interdecade switches S_{r1} and S_{r2} are ganged. These switches are shown in the add position. Note that glow-tube triggering circuits of the type shown in Fig. 5B are used to interconnect the decades. For example, when the counter is adding, positive signals are taken from the cathode of the 0 tube of the units decade to trigger tube T_{t2}, which in turn advances the count in the tens decade by one digit.

When the counter is subtracting, positive signals are taken from the cathode of the 9 tube of the units decade to trigger the tens decade. Similar considerations apply to the circuit interconnecting the tens and hundreds decades.

Since positive voltage pulses are used for interdecade triggering, the time constant of the interdecade coupling circuit connected to each 0 tube must be made sufficiently short that the falling edge of the waveform of Fig. 2B is effectively differentiated. In this way the rising edge, which follows later in time, can be used to supply the positive pulse required to ignite the triggering tube.

When interdecade triggering pulses are taken from the cathode of a 9 lamp, the rising edge of the waveform which results when the lamp ignites must be used as the triggering signal. However, after the 9 tube is extinguished at the following count, the waveform of Fig. 2A is generated, and in this case the falling edge, such as that shown at time t_1, must not be differentiated, else the rising edge, such as at time t_2, will again ignite the triggering tube. Hence the interdecade coupling capacitor associated with each 9 tube is connected in series with a crystal diode so poled as to increase the time constant of the coupling circuit on negative-going input pulses.

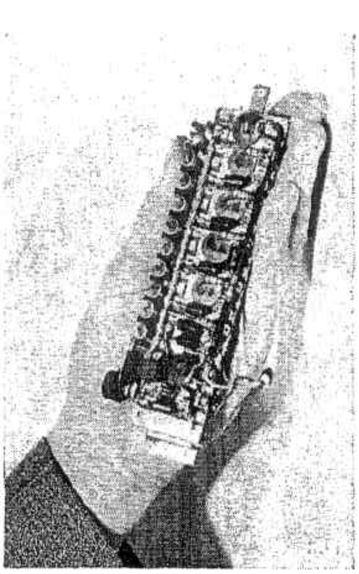
Switch-triggering circuits involving the switches S_{t1}, S_{t2}, and S_{t3} are provided so that each decade may be preset manually to any desired number before input pulses are applied. The resistance-capacitance networks associated with these switches apply negative voltages to the cathodes of the triggering tubes when the switches are closed. Each 0.001-μf capacitor is charged to 45 volts while the associated switch is open, and when the switch is closed, the cathode of the corresponding triggering tube becomes negative with respect to ground and the tube ignites from the capacitor discharge.

The time constant of the discharge of each of these capacitors is made sufficiently small that the discharge is essentially complete before the associated triggering tube is extinguished. This prevents the tube from firing a second time.

Predetermining

A very simple predetermining circuit is shown in Fig. 4. As noted previously the purpose of this circuit is to activate some external circuit or produce a signal when the counter reaches any desired number within its range. Such a signal might be required in a packaging process, for example, to halt the process after the accumulation of a given number of units. Three 0.25-watt neon glow tubes T_{p1}, T_{p2} and T_{p3} are arranged as shown, each in series with the operating coil of a sensitive relay.

Suppose that the circuit is to detect the number 123. The switches S_{p1}, S_{p2} and S_{p3} would be set to connect the anodes of the three predetermining tubes through their coupling capacitors to the cathodes of the tubes 1, 2 and 3 of the hundreds, tens and units decades respectively. The coupling capacitors are sufficiently small that waveforms of the type shown in Fig. 2B are differentiated and hence positive pulses are always available to



Relative size of a single decade

trigger the predetermining tubes.

The anodes of the predetermining tubes are connected to a source of voltage which is a few volts below their striking voltage, but only the relay in series with tube T_{p3} is permanently connected to ground. Tube T_{p2} cannot be ignited until the relay in series with T_{p3} operates, and T_{p1} cannot be ignited until the relay in series with T_{p2} operates. Hence at the instant the counter records the number 100, T_{p3} is triggered by the positive pulse from the cathode of the 1 tube in the hundreds decade. Relay P_3 then closes and primes tube T_{p2}.

After 20 more pulses T_{p2} is ignited by the positive pulse from the cathode of tube 2 in the tens decade and relay P_2 operates. Similarly after three more pulses, relay P_1 operates and generates the required predetermining signal.

Special provision must be made in order to obtain a predetermining pulse after a number such as 100, or more specifically, after any number containing the digit 0.

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Bibliography

United Kingdom Patent Specification 436,420.

C. E. Wynn-Williams, The Use of Thyratrons for High Speed Automatic Counting of Physical Phenomena, *Proc. Roy. Soc.*, 132, p 295, 1931.

C. E. Meinheit and W. W. Snyder, Electronic Counter and Divider Circuits, *Sylvania Technologist*, 1, p 5, July 1948.