THE DESIGN AND CONSTRUCTION OF
A DOUBLE PULSE GENERATOR

By

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Acknowledgments

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Abstract

The subject matter of the thesis is concerned with the design and construction of a double pulse generator and an associated calibrating pulse marker generator.

The double pulse generator is to be used for calibrating the resolving times of three specific paralysis circuits to be used by Professor C. H. Westcott in counting experiments. It has been built to perform this function for the range from about two microseconds to about fifteen milliseconds to an accuracy of about one percent.

Table of Contents

Introduction

The finite resolving time of any electronic device introduces losses in the counting rate. Following a recorded count, the counting device requires a certain time, variously known as resolving time, paralysis time, or dead time, before another count may be recorded. During this interval, one or more counts may have occurred and not been recorded. These are the counting losses.

Calculations for the probable losses in the counting of particles from a source of constant intensity were done by Locher (1933), Volz (1935), Skinner (1935), and Ruark and Brammer (1937). These applied to Geiger-Muller counters which have a relatively long dead time, of the order of one hundred microseconds, and which possess the property that the dead time follows all counts whether recorded or not.

Quite different expressions for the counting losses are obtained when the source is pulsed as it is from a high energy accelerator such as the cyclotron. The probable loss rates in the counting of particles from such a source have been calculated by Professor C. H. Westcott of McGill University. The reader is referred to his paper "A Study of Expected Loss Rates in the Counting of Particles from Pulsed Sources", Proc. Roy. Soc. A Vol 194 1948.

Apparatus, as shown in block diagram appendix 1, has been built to verify these expressions in the Radiation Laboratory at McGill. The arrangement requires the use of two variable paralysis units and a variable resolution coincidence unit. The paralysis circuits each appear in a channel in which coincident counts may be simulated and are to provide accurately known dead times. The variable delay coincidence unit will provide a means of determining the real and apparent coincidences between the two channels.

It was for the purpose of calibrating the circuits that the double pulse generator, which forms the subject matter of this thesis, was designed and constructed.

Requirements

The function of the double pulse generator is to produce pairs of pulses similar in size and shape to those which normally operate the paralysis circuits. The pairs are fed into a paralysis unit and the time interval between the two members of the pair is reduced until only the first of the two is recorded.

Since the resolving time of the paralysis circuits depends upon the average counting rate, the pulse pair recurrence frequency must be variable.

The particular requirements to be met by the double pulse generator are determined by the experimental arrangements shown in block diagram of appendix 1.

Alpha particles from a weak source of polonium provide a slow counting rate, which is to average between fifteen and one thousand counts per second.

The pulsed nature of the source is obtained by means of an aperture in a rotating disc which exposes the proportional counters once during each rotation.

Pulses which appear in the proportional counters due to ionization by an alpha particle, are amplified by linear amplifiers and then appear in a mixing circuit, which operates such that a pulse from the centre channel is fed into both channel 1 and channel 2 in order to simulate coincidences. Accurately known dead times, long compared with that of the remainder of the circuitry, are produced in each channel by means of the paralysis circuits. The signals from this are then fed into scalers and counted.

Coincidences which may occur between any two pulses of channel 1 and channel 2 may be found by feeding both paralysis circuits into the variable resolution coincidence unit and then to a scaler. The counts lost may be obtained by subtracting the number observed after the paralysis circuit from the number observed before the paralysis circuit. This arrangement is particularly useful for finding counting losses which may be encountered in scattering experiments in which two counters are used in coincidence.

Since the resolving time of the paralysis circuits depends upon the counting rate, the pulse pair recurrence frequency must be variable over a range of from about fifteen to about one thousand per second. Similarly, since the paralysis units to be calibrated are required to produce dead times anywhere from one or two microseconds up to about fifteen milliseconds, the time interval between the two members of the pairs of pulses must also cover this range.

Each pulse of the pair is to be separately variable in amplitude from about five to fifty volts, and at most the rise time may be 0.5 microseconds and the decay time 5 microseconds. This latter will provide pulses similar to those at the output of the linear amplifiers.

The accuracy of the pulse pair recurrence frequency is not critical, but the pair time interval should be accurate to within one percent for good results.

Choice of Method

For time intervals greater than a few microseconds, there are two methods of obtaining a delay between an input pulse and a delayed output pulse.

The first is by means of a sawtooth generator which is coupled to an amplitude discriminator. A unit is required for the basic recurrence rate of the pair of pulses, normally a multivibrator, which will furnish a gating signal to a sawtooth generator, which in turn, will feed two discriminators adjusted to fire at different points on the sawtooth. The two pulses thus obtained are fed into separate gain units and from there to a mixing circuit.

One of the most linear sawtooth generators is the Miller integrator which generates a negative sawtooth, requiring that the positive supply line for the discriminator, a Schmidt trigger circuit, be placed at a voltage somewhat higher than that for the Miller integrator. A method which would obviate the necessity for the two positive supply lines is one in which a positive sawtooth is generated by some circuit such as that presented in Elmore (p. 73). The Schmidt trigger circuit also requires a well regulated negative supply line.

From the construction point of view, the above method requires one regulated negative supply line and either one or two regulated positive supply lines. Also a separate winding in a transformer would be necessary for separate heaters for the Schmidt circuits since their cathodes would be sitting at about 300 volts above ground.

The second method, chosen as an alternative to the first, makes use of the properties of the univibrator. It is capable of providing an output pulse delayed for controllable times over a wide range after the occurence of a trigger pulse. It will also provide negative rectangular voltage pulses for gating a pulsed L-C oscillator, which in turn, provides calibration pulses over the range between the pairs of pulses. With its incorporation in the final circuit, it is necessary to build only one well regulated positive power supply. The small negative voltage is suppled by a reversed dry cell.

Operation of the Circuits

Double Pulse Generator (refer to Block diagram appendix 2)

The relaxation oscillator provides the basic recurrence rate for the pairs of pulses. It is a free running thyratron oscillator which generates triggering signals for the univibrator at a controllable rate from about fifteen per second to about eleven hundred per second.

The univibrator, upon receipt of a triggering signal, passes over into a quasi-stable state and remains there for a time determined by circuit constants. During this period one plate is positive relative to its stable state, the companion plate negative relative to its stable state. Thus, two rectangular voltage waves, one positive and one negative, are initiated by the triggering signal. It is the duration of the quasi-stable state, variable from about two microseconds to about fifteen milliseconds, which determines the pulse pair time interval.

The positive and negative rectangular waves are fed into separate channels, each consisting of a differentiator, an amplifier and a thyratron.

In one channel, the process of differentiation and amplification provides a positive pulse corresponding to the leading edge of the negative rectangular wave. In the other channel, the same process provides a similar pulse corresponding to the trailing edge of the positive rectangular wave. These pulses, in turn, trigger their respective thyratrons. The result is that for each pulse produced by the relaxation oscillator, two are produced at the output, one at each thyratron, separated by an interval determined by the quasi-stable period of the univibrator.

Each pulse may be viewed separately at its own thyratron, or the pair together at the output of the mixer.

Pulse Marker Generator

The calibration of the pulse pair time interval is performed by the associated pulse marker generator circuit. This provides a series of evenly spaced pulses, separated by accurately known times, which appear only between the two pulses of the pair from the double pulse generator.

Design Considerations

Double Pulse Generator (refer to Circuit diagram appendix 4)

Relaxation Oscillator

The period of oscillation is very nearly proportional to the value (R_1+R_2) (C_1+C_2). Various values of C_1 can be selected by means of a multiple position switch Range Pulse Recurrence. For a given setting of this, the period of oscillation may be continuously varied by the Fine Control potentiometer R_1.

Five values of C_1 were chosen so that the range from sixteen cycles per second to eleven hundred cycles per second is covered in overlapping steps. The frequency of oscillation is not so stable as that for a sinusoidal oscillator. This point is not critical however, since there is no need for great accuracy in the pulse recurrence rate.

The signals are taken from the cathode which provides a low impedance source. The coupling condenser C_3 was chosen quite large (0.1 microfarads) in order to produce signals large enough to fire the univibrator. The signals which appear at the grid of the univibrator are about sixteen volts in magnitude with a rise time of a few tenths of a microsecond and a decay time of 0.5 microseconds. This latter value is determined by the time constant C_2R_3.

Univibrator

The duration of the quasi-stable state is roughly proportional to $R_{11}C_5$, for a given setting of the grid T_1. Hence, with suitable values of C_5, using a multiple position switch labelled Range Control Pulse Separation, together with the potentiometer R_9, the duration of the quasi-stable state may be varied continuously over a wide range from about two microseconds to sixteen miliseconds.

In the stable condition, tube T_2 is conducting and T_1 is cut off. This is obtained by means of the large resistor R_{33} which draws grid current from T_2. Thus T_2 draws about 6 milliamps and sits at about 210 volts or so. Plate T_1 sits at H.T. or 280 volts. The voltage range of the potentiometer R_9 is arranged so that at its maximum value, it is considerably less than the cathode voltage of T_1 (or T_2). This maintains the univibrator in a stable state in the absence of any positive triggering signal on the grid of T_1.

The circuit possesses the property that the duration of the quasi-stable state is dependent upon the relative voltage of grid and cathode of T_1. Hence the resistors R_{13} (cathode circuit) and R_6, R_7, and R_{10} in the voltage divider circuit are all cracked carbon. For the same reason, R_9 is a precision wound potentiometer. Similarly, the duration of the quasi-stable state is a function of $R_{11}C_5$, so R_{11} is also of cracked carbon.

With the univibrator initially in a stable state, the receipt of a positive pulse at the grid of T_1 triggers the tube T_1 so that it conducts. This reduces the voltage plate T_1 in a step-function, which in turn reduces the voltage on the grid of T_2 via C_5. This state is maintained until the condenser C_5 has time to recharge exponentially through R_{11} to a point where grid T_2 is high enough to allow T_2 to begin conducting again. At this point the circuit resumes its original stable condition. It is to be noted that the recovery to normal is not so rapid as the change over from normal to quasi-stable. This may be due to the fact that the signal triggering the tube T_1 to the quasi-stable state is a large pulse with a comparatively small rise time, giving the circuit a "hard fast punch" as it were; whereas, at some point in the recovery of C_5 to its normal state, the grid T_2 reaches a value where it just begins to conduct again. There is an absence of a sudden large postive swing in the grid of T_2 to force it back rapidly to its stable state of conduction.

In order to speed the rapid recovery of the grid T_2, the diode ½6AL5 was added to the circuit as shown. Its cathode voltage must be so arranged that during the stable period, it is non-conducting. The cathode voltage of the diode determines the grid voltage of T_2 which in turn determines the range of variation over which the grid of T_1 is operative, since it is limited on the upper side by the low setting of grid T_2 and on the lower side by the size of the input triggering pulse. The low grid settings also limit the current and thus the size of the rectangular waves.

From experiments, it was found that the optimum setting for the cathode of the diode turned out to be about seventy volts. This provided the largest amplitude of the rectangular waves, and the largest operative range for the grid of T_1.

The voltage regulator tube VR105 provides a constant voltage at C.

Stability depends upon voltage changes of supply and upon changes of components. These were minimized by using a well regulated positive supply line and cracked carbon resistors as shown in the circuit diagram.

Differentiator

The pulses produced by the differentiation of the rectangular waves are from four to five volts in magnitude, too small to fire a thyratron. Their small size is due to the relatively long rise and decay times of the rectangular waves.

Amplifier

Amplification of the differentiated pulses to about 50 volts distorts them considerably giving a long decay time of the order of 6 microseconds. The long decay time makes these pulses not suitable for meeting the requirements. However, they may be used as triggering signals to fire a thyratron whose output is not dependent upon the triggering signal where the latter is less than ten microseconds duration.

Thyratron

The thyratron produces large fast uniform signals in response to input signals of undersirable shape.

R_{23} and R_{31} are inserted in series with the input on the grids of the thyratron circuits in order to prevent excessive grid current being drawn during a discharge.

The main consideration with this circuit is the choice of R_{22} and C_{11} (and R_{26} and C_{14}). The time constant R22C11 must be small compared with the minimum time between signals in order to allow the circuit C_{11} to recover after discharging. The values chosen were 1.5 megohms and 500 picofarads or a time constant of about 250 microseconds. The fastest repetition rate is about 1100 per second or about one per 1000 microseconds, so that the condenser becomes charged satisfactorily before receipt of another signal. Another property of the thyratron which must be considered is its relatively long deionization time. For the particular tube chosen it is recommended that signals be separated by not less than 500 microseconds so that the requirement is met. This is one reason for having two thyratrons instead of one.

This output is taken from the cathode of the thyratron, providing a low impedance output. A signal of any desired magnitude up to 180 volts may be taken off via the cathode potentiometer. The rise time of the pulse produced is a few tenths of a microsecond, and the decay time about one microsecond.

<u>Mixer</u>

Provides a common low impedance output for both pulses.

<u>Pulse Marker Generator</u> (refer to block diagram appendix 3)

Since this is to provide evenly spaced pulses which will appear only between the two pulses of the pair from the double pulse generator, it is necessary to use the negative rectangular wave of the univibrator as a gating signal which will allow an L-C circuit to oscillate during the time between the pair of pulses. These oscillations are then "shaped" by two stages of amplification, each of which is overloaded so that square waves are produced. The square waves are then differentiated by a negatively biased-off differentiation circuit so that only the positive pulses appear. These are then fed into a cathode follower and out. So for each oscillation, one pulse appears out. The frequency of the oscillator can be adjusted in order to obtain the required time spacing between the pulses.

(Refer to circuit diagram appendix 5). The ordinary method of producing oscillations for a time determined by the width of the gating signal is shown on page 65 of Elmore. This uses a variety of the well-known Hartley circuit to provide current feedback. It requires the use of centre-tapped r.f. chokes for the frequencies 4 kc/sec., 20kc/sec., and 100 kc/sec. A modification of this method as shown in the circuit diagram for the pulsed oscillator does not require centre tapped r.f. chokes. Here, the feed-back is regenerative through the condenser C5. This arrangement is essentially an amplifier with no phase shift. The conditions for oscillation is for the gain to be 3 (G-3)-Elmore p. 64. In practice, however, it is found that with approximately that gain, the condenser C5 must be large enough to provide enough feedback without distorting the oscillations of the L-C circuit.

The remainder of the circuit consists of two amplifiers for shaping the sine waves into square waves, and finally a differentiator and cathode follower.

The action of the negative rectangular gating wave is to cut off the gate tube and allow an L-C circuit to oscillate. For frequency stability, the losses in the inductance L should be small, that is the Q of the oscillator should be high.

The negative rectangular wave from the univibrator into the pulsed oscillator is somewhat modified by serving as a gating signal. As the trailing edge travels back to a positive value, a point is reached where the grid draws current from the cathode, some of the oscillations thus getting fed onto the trailing edge of the negative gate. These in turn are fed back into the univibrator plate T1, and are amplified, differentiated with the negative rectangular wave. However, this signal which varies sinusoidally with the width of the square wave appears only with the second pulse and is small in comparison, having a maximum value of some 3 volts or so.

In order to make certain that the 6SF5 is off during the gating signal, the resistor R1 is tied to about 12 volts by a voltage divider from the 100 volt supply. This time constant is long enough to accept the maximum 15 millisecond wave without distorting it sufficiently so that it cannot cut off the tube 6SF5 for the whole 15 milliseconds.

Keeping the pulsed oscillator leads separated from the double pulse generator leads to the output plugs reduces cross-talk to a negligible amount.

Also, by tying all ground leads to the input ground, spurious oscillations via ground loops are kept from getting into the double pulse generator.

Calibration

Pulse Marker Generator -- adjustment of oscillator frequency.

Using two scalers to count the free running pulses from the pulsed oscillator, the adjustment of the frequencies is done by adjusting the condensers of the L-C circuits with trimmers. With the trimmers adjusted, the following observations were taken:

Freq. Desired kc/sec	Time secs	Counts	Av.No. Counts	Av. Freq.	% Dev. from Freq. Desired
4	60	240503 239973 240360	240279	4.004	1/10 of 1%
20	60	1198771 1201216 1201421	1200469	20.008	1/10 of 1%
100	20	2007764 2014928 1998322	2006971	100.348	3/10 of 1%

In all three cases three measurements were taken upon adjustment of condensers until at least one of each set was below the required frequency.

The error given is the mean deviation. The percentage error in the last case is higher since the time interval was shorter and the rate higher. The reason for the shortened time interval is that at this rate, the mechanical counter is being run at its maximum speed, namely ten movements per second and it is advisable not to maintain this rate too long if at all.

The values are all above the required frequencies but only by a very small percentage. More accurate adjustments may be made if required by successively taking a series of a large number of readings and adjusting the trimmer condensers. By this method it should be possible to obtain a high degree of accuracy.

The three oscillators thus provide a choice of calibration pips with any one of the intervals 10 microseconds, 50 microseconds, and 250 microseconds.

Due to a distortion in the initial part of the sine wave generated by the oscillator at the beginning of the gate, the first of pulses of the series is abnormally displaced. This, too, has been measured on the linear part of a CRO as follows:

10	microsecond pulses--first pip occurs	11 ± 0.5	microseconds
50	" "	48 ± 0.5	"
250	" "	200 ± 2	"

This is taken into account in using these pulses for calibration purposes.

Double Pulse Generator

Pulse Pair Recurrence Rate Adjustment and Calibration

Any one of five condensers on a multiple position switch may be used on the Range Pulse Recurrence.

The choice of condensers for C_1 is such that for the five positions of the Range Control Recurrence Rate, there is a complete coverage of frequencies from sixteen cycles per second to eleven hundred cycles per second. Each successive range control setting allows for an overlap of from about one-third to about one-half of the range of the previous setting. In this way, there is no gap in the continuity, and some frequencies may be obtained in two range settings.

The calibration curves for the Pulse Recurrence Rate are given in the appendix.

This calibration was done with an audio oscillator which may be accurate to within 5% or so, sufficiently accurate for the pulse recurrence frequency.

Pulse Pair Interval

The calibration was done for a H.T. voltage of 280. This is critical since the condenser C_5 recharges towards this value during the quasi-stable state of the univibrator, thus determining the length of that state or the interval between the pair of pulses.

The condensers C_5 on the multiple position switch Range Control Pulse Pair Interval are chosen with the voltage range covered by the Fine Control potentiometer R_9 to give a continuous coverage of pair intervals from about 2 microseconds to about fifteen milliseconds.

The calibration curves for the pulse pair interval are given on the graphs in the appendix.

The overlap from one range to another is such that every pulse pair interval from fifteen microseconds to 7.5 milliseconds may be obtained by using more than one range control setting.

In general, it is observed that for the larger condenser values of C_5 required to give comparatively long pulse pair intervals, there is quite a noticeable variation in interval with recurrence frequency. Over a long period of time, the voltage on a plate of the univibrator has the same average value regardless of the recurrence rate. Thus, at different frequencies of recurrence, for settings otherwise the same, the width of the rectangular wave varies somewhat.

This is a weakness of the circuit, particularly where large values of C_5 are used in order to get relatively long time intervals. Where there is variation with recurrence frequency, a calibration has been done for two repetition rates, a high rate and a low rate. For intervening repetition rates, it was found that linear interpolation is quite satisfactory. It was only for the sake of neatness that two curves are given.

Overshoot of Calibration Error.

A change of the setting of the grid of T_1 of the univibrator means that the square wave will not reach a stable state immediately. If the criterion that the average voltage on the plate must remain constant over a long period of time is to hold, then it follows that a change in the width of the square wave will mean a shift in the voltage on the plate. A certain time is required for it to be restored to the average value. This time, even for the maximum shift of the grid T_1, should not normally exceed one second.

However, another phenomena which cannot be explained by the above discussion, appears when time intervals making use of the 0.001 mfd condenser and larger on the univibrator are used. For an increase in the width of the rectangular wave, it tends to initially go beyond the value to which it finally settles down. For this reason, let us call it an overshoot. For large time intervals, this overshoot amounts to as much as 60 microseconds and requires about one minute to settle down to a steady value. This phenomena appeared only after the output thyrotrons were incorporated into the circuit. It may be necessary to shield the thyrotrons.

However, all calibrations were done for the steady state.

The maximum recurrence rate is determined by the time interval between the two pulses of the pair. In order to get correct results for finding paralysis times, the operator must be careful to see that the pulse separation is less than half the time interval between the first pulse of two succeeding pairs.

<u>Estimate of Probable Error</u>

There are three factors to be considered:

a- The error in the marker pulse intervals, estimated to be about a few tenths of one percent.

b- The error introduced in the measurement of a length to determine the interval between the two members of the pair with the marker pulses present. This error may be of the same order of magnitude as the error introduced by a-, about a few tenths of one percent.

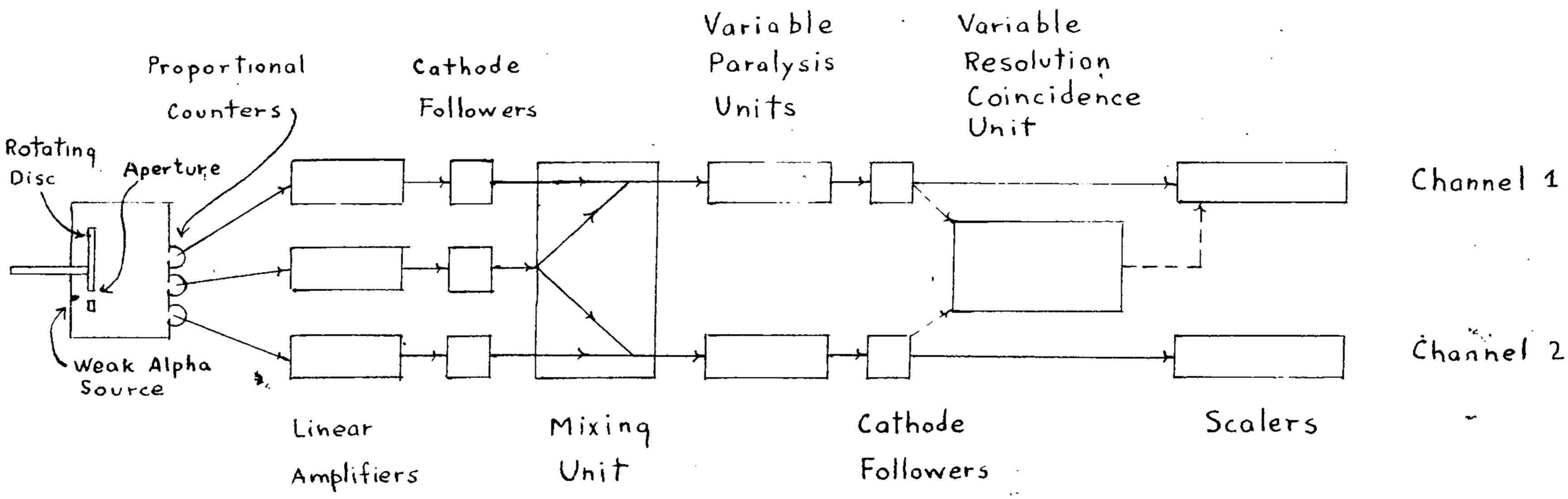
c- The error introduced by the phenomena of overshoot which may be reduced to a very small quantity also by allowing enough time to elapse before a measurement is taken.

d- Variation of resistor values in timing circuits due to temperature changes. Wherever this is likely to occur, cracked carbon resistors have been used which will vary no more than 1%. Thus, the instrument should be capable of measuring resolving times to an accuracy of approximately 1%.

It is suggested that the best way of measuring a particular resolving time is to average several independent readings.

Conclusion

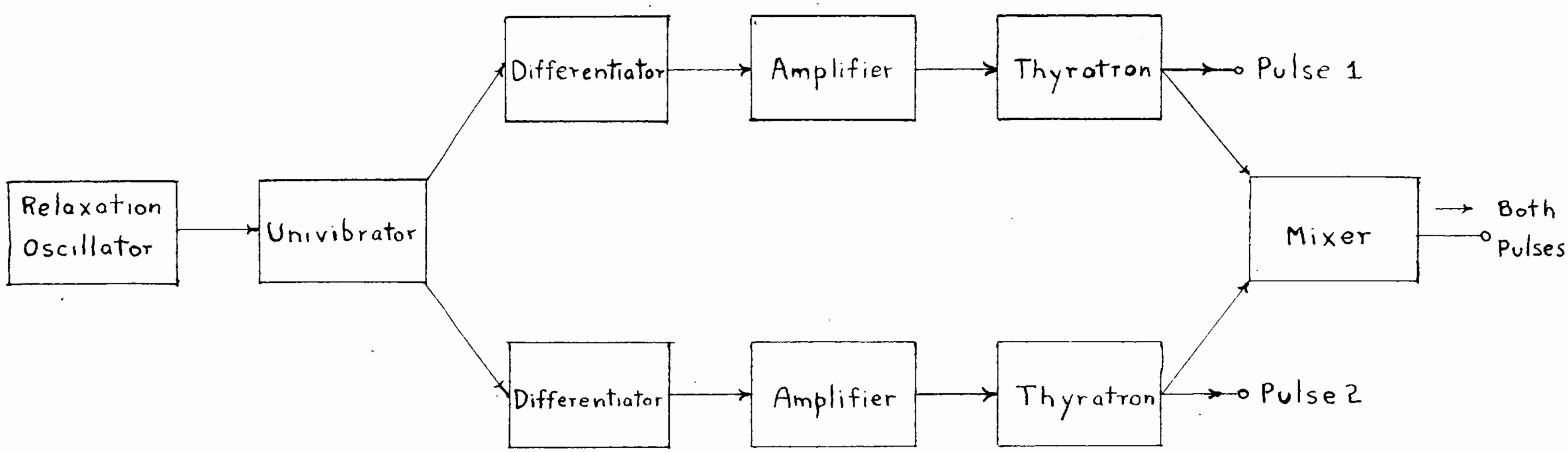
The double pulse generator built under this design meets the requirements, but possesses two outstanding weak points: the pulse pair time interval varies with recurrence frequency for relatively long time intervals, and the phenomenon of overshoot occurs for relatively long time intervals. Although this latter weakness may be eliminated by the shielding of the thyratrons, the first weakness is a weakness of the design. It is therefore submitted that this design is not so suitable as it might be for producing pairs of pulses separated by times much larger than 100 microseconds.



Experimental apparatus for a study of the expected loss rates in the counting of particles from pulsed sources.

Block Diagram

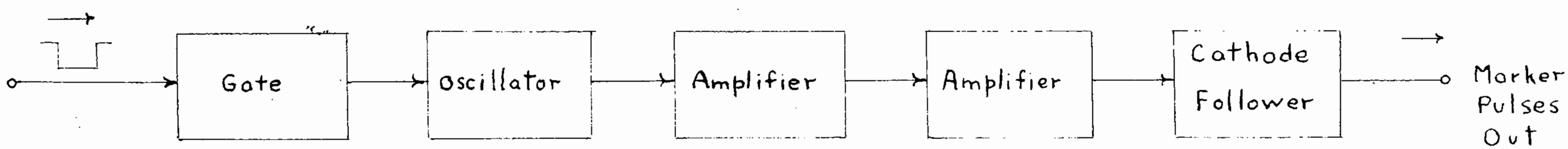
Appendix 1



DOUBLE PULSE GENERATOR

Block Diagram

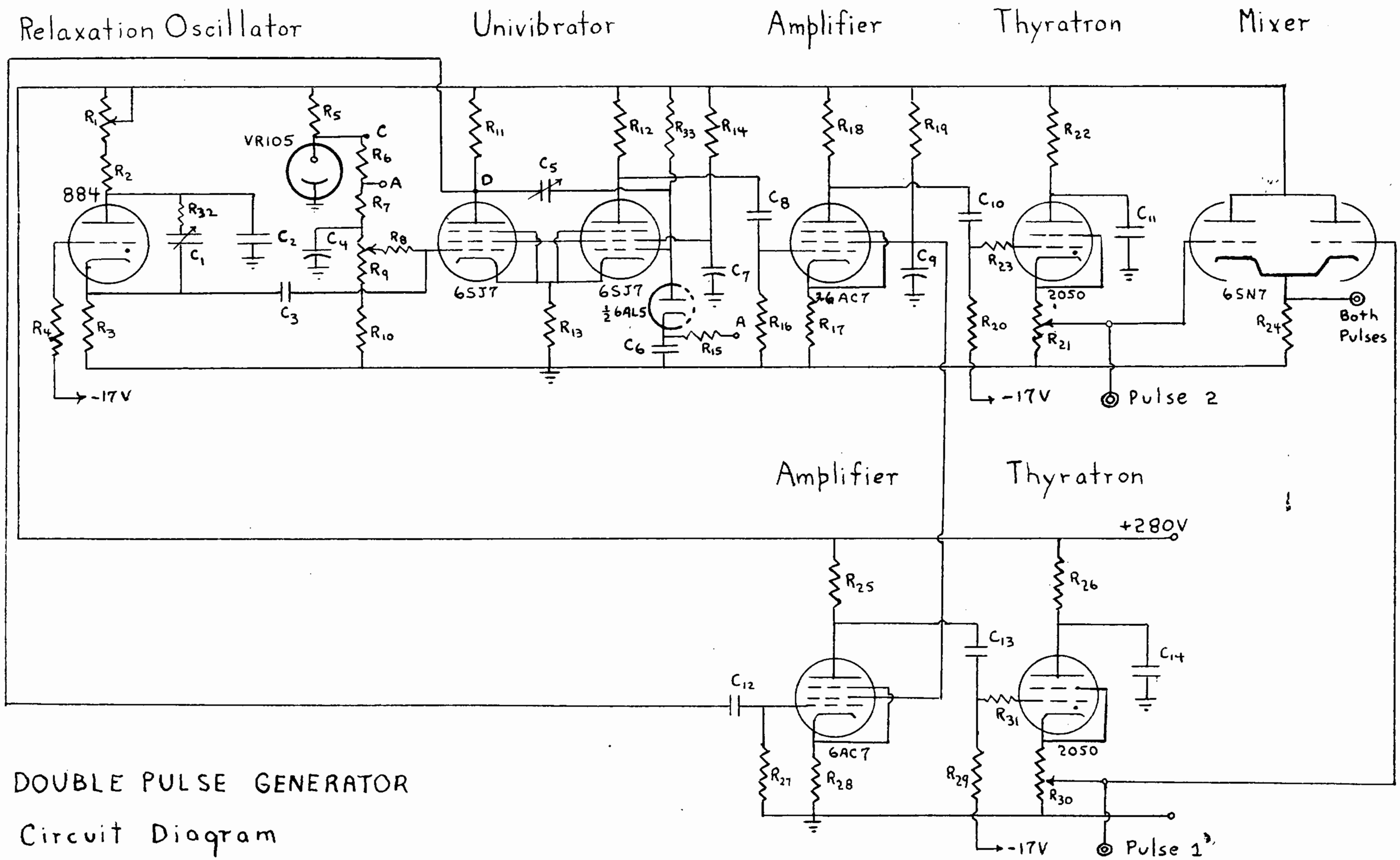
Appendix 2



PULSE MARKER GENERATOR

Block Diagram

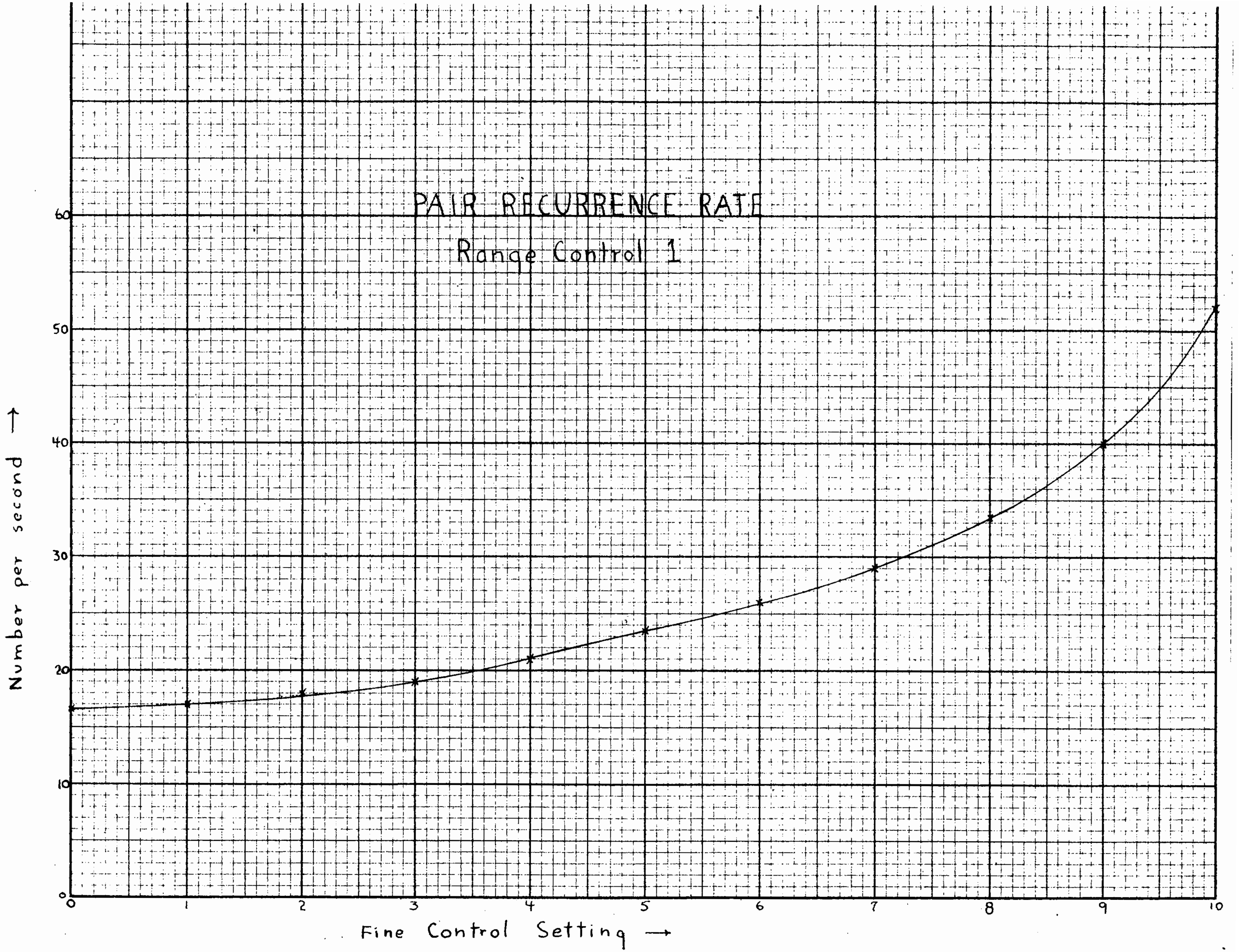
Appendix 3

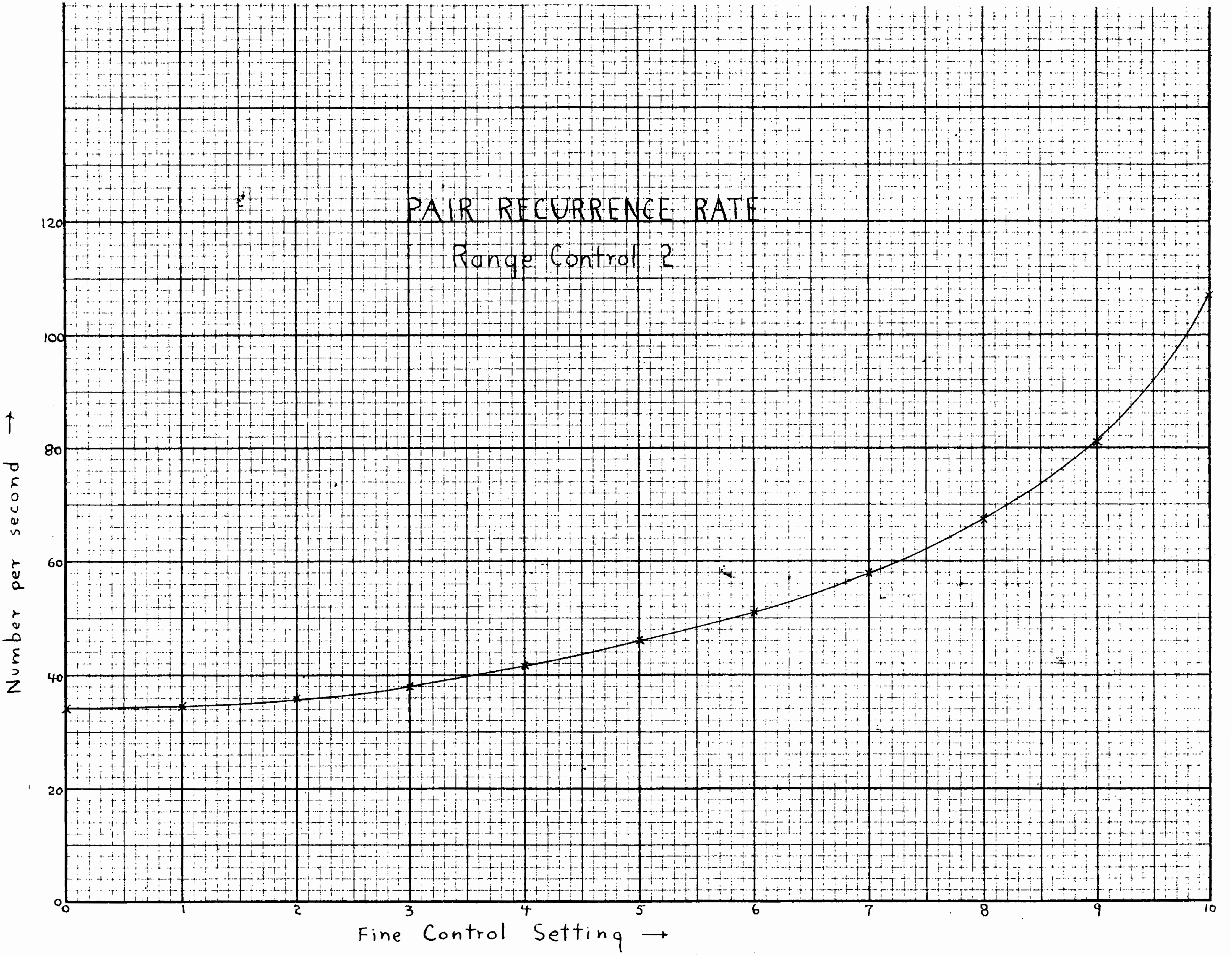


DOUBLE PULSE GENERATOR

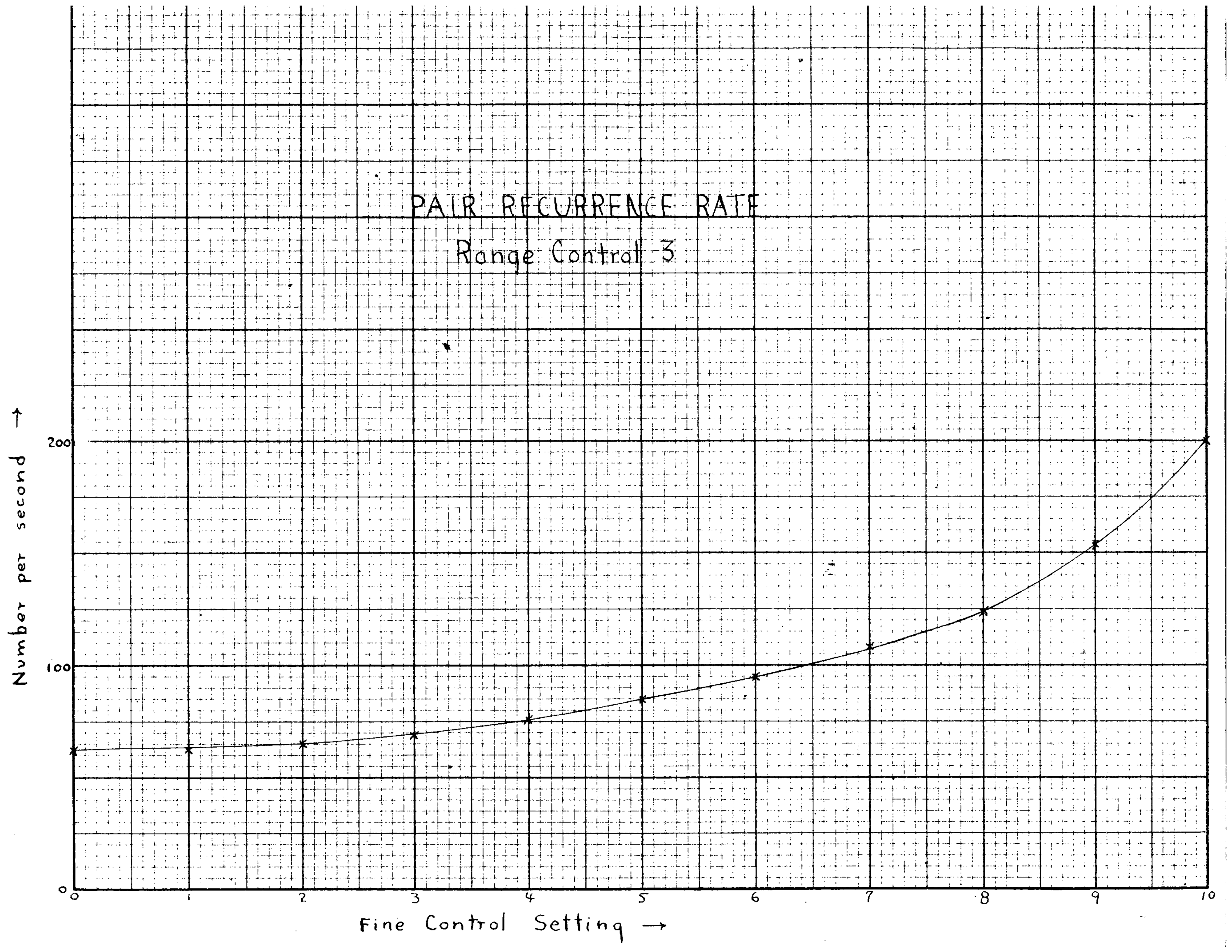
Circuit Diagram

Appendix 4

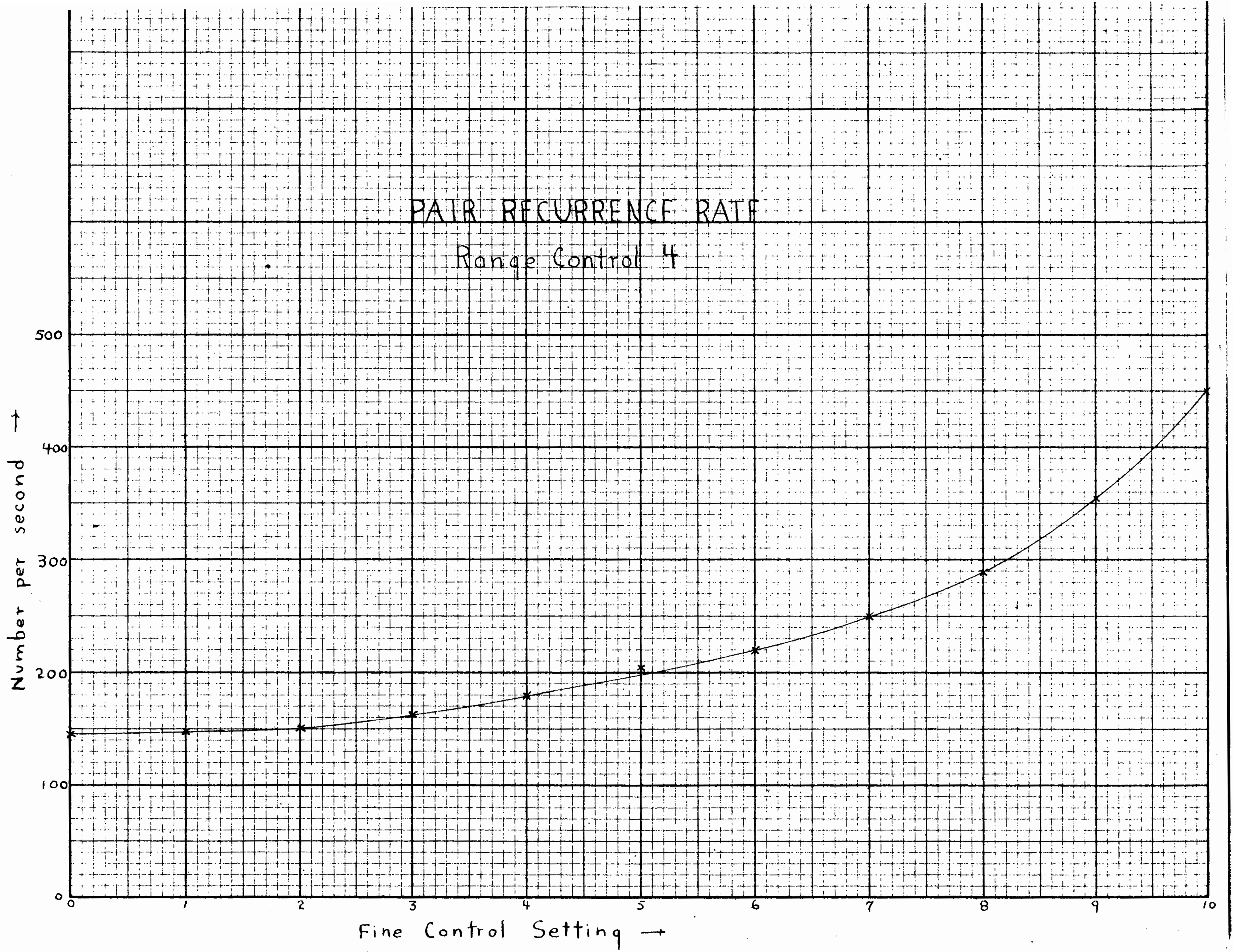

PAIR RECURRENCE RATE
Range Control 1
Number per second →
Fine Control Setting →
0
10
20
30
40
50
60
0
1
2
3
4
5
6
7
8
9
10



PAIR RECURRENCE RATE
Range Control 2
Number per second →
Fine Control Setting →
0
20
40
60
80
100
120
0
1
2
3
4
5
6
7
8
9
10



PAIR RECURRENCE RATE
Range Control 3
Number per second →
200
100
0
0
1
2
3
4
5
6
7
8
9
10
Fine Control Setting →


PAIR RECURRENCE RATE
Range Control 4
Number per second →
Fine Control Setting →
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500
0
1
2
3
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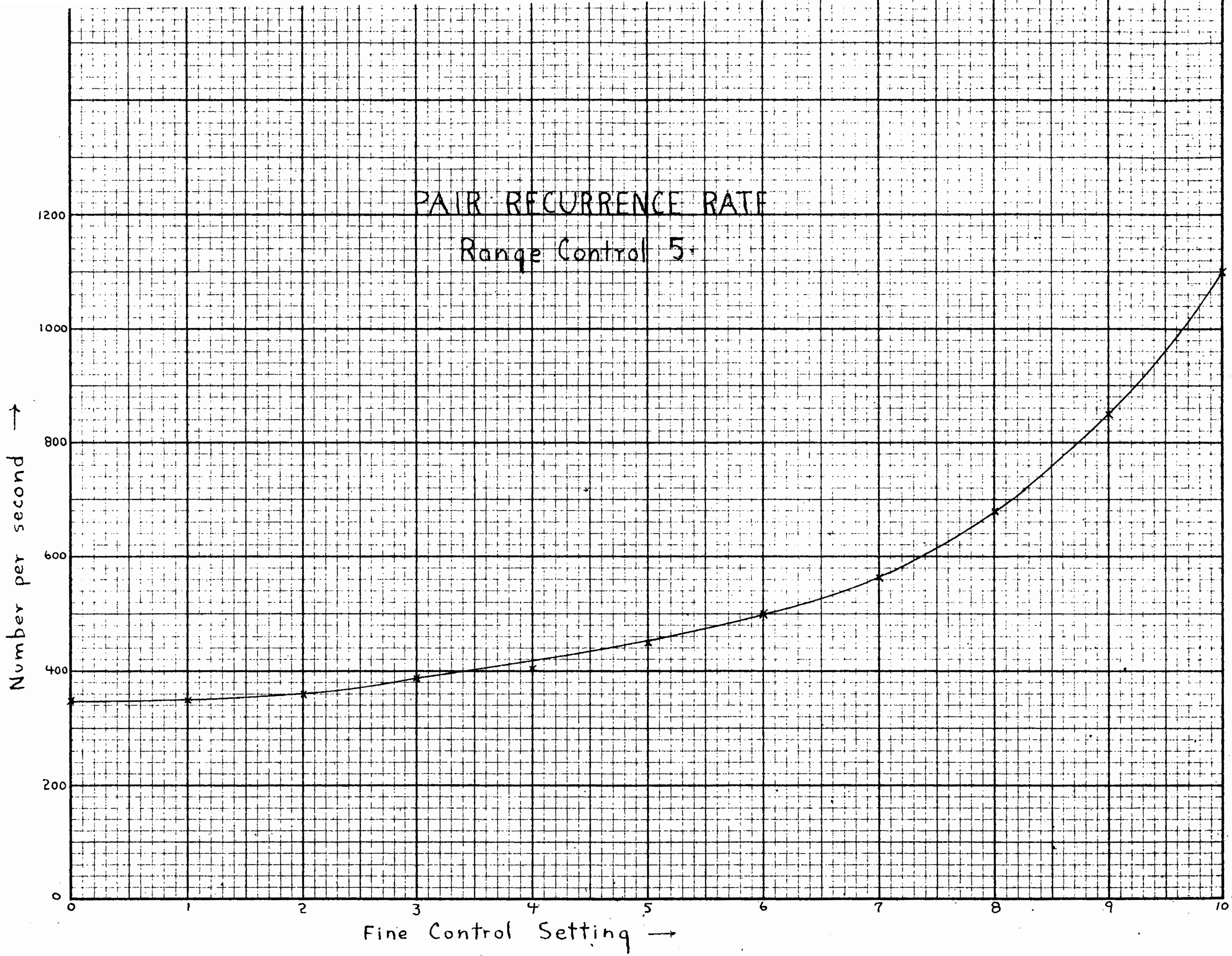
6
7
8
9
10


PAIR RECURRENCE RATE
Range Control 5
Number per second →
Fine Control Setting →
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800
1000
1200
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1
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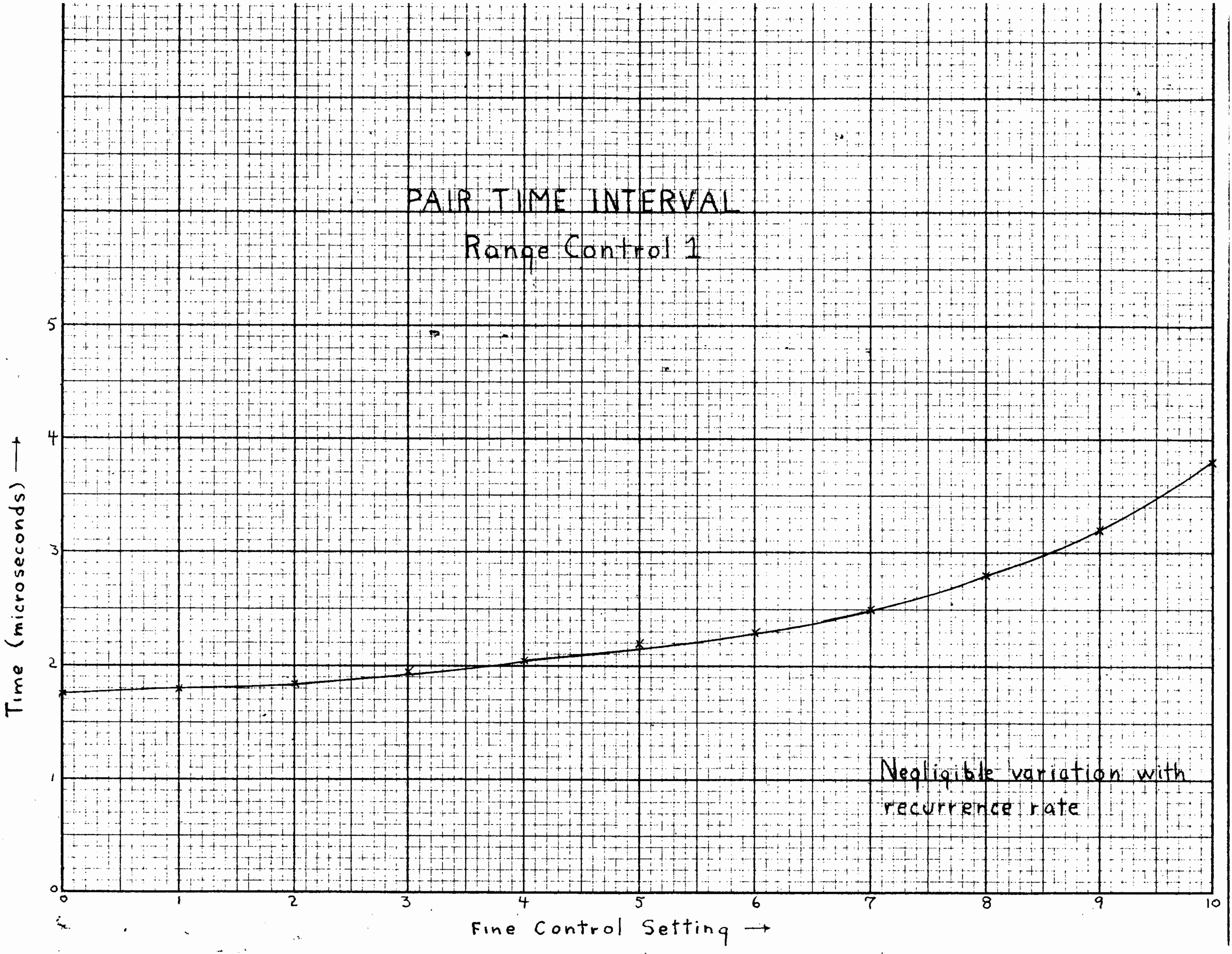
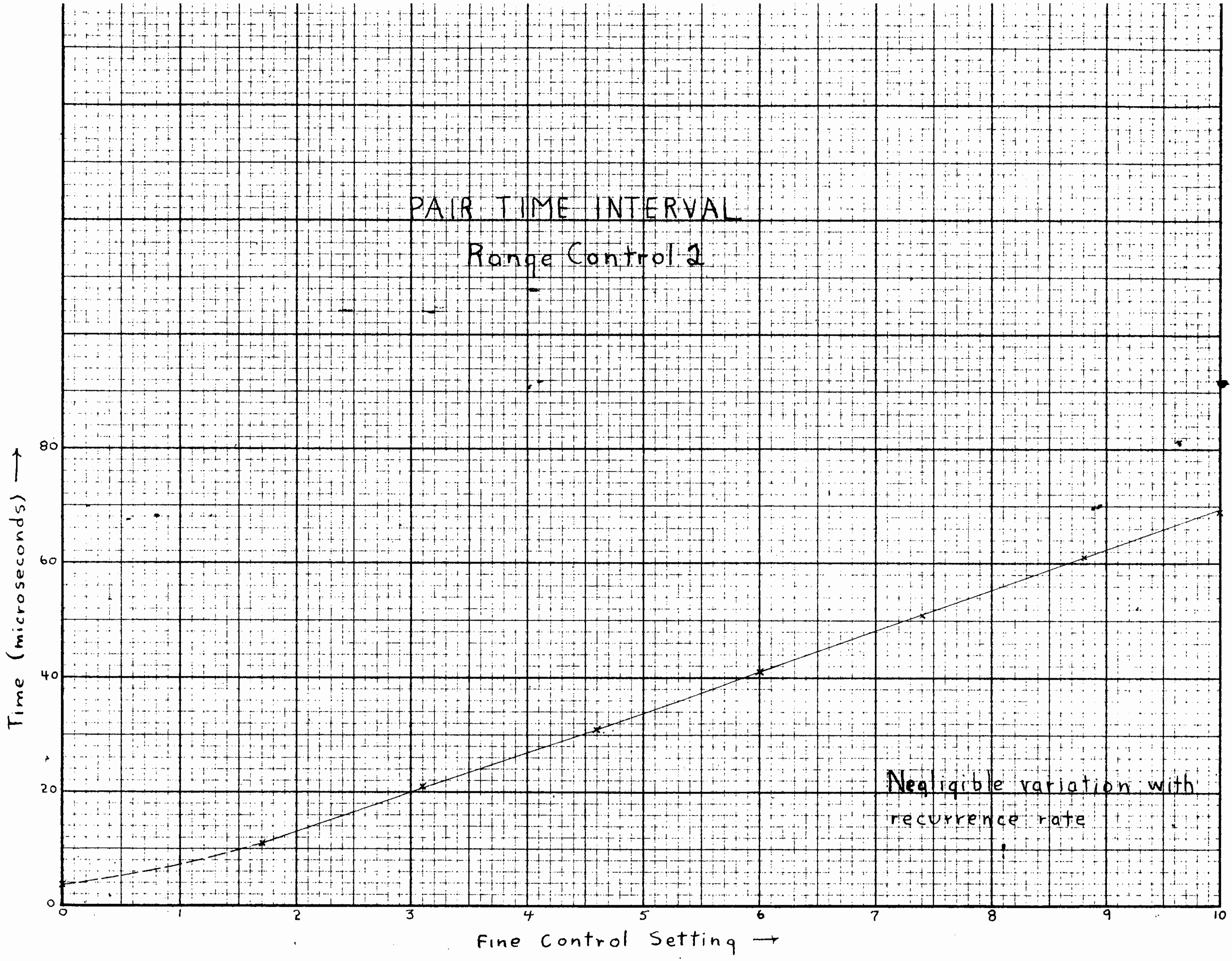
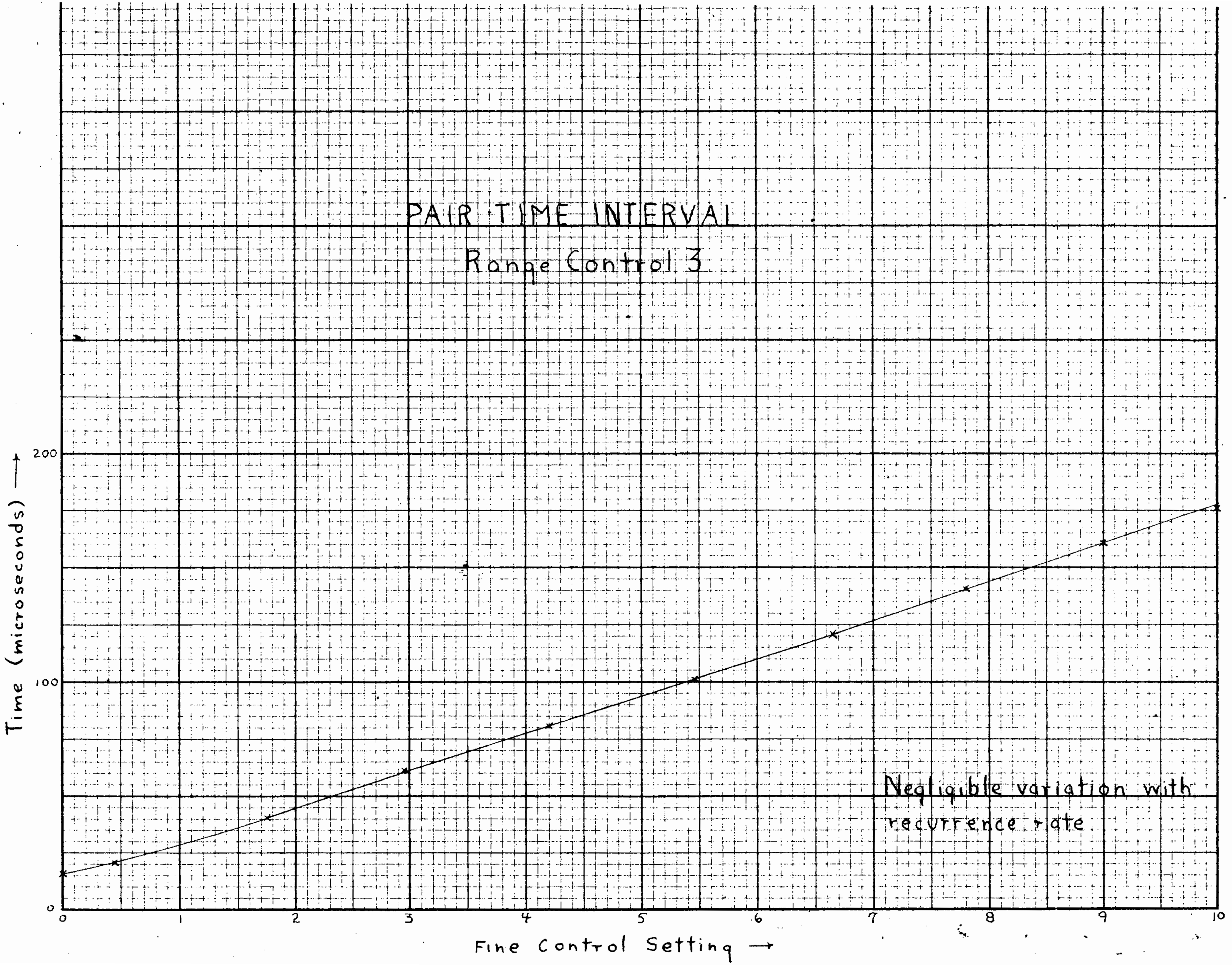
6
7
8
9
10



PAIR TIME INTERVAL
Range Control 1
Time (microseconds) →
0
1
2
3
4
5
6
7
8
9
10
Fine Control Setting →
Negligible variation with recurrence rate


PAIR TIME INTERVAL
Range Control 2
Negligible variation with recurrence rate
Time (microseconds) →
0
20
40
60
80
0
1
2
3
4
5
6
7
8
9
10
Fine Control Setting →


PAIR TIME INTERVAL
Range Control 3
Negligible variation with
recurrence rate
Time (microseconds) →
200
100
0
0
1
2
3
4
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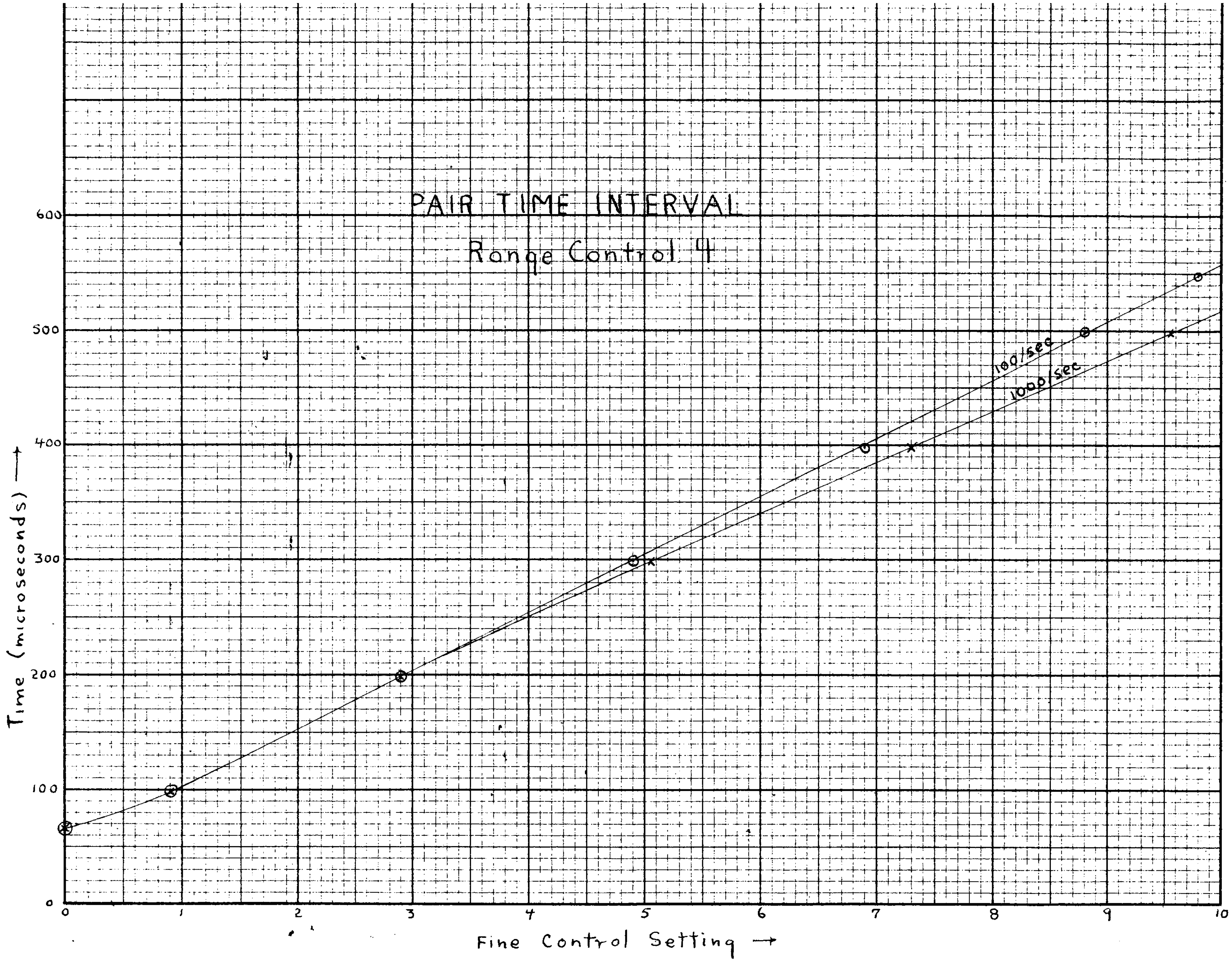
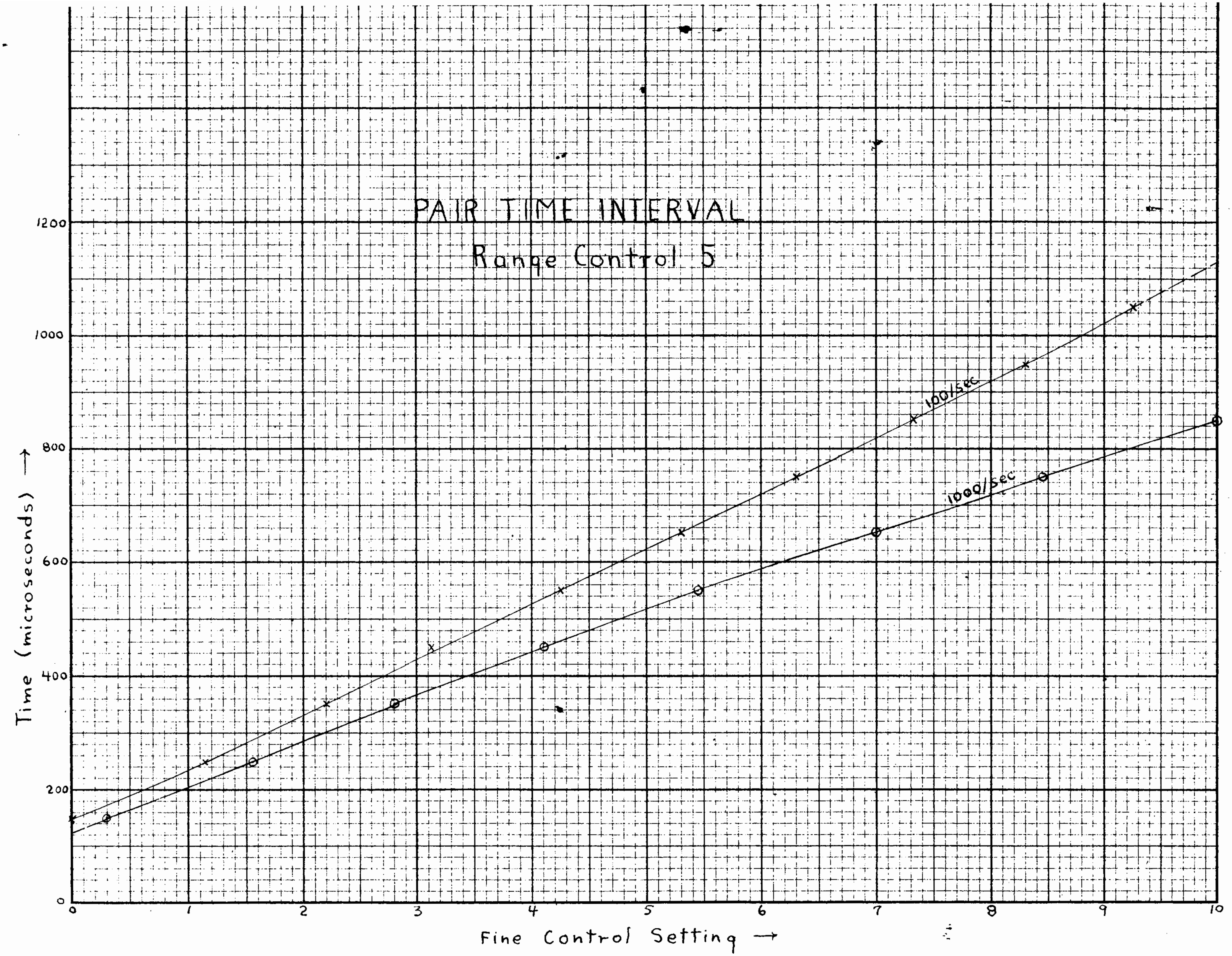
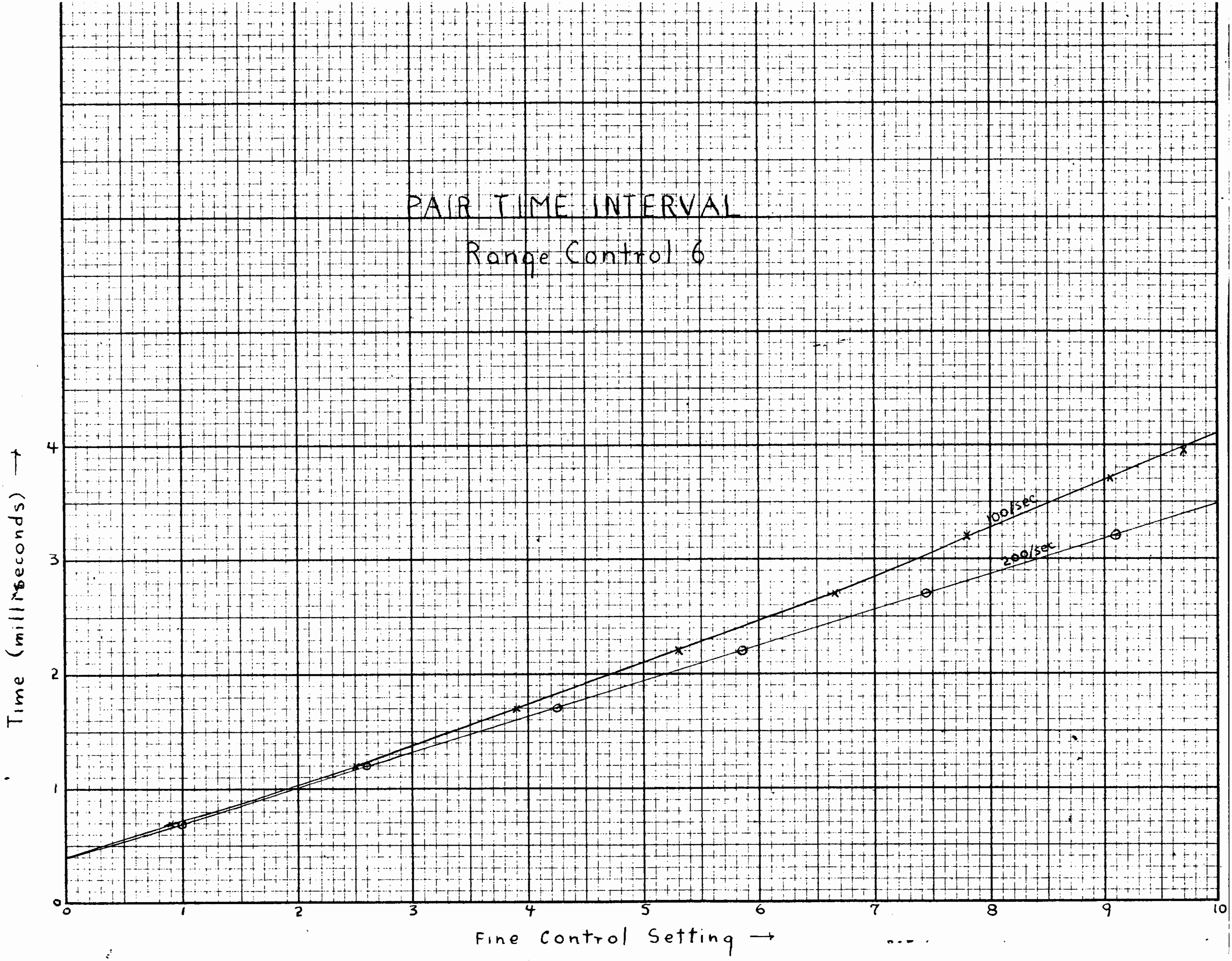
6
7
8
9
10
Fine Control Setting →

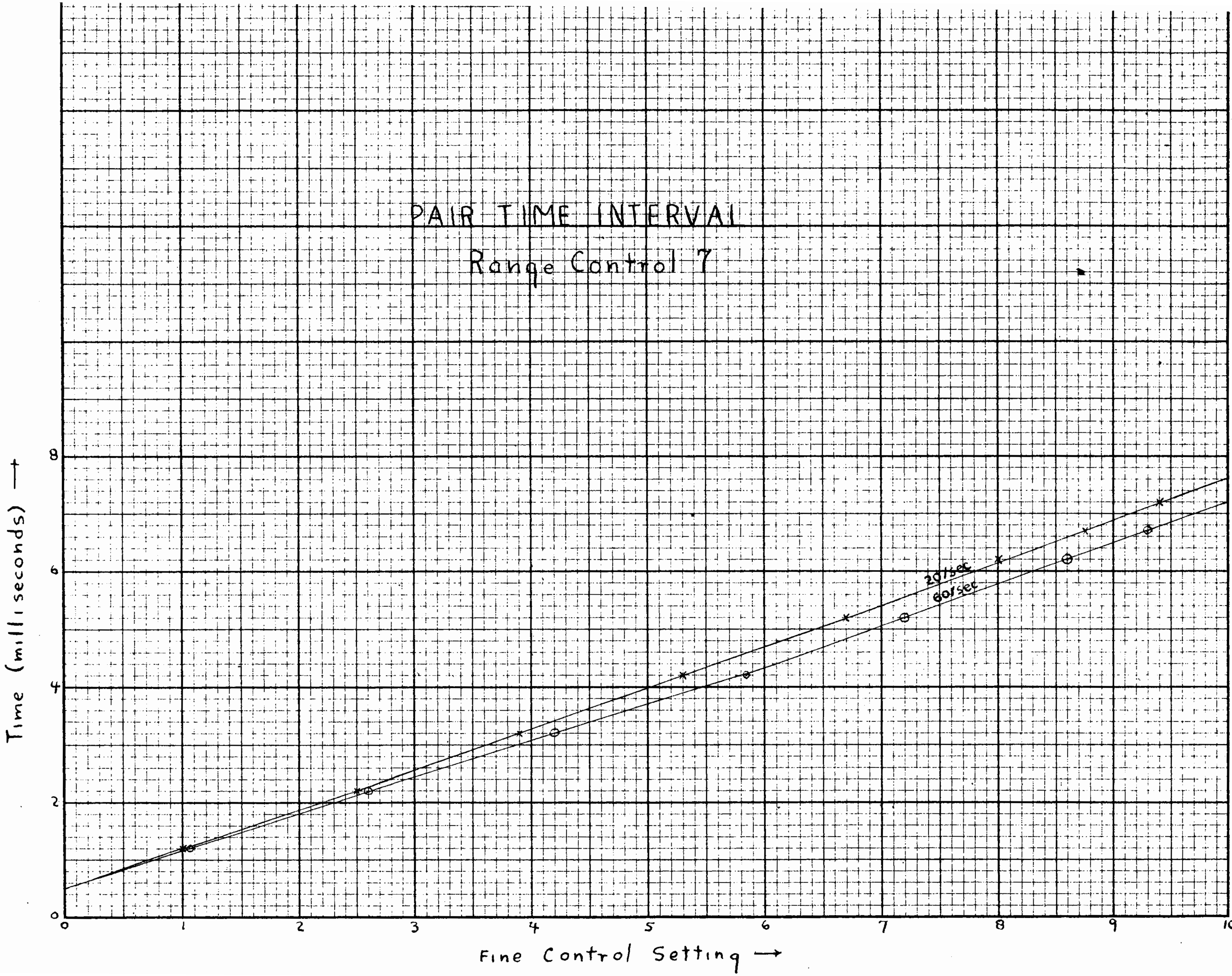


PAIR TIME INTERVAL
Range Control 4
100/sec
1000/sec
Time (microseconds) →
Fine Control Setting →
0
100
200
300
400
500
600
0
1
2
3
4
5
6
7
8
9
10

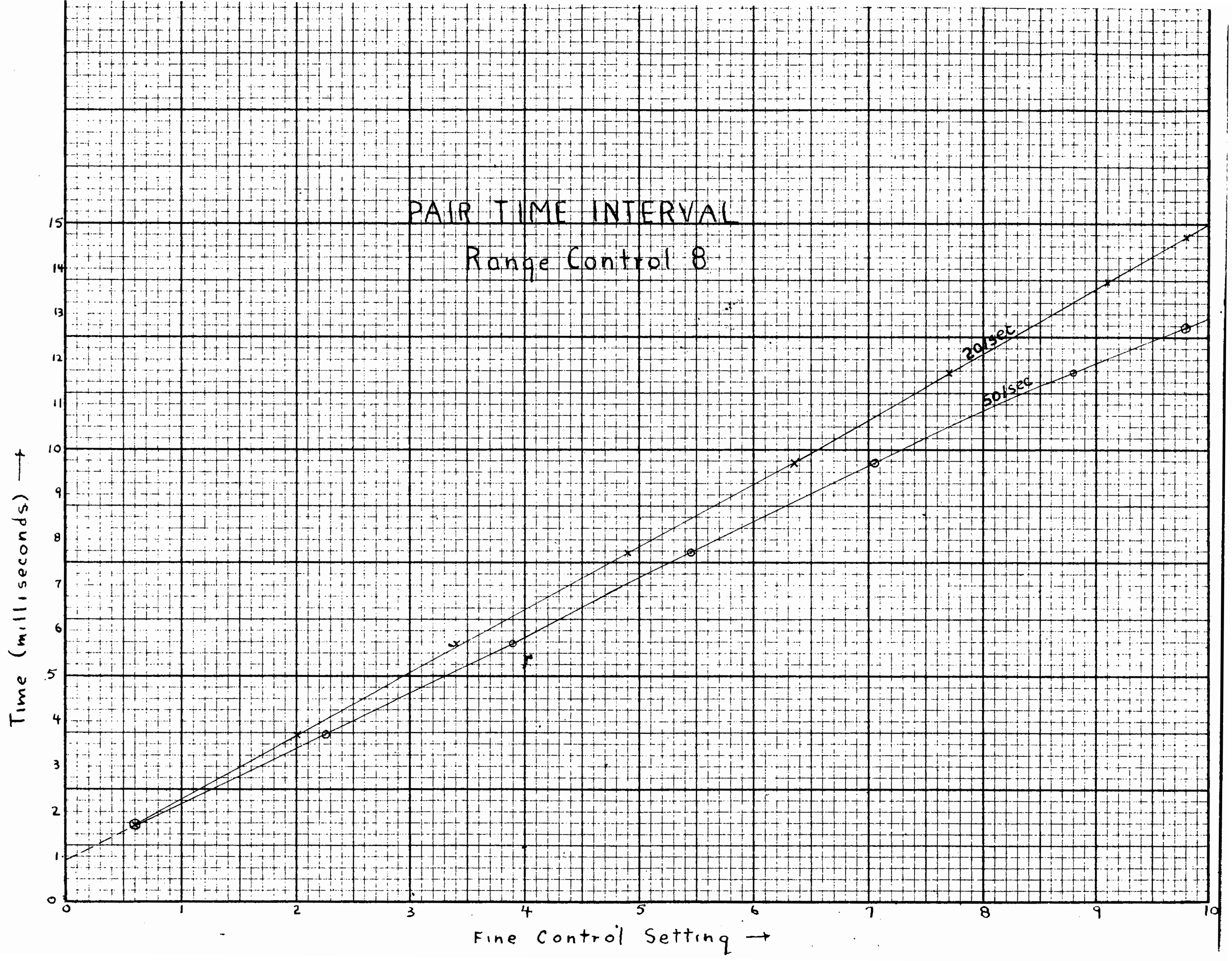

PAIR TIME INTERVAL
Range Control 5
100/sec
1000/sec
Time (microseconds) →
Fine Control Setting →
0
200
400
600
800
1000
1200
1
2
3
4
5
6
7
8
9
10



PAIR TIME INTERVAL
Range Control 6
100/sec
200/sec
Time (milliseconds) →
0
1
2
3
4
0
1
2
3
4
5
6
7
8
9
10
Fine Control Setting →



PAIR TIME INTERVAL
Range Control 7
20/sec
60/sec
Time (milliseconds) →
Fine Control Setting →
0
2
4
6
8
1
3
5
7
9
10



PAIR TIME INTERVAL
Range Control 8
20/sec
50/sec
Time (milliseconds) →
Fine Control Setting →
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Appendix 5

List of Components

Double Pulse Generator

Resistors

R_1	1M		Potentiometer
R_2	330K		
R_3	1K	1 Watt	
R_4	22K		
R_5	7K	4 Watt	
R_6	37.5K (cc)		
R_7	7.5K (cc)		
R_8	22K		
R_9	20K		Precision Potentiometer
R_{10}	50K (cc)		
R_{11}	10K (cc)		
R_{12}	6.8K		
R_{13}	10K (cc)	1Watt	
R_{14}	3.3M (cc)		
R_{15}	22K		
R_{16}	50K		
R_{17}	200	1 Watt	
R_{18}	10K	1 Watt	
R_{19}	22K		
R_{20}	220K		
R_{21}	1K		Potentiometer
R_{22}	0.5M	1Watt	
R_{23}	10K		
R_{24}	5K	1 Watt	
R_{25}	10K	1 Watt	

Appendix 5 continued

Double Pulse Generator

		Resistors	
R_{26}	0.5M	1 Watt	
R_{27}	50K		
R_{28}	200	1 Watt	
R_{29}	220K		
R_{30}	1K		Potentiometer
R_{31}	10K		
R_{32}	500		

(cc) - Cracked carbon

Appendix 6

Condensers

C_1 Variable in steps by the Range Pulse Recurrence Switch.

Switch Setting	Condenser
1	0.05 uf.
2	0.02
3	0.01
4	0.005
5	0.0015

C_2 500 Pf.

C_3 0.1 uf.

C_4 8 uf. (electrolytic).

C_5 Variable in steps by the Range Control Pulse Separation Switch.

Switch Setting	Condenser
1	No condenser
2	150 pf.
3	410 pf.
4	0.001 uf.
5	0.003 uf.
6	0.01
7	0.02
8	0.04
9	No condenser

C_6 0.01 uf.

C_7 0.5 uf. electrolytic

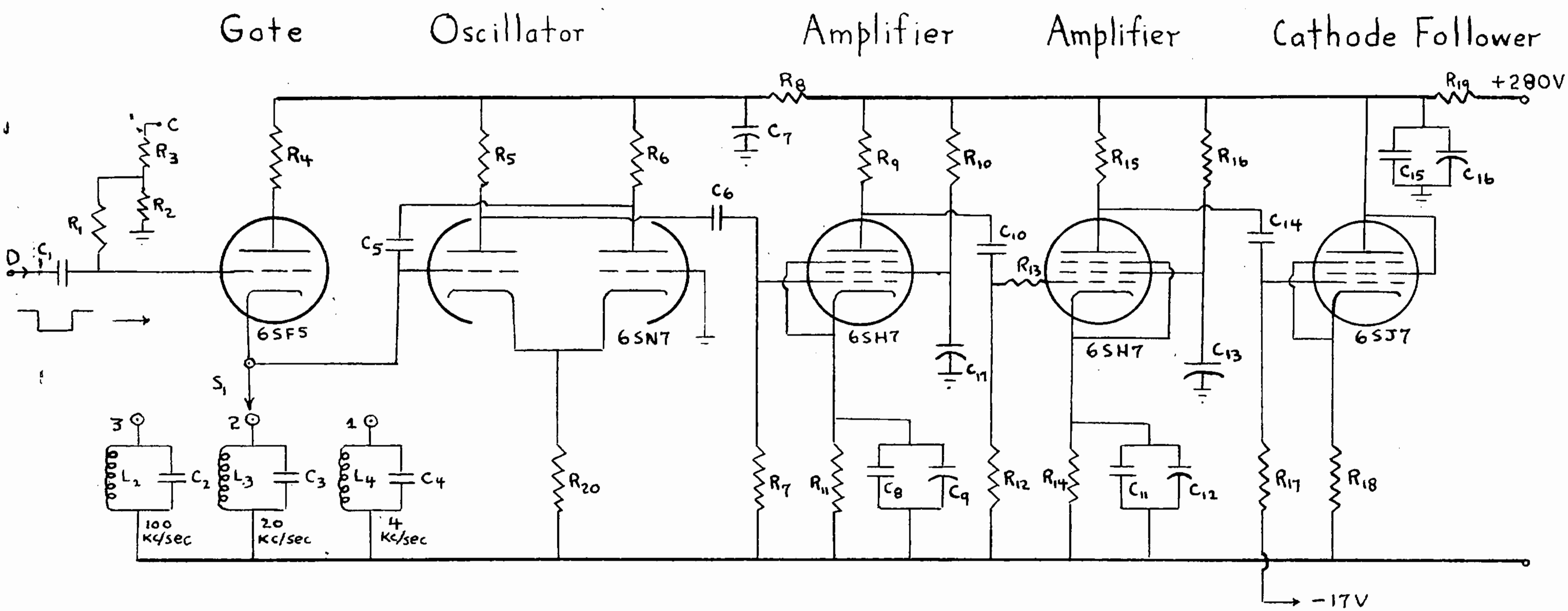
C_8 10 pf.

C_9 8 uf. electrolytic

C_{10} 0.003 uf.

Appendix 6 - continued

C_{11}	500 pf.
C_{12}	10 pf.
C_{13}	0.003 uf.
C_{14}	500 pf.



PULSE MARKER GENERATOR

Circuit Diagram

Appendix 7

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