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TECHNICAL REPORT

A GAS DISCHARGE DECADE COUNTER TUBE FOR ACCOUNTING MACHINE APPLICATIONS

by

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ABSTRACT: This paper describes the IBM 78 self-complementing counter, which has been specifically developed for use in accounting machine accumulators. Its basic operating principles are explained. The physical arrangement of parts and general construction details are shown. There is also a discussion of the basic circuit in which the tube is operated, giving optimum values of circuit elements, operating voltages, and allowable variations of these voltages. In addition, factors determining operational reliability are listed, as well as information gained from life test data.

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INTRODUCTION

In recent years a strong need has arisen for an electronic counter which is faster and less costly than the mechanical and electro-mechanical types now employed in accounting machines. The use of a cold-cathode glow discharge that can be stepped along from one electrode to the next has been widely recognized as a possible solution to this problem, and several descriptions of counter tubes of this category have already appeared in the literature.[1-10] In at least one instance a complete computer has been assembled with gas-tube counters as the basic arithmetic and storage elements.[11] Also, some of the more important schemes by which a glow can be caused to step along have been summarized and explained.[12]

The counter tube to be described differs from previously known tubes in several important respects. For one thing, the transfer of the glow in the desired direction is secured mainly through the use of cathodes comprised of two different materials, although appropriate cathode configuration, cathode coating, and judicious shielding from mica supports are used as additional factors to insure positive operation over a wide range of parameters. The mechanical design of the tube has been worked out so that the entire structure fits into a standard size T-6-1/2 miniature bulb, and the position of the glow may be readily determined by viewing the tube from the side. Further, the tube contains a "self-complementing" feature whereby the digit stored in the tube may be transposed to its 9's complement (its value subtracted from 9) by the application of a single pulse to an appropriate set of cathodes.

Since the tube has been intended for accounting machine applications, the prime factors affecting the design have been simplicity of operating circuits, reliability, and long life. The design and development of this tube was carried on at IBM's Poughkeepsie laboratories, and the tube has been given the designation IBM 78.

ARITHMETIC OPERATION

In accounting machine applications it is usually a requirement that the counter system be capable of both addition and subtraction. Probably the most obvious way to gain both of these functions is through the employment of counters which are capable of counting either forwards or backwards.

Although many different counters possessing this property have been designed, it turns out to be surprisingly difficult to make effective use of them. The difficulty arises not only from the fact that the counters themselves tend to be complicated but also from the fact the "borrow" signal which is sent from one counter to the next when subtracting is not obtained in exactly the same way as the "carry" signal when adding. Another similar, but somewhat more subtle, difficulty is encountered when negative b alances are considered. The exact nature of this latter difficulty depends upon the details of the design of the counter system, but in general it may be said that the read-out of a negative balance, which will appear in complement form in the counters, can be accomplished only by changing the points from which the output signals are taken or by changing the timing of the system (plus operating the counters in reverse).

Subtraction has been made simpler in many machines by using counters which will count in one direction only and by creating the effect of subtraction by adding the 9's complement of the number to be subtracted. Here, the "9's complement of a number" means the number obtained by subtracting each individual digit in the original number from 9. Since this system is not used with the tube to be described, it will not be explained further. It will be only mentioned that the change from true to 9's complement for entry into the counters is not always simple, and the problem of obtaining all balances in true form, whether they are positive or negative, becomes severe.

With the self-complementing counter, both the operation of subtraction and the read-out of all balances in true form are accomplished readily with a minimum of extra equipment. For subtraction, the number initially stored in the counters is transposed to its 9's complement representation and the number to be "subtracted" is then added in the usual fashion but with an "end-around" carry if necessary. If the difference is positive, the result will appear in 9's complement form but it may be readily converted to true form by a second complementing action of the self-complementing counters.

To illustrate the process, assume that the number 0785 is stored in a four-digit accumulator and that 0493 is to be subtracted from it. By the application of a single pulse to all of self-complementing counter tubes 0785 is converted to its 9's complement, which is 9214. The number 0493 is then added (no end-around carry occurs in this example).

$$\begin{array}{r} 9214 \\ \underline{0493} \\ 9707 \end{array}$$

The result, 9707, is the 9's complement of the correct answer, 0292, which can be obtained by applying a second complementing pulse to the counters. If, instead, the number to be subtracted from 0785 had been 0905 the following result would have been obtained (with an end-around carry this time).

$$\begin{array}{r} 9214 \\ \underline{0905} \\ 0119 \\ \underline{1} \\ -0120 \end{array}$$

The result, 0120, is the true representation of the difference, which is negative in this case. The end-around carry may be obtained from the carry signal in the highest-order counter, and it is not difficult to show that the presence or absence of this carry can be used as the indication of negative or positive balance, respectively.

DESCRIPTION

The basic counting process in the gas-discharge counter may be explained with the aid of Fig. 1. Here are represented four hollow, cylindrical cathodes K_1, K_2, K_3, and K_4 of which K_1 and K_3 are connected together and grounded, while K_2 and K_4 are connected to an external lead C. Attached to these cathodes are the transfer wires T_1, T_2, T_3, and T_4, respectively, each having a work function higher than that of the cathodes; a common anode A is equally spaced from each of them. This array is in a sealed envelope containing a gas at a pressure which will insure that the voltage required to start a glow discharge will be considerably higher than the voltage necessary to maintain the glow once it has been started. The positive terminal of a suitable power supply is connected through a series resistance R to the anode and the negative terminal is grounded. If a glow discharge is then established between K_1 and the anode, the following operation can be effected. When a voltage source initially positive with respect to ground is connected to C and is reduced to a value negative with respect to ground, sufficient voltage will exist between K_2 and K_4 and the anode to maintain a glow discharge on T_2 or T_4. Since the free end of T_2 extends into the ionized region between K_1 and the anode, a glow will begin on T_2 and not T_4 or any other transfer wire because of the high density of ions in the region of K_1 will reduce the initiating voltage for T_2. As the voltage becomes more negative this glow will spread until it covers the entire surface of T_2. Additional voltage change will force the glow to spread onto the main body of K_2, and since the outer surface is covered with an insulating material, the glow will locate on the inside surface of the cylinder. The cylinder material has a lower work function than that of the transfer wire with the result that when the glow reaches K_2, the voltage drop between K_2 and the anode will be less than the voltage required to maintain a glow on T_2. Therefore, the glow on T_2 will be extinguished. Further change of the voltage on C will be accompanied by a decrease in the anode voltage, since the voltage difference between the anode and K_2 will remain essentially constant. This action will result in reducing the voltage between K_1 and the anode to a value less than its sustaining voltage. Therefore, the glow on K_1 will be extinguished also. If the voltage applied to C is now allowed to return to its original positive value, the anode voltage will rise with the voltage on K_2 until it is of a sufficiently positive value to maintain a glow on T_1 or T_3. This time, the tip of T_3 will pick up the glow because it is in an ionized region and from there it will spread into K_3 and leave T_3 for analogous reasons. The anode voltage will now be stabilized at a potential above ground equal to the drop from the anode to K_3. Further positive increase of the voltage on C will decrease the voltage between the anode and K_2 until glow on K_2 extinguishes.

If K_1 is called the ZERO position and K_3 the ONE position, and if a negative pulse of voltage of sufficient duration is applied to cathodes K_2 and K_4 at C, the glow, will "count" the pulse by moving from K_1 to K_2 to K_3. By interspacing ten digit cathodes and ten "intermediate" cathodes so as to extend the configuration in the form of a closed loop, a ten position counter can be constructed.

There is a great range of choices which may be made for the gas and the cathode materials which may be used in a counter of this type. It has been found that platinum transfer wires and aluminum cathode cylinders, anodized on the outside surface, together with pure argon gas at a pressure of 70 millimeters of mercury will yield a reliable and long-life tube at counting speeds up to 2000 pulses per second.

In the IBM 78, ten additional cathodes are added to the array to provide the self-complementing function and are referred to as "complementing" cathodes. A top view of the counter in schematic form is shown in Fig. 2. The circles represent the thirty cathodes, and the straight, solid lines are their associated transfer wires. The dotted lines show the electrical connections between the intermediate cathodes (labelled I) in one case, and between the complementing cathodes (labelled C) in the other. The digit cathodes are numbered as shown. Positions 1 through 8 are commonly connected to an external lead, and 9 and 0 are separately connected to two additional leads. It can be seen that a glow starting from "0" will travel up the right-hand row of cathodes, over the top, down the left-hand row and around the bottom to its starting position when ten negative pulses are applied to the intermediate cathodes. The figure also shows that each digit cathode is located directly opposite its 9's complement digit cathode, and between each such set is a pair of complementing cathodes with transfer wires so arranged that a glow can be transferred from one digit position to the other in either direction upon application of a negative pulse to these complementing cathodes. This tube is thus able to convert a true digit to its 9's complement and vice versa, in addition to functioning as a decade counter.

The photograph of Fig. 3 shows the construction of the counter. U-shaped cathodes are fastened to mica support plates which are then sandwiched to form the desired array. A wire mesh anode is located above this assembly, and the entire unit is mounted on a standard nine pin miniature button base and sealed into a T-6-1/2 glass bulb. The result is a tube 7/8 inch in diameter with an overall length of 2-5/8 inches.

BASIC CIRCUIT AND ELECTRICAL CHARACTERISTICS

Fig. 4 shows the symbolic representation of the counter tube in its basic operating circuit. V_1 and V_2 represent the driving tubes for counting and complementing, respectively. Any type of tube may be used in either position as long as it is capable of driving the cathodes to which it is connected to the required voltage level when in full conduction. Resistors R_1 and R_C must be inserted as shown when the plate voltages of the drivers during conduction are lower than the voltages to which the connected cathodes must be driven, as determined by the remainder of the circuit. The voltage divider formed by R_1 and R_2 establishes the potential (E_1) at which the intermediate cathodes are held between driving pulses. R_3 and R_4 act similarly in the complementing circuit (E_C). For best results, E_1 and E_C should be the same, and the driving pulses applied to the intermediate and complementing cathodes should have equal amplitudes. Switches S_1 and S_2 are used for resetting the glow to its zero position. S_1 is first opened to extinguish the glow if it is in any position but zero. S_2 is momentarily closed to apply the full anode supply voltage between the anode and zero cathode and thus establish a glow there. Then S_1 is closed again. An output signal is available from the "9" cathode for carry initiation, and the read-out signal is taken from the "0" cathode.

Some typical values of resistance and voltage for this circuit are as follows:

R_A	= 68 K ohms
R_K	= 36 K ohms
R_1, R_3	= 680 K ohms
R_2, R_4	= 390 K ohms
R_1, R_C	= depend on driver tubes used
E_A	= 500 volts
E_K	= 135 volts
Driving pulse	= 100 volts (negative)
Output pulse	= 70 volts

The voltage required to initiate a glow discharge within a tube (breakdown voltage) is from 325 to 450 volts, while the voltage drop across such a discharge, (sustaining voltage), is 150 volts.

An average tube, operating in this circuit with the values listed, will count reliably over relatively wide potential variations. Some examples, based on the variation of one parameter at a time include:

Voltage across tube (E_A - E_K)	315 to 405 volts
Output voltage (depending on E_A - E_K)	57 to 88 volts
E_1 and E_C (with respect to E_K)	15 to 75 volts
Driving pulse amplitude	60 to 110 volts

The operational reliability of this tube is primarily determined by the magnitude of the difference between the voltages required to cause a glow transfer in the backward and forward directions. In the circuit illustrated and with the component and voltage values as listed, typical transfer voltage values are as follows:

(a) A forward direction glow transfer from a digit cathode to an intermediate or complementing cathode will occur when the latter has been driven down to 120 volts. In the absence of such a transfer, a backward direction movement of the glow will not occur until this voltage has been further reduced to 25 volts.

(b) A forward direction glow transfer from an intermediate or complementing cathode to a digit cathode will occur when the voltage on the former has risen to 175 volts at the end of a driving pulse. In the absence of a forward transfer, a backward transfer will not occur until this voltage has further increased to 320 volts.

TUBE LIFE

Life tests were conducted with fifty experimental tubes, and thirty-three of these were still operating satisfactorily at the end of 14,000 hours. These tests were designed to determine the effect of several types of operation of tube life, and the following conclusions can be drawn from the results:

(a) Most failures have been caused by the sputtering of cathode material which eventually builds up conductive deposits on insulator surfaces.

(b) Counting accuracy during useful life is very high.

(c) Reliable counting occurs in response to minimum duration driving pulses spaced as much as 6-1/2 days apart.

Significant improvements in processing of cathodes have been made since the manufacture of the tubes used in the life tests. These improvements have resulted in retarding the sputtering of cathode material to a point where it is expected that the average life of the tubes will be appreciably extended.

SUMMARY

The IBM 78 was developed specifically for use as a counter in accounting machines. It may be used with relatively simple external circuitry to add, subtract, and store a decimal digit, and to read-out in true number form both positive and negative balances. The maximum operating speed is 2000 counts per second. Reliable counting can be obtained over relatively wide ranges of variation of applied voltages. Results of life tests, and subsequent

improvements in processing, indicate expected lifetimes in excess of 5000 hours under normal accounting machine use.

ACKNOWLEDGEMENT

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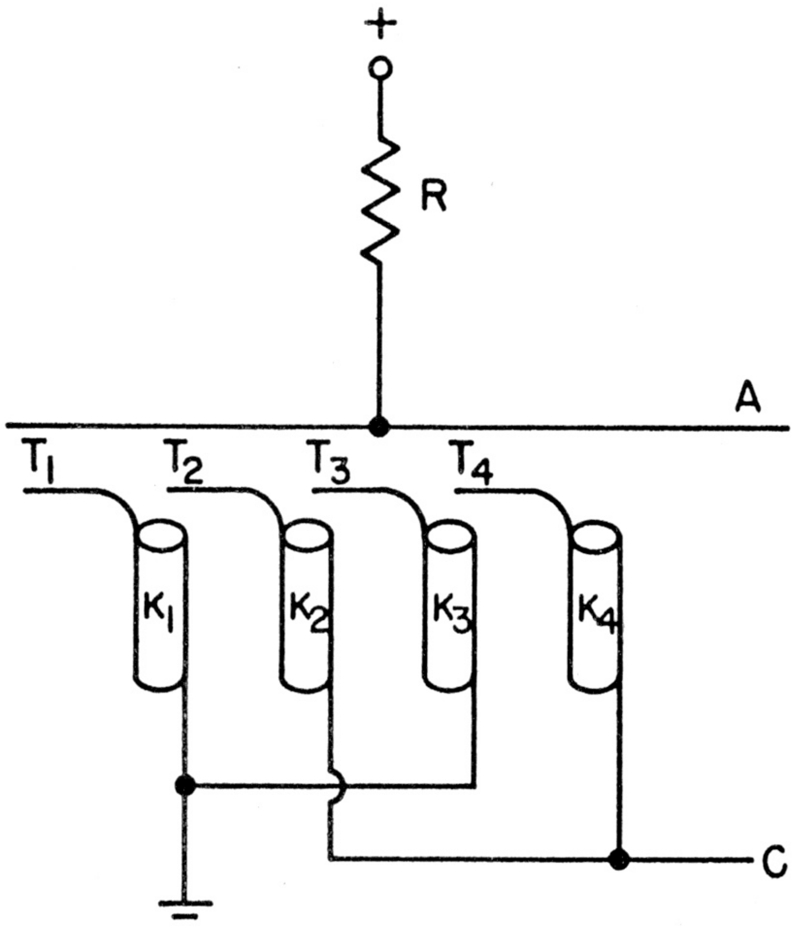
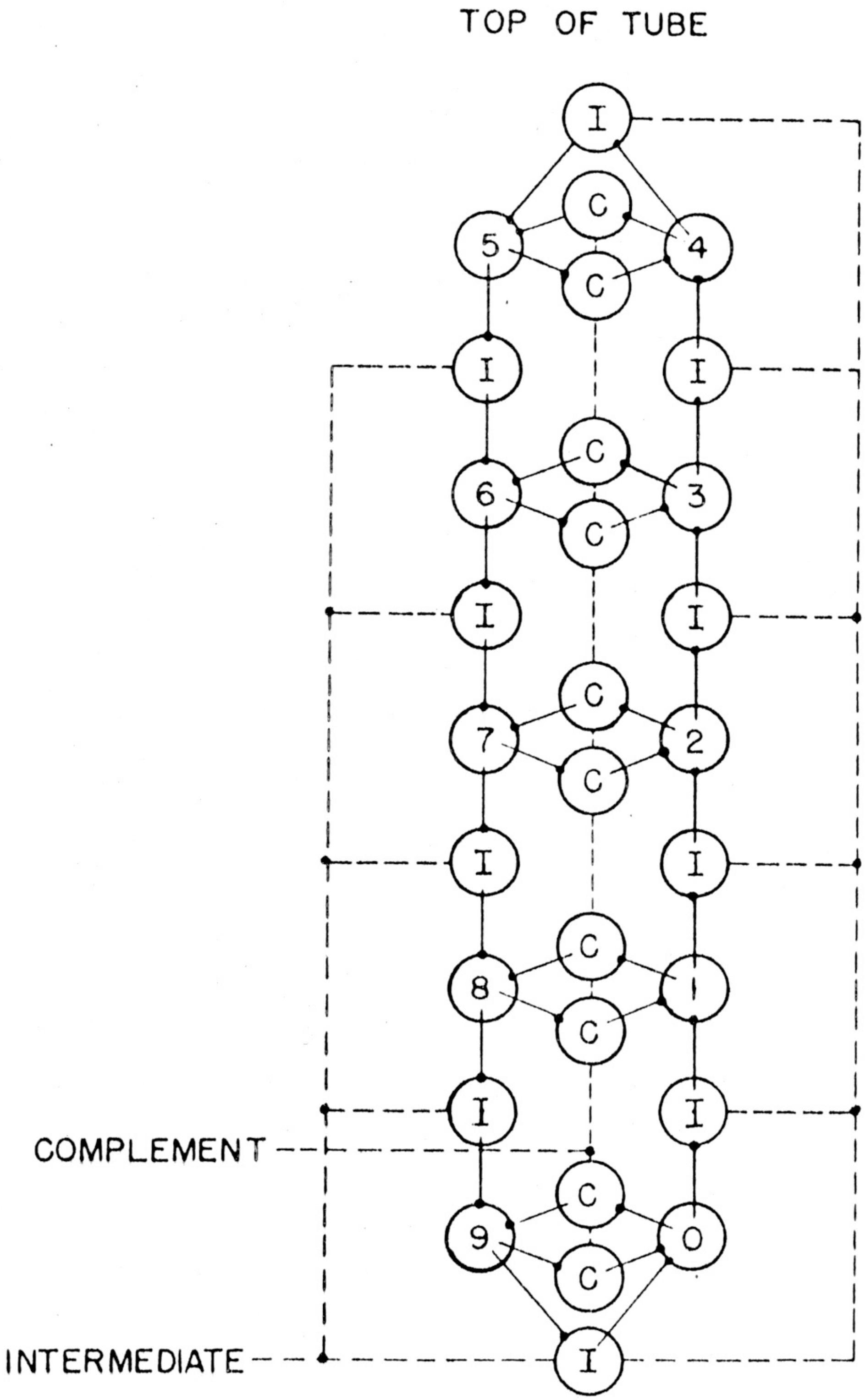


BASIC CATHODE CONFIGURATION

FIGURE 1



TOP VIEW OF ACTUAL CATHODE ARRANGEMENT

FIGURE 2

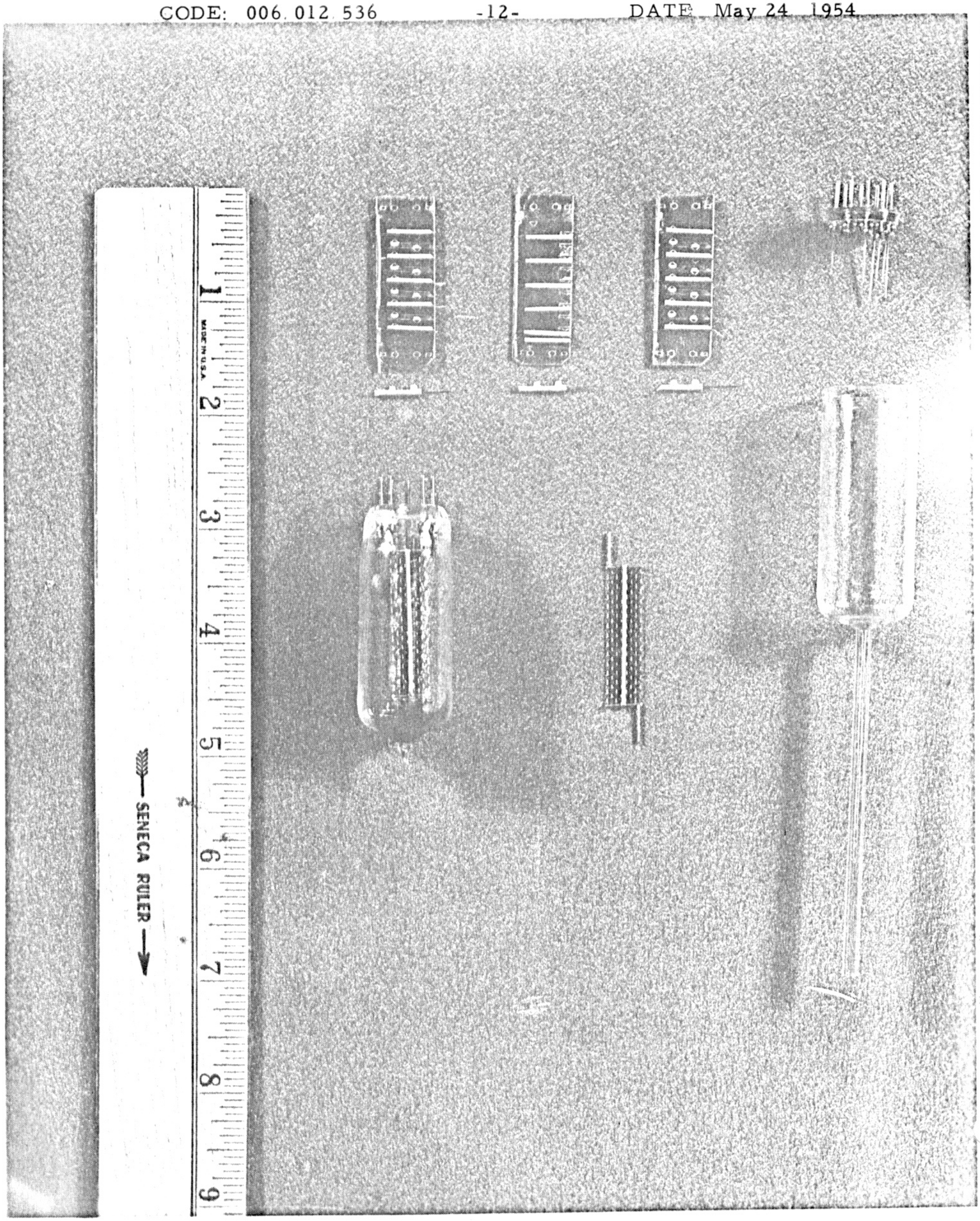
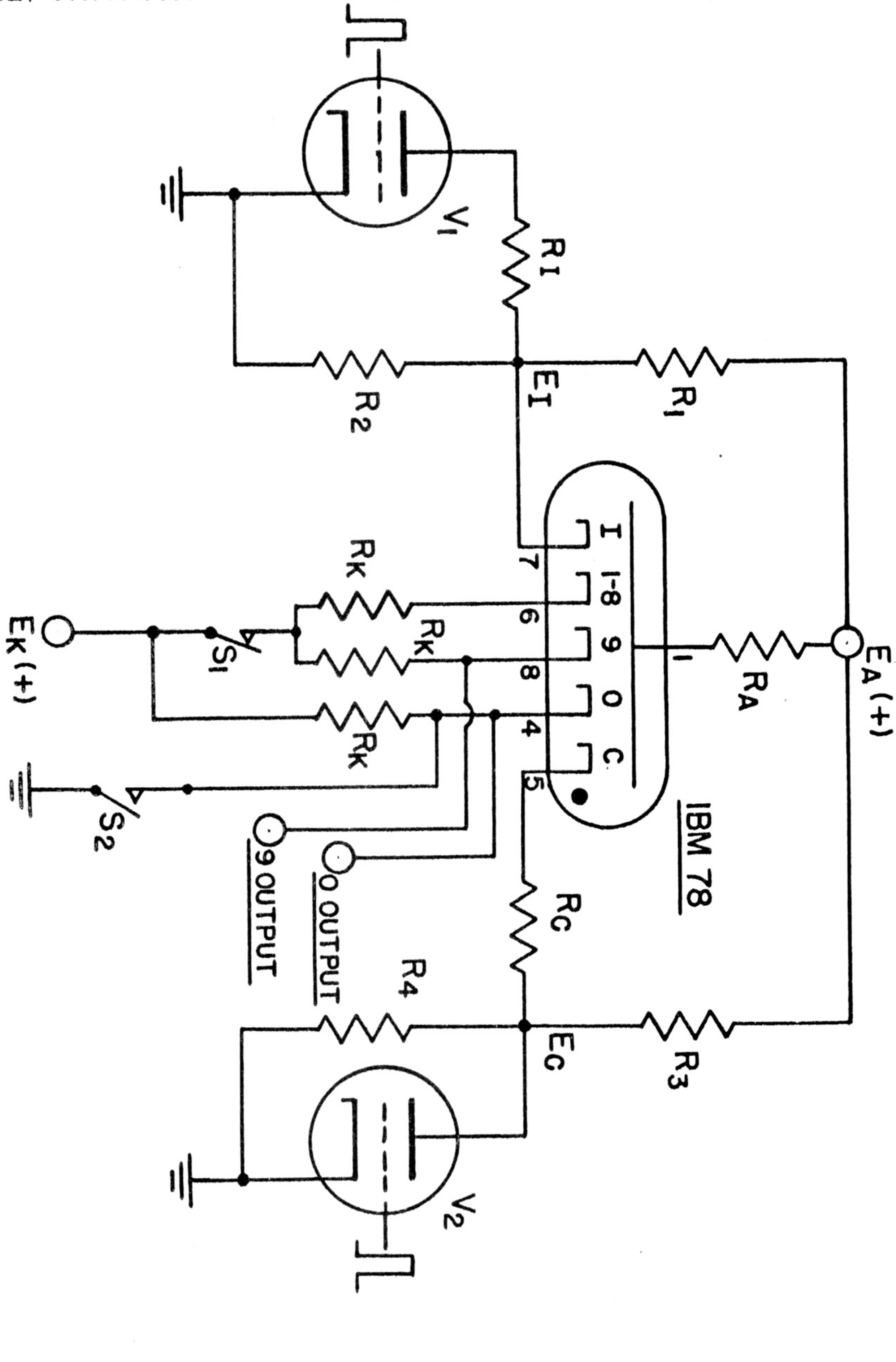


FIGURE 3



BASIC OPERATING CIRCUIT

FIGURE 4