AN ELECTRONIC INTERVAL TIMER

AN ELECTRONIC INTERVAL TIMER

By

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CHAPTER I

INTRODUCTION

The accurate determination of time intervals has become a factor of major importance in our modern life. Many industrial processes must be accurately timed in order to assure the rapid production of quality products. In continuous flow cycles the precise measurement of the rate of flow of fluids and gases is closely determined. These applications, together with the necessity for the accurate timing of sport events, have resulted in a demand for a more precise method of measuring time intervals.

Members of the School of Industrial Engineering of the Oklahoma Institute of Technology, inspired by the able leadership of Professor H. G. Thuesen, have made notable contributions in the art of automatic timing devices for the field of motion and time study.[1] As a result of their successes, the Official Timer of the National Air Races in conjunction with the Academy of Time made an inquiry to Professor Thuesen concerning the possible development of a device for accurately determining the interval of time involved between the start and finish of an aircraft race.

The accurate timing of aircraft races has become a major problem in recent years. The use of jet-propelled aircraft has rendered obsolete the old techniques which employed synchronized stop watches. Consideration has been given to the possibility of using electric clocks driven by the sixty cycle per second power line frequency. This would undoubtedly be acceptable if the frequency were constant. However, since the frequency usually is between fifty-eight and sixty-two cycles per second over a given length of time, this particular solution is not regarded as satisfactory.

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[1] Ralph M. Barnes and E. D. Williams, Jr., "The Automatic Time Recorder," Modern Management, IX (May, 1949), 4.

The National Bureau of Standards has developed a timing device that is very accurate and independent of any outside source. This device employs the usual weight driven mechanism and is controlled by governors and gearing in order to accomplish the desired results. The mechanism is rather bulky and in addition requires a trained operator.

The Academy of Time requested that a device be developed that would meet a number of exacting requirements. First, it must be accurate over a period of a few hours to one one-hundredth of a second. Second, the results must be presented in such a manner that they may be easily interpreted without complicated calculations which would require a delay in the publication of the official time. Third, the operation must be simple in order that it may be operated by non-technical personnel.

The general requirements of the problem made possible considerable lattitude in the final solution. Since the accuracy required was such as to preclude the use of mechanical devices such as gears, cams, and clockwork mechanisms, it was decided that an electronic device would be an ideal solution. The problem resolved into a number of general considerations. The development of an accurate time base, independent of the line frequency and possessing stability over a considerable length of time, was the first consideration. A method of controlling the starting and stopping of the timing signal with accuracy commensurate to that of the rest of the device was also a critical part of the total problem.

The number of timing pulses must be determined for the period of the time interval. It was therefore necessary to design a counting circuit which would accomplish this purpose. The results must be presented in a logical manner in order to meet the qualifications stated previously. Consequently an indicating panel, consisting of a series of lamps which would be illuminated in rotation, was considered to be the simplest solution of this phase of the project. The complete system is shown in the block diagram in Figure 1.

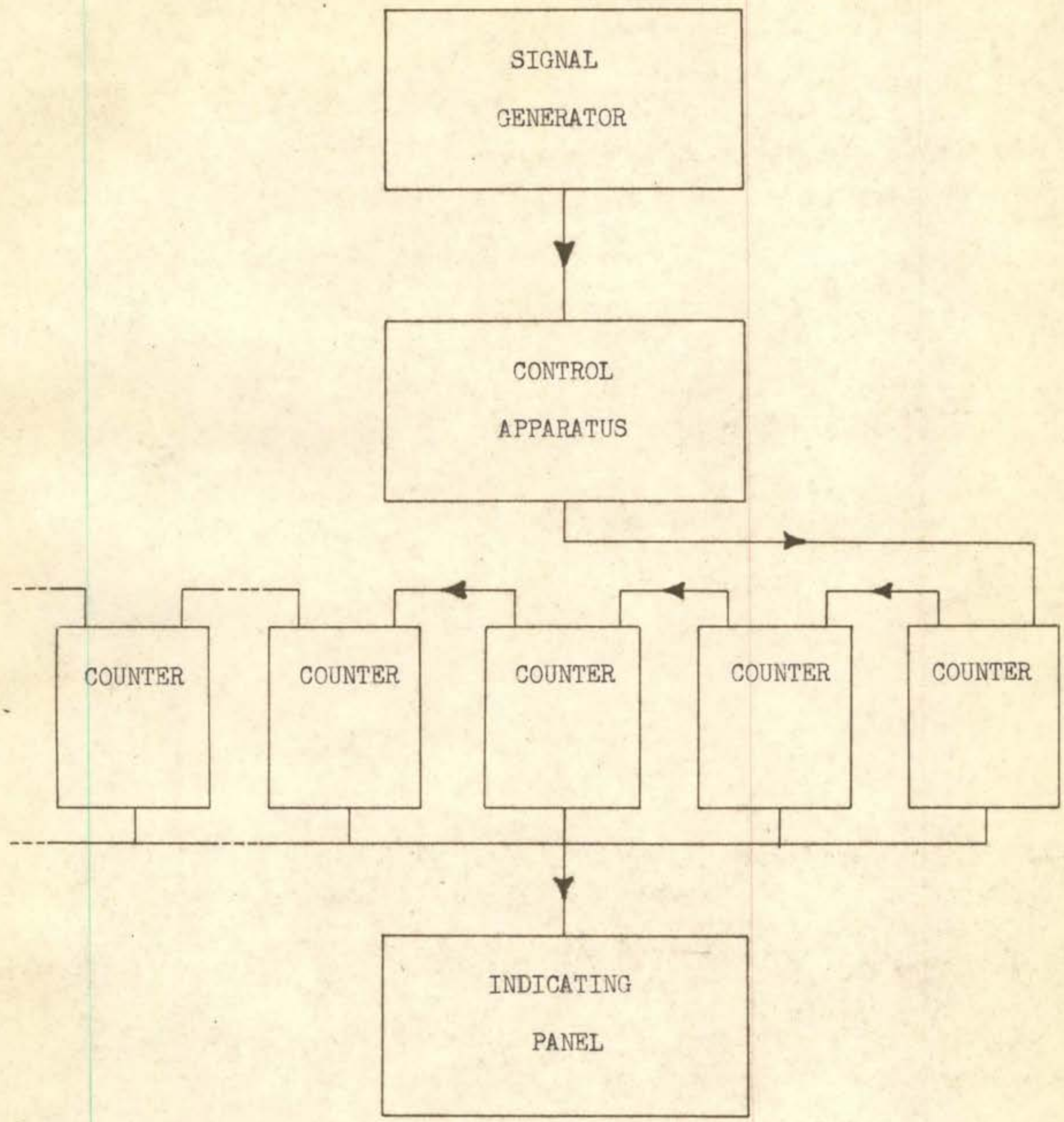


FIGURE 1. BLOCK DIAGRAM OF COMPLETE TIMER

CHAPTER II

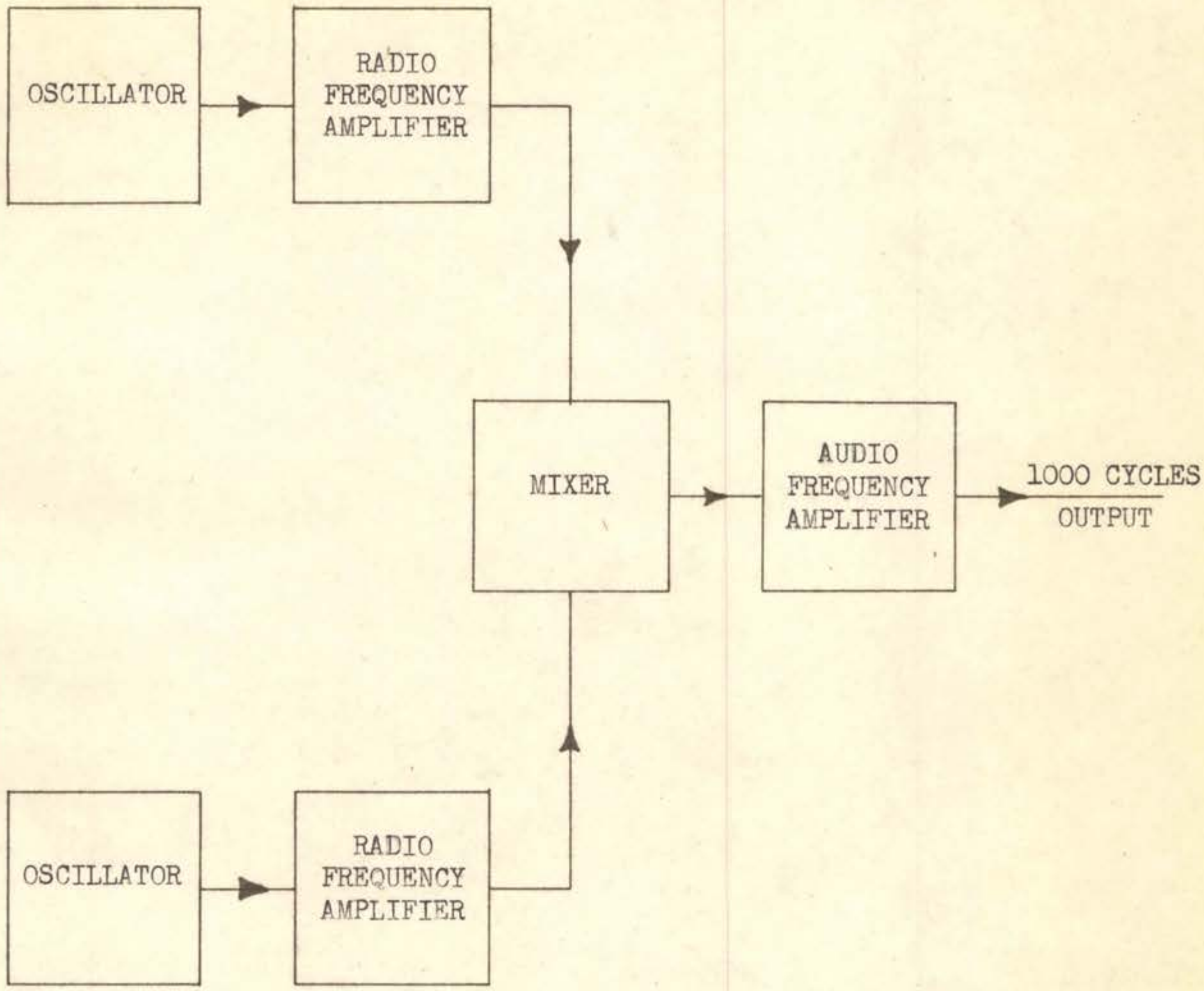
DISCUSSION OF CIRCUIT CONSIDERATIONS

SIGNAL GENERATOR

The accuracy required for the solution of the problem made it imperative that the time interval be controlled very precisely. Careful consideration was given to various methods of control. A crystal-controlled oscillator with a frequency of one-hundred cycles per second is not practical. Likewise, crystal-control at a frequency of one-thousand cycles per second is impractical but not altogether an impossibility. Various research laboratories have developed audio frequency crystals for use in oscillator circuits. Also tuning forks have been used as the frequency stabilizing device in a great many commercial audio oscillators. However, neither of the above two mentioned articles were considered to be practical for the present application. After considerable research and investigation it developed that a circuit using two crystal-controlled radio-frequency oscillators at frequencies differing by one thousand cycles per second would be the best solution.

The outputs of the two oscillators were amplified and beat together in a mixer stage. The audio frequency difference was filtered out as the usuable signal. This audio frequency signal was then employed as the controlling time base for the system. Figure 2 shows the detailed block diagram of the Signal Generator.

The output of the Signal Generator must be controlled. It is the function of the Control Apparatus to start and to stop the signal at the desired times. The determination of the number of cycles in this time interval is performed by the Counter Circuit. The Indicating Panel is used to give easily interpreted delineation of the time interval.


OSCILLATOR
RADIO FREQUENCY AMPLIFIER
MIXER
AUDIO FREQUENCY AMPLIFIER
1000 CYCLES OUTPUT
OSCILLATOR
RADIO FREQUENCY AMPLIFIER

CONTROL APPARATUS

The detection of the object to be timed was given serious consideration. It is necessary that the precise instant of starting and finishing be known. This information should be determined by the Control Apparatus and transmitted to the Signal Generator. Various possibilities were discussed in order to determine this precise instant. The use of radar, magnetic detection, and photocells was explored. Infra-red radiations from hot objects detected by a bolometer could perhaps be used for some applications. All except the use of photocells were considered to be impractical insofar as a start and stop process is concerned.

The apparatus was designed to also operate as a free running clock. This added flexibility was for the specific purpose of increasing the utility of the timer. In the case of a free running type of indication, it is proposed to use motion pictures of the start and finish of a race. The Indicating Panel and the lens of the camera must be aligned with the exact start and finish of the race. In this way, since the camera is able to take pictures of both the Indicating Panel and the event at the time of its happening, the added advantage of a permanent record of the exact time is obtained.

Certain specific conditions of operation were considered in the application of the timer. It was thought that the usual operation will involve a situation in which the starting and finishing points are either at the same place or within a reasonable distance of each other. In either case the time interval required for the transmission of the signal from the starting point and the Control Apparatus to the Signal Generator and from there to the Counting Circuit and Indicating Panel would be of a value comparable to that required for transmission from the finishing point. Consequently no serious error would occur in the presentation of the time interval involved.

In the case where the starting and finishing points are of a considerable distance from each other, it may be necessary to compensate for the difference in arrival times at the Signal Generator of the control pulses received from the two points. This would merely entail the design of delay networks of the proper value to insure accurate timing.

The present design is sufficiently flexible to permit the use of radio transmission of the control signals. Where the distance is too great for the use of cables this would be the most practical method of control.

COUNTER CIRCUIT

The Counter Circuit is used to determine the number of time pulses that are present between the start and stop of the signal source. Since one of the main requirements in the solution of this problem was simplicity of presentation, it was considered desirable to use a Counter Circuit with the common base of ten. While it is a well known fact that the binary system (1,2,4,8,etc.) is more adaptable to electronic circuits[1], the confusion that may be caused by the employment of this type of numbering system far outweighs the added circuit requirements and complications involved in the use of the decade system. For these reasons, a series of ring-of-ten decade counters[2] was decided upon as the basis for counting the time pulses. A block diagram of one decade is shown in Figure 3.

The entire counter is composed of a series of decades. The number of decades depends entirely upon the maximum length of time for which operation

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[1] C. E. Wynn-Williams, "High Speed Thyratron Automatic Counting," Royal Society of London Proceedings, 136 (May, 1932), 312.

[2] C. C. Shumard, "Some Electronic Switching Circuits," Electrical Engineering, 57 (May, 1938), 209.

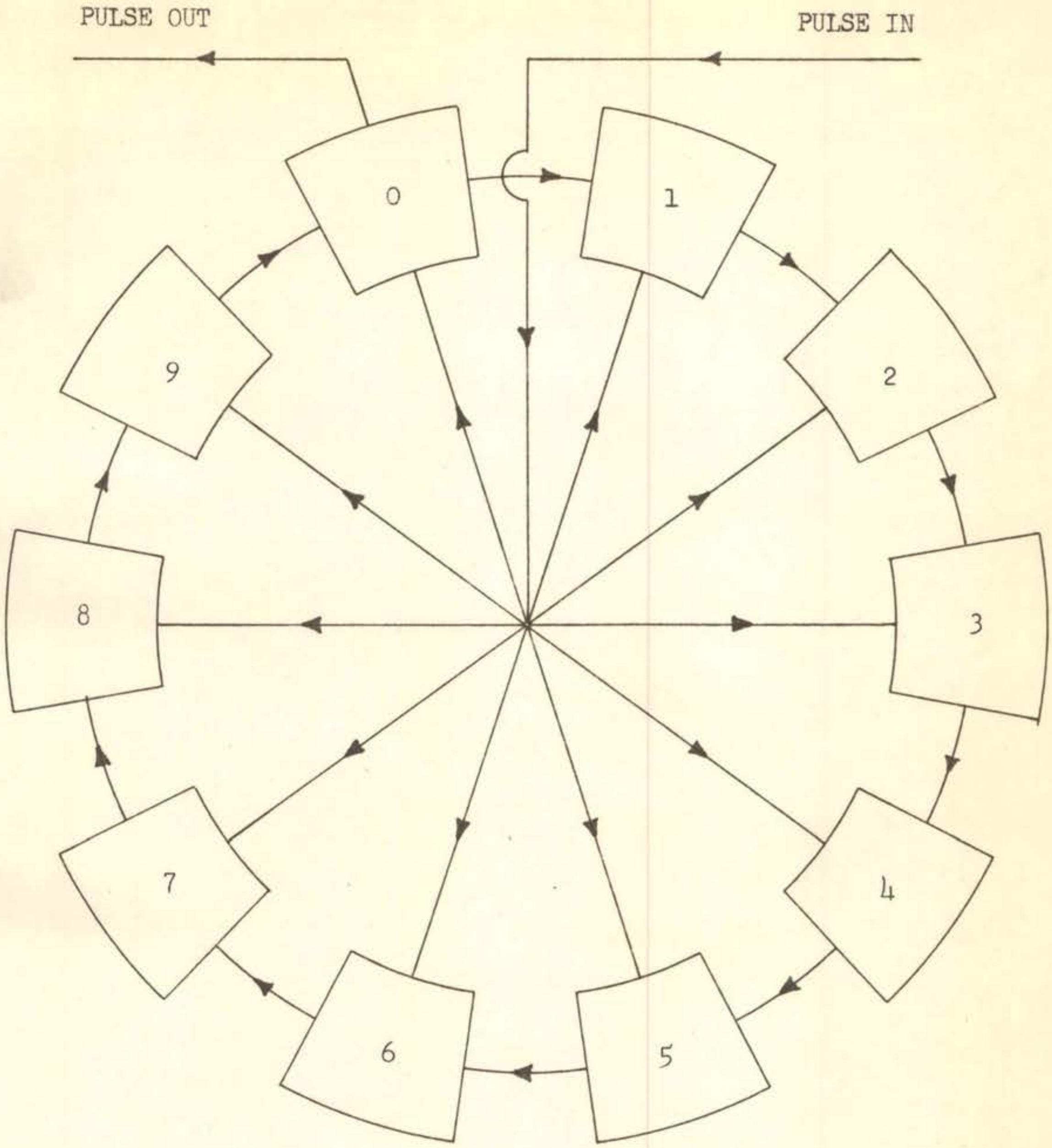
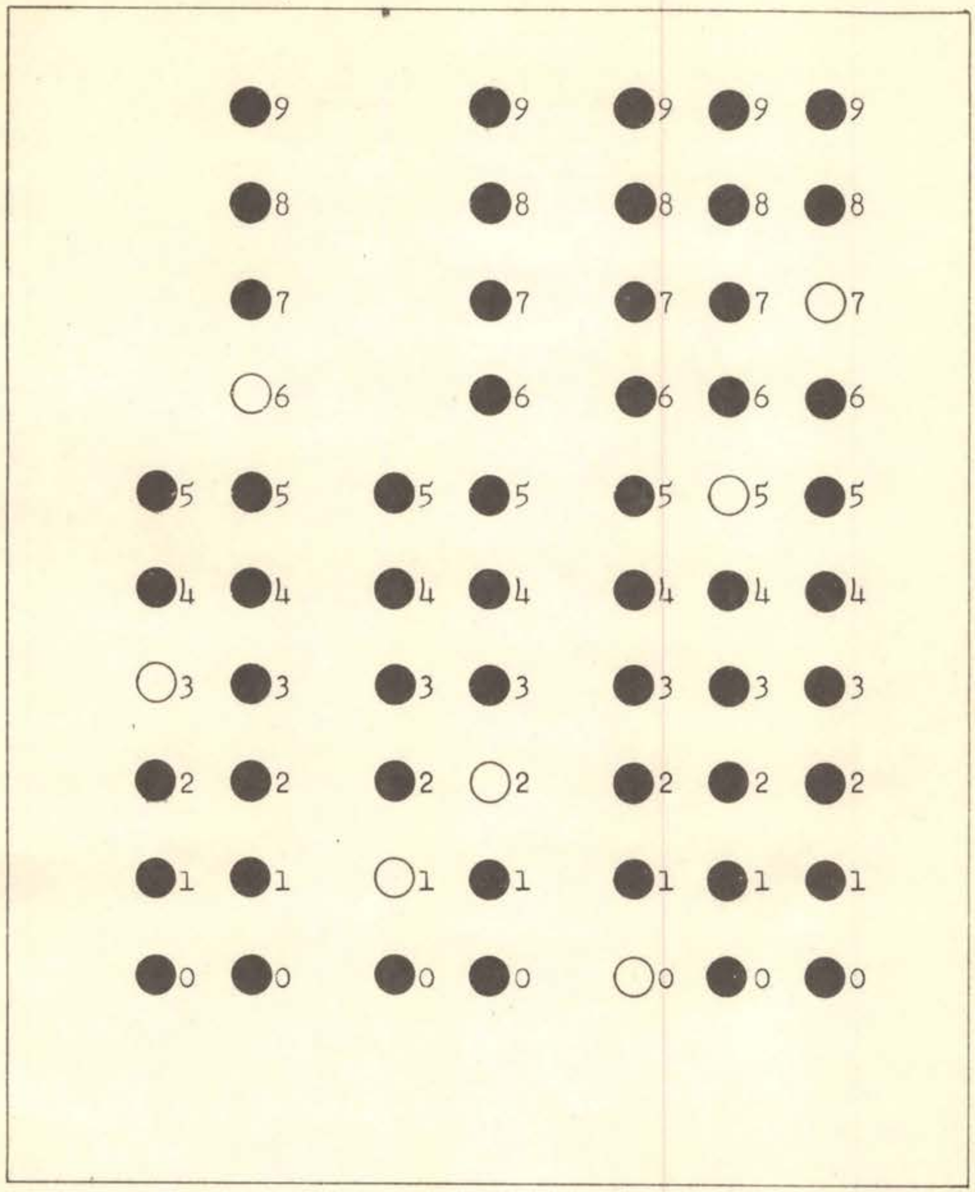


FIGURE 3. BLOCK DIAGRAM OF TYPICAL RING COUNTER

is desired. It develops that either vacuum tubes or gaseous tubes can be employed in the counter circuit. Regardless of the type of tube selected, it is necessary for the circuit to conduct and then to cease conduction at the application of each successive timing pulse. Since the thyratron inherently meets this requirement it is well adapted for use in the counter.

INDICATING PANEL

Ease of interpretation of the results was the major consideration in the design of the Indicating Panel. Indicating lamps were placed in columns with the lamps corresponding to zero at the bottom and increasing to nine at the top. For example, if the maximum length of time over which a precise interval would be desired is one hour, the completed Indicating Panel would have the following appearance. The first column on the right would represent thousandths of a second and would consist of ten indicating lamps. The next column to the left would also have ten indicating lamps and would represent hundredths of a second. The third column would represent tenths of a second and would, of course, have ten lamps. The columns representing seconds would have ten and six indicating lamps in the units and tens columns respectively. Minutes, up to sixty, would be represented in a similar manner. Therefore, with these seven columns of lamps, it would be possible to measure with complete accuracy any interval of time from one thousandth of a second to one hour in intervals of one thousandth second. A sketch of the proposed Indicating Panel is illustrated in Figure 4.



TIME: 36 MINUTES, 12.057 SECONDS

FIGURE 4. SKETCH OF INDICATING PANEL

CHAPTER III

CIRCUIT DESIGN

In the design of electronic apparatus there is always a wide variety of choices for the engineer to consider. Before any definite selection can be made, various phases of the problem must be considered with a view toward the elimination of all but a few of the many possibilities. It is in this light that the final design of the various units in the solution of this problem was evolved. The desirability of using a particular vacuum tube, thyratron, or circuit component was tempered by the fact that there were definite limitations placed upon the solution by the availability of various materials in the Electrical Engineering Laboratory stockroom. In the actual construction of the units serious consideration was given to the fact that it was necessary to keep the cost at an absolute minimum. Consequently, engineering compromises have been made and it follows that the present design could undoubtedly be improved if more costly equipment were employed. All of the parts used were readily obtainable in the Electrical Engineering laboratory.

SIGNAL GENERATOR

Reasons have already been given for the selection of the pair of beat frequency oscillators as the primary signal source. The type of oscillator used in the solution of this problem is a form of the tuned-grid oscillator, and is commonly referred to in the literature as a Pierce Oscillator[1]. There are a number of reasons why this circuit was chosen for the present application. Relatively few circuit components are required, a tuned tank circuit is not needed in the plate load, and the oscillator is relatively stable. The feedback

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[1] Britton Chance, Vernon Hughes, Edward F. MacNichol, David Sayre and Frederick C. Williams, Waveforms, pp 107-108.

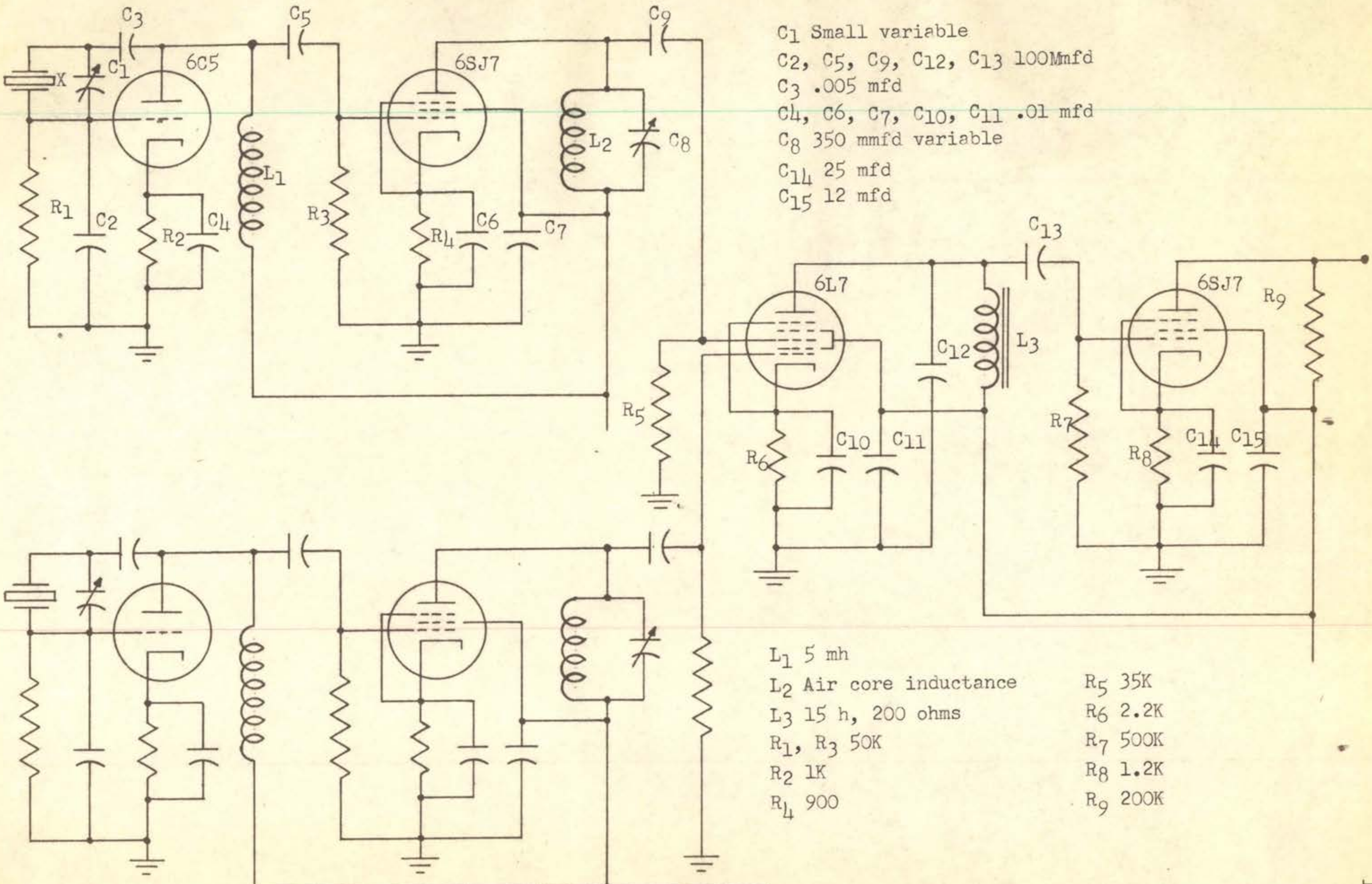


FIGURE 5. CIRCUIT DIAGRAM OF SIGNAL GENERATOR

circuit from the plate to the grid consists solely of a blocking capacitor, C_3, and a crystal, X, the crystal being resonant at the frequency of oscillation. The symbols used refer to the circuit diagram of the Signal Generator, Figure 6. The plate load is an inductance of five millihenries, L_1, a parameter that yields the proper phase relationship between the output voltage and the input voltage. The amount of feed-back present on the grid of the tube is determined primarily by the size of the by-pass capacitor, C_2, between the grid and ground.

The tube chosen for the oscillator is a 6C5 triode, this choice being made due to its general availability and the resultant simplicity of circuit design. The two oscillators are identical with the exception of the crystals. The frequencies are such that the difference is one thousand cycles per second. Coupling to the next stage, a tuned radio frequency amplifier, is accomplished by the use of C_5, a one hundred micro-micro-farad capacitor. In order to assure that a frequency differential of exactly one thousand cycles per second is obtained, small variable capacitors, C_1, were placed across each crystal to permit tuning of the oscillator circuits to the exact frequency difference.

The radio frequency amplifier is conventional in design. It consists of a 6SJ7 pentode with a tuned plate load, L_2 and C_8. The purpose of this stage is two-fold. First, it is used to amplify the output of the oscillator to such a value that it will be effective when applied to the mixer stage. Second, it is used as a buffer to isolate the oscillator from the mixer in order to alleviate the possibility of interlocking between the two oscillators. This is not an impossibility because of the very small frequency difference involved. The next stage consists of a penta-grid convertor operating as a mixer where the two radio frequency signals are beat together. Capacity coupling is employed between these stages.

The mixer is a type 6L7 pentagrid heptode, the two signal grids of which are controlled by the outputs of the two radio frequency amplifiers. The design of the stage was carried out as though there were two amplifiers present in the same envelope. The output of this tube contains not only the two input frequencies but also the sum frequency and the difference frequency. The plate circuit of the mixer stage is designed to offer a high impedance to audio frequencies and a low impedance to radio frequencies. The load is in the form of a filter consisting of an audio frequency choke, L_3, and a one hundred micro-micro-farad capacitor, C_{12}, connected in parallel. The circuit therefore by-passes radio frequencies, the only component present in the output being the one thousand cycle frequency difference. This is the signal source used to fire the thyratrons in the decade counter.

Wave form requirements of the signal are not critical and even though the output contains a slight bit of distortion it is considered to be of minor consequence in this application. An audio frequency amplifier follows the mixer stage. The output of this tube, a 6SJ7, tends to be flat-topped on both top and bottom. Following the signal generator an additional audio amplifier is used for each individual counter.

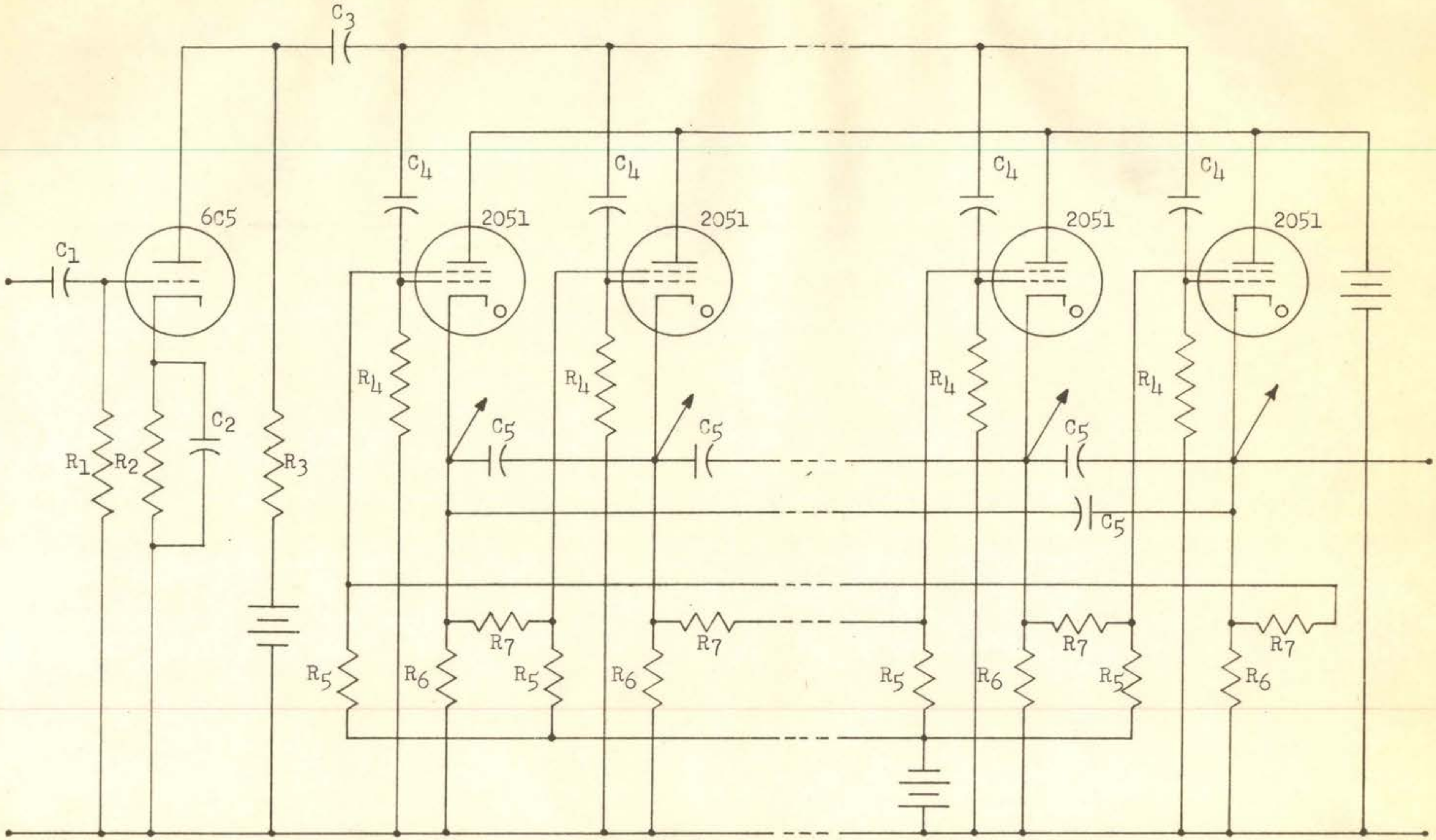
CONTROL APPARATUS

There are a great many types of control circuits that may be used as associated equipment with the Signal Generator. The simplest of these can be merely a push-button or toggle-switch. The circuit may be closed to initiate the chain of timing pulses and opened to cause the pulses to cease. Other more complicated circuits may be devised, one example of which might be a circuit consisting of two photocells, one for controlling the beginning of the time interval and one for controlling the ending. The first photocell can be connected in a thyratron circuit which in turn actuates a relay starting the timing pulses. The second photocell can be used to interrupt the current in the relay circuit and thus terminate the timing process. It is recognized that there may be a slight delay present between the interrupting of the light beam and the closing of the relay. A similar situation exists when the relay is caused to open. Since the method of control is similar in both instances compensating errors will obtain.

A more complicated type of circuit is one in which a microphone is employed to pick up the sound of a starter's gun. This sound impulse is amplified and fed to a thyratron which in turn causes a relay to close in a manner similar to that of the previous control circuit. Either a photocell or a switch may be used to stop the timing cycle. It may be necessary for precise measurement to incorporate delay compensating circuits in this application. Where an interruption type of control is not feasible, the circuit may be set up as a free running clock. Motion pictures must be taken in conjunction with the use of the timer in this instance.

DECADE COUNTER CIRCUIT

The design of the decade counter incorporates the thyratron as the basic element. One tube corresponds to each of the ten units in the decade. The general type of circuit configuration is referred to in the literature as a ring-of-teh decade counter. It is possible, of course, to design counters employing a different number of units. Since our conventional timing system is composed to multiples of sixty, one ring-of-ten counter and one ring-of-six counter is needed to indicate all of the possible combinations of seconds in the minute. The same types of counters must, of course, also be used to indicate all combinations in the number of minutes in the hour. To indicate twenty-four hours in a day it is necessary to use one ring-of-ten counter and one ring-of-two.



C1 200 mmfd
C2 25 mfd
C3 .01 mfd
C4 .002 mfd

C5 .005 mfd
R1, R3 10K
R2 500

R4 1Meg
R5 2.5K
R6 75K
R7 100K

FIGURE 6. CIRCUIT DIAGRAM OF COUNTER

It would be possible to accomplish the same result using vacuum tubes. Since one of the primary considerations in the design of this timer is to be able to present the results in an easily interpreted manner, it is necessary that the conventional scale of ten be utilized in preference to a binary or other type of numbering system. This requires ten units, each unit representing one cycle of on-off conduction in the circuit. A vacuum tube type of decade could be designed with a multi-vibrator for each unit. Two triodes or a dual triode with the accompanying circuit elements would be required if this type of circuit were used. One thyratron is capable of accomplishing this same function with the advantage of fewer circuit components. Since the thyratron is also very well adapted to the on-off type of circuit control, it has been used in this problem.

The general method of operation of the circuit can be explained briefly in the following manner. Assume that one of the thyratrons is conducting. The normal screen grid bias is well below the cut-off value and therefore none of the tubes will conduct unless the bias is changed. Due to the circuit configuration the voltage drop across the cathode resistor associated with a conducting tube cancels part of the grid bias on the following tube.

Reference to the circuit diagram of the counter will show that the screen grid bias on any tube is normally four-sevenths of the bias supply of 143 volts or 82 volts. This voltage is obtained by tapping the junction between R_5 and R_7 in the bleeder network across the bias supply which consists of R_5, R_6 and R_7. Upon conduction, the voltage at the junction of R_6, which is the cathode resistor, and R_7 is raised from approximately zero to 95 volts. This places a total voltage of 95 plus 143 or 238 volts across R_7 and R_5. The voltage at the screen is therefore changed from 82 volts negative to a minus 40 volts. If a signal is now applied to all control grids simultaneously it will be found that as long as the value of this signal is between two predetermined values, only the tube whose bias has been reduced will fire.

The application of the impulse to the tube with the reduced bias will cause it to fire and there will be two results. The bias on the following tube will be decreased, and simultaneously the charge on the capacitor connecting the cathodes of the first and second tubes will be caused to flow through the cathode resistor of the first tube. This will increase the voltage on the cathode of the first tube to a point where it approaches the plate voltage, and the tube will be extinguished. Therefore, it follows that the application of a series of pulses will result in the consecutive firing of successive thyratrons.

In actual operation of the timer the first step is to reset all of the decades to the zero indication. To accomplish this a button connected in the plate supply can be depressed, breaking the supply circuit for an instant. Since the normal bias supply is sufficient to prevent conduction, none of the tubes will be conducting, and none of the indicating lamps corresponding to the tubes will be illuminated. The grids of the tubes representing zero in all decades are then grounded, and hence these tubes will be in the conduction state. The tubes representing number one are primed and the counter is ready for operation.

The series of pulses will fire each tube in the first decade in succession until tube number nine is reached. The tube representing zero is now primed. The next pulse will fire the zero tube. In order to have 1-0 or "ten" represented on the Indicating Panel, two lamps must be illuminated. To accomplish this the voltage across the cathode resistor of the zero tube in the first decade is applied to the grids of the next decade, firing the tube representing "one". This next pulse then, will cause two tubes to fire and will result in the representation of "ten" on the Indicating Panel.

The value of the capacitor, C_5, connecting the two cathodes must be large enough to bring the potential of the cathode of the tube preceding the conducting tube to the value needed for extinction. The RC network consisting of the cathode resistor and this extinguishing capacitor will determine the voltage that is applied at the cathode.

INDICATING PANEL

The Indicating Panel contains one lamp for each possible unit in the resulting time interval. The voltage developed across the cathode resistors of the thyratrons is used as the source of potential for these lamps. Since the drop across the thyratron is relatively small, the voltage applied to the indicating lamp will approximate the plate voltage. Circuit requirements of the lamp and its associated components are two-fold. First, the lamp should conduct upon the application of a voltage of ninety volts. The second requirement is that the current drawn by the lamp must be negligible.

The indicating lamp circuit consists of a 50,000 ohm resistor and a type 991 neon glow tube. Upon the application of the cathode voltage to the circuit the entire potential appears across the glow tube and causes it to fire. The resistor limits the current through the glow tube to a safe value of approximately one and one-half milliamperes. This current is negligible when compared to the approximately fifty milliamperes of current through the thyratron.

CHAPTER IV

OPERATION

It is entirely possible that the Control Apparatus and Indicating Panel may be located at any convenient place. Multiple conductor cables may be used to connect these two units with the Signal Generator and the counters. Thus, the disadvantage of having a large array of electronic apparatus at the scene of the operation is avoided. As a typical operating example, let us suppose that the interval timer is to be used to time a foot race on a college track similar to the type found at most college athletic fields. The bulk of the apparatus may be located under the stands. The control and indicating circuits may be brought to the time-keeper's table as a small compact unit.

The method of control utilizing the microphone and photocell may be used for this application. It is then a simple matter for the timer to read the interval involved between the start and the stop of any race. It may be advisable to place the microphone at the starting line in order to prevent any time difference between the start of the timer and the hearing of the starter's gun by the contestants. A photocell and lamp placed across the finish line along with the finish tape will enable accurate determination of the exact time of the winner crossing the line. In its present form the timer is capable of recording only the time of the winner. It is not thought that this is a serious disadvantage since the fastest time in a race is usually the most important.

If it is desired to measure the time of all of the contestants, the timer may be set as a free running clock and motion pictures made of the finish line as each contestant passes the mark. This same general type of application may be used for horse-racing or automobile racing.

In applications where it is necessary for the timer to be effective over a period of twenty-four hours it would be necessary to have six ring-of-ten counters, two ring-of-six counters, and one ring-of-two counter. Additional counters may be used to indicate the passage of days, weeks, months, or even years. Any desired interval of time may be measured. It must be remembered that time is always determined with an accuracy of one one-thousandth of a second.

CHAPTER V

CONCLUSIONS

The Signal Generator and Counter Circuit components described in the previous chapters were constructed in the laboratory. A technique of construction was utilized that is considered to be rather unusual. Since this was a part of the work done it is discussed here briefly.

The government surplus chassis were modified to accomodate the tubes required for the particular unit. Four legs, made of surplus angle iron, were attached to each of the four corners of the chassis, supporting it above the table. The tubes were mounted inside the chassis where it is customary to place the components. The chassis was then placed in position with the tubes down and the socket terminals exposed on the top. This arrangement facilitated the construction and testing of the apparatus. The name of "metallic breadboard" could aptly be used to describe this method of construction.

One of the primary items of interest in this thesis is the wide variety of electronic circuits employed in the solution of the problem. The Signal Generator utilized radio frequency oscillators and amplifiers, a mixing stage and an audio amplifier. Industrial circuits came into play in the Counter Circuit with thyratrons and switching techniques. It is easily conceivable that the Control Apparatus could be activated by photocells and thereby introduce another phase of electronics.

After building the Signal Generator and one ring-of-four counter, the equipments were tested in order to determine the action of the circuits. The two crystal-controlled radio-frequency oscillators were used to assure a reliable time base. Once the output is calibrated, the signal source should remain on frequency. The crystals will normally react to changes in voltages and temperature, but since both oscillators are identical, they will both

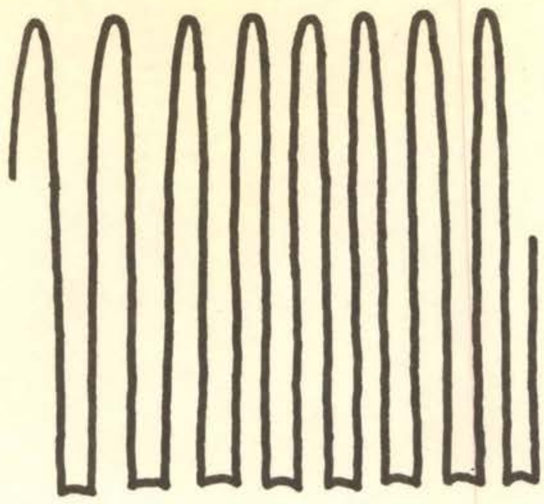


FIGURE 7. OUTPUT OF SIGNAL GENERATOR

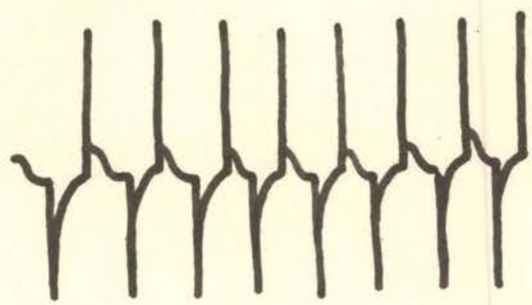


FIGURE 8. INPUT VOLTAGE TO THE COUNTER

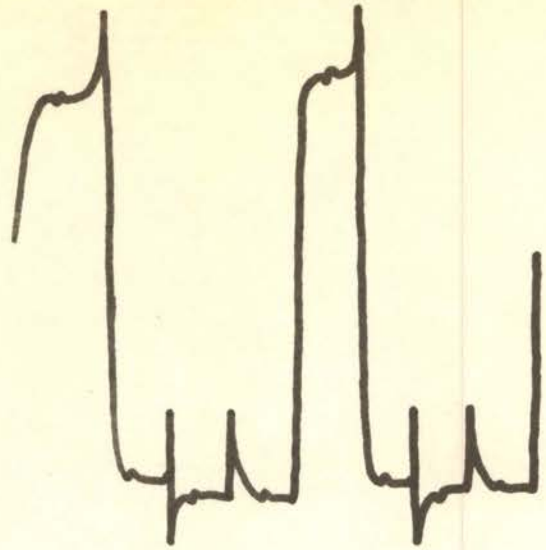


FIGURE 9. CATHODE VOLTAGE WAVEFORM

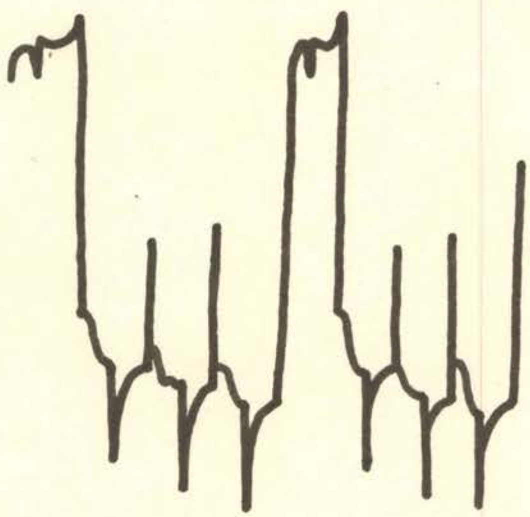


FIGURE 10. VOLTAGE AT THE CONTROL GRID

drift in the same direction. Because this is true, the timing base, or difference frequency should be constant. The two radio-frequency amplifiers were easily adjusted to the proper frequencies. It was found that harmonics and poor wave form would be obtained if the tuning was not correct in the plate loads of these amplifiers. The Signal Generator was first tested without an audio-frequency amplifier. The output was low and dropped considerably lower when loaded. With the addition of the audio-frequency amplifier greater output and more stable operation was the result. The output of the Signal Generator is shown by the oscilloscope trace in Figure 7 and also in the photographs on Page 28.

The Counter Circuit was tested by applying a d.c. voltage momentarily to the grids of the thyratrons. The original purpose of indexing, extinguishing and priming took place with marked effect. The two pieces of equipment were connected and tested. The waveforms of Figures 8 to 12 and the photographs on Page 28 present the operation of the circuits with marked clarity.

The input to the Counter Circuit is differentiated and then amplified in the triode amplifier associated with each ring counter. The output of this tube is shown in Figure 8 and in the photographs. These pulses are applied to the grids of all tubes simultaneously, the waveform at the grids being that in Figure 10 and in the photographs on Page 28. It can be noticed that the grid voltage of the tube that is conducting is very positive. After the tube is extinguished, the input pulses are ineffective for three time periods. Upon the application of another pulse the tube is then again conductive.

The cathode voltage is very positive for one unit of time and zero for three units of time. During the positive period the indicating lamp associated with the tube is conducting. When the voltage drops, the lamp will be extinguished and will not conduct until that particular tube again fires. This action is

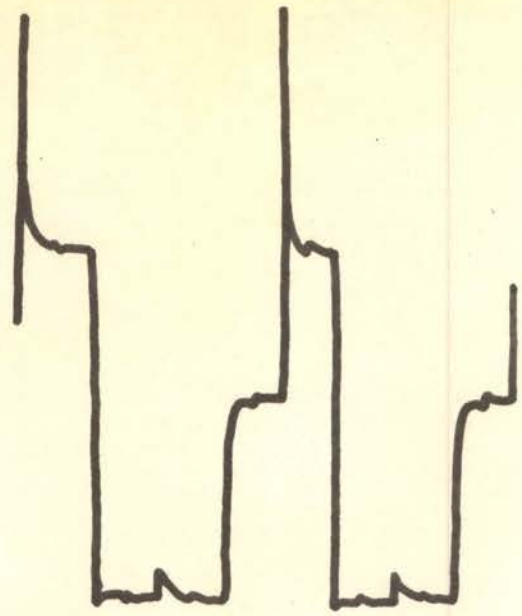


FIGURE 11. SCREEN GRID VOLTAGE WAVEFORM

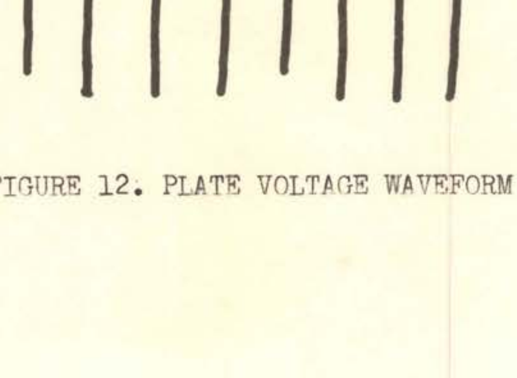
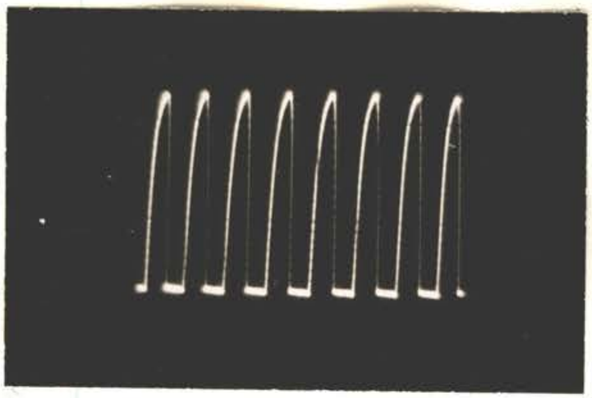
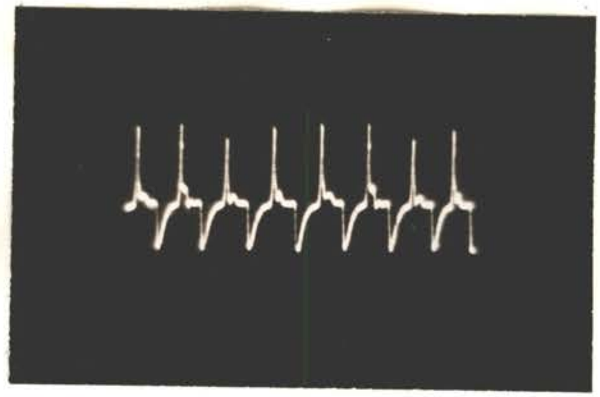


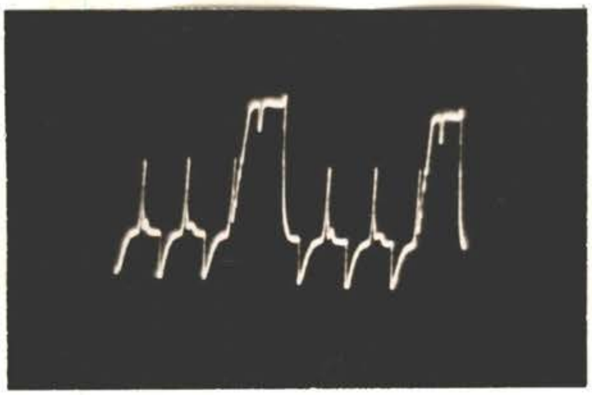
FIGURE 12. PLATE VOLTAGE WAVEFORM



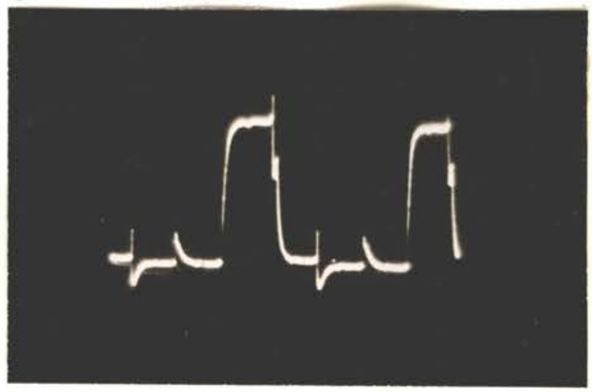
Generator Output



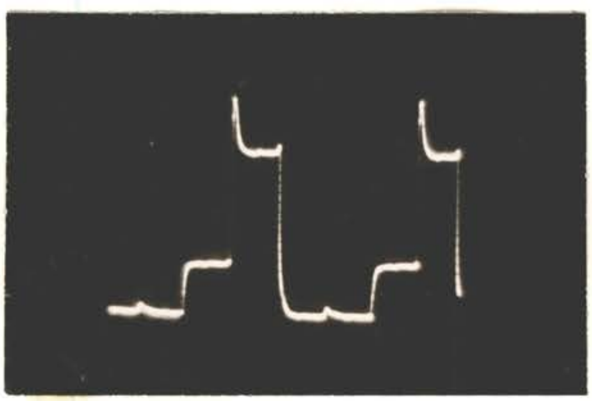
Input to Grids



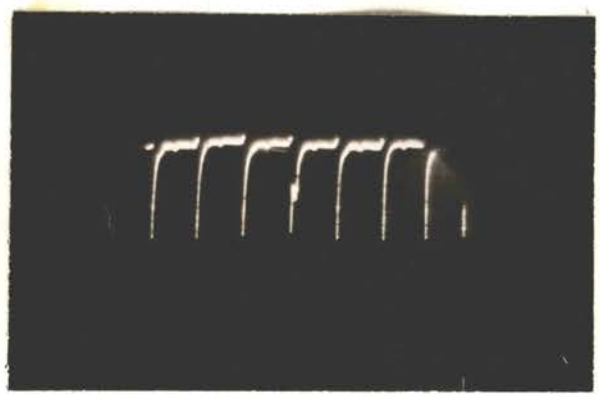
Voltage at Grids



Voltage at Cathode



Voltage at Screen



Voltage at Plate

apparent from the trace and photograph of the cathode voltage.

The trace of the screen grid voltage illustrates the priming action discussed previously. As can be noted on the waveform, Figure 11, bias is very negative until the tube is primed. This period of high bias in this case is two one-thousandths of a second. Following the two periods of high bias there is one period of lower bias during which time the tube is primed. Conduction occurs at the next pulse and is shown by the sharp rise in voltage and the attendant reduced bias.

The plate voltage is driven in the negative direction as each tube fires. These sharp drops are well portrayed in the photograph and on the oscilloscope trace, Figure 12.

The writer plans on constructing a complete one-hour timer. By purchasing surplus parts the cost should be between $85 and $100. If bought on the market the cost of the parts would be approximately $200. These estimates do not include the cost of the power supplies. It is intended to use a dry plate rectifier power supply for each unit of the completed instrument. A geophysical company in Tulsa, Oklahoma, has expressed interest in the device in its present form. Indications are that the company would be willing to pay in the neighborhood of $500 for a completed timer built to perform specified operations.

It is evident that with the inclusion of various types of Control Apparatus the timer can be made very flexible. The cost of building a particular item will vary over a wide range depending upon the nature of the problem. Photocells and their accompanying auxiliary equipment are rather expensive. Mechanical control, on the other hand, is much more economical.

The actual success of the interval timer on any market is necessarily determined by the cost and the necessity for a precision instrument. It appears to be entirely feasible that this interval timer will be in demand wherever extreme accuracy is desired.

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