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DELAY LINE MANUFACTURE

ROLAND M. BENDEL

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DELAY LINE MANUFACTURE

by

Roland M. Bendel

Lieutenant, United States Navy

Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE
IN
ENGINEERING ELECTRONICS

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the thesis requirements for the degree of

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PREFACE

All laboratory work performed in connection with this paper was done at Brubaker Electronics, Incorporated, Los Angeles, California.

The writer wishes to thank Mr. Royal V. Keeran and all other employees at Brubaker for making his tour there a most enjoyable experience.

The writer also wishes to thank Mr. Earl G. Goddard of the U. S. Naval Postgraduate School for his help in the preparation of this paper.

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CHAPTER I

INTRODUCTION

The nature of delay lines is such that their production in limited quantity is an expensive undertaking. The principal cause of this expense is the close tolerance specifications ordinarily associated with experimental equipments. Some of the delay line characteristics with which these specifications are concerned are:

1. Characteristic impedance
2. Electrical configuration
3. Absolute delay
4. Band pass
5. Input pulse
6. Reflection characteristics
7. Attenuation
8. Distortion
9. Volumetric displacement
10. Physical configuration
11. Weight
12. Environmental tests
13. Electrical connections

Since nearly every delay line requirement involves particular characteristics for each of the above quantities, it becomes economically impractical to manufacture "standardized" delay lines from which the design engineer can make a suitable selection.

A typical delay line requirement may originate in the following manner:

A design engineer developing a piece of electronic equipment finds that a delay line having certain characteristics will best meet his requirement in a particular electronic circuit. He then states the necessary characteristics and attempts to find a delay line which may be used in his application. Very often he will be unable to obtain the line meeting his requirements from normal commercial sources. Since the equipment on which he is working may be experimental, he will require possibly only one delay line. If the organization for which he is working considers his need warranted, the organization will either attempt to construct a suitable delay line for him, or it will state his requirements to delay line manufacturers and request bids for its construction. In the latter case the organization may find that the price asked by the delay line manufacturers prohibits its use. A single delay line having rather close specifications can easily cost over a thousand dollars and may increase the cost of the equipment for which it is intended by as much as 100 percent. In this event the design engineer may drastically change his requirements, or he may go to a different method of obtaining his delay.

In the light of the discussion of the previous paragraph, it is well to consider why the cost of manufacturing a single delay line should be so high.

It is a fact that the problems of delay line manufacture are not generally well understood by the electronics industry. The theoretical formulae for determining the electrical configuration of delay lines are well known, but nearly every line involves many inductive and capacitive components, and the close physical relationship of these components, as required by modern applications, makes stray capacity and mutual inductance become such a significant part of the total reactance that the simple design formulae become essentially useless.

The successful manufacturers of commercial delay lines rely almost entirely on empirical design criteria. They cannot rely on a single electrical configuration such as M or pi section or distributed lines. They must be well balanced in application of any theoretically possible configuration, and they must have vast practical experience with all types in order to intelligently bid for contracts. The result is that an organization engaged in the manufacture of delay lines has a few well-experienced men who do nearly all design work. These men are artists in every sense of the word.

Let us consider a typical series of events that may occur in the organization of a delay line manufacturer upon receipt of a request for a bid to construct one delay line. Assume that the agency requesting the bid has made the following specifications for the line:

1. Characteristic impedance 560 ohms.
2. Absolute delay one microsecond, plus or minus 0.01 microsecond.

3. Line to pass all frequency components to twenty megacycles. (Down to 3 db at 20 megacycles.)
4. Input pulse 0.1 microsecond, 50 volts positive amplitude, rise and fall time 0.03 microsecond, less than 10 percent overshoot or undershoot.
5. Repetition frequency 1500 cps.
6. First reflection to be down 40 db when line is terminated in 560 ohm, 2 watt, carbon resistor.
7. Output distortion less than 10 percent.
8. Rectangular physical configuration 2" x 3" x 4".
9. Unit to weigh less than three pounds.
10. Unit to maintain delay characteristics throughout military tests nos.-----, -----, -----, -----.
11. Case to be common ground.
12. Input and output connections via BNC UG-290/U connectors located at center of each 2" x 3" face of case.

It is pointed out that the above specifications are not excessively complex since delay line specifications often require multiple taps and unusual physical configurations.

In bidding for the contract to construct this delay line, the manufacturer may have several motives. One motive may be influenced by his knowledge of the equipment for which the line is intended. If it appears that successful construction of this equipment will result in an order for a number of similar lines at a later time, he may be willing to accept a

loss on the prototype. However, if it appears that successful completion of the equipment will result in a request for an unusually large number of the lines, he may feel that he would be able to successfully absorb the development costs at that time, although another manufacturer has made a prototype. It may occur that the equipment for which the line is intended is of a classified nature, and all information as to its purpose will be denied him. In this event he will have to consider the request for a single delay line by itself and bid solely on the basis of making a reasonable profit on this unit. Unless he is particularly anxious to provide work for his laboratory, he will probably not consider undertaking the construction unless his profit is substantial.

As will be seen, the actual construction and testing of a line is quite expensive. If this expense could be considerably reduced, the manufacturer could bid favorably on single-item contracts and perhaps have a lucrative business on these contracts alone. Considerable effort is made by Brubaker Electronics, Incorporated, to do this. The following is a description of their manufacturing process.

Specifications are studied by the design engineer. Drawing heavily on his past experience and on the company's empirical design file, he produces a schematic and physical component arrangement. The delay line laboratory then constructs the line. Progress to this point is relatively rapid, and it may appear that the line is essentially ready for shipment. However, experience has shown that progress to this

point of manufacture requires only about a half of the total time between design and shipment. It is the last half of the period that adds the unusual expense to delay line manufacture, and it is here that new techniques may greatly increase the manufacturer's profit.

On completion of construction by the delay line laboratory, measurements are made on the line. It is perhaps surprising that at this point the line invariably passes all specifications except delay. However, it is evident that if the line did not pass all specifications except delay, a completely new line would have to be constructed, and the days already spent would be wasted. In this event there would certainly be no profit from the venture.

Absolute delay is rather easily adjusted to meet specifications by changing the position of the output tap to different sections of the line.

Most frequently the electronic components of the line will be placed in a suitable container meeting physical requirements and then potted. After potting, it is, of course, impossible to make any further adjustments to the line, but the potting itself will make small changes in the distributed capacity and mutual inductance. Where delay specifications are exceedingly rigid, these changes are significant, and due allowance must be made for them. The process involves building and testing the unpotted line to an "out-of-spec" tolerance, and then relying on the container and the potting com-

pound to bring the line "in-spec." Once again the experience and art of the design engineer is most important.

After potting, the line is sent to test, and on completion is shipped.

At this point the reader may well ask why the procedure is expensive. The answer lies in the means of delay measurement, which can be a tedious and time-consuming procedure. The method of measuring the delay of a particular line is not readily apparent. When first considered, a person may think of several methods. It is the writer's opinion that if a hundred engineers were given the problem, there would be nearly as many solutions. In Chapter III the method used by Brubaker Electronics will be described. First, let us consider some of the requirements of a measuring technique.

1. The measuring technique must be at least as efficient as techniques used by competitive manufacturers. If the manufacturer intends to make a substantial profit by his method of delay measurement, his technique must be greatly superior to his competitor's.

2. The measuring technique must be quite versatile since the types of lines that may go under test are limited only by the imaginations of the country's design engineers.

3. The measuring technique must have a high order of accuracy. Modern applications require that this accuracy be approximately 0.1%, and this often requires measurements of delay to a few milli-microseconds.

4. The measuring technique must be reliable. Modern delay line applications require that they pass rigid military tests with regard to vibration, atmospheric pressure, temperature, and humidity. The equipment necessary to make these tests is expensive, and any failure of the measuring equipment during a run will void the test. In this event the manufacturer can easily lose his profit.

CHAPTER II

DESIGN OF A DELAY-LINE MEASURING INSTRUMENT

The work performed by the writer in connection with this paper was the design of a test instrument suitable for making delay line measurements and embodying the desirable qualities of such an instrument as indicated in Chapter I. A block diagram of the device in use by Brubaker Electronics at the time work was started by the writer is givenin Figure 1. This instrument satisfied nearly all requirements except those of reliability. The following is a description of the characteristics of the instrument:

PULSE	
Duration	.01 to 10 usec
Rise and fall time, variable	.02 to 0.1 usec
Repetition rate	1 to 10 kc
Amplitude variable in five steps	10 to 40 volts positive
Delay	0 to 50 usec with respect to sync output
Impedance	nominal 100 ohms
SYNC	
Duration	1.0 usec
Rise time	0.1 usec
Amplitude	20 volts positive
Delay	0 to 50 usec
MARKERS	
Spacing	1.0 and 0.1 usec
Amplitude	50 volts negative

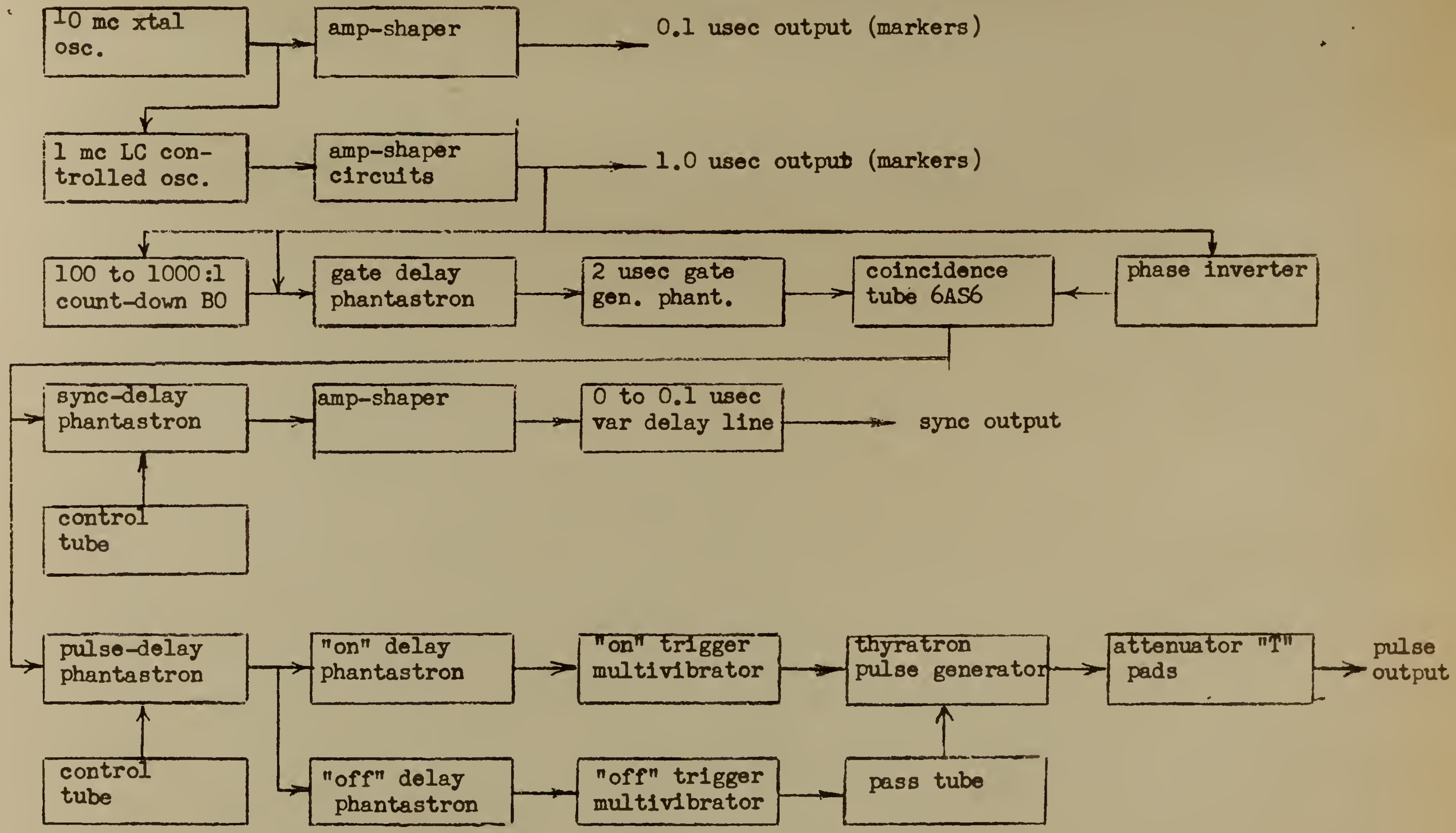

Figure 1. Original Marker-Pulser, simplified block diagram.

The initial phase of work consisted of critically examining these characteristics to determine if they were adequate for the desired function of delay-line measurements. The results of this study are given below:

1. Pulse duration of 0.1 to 10 usecs was considered adequate.

2. Pulse rise and fall time of 0.02 to 0.1 usec was considered desirable, but it was felt that if a symmetrical pulse having rise and fall times of 0.02 usec could be obtained, the variable rise-time feature could be omitted without seriously affecting the usefulness of the instrument.

3. Repetition rate of 1 to 10 kc was considered adequate.

4. It was felt that it would be desirable to have pulse amplitude continuously variable from 0 to 100 volts instead of variable in steps between 10 and 40 volts. It was further considered desirable to have either positive or negative pulse output.

5. The purpose of variable pulse delay as used in delay line measurement is to provide movement of markers with respect to the pulse. It was therefore felt that the delay of 0 to 50 usecs was excessive, and a delay of only 0 to 1 usec would permit the operator to interpolate between markers with a higher order of accuracy. The figure of 0 to 1 usec for the pulse delay was taken as a design target.

6. Sync output with regard to duration, rise-time, and delay were considered satisfactory.

7. Sync amplitude of 20 volts positive was considered unsatisfactory because this voltage without attenuation saturated the sweep trigger channel of several commercial oscilloscopes. Therefore, a pulse amplitude of 5 volts was considered more desirable. To improve the instrument's versatility, it was decided to provide both positive and negative sync output triggers.

8. Marker spacing and amplitude was considered adequate.

The next design phase consisted of critically examining the existing instrument's operation. The following characteristics were considered unsatisfactory:

1. Long-time stability of markers with respect to sync and pulse delays was unsatisfactory.

2. As normally used, the sync output triggered an oscilloscope sweep. When viewing the pulse output on this trace, it could be made to move right or left by adjustment of the sync delay controls. One of these, the FINE SYNC DELAY, was calibrated for exactly 0.1 usec movement. To measure this movement, it was necessary to center a 0.1 usec marker on a grid line of the oscilloscope screen. In operation it was found that a marker would not return to its exact position when the FINE SYNC DELAY was returned to its initial calibration point. This action made delay measurement uncertain and destroyed the operator confidence in the instrument.

3. Pulse output with the variable rise-time control set for fastest rise time was characterized by a sharp spike on

the leading edge of the pulse. In order to eliminate this spike, the rise-time control was adjusted for a lower rise time. Although this adjustment improved the leading edge of the pulse, the fall-time became very long and was unsatisfactory for many applications.

4. Adjustment of the pulse amplitude control changed the shape of the pulse at the various steps. This action resulted in the operator normally operating with the pulse amplitude control adjusted for maximum output.

5. The instrument had approximately fifteen technician adjustments. Alignment procedure for satisfactory operation required approximately two hours of work by a skilled technician. Adjustments were inter-related, and failure in any section of the device normally required a complete realignment procedure.

On completion of the above study, a study was made of the existing circuitry in order to seek means of improvement.

The existing marker circuitry was considered satisfactory and was essentially that as shown in the circuit diagram, Appendix II. In order to obtain syncronization between markers and sync and pulse outputs, the 1.0 usec markers were used to syncronize a blocking oscillator as shown in Figure 1. The RC recovery components of the blocking oscillator were adjustable in order to give the required repetition rate variation of 1 to 10 kcs. It is seen that this required a count-down of 1000 to 100 to 1 between the blocking oscillator and the 1.0 usec markers. The jitter inherent in blocking

oscillators made this output unsatisfactory for triggering the sync and pulse outputs. Therefore, the blocking oscillator output triggered a phantastron which in turn triggered another phantastron which generated a 2 usec pedestal. This pedestal was put on the #1 grid of a 6AS6 dual control pentode. Input to the suppressor of this tube was from the 1.0 usec marker channel. The theory of operation required that the delay of the phantastron following the blocking oscillator be such that the leading-edge of the 2.0 usec pedestal occur midway between two 1.0 usec markers. Inthis way the 6AS6 operated as a coincidence tube, and the desired output was a 1.0 usec marker gated at a 1 to 10 kc rate determined by the blocking oscillator. This marker was used to directly trigger the sync and pulse sections.

This circuit was considered unsatisfactory for the following reasons:

1. Inherent blocking oscillator jitter and significant rise-time of the 2 usec pedestal put extreme stability requirements on the phantastron following the blocking oscillator if exact coincidence was to be obtained in the 6AS6 dual-control pentode.

2. For satisfactory triggering of the sync and pulse sections, exact coincidence is required because the gated 1.0 usec marker is used to directly trigger these sections. Both sections are triggered by the 1.0 usec marker and switching initiates for each section at a particular amplitude on the

rise of the marker. If coincidence is not perfect and the gated marker is riding on the leading edge of the 2 usec pedestal, the triggering of the sync and pulse sections will not be stable with respect to each other.

3. Stability problems are aggravated by placing variable delays in series.

The sync section was triggered by the gated 1.0 usec marker. This trigger switched a phantastron with a variable delay, and the phantastron output was taken via a cathode follower. The cathode follower output was via a variable delay line. The control of the variable delay line was the FINE SYNC DELAY control which has been discussed previously.

This circuit was considered unsatisfactory for the following reasons:

1. The phantastron tube, a 6AS6, was underpowered with regard to filament power and did not provide long-time stability.

2. The variable delay line was most undesirable since it was an expensive item and did not perform satisfactorily.

The pulse delay section was identical to the sync delay section and had the objectionable feature with the 6AS6 filament power.

The output of the pulse delay phantastron triggered two more phantastrons which in turn triggered two multivibrators. The action of one of these multivibrators (the "ON" multivibrator) was to switch on a hydrogen thyratron. The other multivibrator (the "OFF" multivibrator) cut off a pass tube

in the plate of the hydrogen thyratron to terminate the pulse.

This circuit was considered unsatisfactory for the following reasons:

1. The hydrogen thyratron was expensive.

2. In the event of failure in the "OFF" channel, the thyratron rapidly passed maximum ratings and was destroyed.

3. The large amount of ions in the thyratron made the fall-time obtained by cutting off the pass tube unsatisfactory.

4. The nature of gas tube operation creates a spike on the leading edge of the output pulse which is very difficult to eliminate.

The pulse amplitude attenuator consisted of five "T" resistor pads. These were considered unsatisfactory for the following reasons:

1. Amplitude is not continuously variable.

2. Resistor pads providing exact relative attenuation of all frequency components in the complex pulse generated by the thyratron circuit are difficult to produce. The result is distortion of the waveform at different attenuator positions as previously discussed.

From the previous considerations it was concluded that complete redesign of the existing instrument was warranted. It was considered that the outputs of the device as modified by the foregoing considerations would be satisfactory for the desired application of delay-line measurement. However,

considerable change in the means of obtaining these outputs was considered necessary.

One change in the output characteristics that was considered desirable was to place the precision 0.1 usec variable delay in the pulse delay channel instead of in the sync delay channel. This change makes it unnecessary to center a marker on a grid line of the oscilloscope screen since movement of markers is then observed relative to pulse position. This change was requested by the delay-line measurement group of Brubaker Electronics.

It was considered that the philosophy of gating a 1.0 usec marker to provide a trigger for the sync and pulse sections was satisfactory. However, the difficulties of obtaining exact coincidence to provide a stable trigger for these sections suggested that the coincidence output trigger an auxiliary trigger device which would in turn trigger the sync and pulse sections. In this way the sync and pulse sections would be provided with an input that would not change with regard to amplitude and rise time. It was hoped that any output of the coincidence tube of sufficient amplitude to trigger the auxiliary trigger device would then provide a stable trigger for the sync and pulse delay sections. Accepting this philosophy, it was felt that stable operation might be obtained if no means whatsoever for syncronization between the repetition rate oscillator and the 1.0 usec markers were provided. Therefore, a simple multivibrator to provide both the 2.0 usec pedestal gate and the required repetition rate was designed and constructed.

The pedestal from this multivibrator and 1.0 usec markers from the marker section were applied to the two grids of a dual-triode push-push coincidence circuit. The output of this circuit triggered a one-shot multivibrator. It was found that very loose syncronization between the 1.0 usec markers and the multivibrator was all that was required to stabilize the leading edge of the one-shot multivibrator with respect to the markers. Differentiation of this leading edge provided a stable trigger for sync and pulse delay sections.

The circuit described above employed four vacuum tubes (V-6, V-7, V-8, and V-9 in Figure 4 and Appendix II), no expensive components, had no technician adjustments, and provided a stable output pulse. The original circuit employed five vacuum tubes, three of which were relatively expensive dual-control pentodes, required a relatively expensive pulse transformer, had five technician adjustments, and provided an output pulse which was quite sensitive to ambient voltage, vibration, and temperature conditions.

Redesign of the sync and pulse delay circuits consisted of replacing the 6AS6 tubes with more rugged and powerful 6BY6 (V-10 and V-13) tubes and redesigning the output stages.

The general philosophy employed during the search for a better pulse generator was that a hard-tube generator would be superior to a gas-tube type if the rise-time requirements could be met. Assuming that the output stage would be a

cathode follower or amplifier, amplitude might be easily adjusted by variation of the driving signal amplitude.

The pulse generator finally designed was of the hard-tube type and provided a continuously variable amplitude from 0 to 100 volts. The design originated from discussions between engineers of Brubaker Electronics. Figure 2 indicates the basic circuit.

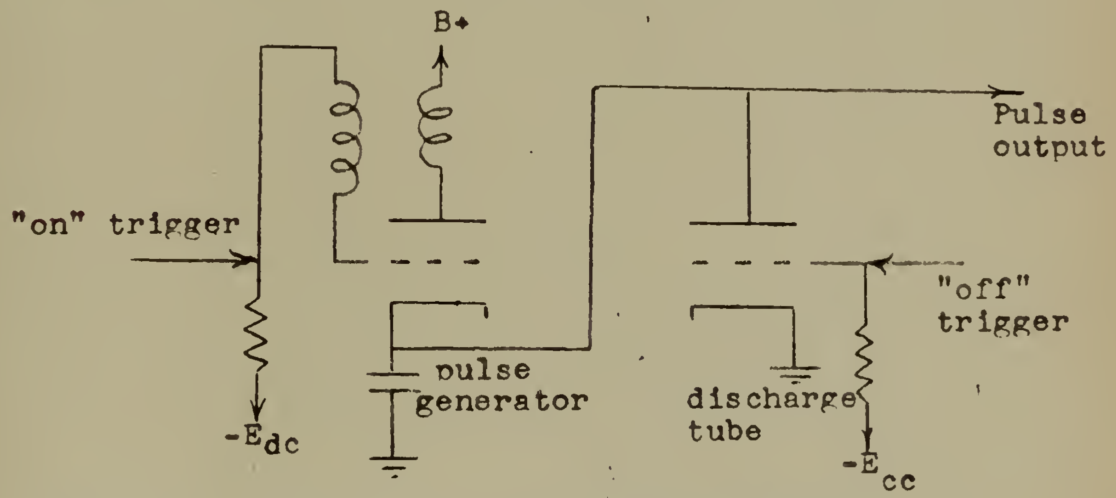

Figure 2. Basic circuit of pulse generator.

A description of the operation of this device follows:

The pulse generator is a blocking oscillator employing a pulse transformer of approximately 0.1 usec period. The tube is held in hard cutoff by the negative DC bias. The discharge tube is also held in hard cutoff so that there is no DC current path for the pulse generator tube. On application of the "ON" trigger, the violent switching action of blocking oscillator rapidly charges the condenser in the cathode circuit. Since there is no DC path, the charge

assumed by the condenser is held until the "OFF" pulse brings the discharge tube into conduction. At this time the condenser is rapidly discharged via the discharge tube, thus terminating the pulse. Pulse amplitude is controlled merely by changing the value of the B+. These tubes are V-18 and V-22 in Figure 4 and Appendix II.

A complete description of the instrument, along with suggestions for its application are given in Chapter III.

CHAPTER III

THE BRUBAKER MARKER-PULSER AND ITS APPLICATIONS

The Brubaker Marker-Pulser provides a straightforward method of determining the delay of a given delay line. A pulse is generated, and a means provided for observing both the generated pulse and its delayed counterpart on an oscilloscope. Markers having spacings of either 1.0 or 0.1 usec are stabilized with respect to the pulses so that the actual delay may be determined by counting the number of markers between corresponding points on the two pulses.

The procedure is complicated by several factors;

In order to position a marker accurately on a portion of the leading edge of a pulse, three conditions must be met: (1) the oscilloscope sweep must be initiated a period of time prior to pulse generation, (2) the oscilloscope sweep must be fast enough to expand the pulse leading edge sufficiently to observe the marker accurately, and (3) the position of the marker must be moveable with respect to the pulse. Condition (1) requires that the pulse generation be delayed a fixed period of time after a sweep trigger has been generated. Condition (2) generally requires that the sweep speed be so high that both the generated pulse and its delayed counterpart cannot be observed simultaneously. Therefore, the oscilloscope sweep trigger must be moveable in time from a point just prior to

pulse generation to a point just prior to the delayed pulse for any delay line which may be desired for test. Condition (3) requires that the pulse be moveable with respect to any particular 1.0 usec marker for a total delay of plus or minus ½ usec. Furthermore, this movement must be absolutely stable with respect to the markers in order that the operator may be confident that the marker he has accurately placed on the leading edge of the input pulse has not moved while he is observing the delayed pulse. The Marker-Pulser meets the above conditions. In addition, a control, FINE PULSE DELAY, has been incorporated. This control moves the markers exactly 0.1 usec with respect to the pulse. It is calibrated on the front panel from 0 to 10 so that moving this control through one division will move the marker 0.01 usec with respect to the pulse. Experience with this control enables the operator to make measurements to accuracies of a few milli-microseconds.

Brief description of Brubaker Marker-Pulser:

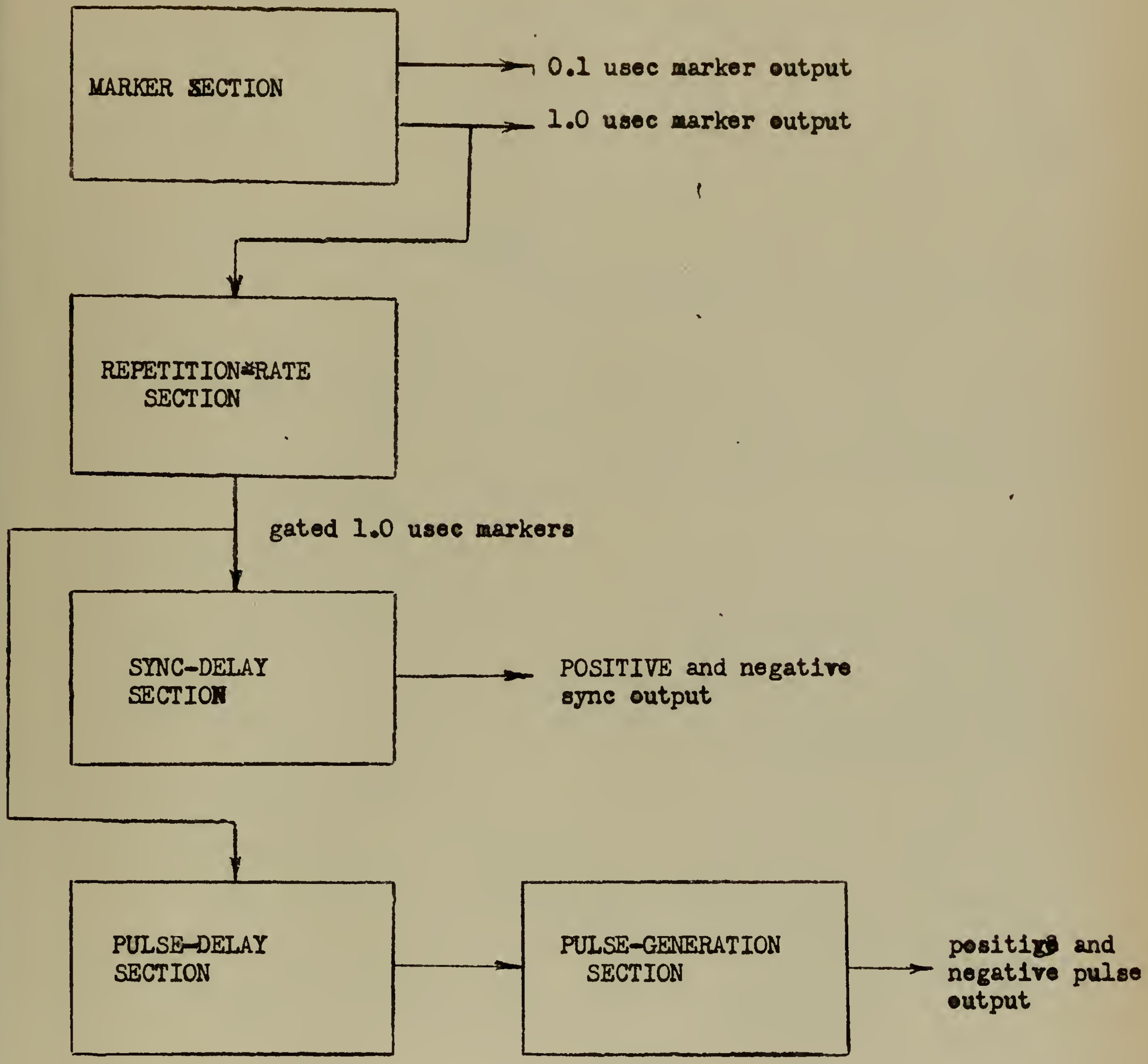

Figure 3. Marker-Pulser, simplified block diagram.

Refer to Figure 3.

1. Marker Section

   0.1-usec markers are obtained from a 10-mc crystal controlled oscillator.

   0.1-usec markers are obtained from a 10 to 1 frequency-divider circuit.

2. Repetition-rate Section

   The Repetition-rate Section gates a 1.0-usec marker.

3. Sync-Delay Section

   The Sync-Delay Section provides a variable-delay output, which permits the oscilloscope sweep to be delayed over a 50-usec range.

4. Pulse-Delay Section

   The Pulse-Delay Section is similar to the Sync-Delay Section except that it provides a total variable delay over only 1.0 usec. The output of this section triggers the pulse generator.

5. Pulse-Generation Section

   The Pulse-Generation Section, triggered by the output of the Pulse-Delay Section, develops the output pulse and provides variable pulse width and amplitude.

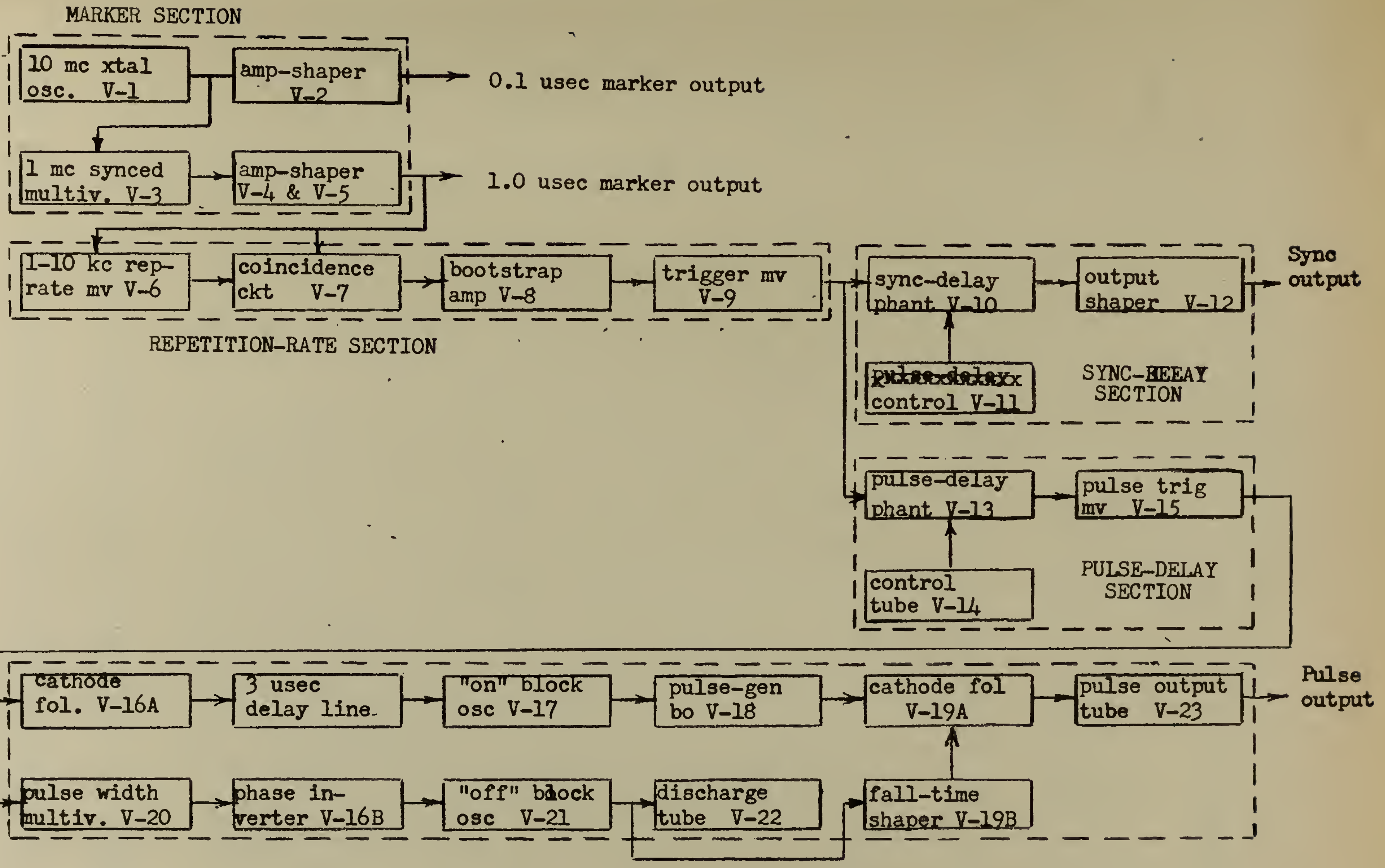

Figure 4. Marker-Pulser, detailed block diagram.

Complete description of Brubaker Marker-Pulser:

Refer to Figure 4 and Appendix II.

V-1 is a 10 mc Pierce crystal oscillator.

V-2 is a 10 mc radio-frequency amplifier providing transformer matching to the 0.1 usec marker output.

V-3 is an LC-controlled multivibrator operating at 1 mc and syncronized to the 10 mc oscillator by grid injection from the crystal oscillator plate.

V-4 and V-5 are shaping and matching circuits to provide 1.0 usec marker output.

V-6 is the repetition-rate multivibrator which determines the basic pulse and sync frequencies. Its operation is unsymmetrical so that the short-time part of its frequency period is always 2 usec. This 2 usec pulse is used as a gate for subsequently selecting a marker from the 1.0 usec marker channel. Since the multivibrator also provides the repetition rate of 1 to 10 kcs, it is apparent that the long-time part of the frequency period must be variable between 98 and 998 usecs. This variation is obtained by changing the time constant in the grid of the long-time section of the multivibrator. The capacitor associated with this time constant must be quite small in order that it may be completely recharged during the 2 usec period that the short-time section is conducting.[1] A value of 15 uufds was found to be satisfactory in this application.

V-7 is a push-push dual-triode coincidence or adding

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[1] Waveforms, MIT RadLab Series, Vol. 19, McGraw-Hill, p.171

circuit. 1.0 usec negative amplitude markers are impressed on one grid to generate positive 1.0 usec markers in the plate circuit. The positive 2 usec gate is impressed on the cathode of the other section to generate a positive 2 usec pulse in the plate circuit. When these two inputs occur simultaneously the 1.0 usec markers "ride" on top of the 2.0 usec gate. The amplitude of both the gate and marker inputs is sufficient to cut off their respective sections of the dual triode.

The germanium diode following V-7 is biased so that there will be no conduction through it unless a marker is riding on the gate. Therefore, there is no input to V-8 except at times determined by the repetition-rate multivibrator. At these times the input is a 1.0 usec marker. This action assures that operation in stages subsequent to V-8 will be synchronized to the 1.0 usec markers and hence to the 10 mc crystal oscillator.

V-8 is a boostrap amplifier. Its purpose is to maintain polarity of the output from V-7 and to enhance its amplitude.

V-9 is a one-shot multivibrator. Its purpose is to provide a constant-amplitude trigger for the pulse and sync delay sections. This circuit requires a particular amplitude at the input to affect switching. If the leading edge of the 2.0 usec gate and a 1.0 usec marker occur simultaneously in V-7, there is a possibility that the output of V-7 and V-8 will not be sufficient to trigger V-9. This occur-

rence, however, will not adversely affect circuit stability because the next 1.0 usec marker will occur squarely on the gate and trigger V-9. If the 1.0 usec pulse at the coincidence tube output is riding on the leading edge of the gate in such a manner as to just barely trigger V-9, stability will still not be adversely affected since the output of V-9 will again be directly related to the 10 mc crystal oscillator frequency. As a result of this operation, excitation voltage from V-9 to subsequent stages of the instrument is always of the same amplitude and waveform and is always directly related to the crystal frequency in the time domain.

The differentiated output of V-9 triggers V-10 and V-13 which are conventional phantastron delay circuits. The control tubes V-11 and V-14 set the quiescent voltages on the "Miller run-down" capacitors. These tubes also set the voltage level at which the phantastron will switch back to the quiescent state. Since this is a fixed value, stability with respect to delay period is high.[2]

V-12 provides wave shaping and impedance matching for sync output.

V-15 is a one-shot multivibrator, the purpose of which is identical to that of V-9 in providing a large, stable trigger pulse. In this case the pulse is desired for triggering the pulse-generation section.

The principle on which the pulse-generation section operates is that two triggering pulses are generated with

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[2] <u>Waveforms</u>, MIT RadLab Series, Vol. 19, McGraw-Hill, p.287

the time between their occurrence being variable. If one pulse determines the time of the leading edge of the output pulse and the other the time of the trailing edge, it is seen from the required output characteristics that the time variation between pulses must be 0.1 to 10 usecs. A device which will provide this variation is not easily obtained; therefore, the generator section of this instrument delays the leading-edge or "on" pulse approximately 3 usec. The trailing-edge or "off" pulse is delayed approximately 2.5 to 13 usecs in a simple one-shot multivibrator. In this way the "off" pulse may be moved "through" the "on" pulse, and extremely short pulses are obtainable.

With reference to the preceding paragraph, V-16A is a cathode follower which matches the output of V-15 to a delay line of 3 usec delay. The output of this line triggers V-17, the "on" blocking oscillator. The purpose of the "on" blocking oscillator is to provide a sharp (0.1 usec, 150 volts positive) "on" pulse for the pulse-generator tube input. V-20 is the pulse-width multivibrator which provides the desired 2.5 to 13 usec delay for the "off" pulse. The output of this multivibrator is inverted through V-16B and then triggers V-21, the "off" blocking oscillator. The operation of V-21 is identical to that of V-17.

Operation of the pulse-generator tube, V-18, and the pulse-discharge tube, V-22, has been discussed in Chapter II. The 4-30 uufd trimmer in the circuit of V-18 is a pulse-shaping

adjustment.

V-19A is a cathode follower. V-19B operates in a manner similar to the pulse-discharge tube; however, in this case its purpose is to maintain the fall-time of the cathode follower (V-19A) output.

V-23, the pulse output tube, is a cathode follower biased to cutoff; or if negative output is desired, the function switch places a 100 ohm resistive load in the plate circuit and output is taken from this side of the tube.

Alignment procedure for the Brubaker Marker-Pulser:

Refer to Appendix II.

1. C-2 in the plate of V-1 is adjusted for maximum 10 mc output as observed at the plate of V-2.

2. T-5 in the plate of V-2 is adjusted for maximum 0.1 usec marker intensity as observed on a suitable oscilloscope with the desired connecting cable in place. Different 72 ohm cables for marker output may require readjustment of this control.

3. With R-9 in the grid of V-3A set at approximately mid-range, C-12 in the grid of V-3B is adjusted for 10 to 1 syncronization as observed at the cathode of V-4A. R9 is then adjusted for most stable synchronization.

4. C-15 in the plate of V-4B is adjusted for balance of 0.1 and 1.0 usec marker intensity as observed on a suitable oscilloscope with the desired marker cable in place. When this adjustment is completed, it must be assured that the

trigger multivibrator, V-9, is firing. If no waveform appears at the cathodes of V-9, 1.0 usec marker intensity must be increased with C-15 until V-9 is firing.

5. R74 in the cathode of V14B is adjusted in the following manner: Trigger the oscilloscope sweep with the pulse output. Inject 0.1 usec markers on the CRT cathode. With Fine Pulse Delay control fully counterclockwise, center a marker on a grid line of the oscilloscope screen. Adjust R74 until full clockwise movement of the Fine Pulse Delay control moves an adjacent marker to the exact position occupied previously by the centered marker. Centering and adjusting R74 will be found to be inter-related, and several successive adjustments will be required before operation is correct.

6. C-53 in the plate-cathode circuit of V-18 is adjusted for stable pulse output and optimum wave shape. This adjustment should be made at the highest repetition rate (10 kc).

7. R-110 in the grid circuit of V-23 is adjusted for optimum output waveshape. In this condition the DC voltage of the V-23 grids is approximately -45 volts.

The output stage is a conventional cathode follower or amplifier depending on whether positive or negative pulse output is selected.

Delay line measurement techniques using the BMC Marker-Pulser will vary with the type of line under test and with operator preference. Techniques are classified into two

general categories depending on whether or not electronic switching is employed.

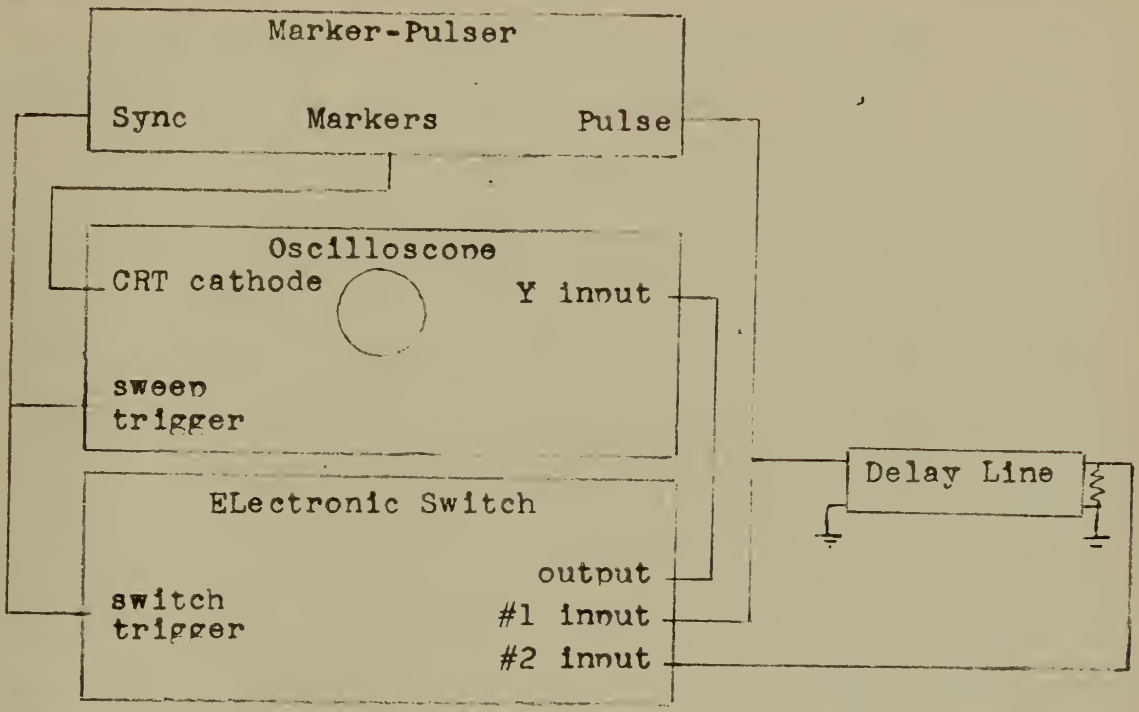

Figure 5. Delay-line measurement employing electronic switching.

With the test arrangement shown in Figure 5, both the input and delayed pulses may be observed simultaneously if the oscilloscope sweep time is somewhat greater than the one-way travel time of the delay line. If the delay time is short (0.5 usec or less), the delay may be determined directly by counting 0.1 usec markers between corresponding points of the two pulses, and using the fine pulse delay control to interpolate between markers. If the total delay of the line under test is appreciably greater than 0.5 usec, the same technique is employed. However, in this instance both the pulses cannot be viewed simultaneously on a sweep that is fast enough to adequately discriminate between 0.1 usec markers. In this case,

each pulse is viewed independently by changing the sync delay control and counting the markers between corresponding points of the two pulses. This procedure is simplified by switching between 1.0 usec and 0.1 usec markers.

Before undertaking this measurement technique, it is well to consider the effect that connections may have on the delay line characteristics. In most cases it is necessary to use a high-impedance probe for observation of the delayed pulse. In all cases the line must be properly terminated to avoid distortion caused by reflections. It is, of course, necessary that switching action of the electronic switch take place with the same order of speed and stability as that obtainable in the oscilloscope sweep trigger circuits. Measurement with the test setup shown in Figure 6 is essentially the same as with electronic switching except that the probe must be moved from the input to the output of the line. It is, therefore, more difficult to obtain a new reference on the position of a marker on the input pulse in the event an error is made counting markers between pulses. For this technique it is most convenient to make an initial estimate of the delay time using 1.0 usec markers.

If the line is left unterminated, an excellent estimate of the delay time may be made by placing the probe on the input terminal and measuring the time delay between the input pulse and the first reflection. This measurement is made in the same manner as that made employing electronic switching.

The measured delay is, of course, the two-way travel time of the line, and accuracy will be affected by the attenuation and distortion characteristics of the line.

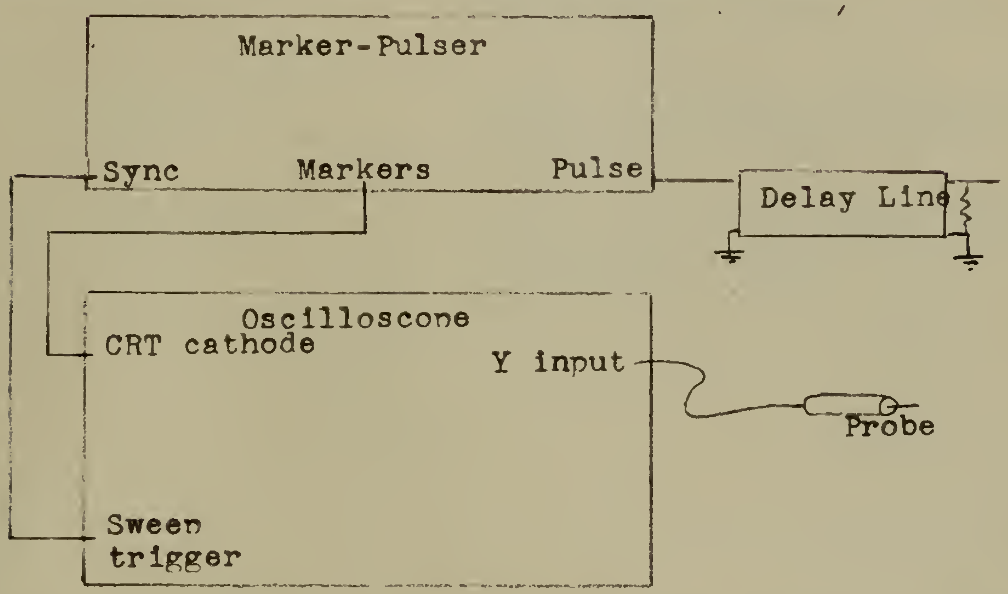

Figure 6. Delay-line measurement not employing electronic switching.

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MARKER PULSER

Brubaker Electronics MARKER PULSER is the first combi- ion precision marker generator and pulse generator in which outputs are locked together to provide completely jitter-free ichronization of output pulses, scope-marker pulses, and scope- ichronizing pulses. Additionally, and for optimum flexibility end use, the output pulses and the scope-synchronizing pulses variable with respect to each other as well as to the scope rkers. Measurements of time delays in increments of 0.01 crosecond are made rapidly and easily by means of the cali- ated dial which reduces to a minimum the necessity for opera- interpolation of scope traces.

In the Brubaker Electronics MARKER PULSER, a ten- gacycle crystal oscillator is used to achieve over all synchron- tion. The output of this oscillator is counted down to a -megacycle output which, in turn, is further counted down to -to-1 kilocycle output which appears as pulses. These pulses feed variable-delay circuits which trigger the output-pulse generator and the synchronizing-pulse generator. Both the ten-megacycle controlling-frequency signal and the counted-down one-megacycle signal are furnished as markers for the Z-axis input of the oscilloscope.

Prime uses of Brubaker Electronics MARKER PULSER include fast, precision time measurements both in the laboratory and on the production line. When used in conjunction with a broad-band trigger-sweep oscilloscope, the MARKER PULSER may be used for making measurements of delay lines, filters, video-pulse amplifiers, pulse transformers, pulse-forming networks, for the calibration of other test equipments and for many other applications. The MARKER PULSER is an extemely accurate measuring device for determining system or equipment delays. It can be used separately as a pulse generator.

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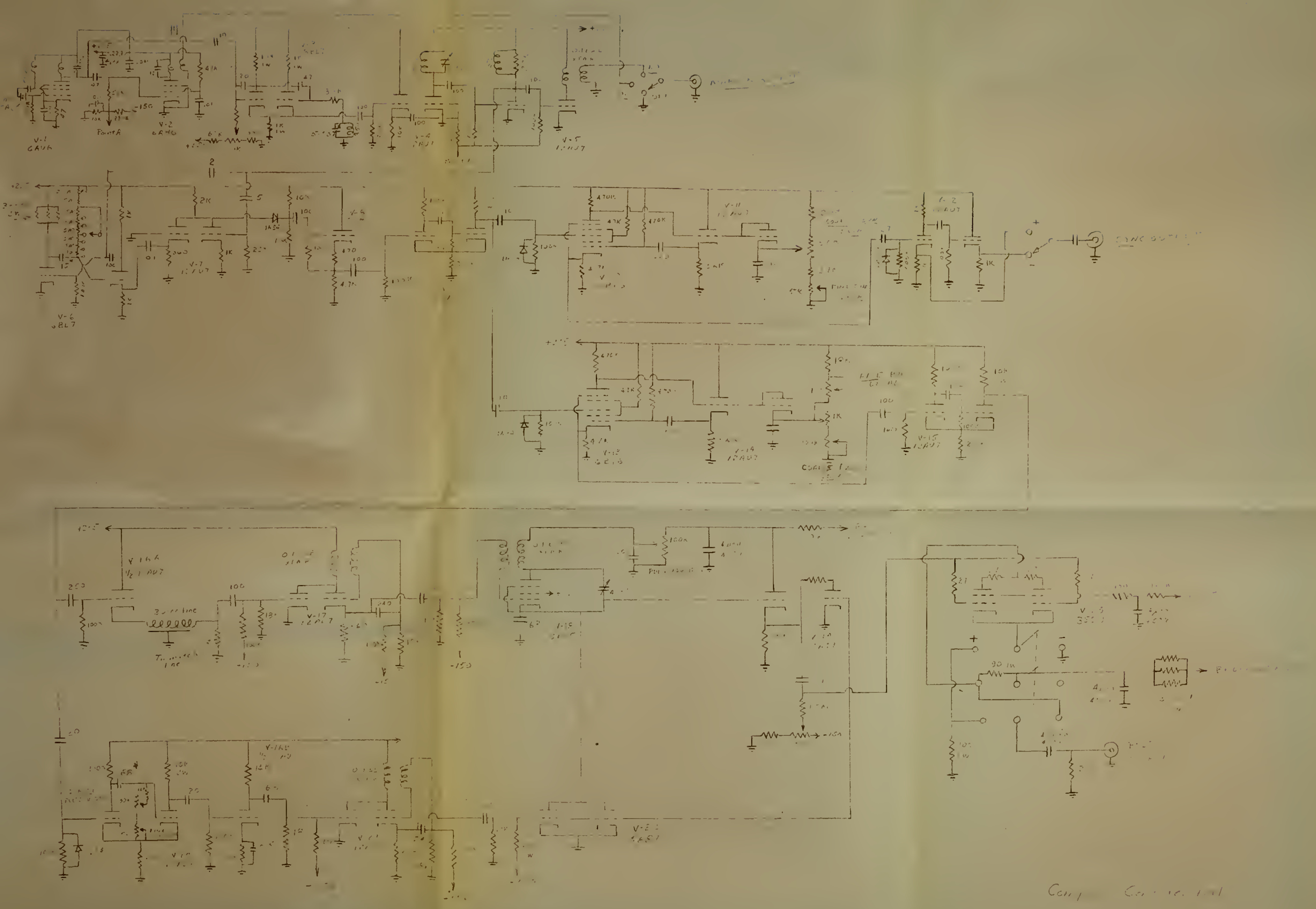

Complete Circuit

*Th [illegible]

*[illegible]

[illegible] noted

[illegible]

Power Requirements

+[illegible]

1400 [illegible]

-150 [illegible]

APPENDIX II

BRUBAKER MAGNET PULSER

[illegible]

Bendel

Delay line manufacture.

Bendel

Delay line manufacture.