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University of California, Berkeley, California

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ABSTRACT

The University of California Bevatron magnet-pulsing equipment provides a means of adjusting the pulse-repetition rate and the pulse length of current flowing in the magnet. The unit also provides synchronizing pulses for the linear accelerator injector as well as various trigger pulses before, during, and after the flow of magnet current. The unit derives its timing from a master oscillator operating at 2 pps. Pulses from the master oscillator are scaled down to produce the selectable repetition rates for the magnet current. Other timing functions, except the magnet pulse length, are derived from standard time-delay circuits. Magnet pulse length is generated by a new type of Schmitt trigger circuit, which maintains a long-term time stability of better than 1 part in 2,000.

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INTRODUCTION

The University of California Radiation Laboratory Bevatron is a proton synchrotron which accelerates particles to an energy of 6 billion electron volts. The injected particles are protons with an energy of 10 million electron volts. These protons are maintained during acceleration at a constant radius of 600 inches by an increasing magnetic field and accelerated by power of increasing radiofrequency.

Two identical motor generator sets are used as 12-kv phase changers (3-phase to 12-phase).[1] Each set is composed of a 65-ton flywheel, a 3600-hp drive motor, and a 46,000-kw generator. The two driving motors compensate only the losses incurred during each cycle of current flow, since most of the energy supplied to the magnet is derived from the rotational energy of the flywheels, generators, and driving motors. Figure 1 shows the plan view of the Bevatron and associated motor generator room.

In Fig. 2 it can be seen that the magnet and the two motor generator sets are electrically in series. During the rectification portion of the cycle, power is transmitted from the flywheels to the magnet. The initial magnet voltage is 18,000 volts, which falls to 12,000 volts as the magnet current increases from zero to 8,333 amp (Fig. 3). The time required for this operation is about 1.85 seconds. (This portion of the cycle is used to accelerate the protons, which are injected into the Bevatron when the magnetic field is 300 gauss. The magnet field rises to about 16,000 gauss when the magnet current is 8,333 amp). During the inversion portion of the cycle, which follows rectification, power is returned from the magnetic field through the mercury arc rectifiers, now operating as inverters, to the flywheels. At the peak of magnet current (8,333 amp), the generator speed has dropped about 7% from the initial value of 860 rpm. The total energy stored in the two

[1] J. V. Kresser "The Bevatron Power Plant", Elec. Eng. 71, 338 (1952)

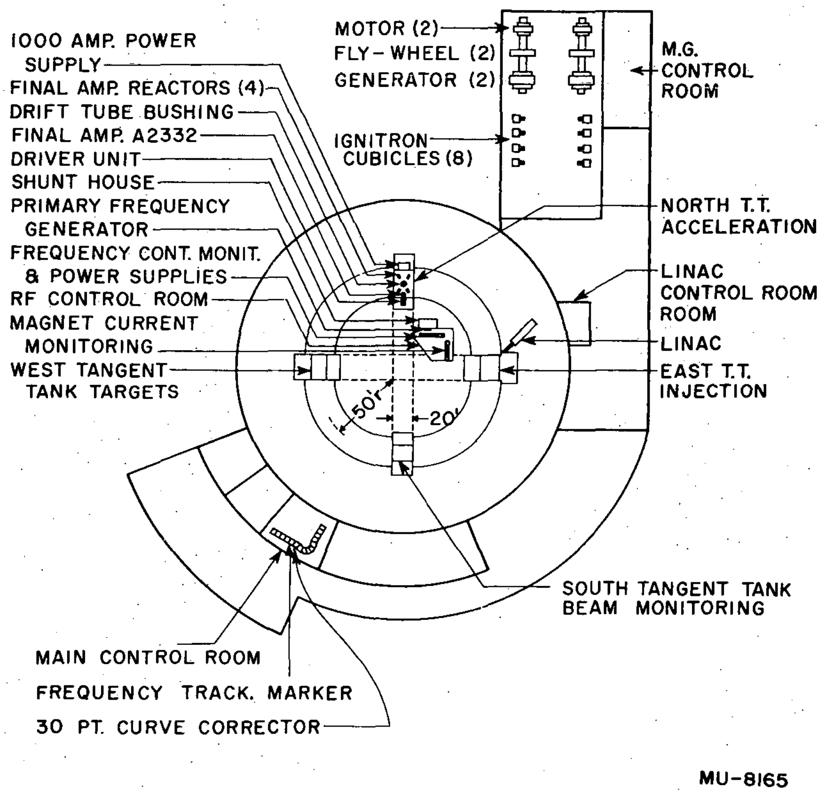

1000 AMP. POWER SUPPLY
FINAL AMP. REACTORS (4)
DRIFT TUBE BUSHING
FINAL AMP. A2332
DRIVER UNIT
SHUNT HOUSE
PRIMARY FREQUENCY GENERATOR
FREQUENCY CONT. MONIT. & POWER SUPPLIES
RF CONTROL ROOM
MAGNET CURRENT MONITORING
WEST TANGENT TANK TARGETS
MOTOR (2)
FLY-WHEEL (2)
GENERATOR (2)
IGNITRON CUBICLES (8)
M.G. CONTROL ROOM
NORTH T.T. ACCELERATION
LINAC CONTROL ROOM
LINAC
EAST T.T. INJECTION
50'
20'
SOUTH TANGENT TANK BEAM MONITORING
MAIN CONTROL ROOM
FREQUENCY TRACK. MARKER
30 PT. CURVE CORRECTOR
MU-8165

Fig. 1

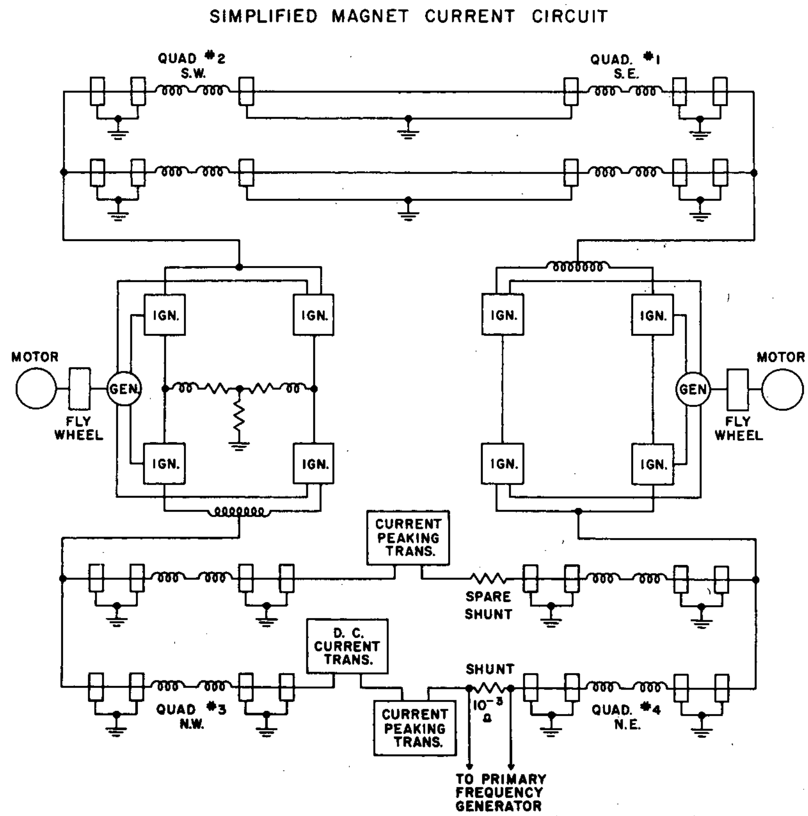
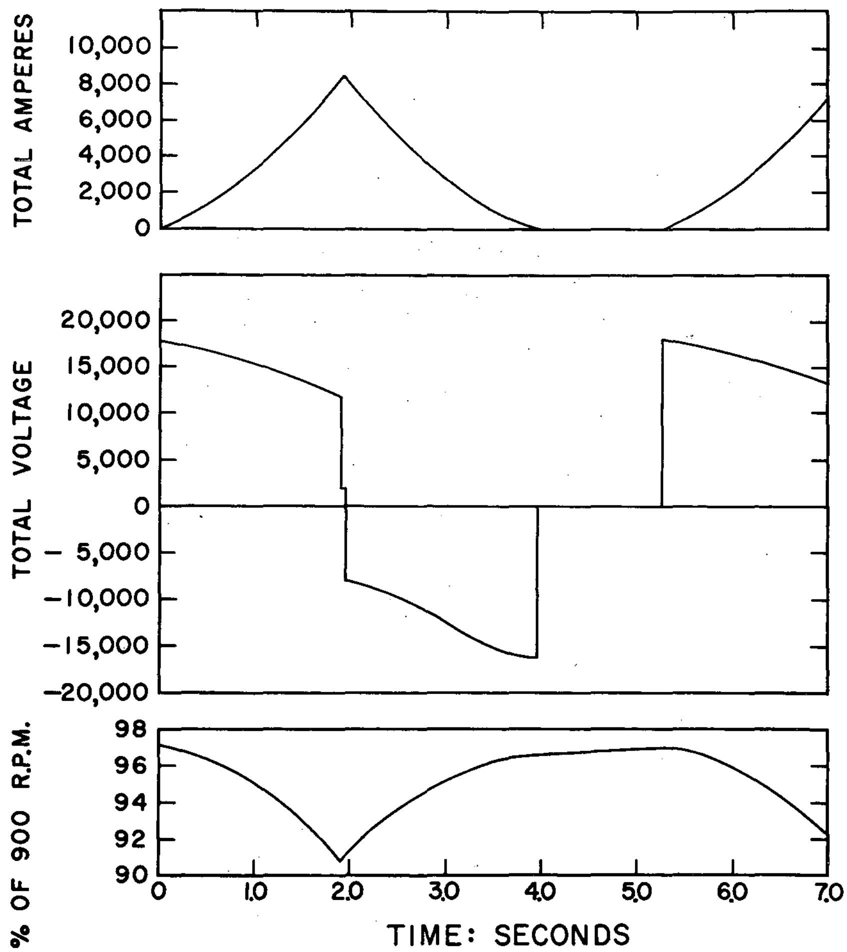

SIMPLIFIED MAGNET CURRENT CIRCUIT
QUAD #2 S.W.
QUAD. #1 S.E.
IGN.
MOTOR
FLY WHEEL
GEN.
CURRENT PEAKING TRANS.
SPARE SHUNT
D. C. CURRENT TRANS.
SHUNT
10^{-3} Ω
QUAD #3 N.W.
QUAD. #4 N.E.
TO PRIMARY FREQUENCY GENERATOR
MU-8168

Fig. 2



CHARACTERISTICS OF MAGNET/POWER SUPPLY

MU-8169

Fig. 3

rotating flywheels is about 500 megajoules or 125 kilowatt-hours. The motor generator system was designed to provide 10 pulses per minute at full power. The pulsing equipment, however, has been designed to allow selection of 12 repetition rates between 4.0 pulses per minute and 20 pulses per minute, and pulse lengths from 0.1 sec to 2.5 sec.

The pulse-timing equipment is contained in two chassis in the motor generator control room. The pulse repetition-rate chassis (Fig. 4) contains the master oscillator and repetition-rate scaling equipment. This unit supplies the synchronizing pulses for the injector, and trigger pulses for the magnet-pulser chassis (Fig. 5). The magnet-pulser chassis supplies timing triggers and gates to control the pulsing sequence of the Bevatron.

REPETITION-RATE CHASSIS

The repetition-rate chassis supplies two pulses, spaced 500 msec apart, and determines how often these pulses are produced. The chassis may be synchronized with one of the motor generator ignitor peaking-transformer pulses. Discrete repetition rates of from 4.0 to 20 pulses per minute, as well as single-pulse operation, may be selected by a multiposition front panel switch.

The Functions of the Circuit — Fig. 4

V1 and V2 comprise the primary multivibrator circuit for the injector repetition-rate sections, providing an asymmetrical square-wave output. This asymmetrical signal is applied to V3, which is used as a gate in the "synchronize" (operate) position of the test-operate relay. Since this gate is open for about 28 msec, during which time two synchronized pulses may be received, the output of this gate triggers a 50-msec one-shot V4, which is used as a lockout circuit (only one pulse is produced at its output for two or more input pulses).

The single output pulse from Pin 6 of V4B is applied to a phase inverter stage and to a cathode follower (CF). The CF supplies the injector thyratron V7 with a trigger pulse, and the phase inverter supplies a trigger to V9, the first of five "flip-flop" (F-F) scalers that drive the readout diode matrix. V9 through V13 are similar with respect to components and functions. V25 through V29 are cathode followers, which supply low-impedance signals to the diode matrix. V14 and V21B supply the scaler-reset pulse to V9 through V13 when the diode matrix produces a coincident pulse at S1. V21B has a 1-msec time constant in its output to delay the resetting of V9 through V13.

ZN-1218

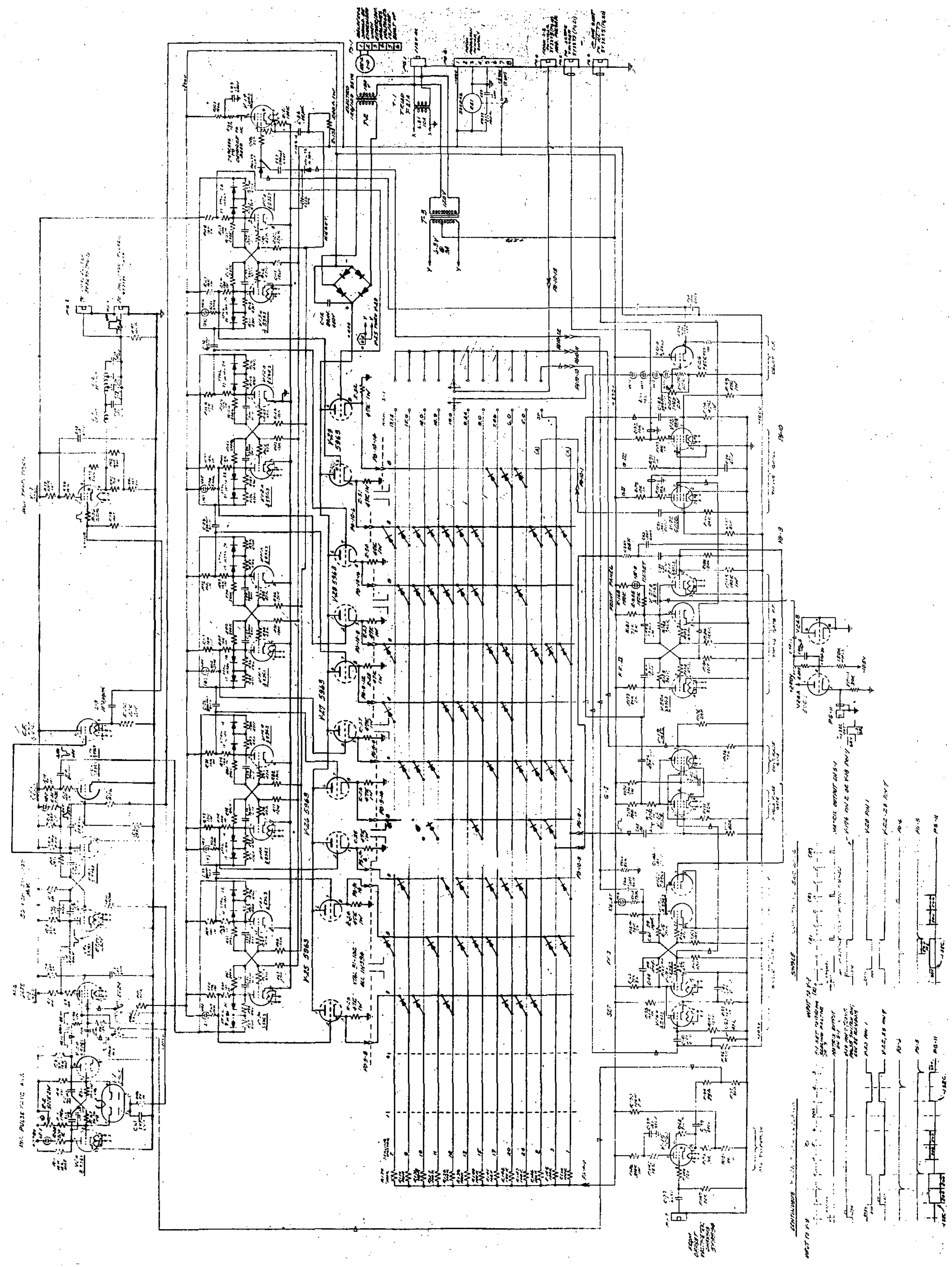


Fig. 4

The matrix has 13 scaling factors, that is, it produces an output pulse (coincidence) for every 6 input pulses to V9 when S1 is in the 20-ppm position, and so on. The matrix also supplies two other pulses, with scaling factors of 2 and 1, but these do not appear on S1.

V15 shapes the rather broad peaking-transformer pulses before they are applied to V3, the gate tube. V16 and V17 are employed for single-pulse operation only. This circuit insures that one, and only one, single pulse is initiated no matter how many times the single-pulse button is depressed. The maximum repetition rate of this chassis is determined by the lockout circuit in the magnet-pulser chassis.

Single-Pulse Sequence

When Pin 2 of V16 is grounded from the magnet-pulser chassis through the single-pulse position of S1, F-F I (V17) is set and the scaler (V9 through V13) is reset to zero. F-F I is reset when three counts have been received by the scaler. In the single-pulse position, the scaler is reset about 1 msec after the third trigger pulse is supplied to the scaler and matrix--provided the single-pulse button is not depressed in the meantime. Refer to the wave shapes shown in Fig. 4 , "Single-Pulse Timing Sequence."

F-F I controls Gate I (i.e., V18). When V17 is in the set position (V17A conducting), V18 accepts Pulse No. 1 from the matrix and sets F-F II, V20. V20 opens both timing gates, V22 and V23, and allows pulses to appear at PG5 and PG6 when Pulse 2 and Pulse 0 (3) are supplied to their respective gates. Also note that the instant the ground is supplied from the magnet-pulser chassis, the scaler is reset to zero. This is necessary to reduce the time for the push button to initiate operation. The pulse from PG6 is used by the magnet-pulser chassis to supply the prepulse time delay. The pulse from PG5 starts the -40 msec scope-trigger time delay in the magnet pulser. V17 and V20 are reset by pulse 3 (0) from the matrix.

Continuous-Pulse Sequence

When a ground is supplied from the magnet-pulser chassis through a continuous pulse contact of S1, V19 is allowed to accept Pulse No. 1 from the matrix and set V20, F-F II. V20 opens both timing gates, V22 and V23, as in the single-pulse sequence described above, passing signals to PG6 and PG5 as long as the ground is completed. The ground in this operation is connected through a sealed relay contact in the magnet-pulser chassis.

F-F I (V17) and F-F II (V20) are reset by Pulse 3 from the matrix. The scaler resetting occurs 1 msec after the selected coincidence has been achieved, as determined by the position of S-1.

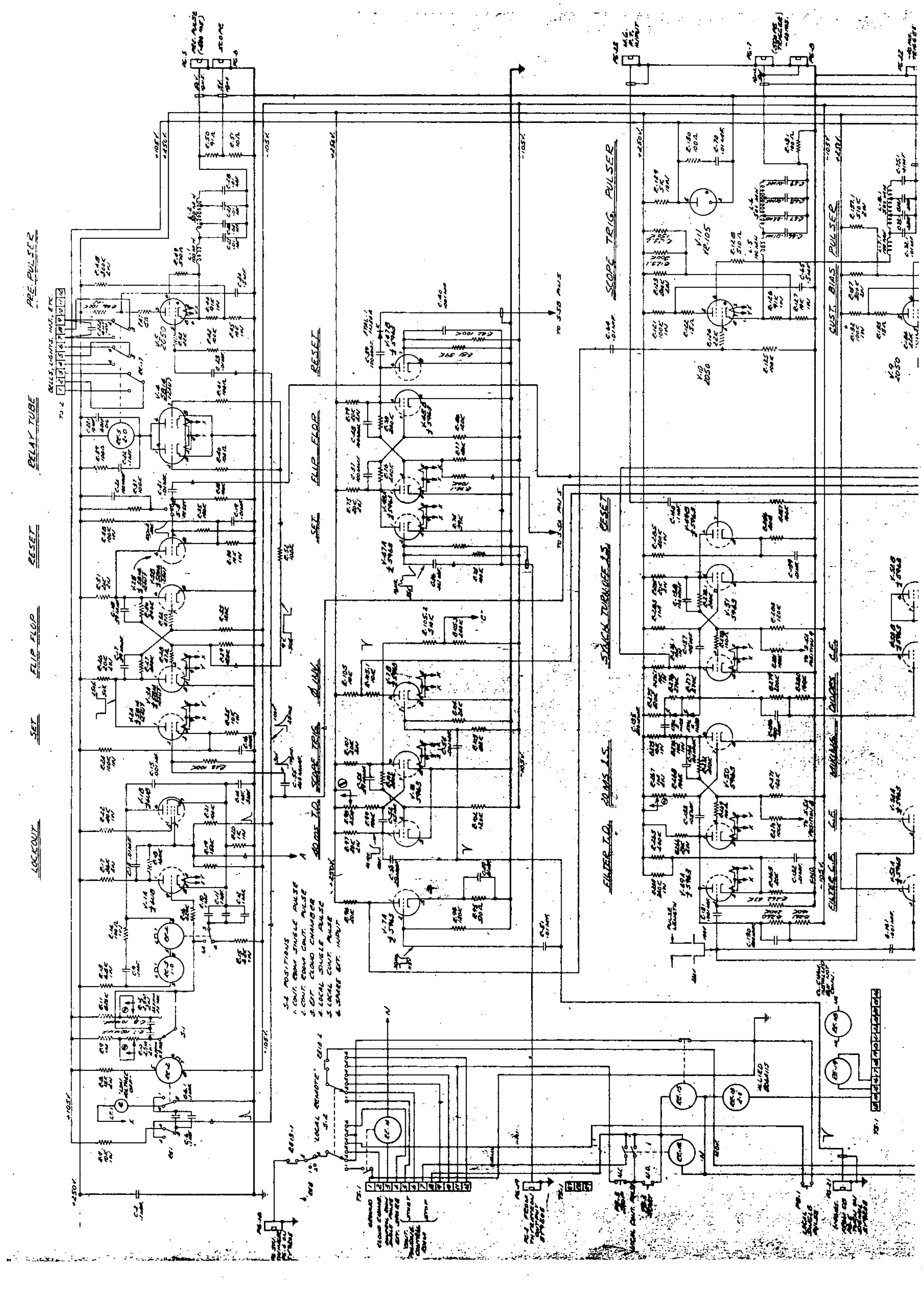
Note that in either position, i.e., "continuous pulse" or "single pulse", V22 and V23 (GII and GIII) allow only Pulse 2 to produce a prepulse and Pulse 3 (0) to produce the scope-trigger pulse.

BEVATRON MAGNET PULSER TIMING CHASSIS AND BLOCK DIAGRAM -Fig 5

Two pulses are supplied from the repetition-rate chassis to the magnet-pulser timing chassis. These pulses are negative and are separated in time by 500 msec. The first pulse is called the prepulse and enters the timing chassis at PG20. This pulse produces a 10-μsec 50-volt trigger pulse.

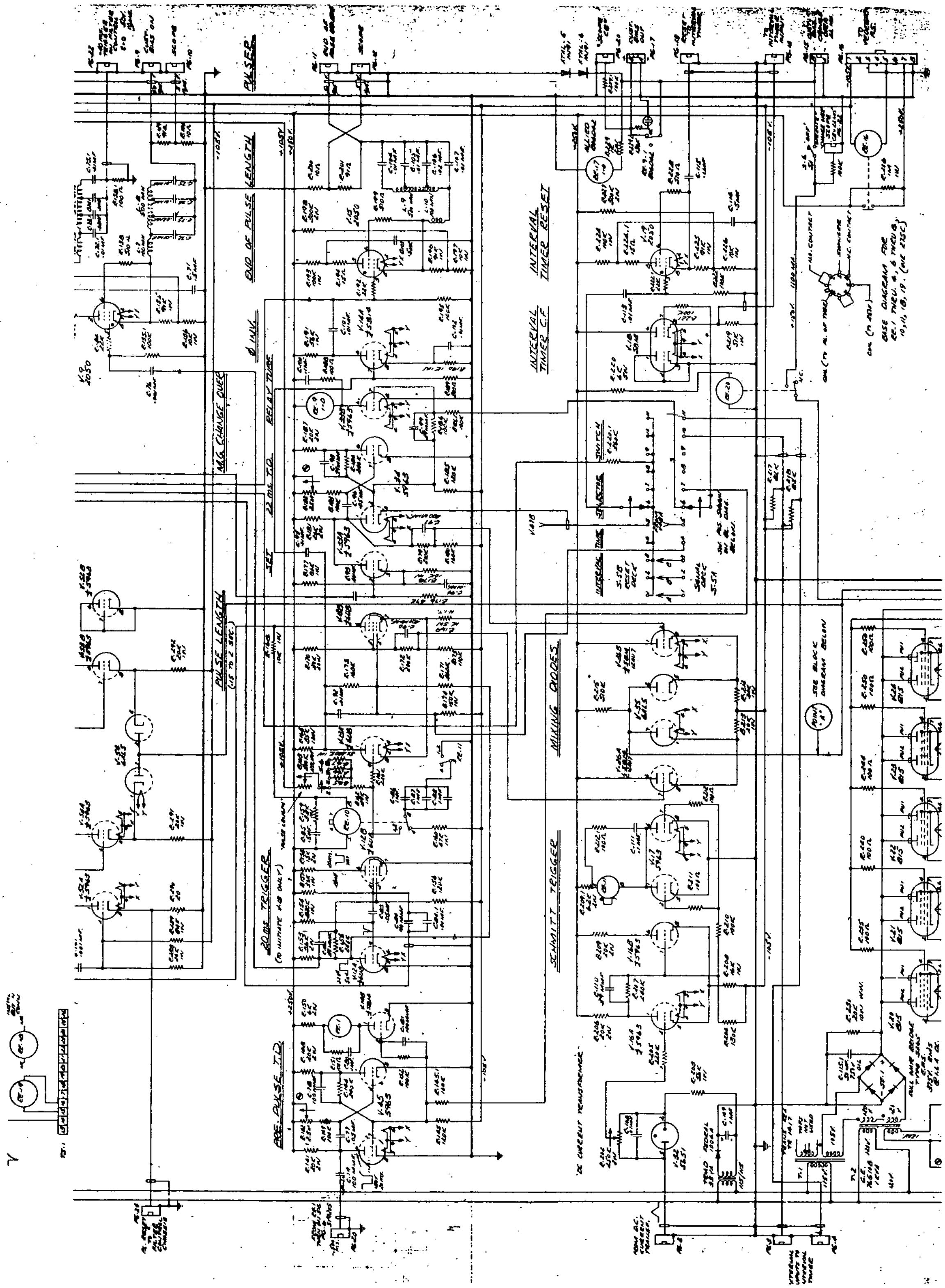
The second pulse from the repetition chassis enters the magnet-pulser timing chassis at PG21 and is used as a scope trigger 40 msec before current is caused to flow through the Bevatron magnet. After entering the timer chassis, the scope-trigger pulse is delayed 40 msec, then is applied to the pulse-length circuit (V13). This circuit determines the length of time that current flows into the magnet. When the pulse-length circuit has timed out, a trigger is sent to the filter time delay. This delay is necessary to assure that a series-resonant harmonic filter is disconnected from the magnet before the reversal of magnet voltage at the end of rectification. When 20 msec have elapsed, a trigger is sent to the synchronized turn-off multivibrator. The next motor generator (MG) synchronizing pulse (obtained from the mercury-arc rectifier ignitor circuit) that arrives resets this circuit and sends a trigger to the 22-msec MG change-over circuit. This circuit is necessary to limit the torque on the MG shafts when the mercury-arc rectifiers are switched from rectifying to inverting units. Actually one half of each rectifier unit is changed over to inversion 22 msec before the other half. The change from inversion to rectification is accomplished by raising the bias on the mercury-arc rectifier firing tubes. The magnet-pulser timing chassis produces a 150-volt positive gate to cause the system to rectify. The removal of this 150 volts causes the system to invert. The system is in inversion at all times except when power is applied to the magnet.

The 150-volt "Customer's Bias" supply is regulated to 1% and can supply a current of 1.1 amp. A selenium rectifier supply, using screen-regulated


LOCKOUT
SET
FLIP FLOP
RESET
RELAY TUBE
PRE PULSER
SCOPE TRIG. PULSER

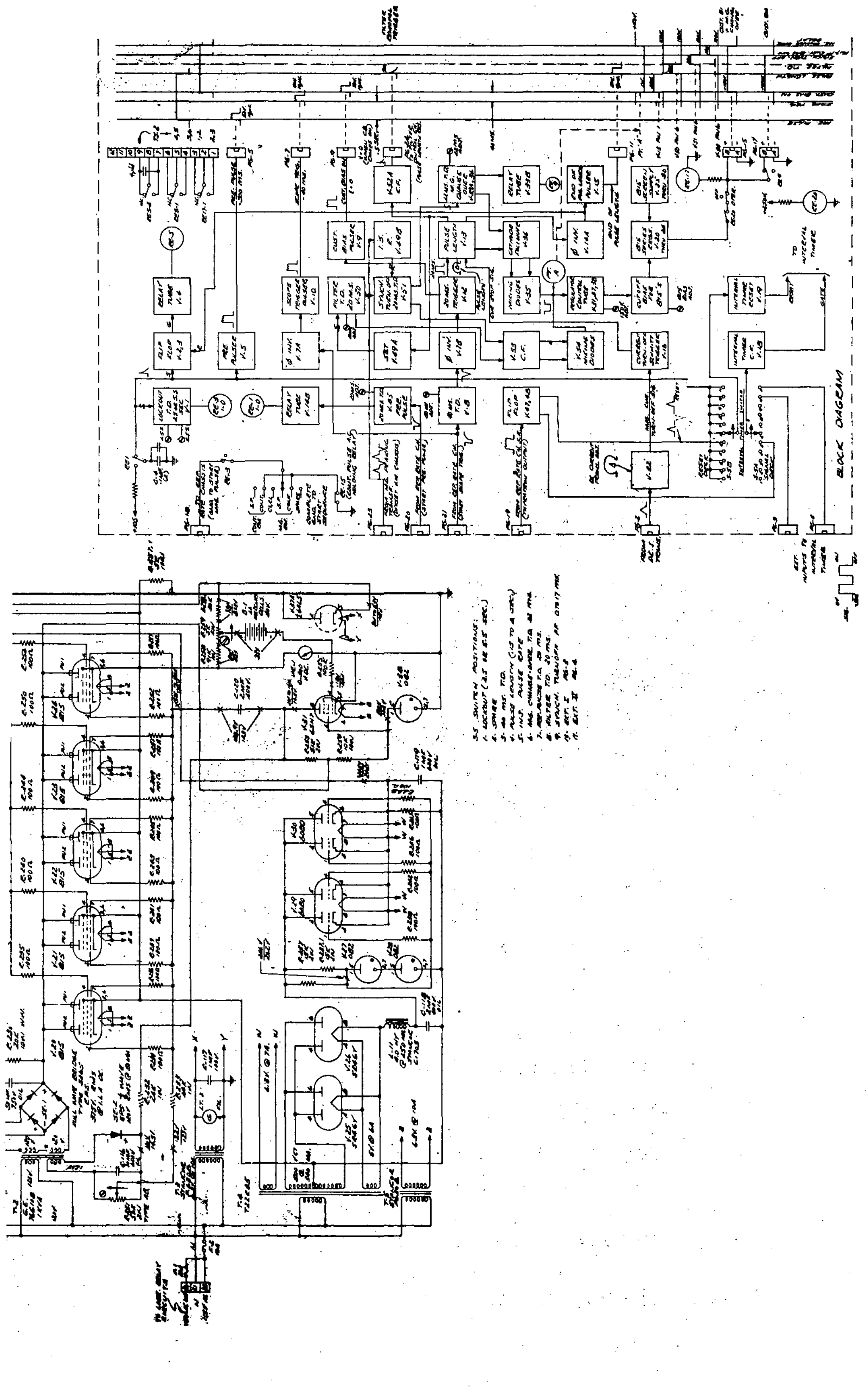
ZN-1219

Fig. 5


PULSER
END OF PULSE LENGTH
INTERVAL TIMER RESET
INTERVAL TIMER C.F.
MAG CHANGE OVER
22 MS. T.D.
RELAY TUBE
SET
PULSE LENGTH (15 TO 2 SEC)
MIXING DIODES
SCHMITT TRIGGER
20 MS. TRIGGER
PRE-PULSE T.D.

ZN-1220

Fig. 5



ZN-1221

Fig. 5

815 series tubes, is used for this purpose. The supply gating is accomplished by changing the control grid bias on the 6SH7 dc amplifier tube. This gate must be controlled sequentially by the pulse-length circuit (V13), the filter time-delay circuit (V50), the synchronized turn-off circuit (V51), and finally the 22-msec MG change-over circuit (V34). The dc signals are derived from the four above-mentioned circuits and mixed, after which they are applied as a gate to the 6SH7 control tube. In addition to a time control of pulse length, a circuit has been provided to stop the magnet pulse at any predetermined value of magnet current (dc current-transformer circuit V32). A Berkeley Model 510 time-interval meter has been provided, external to this chassis, so that accurate pulse lengths and time delays may be determined.

The timing unit contains a new circuit to determine the magnet pulse length (V13) and lockout (V1). The basic circuit, a modified form of Schmitt Trigger[2], is shown in Fig. 6 . The triode is normally conducting and the de-energized relay is in Position 1 as shown. When a positive start gate is applied to the pentode control grid, the pentode is caused to conduct, energizing the relay and moving the swinger to Position 2. The grid of the triode is immediately lowered to the negative bias voltage. Because the variable timing resistor R is returned to positive bias potential, the capacitor charges toward this potential until the triode just passes the cutoff point, at which time positive feedback forces the triode to zero bias and the pentode to cutoff. Because the timing capacitor C is alternately charged and discharged between equal but opposite potentials with respect to ground potential, the time required for the capacitor to charge from its original negative potential to ground potential is essentially independent to supply voltage variations.[3]

RACK LAYOUT AND CHASSIS CONSTRUCTION

The magnet-pulse timing equipment is entirely contained in two racks in the Bevatron motor generator control room. (See Fig. 7) Rack S04 contains, from top to bottom; the time-interval meter, the magnet-pulser chassis, and a regulated 300-v, 0.3-amp power supply. Rack S05 contains the repetition-rate chassis and a dual-beam Radiation Laboratory oscilloscope.

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[2] Otto Schmidt, A Thermionic Trigger, J. Sci. Instr. 15, No. 1, 24 (1938).

[3] S. Wald, Precision Interval Timer, Electronics 21, No. 12, 88 (1948).

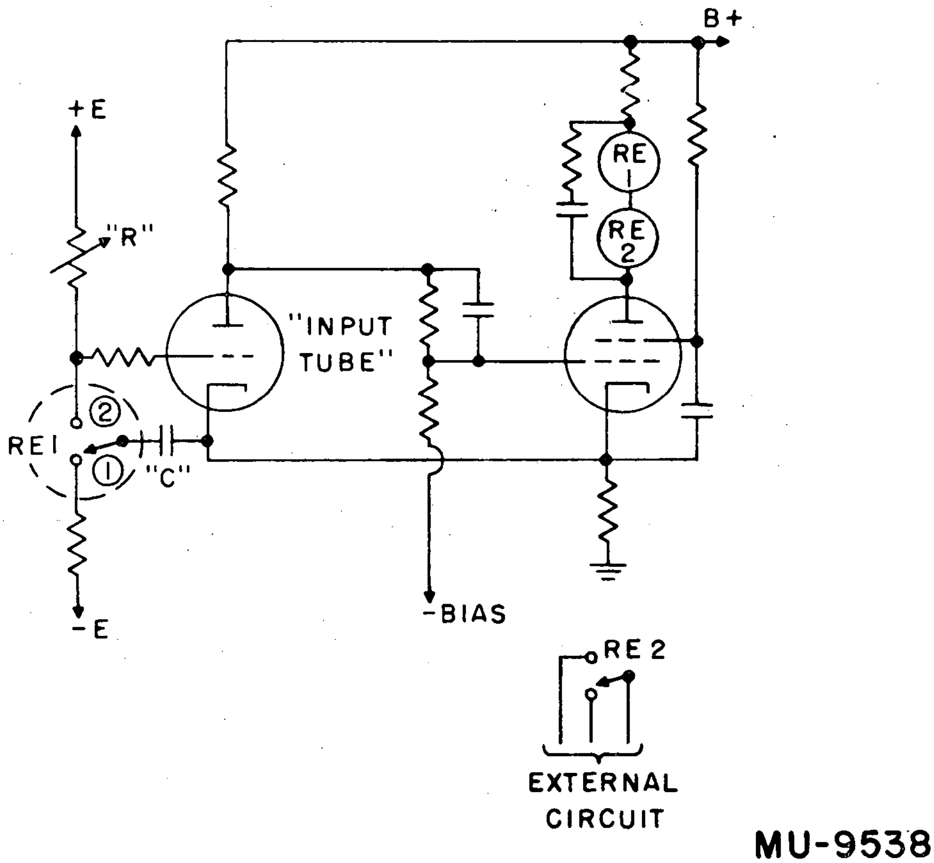
B+
+E
"R"
"INPUT
TUBE"
RE
1
RE
2
RE1
2
1
"C"
-E
-BIAS
RE 2
EXTERNAL
CIRCUIT
MU-9538

Fig. 6

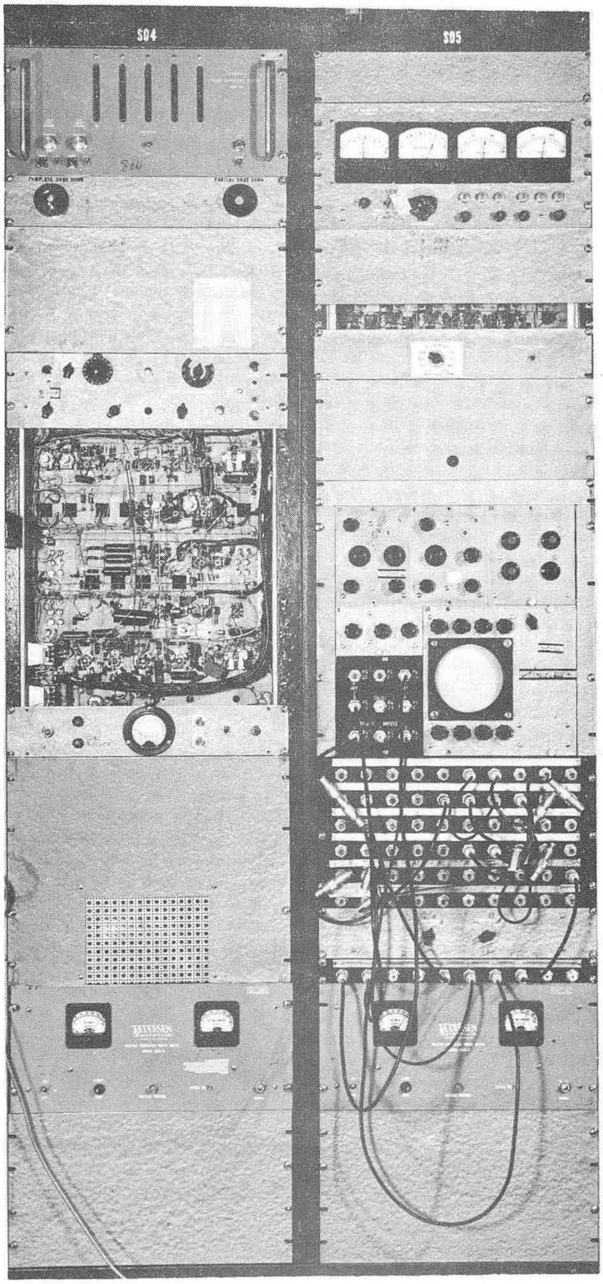

Fig. 7 ZN-1269

Both the magnet-pulse timing chassis and the repetition-rate chassis are built on 3-inch-deep "bathtubs". The tubes and transformers are mounted on the backs of the bathtubs. Voltage buses and small components are located inside. A system of fixed and removable panels is used to permit bringing controls out to the front (fixed panels), while allowing service of the units in place by removing the remainder of the panels; maintenance is of greater importance than space requirements. To further simplify the maintenance, all supply voltages are bused horizontally across the chassis with bare wire which is plainly labeled. The schematic prints and the chassis layouts are physically similiar. For example, V1 is at the top left-hand position on the schematic and on the chassis (front view), and each higher-numbered tube follows to the right and downward by rows.

The diode matrix has been built so that it is readily slipped out for maintainence purposes. The matrix employs slip-fit quick-connect plugs, and is supported by a lucite enclosure. Small neon bulbs have been attached to all F-F plates and may be viewed through a 1.75-in. lucite front panel.

ACKNOWLEDGMENTS

Mr. D. A. Mack is the Bevatron Project Engineer in charge of all monitoring and controls. Mr. Mack's conception of the magnet pulser led to its design and development by the author.

All Bevatron work has been done under the auspices of the U. S. Atomic Energy Commission.