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DEVELOPMENT OF AN IMPROVED SAMPLE CONTROL AND COUNTING SYSTEM FOR ACTIVATION ANALYSIS WITH A NEUTRON GENERATOR

D. W. CARSON

MINERAL SCIENCES DIVISION

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DEVELOPMENT OF AN IMPROVED SAMPLE CONTROL AND COUNTING SYSTEM FOR ACTIVATION ANALYSIS WITH A NEUTRON GENERATOR

by

D. W. Carson*

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ABSTRACT

An improved sample control and counting system has been developed for activation analysis with a neutron generator, replacing the original system developed earlier (1965).

The new system, which uses low-level, low-noise, solid-state logic circuitry and includes timing, counting and readout subsystems, provides improved frequency response and eliminates spurious counts created by the original relay-controlled circuits.

* Electronic technologist, Mineral Sciences Division, Mines Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

Direction des mines

Bulletin technique TB 116

MISE AU POINT D'UN SYSTÈME AMÉLIORÉ DE CONTRÔLE ET DE COMPTAGE D'ÉCHANTILLONS POUR L'ANALYSE PAR ACTIVATION À L'AIDE D'UN GÉNÉRATEUR DE NEUTRONS

Par

D. W. Carson*

Résumé

L'auteur décrit la mise au point d'un système amélioré de contrôle et de comptage d'échantillons pour l'analyse par activation à l'aide d'un générateur de neutrons, remplaçant le système original mis au point en 1965.

Le nouveau système qui fait usage de circuits logiques de corps solides à faible puissance et à faible bruit et qui comprend également des sous-systèmes de minuterie, de comptage et de lecture, donne une réponse de fréquence améliorée et élimine les comptes erronés que donnaient les circuits originaux contrôlés par relais.

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INTRODUCTION

A fast neutron generator is currently used in the Mineral Sciences Division of the Mines Branch, Ottawa, for the quantitative determination of a number of elements by neutron activation analysis (1). As a result of the operating characteristics of the generator, most of the irradiations are for a short time (usually only a few minutes) and emphasis is placed upon the formation of isotopes of half-lives of a few seconds to a few minutes. Most samples to be analysed are irradiated, and subsequently counted, using a pneumatic transfer system to transport the sample between the irradiation and counting positions. In order to obtain accurate results, the transfer, irradiation and counting times must be reproducible. A control system was developed for this purpose which allowed reasonable flexibility in the selection of the irradiation and counting parameters. However, the system was subject to electrical noise interference produced by the electromechanical relays, and the scalers used to record the neutron flux and the gamma count rates were obsolescent. A complete reorganization of the control and counting circuitries has been made by using solid-state modules, in order to improve the flexibility of the control system and replace the scalers.

This report describes the circuit designs used and also the operational procedure for this system.

GENERAL DESCRIPTION

The neutron generator is enclosed in a shielded room. A transfer tube (1) is used to transport the sample to the irradiation position of the generator inside the shielded room and, after the irradiation, back to the gamma detector, located outside the room. Compressed nitrogen is used to propel the sample through the transfer tube. The gas is admitted to the transfer tube through a solenoid valve (Versa Products Company, Inc. Model VSG-4322) for a preset time. There is a solenoid valve at each end of the transfer tube, each valve having its own timer.

While the sample is being irradiated for a preset time in the irradiation position, it is rotated to ensure a uniform neutron flux across the sample. A boron trifluoride counter, located in the shielding wall of the generator room, monitors the total nuetron count during irradiation. The neutron count is displayed on a neutron scaler.

At the end of the preset irradiation time, the sample is automatically returned to the start position in front of the gamma detector, by the OUT solenoid circuit. The gamma radiation from the induced activity in the sample is then measured by an NaI (TI) scintillation detector and analysed by a single-channel analyser for another preset time. The resulting counts are displayed on a gamma scaler. The complete gamma spectrum can also be analysed by a multi-channel analyser and the spectrum displayed on an X-Y recorder. There are manual over-rides on the automatic system to facilitate either the setting of the solenoid operating times that regulate the sample transfer time according to sample weight, or the recounting of the isotopes that have long half-lives.

The solid-state logic circuitry is contained in a 19-in. console (Hammond Model 1464 C 19) and provides noise-free control, with scaler counting rates of up to 2 megahertz. The scalers have binary-coded-decimal (BCD) lamp readouts. The modular console affords easy access to the circuit modules and hardware through a full door in the rear. The lower front panel can be removed to provide access to the logic wiring.

The logic circuitry was designed and built from R-series and W-series modules (Digital Equipment Corporation) (2). All control switches and scaler readouts are located on the upper front panel for ease of operation (Figure 1).

Since it is planned to construct a double transfer system to make possible the simultaneous irradiation and subsequent counting of a sample and a standard, provision has been made in the console to extend the present circuitry.

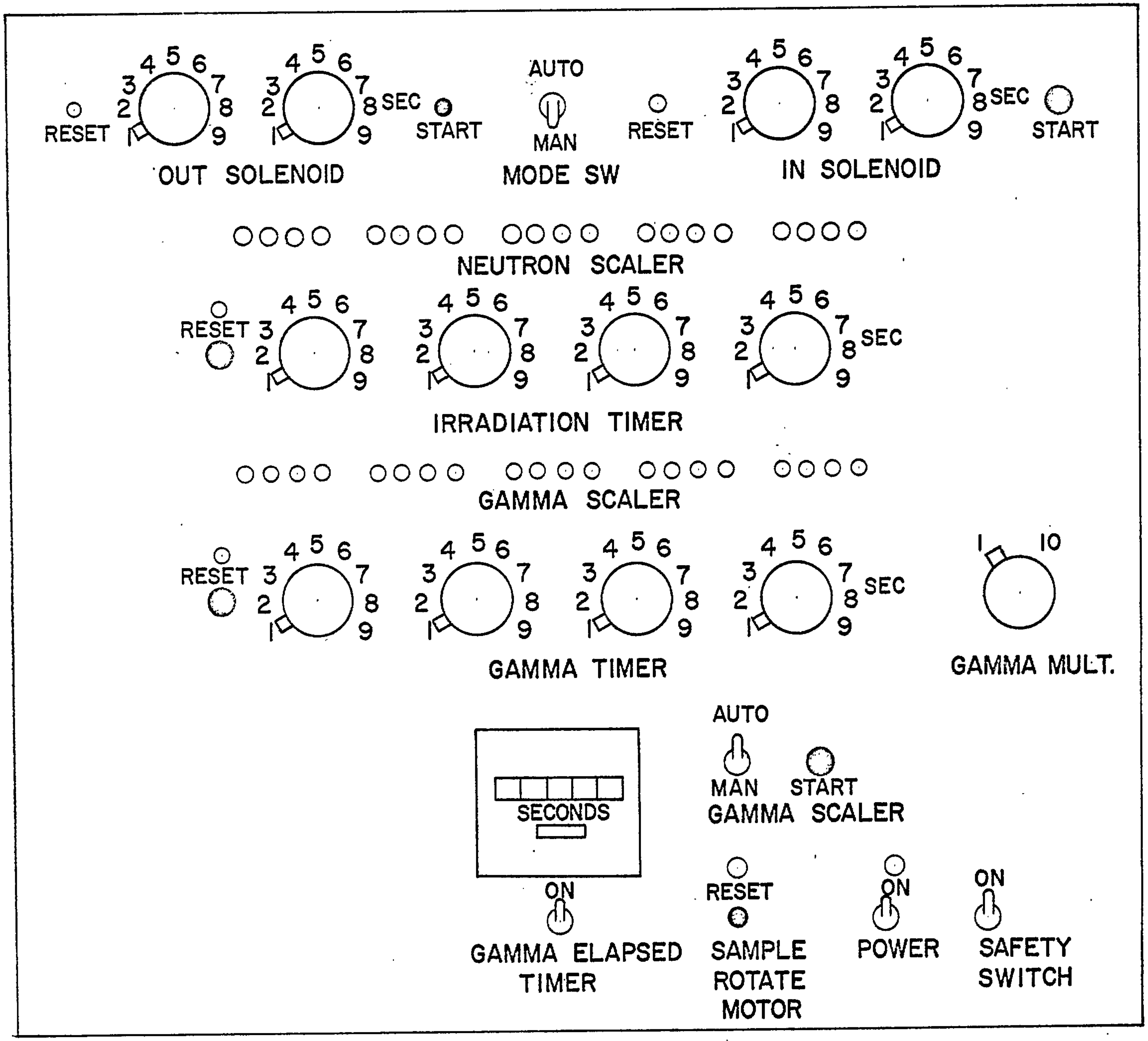

Figure 1. The control panel.

THE CIRCUIT SPECIFICATIONS

The Power Supply:

Power Supply	Digital Equipment Corp. Model 783	
Line Voltage	115V, 60 hertz	
Power	200 W-max	

Logic Circuitry:

Logic Levels	0 to -0.3V	Upper level
	-3.2 to -3.9V	Lower level
Voltage Requirements	+10V Nominal	Module Pin A
	-15V Nominal	Module Pin B
	Ground	Module Pin C
Frequency Range	DC to 2 Megahertz	
Noise Immunity	Typical noise rejection for diode gates at 0V is 1.0V; at -3V, it is 1.5V.	
Operating Temperature Range	-20°C to +50°C	

OPERATING PROCEDURE

In the fully automatic mode the sample is transferred to the irradiation position of the generator by pressing the IN solenoid start button. It is then irradiated for a preset time, during which the neutron output is monitored; the sample is then returned to the gamma detector. Its activity is next measured and recorded by the single channel or multi-channel analyser.

The operating procedure for setting the control switches is contained in the following sixteen instructions and a brief description of their control functions is included:

1. Place safety switch on.
2. Turn power switch on.
3. Select IN solenoid time.
4. Select OUT solenoid time.
5. Set the mode switch to Automatic or Manual operation.
6. Set the irradiation timer for required irradiation time.
7. Set the gamma timer for the required sample counting time.
8. Set the gamma scaler switch for Automatic or Manual operation.
9. Turn switch SW4 (on 19-in. rack panel) on.
10. Set switch SW3 (on 19-in. rack panel) for Automatic or Manual operation.
11. If SW3 is on manual, set the required gamma counting time, for the multi-channel analyser, on the manual timer and turn switch SW1 on to start the count.
12. Switch the gamma elapsed-time counter on, if it is required.
13. Turn safety switch off.
14. Press reset to clear gamma scaler.
15. Press reset to clear neutron scaler.
16. Press IN solenoid start button to initiate cycle.

The Safety Switch

The safety switch has two functions: (a) to prevent the control flip-flops from randomly switching to the ON state when power is first applied to the console, and (b) to prevent a control flip-flop from changing its state when timing switches are adjusted. The safety switch forces the control flip-flops to the OFF state and therefore must be ON before power is applied to the console, and while timing switches are being adjusted.

The IN and OUT Solenoid Timers

The times during which the IN or OUT solenoid valves are open can be adjusted through up to 4 seconds in 0.1-second units. After four seconds the timer circuits reset automatically to zero, as indicated by their reset lights. There are two timing switches for each solenoid. One switch is in 0.1-second units and the other switch is in 1-second units (Figure 1).

NOTE: For a sample of average weight (15 g), 0.6 second is a sufficient time setting for both the IN and the OUT solenoids with 60 psi of gas pressure.

The Mode Switch

In the manual position the two solenoid circuits are isolated from the rest of the circuitry, and are manually actuated from their respective start buttons.

In the automatic position, pressing the IN solenoid start button actuates the IN solenoid and initiates the irradiation cycle. The OUT solenoid is then actuated automatically at the end of the irradiation cycle.

Irradiation and Gamma Timers

The irradiation timer controls the time during which the sample is in the target position of the neutron generator, and the gamma timer the time during which the gamma radiation from the sample is counted while the sample is in front of the gamma detector. These timers can be adjusted to 9999 seconds in 1-second units.

The Neutron and Gamma Scalers

The neutron scaler accumulates the count from the neutron detector during the irradiation and gives a readout, displayed in binary-coded-decimal (BCD) notation (Appendix 1). This scaler can accommodate up to 99999 counts. For counts greater than 99999, the gamma scaler has a times-ten switch that allows the accumulation of up to 999990 counts with the least significant digit not displayed.

The Gamma-Scaler Switch

This switch provides automatic or manual control of the single-channel gamma counter. In the automatic mode, the single-channel gamma scaler is started two seconds after the sample leaves the neutron generator. For manual operation, counting is initiated by pressing the gamma-scaler start switch. The manual control allows the successive counting of isotopes with long half-lives.

Switch SW3 and Switch SW4

These switches control the operation of the multi-channel analyser. With Switch SW3 in the automatic position, the analyser is controlled by the single-channel gamma timer and runs simultaneously with the single-channel system. In the manual position, the analyser is controlled by the manual timer, which has its own start switch, SW1. Switch SW4 is a power switch that must be on when using the multi-channel analyser.

The Elapsed-Time Indicator

When the elapsed-time indicator switch is on, the timer starts automatically at the same time as the single-channel gamma scaler. The timer is stopped by placing the timer switch to OFF. The elapsed timer indicates the decay time of the sample.

THE SOLENOID CIRCUITS

The sample for analysis, contained in a 7-ml plastic vial, is transferred by nitrogen pressure, through a 3/4-inch-diameter plastic transfer tube, to and from the irradiation position of the neutron generator. The solenoid circuits control the time that the compressed nitrogen is released, which determines the transit time of the sample. There are two solenoid circuits: one to control the actuation time of the IN solenoid, and the other to control the actuation time of the OUT solenoid.

When the mode switch is in the manual position, the OUT solenoid circuit is identical to the IN solenoid circuit. In the automatic position, the start pulse for the OUT solenoid circuit comes from the control gate of the irradiation timer. Since both solenoid circuits are alike, only the IN solenoid circuit will be described.

The safety switch (Figure 2) initially forces the control flip-flop to the OFF state (solenoid not actuated) and the timer to zero. Pressing the start button produces a standard pulse at the output of the Schmitt trigger. This pulse is fed to the gate of the control flip-flop and to the gate of the reset module. The control flip-flop, driver, and switch are turned on, which actuates the solenoid. The control flip-flop also "enables" the solenoid timer. After a preset time (as set on the timing switches), the control gate turns the control flip-flop off, which de-actuates the solenoid and "disables" the timer. The reset module resets the timer to zero four seconds after it is pulsed by the Schmitt trigger, completing the IN solenoid cycle. The reset light indicates that the timer is at zero.

Initially, the safety switch forces the control flip-flop B19A (Appendix 2) to the OFF state and sets the timer circuit to zero, by placing a ground level at Pin F of the control flip-flop, and at Pins F and R of the Timer Flip-flop (Figure 3). With B19A in the OFF state, Pin H is at -3 volts and Pin J is at ground. A ground level at Pin D of the driver B24A produces a -3 volt level at its output (Pin F) which is the input of the switch B31A. With -3 volts at the input, the switch is open and the solenoid valve is closed.

Ten-hertz pulses from the clock circuit are always present at the gate of the first timer flip-flop, C17, Pin D. These clock pulses accumulate in the timer if the voltage at Pins E and L of C17 is at ground level. Initially this voltage level is -3 volt, as set by the control flip-flop, which "disables" the timer.

The ground level is first removed from the control flip-flop and the timer circuit, by the safety switch. Pressing the IN solenoid start button produces a pulse at the output of the Schmitt trigger (-3 volts to ground) which is applied to the control flip-flop B19A and to the reset module B18A. This pulse from the Schmitt trigger switches the reset module whose output goes from ground level to -3 volts, allowing the pulse from the Schmitt trigger to switch B19A to the ON state, forcing Pin H to ground and Pin J to -3 volts. The -3 volt level at Pin J of the control

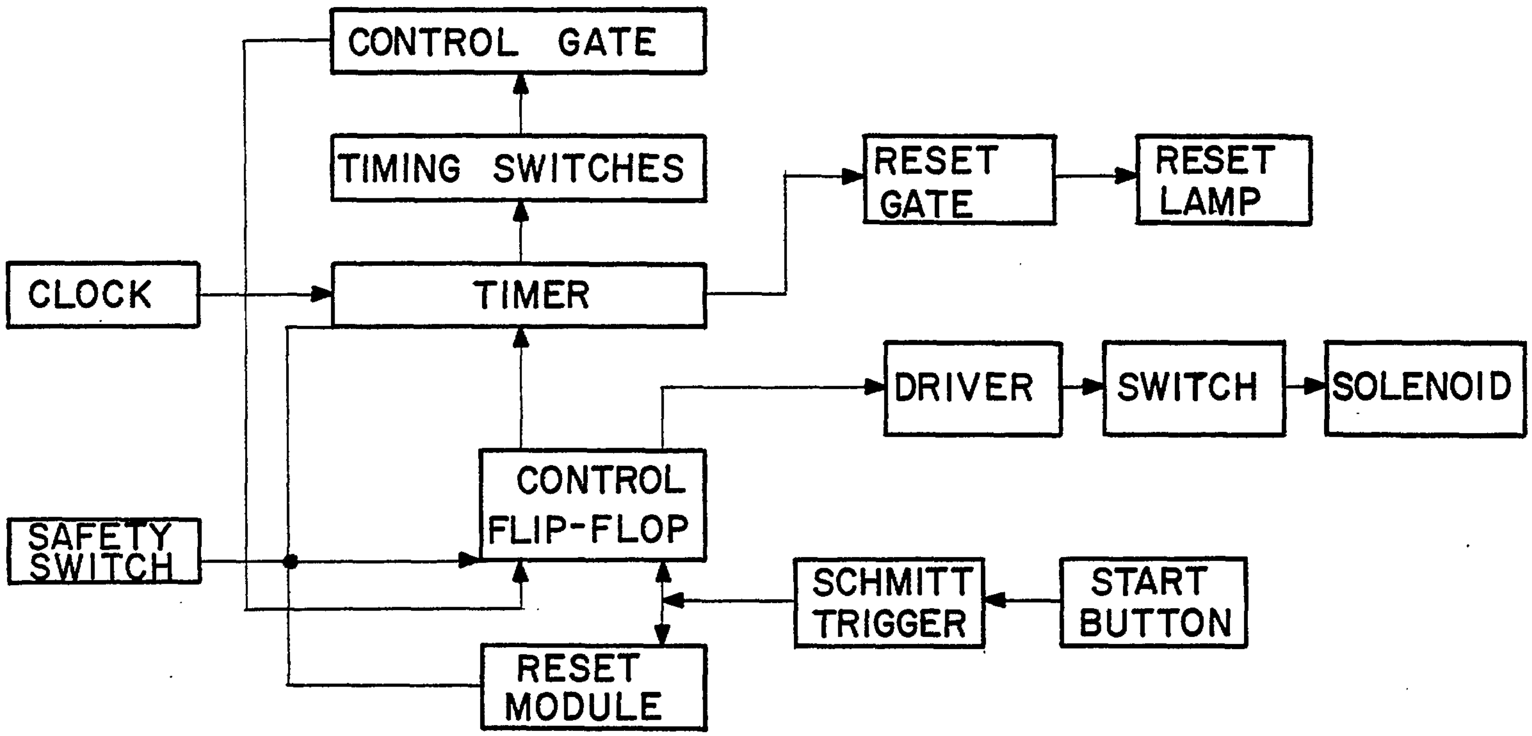

Figure 2. Block diagram of IN solenoid circuit.

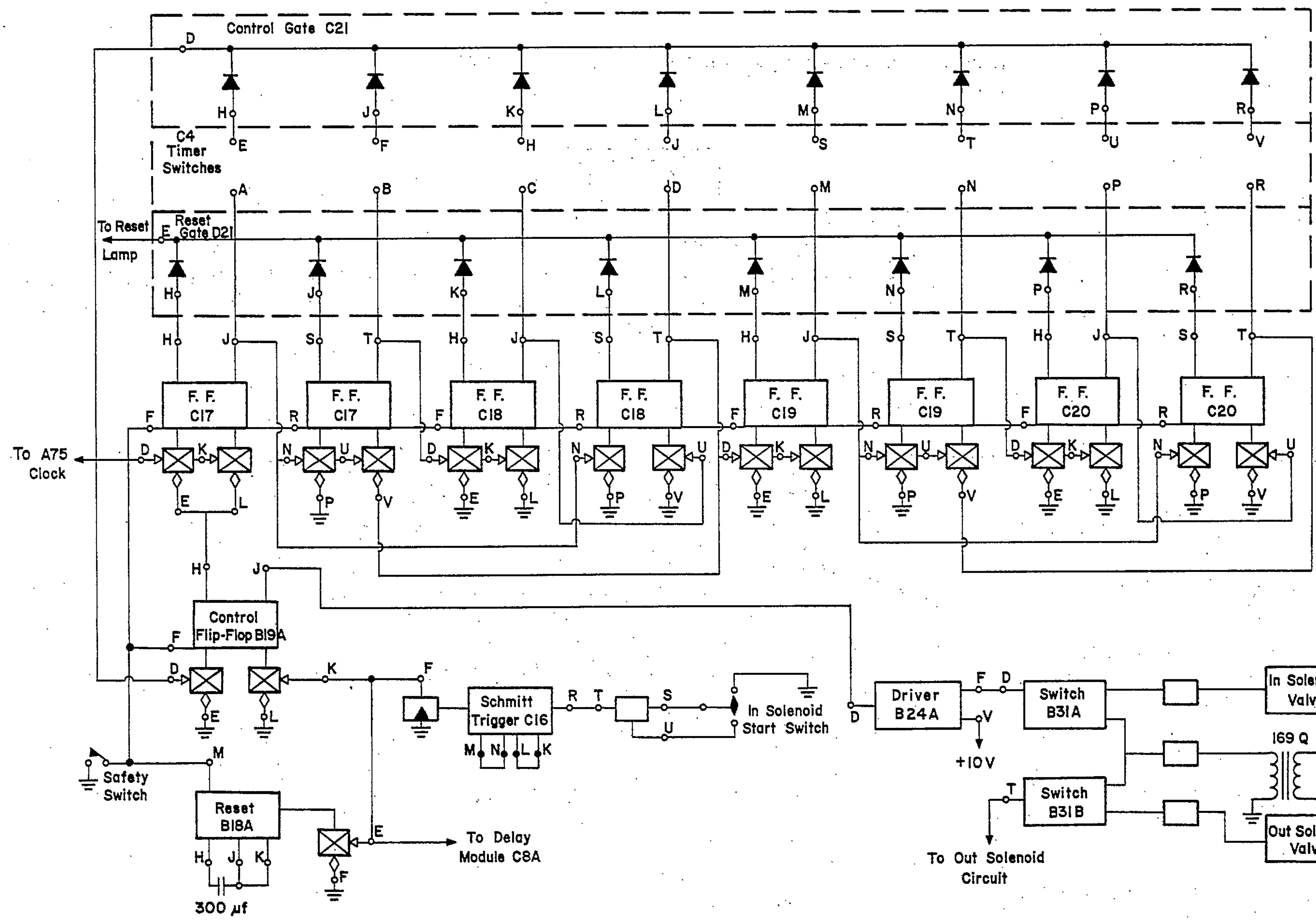

Figure 3. Schematic diagram of IN solenoid circuit.

flip-flop forces Pin D of the driver B24A to -3 volts and Pin D of the switch B31A to ground, turning the switch on and actuating the solenoid.

Placing a ground level at E and L of C17 enables the clock pulses to accumulate in the IN solenoid timer. When the timer is set to zero (Pins H and S at -3 volts, Pins J and T at ground level) the output E of the lamp gate S21 (-3 volts) lights the reset lamp 4906 (2). As soon as one clock pulse is stored in the timer, the output voltage of the gate falls to ground level and the light goes out.

When the number of pulses accumulated in the timer corresponds to the timing switches, the output voltage of the gate will rise from -3 volts to ground level. This voltage change (-3V to ground), which is applied to Pin D of B19A, switches the control flip-flop to the OFF state, turns the solenoid off, and "disables" the timer.

The output of the reset module B18A, which is tied to the reset Pins of the control and timer flip-flops, automatically returns from -3 volts to ground level, four seconds after it receives the start pulse from the Schmitt trigger. This ground level resets the control and timer flip-flops to zero, completing the IN solenoid cycle.

Both timer switches are 4-pole, 10-position wafer switches wired in BCD. The timer flip-flops are also wired in BCD and can handle 99 clock pulses. Since a 10-hertz pulse train is used, the solenoid actuation time can be varied in units of 0.1 second.

NEUTRON AND GAMMA SCALING CIRCUITS

The irradiation timing and neutron counting circuits (see Figure 4) are actuated, two seconds after the sample leaves the start position, by a pulse from the delay module C8A. This delay time allows for the transfer time of the sample. During the irradiation, the total neutron count is measured by the neutron scaler. At the end of the preset irradiation time, the irradiation timer and scaler are disabled and the sample is transferred

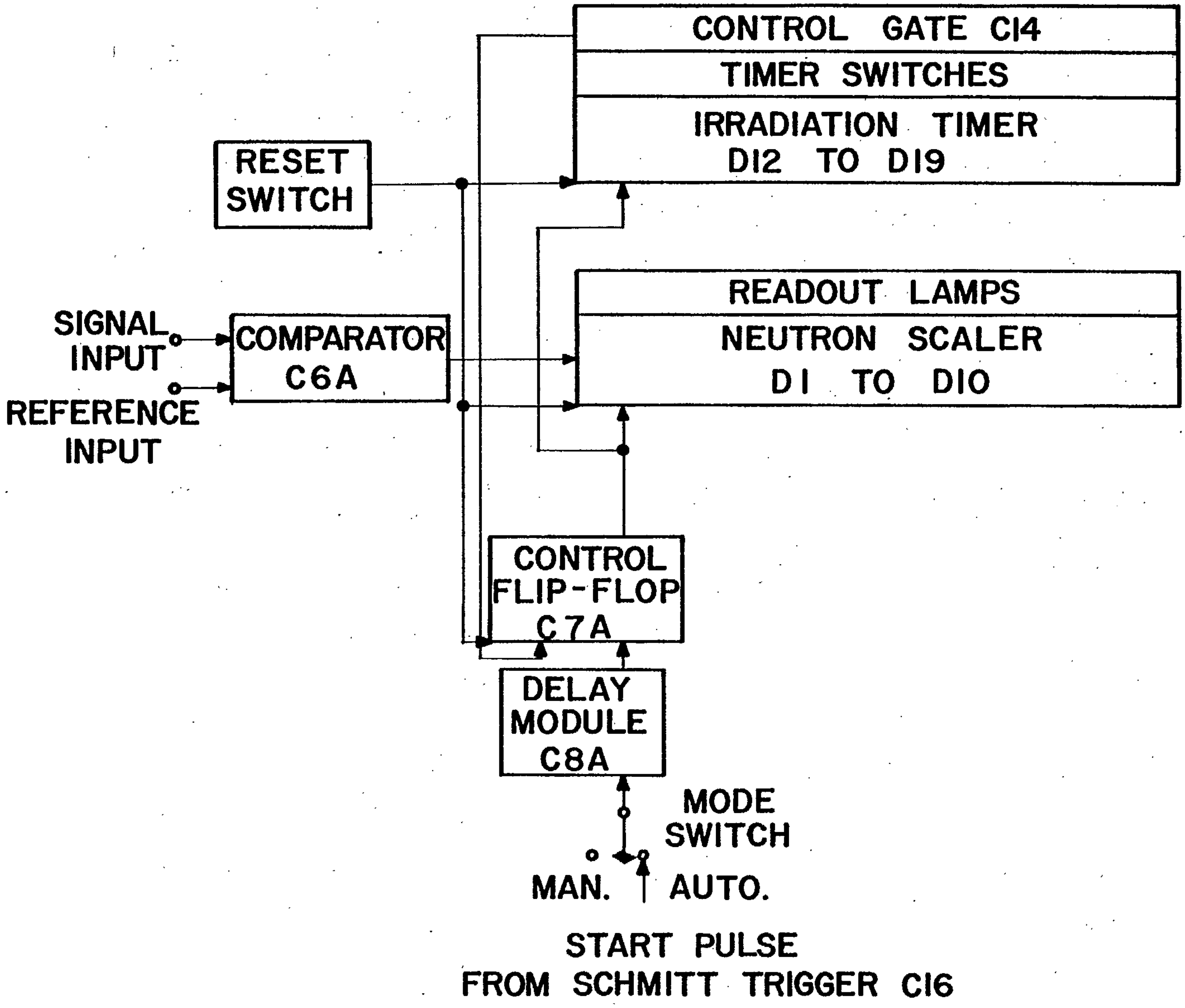

Figure 4. The irradiation timer and neutron scaling circuit.

back to the start position. The gamma timer and scaler are "enabled" two seconds after the sample leaves the irradiation position, to allow for the return transfer time. The gamma scaler now stores the gamma counts for a preset time as set on the gamma timer. At the end of this counting time, the gamma timer and the gamma scaler are "disabled" and the cycle is complete.

When the delay module is pulsed by the Schmitt trigger, its output drops from ground level to -3 volts for the delay period and then returns to ground level. This positive transition, which is applied to the gate of the control flip-flop C7A, switches it on. The output of the control flip-flop (Pin H) changes from -3 volts to ground level, "enabling" both the irradiation timing and the neutron counting circuits.

The irradiation timing and the gamma timing circuits are identical in operation to the solenoid timing circuits, except that one-hertz clock pulses are used; therefore, a detailed description of these timers will not be included herein.

The relative neutron output from the generator is monitored by a boron trifluoride detector, the output of which is fed via a preamplifier to a ratemeter and to the input of the comparator C6A. The value of the output voltage (at Pin H) of the comparator (either -3 volts or ground level) depends on the relative voltages of the two input lines D and E. The signal is placed at Pin D and a reference voltage at Pin E. If the voltage at Pin D is more positive than the voltage at Pin E, then the output voltage of the comparator will be at ground level. The output will switch to -3 volts when the voltage at Pin D becomes more negative than the voltage at Pin E. The output of the comparator is fed into the neutron scaler, which contains five decades of counting circuitry. There are four flip-flops per decade, which are wired to produce a BCD output (Figure 5). The outputs of the counter flip-flops are fed through connectors W020 and W023 to the readout lamps (module 4918).

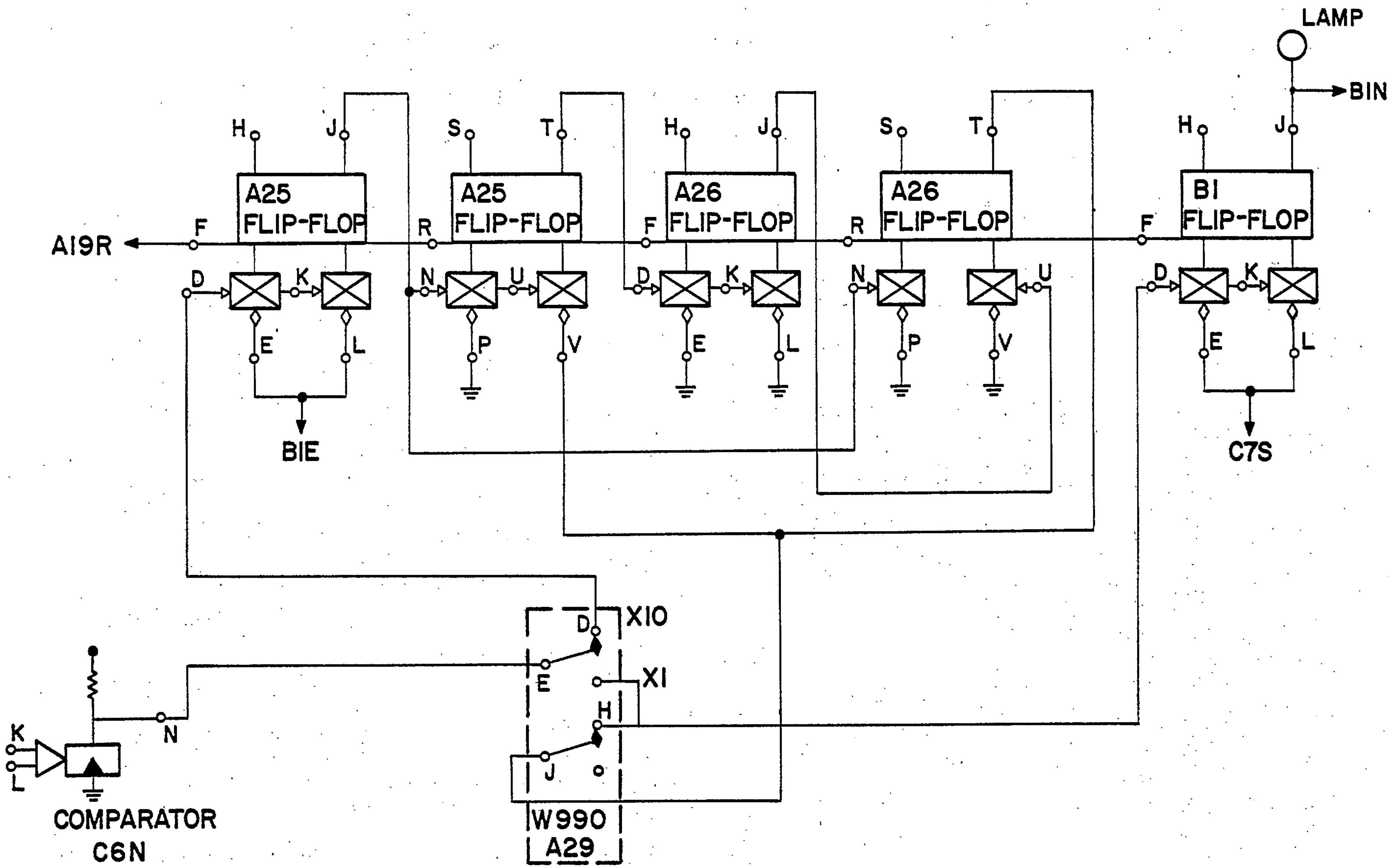

Figure 5. Gamma-multiplier switch circuit.

At the end of the irradiation time, the irradiation-timer control gate (C14) sends a pulse (-3 volts to ground level) to the control flip-flop C7A, turning it off. The -3 volt level at the output of the control flip-flop then "disables" the timer and stops the counter. The output pulse from the control gate C14 also starts the OUT solenoid and gamma-counting circuits.

The compressed gas, controlled by the OUT solenoid valve, propels the sample back to the start position, which is in front of the NaI(TI) scintillation detector. Since a finite length of time is taken for the sample to travel back along the transfer tube, delay module C8B turns on the gamma control flip-flop C7B after the sample arrives. The gamma-timing and the gamma-counting circuits are basically the same as the irradiation timing and counting circuits. A times-ten multiplier has been added to the gamma-scaler circuit (Figure 5) to allow counting to 999990.

Both the irradiation-timing and neutron-scaling circuits and the gamma timing and counting circuits must be manually set to zero by depressing their reset switches.

With the gamma Automatic/Manual switch in the manual position, the gamma timer and scaler can be started by pressing the gamma-scaler start button. This actuates the Schmitt trigger A23 which sends a start pulse to the gamma control flip flop. The cycle then continues as in the automatic mode.

GAMMA SIGNAL CONTROL

The signal from the gamma detector is split into two paths, as shown in Figure 6. The signal to the multi-channel analyser is controlled by a relay mounted in the linear amplifier (Franklin Electronics Inc. Model 348). This relay is operated either from the console or from a manual timer (Figure 7), depending on the position of the Automatic/Manual switch SW3, located on the 19-inch rack.

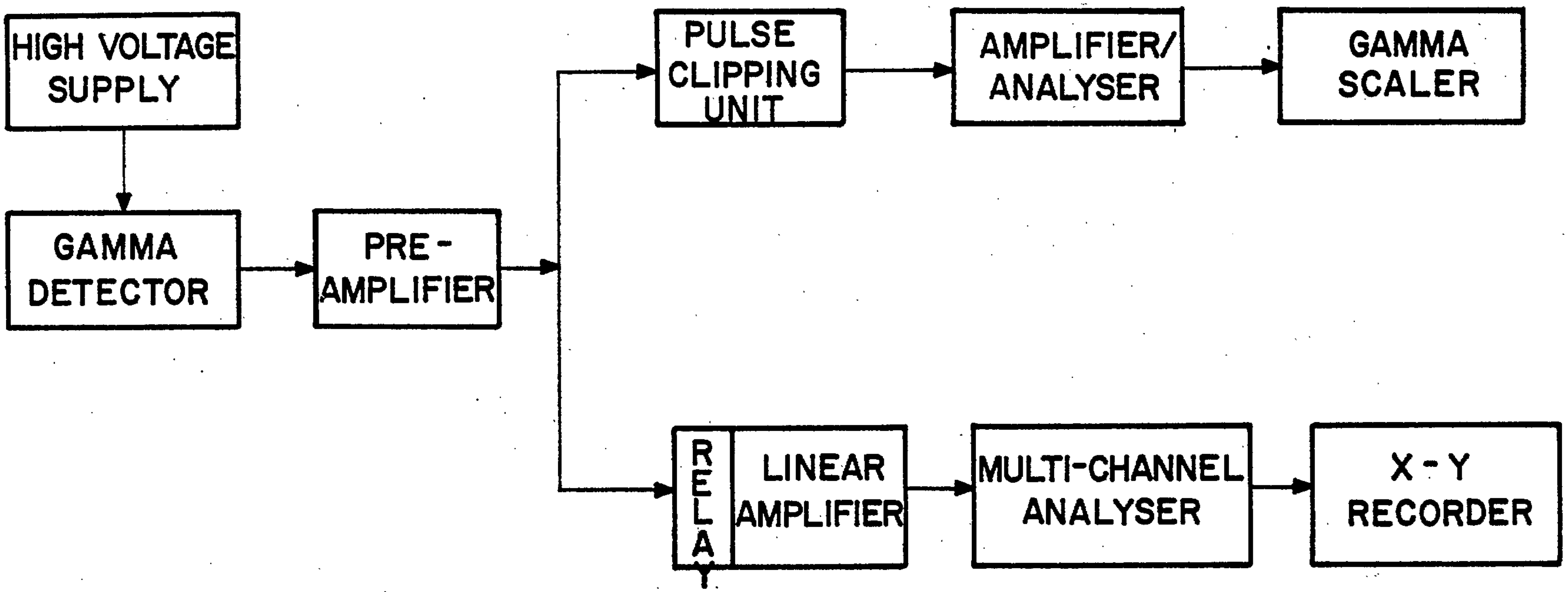

Figure 6. Gamma signal paths.

Further information:

High-voltage supply, Philips Model PW 4025.
Preamplifier, Hammer Model SX-7.
Pulse clipping unit, Philips Model PW 4272.
Amplifier/Analyser, Philips Model PW 4280.
X-Y Recorder, F.L. Moseley Co., Model 2D.

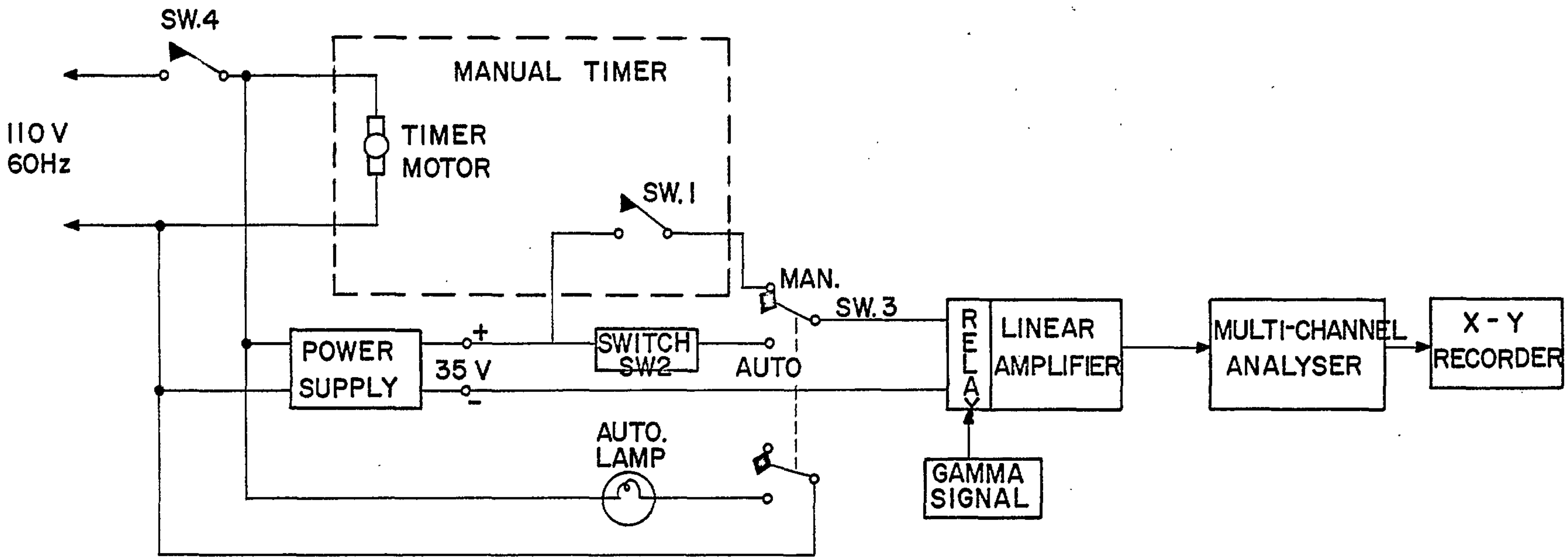

Figure 7. Relay control circuit.

With switch SW3 in the manual position, the relay is controlled by the manual timer, switch SW1. If switch SW3 and the gamma scaler switch are in the automatic position, the relay is controlled automatically by the gamma timer circuit, through the automatic switch SW2.

From time zero (two seconds after the sample leaves the irradiation position), the gamma scaler and multi-channel analyser may be run simultaneously, by setting the gamma scaler switch and SW3 to automatic. It is necessary at times to operate the single-channel gamma-scaler and the multi-channel analyser independently, to allow the single-channel system to accumulate data while the multi-channel system is transferring its data to the X-Y recorder (F. L. Moseley Co. Model 2D). This is accomplished by placing both switches to the manual position.

The automatic-switch circuitry (Figure 8) operates in the same manner as the switch circuitry for the IN solenoid. The control flip-flop (C23) is initially forced to the OFF state (Pin L to ground level) by the gamma reset switch at A12F. With the gamma-scaler switch (located on the console) in the automatic position, the control flip-flop is turned on by the pulse from the gamma delay model C8. This is the same pulse that starts the single-channel gamma-scaler. The pulse from the control gate of the gamma timer is fed to C23 to turn it off.

With the gamma-scaler switch in the manual position, and switch SW3 in the automatic position, the automatic switch SW2 will not be actuated by pressing the manual gamma-start button, and thus the two systems can be operated independently.

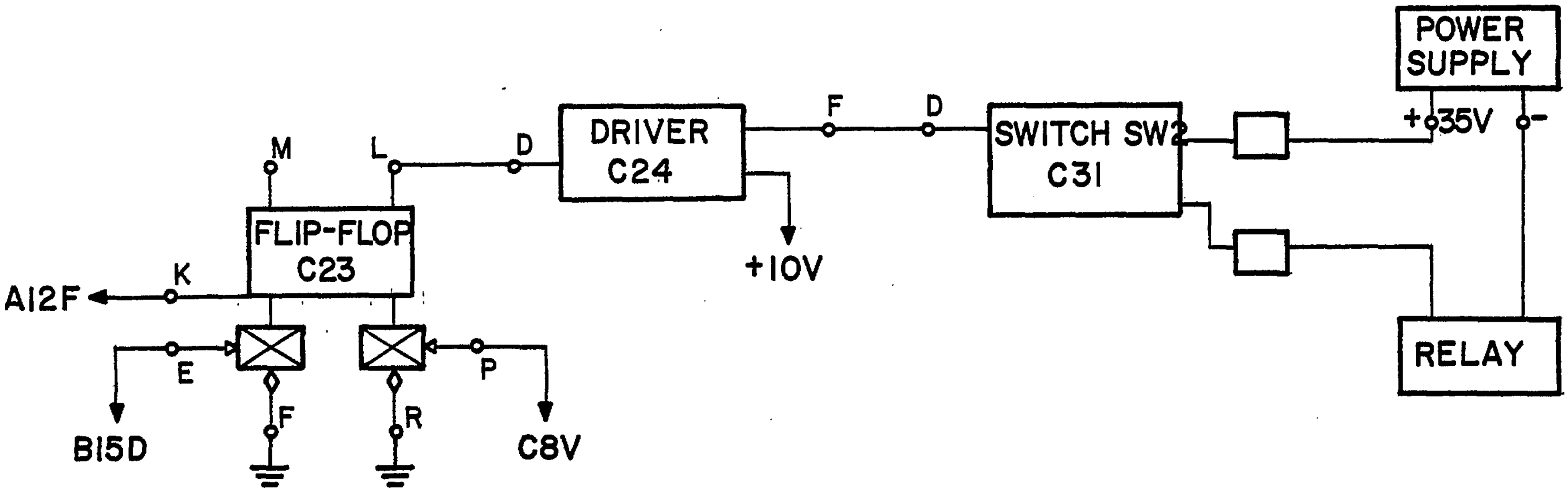

Figure 8. Automatic relay control.

THE SAMPLE ROTATION MOTOR

While in the irradiation position of the neutron generator, the sample is rotated to ensure homogeneous irradiation. The rotation motor (Bodine Electric Co. Model NSI-12R) is started automatically when the sample is transferred to the target position and is stopped automatically when the sample leaves. The switching circuit is shown in Figure 9.

The safety switch initially forces the control flip-flop A24B to the OFF state. A pulse from B19H, the IN solenoid control flip-flop, turns A24B on, which in turn closes switch A31B, placing a ground level at the gate of the triac (General Electric Co. Type SC40B). This ground level turns the triac on and starts the motor. The pulse that triggers the OUT solenoid is fed to Pin N of the motor control flip-flop, turning it off. With A24B off, the switch (A31B) opens and 110 volts is applied to the gate of the triac, turning it off and stopping the motor.

By means of the reset switch, the control flip-flop A24B can be manually forced to the OFF state.

THE ELAPSED-TIME INDICATOR

This indicator (Cramer Type 636Y) counts to 99999 seconds, in one second units, and starts at the same time as the gamma scaler. With the elapsed time known, successive counting of samples of long half-life can be accomplished. A switch is provided so that the timer can be turned off manually. The control circuit for the timer is shown in Figure 10.

The elapsed time indicator is turned off by placing the ON/OFF switch to the OFF position. The timer is then reset to zero by pressing its reset button. Placing the ON/OFF switch in the ON position allows the

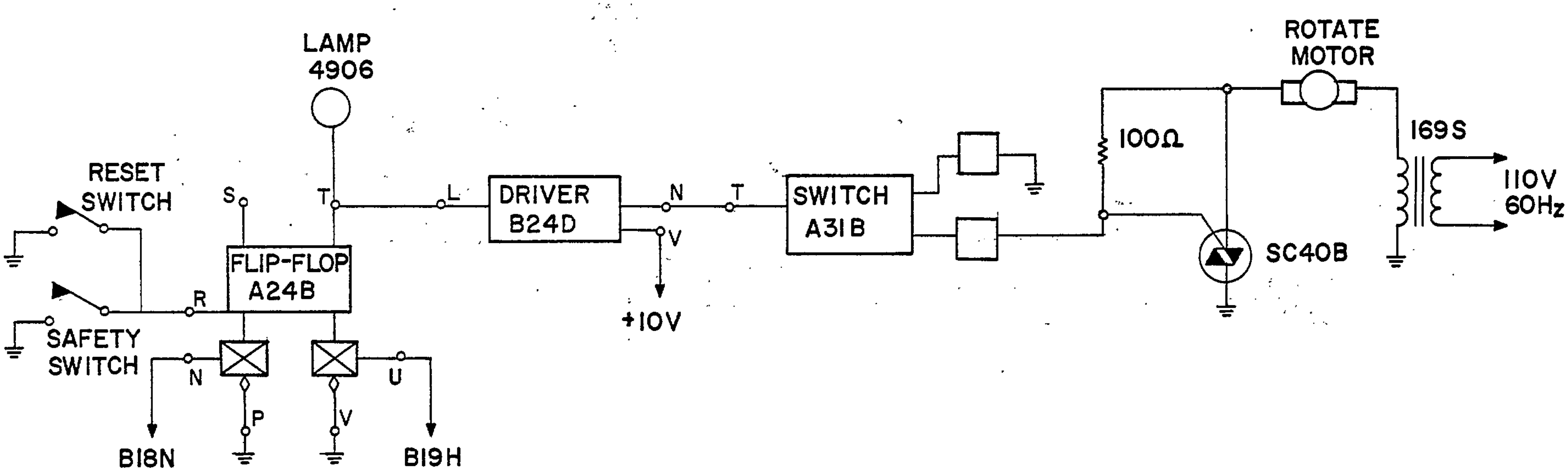

Figure 9. Rotation motor control circuit.

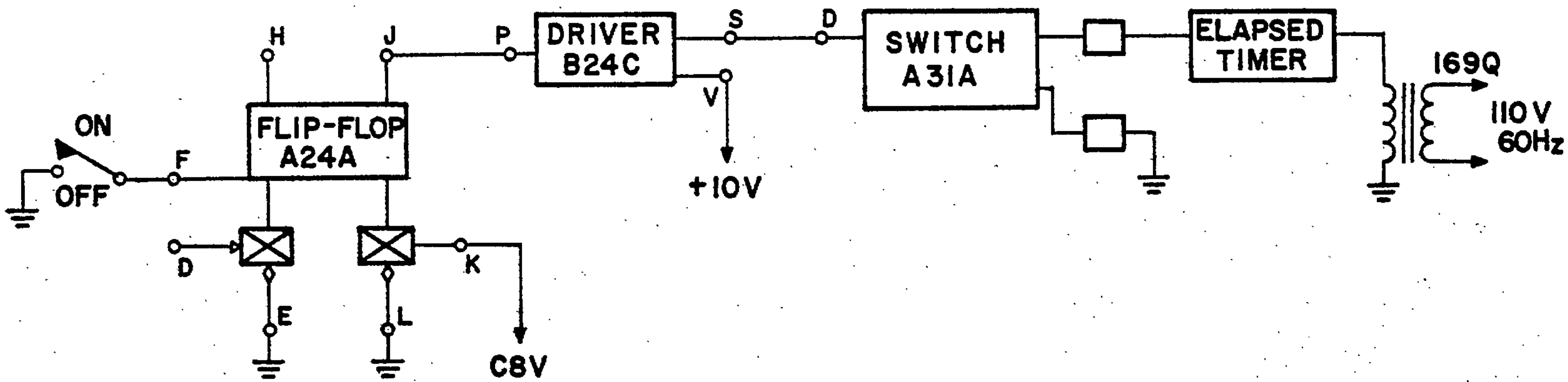

Figure 10. Elapsed time indicator control circuit.

start pulse from C8V (the gamma-timer start pulse) to turn on the timer control flip-flop. The control flip-flop then turns on the driver, switch, and timer. For the voltage levels involved, refer to the description of the IN solenoid (page 7).

THE CLOCK

The clock circuit (Figure 11) provides a ten-hertz pulse train for the solenoid timing circuits and a one-hertz pulse train for the neutron and gamma timing circuits.

The line frequency (60 hertz) is applied to the input of the Schmitt trigger via a 6.3-volt isolation transformer and an integrating circuit. The output of the Schmitt trigger, as standard-shaped pulses at 60 hertz, is fed into the divide-by-six circuit to produce ten-hertz pulses, and then into the divide-by-ten circuit to give one-hertz pulses.

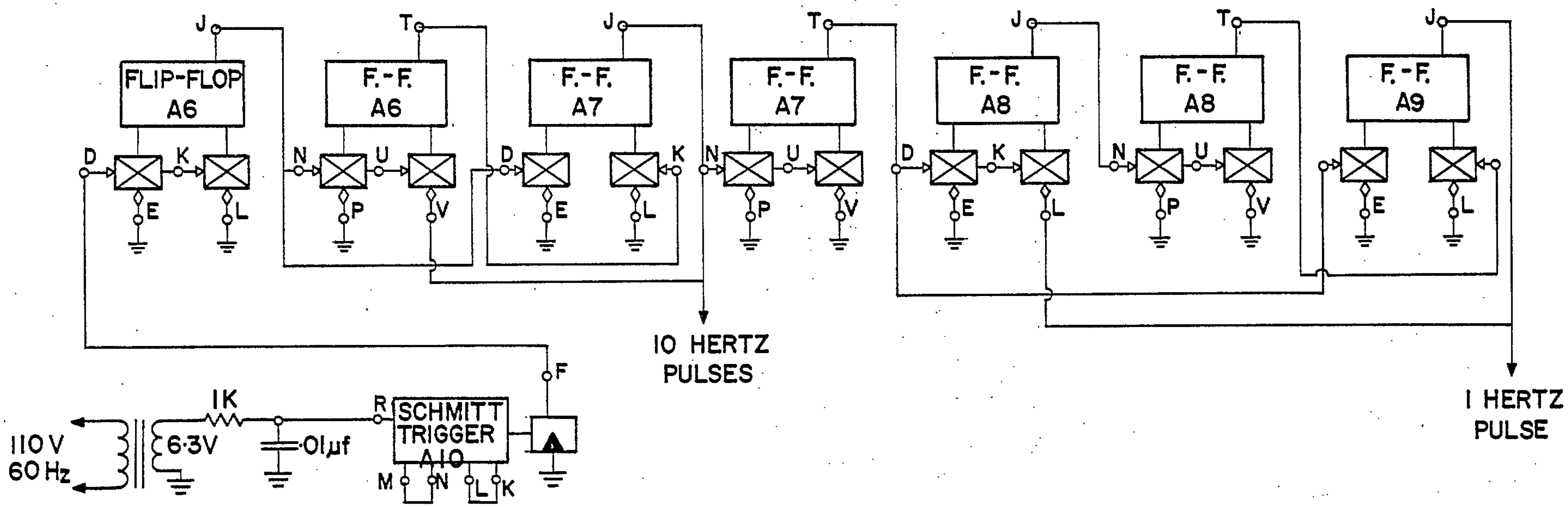

Figure 11. The clock circuit.

REFERENCES

1. H. P. Dibbs, "Activation Analysis with a Neutron Generator", Research Report R 155, Mines Branch, Department of Energy, Mines and Resources, Ottawa, February 1965.

2. Digital Logic Handbook, 1968 edition, published by Digital Equipment Corporation, Maynard, Massachusetts. Received from Digital Equipment of Canada, Limited, Carleton Place, Ontario, Canada.

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DWC:(PES)vm

(Appendices 1 and 2 follow, on pages 26 to 28.)

APPENDIX 1

BINARY-CODED DECIMAL (BCD)

The lamp readouts of the scalers are in binary-coded decimal. Figure 12, below, illustrates this code, and an example of a scaler read-out is given.

BCD	DECIMAL
○ ○ ○ ○	0
○ ○ ○ ●	1
○ ○ ● ○	2
○ ○ ● ●	3
○ ● ○ ○	4
○ ● ○ ●	5
○ ● ● ○	6
○ ● ● ●	7
● ○ ○ ○	8
● ○ ○ ●	9

● LAMP LIT

○ LAMP NOT LIT

Figure 12. Binary-coded-decimal conversion.

Example of Scaler Readout:

●○○●	○○○○	○○●○	○●●●	○●○●
9	0	2	7	5

This scaler reads 90275 counts.

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APPENDIX 2

THE MODULE RACK

The modules are located in the module rack in the positions illustrated in Figure 13. The view in Figure 14 is from the module side of the rack. The letters A, B, C and D along the left-hand side of the diagram, and the numbers 1 to 32 along the top, give the location of the modules as referred to throughout the report. In some cases a module has the notation B19A. The B19 refers to the module location, and the A refers to one of the circuits on the module board. On the reverse side of the module rack are the pin connections (Figure 13). Each module has a set of 18 pins listed alphabetically as shown in the diagram below. These pins provide a means of wiring the modules by the wire-wrapping method.

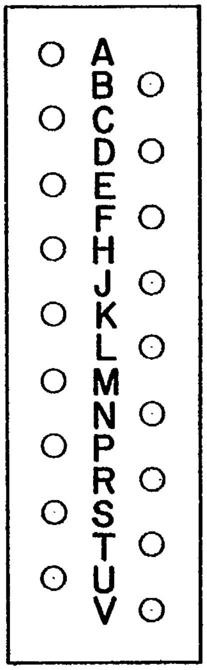

Figure 13. The pin connections.

(Cont'd) -

	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
A		W080	W992	W990			R202	R202	R202	W501	B171	B171		R202	R202	R202	R202	R202	R202	R202	R202	W005	W501	R202	R202	R202	R202	W990	W990	W990	W990	W018
B		W080	W992						W061	R202	R202	R202	R202	R202	R302	W501		B171	R001	B171	R001	R107	R202	R202	R202	R202	R202	R202	R202	R202	R202	R202
C		W080	W992						W061	R201	W005	B171	R202	R202	R202	R202	W501	W005	B171	R001	B171	R001	W501		R302	R202	W520	W990	W990	W990	W990	W018
D												B171		R202	R202	R202	R202	R202	R202	R202	R202		R202	R202	R202	R202	R202	R202	R202	R202	R202	R202

Figure 14: The module rack.

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