Spring 5-31-1962

Counter Circuits Using Gaseous Discharge Tubes and Rectifiers

Robert Creveling

CREVELING — COUNTER CIRCUITS

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COUNTER CIRCUITS USING
GASEOUS DISCHARGE TUBES AND RECTIFIERS

A Thesis
Presented to
The Faculty of the Graduate School
University of New Mexico

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in Electrical Engineering

by
Robert Creveling
1952

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

E F Castetter
DEAN

5/31/52
DATE

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Ralph W. Tapy
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CHAPTER I

INTRODUCTION

This thesis pertains to an electric circuit consisting of gaseous discharge tubes and rectifiers arranged to comprise a counting or integrating device for electrical impulses impressed on the system. The ideas presented herewith are wholly those of the author and were submitted in the form of a patent application via the New Mexico School of Mines in June of 1950. The basic idea for such a circuit was conceived on November 14, 1949.

The author has attempted to produce a simplified counting circuit which may be compactly arranged. The ultimate device is visualized to occupy the space of a miniature tube in contrast to a strip containing 5 tubes and the associated electronic components, as is now the usual method for decade counters. Certain adaptations of the counting circuits unfold an entirely new concept of counting. In place of a decimal form of counting a coded form is described. While only an indication of the possibilities is revealed here, no doubt a complete mathematical theory could be developed.

Various forms of the basic circuits have been tried and made to work, but the various limitations such as

counting rates, effect on reliability with tube aging, temperature and light changes, are not yet fully established. Readily available components were used for the experimental circuits and in spite of the known inadequacies of the components the circuit was made to function. It is believed that complete reliability and usefulness may be realized with proper design and selection of components. Counting speeds up to 100,000 counts per second may be expected with deionization times of gaseous discharge tubes of the order of 10 microseconds.

In a preferred form of the circuit the gaseous tubes are paired to reduce the number of rectifiers needed, moreover, this offers certain advantages, such as an increase in counting speed and a wider range of variation of the starting voltages of the gas discharge tubes. The basic circuit is in the form of a ring and makes possible the use of gaseous discharge tubes, such as 1/25 watt neon glow tubes, (NE-2, for example), as basic elements of the counter. In addition, they indicate the count. The direction sense of the counter is derived from the use of rectifiers such as the dry disk type selenium rectifier.

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rectifiers are essentially constant voltage drop devices in the forward direction and have a high resistance in the reverse direction. The fact that the starting voltage of a well-aged gaseous type tube used at reduced current is quite constant and appreciably higher than the operating voltage is also used to advantage.

The glow discharge tube may be concentrated into one envelope, and hence become a single tube with multi-elements. In this form, in addition to compactness, since all the elements may be produced to the same specifications and operate under identical conditions an inherent consistancy will result. For example, the elements would be in the same gas "atmosphere." A further advantage would be provided by virtue of the proximity of the glow discharge of the preceding electrode to the electrode next in line so as better to determine the proper transfer of count. The element adjacent to the glowing element in the "wrong" direction is held sufficiently low in voltage so that it will not count out of turn, whereas the second one in the progressive direction has a voltage fairly close to the favored one. This form of a tube will also be useful in conventional counting circuits for indicating visually the count in place of four or ten tubes per decade as is generally done.

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The main objective of the circuits described herein

is to provide a simple, inexpensive counting device with a relatively fast counting rate. Vacuum tubes are dispensed with, or their use is kept to a minimum, with a resulting saving in cost and power consumption. In the present art of electronic counting, the decade systems using the Eccles-Jordan orthyratron ring type circuits require four or more tubes with the associated components. This is expensive circuitry compared with the proposed system.

Only a few of the many possible combinations of tubes are discussed in this paper. Tubes may be connected to form stages such as a count of ten. Any number of stages may be used in tandem to make the counter capable of recording various number systems. Thus, using decade groups, a decimal system may be established. The counter can be arranged to be set to zero or to any desired value by presetting circuitry. Also predetermining circuits can be added to detect the accumulation of any given number of counts within the range of the counter. It can be seen that this system can be used as a predetermined limiting counter, such as those used in packaging machinery. In addition, this device has utility as a frequency divider, in electronic devices such as television synchronization circuits. Further applications are possible in time interval control, automatic machine control, lineal measurements, and frequency measurements, to list a few. It is also

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possible to trigger the circuits from the same source and to operate the stages together. With the appropriate number counts in each stage and a suitable means of detecting the coincidence of certain tubes conducting current a unique counting system may be produced. This type of operation may be thought of as a form of coding. The big advantage of such a system is the elimination of interconnections between the various stages since they are all operated from the same input signal.

The system may be made to subtract (or count backward) by reversing the rectifier units either physically through a switching arrangement or by use of triodes used in pairs and connected in opposite directions. The desired triodes may be made active rectifiers in the desired direction by proper application of a grid sensitizing voltage.

The object of the described circuit may be summed up briefly as follows:

1) to provide a simple means of counting rapid or random impulses in any numbering system and visibly registering that count.
2) to make possible a self-setting counter which can be reset to zero or a predetermined value.
3) to provide an electronic device which will yield one output impulse in response to the

accumulation of each predetermined number of input impulses.

4) to provide a means of either adding or subtracting counts as desired.

Before discussing the circuit it would be well to consider the characteristics of the two prime components, namely, the gas discharge tubes and dry disk type rectifiers.

CHAPTER II

CHARACTERISTICS OF GASEOUS DISCHARGE TUBES

Gaseous discharge tubes, known commercially as Glow Lamps, are used in the counter described because in addition to serving as indicators, they have characteristics which permit their use as a prime component of the counter circuits. The characteristics of the devices which make them suitable are that the tubes break down at a critical starting voltage and then operate at a lower voltage, and, with nominal current flowing, give rise to a visible radiation of light. In the case of the smallest neon glow lamp normally available (the NE-2, 1/25 watt), the breakdown voltage is of the order of 90 volts while the operating voltage is approximately 57 volts. It might be well to discuss the characteristics of a gas-filled cold cathode diode to illustrate the general principles involved.[1] Refer to Figure 1. As the voltage is increased across the tube there is a flow of current which is made up of the residual ions present between the two electrodes. The availability current is soon reached at point "a" with the application of a small amount of voltage. A further increase in voltage does not increase the current until point

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[1] Reich "Theory and Application of Electron Tubes" page 366, McGraw-Hill Publication.

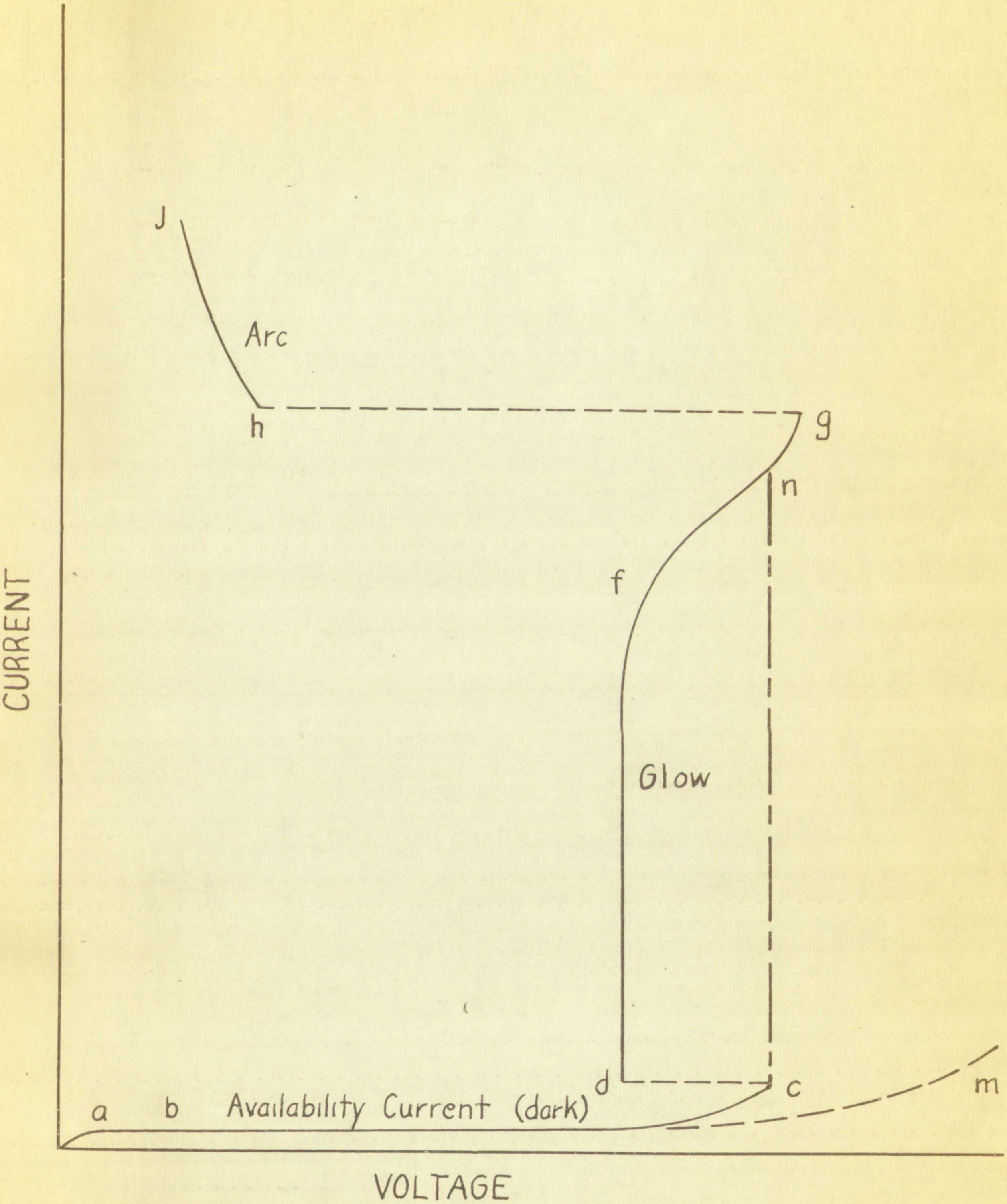
J
Arc
h
g
n
f
Glow
d
c
m
a
b
Availability Current (dark)
CURRENT
VOLTAGE

Fig. 1

"b" is reached. Then, as the voltage is increased, the current will rise slightly. If the electrode spacing is very small and the pressure sufficiently low, the current can be increased beyond "b" only by increase of voltage, and the characteristic is of the form shown by the dashed curve "bm." With electrode spacing and pressure used in most glow-discharge tubes, on the other hand, a current is reached at "c," called the threshold current, at which the current begins to rise abruptly without further increase of voltage. The current up to the threshold current is only of the order of one or two microamperes; it is greatly exaggerated on the figure for the purpose of illustration. If the external circuit resistance is low, the voltage of the discharge remains practically constant, and the current jumps to a high value corresponding to "n." If the external circuit is such as to prevent the current from rising abruptly, then the voltage drops abruptly to some lower value, as at "d." This is the type of operation that will be employed in the counting circuits under consideration. The value of the current at "d" and the path along which the charge takes place, appear to depend almost entirely upon the external circuit. As the current is increased the voltage will increase slightly until the value shown at f is reached. Beyond this point a much larger increase in voltage is required to produce a given change

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in current. In the vicinity of g, however, the current is so high that if maintained for an appreciable time the cathode becomes hot enough to emit electrons. The thermionic emission reduces the voltage drop through the tube and the point h reached where the discharge becomes an arc. Unless limited by circuit resistance, the current may then rise to destructive values as the point j is approached in the cumulative action of increasing emission with increasing temperatures. The discharge will become an arc and the current will be quite large and capable of producing destructive effects to the electrode which is heated to produce the emission necessary to satisfy the current demands.

The threshold current (corresponding to the breakdown voltage) will depend on many factors such as the size and shape of the electrodes, particularly the cathode (negative), the material coating, and the gas used.[2] While normally the breakdown is designed to be of the order of 100 volts it may be as high as 400 volts or as low as 37 volts[3] depending on the various factors involved.

Aging of the glow lamp for about 100 hours at normal current will cause it to yield more constant and

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[2] J. Slepian and R. C. Mason, "Electrical Engineering," pp 53, 511, (1934).

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The threshold current (corresponding to the break-down voltage) will depend on many factors such as the size and shape of the electrodes, particularly the cathode (negative), the material coating, and the gas used.[2] While normally the breakdown is assigned to be of the order of 100 volts it may be as high as 400 volts or as low as 37 volts[3] depending on the various factors involved.

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reproducible starting and maintaining voltages. The life at normal currents is of the order of 25,000 hours (3 years) and then only the respective voltages are increased slightly and the tube becomes somewhat darkened. If the current load is reduced the useful life of the tubes is increased materially. Since the life varies inversely with the cube of the current, a reduction in the current of 50% will yield an increase in life of eight times. Thus, in the usual case, the life of the tube will approximate a quarter of a century.

The glow lamp, when conducting, can be considered in an electrical circuit as the equivalent of a constant arc drop in series with an internal resistance.

The following equation shows the relation of the tube current to the voltage and resistance values

$$I = \frac{V_b - V_m}{R_i + R_e}$$

where I is the lamp current, V_b the line voltage, V_m the minimum maintaining voltage, and $R_i + R_e$ the internal and external resistance respectively. In the case of the NE-2 (½ watt) glow lamp operating on 117 DC with 200,000 ohms limiting resistance

$$I = \frac{117 - 55}{6,000 + 200,000} = 0.3 \text{ milliamps}$$

The glow lamp has certain limitations which should

be considered. There is a certain response speed both in the establishment of the glow discharge by ionization and in extinguishing of the arc.[4] The breakdown voltage will be lowered somewhat when the lamp is exposed to light, due to photo-electric effect. However, ambient temperature changes from normal up to 300°F have little effect on the tube characteristics. It thus becomes apparent that the glow lamp offers possibilities of becoming a prime component of a counting circuit as well as an indicating device. All one must do is arrange a multiplicity of the two element lamps in a circuit so that they can be made to carry current when it becomes their turn. This means that the tubes must be readied in a systematic fashion so that when the proper trigger is supplied the correct tube will break-down and carry the load, thus relieving the tube formerly carrying the load. In order to furnish this sense of direction rectifiers may be used in ring circuits.

For this particular application, as will be seen later, it would be highly desirable to have a rectifier with a resistance characteristic that displays a negative slope in the forward direction and an infinitely high resistance in the reverse direction. For lowest forward currents the voltage drop should be of a value sufficiently large to

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[4] Reich, "Theory and Application of Electron Tubes," pp 366-367.

discriminate against any "unwanted" glow tube and if the drop were decreased with increasing currents more of the voltage spread between the starting and running values of the grid glow tube could be allocated to the portion of the circuit where it would do the most good. Since we must use practical or readily available components, then the compromise is for a forward resistance characteristic which approaches a constant drop. Fortunately, the tendency of most rectifiers is for them to be a constant voltage drop device. Special components such as thermisters or thyrite units placed in series with the rectifiers will help attain this property and augment the voltage drop to establish proper working values.

Before continuing further it would be well to discuss the characteristics of a dry disk type rectifier as these seem most suited to use in the circuits under consideration to provide the direction sense previously noted.

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CHAPTER III

THE DRY DISK TYPE RECTIFIER

The most suitable rectifier at the present time seems to be the selenium rectifier. It is readily available and relatively inexpensive. It may be made into small, compact elements. The copper oxide and copper sulphide rectifiers are possible alternates. Silicon and germanium crystal rectifiers are also worth consideration, especially if high frequencies are to be handled. The welded germanium crystal rectifiers perhaps offer the best characteristics of these types and would be most reliable if subjected to vibration. The latter types are most expensive and less uniform in their characteristics from unit to unit. All of these rectifiers exhibit the same general characteristics so a discussion of the selenium rectifier will serve to illustrate the principle involved.

The selenium cell consists of a metal, usually aluminum, base plate coated with selenium, over which is sprayed a low melting point alloy. The base plate acts as one electrode and the alloy as the counter electrode. The junction between the selenium and the alloy coating films is called the <u>barrier</u>, or blocking layer. In the counter electrode there is an abundance of free electrons which are

available for electron flow in the direction from the counter electrode through the selenium film to the aluminum plate. The selenium film or semi-conductor has a limited number of electrons available, which results in a restricted flow of electrons from the aluminum plate through the selenium and blocking layer to the counter electrode. Having in mind that conventional current flow is opposite to electron flow, we may now state that the current flows readily from the base plate through the selenium to the alloy layer, but only with extreme difficulty in the opposite direction. The high resistance to flow is called the reverse resistance, while the low resistance in the opposite direction is known as the forward resistance. The higher this ratio, the more efficient the rectifier and the more suitable for use in the circuit under consideration. It will be shown that the forward resistance should not be zero because a certain voltage drop is needed for proper operation of the circuit. If the resistance is too low, resistance elements of the proper value may be introduced in series with the rectifier to correct the condition. In general, if a combination of cells is used in series to give the correct forward drop, a corresponding multiplication of the high reverse resistance will be achieved. (Some types have values as high as 70 volts). This value is sufficient to take care of the expected reverse voltages, which are actually established

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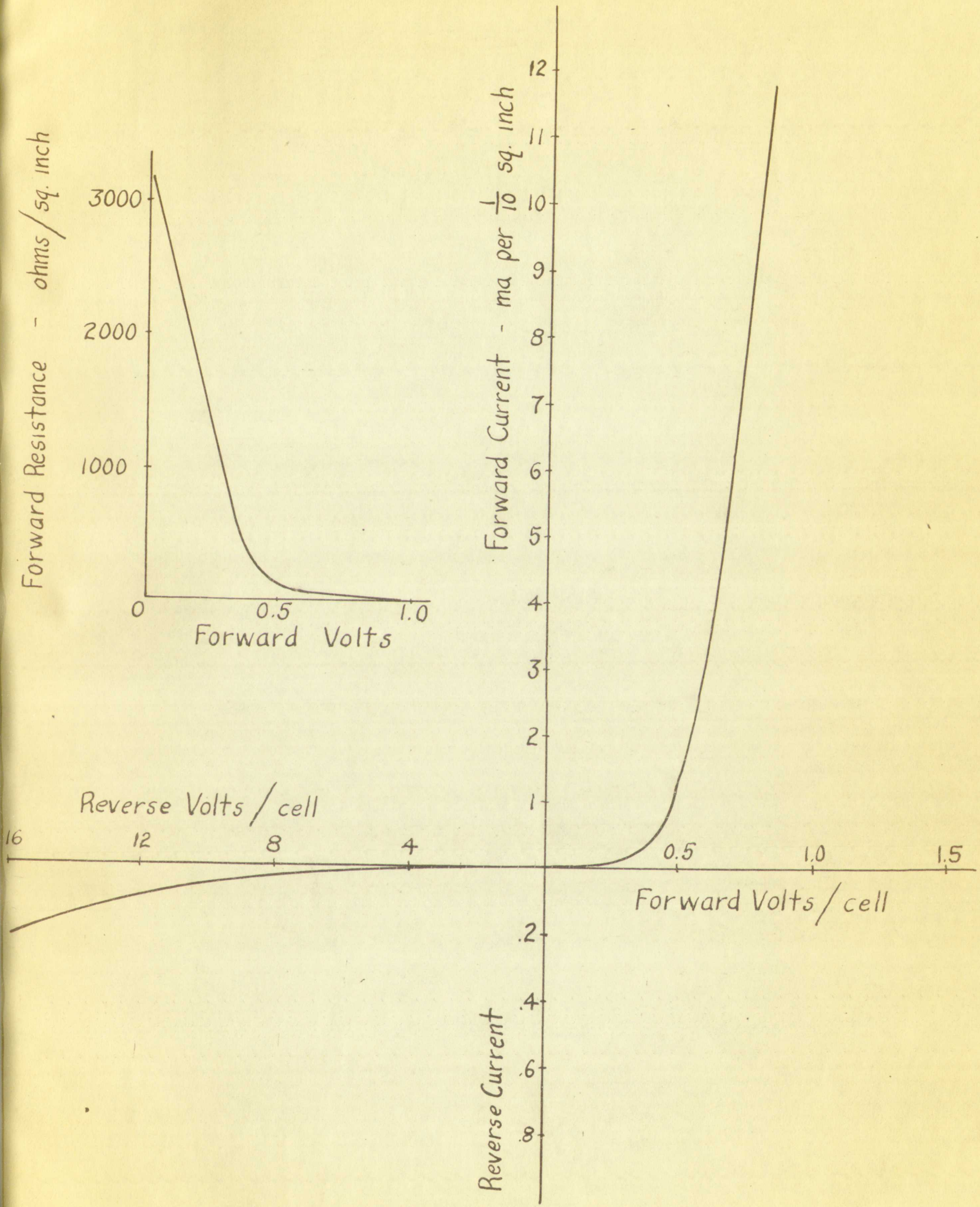
by the difference of the break-down and the running voltages of the glow discharge tube used. It is likely that if more than one cell will be used, as noted in the foregoing discussion, there will be more than ample reverse voltage rating available.

Figure 2 shows the voltage-current relationship of a single selenium rectifier cell. For illustration, the values for a cross section of 1/10 square inch of surface is plotted. We see that for very low values of current, a voltage drop of ¼ volt per cell is attained. While the rectifiers could be used in this region, it is safer to work up on the curve, say just beyond ½ volt drop which corresponds to a current of one milliampere. This region gives a more nearly constant voltage drop for changes in current. The actual current requirement to produce this drop may be modified by choosing the correct cross sectional area. The current requirement will depend on the glow tube and circuit values chosen. If the 1/25 watt neon glow lamp (NE-2) is used in a decade circuit, then one fourth of the area, or 1/40 square inch, would require ¼ of a milliamp to give the ½ volt drop. It will be noted that increasing the current four times will only increase the drop by 30%. The inset curve gives the relation between the



Forward Resistance - ohms / sq. inch
3000
2000
1000
0
0.5
1.0
Forward Volts
Forward Current - ma per 1/10 sq. inch
12
11
10
9
8
7
6
5
4
3
2
1
Reverse Volts / cell
16
12
8
4
0.5
1.0
1.5
Forward Volts / cell
.2
.4
.6
.8
Reverse Current

Fig. 2

forward voltage and corresponding forward resistance for a typical selenium rectifier.

The current rating of a selenium rectifier is based on the spacing and amount of fin cooling provided. In general, currents can be carried which give a voltage drop of one volt per cell. In the proposed circuit a very small rectifier cross section will be used, yielding an increase of cooling surface for a given volume. Hence heating will not be a problem. As will be shown later, the rectifiers will normally have an "easy" duty cycle. The duty cycle of the rectifier is "easy" because, while the circuit is counting, the current through the rectifier is usually well below the normal rating. In case the counting is stopped, one rectifier will carry the greatest current continuously. In this case, if heating is a problem, it would be advisable to stack the rectifier discs into one composite unit so that conduction may distribute the heat to adjacent cells which are carrying lighter loads. It is also contemplated, for convenience of handling and utilization of rectifiers, that they should all be in one integral unit.

The rectifiers, being made up of plates, naturally have an associated capacitance. While the equivalent condenser values are small, they are still sufficiently large to be useful in the circuitry action and yet not slow down the counting beyond the limitations imposed by the glow

ionization and deionization times. The time constants are quite complicated because of the nonlinear and unsymmetrical rectifier resistance.

The action of the rectifiers in the circuit will be seen later when the circuits are described in more detail. For the present we may consider the rectifiers arranged in a progressive manner in the tube line up so as to determine the direction of advancing count. They also become a condenser voltage dividing network, and play an important role in the counting action. In general, when a new tube conducts, its voltage drops and it will pull the voltages of the other tubes down with it in amounts which drop off as we move away from this particular tube. This works to an advantage, since the two adjacent tubes are most in need of the resulting action. The preceding tube must be extinguished and the succeeding tube must be prevented from conducting ahead of schedule. After the effect of this transient the voltages will rise on all tubes except the one which just came on, and all will take on voltages formerly impressed on the tube just ahead. This results in a shift of the voltage distribution of the array in the direction of the count and sets up conditions to make an advancing count possible. This action will be brought out more clearly when specific circuits are discussed later.

CHAPTER IV

COUNTING CIRCUITS

Having covered the two main components used in the counting circuits let us consider the basic circuit and then proceed to various ramifications of this circuit.

Figure 3 shows a decade of gaseous discharge tubes which may physically be lined up as shown or arranged in a circle much as the numbers on a clock are arranged. The rectifiers are connected to form a ring. They may be in individual units grouped into a convenient cluster or they may all be assembled together into a rod and the ends connected together to complete the ring with connection taps taken off as shown. Resistors indicated R are used to complete the basic tube circuits. Resistance R_1, which may better be a reactance, is used to isolate the voltage supply from the triggering pulse injected through condenser C. Resistance R_2 is used to produce a voltage output useful to trip the next decade through suitable circuitry. The other resistances (R_3) in the cathode circuit are useful to permit a change in voltage of the array and thus trigger the ready tube in the circuit to advance the count.

The way the rectifiers are drawn in help in the visualization of the voltage distribution. As shown,

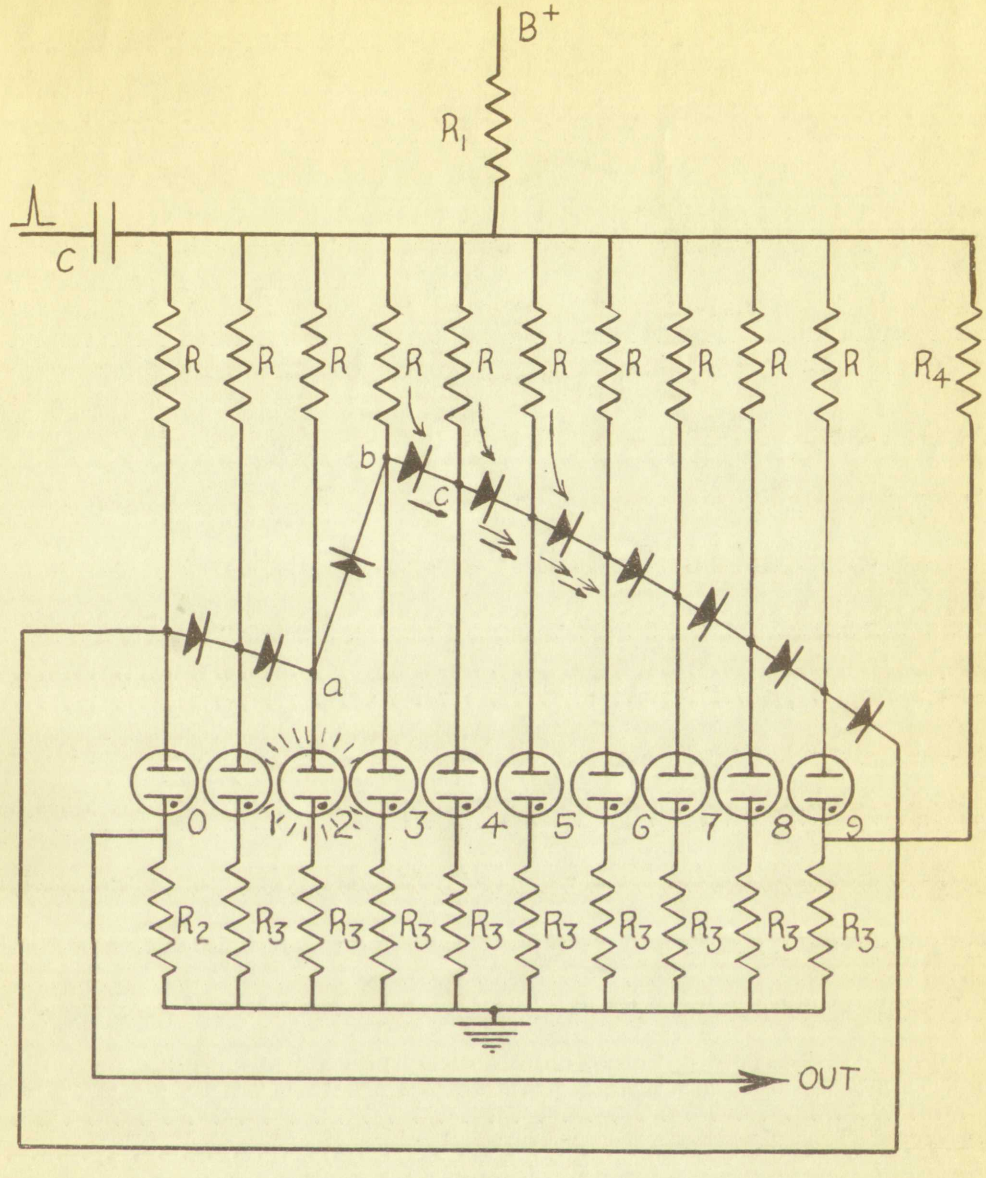

B+
R1
C
R
R
R
R
R
R
R
R
R
R
R4
b
c
a
0
1
2
3
4
5
6
7
8
9
R2
R3
R3
R3
R3
R3
R3
R3
R3
R3
OUT

Fig. 3

tube 2 is carrying current ("on") and point "a" is held down to about 57 volts plus the drop in cathode resistance, the rest of the points associated with the rectifiers are held down in varying amounts depending on the voltage drop in each rectifier of the string with point "b" of tube number 3 at the highest potential, say 87 volts, or three volts below the firing potential of 90 volts. The action of the rectifiers can now be seen. Assume the B+ voltage to be very great with respect to the tube voltage difference, b - a = 87 - 57 = 30 volts, then the currents flowing in each resistance will, to all practical purposes, be the same. We can call each a unit of current. Also assume that a negligible amount of current flows through the rectifiers in the reverse direction, or in the present example, from b to a. We then have one unit of current flowing through the rectifier connected between b and c. This current is increased by another unit of current picked up from the next resistor which flows on through the next rectifier. As we proceed along through each rectifier we must add additional units of current until in the last rectifier (between tubes 1 and 2) we will have nine units of current. Tube 2 will conduct all of this current plus that current in the resistance immediately above it, or a total of ten units of current.

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tube 2 is carrying current ("on") and point "a" is held down to about 57 volts plus the drop in cathode resistance, the rest of the points associated with the rectifiers are held down in varying amounts depending on the voltage drop in each rectifier of the string with point "b" of tube number 3 at the highest potential, say 87 volts, or three volts below the firing potential of 90 volts. The action of the rectifiers can now be seen. Assume the B+ voltage to be very great with respect to the tube voltage difference, b - a = 87 - 57 = 30 volts, then the currents flowing in each resistance will, to all practical purposes, be the same. We can call each a unit of current. Also assume that a negligible amount of current flows through the rectifiers in the reverse direction, or in the present example, from b to a. We then have one unit of current flowing through the rectifier connected between b and c. This current is increased by another unit of current picked up from the next resistor which flows on through the next rectifier. As we proceed along through each rectifier we must add additional units of current until in the last rectifier (between tubes 1 and 2) we will have nine units of current. Tube 2 will conduct all of this current plus that current in the resistance immediately above it, or a total of ten units of current.

The voltage drops across each rectifier are approximately the same and the sum of these drops is applied in

reverse across the one rectifier which separates the on tube (2) and the ready tube (3). This total accumulative voltage should be nearly equal to the voltage difference between the starting and running voltage if the voltage drop in the cathode resistance is neglected. This voltage distribution will subject tube number 3 to the highest voltage, thereby making it the ready tube or the one that will conduct when a triggering pulse is applied to the array. The next tube (4) will have less voltage by virtue of the drop in the separating rectifier. The succeeding tubes will have correspondingly less voltage impressed across them. When a positive voltage pulse is injected at the input the entire array is raised primarily by the increase in drop in the cathode resistance of the conducting tube (2) and tube 3 will be the first to reach a voltage sufficient to cause it to break down. When tube 3 conducts it will, because of the rectifier capacitance, decrease the anode circuitry voltage preventing any other tube from firing, and at the same time it will extinguish the previously running tube (2) by reducing its voltage below that required to maintain conduction. This tube must be held off long enough to allow it to completely deionize. An alternate scheme would be to inject a negative input pulse of long enough duration to allow the running tube to deionize, and, when the voltage returns toward B+, the proper tube will come on by virtue of the

voltages stored in the rectifier capacity network. In this case the individual cathode resistances may be eliminated, however, an inductance or resistance will be needed for the group. Resistance R_2 may be retained to be used to produce a voltage drop when the zero count tube comes on; this voltage signal may be used to trip the next decade through suitable circuitry. It might be mentioned that currents could be delivered to these cathode resistances through suitable resistances so as to produce voltages which may be used to compensate the tubes in accordance with their starting voltage. R_4 is included to illustrate this point. It is assumed tube 9 has a lower starting voltage than the rest. The cathode potential may be raised by an amount equal to the starting voltage advantage that it has over the other tubes.

In case the tubes have different breakdown voltages this idea may be expanded to all the tubes and each may be made to break down for the same amount of increase in voltage when it is its turn to conduct. As an example of how this particular case (shown in Fig. 3) will work out from the standpoint of voltage, assume that the curve of Fig. 2 for the rectifier characteristic is used. Further assuming that three rectifier cells are used per unit so that forward currents in units of one milliamp per 1/10 square inch are used, the voltage drops in the rectifier

chain, starting from the ready tube, will be 1.9, 2.1, 2.3, 2.5, 2.6, 2.7, 2.8, 3.0, and 3.1 volts respectively. These voltages accumulate to a total of 23 volts and this will be the reverse voltage impressed across the rectifier between the conducting and the ready tubes. Assume that 30 volts is the difference between the breakdown and conducting voltage and that 4 volts is developed in the cathode resistance; this will leave a 3 volt margin to prevent the ready tube from coming on and will be the voltage required to trigger the same tube. The input pulse used to trigger the counting circuit must be great enough to double at least the drop in the cathode resistance if the first method for counting is used. The point brought out by this example is that there will be nearly a 2 volt preference given to the ready tube over the next in line, and a 4 volt preference over the next one, and progressively greater preference on down the line.

It would be well to review the condenser action of the rectifiers as applied to this simple basic circuit. When a new tube conducts, the anode voltages on all of the tubes is suddenly decreased, but thereafter all of the voltages except that of the conducting tube rise to values slightly larger than their previous values. In fact, they will return to the voltage formerly impressed across the preceding tube, as if the voltage distribution were shifted

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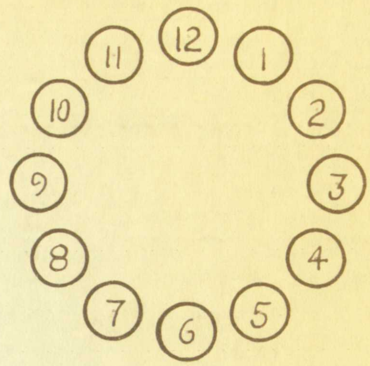
one position to the right. A circuit similar to the one described was made to operate by the author. The rectifiers used were rated at 20 milliamp and consisted of 5 cells. They were run far below the optimum current density, only about 1/10 to 1 milliamp, since 1/25 watt NE-2 neon glow lamps were used. To make up for the inefficient use of the rectifiers, the glow tubes were chosen with starting voltages of very close tolerances. It might be mentioned in passing that if the tubes are selected from a group of 100 hundred tubes, it is relatively easy to find groups of ten tubes which start within a ½ volt range. The effective number of tubes to choose from is doubled, since in general the tubes have different starting voltages depending on which way they are connected. Some which are abnormal as to their breakdown voltages in one direction may be nearly average in the other direction. The tubes should be aged at rated current (AC) for a hundred or more hours to stabilize the starting and running voltages. By operating the tubes at increased currents for proper lengths of times it is possible to raise these voltages, and, theoretically, the tubes may be conditioned to give a desired starting voltage.

CHAPTER V

OTHER CIRCUITS

Having analyzed the basic circuit we may now proceed to a general circuit on which the tubes are grouped and connected in such a way that rectifier rings may also be introduced into the cathode or lower part of the circuit. In order for a systematic count to take place, it is necessary to have the number of groups and the number of tubes per group such that they are not divisible by the same number unless special modifications are employed. A few of these are discussed later. If precautions are not taken in such cases, then after counting through a certain series of numbers the sequence will repeat without including all of the tubes. The simplest case, using rectifiers in both anode and cathode circuits, is that where four groups of three tubes each, (or three groups of four tubes each), are used as shown by Fig. 4. In this arrangement a count of twelve will be given. The circuit is shown with tube 9 on. This will, by virtue of the rectifier action, make tube 10 the ready tube. The group containing 6, 2, and 10 has the greatest voltage on the anodes, and tube 10 of the group, which is connected to lead C, has the greatest negative voltage on the cathode. It is common with cathodes



1	10	7	4
5	2	11	8
9	6	3	12

Fig. 4A

0	9	6	3
4	1	10	7
8	5	2	11

Fig. 4B

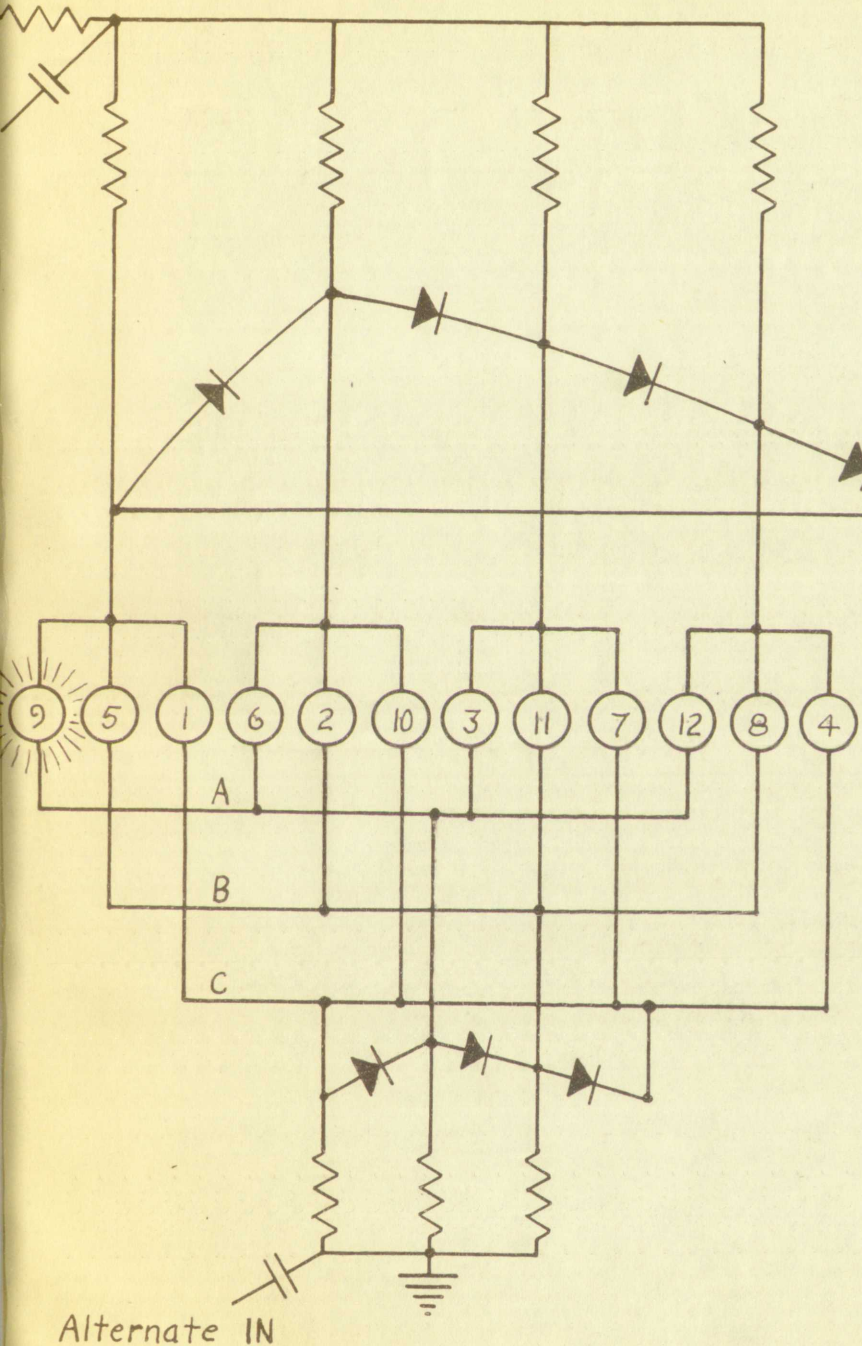


Fig. 4

of tubes of 4, 7, and 1. When tube 10 comes on, lead C will be raised in voltage to occupy the position previously held by lead A. The rectifier ring will now cause leads A and B to drop down in voltage to the positions held just before by leads B and C respectively. As in the basic circuit, when tube 10 comes on, the voltage on the anode lead will drop to that of the group just ahead as previously established when tube 9 was on. The new ready tube will be 11 since the anodes of the group will then be at the highest positive level and its cathode is at the lowest potential. Following this pattern, tubes will be made to come on in numerical order as shown when the proper input firing impulses are injected. When tube 9 comes on again, a complete counting cycle will have been made for a total of 12 counts. Tube 12 may be numbered 0 if another counting circuit is tripped for a count of 12 and a new count is begun again with 1, etc.

The pattern established by the firing sequence may be shown by Fig. 4A where the vertical columns are the tubes in one group (common anode rectifier) and the numbers in a horizontal row are the tubes with a common cathode rectifier connection. Fig. 4B shows the second case where a new cycle started with zero count. When the count returns to zero a signal may be produced to advance the count in the next set and thus produce a duodecimal (12) system.

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If only nine tubes were used, with three groups of three tubes each, then, in the case just discussed, by omitting the last group (tubes 4, 8, 12), it can then be seen that when the count is started on one, after counting to three, the count will go back to one, thus six of the tubes will not be used. This illustrates the need for having the correct number of tubes and groups. For this case, both numbers are divisible by three. Another case where the count would not work out properly would be six groups of four tubes each. Here both numbers are divisible by 2. An analogy for proper counting action can be found in gear action. That is, it is necessary for sets of gears to have the proper numbers of teeth so that any tooth of one gear comes in contact with all the slots of another gear before repeating on a particular slot.

Going back to the circuit under consideration, we can see that a count signal may be injected into the anode side or into the cathode side of the circuit. It may be either positive or negative, as in the basic circuit, depending upon the action desired. Reversing the polarity of the supply voltage will give a count in the reverse direction and interchange the conception of how many tubes and how many groups we have. Reversing one rectifier ring will give a new progression of tube firings and will, consequently, require a new set of numbers if counting sequence is to be considered.

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In the simplest case where there are only two groups of one tube each, we have a flip-flop type circuit or binary counter. The two rectifiers connected back-to-back can be considered as a pure resistance in parallel with a condenser. The next step is to three groups of two tubes each. We now have a ring of three rectifiers in anode circuit and the cathode circuit with a ring of two rectifiers as in the anode circuit of the previous case. Here the count will proceed to six before repeating. Outside of using the basic circuit with a given number of tubes, this circuit seems to offer a very good and economical counting array if it will work into a particular numbering system. We may, for example, use a count of six and a decade count in tandem to count up seconds from a sixty cycle voltage supply. Repeating this combination we may count down to minutes. Now we may have a decade system to keep track of the minutes, indicating the number by the glowing of a lamp. A count of six may indicate the tens of minutes and these, in turn, may drive a count of twelve which will show the hours. This would make a clock which, for example, could be photographed along with a record to keep track of the time. With seven rows of lights and reference lights to fix the position of the group and also to indicate A.M. or P.M. we may indicate time to the nearest sixtieth of a second for a complete day.

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With the foregoing for a background we may make a detailed study of the possible simple circuits of the type already covered. Remembering the rule that the number of rectifiers used in the upper portion and the lower portion should not be divisible by the same number we may develop a set of numbers of the counts readily obtainable. By proper handling of the circuit some numbers may be included which are divisible by the same number, and, in particular, where one is equal to the other. First, remember that we can not use the same number of rectifiers on each side, since both are divisible by the number itself. As long as one side contains a prime number, the other side may contain any number except the same prime number or any multiple of it. Perhaps the most economical combination is nearly a square, or where the numbers differ by one. Assuming that we limit ourselves to ten rectifiers in a ring, we may make up a table of the possible combinations. Such a table would include the use of no rectifiers on one side as in the basic circuit. A two rectifier ring needs no rectifiers, since a resistance shunted by a small condenser may be substituted as explained previously in the case of three and two combinations (six count). Perhaps there is a mathematical explanation or theory, but since we do not need to go beyond ten rectifiers in a ring to obtain a count up to 90, we will not need to develop such a theory. If a

higher count is desired, then the pattern of the table will point the way. In reality it is much better to cascade the circuits, much as a worm and gear arrangement, to arrive at higher counts. For example, in conventional counting circuits using tubes, the cascaded binary system is the most economical with regard to the number of tubes used. In our case two decades, requiring 10 rectifiers (5 for each decade), will give a count of 100 with a total of 10 counts per rectifier used.

Table I shows the count that may be obtained for a complete cycle. The rectifier ring per circuit is indicated with the total rectifiers used and the "rectifier use factor" which numerically is the count obtained per total number of rectifiers used. In this system we will use one tube for each count. Later we will show the number of tubes used may be decreased to the order of the number of rectifiers used if a counting code is used.

TABLE I

Count	Rectifiers Upper	Rectifiers Lower	Total Rectifiers	Count/Rectifier
2	2#	1#	0	
3	3	1#	3	1
4	4	1#	4	1
5	5	1#	5	1
6	3	2# (6-1)##	3 (6)	2 (1) ##
7	7	1#	7	1
8	8	1#	8	1
9	9	1#	9	1
10	5	2# (10-1)	5 (10)	2 (1) ##
12	4	3	7	1.71
14	7	2#	7	2
15	5	3	8	1.87
18	9	2#	9	2
20	5	4	9	2.22
21	7	3	10	2.1
24	8	3	11	2.18
28	7	4	11	2.54
30	6	5 (10-3)	11 (13)	2.78 (2.3)
35	7	5	12	2.92
36	9	4	13	2,77
40	8	5	13	3.08
42	7	6	13	3.23
45	9	5	14	3.21
56	8	7	15	3.74
63	9	7	16	3.94
70	10	7	17	4.12
72	9	8	17	4.24
90	10	9	19	4.73

Numbers in ( ) are for simple basic circuit where one rectifier is used per count.

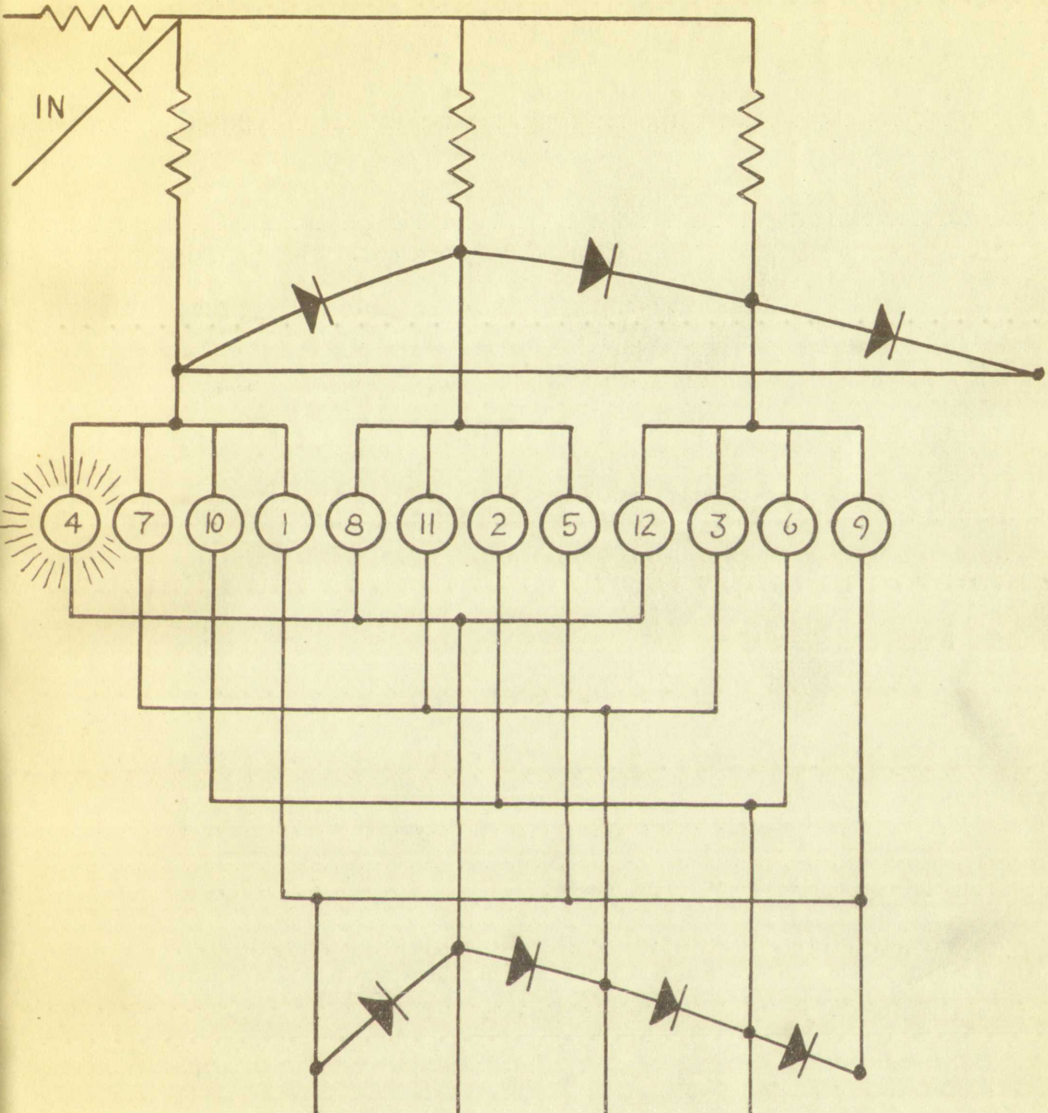
\# Note: Where circuit shows 2 rectifiers, actually none are needed as the equivalent is a resistance shunted by a small condenser. One rectifier in a ring amounts to having none at all.

CHAPTER VI

SPECIAL CASE CIRCUITS

By resorting to some special methods, counts other than those already shown are obtainable. The same counts in some cases are obtainable with rectifier ring combinations which, while somewhat extravagent, may prove more reliable because greater voltage differentials may be used. As an example, the count of eight in the basic circuit may be near the limit of the revolving power of the rectifiers, while a circuit equivalent of the count of 12, using a ring of three and a ring of 4 rectifiers, may be used with a certain group of four tubes omitted. This circuit will be discussed subsequently, but first it might be mentioned that the same method can be used to obtain a count of 9, 16, 25, etc., (squares) by forming a rectangle of lights, by adding more rows of lights than needed to determine the rectifier arrangement; then by removing certain lights only those actually wanted are retained.

To explain the method used we may take the particular case where a count of eight may be obtained. Reviewing the circuit to give a twelve count in which we used 3 rectifiers on one side of the tubes and 4 rectifiers on the other side, we see from Fig. 5 that there is a certain



1	5	9
10	2	6
7	11	3
4	8	12

Fig. 5A

Fig. 5

pattern to the way the numbers appear. Make a matrix of the tubes with the number of tubes per group as one dimension and the number of groups as the other. Numbers may be written in accordance with the pattern as shown in Fig. 5a. Thus it can be seen that there is a definite order to the way the count will progress. For this particular case progression is diagonally down and to the right. When at the extreme right, drop down one row and start back in on the first column (left). When at the bottom, go to the right one column and start in again up at the top row. This procedure may be used for all the combinations and is useful to show the pitfall; for example, if the matrix is a square, the count will progress diagonally down to the right hand bottom corner and then repeat the count again at the beginning without including the other tubes. Having seen how the 12 count circuit functions we may remove the number three tube; then since this tube will be skipped we will progress to a corresponding tube in the first group if the rectifier voltage differential of the upper rectifiers is greater than the lower rectifiers or tube seven will come on. If the rectifier voltages were the other way around, then it would be dictated that the next eligible tube in the third group would come on. In such a situation, tube twelve would come on and the count would revert to the beginning, or one. This is undesirable, so the first case

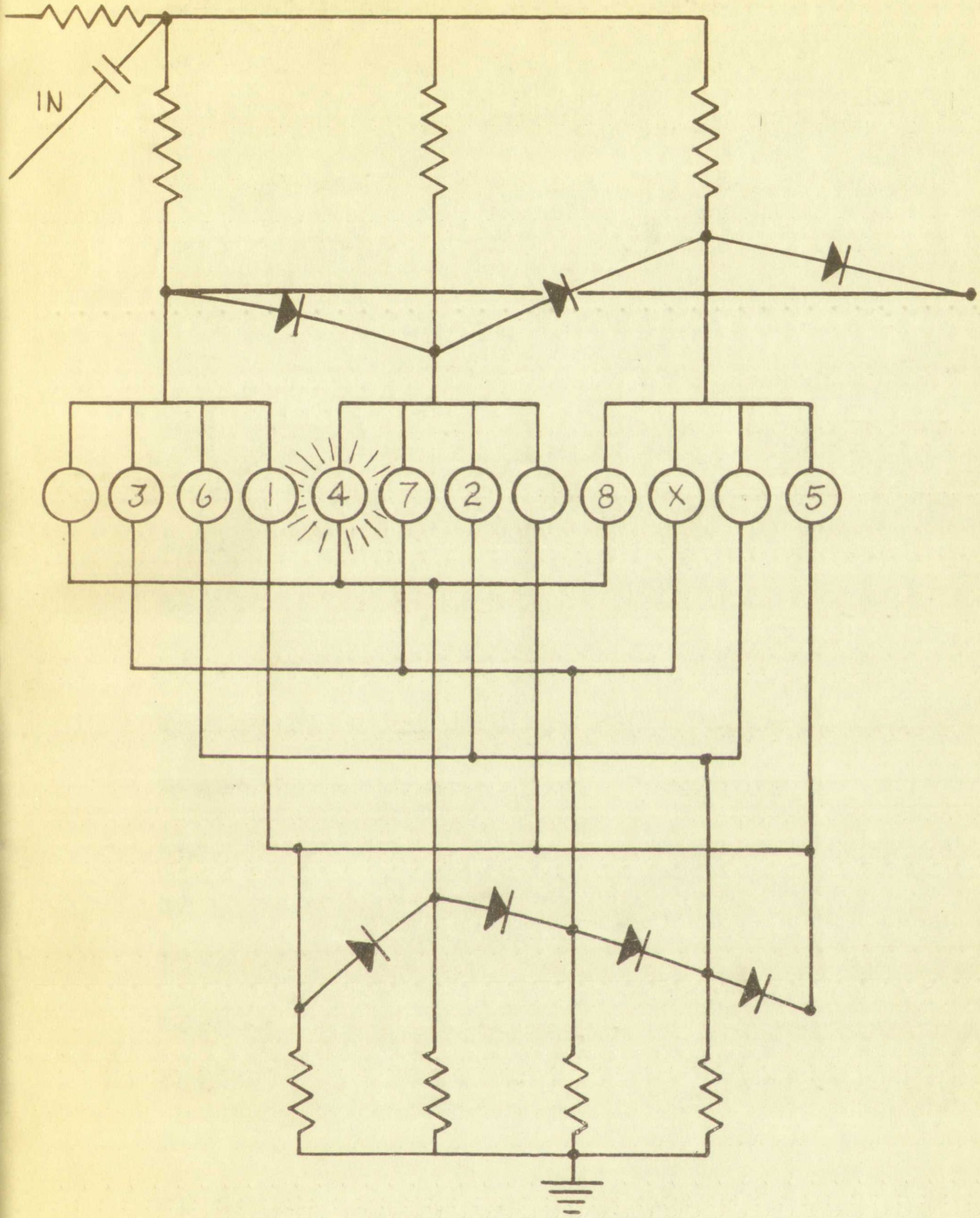
pattern to the way the numbers appear. Make a matrix of the tubes with the number of tubes per group as one dimension and the number of groups as the other. Numbers may be written in accordance with the pattern as shown in Fig. 5a. Thus it can be seen that there is a definite order to the way the count will progress. For this particular case progression is diagonally down and to the right. When at the extreme right, drop down one row and start back in on the first column (left). When at the bottom, go to the right one column and start in again up at the top row. This procedure may be used for all the combinations and is useful to show the pitfall; for example, if the matrix is a square, the count will progress diagonally down to the right hand bottom corner and then repeat the count again at the beginning without including the other tubes. Having seen how the 12 count circuit functions we may remove the number three tube; then since this tube will be skipped we will progress to a corresponding tube in the first group if the rectifier voltage differential of the upper rectifiers is greater than the lower rectifiers or tube seven will come on. If the rectifier voltages were the other way around, then it would be dictated that the next eligible tube in the third group would come on. In such a situation, tube twelve would come on and the count would revert to the beginning, or one. This is undesirable, so the first case

should be returned to. The new count obtained is shown in Fig. 6, with Fig. 6a showing the new matrix arrangement. It will be noted that since the tube marked X (Tube 3, Fig. 5) is removed three other tubes will be by-passed. Since they are not utilized they may be omitted. The tubes may now be renumbered in the appropriate order. Without drawing the circuit for obtaining a count of sixteen, the arrangement of tubes may be shown by a matrix and the tubes to be omitted may be indicated. Six rectifiers may be used on one side and four on the other. Ordinarily with ten rectifiers (7 - 3) a count of 21 could be obtained, but in this instance a count of 16 suffices. With nine rectifiers (1 less) in a 5-4 combination a count of 20 could be realized.

1	X	13	9		5
6	X	2	14	10	
	7		3	15	11
12		8		4	16

Fig. 7

Fig. 7 shows the tube arrangement with the number count obtainable. There are other combinations where eight tubes may be omitted and a count of 16 may still be realized. It will be noted that going from the count of one, preference is given to the third column (tube marked 2) since the normal tube (second row, second column) is missing; then later it is necessary to omit another tube to shift the 13 count into a free path. These positions are indicated with an X. To develop the pattern further so as to establish a procedure for obtaining these special counting arrangements, a simple rule of omitting one tube for each two rows as we



1		5
6	2	
3	7	X
	4	8

Fig. 6A

Fig. 6

proceed with our count may be used. Starting with 1 in the upper left hand corner, and proceeding diagonally down and to the right, see Fig. 8, omit the next tube encountered; this makes #2 fall one position to the right. Then proceeding normally until we have come around to the second pair of rows, omit a tube from the last row (marked X) to shift the count of 8 one position to the right. If the tube of position 7 were omitted, the 8 count would still come at the same place and the count would carry on as shown to 16 where it would repeat. If tubes were included where the blanks occur, they would be skipped over anyway, and hence are superfluous. However, it is necessary to omit the tubes indicated with an X to obtain the count as shown. If all tubes had been used, then the count shown in Fig. 9 would have resulted and a count of 12 or only ½ of the tubes would be useful. In this case, the rectifiers are arranged in a 6-4 combination and both numbers are divisible by 2. When 6 is divided by 2 a 3-4 combination is yielded. This will also give the count of 12 but uses 3 less rectifiers.

1		13		9	5
6	X	2	14		10
11	7		3	15	
	12	X	8	4	16

Fig. 8

1		9		5	
	2		10		6
7		3		11	
	8		4		12

Fig. 9

Using this method other counts which may be needed can be worked out. A few of the more representative

combinations are shown on the following pages. No attempt will be made to show the circuits, since they will be evident from considering the circuits already discussed and remembering that the number of rows indicate the rectifiers in the ring circuit on one side of the lights and the number of columns the rectifiers on the other side. The numbers included in the matrices will indicate the number of lights and their number count. Referring to Fig. 10A it may be seen that counts which are multiples of 5 may be derived by merely using 5 rectifiers in one ring and the required multiple in the other. This case is relatively simple, since 5 is a prime number. It will be noticed that 5 or a multiple of it may not be used on the other side since the proper progression will not be forthcoming. In another case where 6 is used for one side one must use special methods when the number on the other side is divisible by 6 or either of its factors, 2 or 3. For example, to get counts of 18, 24, 48, etc., extra rectifiers (columns) must be added and then by omitting certain lights the counts may be made to come out correctly as shown on Fig. 10B. Two matrices, one for a 8 X 6 (48) and one for a 9 X 6 (54) counts are also included (Fig. 10C) to show how this method may be expanded. For comparison on Figs. 10B and 10C respectively the 6 X 7 and 9 X 8 matrices are included to indicate the simple pattern for one more rectifier on one side than on the other.

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1	6
7	2
3	8
9	4
5	10

1	11	6
7	2	12
13	8	3
4	14	9
10	5	15

1	6	11	16
17	2	7	12
13	18	3	8
9	14	19	4
5	10	15	20

1	26	21	16	11	6
7	2	27	22	17	12
13	8	3	28	23	18
19	14	9	4	29	24
25	20	15	10	5	30

1	16	31	11	26	6	21
22	2	17	32	12	27	7
8	23	3	18	33	13	28
29	9	24	4	19	34	14
15	30	10	25	5	20	35

A

1		13	7
8	X	2	14
15	9		3
4	16	X	10
11	5	17	
	12	6	18

1		7	13	19
20	X	2	8	14
15	21		3	9
10	16	22		4
5	11	17	23	
	6	12	18	24

1	X	31	13	43	25		7	37	19
20	X	2	32	14	44	26		8	38
39	21		3	33	15	45	27		9
10	40	22		4	34	16	46	28	
	11	41	23		5	35	17	47	29
30		12	42	24		6	36	18	48

1	37	31	25	19	13	7
8	2	38	32	26	20	14
15	9	3	39	33	27	21
22	16	10	4	40	34	28
29	23	17	11	5	41	35
36	30	24	18	12	6	42

B

1		9	17	25	33	41
42	X	2	10	18	26	34
35	43		3	11	19	27
28	36	44		4	12	20
21	29	37	45		5	13
14	22	30	38	46		6
7	15	23	31	39	47	
	8	16	24	32	40	48

1		10	19	28	37	46	
	X	2	11	20	29	38	47
48			3	12	21	30	39
40	X	49		4	13	22	31
32	41		50		5	14	23
24	33	42		51		6	15
16	25	34	43		52		7
8	17	26	35	44		53	
	9	18	27	36	45		54

1	10	19	28	37	46	55	64
65	2	11	20	29	38	47	56
57	66	3	12	21	30	39	48
49	58	67	4	13	22	31	40
41	50	59	68	5	14	23	32
33	42	51	60	69	6	15	24
25	34	43	52	61	70	7	16
17	26	35	44	53	62	71	8
9	18	27	36	45	54	63	72

C

Fig. 10

On Fig. 11 is developed a system for counting by squares. In general, two extra columns are added and a corresponding number of lights are not utilized. This procedure gets the count over the hurdle presented if a square matrix is used. By resorting to the foregoing methods it is possible to add many number counts to our table of possibilities.

It is impossible, using the ideas developed so far, to count prime numbers (2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 53, 59, 61, 67, 71, 72, 79, etc.). However, it is possible to resort to other methods to count them. For example, if 7 is to be counted, then a circuit shown in Fig. 12A may be used. The basic circuit for the count of 6 (3 X 2) has one more rectifier added to the upper ring. The count of 4 follows the three count normally since it is next in line. However, a rectifier is used as a buffer to isolate the voltage drop in the cathode resistance of Tube 4. Tube number 5 is either chosen to have a breakdown voltage advantage over tube 1, or else a battery (or resistance carrying current) may be used to give it the necessary advantage over Tube 1. This will permit the count to proceed to 5 from the 4 count. This same rectifier is also used to prevent a count of 4 from following the 7 count, and in this case the count will not go to the favored tube 5 since it is held off by the direct

1		7		4
5	X	2	8	
	6		3	9

3^2 (9)

1		91	81	71	61		51	41	31	21	11
12	X	2	92	82	72	X	62	52	42	32	22
23	13		3	93	83	73		63	53	43	33
34	24	X	14	4	94	84	X	74	64	54	44
45	35	25		15	5	95	85		75	65	55
56	46	36	X	26	16	6	96	X	86	76	66
67	57	47	37		27	17	7	97		87	77
78	68	58	48	X	38	28	18	8	98		88
89	79	69	59	49		39	29	19	9	99	
	90	80	70	60	X	50	40	30	20	10	100

10^2 (100)

1		13		9	5
6	X	2	14		10
11	7		3	15	
	12	X	8	4	16

4^2 (16)

1		73	64	55	X	46	37	28	19	10
11	X	2	74	65	56		47	38	29	20
21	12		3	75	66	X	57	48	39	30
31	22	X	13	4	76	67		58	49	40
41	32	23		14	5	77	X	68	59	50
51	42	33	X	24	15	6	78		69	60
61	52	43	34		25	16	7	79		70
71	62	53	44	X	35	26	17	8	80	
	72	63	54	45		36	27	18	9	81

9^2 (81)

X	1	21		16	11	6
7		2	22		17	12
13	X	8	3	23		18
19	14		9	4	24	
	20	X	15	10	5	25

5^2 (25)

1	X	31	25		19	13	7
8	X	2	32	26		20	14
15	9		3	33	27		21
22	16	X	10	4	34	28	
	23	17		11	5	35	29
30		24	X	18	12	6	36

6^2 (36)

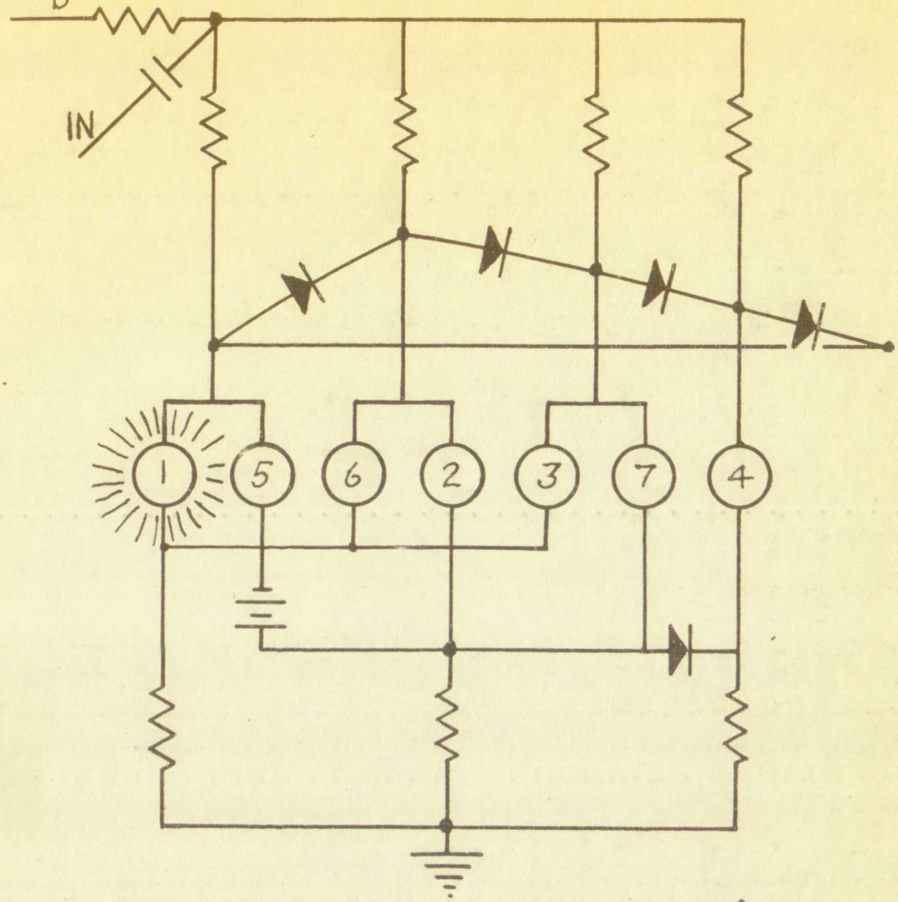
1	X	57	49	X	41	33	25	17	9
10	X	2	58	50		42	34	26	18
19	11		3	59	51		43	35	27
28	20	X	12	4	60	52		44	36
37	29	21		13	5	61	53		45
46	38	30	X	22	14	6	62	54	
	47	39	31		23	15	7	63	55
56		48	40	X	32	24	16	8	64

8^2 (64)

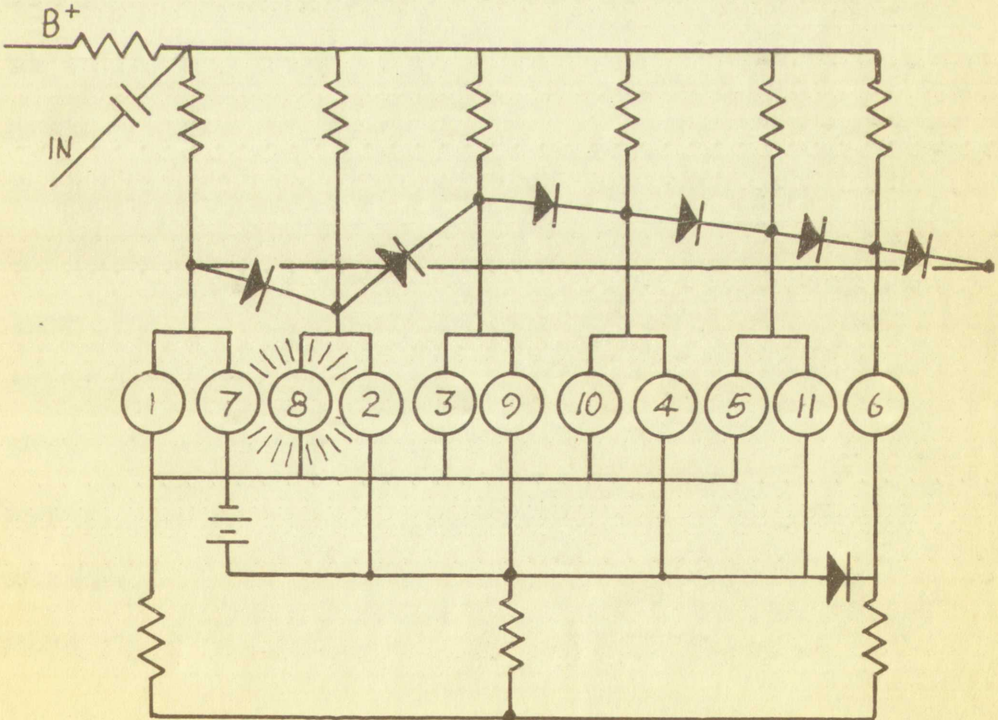
X	1	43	36		29	22	15	8
9		2	44	37		30	23	16
17	X	10	3	45	38		31	24
25	18		11	4	46	39		32
33	26	X	19	12	5	47	40	
	34	27		20	13	6	48	41
X	42	35	X	28	21	14	7	49

7^2 (49)

Fig. 11



A



B

Fig. 12

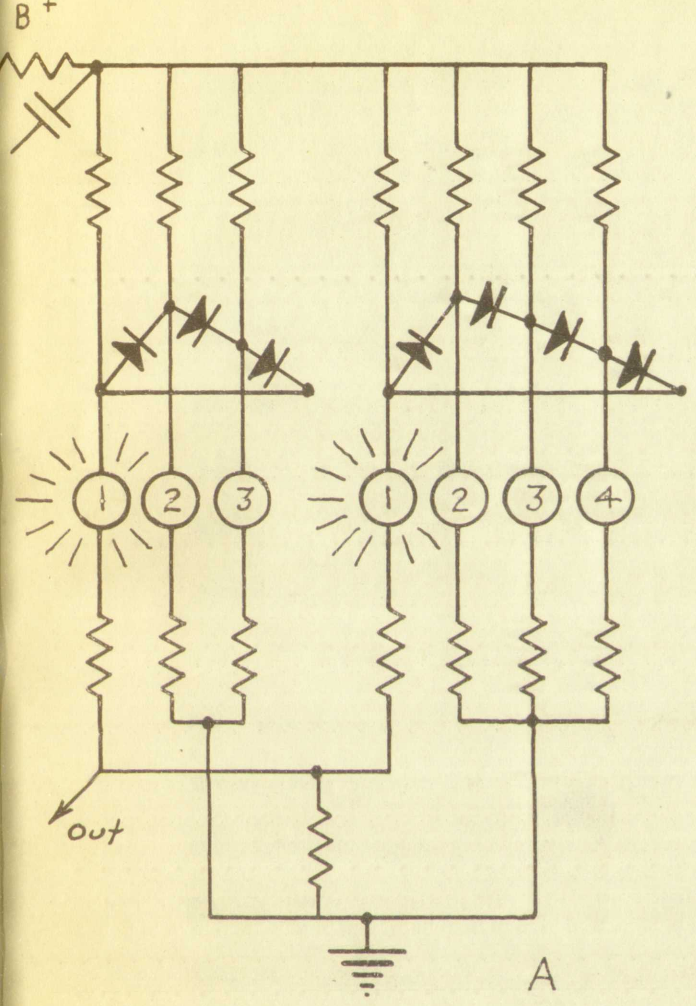
connection to Tube 7. This will permit Tube 1 to come on to repeat the cycle. A similar circuit to count 11 is shown in Fig. 12B. This is merely an extension to the 7 count circuit. With a similar approach, but using more complicated circuits with additional rectifiers, it is possible to expand the counts from other arrays. For example, if the prime number count of 13 is desired, an extension of the 11 count just discussed may not be used because the count to 12 with the two by six arrangement (6 is divisible by 2) is not feasible. Using the twelve count (3 X 4) array (similar to Fig. 4) and adding one more rectifier in the upper ring, a thirteenth tube may be included. As was done with the circuits just discussed, the thirteenth tube is kept from coming on after counts of 8 and 4 by the additional rectifiers in the cathode circuit, but it will be allowed to come on after the count of 12. With tube 1 handicapped favorably it will come on after the 13 count. This explanation is sketchy, but the idea should be sufficiently clear for the development of such counts of this type as may be desired. Generally, the simpler and more straightforward circuits will be favored. It is now seen that circuits can be devised for nearly all numbers. It appears to be impossible to count the prime number of 5 with anything other than the basic circuit wherein a rectifier ring of 5 is used. This is probably because it is

impossible to make a count of four with other than the basic circuit and it is needed before the count of 5 may be added, as in the case just discussed where a count of 6 is expanded to a count of 7 (Fig. 12A).

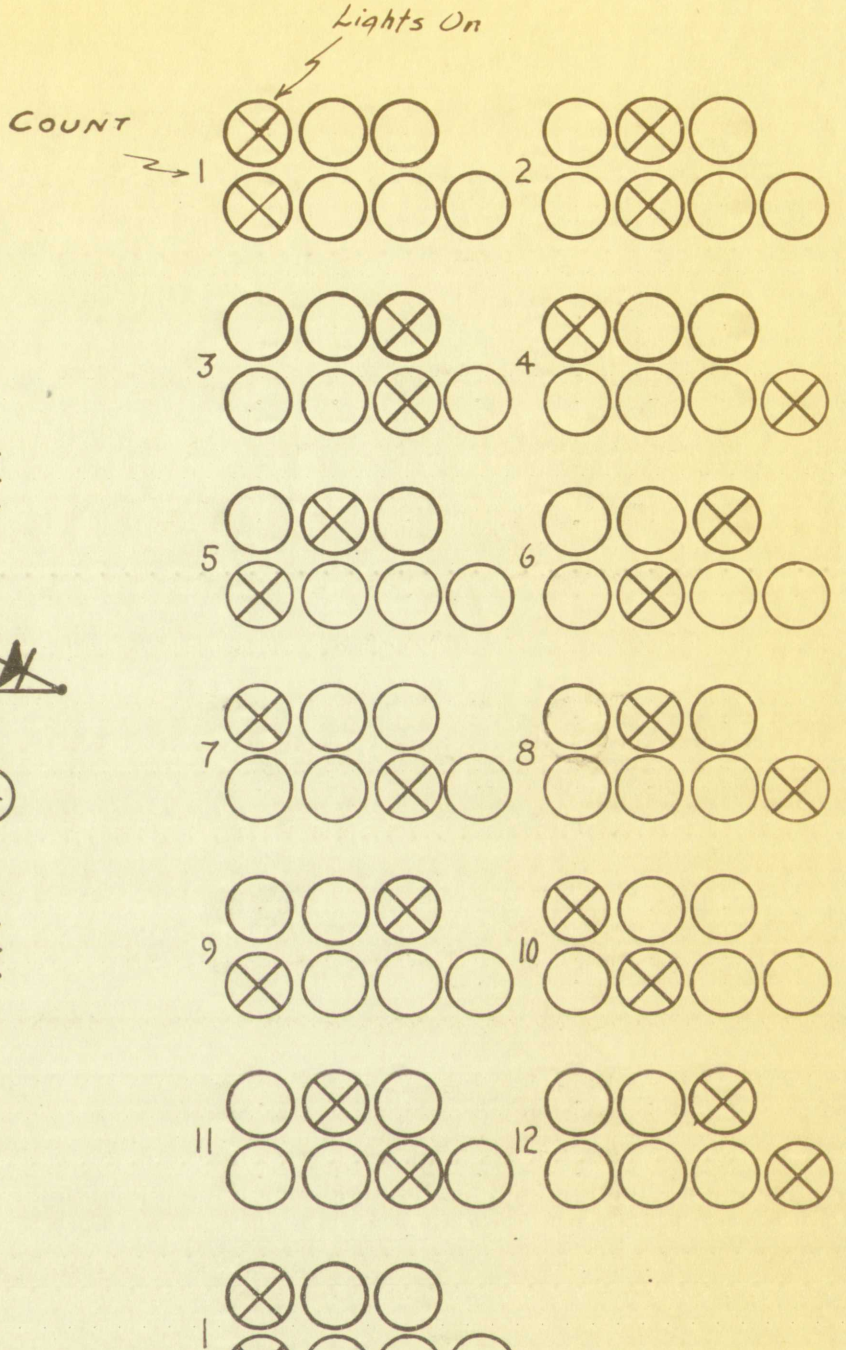
CHAPTER VII

COINCIDENCE CIRCUITS

It is possible to use the circuits described in a slightly different form to act as coincidence circuits, and, with a form of coding, number counts of various combinations may be developed. There is a gain in simplicity. The number of glow lamps may be reduced to the number of rectifiers used. It is also possible to drive the circuits from a common trigger source and thus avoid the necessity of having intermediate trigger or buffer stages between the counting stages. The general idea is to use the basic circuits for the most part. These may be used in multiples to formmultiple dimensions. For example, the use of three and four ring circuits as shown in Fig. 13 would represent a 2 dimensional matrix. This corresponds to the 12 count circuit using similar rectifier rings in the anode and cathode circuits (4 X 3), but now only 7 lights instead of 12 are needed. As the numbers are increased the percentage of lights required decreases materially. The coding is brought out by this example. It may be seen from the matrix when light 2 of each group is on a count of 2 is indicated, and when the third light of the 3 ring and the fourth light of the 4 ring circuit are on the count is 12. The next count will bring on the first



A



B

1	10	7	14
5	2	11	8
9	6	3	12

4 Count Ring

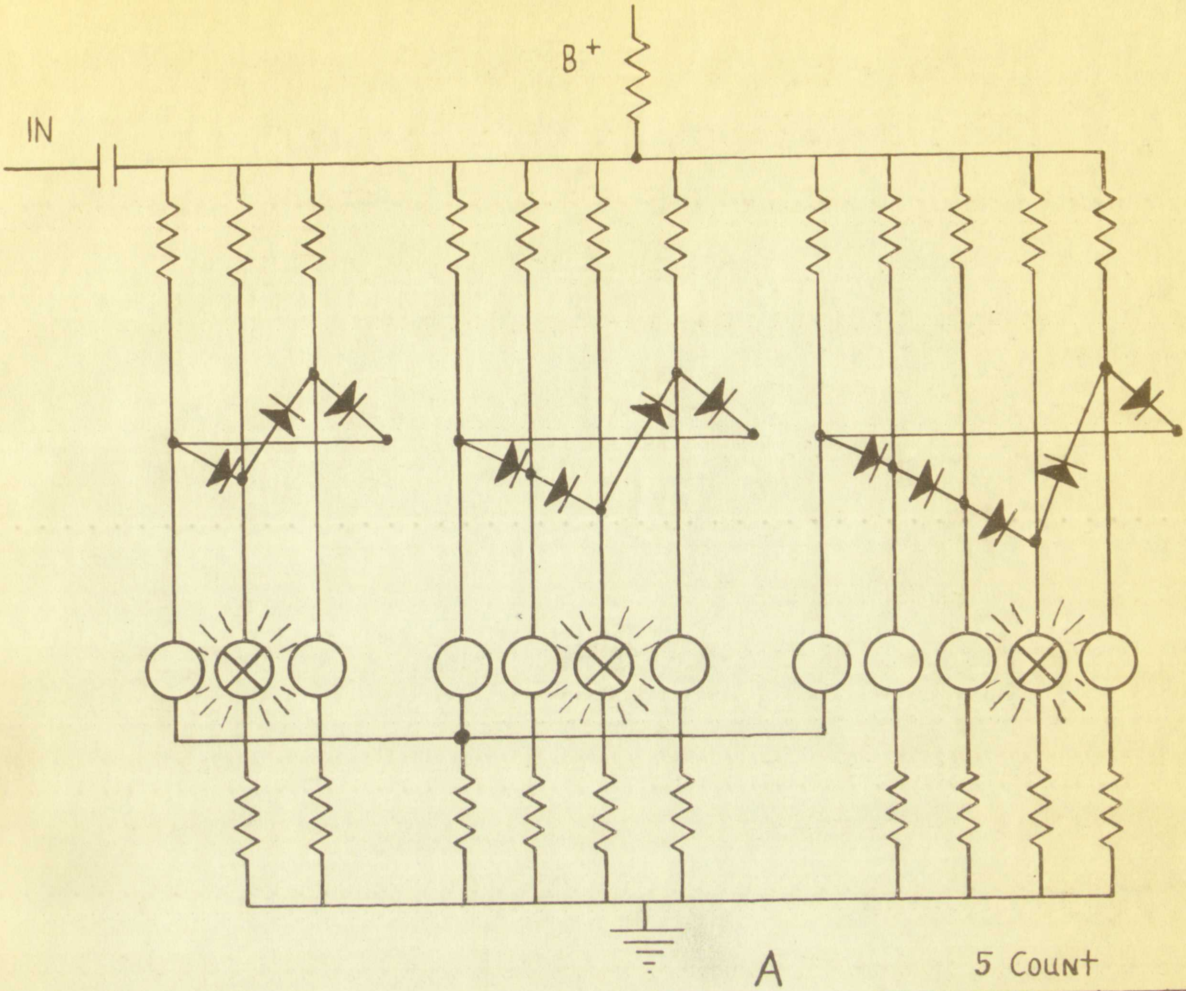
3 Count Ring

C

Fig. 13

light of each for a new cycle on the count of one. See lights indicated for corresponding count on Fig. 13b. Fig. 13c gives the table which follows previous thinking. Any particular number may be detected by coincidence circuits. They may be arranged so that when two lights are on, the two grids of a tetrode may be energized at the same time, allowing plate current to flow which, in turn, may be used to produce a signal and to indicate a particular number. In Fig. 13, tubes 1 of each group are connected to a common resistor. The drop in this resistance may be made sufficient to trigger an indicating tube only when both tubes are on and two units of current are flowing through the resistor.

This idea may be expanded to include a third group of tubes with a 5 count added as shown in Fig. 14. This results in a three dimensional matrix which is shown in two of the various ways this combination may be represented. Here for a count of 59 (circled), the second light of the three group, the third light of the four group, and the fourth light of the five group are all on together. In a counting sequence the first light of all the groups are on together every sixtieth count (product of 3 X 4 X 5). These lights may have sufficient drop in the common resistor to trigger the proper kind of voltage discriminator circuit.



A

5 Count

B

1	37	13	49	25
46	22	58	34	10
31	7	43	19	55
16	52	28	4	40

41	17	53	29	5
26	2	38	14	50
11	47	23	(59)	35
56	32	8	44	20

21	57	33	9	45
6	42	18	54	30
51	27	3	39	15
36	12	48	24	60

4 Count

B

3 Count

C

1	46	31	16
37	22	7	52
13	58	43	28
49	34	19	4
25	10	55	40

41	26	11	56
17	2	47	32
53	38	23	8
29	14	(59)	44
5	50	35	20

21	6	51	36
57	42	27	12
33	18	3	48
9	54	39	24
45	30	15	60

5 Count

C

4 Count

Fig. 14

This arrangement would be ideal for integrating 60 cycle power and producing a signal "pip" every second. Minute pulses could be produced by counting these "pips" with another similar arrangement.

Before going further, it should be mentioned once more that as in the previous case, the numbers used in a matrix must not be divisible into each other nor by the same number. For example, 3 and 6 must not be used together, as a coincidence will occur every sixth count in place of every eighteenth as might be desired. Two and 3 ring circuits would serve the same purpose.

This type of circuit may be extended to any number of dimensions and arrangements. A few examples should be discussed to disclose the possibilities of these circuits. Referring to Fig. 15, the matrix arrangement for a 3, 4, 5, and 7 circuits combination is shown. It is not necessary to draw the circuit because it is an extension of Fig. 14. In this case, the fourth dimension has been added. After studying the number sequence, it is clear that there is a certain pattern which simplifies the way the numbers may be written. Fig. 16 shows the skeleton of the number system and from this it can be seen that, for an increase in count of 12, the count has returned to the same rectangle. For example, starting with 1 in the upper left hand corner at the count of 13, the number returns to the same group. In

3 X 4 X 5 X 7 = 420 Count.
Rectangle Row

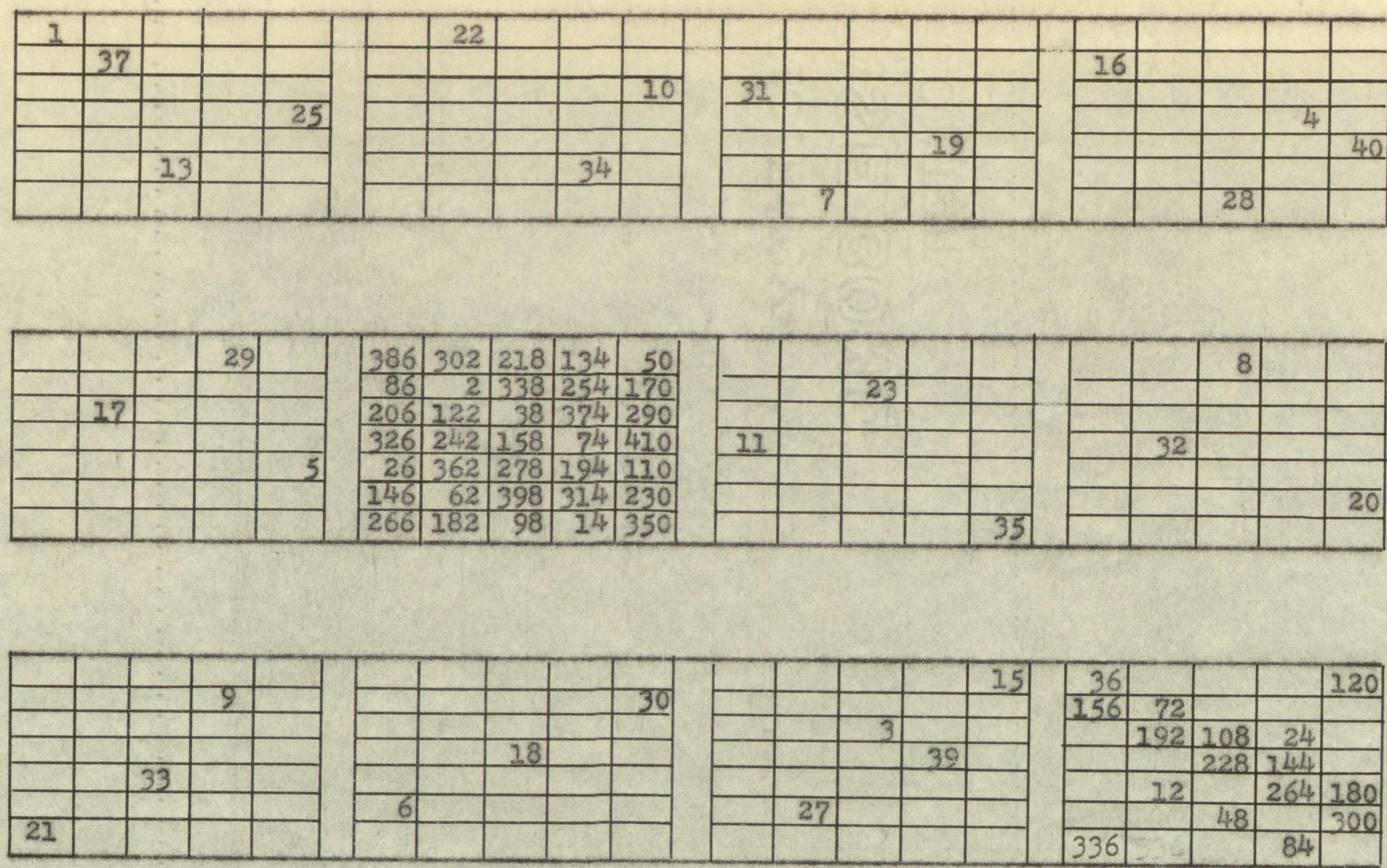
1	337	253	169	85	106	22	358	274	190	211	127	43	379	295	316	232	148	64	400
121	37	373	289	205	226	142	58	394	310	331	247	163	79	415	16	352	268	184	100
241	157	73	409	325	346	262	178	94	10	31	367	283	199	115	136	52	388	304	220
361	277	193	109	25	46	302	298	214	130	151	67	403	319	235	256	172	88	4	340
61	397	313	229	145	166	82	418	334	250	271	187	103	19	355	376	292	208	124	40
181	97	13	349	265	286	202	118	34	370	391	307	223	139	55	76	412	328	244	160
301	217	133	49	385	406	322	238	154	70	91	7	343	259	175	196	112	28	364	280

281	197	113	29	365	386	302	218	134	52	71	407	323	239	155	176	92	8	344	260
401	317	233	149	65	86	2	338	254	170	191	107	23	359	275	296	212	128	44	380
101	17	352	269	185	206	122	38	374	290	311	227	143	59	395	416	332	248	164	80
221	137	53	389	305	326	242	158	74	410	11	347	263	179	95	116	32	368	284	200
341	257	173	89	5	26	362	278	194	110	131	47	383	299	215	236	152	68	404	320
41	377	293	209	125	146	62	398	314	230	251	167	83	419	335	356	272	188	104	20
161	77	413	329	245	266	182	98	14	350	371	287	203	119	35	56	392	308	224	140

141	57	393	309	225	246	162	78	414	330	351	267	183	99	15	36	372	288	204	120
261	177	93	9	345	366	282	198	114	30	51	387	303	219	135	156	72	408	324	240
381	297	213	129	45	66	402	318	234	150	171	87	3	339	255	276	192	108	24	360
81	417	333	249	105	186	102	18	354	270	291	207	123	39	375	396	312	228	144	60
201	117	33	369	285	306	222	138	54	390	411	327	243	159	75	96	12	348	264	180
321	237	153	69	405	6	342	258	174	90	111	27	363	179	195	216	132	48	384	300
21	357	273	189	105	126	42	378	294	210	231	147	63	399	315	336	252	168	84	420

Fig. 15

Tier, Column
3 x 4 x 5 x 7 = 420 Count
Rectangle, Row



3 X 4 X 5 X 7 = 420
12 35

No. Rect. $\frac{420}{35} = 36$

Diagonal Diff.

3 X 4 X 7 = 84 (Horizontal Diff.)
3 X 5 X 7 = 105 (Adj. Rect. Diff.)
2(3X4X5) = (60)2 = 120 (Ver. Diff.)
4 X 5 X 7 = 140 (Tier Diff.)

Fig. 16

the process the count has progressed five rows down and moved two columns to the right, just as though the count had gone on in one rectangle as in the previous example. Each time around, an additional count of twelve will be added until, on the third time around, the number will appear adjacent to the number one. The number will now be greater by 36 and its position will be one row down and one column to the right, as given by the position of 37 relative to 1.

Referring to the lower right rectangle (Fig. 16) one may see how the numbers may be written in. Starting in the upper left hand corner of this rectangle with the number 36 and increasing each number by 36, the original rule may be used; write the numbers in diagonally down and to the right. When progress is blocked going down, start in again at the top (going from 84 to 120), and when stopped at the right, shift over to the left column (as in going from 300 to 336). The number is never allowed to exceed the maximum count of the squares. Hence, in this case the number 420 (3X4X5X7=420) should be subtracted from any number over that amount. This rectangle contains all the multiples of 12 since it is the 12th rectangle in the counting sequence. The second rectangle in the second tier is filled in completely to show the pattern. It will be noticed that the number differences in the rows and columns bear a certain relationship to the number combinations. The numbers in

the columns increase by 120 (3 X 4 X 5)X2 going down the column or 300 (420 - 120) going up. In either case the number 420 is not allowed to be exceeded by always subtracting 420 from sums that go over that amount. Corresponding numbers in the various tiers differ by 140 or 280 based on the product, 4 X 5 X 7. Numbers in the rows differ by 84 (3 X 4 X 7). Numbers in corresponding positions in adjoining rectangles differ by 105 (3 X 5 X 7). It will be noted that there is a very definite arrangement of the numbers. All the odd numbers are in alternate rectangles and the even numbers in the others. The last number in every column is the same. If it is desired, a five dimensional number arrangement may be made using the numbers 2, 3, 5, 7, 11, which will give a total count of 2310 (= 2 X 3 X 5 X 7 X 11). Without working it out, we know that it will resemble the example just covered except that there will be two sets of three tiers containing 5 rectangles each with 77 spaces (7 X 11) in each rectangle. One could no doubt find some simple relation to the numbers and thus establish the necessary system. Many combinations of numbers may be built up in this manner. It should be remembered not to have numbers divisible by the same number; this will make the use of prime numbers quite desirable. In any of these systems, with suitable circuitry, the pulse

may be used to reset the number system at a particular count and thus allow it to start the count over again at the beginning. For example, a 3 X 5 X 7 system which normally would count up to 105 could be made to repeat at the count of 100. This will permit a system to fit into a decade or another suitable count pattern. A 3 X 4 system could count to ten and then revert to one. For example, using the system shown in Fig. 13 but starting the numbering with 0 in place of 1 an arrangement will be needed to have the count of 0 made to come on in place of the count of 10 (Fig. 17), or else when the count of 9 comes on the next count should make the 4 ring go backwards and prevent the 3 ring from advancing from the first glow lamp since the count of zero is indicated with the first two lights on. In effect, the decade count is accomplished by skipping the last two counts of the 12 count (duodecimal) scheme.

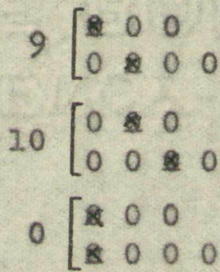


Fig. 17

By limiting the ring counting circuits to a maximum of eleven rectifiers, then with a four dimensional circuit using 7 X 9 X 10 X 11, a total count of 6930 could be attained. A three dimensional arrangement of 9 X 10 X 11 would yield a count of 990 and a two dimensional 10 X 11 would give a 110 count.

In general, this system will not produce numbers that are compatible with the decade system, but because of its simplicity and the possibility of restarting the count at any place as just disclosed, it should be useful in the art of counting or computing. As in the basic circuits this coincident type circuit can be made to count backwards with suitable "reversible" rectifiers.

Having discussed the possibilities of the various counting circuits it would be well to show how these may be put in tandem. Fig. 18 shows two decades (10 count each), one used to trigger the other when it completes a count of ten as it returns to zero. A flip-flop vacuum tube circuit may be used between each stage. This tube not only permits simple reliable triggering, but it becomes a positive means of advancing the count each time it receives an impulse from the preceding stage (its zero count). With this circuit we no longer need to depend on discharge lamp action to extinguish an on lamp. The two cathode voltages on the decade it controls are interchanged each time the tube is flipped. This will cause the ready glow lamp to come on. The glow lamp which was on will be extinguished since the voltage applied to its cathode is raised. At the same time the anode voltage will be lowered from the action of the lamp just coming on; this will help as brought out in the previous explanations.

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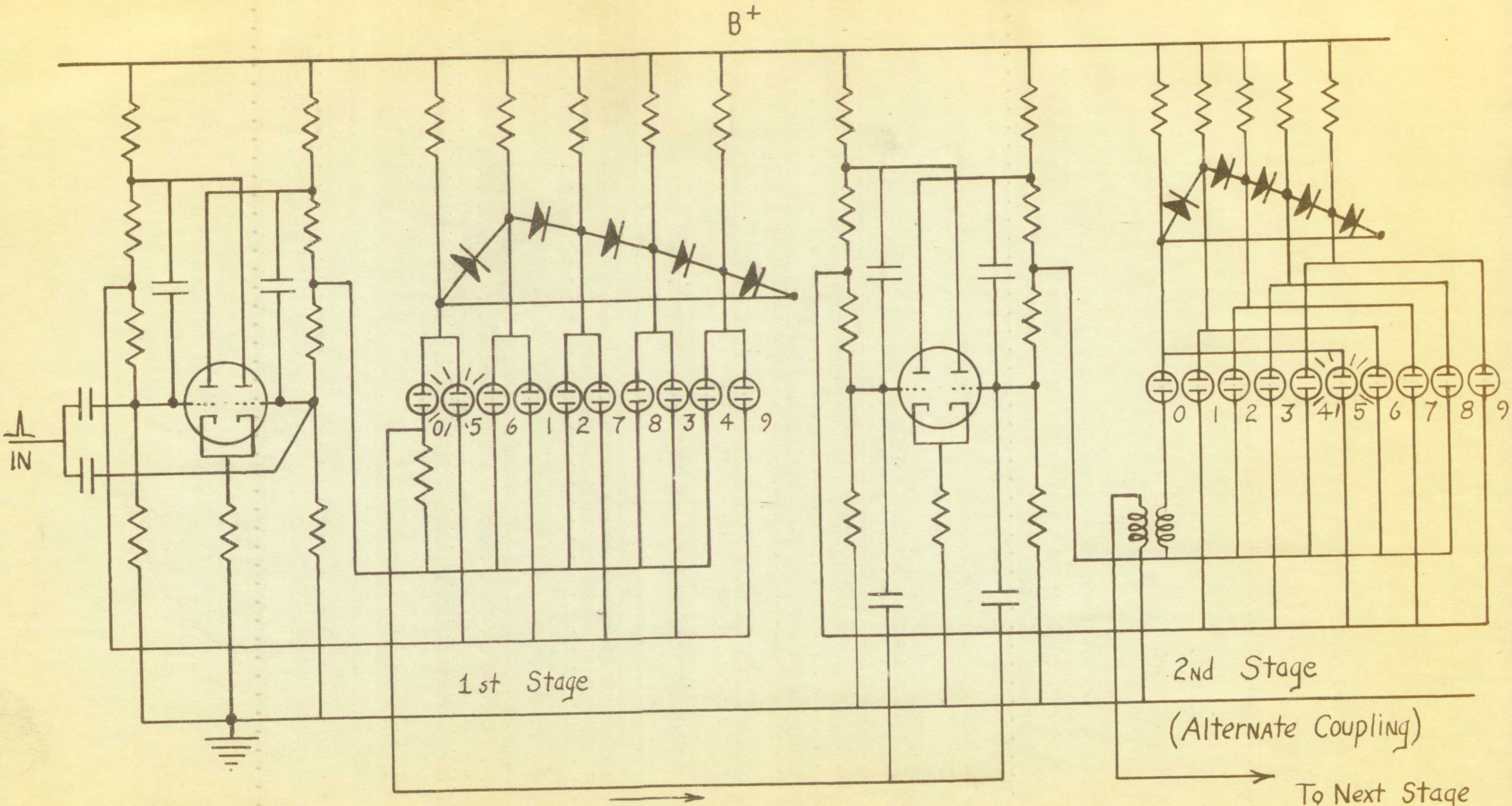
B+
IN
0/ 5 6 1 2 7 8 3 4 9
1st Stage
0 1 2 3 4/ 5 6 7 8 9
2nd Stage
(Alternate Coupling)
To Next Stage

Fig. 18

Both decades are the same, but are drawn differently to show a comparison between the paired arrangement, which follows along lines of previous discussions, and the tubes arranged in numerical order as shown by the way the second decade is drawn. The Flip-Flop circuit has resistance values suitable for its proper operation and for the production of proper cathode voltages to advance the decade in accordance with the preceding description.

Using the two simple six count circuit shown on Fig. 19 drawn in pairs and with tubes in order of count the possibility of using a gaseous discharge tube similar to the counting tube to trigger one set from the preceding set when it returns to zero may be investigated. The first set is advanced each time tube V_1 is made to discharge C_1 when it is tripped by an impulse impressed through condenser C_2. The action in this case is such that the sudden voltage drop (of the order of 30 volts) impressed at point A will lower the voltage across the on tube long enough for it to deionize and when the voltage rises the ready tube favored by the rectifier array will be the one to come on. The capacity of the cathode circuits to ground should be sufficient to maintain a voltage difference so as to favor the ready tube also. It may be necessary to place a suitable condenser across the cathode circuits to insure this action.

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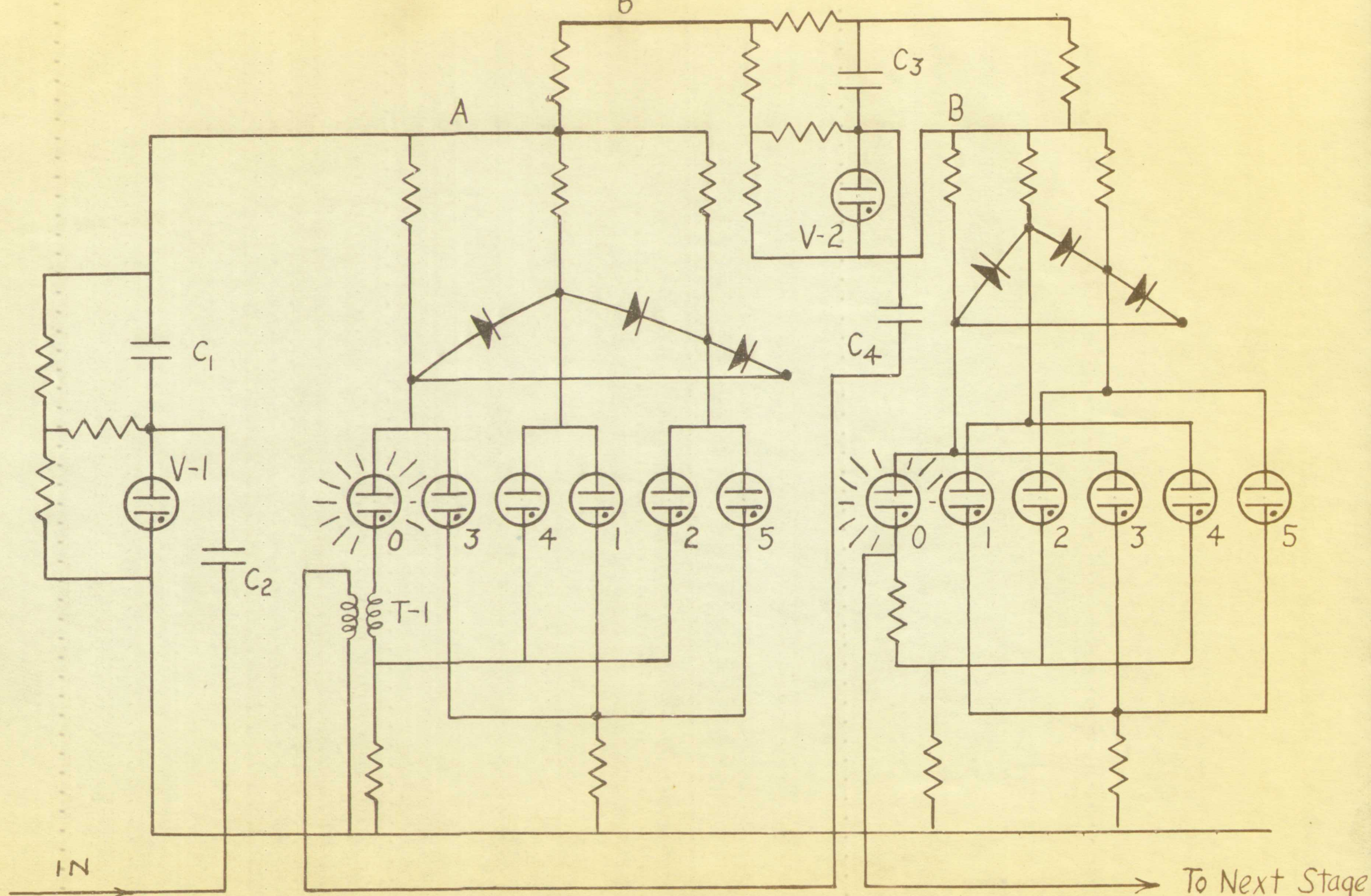

Fig. 19

In order to bring out another way that we may advance the count, the second group of tubes is triggered in a different fashion. Tube V_2 is triggered through the condenser C_4 by a positive pulse derived from the drop in the transformer T-1 in the cathode of the zero tube of the previous stage when it comes on. When tube V_2 breaks down the sudden drop in voltage across it (30v) will be impressed as a rapid rise on point B, thereby increasing the voltage across the tubes. This will cause the ready tube (#1 of the second group) to come on and this will prevent any other of the tubes from coming on for that particular count and the tube which was on will also be extinguished in the process.

While the transformer T-1 is used to couple into the zero count tube to provide a trigger for the succeeding stage a resistance could be used instead as indicated in the cathode circuit of the zero tube in the second stage.

Before closing, it should be mentioned that a transformer similar to the one T-1 in Fig. 19 might be used to couple counting circuits stages similar to those covered in Fig. 4 where rectifier rings are used in both the anode and cathode circuits. Otherwise special circuits will have to be devised to pick off trigger voltage at the right time. As an example, an auxiliary tube may be shunted across tube 2 of Fig. 4. It should include a high enough

resistance to prevent it from disturbing the circuit. When tube one comes on for a new count tube 2, being the ready tube, will have the highest voltage across it and hence can be sufficient to cause the auxiliary tube to conduct current and be useful to produce a trigger signal. This of course will correspond to the time that the count one came on in this case or to the time a new cycle was started. Generally however the zero count will be associated with the completion of a cycle for it is then that a signal will be needed to advance the count of a succeeding stage.

SUMMARY

Gaseous discharge tubes may be used to form counting circuits and may be given a sense of direction by the use of rectifiers. Many combinations are possible and various counting systems are feasible. Counting may be reversed by reversing the rectifiers physically or electrically. A novel operation of ring circuits of appropriate count simultaneously yields a count in the form of coding. Coincidence circuits may be used to detect desired counts.