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Authors
Jackson, Horace G.
Mack, Dick A.
Wiegand, Clyde.

Publication Date
1958-10-30

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UCRL-8386 Rev.

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Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

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December 2, 1958

Printed for the U.S. Atomic Energy Commission

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ABSTRACT

This paper describes an instrument for displaying intensity profiles of charged-particle beams that emerge from high-energy accelerators. The intensity versus position on a strip of 21 scintillation counters each 1 by 1 cm appears as a histogram on an oscilloscope. The display is accomplished by employing transistor circuits to amplify and integrate the outputs of the multiplier phototubes. The accumulated charge associated with each counter element is then read out in sequence by means of a blocking-oscillator commutator. The output signal is further amplified logarithmically for oscilloscope deflection.

BEAM-PROFILE INDICATOR*,†

Horace G. Jackson, Dick A. Mack, and Clyde Wiegand

Lawrence Radiation Laboratory
University of California
Berkeley, California

December 2, 1958

At the Radiation Laboratory in Berkeley we have constructed a device to aid in aligning the external beams of charged particles emitted by the Bevatron. Typical experiments require beams up to 100 feet in length from the primary target in the machine. Such beams are directed through bending and focusing magnets to determine the momenta of their particles and to concentrate the particles onto special targets. A problem is to align the beams along predetermined trajectories with a minimum of time and effort. The intensity of the beam is too low for practical detection by the darkening of photographic film or by a cluster of ionization chambers. We could expose photographic emulsions, but the time required to develop them and count the individual tracks would be prohibitive.

We have designed an array, which is placed normal to the beam, consisting simply of a row of 21 scintillation counters each 1 cm by 1 cm in cross section. Transistorized circuits are used to amplify and equalize the pulses from each counter and to indicate the number of pulses by electrical integration.

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*Work done under the auspices of the U.S. Atomic Energy Commission.

†For 5th Meeting of Professional Group on Nuclear Science - IRE - San Mateo, Sept. 1958 (not presented verbatim).

An electronic commutator allows the accumulated charge associated with each element to be read out and displayed as a histogram on an oscilloscope. With this apparatus we are able to observe the intensity profiles of the beams and to adjust the various magnet currents to optimum bending and focusing conditions.

Figure 1 shows the photomultiplier assembly and one of the three similar bin assemblies which hold the printed circuit cards for amplifying and integrating the photomultiplier signals, along with commutator cards and gating cards.

Light from the plastic scintillator, 1 cm square, is transmitted by the Lucite light pipes to the side-window photocathodes of 1P21 photomultiplier tubes. From noise considerations it was decided to limit the high voltage across the phototube to a maximum of 1000 v. Approximate design conditions, therefore, were for scintillation-counter output pulses of 10-mv amplitude with rise times of 1 millimicrosecond and width at half amplitude, 10 mμsec. Counting rates were expected to vary from 10 to 1000 counts per Bevatron pulse. The Bevatron produces a beam pulse once every 6 seconds, and the duration of the beam can be adjusted from 30 to 300 milliseconds.

A block diagram of the system is shown in Fig. 2. There are twenty-one channels, one for each scintillator. The output from the scintillation counter is amplified by a three-stage amplifier and thence goes to a discriminator which feeds pulses, equalized in amplitude and duration, to a diode pump circuit for integration. The output of the integrator is amplified by a single-stage vacuum-tube amplifier which also serves as an output gate. The 21 vacuum-tube amplifiers have a common anode load resistance, and are turned on in sequence by a blocking-oscillator commutator. The output across this common anode load is transmitted to a logarithmic amplifier and thence to the amplifier input of a Tektronix 531 oscilloscope. The horizontal sweep of the scope is triggered from the blocking-oscillator commutator, so that time synchronization is maintained between the sweep and the reading out of information from the integrators. The intensity profile of the beam of charged particles therefore appears on the face of the scope in a histogram form.

In order to gate out noise and background counts from the scintillation counter, additional circuits were needed to allow a charge to build up in the integrator only during the time of the Bevatron beam. Also circuits were needed to clear the integrator at the termination of the Bevatron pulse. In normal operation, the charge accumulates in the integrator during one Bevatron pulse.

The circuit diagram of the amplifier-integrator is shown in Figs. 3 and 4. The input to the amplifier is the 10-mμsec 10-mv pulse from the scintillation counter, and a minimum trigger level for the discriminator was set at 0.1 v. with a width at half amplitude of 0.3 μsec. The amplifier, Q1, Q2, and Q3, performs the combined function of amplifying and stretching the pulses. The 2N247 drift transistor was chosen for the amplifier section because it was an economical unit with a gain-bandwidth product of 15 Mc in the common emitter configuration. It can be shown for a pulse whose width is shorter than the rise time of the amplifier that the gain of the amplifier is reduced in proportion to the ratio of the amplifier rise time to input pulse width. In the circuit shown, the gain for an input step function is approximately 420, with an output rise time of 0.4 μsec. With a pulse whose half width is 10 mμsec, the gain is 10, and the width at half amplitude is 0.3 μsec. The bias resistances in the amplifier were determined following the method suggested by Ghandi.[1] The amplified signals trigger a discriminator Q4 and Q5 which has the dual function of discriminating against noise and presenting equalized pulses to the integrator.

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[1] S.K. Ghandi, Bias Considerations in Transistor Circuit Design, IRE Trans. on Circuit Theory, Vol CT-4, p. 194, Sept. 1957.

The millivolt discriminator principle described by Kandiah[2] is used. Here the transistors are biased so that the circuit is potentially unstable, but the collector load of transistor Q4 is shorted out because diode CR2, is normally conducting. Application of a positive pulse to the base of transistor Q4 causes it to conduct heavily, making the diode present a high impedance, and the circuit becomes regenerative. The choice of the time constant in the univibrator was made consistent with the maximum counting rate. For 1000 counts to occur in 30 msec requires a maximum resolution time of 30 μsec; the duration of the pulse out of the discriminator is 10 μsec; the amplitude, 10 v positive. The switching times now involved are slow enough that general-purpose transistors can be used, namely the 2N35. Attempts at varying the trigger sensitivity by changing the bias on the diode CR2 were unsuccessful because the voltage across the timing capacitor C13 also varied directly with the diode bias. Thus the duration of the output pulse varied with the sensitivity setting. To obtain a variable trigger sensitivity a simple form of biased-diode (CR1) discriminator was therefore incorporated between the amplifier output and univibrator input. The circuit responds to a minimum signal of 10 mv at the amplifier input.

The gating transistor Q6 permits the univibrator pulse to accumulate charge in the integrator. A trigger pulse is available from the Bevatron control that is coincident in time with the beginning of the Bevatron beam pulse. This trigger pulse is made to actuate a univibrator gate-generator circuit whose output signal is adjustable in width from 10 msec to 300 msec. This gate pulse is applied to the emitter of transistor Q6, causing it to saturate and thereby allow the pulse from transistor Q5 to be fed into the integrator.

[2] K. Kandiah, A Sensitive Pulse Trigger Circuit With a Stable Threshold, Proc. IEE, p. 239, June 1954.

The integrator is a simple diode pump circuit as described by Elmore.[3] The negative square pulse at the collector of transistor Q5 charges capacitor C15; arrival of the trailing edge of the pulse from the collector causes the charge across C15 to be dumped into C16. Low leakage in the reservoir capacitors is important, and Mylar dielectrics are used.

Cascaded emitter followers were considered for reading out the information in the integrator, but it appeared more practical to use the high input impedance of a vacuum tube. The subminiature CK5702 is used. Diode CR-3 is a high-conductance diode, 1N56A; and CR-4 is a low-reverse-current silicon diode, H-P G111A. One thousand counts into the integrator yields a positive potential of 1.5 v across C16. Resetting is accomplished by rendering diode CR-6 conductive just prior to the onset of the Bevatron beam. A pulse is obtained from the Bevatron control that effectively grounds the cathode of CR-6, cancelling any charge left on the reservoir capacitors.

Normally there exists a 6v negative bias on tube V1. This is due to the 4V Zener diode CR-5, whose anode is at +2V. Storage capacitor C19 holds this anode at 2v when CR-5 becomes forward biased. With 85 v on the plate and screen of the pentode V1, the anode current is normally less than 0.1 μa. Now the application of a negative gating pulse from the commutator circuit on the base of transistor Q7 causes this transistor to conduct, and diode CR-5 becomes forward conducting. With no charge in the integrator the grid-to-cathode bias on pentode V1 is reduced to 2v, and the tube operates in the linear region, drawing an anode current of approximately 0.5 ma. As noted earlier, the anode load of V1 is common to all 21 channels. Therefore, as transistor Q7 on each card is gated on sequentially by the blocking-oscillator commutator, the information stored in the integrators is likewise read out across resistor R38.

The blocking-oscillator commutator is shown in Fig. 5. This consists of a ring of blocking oscillators, 21 in all, each unit triggering the succeeding

[3] W. C. Elmore, Electronics (McGraw-Hill, New York, 1949), p. 250.

one. A delay is introduced at the end of the train of 21 pulses to allow for the retrace time of the beam in the oscilloscope. This is accomplished by having the output from the twenty-first blocking oscillator trigger the delay multivibrator Q8 and Q9. The delayed pulse is used to trigger the first blocking oscillator, and also to trigger the oscilloscope sweep. Type 2N34 PNP transistors are used to yield negative square pulses of 10v amplitude and 100 μsec duration. Thus a horizontal sweep speed of 200 μsec/cm is used on the oscilloscope.

Three bin assemblies are used, each holding seven of the amplifier-integrator cards and one blocking-oscillator card, each with seven blocking-oscillator circuits. The outputs of the amplifier cards are all joined in parallel by connecting cables.

The output of the scintillation counters are fed to the amplifier through coaxial cables which are terminated at the amplifier input. The signals from the plates of the pentodes in the amplifier integrator cards must be transmitted 150 feet by cable to the oscilloscope located in the Bevatron control room. An emitter follower is therefore used to obtain the low output impedance.

In Fig. 6 is shown the emitter follower and the logarithmic amplifier which compresses the counting rate, or intensity scale, for convenient viewing on the oscilloscope. The pedestal due to the commutated signal is removed by the biased diode CR-1, and the information from the integrator is further amplified by the transistor Q2 which has a gain of three. The signal level at this point due to 1000 counts at the input of the integrator is +30v. Finally, an emitter follower is used to develop the signal across a logarithmic element which is a type G-7A diode. This signal is coupled directly to the input channel of a

Type 53/54C plug-in unit of a Tektronix 531 oscilloscope. The vertical deflection sensitivity used is 0.1 v/cm, and 1000 counts at the input of the integrator yields 0.52-v vertical deflection on the oscilloscope face. For 100 counts the deflection is 0.25 v, and for 10 counts, 0.02 v.

A comment might be added about the transistor used in the logarithmic-amplifier section, where the signal is approximately 30 v maximum. This indicates a supply voltage of 40 v or more. Tests on about 80 2N247 transistors showed that about one-half of them had a collector leakage current of less than 10 μa when 100 v was applied between the collector and base; about 25% had a leakage current of less than 5 μa at this same voltage. By comparison all 2N34 and 2N35 transistors tested had collector leakage currents of more than 20 μa when 100 v was applied. Some 2N398 were also checked, and all had leakage currents of more than 5 μa with 100 v applied. Therefore 2N247 transistors were used in this high-level section, and the collector supply potential was 85v.

There are three main power supplies for the unit, +85v, +12v, and -12 v. By means of a meter-insertion switch, the current to each of the bins at all three voltages is easily monitored. Not including the heater supply to the vacuum tubes, the total power dissipation of the unit is less than 5 w. The heater power is about 25 w.

Figure 7 shows the oscilloscope display when the row of scintillation counters has been placed in an external beam of charged particles. The peaking of the intensity profile is clearly shown.

Figure Legends

Fig. 1. The photomultiplier assembly and one of the printed-circuit card bins. An amplifier-integrator and commutator card are shown removed from the bin.

Fig. 2. Block diagram of units used in indicator.

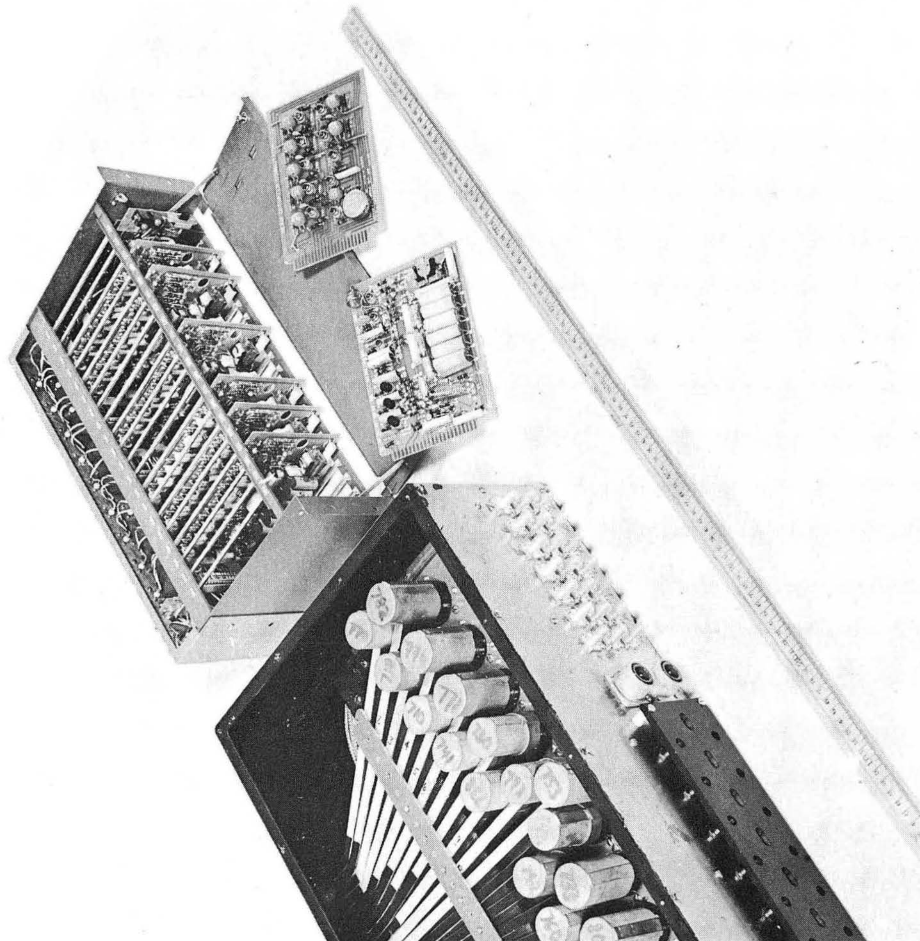
Fig. 3. Circuit diagram of scintillation-counter amplifier.

Fig. 4. The integrator circuit.

Fig. 5. Circuit diagram of blocking-oscillator commutator.

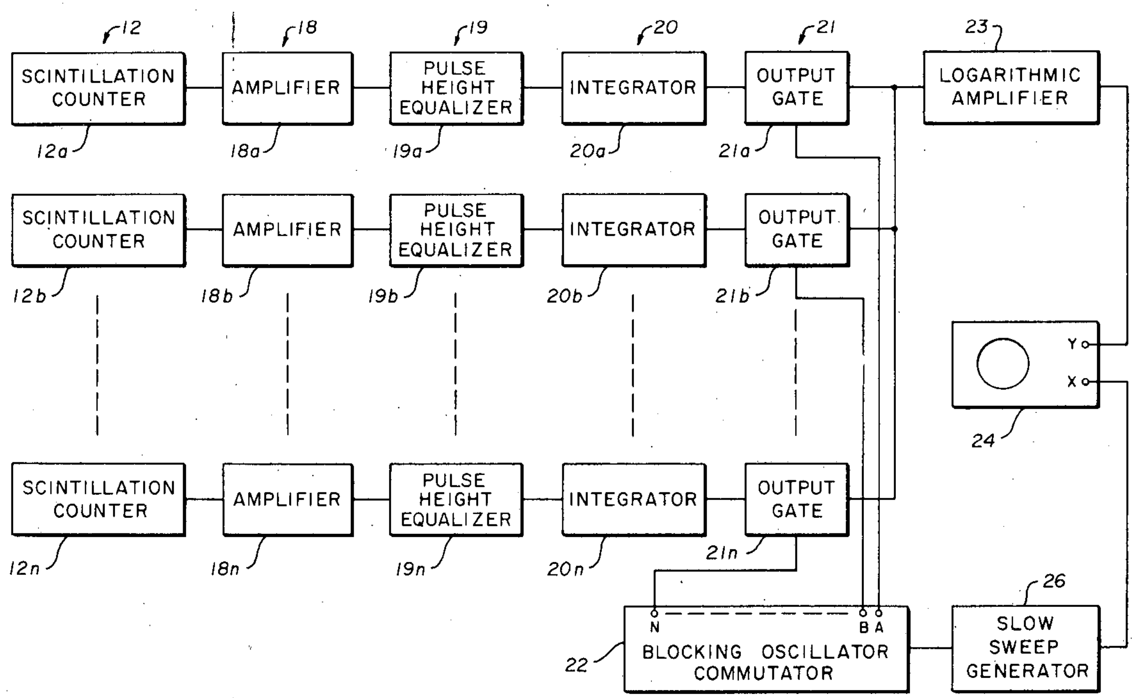
Fig. 6. Circuit diagram of emitter follower and logarithmic amplifier.

Fig. 7. Photograph of the oscilloscope display.

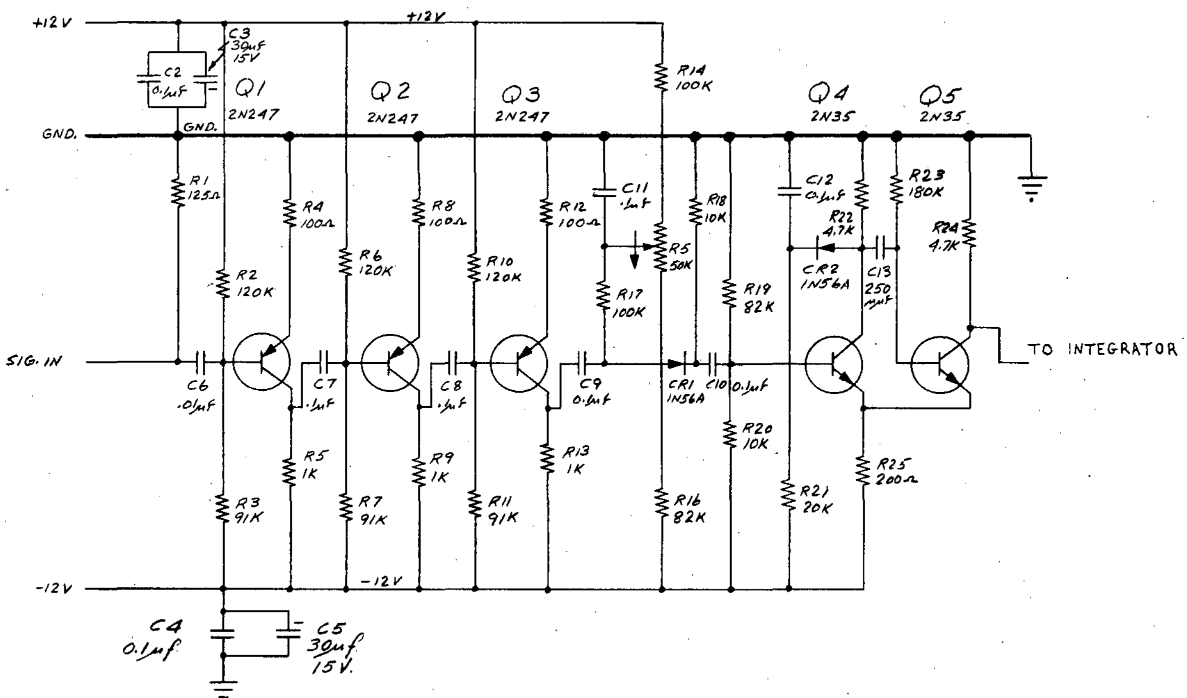


ZN-2020

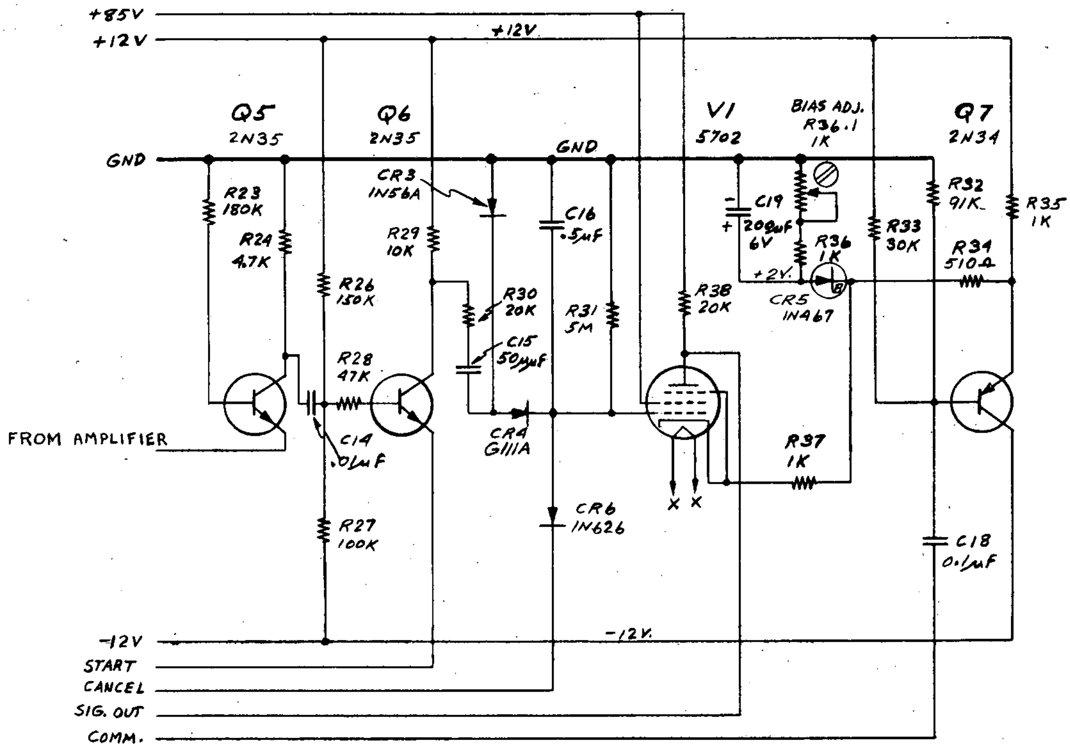
Fig. 1

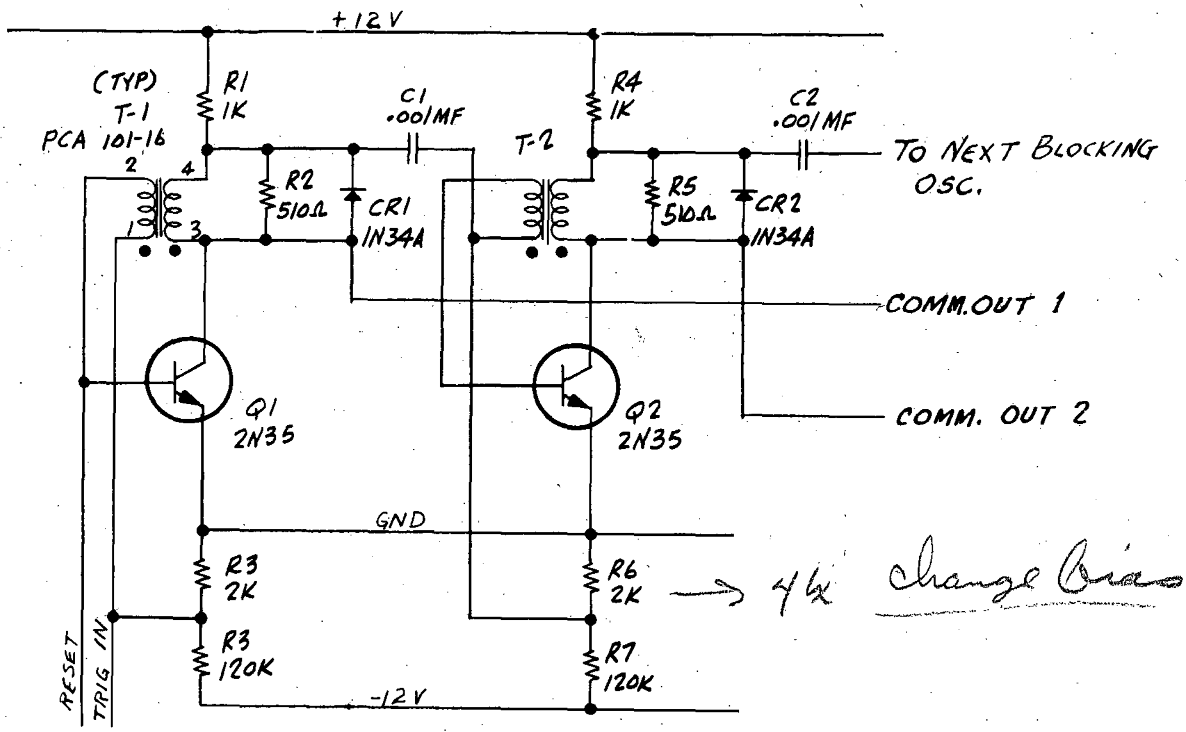

12
18
19
20
21
23
SCINTILLATION COUNTER
AMPLIFIER
PULSE HEIGHT EQUALIZER
INTEGRATOR
OUTPUT GATE
LOGARITHMIC AMPLIFIER
12a
18a
19a
20a
21a
SCINTILLATION COUNTER
AMPLIFIER
PULSE HEIGHT EQUALIZER
INTEGRATOR
OUTPUT GATE
12b
18b
19b
20b
21b
Y
X
24
SCINTILLATION COUNTER
AMPLIFIER
PULSE HEIGHT EQUALIZER
INTEGRATOR
OUTPUT GATE
12n
18n
19n
20n
21n
26
N
B A
22
BLOCKING OSCILLATOR COMMUTATOR
SLOW SWEEP GENERATOR

MU-16187


+12V
+12V
GND.
GND.
SIG. IN
TO INTEGRATOR
-12V
-12V
Q1
2N247
Q2
2N247
Q3
2N247
Q4
2N35
Q5
2N35
C2
0.1μf
C3
30μf
15V
R1
125Ω
R2
120K
R3
91K
R4
100Ω
R5
1K
R6
120K
R7
91K
R8
100Ω
R9
1K
R10
120K
R11
91K
R12
100Ω
R13
1K
R14
100K
R5
50K
R16
82K
R17
100K
R18
10K
R19
82K
R20
10K
R21
20K
R22
4.7K
R23
180K
R24
4.7K
R25
200Ω
C6
.01μf
C7
.1μf
C8
.1μf
C9
0.1μf
C10
0.1μf
C11
.1μf
C12
0.1μf
C13
250
μμf
CR1
1N56A
CR2
1N56A
C4
0.1μf
C5
30μf
15V.

MU-16357


+85V
+12V
+12V
Q5
2N35
Q6
2N35
GND
V1
5702
BIAS ADJ.
R36.1
1K
Q7
2N34
GND
R23
180K
R24
4.7K
CR3
1N56A
C16
.5μF
C19
200μF
6V
R32
91K
R35
1K
R29
10K
R33
30K
R36
1K
R34
510Ω
R26
150K
R30
20K
R31
5M
R38
20K
+2V.
CR5
1N467
R28
47K
C15
50μμF
FROM AMPLIFIER
C14
.01μF
CR4
G111A
R37
1K
CR6
1N626
R27
100K
C18
0.1μF
-12V
-12V.
START
CANCEL
SIG. OUT
COMM.
MU-16358



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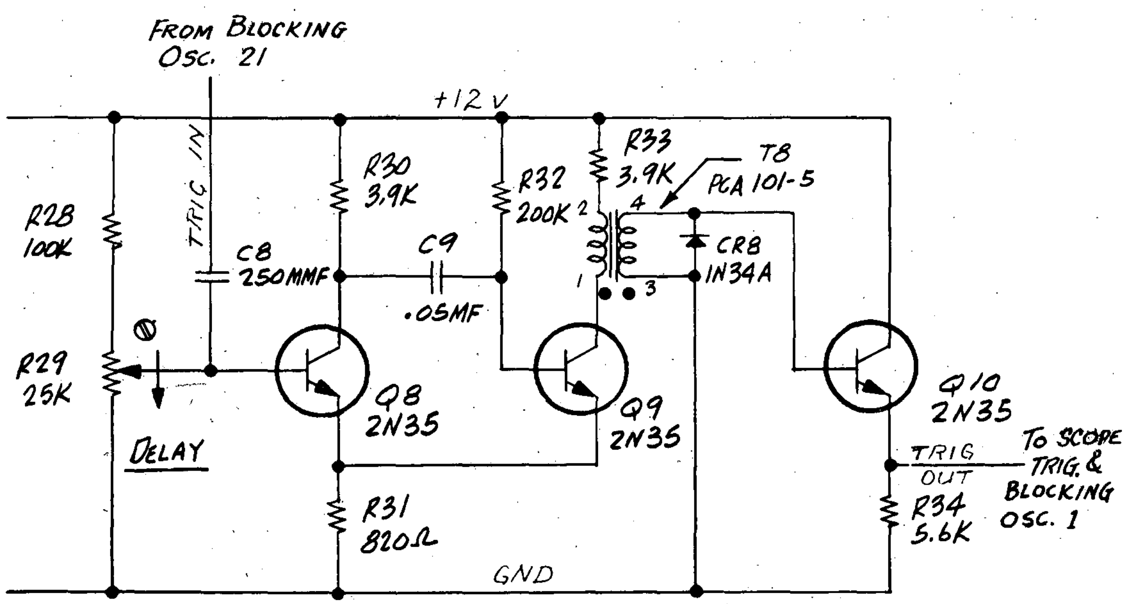

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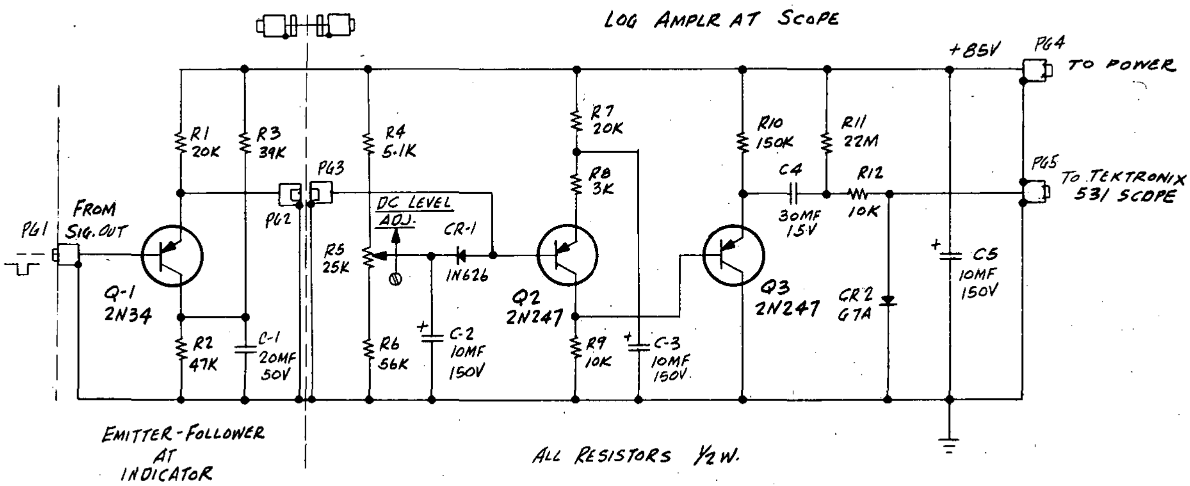
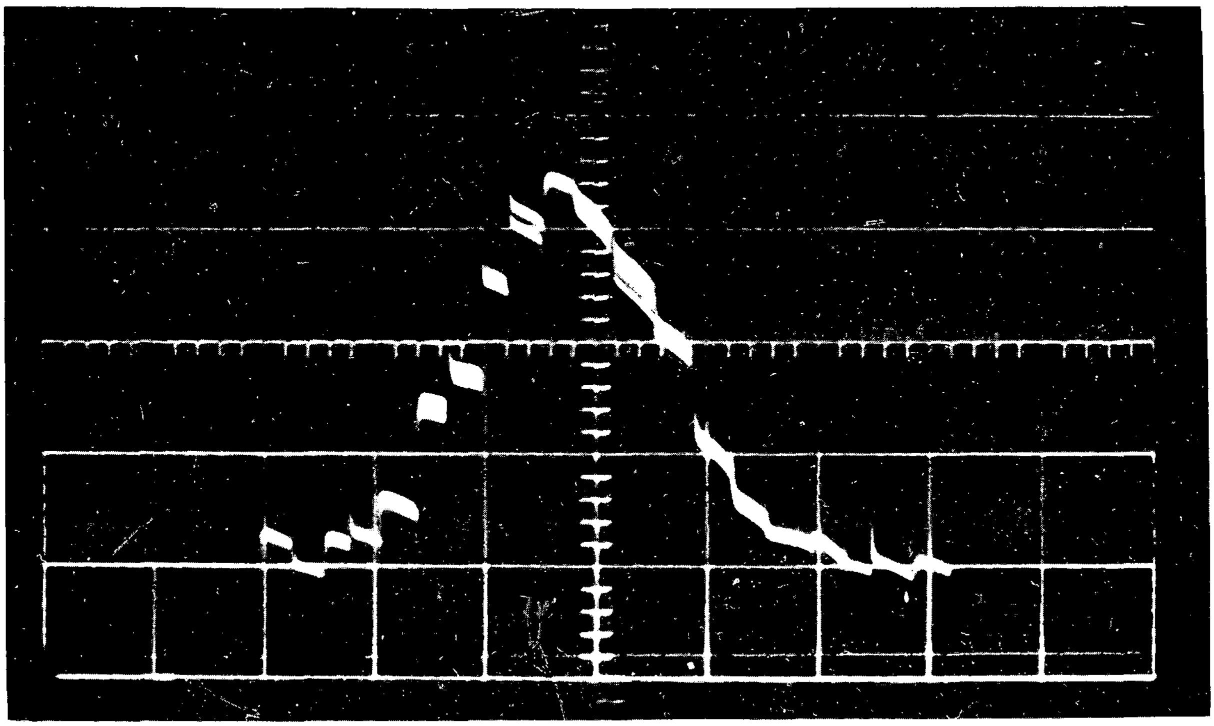

LOG AMPLR AT SCOPE
+85V
PG4
TO POWER
R1
20K
R3
39K
PG3
R4
5.1K
R7
20K
R8
3K
R10
150K
R11
22M
C4
R12
PG5
TO TEKTRONIX
531 SCOPE
FROM
SIG. OUT
PG1
PG2
DC LEVEL
ADJ.
CR-1
1N626
30MF
15V
10K
R5
25K
Q-1
2N34
Q2
2N247
Q3
2N247
CR2
G7A
C5
10MF
150V
R2
47K
C-1
20MF
50V
R6
56K
C-2
10MF
150V
R9
10K
C-3
10MF
150V.
EMITTER-FOLLOWER
AT
INDICATOR
ALL RESISTORS 1/2 W.

MU-16188



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