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THE APPLICATION OF AUTOMATIC TESTING TO COMPLEX NUCLEAR PHYSICS EXPERIMENTS

Frederick A. Kirsten

February 1962

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Lawrence Radiation Laboratory
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Summary

The complexity of the data-acquisition systems required for advanced nuclear physics experiments is increasing. The difficulties involved both in setting up these systems and in detecting failures or drifts in the associated electronic equipment increase rapidly with the complexity of the system. To alleviate these difficulties, some automatic test routines for checking a complete data-acquisition system from phototube to scaler or analyzer have been developed.

One technique involves the use of the nanosecond light pulsers described by Kerns. These are mounted so as to illuminate the scintillators. Relay matrices for routing the electrical triggers to the pulsers have been developed. The routing is programmed to sequentially activate various combinations of light pulsers, thereby simulating the nuclear events under investigation, as well as accidental events.

Control systems are provided to perform the programming, with either automatic or manually controlled sequencing.

Methods of checking or recording the results of the test routine are discussed. Two applications of this technique to actual experiments are described.

Introduction

Many of the nuclear physics experiments now being performed with scintillation or Cerenkov counters require relatively complex arrays of electronic apparatus. Stringent requirements are placed upon timing and amplitude stability of the signals, and the general reliability of the system must be kept on a high level. Quite often there are many information channels in the system, each of which must be timed accurately with respect to the other channels. The reliance placed upon the results of the experiment depends heavily upon assurance that all channels are operating properly. Failures or drifts in any one of them should be detected promptly and brought to the experimenters' attention. The problem of initially setting up all the counter channels properly is also considerable. The setting-up procedure can be expensive if accelerator time is required to produce suitable signals for performing the setup.

The above considerations make it very desirable to have available a method of simulating the nuclear interactions to be studied in the experiment. This paper describes test systems which have been designed to produce these simulated signals, and thereby to provide the means for performing a thorough check of the entire electronic system.

Light Sources

The test systems to be described are based upon use of the triggered nanosecond light source developed by Kerns et al.[1,2] The light capsule, shown in Fig. 1, consists of a whisker of tungsten in contact with a crystal of barium titanate, both in an atmosphere of hydrogen. When the potential of the whisker is suddenly made negative with respect to the barium titanate crystal holder, a discharge through the hydrogen is induced by field emission of electrons. Typically the potential is applied in the form of a pulse approximately 2 nsec in duration. Under such conditions, a short pulse of light is emitted by the capsule. The form of the light pulse is shown in Fig. 2, where it can be seen that the light intensity rises and falls in about 2 nsec. The difference between the time of arrival of the electrical pulse and the emission of the light pulse is constant to within about 1/2 nsec. The intensity of the light pulse can be varied over a 3000:1 range as the amplitude of the electrical pulse is changed from 500 to 2500 volts. The usual practice in applying the light pulsers in an electronic counter system is to use them to illuminate a scintillator-phototube combination. For easy mounting with this combination, the capsules are provided with a male screw thread. The capsule can be screwed into a thin plate (with a mating thread) which is then taped to a scintillator, or the phototube mount can be threaded to receive the capsule.

The electrical pulse generators for exciting the light pulsers are constructed by utilizing mercury-relay switches. They are capable of generating pulses 2 nsec wide and up to 2.5 kv in amplitude in a 50-ohm coaxial system at a rate of 60 per second. (The light capsules are capable of operation at higher repetition rates if a suitable pulse generator is available.)

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

Distribution of Pulses

In an experiment there is almost always more than one counter requiring a light pulser. Means of distributing the electrical pulse to several capsules is therefore required. A transmission-line splitter can be used to produce several simultaneous pulses from one input. The four-way splitter of Fig. 3 has four outputs, each of which emits a pulse of one-half the input pulse amplitude. Nine-way splitters, with a gain of 1/3, have also been used.

In addition, it is usually required that not all light pulsers be excited simultaneously, but rather pulsed in some pre-determined sequence. The commutation of the short, high-voltage electrical pulses is accomplished with relay matrices, consisting of interconnections of single-pole double-throw relays. These relays also utilize mercury-relay switches in their construction. An example is shown in Fig. 4. The single input lead and the two output leads are of 50-ohm coaxial cable with BNC connectors. The mercury-relay switch is mounted inside the 0.5-in.-diameter brass tube. The relay coil is wound around the brass tube and consists of 2000 turns of #29 wire. The etched circuit board mounted on the relay contains some circuit elements, as shown in Fig. 5; the transistorized relay-driver circuit is also given in Fig. 5. The 50-μf capacitor in shunt with the resistor provides a surge of current when transistor Q2 is switched on. This surge is sufficient to close the relay in about 3.5 msec. The 100-ohm resistor limits the steady-state coil current to approximately 100 ma, which is sufficient to hold the relay contacts in the closed position. The incandescent lamp across the 100-ohm resistor is used to indicate that the relay coil is energized.

The pulse transmission characteristics of the relay are shown in the photos of Fig. 6. These were taken on a sampling oscilloscope. The time scale is 1 nsec per large horizontal division. Figure 6a is the pulse from the electrical pulse generator. Figure 6b shows the same pulse after it has traveled through four relays in series. Figure 6c shows the feedthrough pulse at the open contacts of a relay whose closed contacts are transmitting a pulse similar to Fig. 6a. The peak height is about 10% of the input pulse. Feedthrough pulses of this amplitude are tolerable in a light pulser system because the pulse-voltage threshold of the capsules is about 500 volts.

Relay Matrices

In use the relays can be interconnected in a pyramid matrix as in Fig. 7. The matrix shown has seven relays and eight output channels. The input pulse can be switched to any of the eight outputs by properly energizing or de-energizing the relays. The relays are energized in proper sequence by the chain of binary counters shown on the left. Following a reset, all binaries are in the "0" state, causing all relays to be de-energized. The relay contacts are then in the positions shown in the figure, and any input pulses are delivered to output channel "0." If a single pulse is applied to the trigger input of the binary chain, the first binary switches to state "1," and all the relays in the top row are energized. Any inputs then go to output channel "1." A second transfer input causes the relays in the second row to be energized and those in the top row to be de-energized, causing the pulses to go to output channel "2," etc. Notice that the number of relays required is roughly equal to the number of output channels.

A block diagram of a simple control logic for use with a relay matrix is also included in Fig. 7. Inasmuch as the relay coils require more power to operate than the flip-flops can supply, relay-driver blocks ("RD") are required between the flip-flops and the relay coils. With the "advance" switch in the "auto" position, pushing the "start" button gates on the electrical pulser. It then commences generating 2-nsec-wide output pulses at 60 per second. These enter the relay matrix. Following each output pulse, the simultaneously generated trigger pulse advances the count stored in the binary chain. This causes the relay pyramid to change its state so as to route the following output pulse into the succeeding output channel. When one pulse has been routed into each of the eight outputs, a signal from the third flip-flop in the binary chain resets the start-stop flip-flop, terminating the sequence. The system is then idle until the "start" button is again pushed. Pushing the "start" button with the "advance" switch in the "manual" position results in pulses being delivered continuously to the output channel representing the count stored in the binary chain. This count can be changed by pressing the "manual advance" button.

The first, or "automatic," mode of operation as described above is useful for automatic checking of a counting system, in this case, an elementary system having eight counters. Following an automatic sequence, the data-collecting device(s) (e.g., scalers) used with the system should indicate that each counter received one light pulse. If there is no such indication, one looks for trouble in the channel involved. The manual position is useful for localizing troubles. For example, if no counts are stored from channel 3 in the automatic mode, one can send a continuous train of pulses into channels 3's light pulser and trace the signal from the counter to determine where it is going astray.

Checking System for an Experiment

The eight-output channel-checking system described above constitutes a very simple example of the technique. Obviously the number of outputs and sequences can be extended. Two examples of checking systems that have been used in experiments can be given here. A block diagram of the first experiment is shown in Fig. 8.

The incoming pion beam from the Bevatron impinged on a hydrogen target. Counters 1 and 2 in coincidence defined pions entering the target. When a desired reaction occurred in the target, two particles were given off at random angles. One of these reaction products struck one of 26 "π" counters, the other, one of 21 "ρ" counters. The outputs of the sets of π and ρ counters entered a coincidence matrix and certain combinations of coincidence between π and ρ signals were then stored in a multichannel counter.

The test routine constructed for this experiment contained one pyramid relay matrix having 26 outputs and another having 21 outputs. As shown in Fig. 9, the output of the pulse generator was split into four pulses by a pulse splitter. Thus, for each pulse from the pulse generator, a pulse was simultaneously delivered to counters 1 and 2, and to each of the two relay matrices, from whence it was routed to one π counter and one ρ counter. After each pulse from the pulse generator, the scale-of-26 counter caused the π relay matrix to be advanced so that the next pulse fell into the succeeding π channel. After the pulse was delivered to π channel 26, the π scaler reset itself and emitted a carry pulse to the scale-of-21, causing the ρ-relay matrix to become advanced to the next ρ channel. During one complete test routine, every combination of a π and ρ counter was pulsed. The complete cycle contained $21 \times 26 = 546$ pulses and consumed $546/60 = 9.1$ seconds.

The results of a test routine were read out on the same multichannel storage as was used for the experiment. Thus, the entire electronic data-acquisition system was checked during the test routine--from phototube through to the device used to store the experimental data.

The electronics for this test routine is shown in Fig. 10. The two relay matrices are contained in the left-hand rack. The control electronics, including relay drivers, is on the right, in the bin containing the printed circuit cards. Directly above this is the control panel. It has the start and stop buttons, advance-mode selector switch, and lights indicating the π and ρ channels energized. Power supplies are also shown; the high-voltage supply at the top controls the amplitude of the pulse applied to the light capsules. The pulse generator is not shown.

Front and rear views of one of the relay matrices are in Fig. 11. The wiring of the relay pyramid is reproduced in black lines on the front panel; the lights (see Fig. 5) give the condition (energized or de-energized) of the relays at any time.

Checking System for Another Experiment

Another experiment for which a test system has been used involved detection of a neutrons having times of flight of from 10 to 60 nsec. A block diagram of a portion of the experiment is in Fig. 12. Counters 1 and 2 in coincidence and counter 3 in anticoincidence defined beam particles that were stopped in the target. Some of the stopped particles produced neutrons which struck thick scintillator 5, where recoil protons produced light. A thin counter, 4, surrounding scintillator 5, detected charged particles. A time-to-height converter gave a pulse proportional in height to the time of flight of the neutron This pulse was then stored in the pulse-height analyzer.

In instrumenting the test routine for this portion of the experiment, it was necessary to provide means of checking the action of the anticoincidence circuits, and also to check the stability of the time-of-flight measuring circuitry. Figure 13 is a schematic of the relay switching scheme used. Note that six relays (Nos. 3 through 9) are used to switch four different time delays into the light pulses generated at counter 5. By means of relays 1 and 2, pulses could be routed either to counter 3 or 4 or to neither one. The sequence of pulses produced is given in Table I, together with the number of counts stored in the scaler and pulse-height analyzer for each complete cycle.

Following a test-routine cycle there should be a count of 5 in the scaler, and four counts in the pulse-height analyzer -- one in each of the four channels shown. Any departure from these figures is an indication of a malfunction.

It is in order to emphasize the importance of the light pulsers in initially setting up a counter experiment. The cables from the relay matrices or pulse splitters are cut to such a length that the relative times of arrival of light pulses at the counters are the same as for the particles to be experimentally studied. Using the trigger from the electrical-pulse generator to trigger an oscilloscope, one can easily trace the light-pulse-generated signals through the counter electronics, one can time coincidence circuits, set discriminator levels, etc., without an accelerator beam. When the accelerator beam becomes available to the experiment, much of the preliminary "tuning" is already accomplished. It has been estimated that the cyclotron operating time saved by the checking system, described in part above, amounted to about 2 hours per counter. Without the light-pulser system the cyclotron beam would have been required for adjusting the counters.

Further Elaborations

It will be noted that the checking systems described above utilize, as readout devices, the same elements used to acquire data during the actual experiment. This is an advantage in that it also tests the operation of these elements. It is a disadvantage, however, in that the flow of experimental data must be halted in order to perform a test routine. Proposals have been made for check-system readout devices separate from those of the experiment. These could be inserted at any important point in the counter system and, during a test routine, would automatically indicate whether a test-originated pulse were incorrectly present or absent. Since most accelerators are low-duty-cycle machines, there would be ample time available between beam bursts to perform a complete system check with the latter type of readout. This need not interfere in any way with the flow of experimental data signals.

Conclusions

The inclusion in a counter experiment of a check system of the type described has several important advantages.

1. During the initial phases of an experiment it can save appreciable accelerator beam time which otherwise would be required for verifying the presence and time of arrival of signals from the various scintillation counters.
2. During the running of an experiment, it allows periodic checking of the entire electronic systems from phototubes through the data-storage devices.
3. In case of system malfunctions, it provides a source of signals and oscilloscope triggers for signal tracing.

Acknowledgment

The author gratefully acknowledges the assistance of Mr. Leonard Proehl in designing and building the relay matrices.

References

1. Innes, Thomas G., and Kerns, Quentin A., A Pulsed Nanosecond Light Source. Wescon Convention Record, Aug. 1961, Paper No. 23/2.
2. Innes, T. G., and Cox, G. C., A Triggered Nanosecond Light Source, File CC8-31, Lawrence Radiation Laboratory Counting Handbook, UCRL-3307 (Rev.), March 1961.
3. Kerns, Q., and Cox, G., A Bibliography on LRL Nanosecond Light Sources, Lawrence Radiation Laboratory Engineering Note EE-814, Jan. 23, 1962.

Figure Legends

Fig. 1. A light capsule in various stages of disassembly. The bottom portion of the complete capsule on the right is a General Radio 50-ohm coaxial connector through which the electrical pulse is introduced. The light is emitted from the top.

Fig. 2. Shape of light pulse when excited with a 2-nsec electrical pulse. Horizontal scale is 1 nsec per large division.

Fig. 3. A four-way transmission-line splitter.

Fig. 4. A single-pole double-throw coaxial relay for switching the electrical pulses used to excite the light pulsers.

Fig. 5. Circuitry used to drive the relays of Fig. 4.

Fig. 6. Pulse transmission characteristics of relays of Fig. 4:
(a) input pulse; (b) output pulse after traveling through four relays; (c) feedthrough pulse from open contact. Horizontal scale is 1 nsec per large division.

Fig. 7. A simple pyramid-connected relay matrix and associated control electronics. (RD = relay devices; RE = relay coil.)

Fig. 8. Block diagram of a counter experiment.

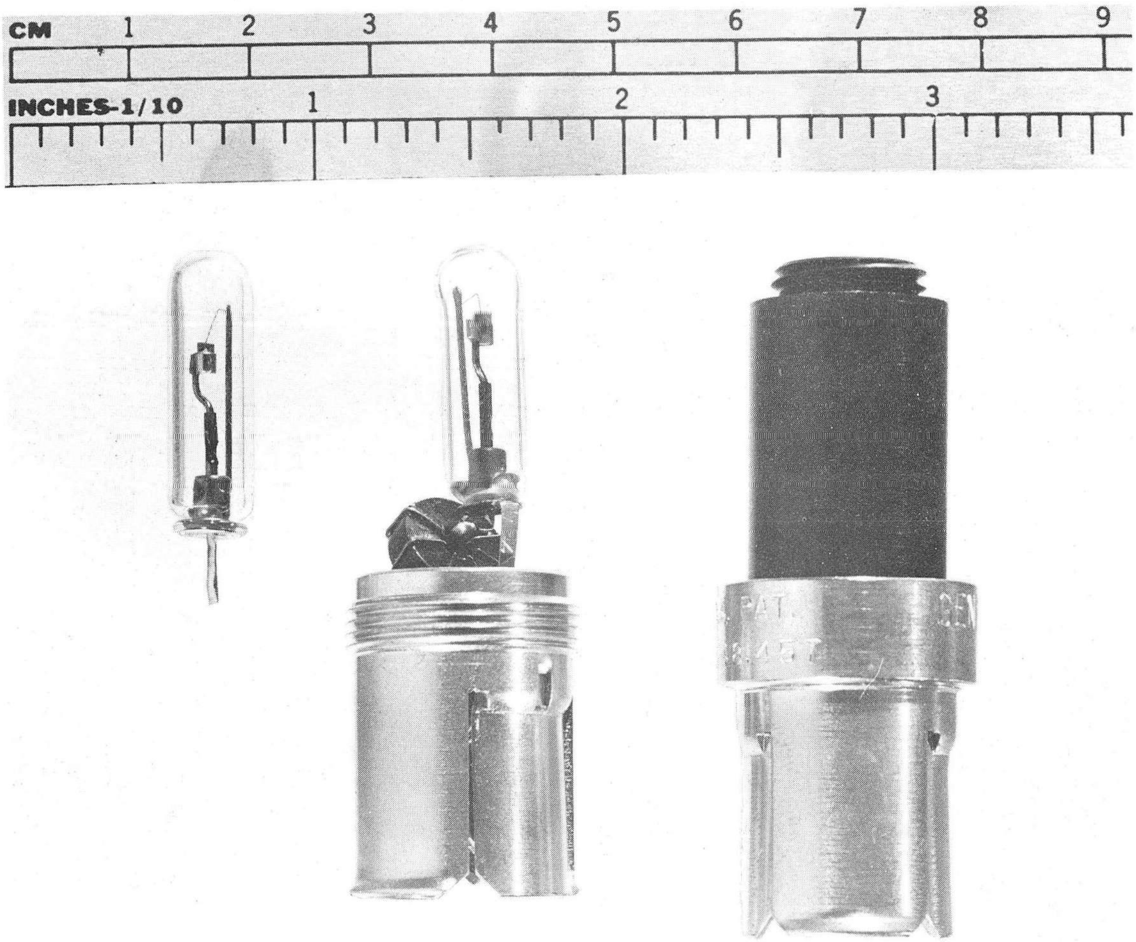
Fig. 9. Block diagram of test system for use with experiment of Fig. 8.

Fig. 10. Test system of Fig. 9.

Fig. 11. Front and rear views of a 21-output relay matrix.

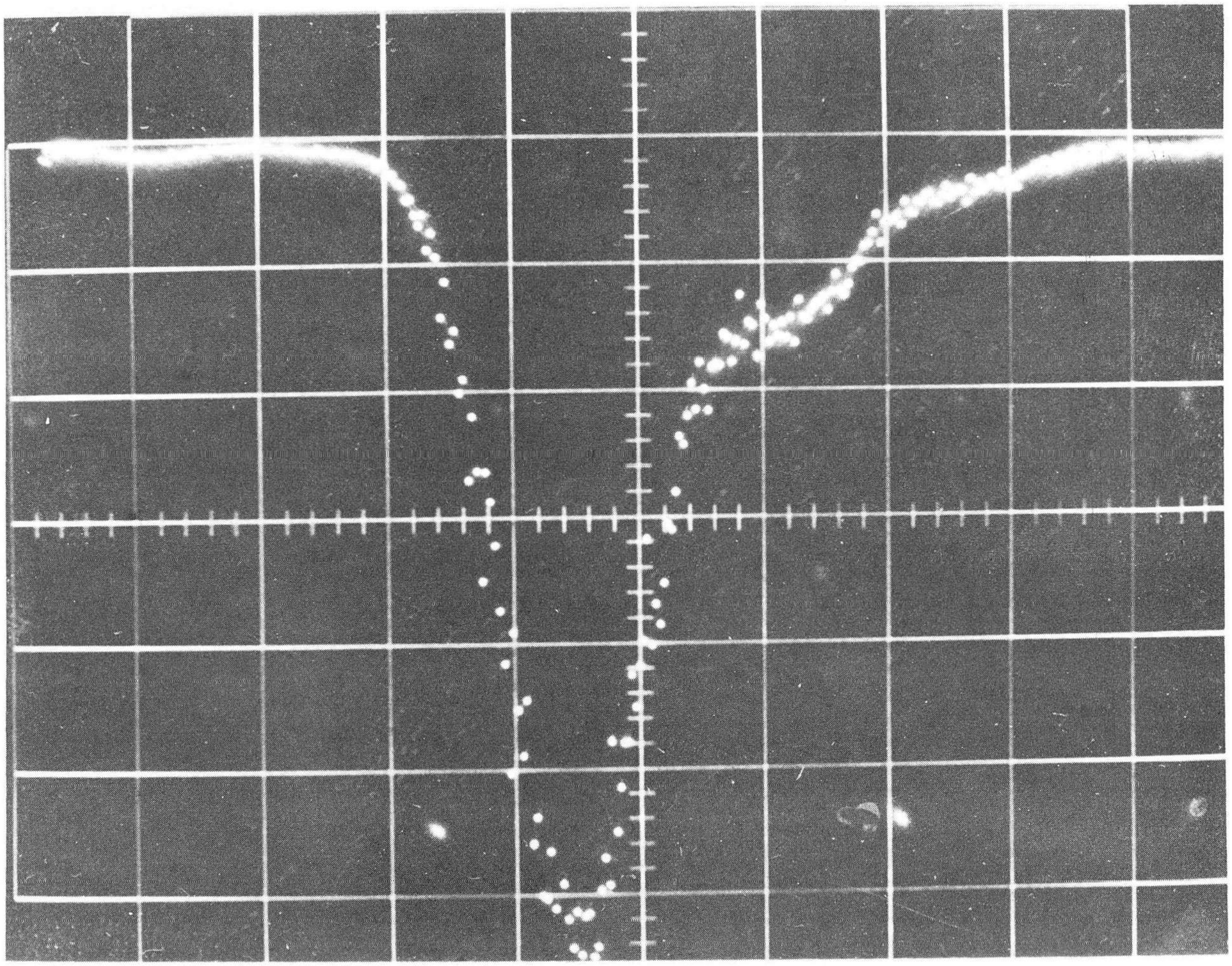
Fig. 12. Block diagram of a portion of a second experiment.

Fig. 13. Block diagram of a test system for use with experiment of Fig. 12.



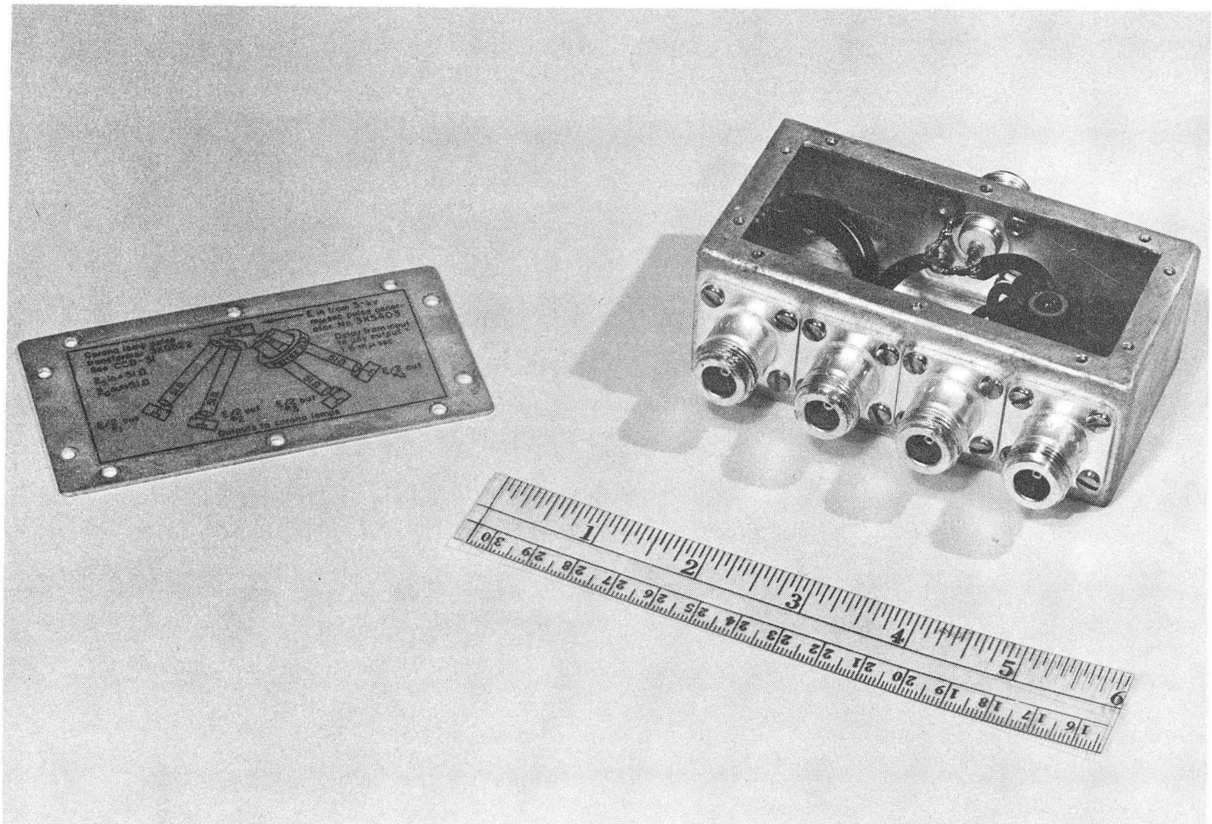
ZN-2867

Fig. 1.



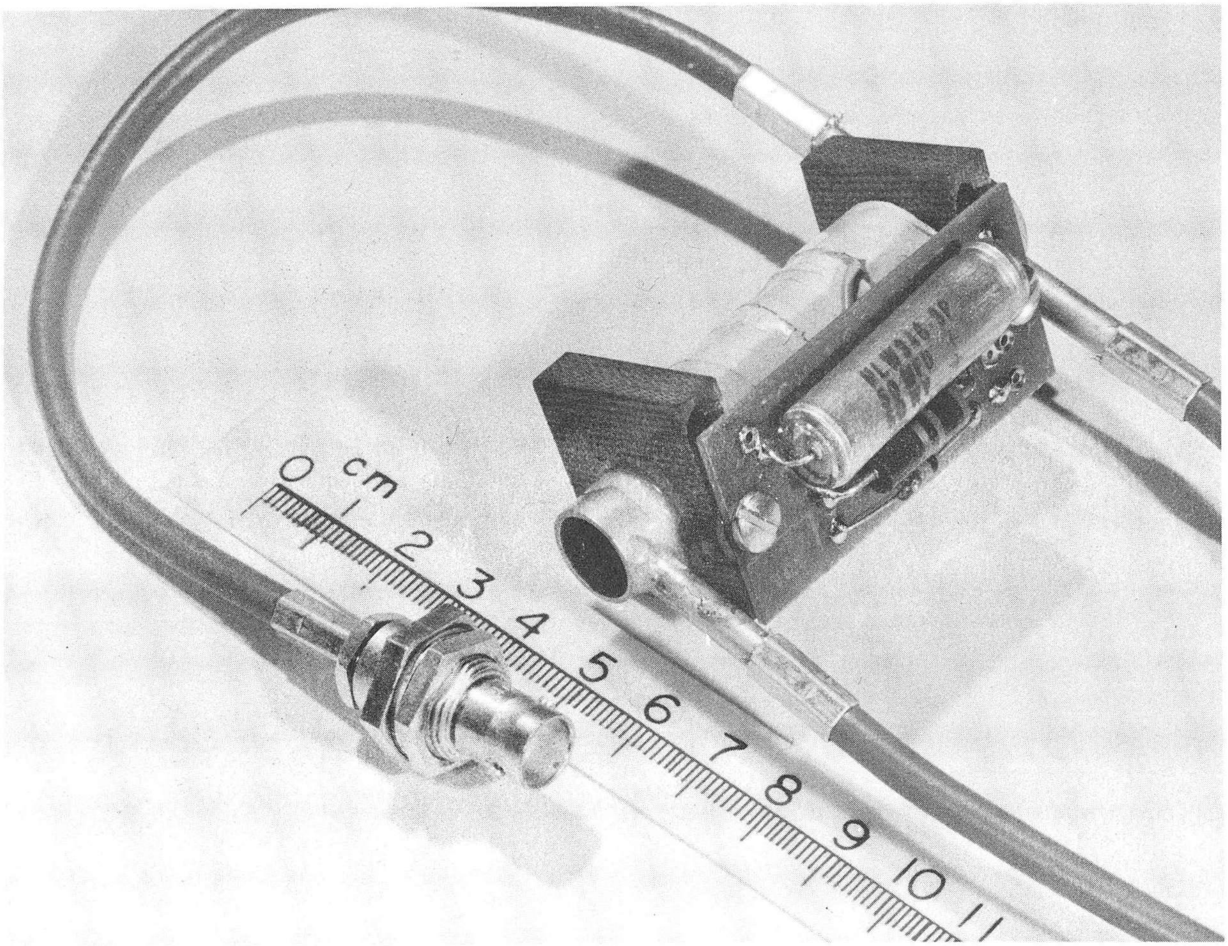
ZN-2868

Fig. 2.



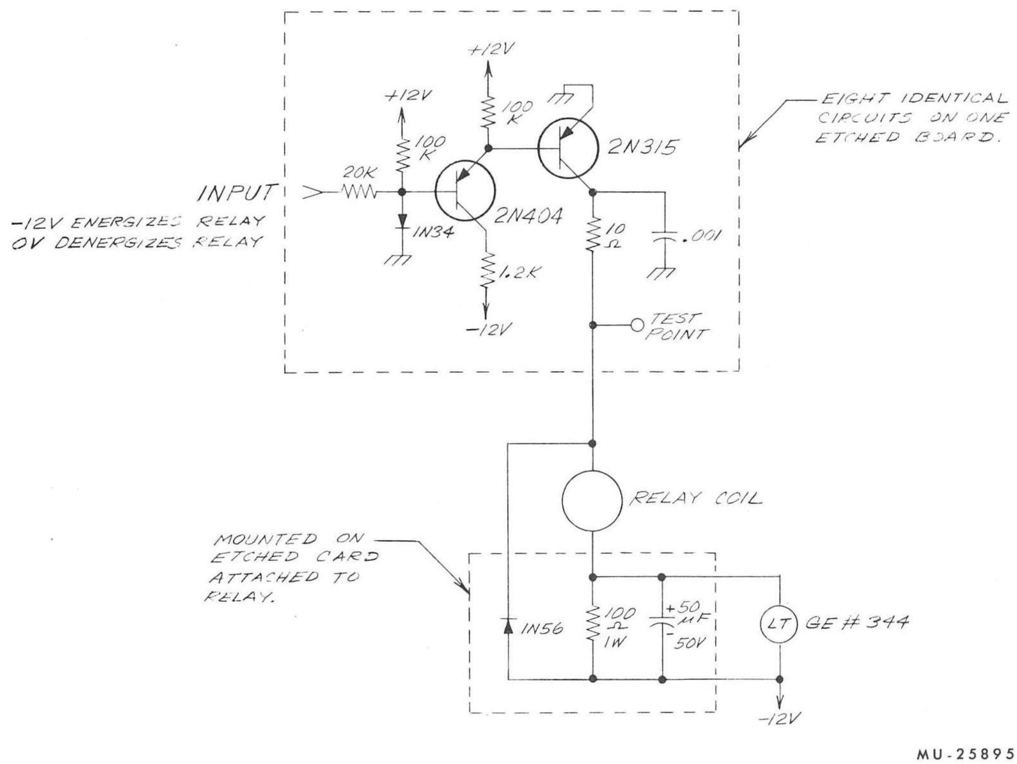
ZN-2869

Fig. 3.



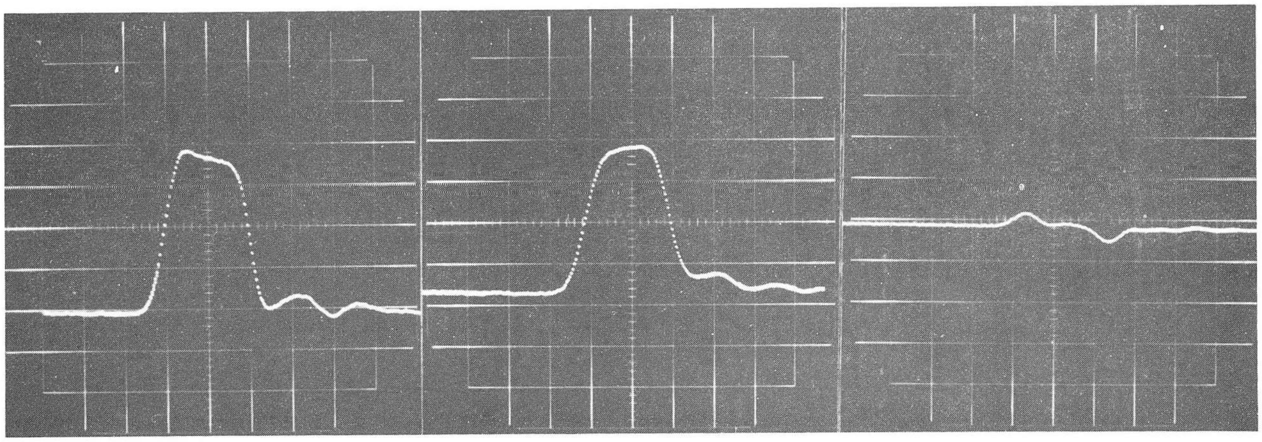
ZN-3022

Fig. 4.



+12V
+12V
100 K
100 K
2N315
EIGHT IDENTICAL CIRCUITS ON ONE ETCHED BOARD.
INPUT
20K
2N404
-12V ENERGIZES RELAY
0V DENERGIZES RELAY
1N34
10 Ω
.001
1.2K
-12V
TEST POINT
RELAY COIL
MOUNTED ON ETCHED CARD ATTACHED TO RELAY.
1N56
100 Ω 1W
+50 μF 50V
LT
GE # 344
-12V
MU-25895

Fig. 5.



ZN-3023

Fig. 6.

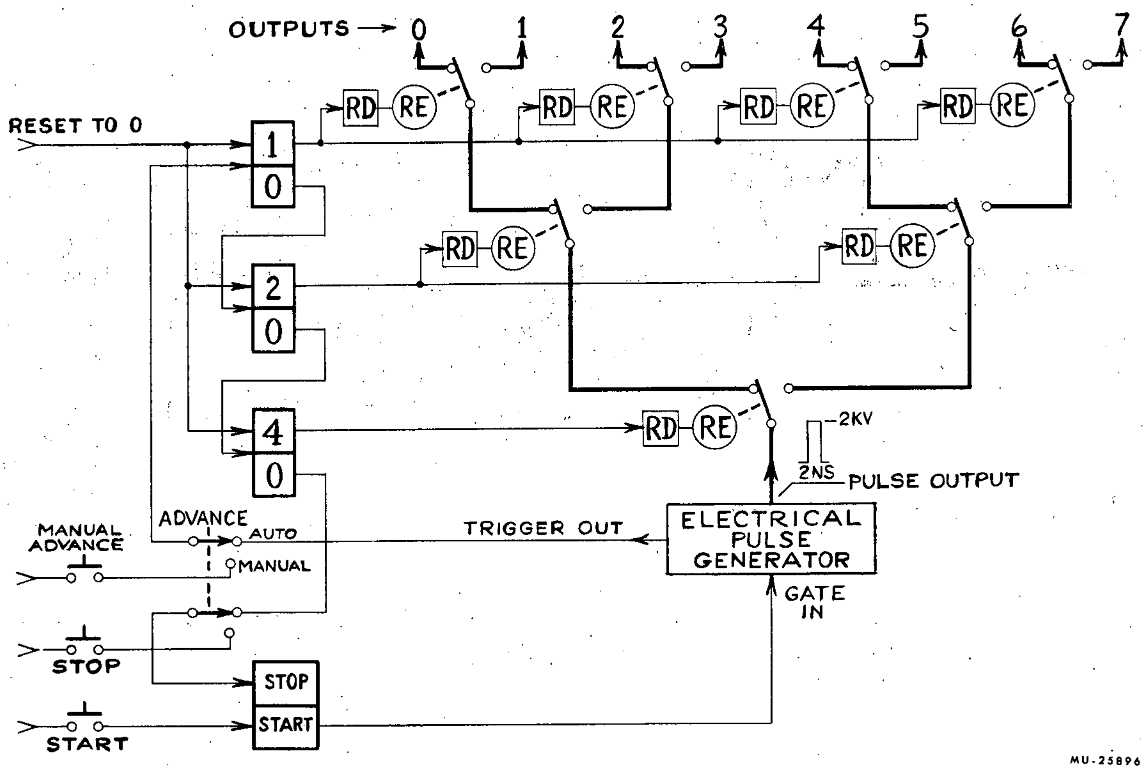

OUTPUTS
0
1
2
3
4
5
6
7
RESET TO 0
RD
RE
1
0
2
0
4
0
2KV
2NS
PULSE OUTPUT
ELECTRICAL PULSE GENERATOR
TRIGGER OUT
GATE IN
MANUAL ADVANCE
ADVANCE
AUTO
MANUAL
STOP
START
MU-25896

Fig. 7.

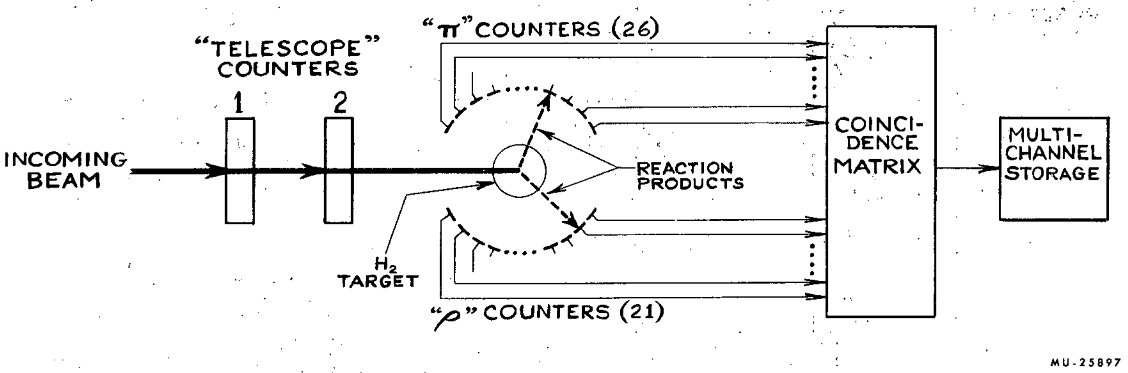

"TELESCOPE" COUNTERS
1
2
INCOMING BEAM
"π" COUNTERS (26)
REACTION PRODUCTS
H_2 TARGET
"ρ" COUNTERS (21)
COINCI-DENCE MATRIX
MULTI-CHANNEL STORAGE
MU-25897

Fig. 8.

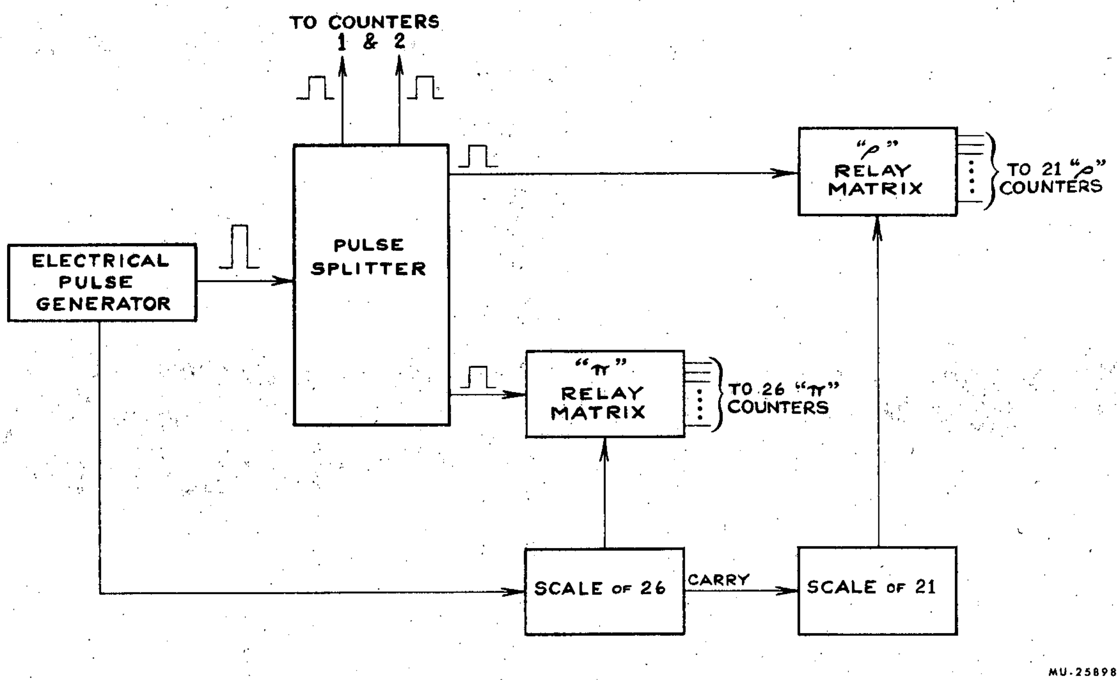
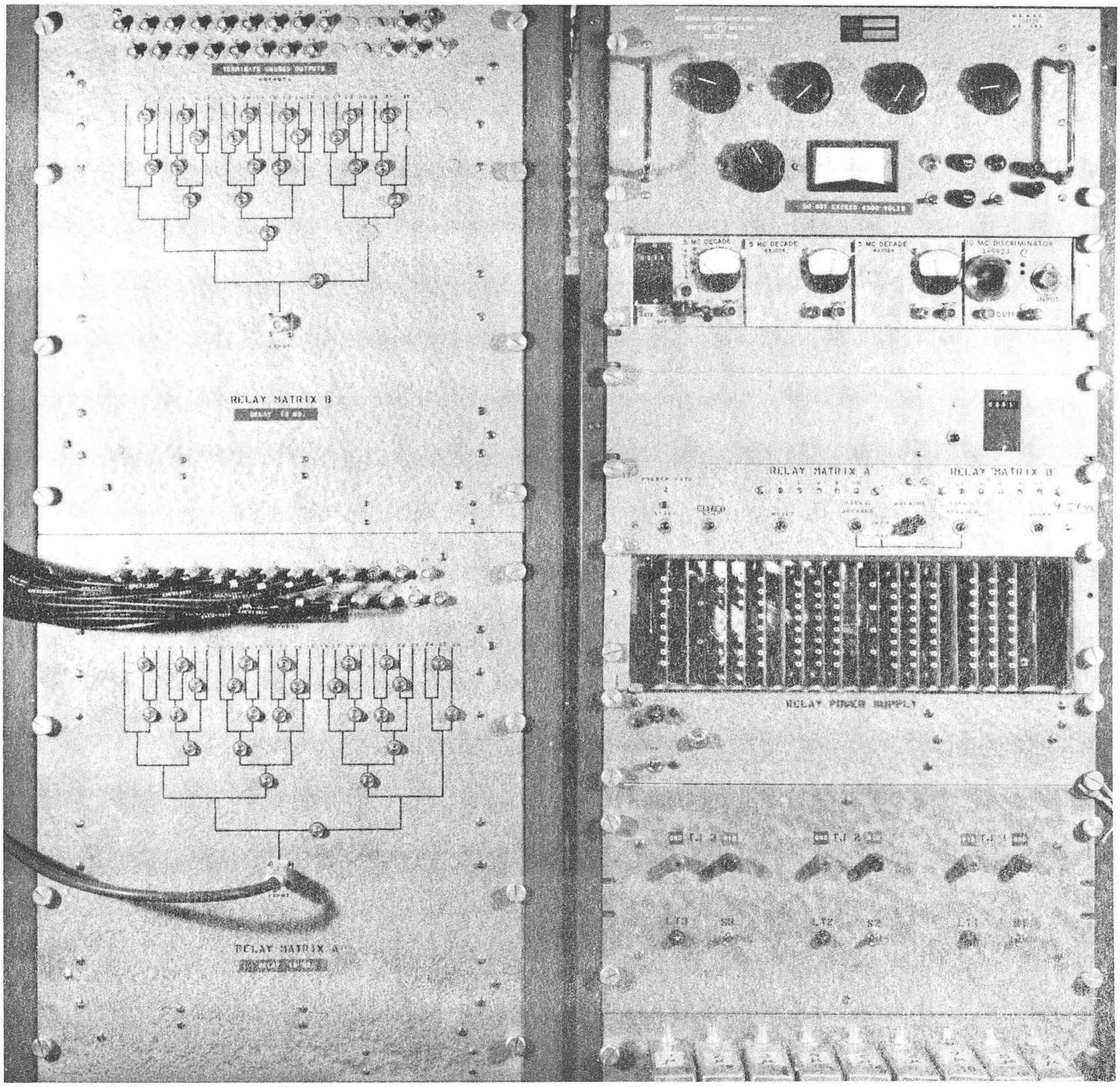
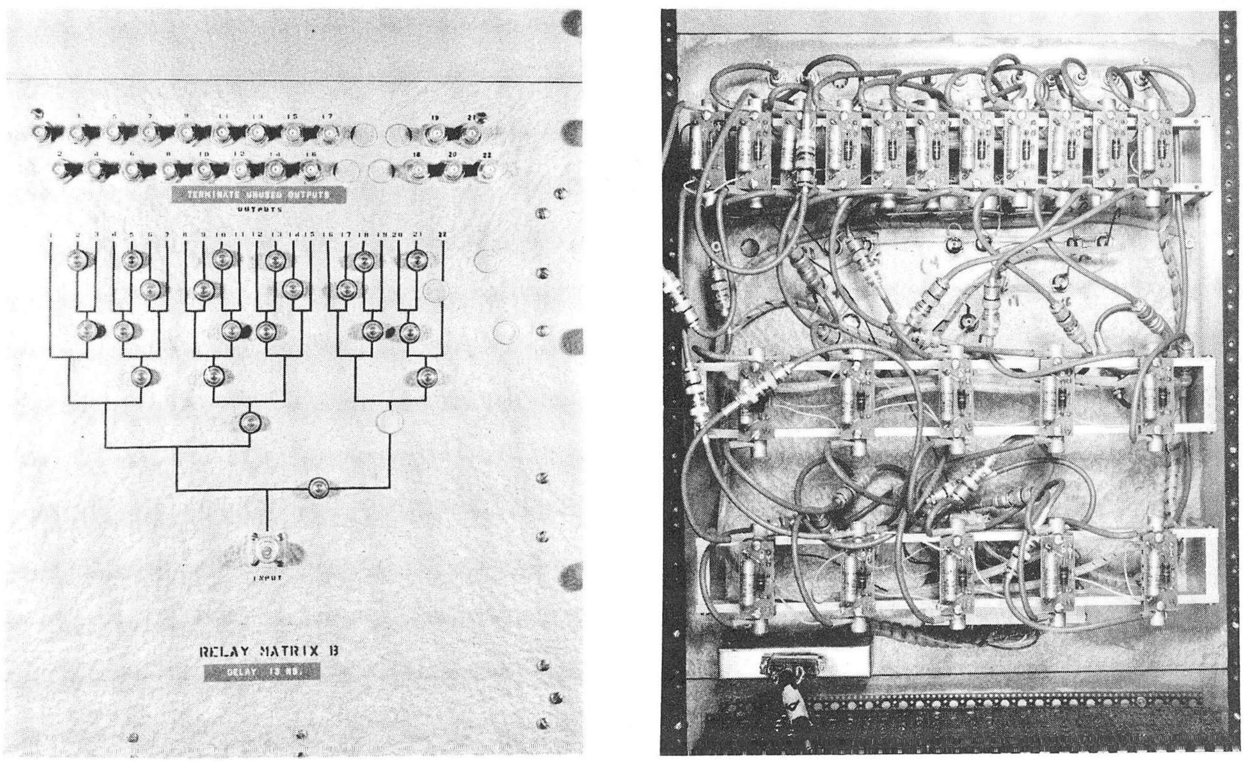

TO COUNTERS
1 & 2
"ρ"
RELAY
MATRIX
TO 21 "ρ"
COUNTERS
ELECTRICAL
PULSE
GENERATOR
PULSE
SPLITTER
"π"
RELAY
MATRIX
TO 26 "π"
COUNTERS
SCALE OF 26
CARRY
SCALE OF 21
MU-25898

Fig. 9.



ZN-3021

Fig. 10.



ZN-3024

Fig. 11.

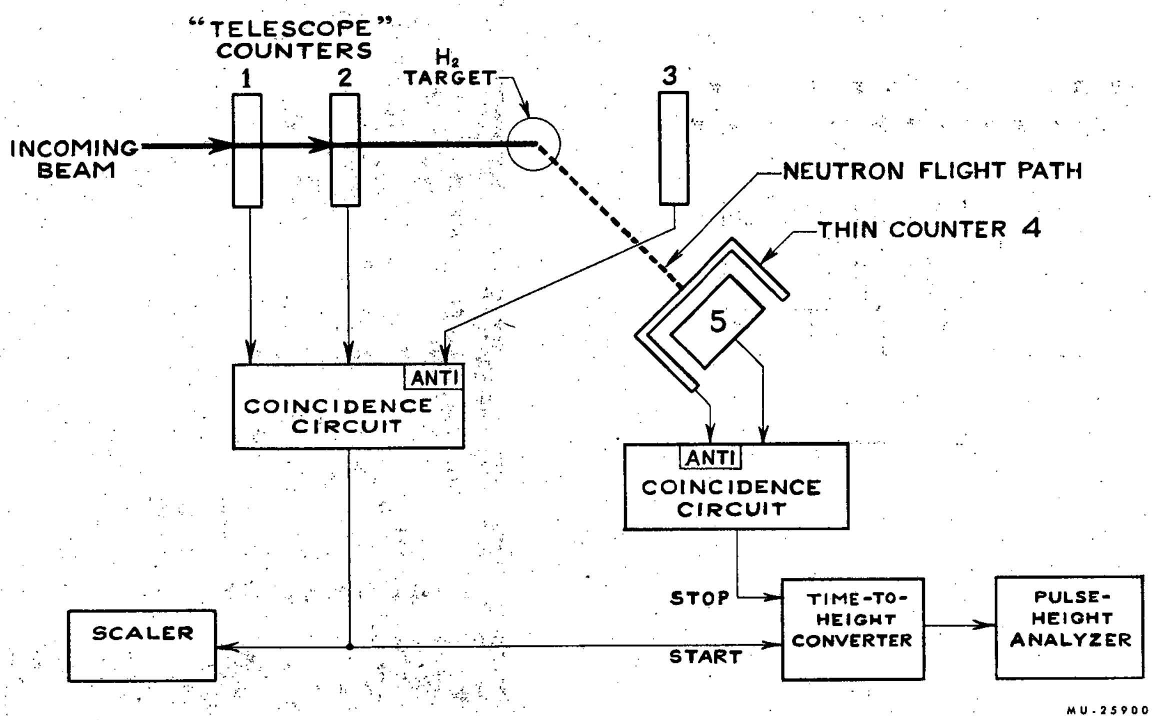

"TELESCOPE"
COUNTERS
1
2
H_2
TARGET
3
INCOMING
BEAM
NEUTRON FLIGHT PATH
THIN COUNTER 4
5
ANTI
COINCIDENCE
CIRCUIT
ANTI
COINCIDENCE
CIRCUIT
STOP
TIME-TO-
HEIGHT
CONVERTER
PULSE-
HEIGHT
ANALYZER
SCALER
START
MU-25900

Fig. 12.

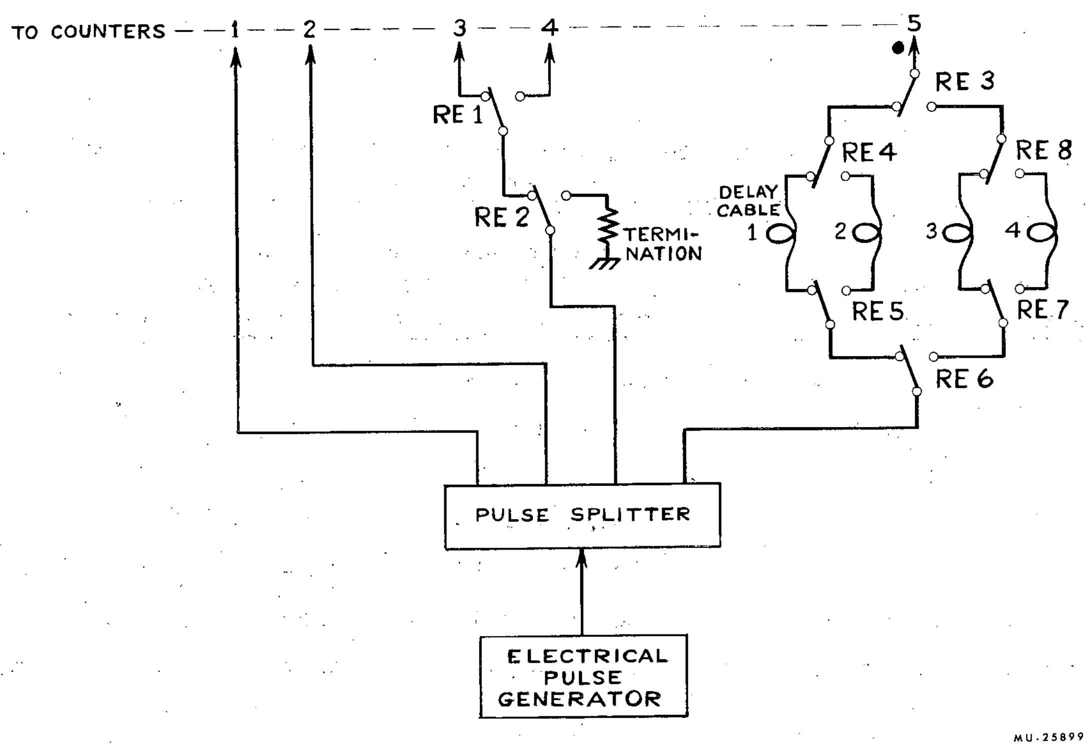

TO COUNTERS
1
2
3
4
5
RE 1
RE 2
TERMI-
NATION
RE 3
RE 4
RE 8
DELAY
CABLE
1
2
3
4
RE 5
RE 7
RE 6
PULSE SPLITTER
ELECTRICAL
PULSE
GENERATOR
MU-25899

Fig. 13.

Table I. Sequence of pulses produced by test routine for experiment of Fig. 11.

Pulse sequence number	Light pulsers energized	Relative delay in output to pulser number 5 (nsec)	Count stored in scaler?	Count stored in pulse-height analyzer
1	1, 2, 3, 5	Delay 1 = 0	No	No
2	1, 2, 4, 5	Delay 1 = 0	Yes	No
3	1, 2, 5	Delay 1 = 0	Yes	Channel 1
4	1, 2, 5	Delay 2 = 16	Yes	Channel 33
5	1, 2, 5	Delay 3 = 33	Yes	Channel 67
6	1, 2, 5	Delay 4 = 50	Yes	Channel 100