# Fast Gray Wedge Analyzer for High Input Rates

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A fast gray wedge analyzer for operation at input pulse rates up to $10^7$ per second has been designed and built. Circuits and operation of the instrument are described. Operation of the instrument depends on two trigger circuits which are initiated by the input pulse. Pulses of fixed amplitude (100 and 30 mμsec long) from the trigger circuits operate two gates, a pulse lengthener, a sweep, and an unblanking circuit. The combination of the two gates allows pulses separated by less than 15 mμsec to be resolved, and the instrument has a fixed deadtime of approximately 100 mμsec. Fast circuit recovery and high-duty cycle are achieved by driving trigger and pulse shaping circuits on both leading and trailing edges of pulses.

## INTRODUCTION

THE gray wedge analyzer is a common laboratory tool for pulse-height analysis, and the basic design principles and applications are well known.[1] As normally used, it provides a simple and economical instrument for pulse-height spectrum analysis at moderate input rates with some loss in precision relative to other methods. It lends itself extremely well, however, to spectrum analysis at very high counting rates, especially for single-phosphor, total-absorption scintillation spectrometry. In addition, the total number of counts in a given time interval which are required for a useful spectrum may vary over a large range if an optical wedge of several decades is used. This is an advantage when dealing with a phenomenon with a rapidly changing rate. The instrument to be described was designed to accept positive input pulses at rates of the order of $10^7$ random per second with less than 10% distortion of the spectrum at the maximum rate.

## GENERAL DESCRIPTION

The analyzer was built on a Tektronix 517A oscilloscope indicator chassis[2] on which the standard heater transformer T901, high voltage (H. V.) for the cathode-ray tube (CRT), the CRT (T54P11H), and vertical positioning, intensity, and astigmatism controls had been assembled. This chassis was extended by approximately 5 in. on one side in order to accommodate all the circuits in one unit. A standard Tektronix 517A power supply was used, with very few minor modifications, to supply dc power. Heater power was supplied by the regulating transformer T901 supplemented by addi-

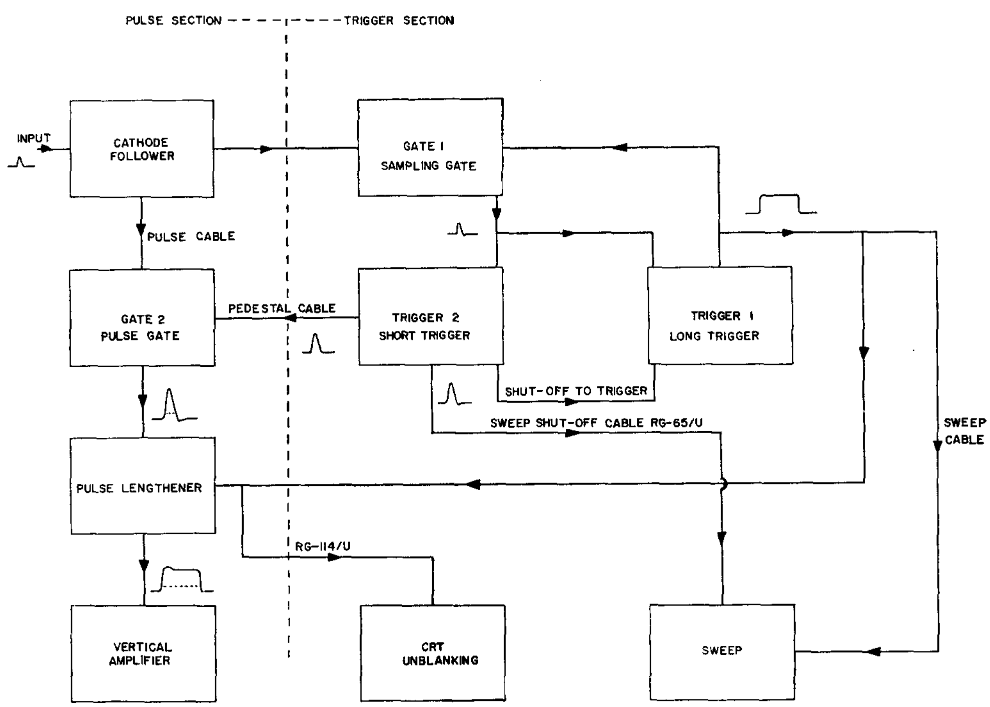


FIG. 1. Block diagram of gray wedge analyzer.

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[1] Bernstein, Chase, and Schardt, Rev. Sci. Instr. 24, 437 (1953).
[2] Tektronix Inc., Portland 7, Oregon.

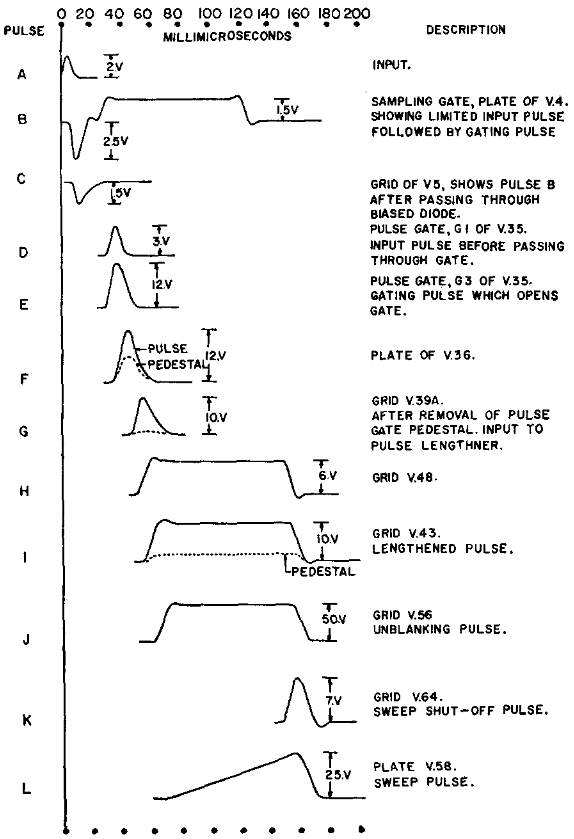


FIG. 2. Pulse shapes and time relationships in analyzer.

tional heater transformers operated from a regulated ac supply.

The over-all method of operation of the analyzer can be understood by reference to the block diagram in Fig. 1. The input pulse passes through the normally open sampling gate and initiates two trigger circuits which produce pulses of fixed duration and fixed amplitude. The pulse produced in trigger 1, the long trigger, is about 100 mμsec in duration and 8 v in amplitude. This pulse closes gate 1, the sampling gate, so that no further input pulses are presented to the trigger circuits until the analyzer has processed the first input pulse and is ready to accept another. The pulse from trigger 1 is also used to produce the sweep for the CRT, to intensify the electron beam in the CRT, and to switch the pulse lengthener. The pulse produced in trigger 2, the short trigger, is 30 mμsec in duration and 3 v in amplitude. This pulse is used as a shutoff to the sweep pulse and to trigger 1. The pulse is also used to open gate 2, the pulse gate, thereby permitting the input pulse to pass through to the pulse lengthener. The lengthened pulse then goes through a vertical amplifier to the vertical deflection plates of the CRT.

Figure 2 shows the pulse shapes which exist at various points in the analyzer, and the time relationship of each pulse to the input pulse is indicated by the displacement of the pulse along the horizontal time axis.

The various circuits which make up the analyzer are shown in Figs. 3 to 9 in which circuit units are labeled to correspond with those indicated in the block diagram. Standard wide-band techniques were employed throughout. All shunt peaking coils were close wound No. 28 wire on ½-in. diam polystyrene rods 1½ in. in length, and the number of turns on each is indicated in the circuit diagrams. Germanium diodes (1N54) were used throughout as dc restorers to maintain grid voltage levels. Microdot 93 ohm cable[3] was used as a delay cable in order to minimize the bulk of the cable required, except in cases where the required pulse height dictated the use of a cable of higher impedance (such as for the sweep shutoff pulse, where RG-65/U was used).

## CIRCUITS

In the circuit of Fig. 3 the positive pulse input (pulse A, Fig. 2) to the analyzer is through the double cathode follower *V*1 to the trigger and via *V*33, to the pulse sections of the instrument. In the pulse section the relative input pulse heights are preserved, whereas in the trigger section the input pulse serves only to initiate the changeover in univibrator type circuits. It is convenient and more appropriate to discuss the trigger section first.

From *V*1 the pulse to the trigger section first goes through a limiting amplifier, *V*2 and *V*3, as shown in Fig. 3. The adjustable bias on the grid of *V*2 controls the threshold sensitivity of this amplifier and so determines the input pulse height below which the trigger circuits will not respond. Thus noise and other unwanted small pulses may be eliminated to any desired degree. The output of the limiting amplifier appears as a positive pulse on the control grid of the 6AS6 gating tube *V*4 of the sampling gate (gate 1). *V*4 is normally conducting until the signal pulse has passed through; gating is then accomplished by switching the suppressor grid from +12 to −10 v with a signal from the long trigger (trigger 1), which effectively reduces the plate current to zero. The signal on the plate of *V*4 (pulse *B*, Fig. 2) therefore appears as a short 2.5-v negative pulse followed after a short delay (15–20 mμsec) by a 1.5-v positive rectangular pulse corresponding to the gating signal. This positive portion of the signal is removed by suitably biasing the 1N54 diode off the plate of *V*4, to yield only a short negative pulse (pulse *C*) on the grid of *V*5. The positive output of *V*5 is cathode follower coupled to the pair of trigger circuits.

The two trigger circuits of Figs. 4 and 5 are essentially similar and are based on the sweep gate multivibrator of Kelley.[4] In these circuits the natural period of the univibrator is much longer than the required duration of the output pulse. The pulse duration is determined by a cutoff which drives the flip-flop into its quiescent state.

[3] Microdot Division, Felts Corporation, South Pasadena, California.

[4] G. G. Kelley, Rev. Sci. Instr. **21**, 71 (1950).

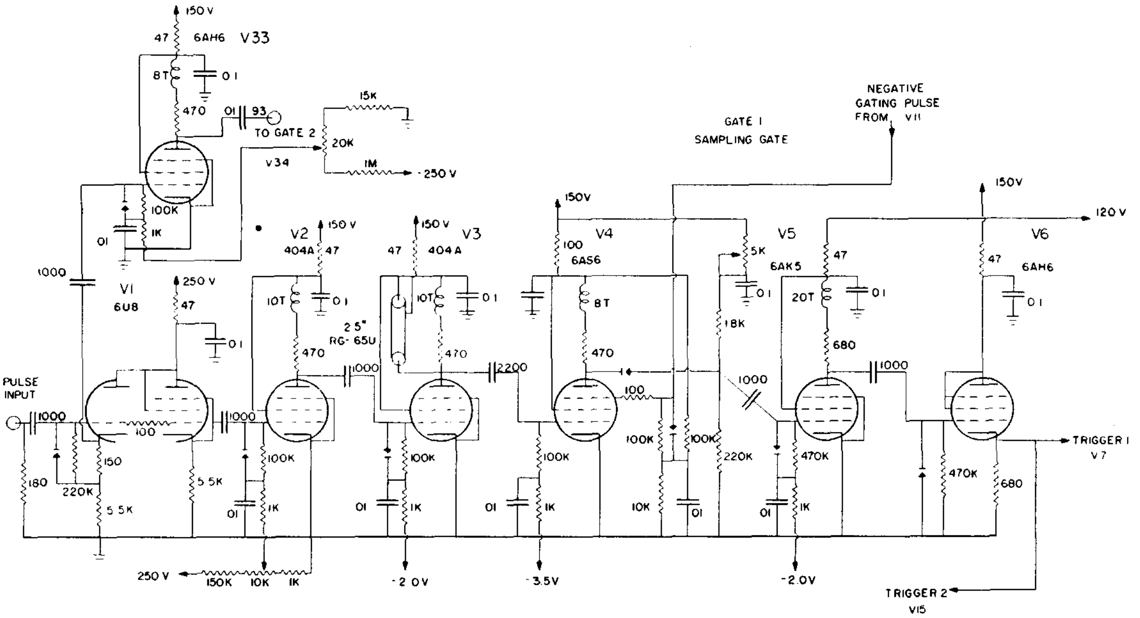


FIG. 3. Input circuit and sampling gate (gate No. 1). In this and other circuit diagrams all resistors are in ohms, and all capacitors whose values contain a decimal point are in microfarads, the remainder in micromicrofarads. All plate and cathode resistors greater than 100 ohms are rated at 1 w except where indicated; all other resistors are generally ½ w.

The short trigger (trigger 2) univibrator *V*16, 17, Fig. 4, is initiated by a pulse on *V*15. Output from the plate of *V*17 goes through the cathode follower *V*18 and is amplified and shaped (*V*19, 20) and returns the system to the standing condition through *V*23 via cathode followers *V*21, 24. The output pulse duration is determined by the time for the pulse to complete the loop from *V*17 to *V*23. The pulse obtained has a rise time of

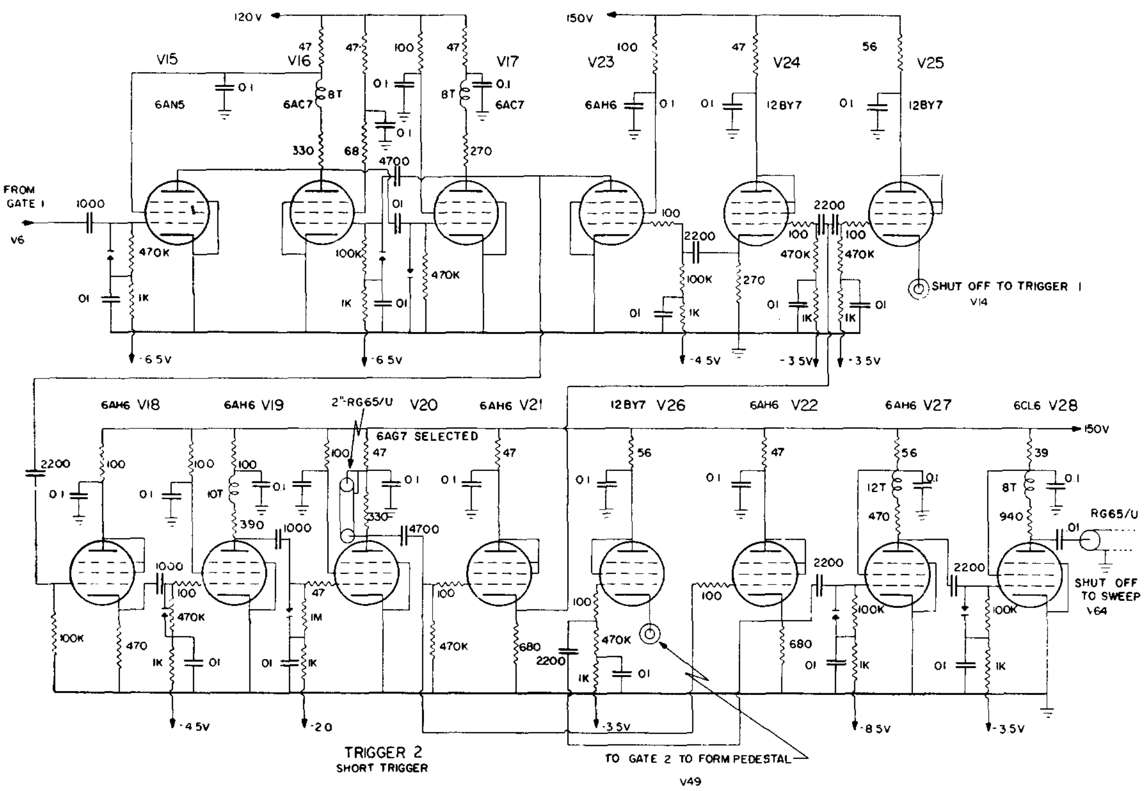


FIG. 4. Trigger No. 2 or short trigger.

about 8 mμsec with a width of 15 mμsec at half-maximum. Output pulses are taken through delay cables from *V*25 to supply the shut-off to trigger 1; from *V*26 to open the pulse gate (gate 2); and from the amplifier *V*27, 28 to supply the shutoff to the sweep circuit.

The long trigger (trigger 1) *V*8 and *V*9 of Fig. 5, is operated in a similar way except that the shutoff pulse is derived from the trigger 2 system through a delay cable and is then amplified and shaped (*V*14, 13) before being applied to the shutoff tube *V*12. The resulting output pulse is 100 mμsec long with a fast rise and fall (8 mμsec). The trigger 1 output is amplified by *V*11 to provide the gating signal on the suppressor of *V*4 (gate 1), and is also amplified (*V*29) and limited (*V*30) to provide 6-v gating signals through cathode follower control grid of *V*35 of the pulse gate (gate 2), Fig. 6. The 6AS6 (*V*35) is normally cut off by a 10-v negative bias on its suppressor grid. Gating is accomplished by applying a positive pulse (pulse *E*) from the short trigger (trigger 2) to the suppressor grid in coincidence with the signal pulse on the control grid. The gating signal from trigger 2 is amplified (*V*49) and limited (*V*50), and passes through the cathode follower *V*51, to appear as a 12-v positive pulse on the suppressor grid of *V*35. The limiter *V*50 ensures constant amplitude gating signals independent of pulse rate, and the cathode follower *V*51 provides a low-impedance driver necessitated by the fact that *V*35 is driven into $g_3$ conduction during gating. The output of *V*35 therefore consists of the gated signal amplified according to the

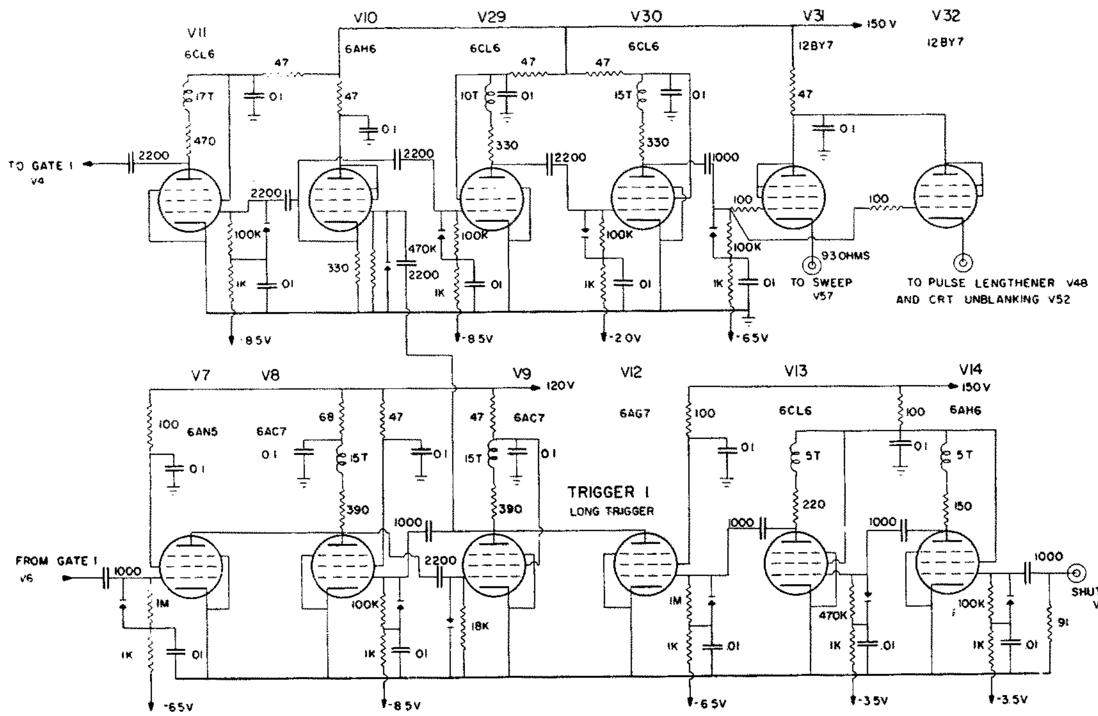

FIG. 5. Trigger No. 1 or long trigger.

driven delay cables to the sweep, the pulse lengthener, and the unblanking circuits.

The use of strong negative feedback in trigger 2 to determine pulse duration provides a short pulse with fast rise and fall and with amplitude and duration relatively independent of circuit parameters. The use of a shutoff pulse in trigger 1 provides a rectangular pulse of fixed amplitude with a fall time of the same order as the rise time, therefore permitting operation with a very high duty cycle.

The pulse section of the analyzer consists essentially of gate 2 or pulse gate, the pulse lengthener and a vertical amplifier. From *V*1 (Fig. 2) the input pulse is amplified by *V*33 before passing through a delay cable to *V*34, and appears as a positive pulse (pulse *D*) on the control grid-plate gain characteristic superimposed on a pedestal produced by the gating signal on the suppressor grid. From *V*35 the negative pulse, consisting of input pulse plus pedestal, goes to the amplifier *V*36 and then to the grid of *V*37 (pulse *F*). This tube is biased beyond cutoff to remove the major portion of the pulse gate pedestal. The pulse is amplified again in *V*38 which partially compensates the nonlinearity in *V*37 and the output of this tube is direct-coupled to the grid (pulse *G*) of a White cathode follower (*V*39*A*, *V*39*B*) which serves as the input to the pulse lengthener, Fig. 7.

The pulse lengthener (Fig. 7) consists of the tubes *V*39*A*, *V*39*B*, *V*40, *V*42, and *V*43, together with the auxiliary tubes *V*41, *V*48, and *V*47. In the absence of a pulse into the pulse lengthener the diode *V*40 and the

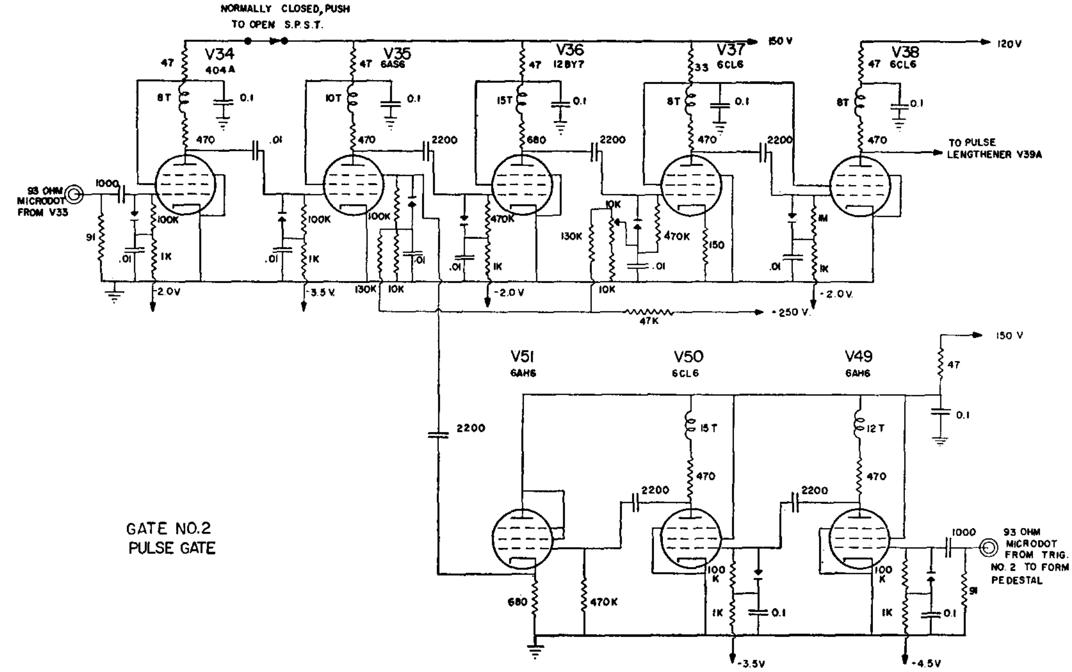


FIG. 6. Gate No. 2 or pulse gate.

tubes $V39A$ and $V42$ are conducting heavily. As a pulse arrives from $V38$ a negative rectangular pulse from $V48$ cuts $V42$ off completely. This rectangular pulse is obtained from the output cathode follower $V32$ of the long trigger (trigger 1) and is conducted as a positive pulse (pulse $H$) to the grid of $V48$ by a length of cable, the delay of this pulse being such that $V42$ just reaches cutoff as the input pulse reaches its peak on the grid of the input cathode follower. With $V42$ cut off the input pulse then charges up the stray capacity in the circuit (grid capacity of $V43$, plate capacity of $V42$, etc.) through the diode $V40$. This charge then leaks off at

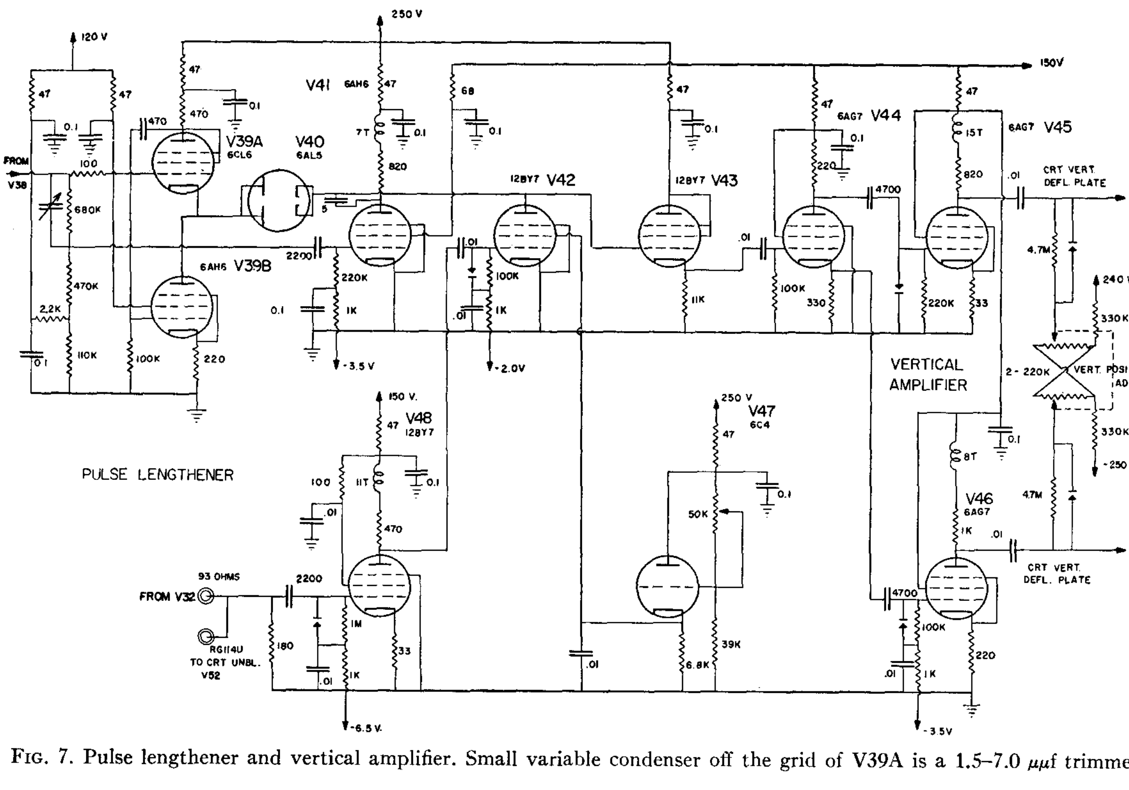


FIG. 7. Pulse lengthener and vertical amplifier. Small variable condenser off the grid of V39A is a 1.5–7.0 $\mu\mu f$ trimmer.

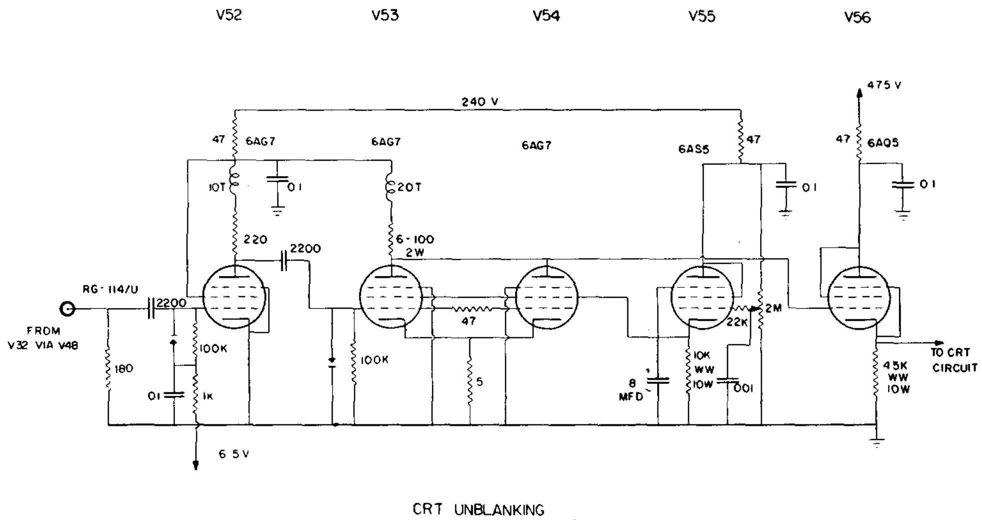


FIG. 8. CRT unblanking.

rate determined by the stray capacity and leakage resistance, and the effective *RC* time constant is long compared to the lengthened pulse. The lengthened pulse (pulse *I*) is superimposed on a pedestal equal to the voltage drop across the diode when it is conducting. Output voltage above the constant pedestal is linear for input voltages from 0 to 10 v. The negative signal from *V*41, derived from the input to the pulse lengthener, is applied to the cathode of the stretching diode in order to partially cancel out that portion of the pulse which is capacitively transmitted through the diode. The duration of the lengthened pulse is determined by the length of the long trigger (trigger 1) pulse. When this pulse on the grid of *V*42 returns to zero *V*42 and *V*40 conduct heavily again and the circuit quickly returns to its original condition.

This method of operation of the pulse lengthener, involving cutting off *V*42 during stretching, was found to be necessary in order to obtain satisfactory performance at a high duty cycle. In the more usual type of circuit the diode would not conduct except during passage of the pulse to be stretched and during resetting, and *V*42 would remain cut off at all times except when driven into conduction at the end of the stretching period. Faster recovery was obtained with the circuit employed since this circuit requires the minimum necessary time to return to its quiescent condition; the nonquiescent condition exists only until the stray capacity is discharged, whereas a pulsed discharge circuit remains disturbed until the driving pulse is fully withdrawn. The output of the pulse lengthener is taken out through the cathode follower *V*43 whose grid is directly coupled to the cathode of the diode *V*40.

From *V*43 the lengthened pulse goes to the vertical amplifier, shown also in Fig. 7. This amplifier consists of the phase-splitter *V*44, and the push-pull amplifier *V*45 and *V*46. The over-all gain of the vertical amplifier is about 4.5 with negative feedback to preserve linearity. The output of the amplifier is condenser coupled to the CRT vertical deflection plates, with diode dc restorers across the deflection plate resistors.

The CRT unblanking circuit shown in Fig. 8 is conventional. The input comes from *V*32 of the long trigger through Microdot cable to the grid of *V*48 and hence through a short length of RG-114/U to the grid of *V*52. The output of *V*52 cuts off the parallel combination of *V*53 and *V*54, and the resulting 50-v positive output pulse (pulse *J*) is taken off through the directly coupled cathode follower *V*56 to the condenser *C*818 of the Tektronix cathode-ray tube circuit. A diode restorer across the 2.2 M resistor (R840) prevents the trace brightness from changing at high input pulse rates.

The sweep circuit, Fig. 9, is designed to drive a Tektronix T54P11H cathode-ray tube operating at 12 kv; a sweep length of two inches on the tube face requires pulses of 80 to 100 v of opposite polarity on the horizontal deflection plates. To keep power dissipation down and to maintain a fast flyback for a high duty cycle the sweep wave form is generated at a relatively low level (25 v) and then amplified. A positive rectangular pulse from *V*31 of the long trigger output is amplified and inverted in *V*57 and goes to cut off *V*58 so that the plate voltage of *V*58 rises at a rate determined by the 15*K* load and the stray capacity to ground. When the pulse on the grid is removed and *V*58 conducts again the output capacity is discharged and the circuit returns to its quiescent condition. Flyback time is decreased by the parallel tubes *V*59*A* and *V*59*B* which are normally biased off and driven into heavy conduction in coincidence with the return to conduction of *V*58 by a short positive pulse (pulse *K*) from the cathode follower *V*64. This shutoff pulse is obtained from the short trigger (trigger 1) and is conducted to the grid of *V*64 by a suitable length of RG-65/U cable from the plate of *V*28. Thus the sweep pulse (pulse *L*) at the plate of *V*58 is a triangular pulse having a slow ($\sim$85 m$\mu$sec) rise and a fast ($<$20 m$\mu$sec) fall. This pulse then goes to the phase splitter *V*63, the outputs of which drive the push-pull amplifier $V61$ and $V62$. The screen voltage for these tubes is obtained from the low impedance source $V60$ and may be varied to adjust the gain of the tubes. The amplifier outputs are directly coupled to the horizontal deflection plates.

## ADJUSTMENT OF THE INSTRUMENT

In setting up the analyzer to display a spectrum on the face of the CRT very few adjustments are involved. Mention has already been made of the fact that the bias across the diode off the plate of $V4$ in the sampling gate (gate 1) must be large enough to prevent the gating pulse from passing through, but once this adjustment has been made no further attention to it is required whatever the size of the input pulse. For input pulses in the range 0.2 to 2 v the vertical deflection of the stretched pulses on the CRT should be large enough to fill the vertical dimension of the gray wedge and the following adjustments enable this to be accomplished:

(1) $V37$ bias, controls the degree of elimination of the pulse gate (gate 2) pedestal. Because of the curvature of the $I_p$-$E_g$ characteristic near cutoff there is an optimum adjustment of this bias since this bias alters the ratio: $\frac{(\text{pulse}+\text{pedestal})-\text{pedestal}}{\text{pedestal}}$ on the plate of $V37$. An optimum value of this ratio may be found for each input pulse height. Choosing a bias which optimizes this ratio for the smallest input pulse height will ensure that maximum use is being made of the available pulse height in the case of small pulses.

(2) $V33$ bias, essentially controls the gain of the pulse section of the analyzer. This bias is set so that the largest of the input pulses gives a deflection on the CRT face which is the full height of the gray wedge. Since this adjustment changes the absolute heights of the pulses into the pulse gate, a readjustment of the $V37$ bias may be necessary.

(3) Zero-line adjustment. In the circuit diagram of Fig. 6 a *SPST* pushbutton switch will be seen in the $B+$line to $V34$-opening of this switch allows the position of the pedestal or "zero line" to be seen on the CRT face, and this line is set near to or below the bottom of the gray wedge by means of the vertical positioning control.

(4) $V2$ bias, adjusted until the space between zero line and the desired low-energy cutoff of the spectrum is devoid of pulses. As was pointed out previously this bias controls the sensitivity of the trigger section to small pulses and serves to reject unwanted pulses.

## DISCUSSION

The deadtime of the analyzer is determined by the time for which the sampling gate (gate 1) remains

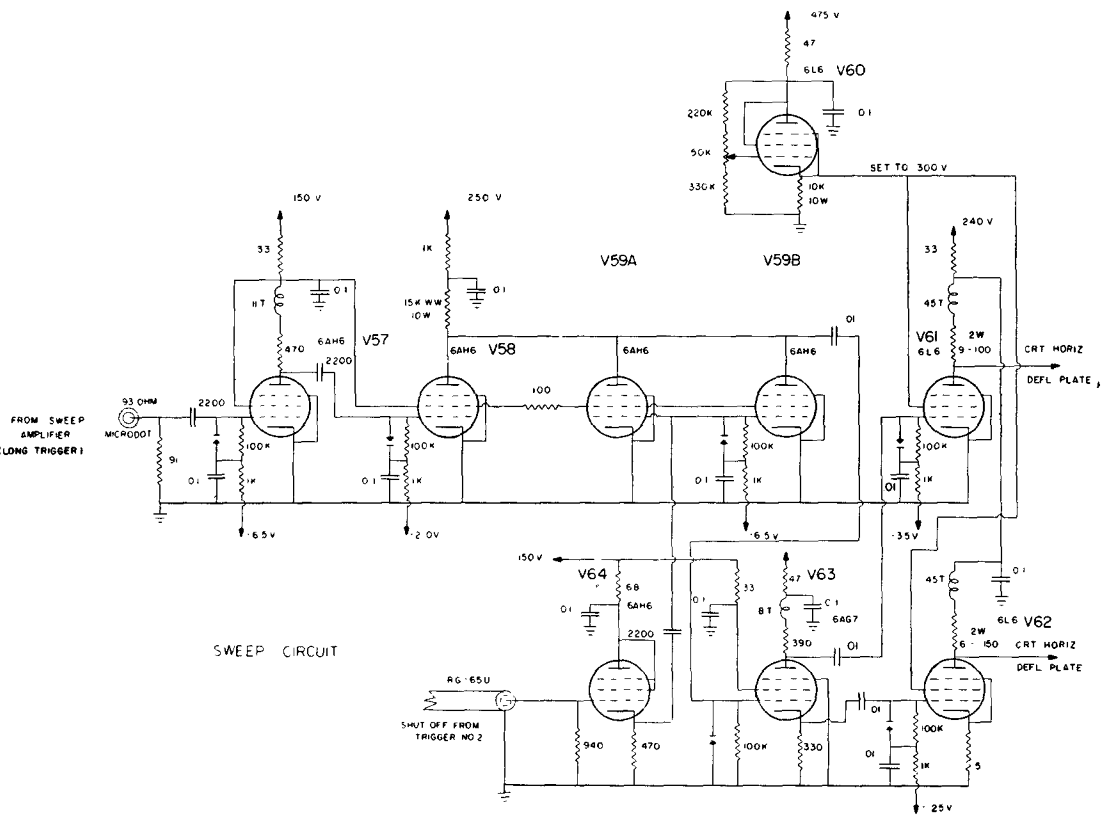


FIG. 9. Sweep.

closed, which in the instrument described is about 100 mμsec. Thus at the maximum rate of $10^7$ random pulses per second approximately 50% of the spectrum is being sampled. The resolution of the instrument, on the other hand, is determined mainly by the speed with which the pulse gate (gate 2) can be closed, and this is determined by the speed of the coincident pulse on the suppressor grid of $V35$ combined with the effect of the steepness of the suppressor grid-plate transfer characteristic. An experiment was performed whereby the coincident pulse on the suppressor was delayed 5 mμsec from true coincidence, so that the signal pulse arrived while the pulse on the suppressor was still rising; in this case the output pulse above the pedestal was reduced to one fifth. From this an upper limit of about 10 mμsec can be given as the resolution of the instrument, and at the maximum input rate less than 10% distortion of the spectrum results. Distortion arises from the fact that if two pulses are able to pass through the pulse gate then the one which sits higher on the pedestal after passing the gate will always be able to pass through the stretching diode of the pulse lengthener and thus will be preferentially recorded. Such a situation can lead to distortion in the case where a small pulse is followed immediately, within the resolution time, by a much larger pulse—the small pulse is in true coincidence with the pedestal but the gate, being only partially closed, may not be able to reduce the amplitude of the larger pulse sufficiently to bring its height on the pedestal below that of the smaller pulse. Thus the smaller pulse will not be recorded and the height of the larger pulse will be recorded incorrectly.

It is important that the sensitivity of the two trigger circuits to small pulses be as nearly identical as possible in order that pulses, occurring as the sampling gate (gate 1) is opening, are not lost. In particular the short trigger (trigger 2) must never be less sensitive than trigger 1 because of the requirement for the shutoff pulse which is provided by the short trigger. If only the long trigger were actuated the deadtime of the instrument would be extended until such a time as the time constants of the circuits would allow the suppressor grid of the gate 1 tube to return to its quiescent operating voltage, at which time an input pulse could then pass through this tube to actuate trigger 2 and so supply the necessary shutoff pulse. Since the time constant associated with the suppressor grid of the 6AS6 of gate 1 is of the order of 200 μsec a considerable number of pulses could be lost in this interval during which the tube is cut off. If trigger 2 were actuated alone, the situation is not serious but the pulse in question would not be recorded; however the instrument could accept another pulse within 30 mμsec.

In the present design of the analyzer the trigger circuits are sufficiently fast that, for an input pulse with a rise time of less than 5 mμsec, their output pulses rise in less than 10 mμsec. Passage of these pulses through subsequent stages tends to increase their rise times somewhat. It is felt that improvements may be made in the speed of the trigger circuits by a slightly different design incorporating tubes with smaller input and output capacities. Thus, in particular, the elimination of the tube type 6AC7 (input 11 μμf, output 5 μμf) and 6AG7 (input 13 μμf, output 7.5 μμf could possibly effect a significant increase in speed and a decrease in circuit delay. In this way it might be possible to decrease the rise and fall times of the gate 1 pulse and to apply this pulse sooner than is presently the case, and also to increase the speed of the gate 2 pulse.

Another improvement could be made in the sweep circuit by allowing this circuit more time to recover when it is operating at its maximum rate. With the present circuit the shutoff pulse to the sweep decreases slightly at rates near $10^7$ per second, with the result that shutoff is incomplete and the zero position of the sweep shifts slightly and the sweep becomes shorter. This does not affect the position of the vertically deflected pulse but it does decrease the useful part of the sweep. Also other pulses in other circuits decrease slightly at rates near $10^7$ per second. These effects could be eliminated by the addition of a third trigger circuit, similar to that of trigger 1, but producing a longer pulse, say 150 mμsec. This longer pulse would be used as the gating pulse for the sampling gate (gate 1), while the previous 100 mμsec trigger 1 pulse would still perform all the other functions it now performs. Thus all critical circuits would have an additional 50 mμsec in which to recover completely and more uniform output pulses could be expected. This of course would have the disadvantage that the number of pulses sampled would be reduced to about 40% at a rate of $10^7$ per second, but if the spectrum is not changing too rapidly this loss would not be serious.

## POWER SUPPLIES

Dc power was obtained partly from the regulated supplies already existing in the Tektronix 517A power supply and partly from other unregulated supplies which used as unregulated inputs the +180 v and +350 v outputs of the Tektronix unit.

## ACKNOWLEDGMENTS

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