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June 28, 1955

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The University of California Bevatron magnet-pulsing system 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 pulses 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. All timing functions are derived from standard time-delay circuits except for the magnet pulse length which is generated by a new type of Schmitt trigger circuit.

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The University of California Bevatron magnet-pulsing system 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 pulses 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. All timing functions are derived from standard time-delay circuits except for the magnet pulse length which is generated by a new type of Schmitt trigger circuit.

## INTRODUCTION

The University of California Radiation Laboratory Bevatron is a proton synchrontron which accelerates particles to an energy of 6.2 billion electron volts. The injected particles are protons with an energy of 10 Mev. These protons are maintained during acceleration at a constant radius of 600 inches by an increasing magnetic field and are accelerated by power of increasing radiofrequency. The maximum magnet current required for 6.2-Bev particles is 8,333 amp, at which time the magnet voltage is 12,000 volts. This power is supplied by two identical motor generator sets and 48 mercury arc rectifiers.[1] which alternately rectify and invert at a maximum repetition rate of 10 magnet pulses per minute.

Each motor-generator set is composed of a 65-ton flywheel, a 3600-hp drive motor, and a 46,000-kva generator. The two drive motors compensate for only the losses incurred during each cycle of magnet 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 Figure 2, it can be seen that the magnet and the two motor generator sets are in series. During the rectification portion of the cycle, energy 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 magnet cycle is used to accelerate the protons, which are injected into the Bevatron when the magnetic field is about 300 gauss. The magnetic 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, energy 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 has dropped about 7% from the initial value of 860 rpm. The total energy stored in the two rotating flywheels is about 500 megajoules or 125 kw-hr. The motor generator system was designed to provide 10 pulses per minute at full power. The pulse-timing equipment, however, has been designed to allow selection of 12 repetition rates between 4.0 pulses per minute and 20 pulses per minute and magnet pulse length from 0.1 to 2.5 seconds.

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

The magnet pulse-timing equipment is contained in two chassis in the motor generator control room. The pulse repetition chassis contains the master oscillator and repetition-rate scaling circuits as well as the associated gate equipment. This unit supplies the synchronizing pulses for the injector, and trigger pulses for the magnet-pulser chassis. The magnet-pulser chassis supplies a positive bias to the mercury arc rectifier control equipment, which causes the rectifiers to supply energy to the magnet. This chassis also supplies timing triggers at -1.04 sec, at -0.54 sec, at -40 milliseconds, at magnet voltage on and at end of rectification. A synchronizing trigger is also sent to the injection equipment between magnet pulses. (The synchronizing pulse for injection is supplied by equipment which accurately marks the proper injection field.)

## Repetition-Rate Chassis

The repetition-rate chassis supplies three pulses, spaced 500 milliseconds apart, and determines how often these pulses are produced. The chassis is synchronized by one of the motor-generator ignitor peaking-transformer pulses. Discrete repetition rates of 4.0 to 20 pulses per minute, or single pulse operation, may be selected by a multiposition front-panel switch. The block diagram is shown in Fig. 4. The operation of the circuit shown in Fig. 4 is as follows: An asymmetrical multivibrator operates continuously (its two periods are 480 msec and 20 msec). During the time that the 20 m sec pulse is supplied to the MG (motor generator) synchronizing gate, the gate can pass the peaking signal fed from the peaking signal shaper to the 50-m sec one-shot MV (multivibrator) and on to the phase inverter -- and CF (cathode follower) -- and the thyratron pulse generator. The 50-m sec one-shot MV assures that one and only one peaking signal can arrive at the phase inverter (CF) each time the 20-m sec pulse is supplied to the MG gate. The pulse fed to the phase inverter is also sent to F-F 1 (flip-flop 1) through F-F 5. Each pulse received by the F-F chain is stored as one count. When the total of the stored counts equals the diode matrix sealing factor, the corresponding matrix horizontal output line is caused to suddenly go positive by about 60 volts. The repetition-rate selector switch then supplies this positive pulse to the delay CF and then to the reset thyratron which in turn resets the five F-F's. A delay of approximately 1 m sec is necessary to allow the associated gate equipment to operate properly. The delay is obtained by an RC circuit which integrates the 60-volt step-function supplied to the delay CF. This much of the circuitry functions continuously whether the magnet is being pulsed or not. When it is desired to pulse the magnet, a ground is supplied to either the single-pulse F-F or to the continuous gate. In either case, the next time that the F-F chain contains one count, a magnet-pulse cycle is started. Pulse No. 1 is fed through the continous gate to the timing gate F-F. The F-F opens both timing gates and allows pulse No. 2 (-0.54 sec) and pulse No. 3 (-40 m sec) to be sent to the magnet-pulser chassis. This cycle is initiated each time a ground is supplied to this chassis. When selector switch "S" is set to single pulse, the F-F chain is reset on 3; however, when a single pulse is initiated, the F-F chain is immediately reset to zero. This feature has been provided to shorten the initiation time. The diode matrix contains 55 germanium diodes and has been made "plug-in" to facilitate maintenance problems.

## Magnet Pulse-Timing Chassis

Three of the four pulses produced by the repetition rate chassis are supplied to the magnet pulse-timing chassis. These are the output of the thyratron pulse generator, the -0.54-sec and the -40-m sec pulses.

The -1.04-sec pulse is used elsewhere in the building. In Fig. 5 we see that the first pulse (-0.54 sec.) which is negative, appears at PG 20 and sets (starts) the 20-m sec time delay (V 45). This tube, in conjunction with V 14B, operates relay No. 1. Relay 1 discharges two 0.1-μfd capacitors which provide a positive set pulse to the lockout time delay V1, flip-flops V2 and 3 and the pre-pulse thyratron V5, and send a reset pulse to the external interval timer.

The second pulse from the repetition-rate chassis appears at PG 21 exactly 500 m sec after the pulse at PG 20. This negative pulse is inverted by V7A and applied to the scope trigger thyratron V10. It also sets the 40-m sec time delay V8. When V8 times out, a negative trigger is sent to V7B and starts the 20-m sec time delay V12. V12 in turn supplies an "on" gate for the pulse-length time delay V13. This delay controls the length of the rectification cycle, which is variable from 0.1 sec to 2.5 sec. When V13 times out, a set trigger is supplied to the filter time delay V49A and V50. This is a fixed delay of 20 m sec to allow two 1400-cycle series-resonant ripple filters to be removed from the magnet terminals before the magnet voltage reverses. After 20 m sec a set trigger is sent to the synchronized turnoff time delay V51. In addition to the set signal, there is a reset pulse, derived from one of the motor generator phases, which is applied as a synchronizing pulse to V51. If this synchronizing pulse fails to arrive, the time delay still operates after 20 m sec. and allows the remainder of the circuit to function normally. Thus, both the rise and fall of magnet voltage can be synchronized with a particular machine phase. A set signal is then sent from the synchronizing turnoff delay V51 to the 22-m sec change-over delay V33A, V34. This circuit, in conjunction with V33B, operates relay No. 9 and removes the rectification bias from half the mercury arc rectifier control tubes, thus allowing half the machine to start its inversion cycle 22-m sec before the other half. This is necessary to reduce the reversal stress on the MG shafts. The pulse-length circuit V13, filter delay V50, synchronizing delay V51, and the 22-m sec change-over delay are all direct-coupled to the bias regulator tubes V31, V37, and V38. From the time that the pulse length is gated on until the end of the change-over (V33A, 34) a gate is supplied to the bias regulator circuit to hold it gated on. The direct coupling is obtained by the use of cathode followers V36 and V53 and mixing diodes V35 and V54. When V13 (pulse length) times out, an end-of-rectification pulse is sent to a thyratron pulser V15. The regulators V20 through V30 required some unusual circuitry because this bias supply was required to supply 150 volts at 1.1 amp regulated to 1%. When available distribution transformers are used the average series regulator tubes have too much drop, so it was decided to use five dual pentode tubes with a common regulated screen supply.

In addition to the circuitry just described, this chassis contains various monitoring circuits so that the timing of each delay circuit may be checked by means of an external interval timer. Switch S5A selects the function to be measured by this unit and the signal is sent to the timer by the cathode follower V18 and a reset signal is generated by V19. The magnet pulse length is determined by two factors; the pulse-length delay (V13) and the actual magnet current. A scaled-down replica of magnet current is supplied to PG 2 and a Schmitt trigger (V16) is used to derive a marker pulse at a predetermined magnet current.

The magnet-pulser chassis contains a new circuit to determine the magnet pulse length (V13) and the lockout time (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 grid, the pentode is caused to conduct, energizing the relay and moving the swinger to position 2. The grid of the triode is almost immediately lowered to the negative bias voltage (-E). Because the variable

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

timing resistor R is returned to a positive bias potential (+E) the capacitor charges toward this potential until the triode just passes the cutoff point, at which time positive feedback around the circuit 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 of 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 SO4 contains, from top to bottom, the time-interval meter, magnet pulser chassis, and a regulated 300-v, 0.3-amp power supply. Rack SO5 contains the repetition-rate chassis and a dual-beam Radiation Laboratory oscilloscope.

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 (under the front panels). 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 similar. 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 in the repetition-rate chassis has been built so that it is readily slipped out for maintenance purposes. The matrix employs slip-fit quick-connect plugs, and is supported by a lucite endosure. Small neon bulbs have been attached to all F-F plates and may be viewed through a 1.75-in. lucite front panel.

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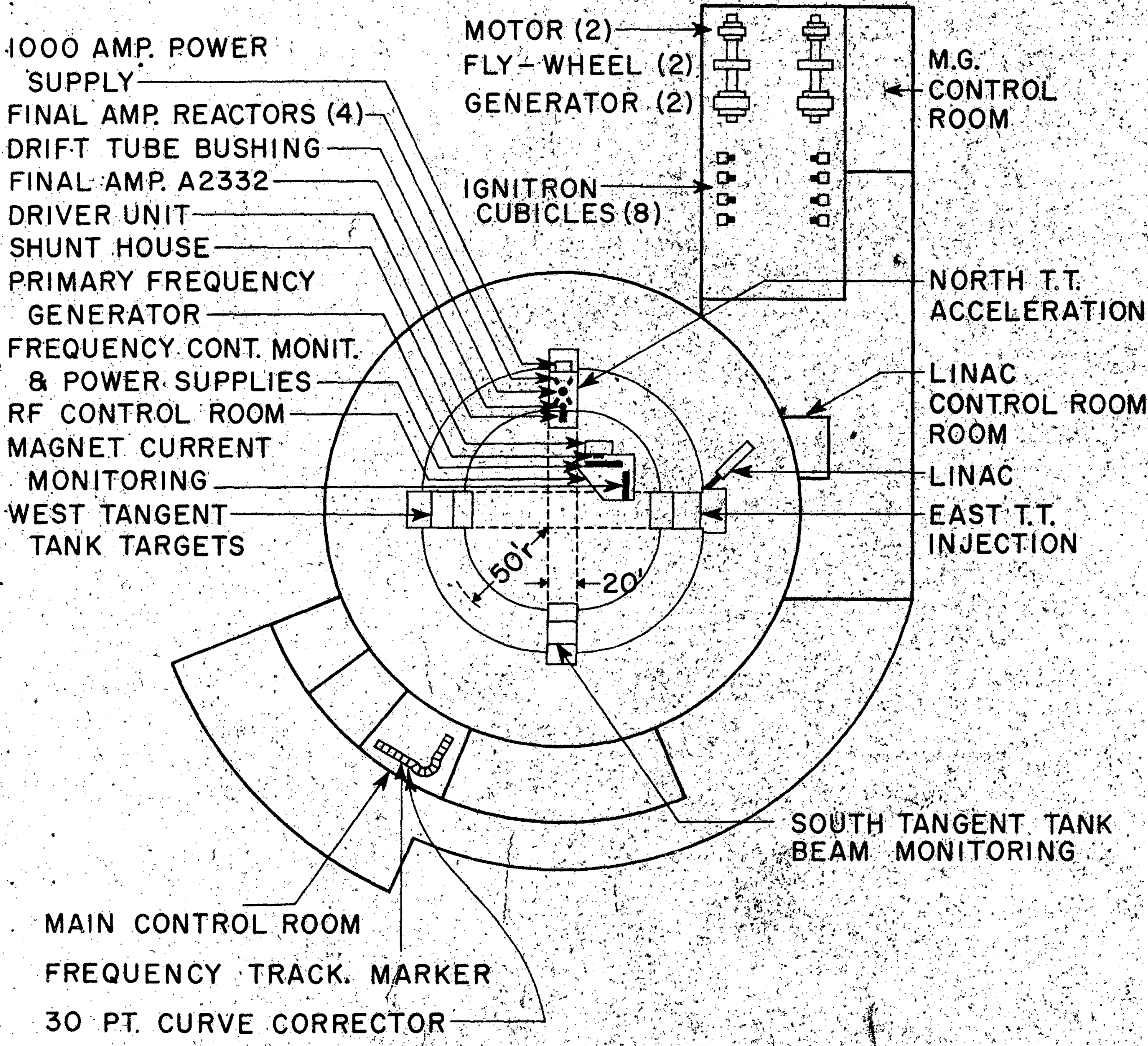
[3] S. Wald, Precision Interval Timer, Electronics <u>21</u>, No. 12, 88 (1948)

## 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.



MU-8165

Fig 1

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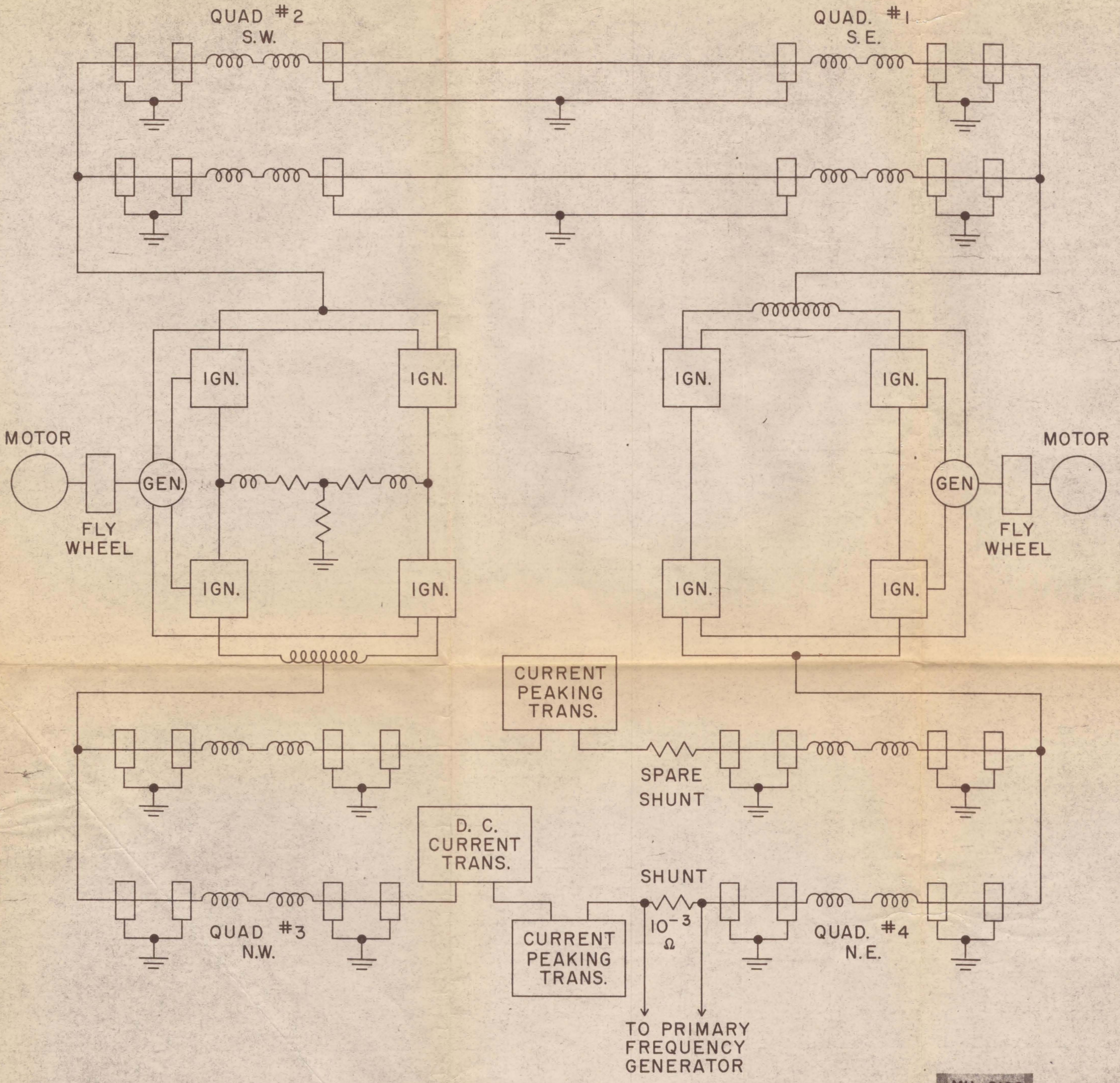
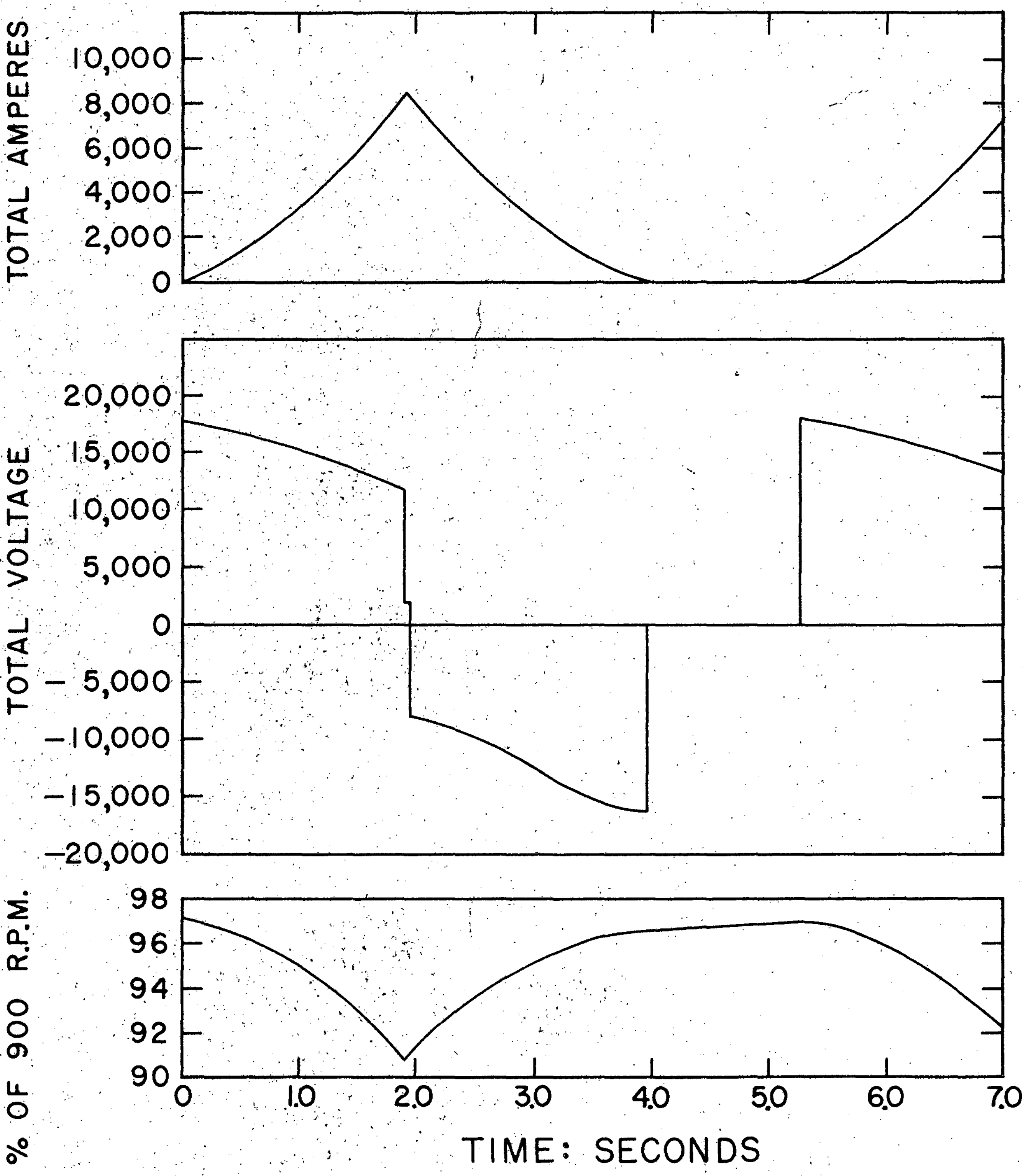
# SIMPLIFIED MAGNET CURRENT CIRCUIT



MU-8168

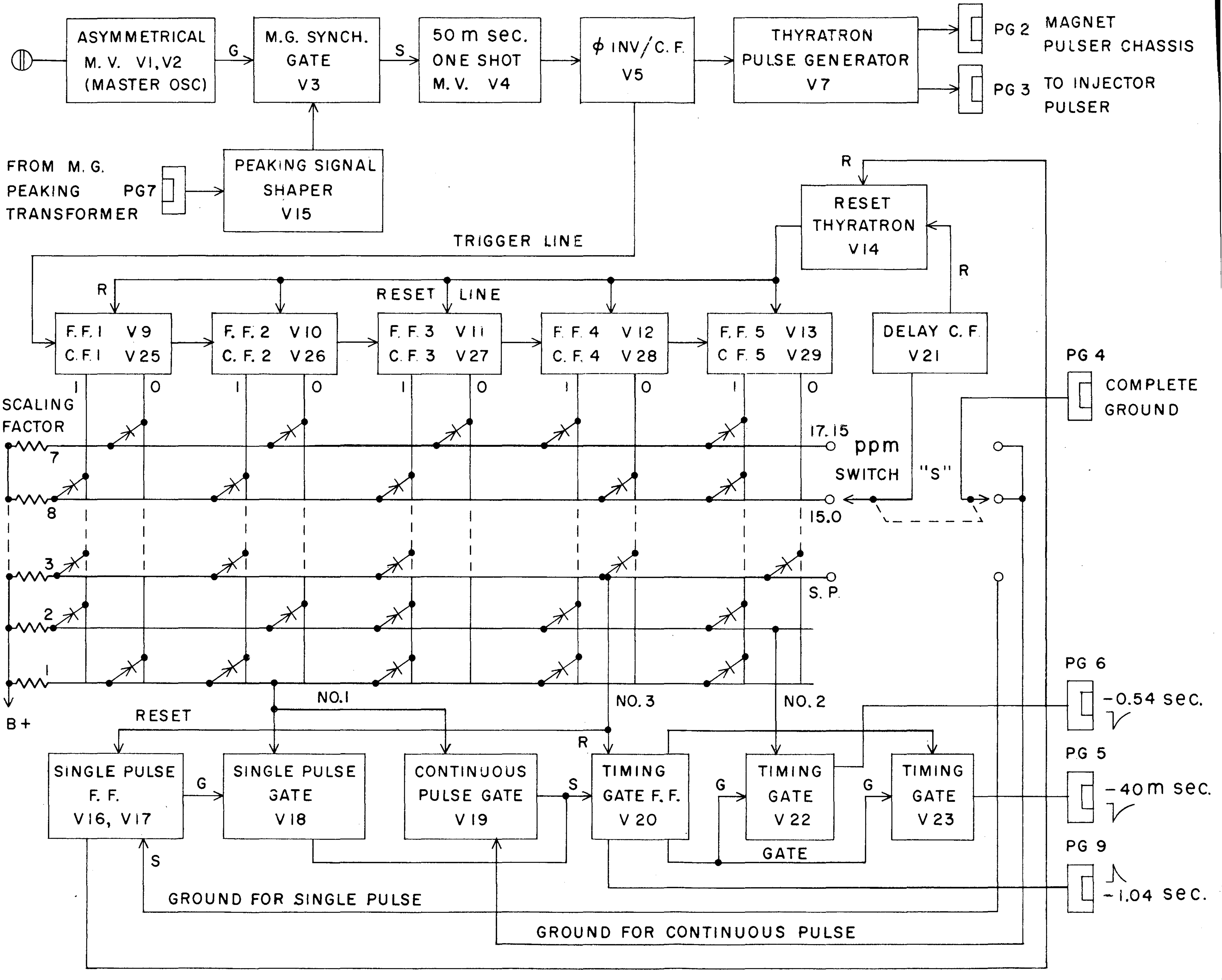


CHARACTERISTICS OF MAGNET/POWER SUPPLY

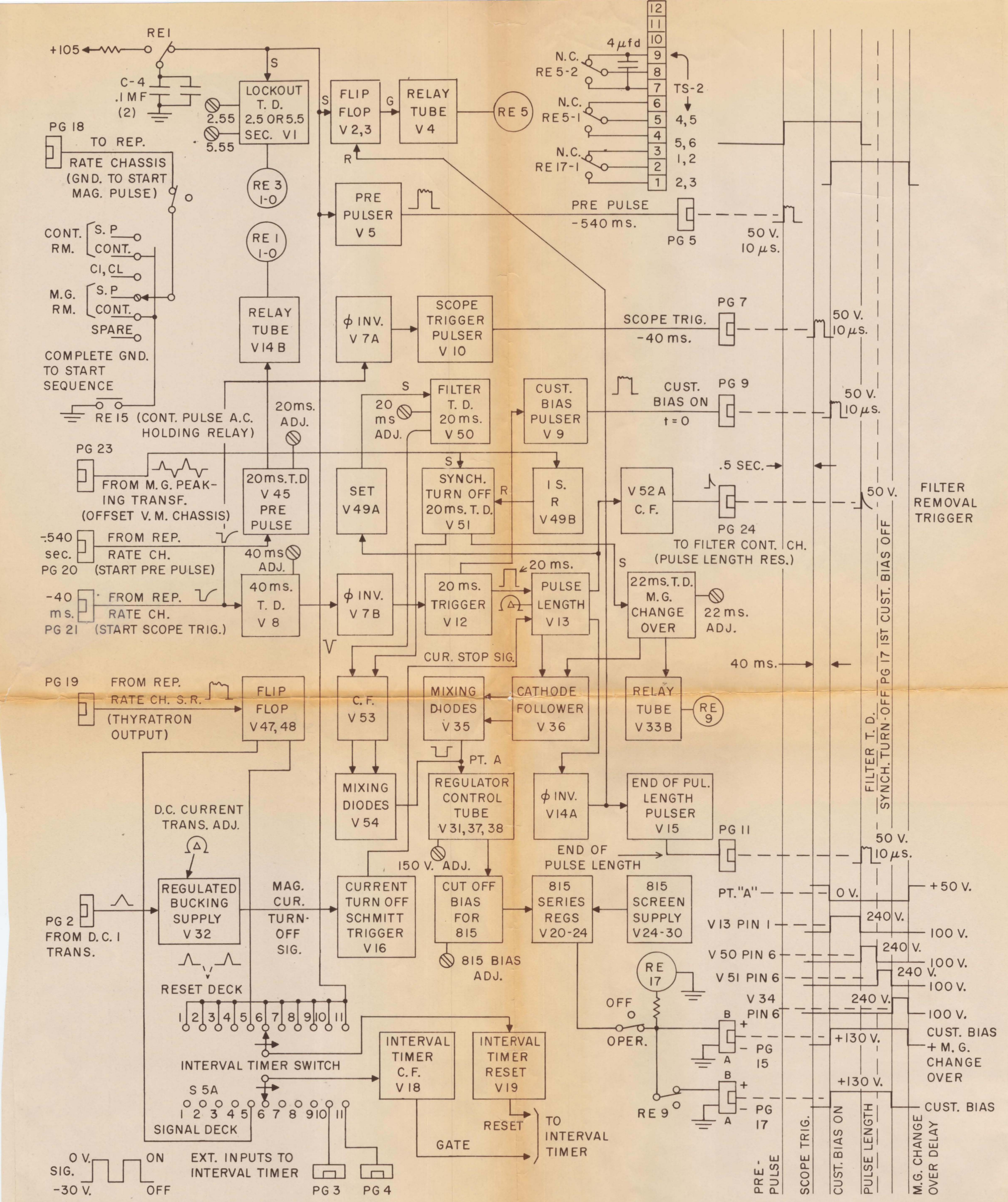
MU-8169

Fig 3

22571-1


ASYMMETRICAL M. V. V1, V2 (MASTER OSC)
G
M.G. SYNCH. GATE V3
S
50 m sec. ONE SHOT M. V. V4
ϕ INV/C. F. V5
THYRATRON PULSE GENERATOR V7
PG 2
MAGNET PULSER CHASSIS
PG 3
TO INJECTOR PULSER
FROM M. G. PEAKING TRANSFORMER
PG7
PEAKING SIGNAL SHAPER V15
TRIGGER LINE
R
RESET THYRATRON V14
R
R
RESET LINE
F.F.1 V9 C.F.1 V25
F. F. 2 V10 C. F. 2 V26
F. F. 3 V11 C. F. 3 V27
F. F. 4 V12 C. F. 4 V28
F. F. 5 V13 C. F. 5 V29
DELAY C. F. V21
1
0
1
0
1
0
1
0
1
0
SCALING FACTOR
7
8
3
2
1
B+
17.15
ppm
SWITCH
"S"
15.0
S. P.
PG 4
COMPLETE GROUND
NO.1
NO.3
NO.2
RESET
R
SINGLE PULSE F. F. V16, V17
G
SINGLE PULSE GATE V18
CONTINUOUS PULSE GATE V19
S
TIMING GATE F. F. V20
G
TIMING GATE V22
G
TIMING GATE V23
GATE
S
GROUND FOR SINGLE PULSE
GROUND FOR CONTINUOUS PULSE
PG 6
−0.54 sec.
PG 5
−40 m sec.
PG 9
−1.04 sec.

23947-2


+105
RE1
S
C-4
.1 MF
(2)
LOCKOUT T. D. 2.5 OR 5.5 SEC. V1
2.55
5.55
RE 3 1-0
S
FLIP FLOP V 2,3
R
G
RELAY TUBE V4
RE 5
4 μfd
N.C.
RE 5-2
N.C.
RE5-1
N.C.
RE 17-1
12
11
10
9
8
7
6
5
4
3
2
1
TS-2
4,5
5,6
1,2
2,3
PG 18
TO REP. RATE CHASSIS (GND. TO START MAG. PULSE)
CONT. RM.
S. P
CONT.
CI, CL
M.G. RM.
S. P
CONT.
SPARE
COMPLETE GND. TO START SEQUENCE
RE 15 (CONT. PULSE A.C. HOLDING RELAY)
PRE PULSER V 5
PRE PULSE -540 ms.
PG 5
50 V. 10 μs.
RE 1 1-0
RELAY TUBE V14 B
ϕ INV. V 7A
SCOPE TRIGGER PULSER V 10
SCOPE TRIG. -40 ms.
PG 7
50 V. 10 μs.
S
FILTER T. D. 20 ms. V 50
20 ms ADJ.
CUST. BIAS PULSER V 9
CUST. BIAS ON t = 0
PG 9
50 V. 10 μs.
20ms. ADJ.
PG 23
FROM M.G. PEAKING TRANSF. (OFFSET V. M. CHASSIS)
20ms. T.D V 45 PRE PULSE
SET V49A
S
SYNCH. TURN OFF 20ms. T. D. V 51
R
R
1 S. R V49B
V 52 A C. F.
.5 SEC.
PG 24
TO FILTER CONT. CH. (PULSE LENGTH RES.)
50 V.
FILTER REMOVAL TRIGGER
-.540 sec. PG 20
FROM REP. RATE CH. (START PRE PULSE)
40 ms ADJ.
-40 ms. PG 21
FROM REP. RATE CH. (START SCOPE TRIG.)
40ms. T. D. V 8
ϕ INV. V 7B
20 ms. TRIGGER V 12
20 ms.
PULSE LENGTH V 13
S
22ms. T. D. M. G. CHANGE OVER
22 ms. ADJ.
40 ms.
CUR. STOP SIG.
PG 19
FROM REP. RATE CH. S. R. (THYRATRON OUTPUT)
FLIP FLOP V 47, 48
C. F. V 53
MIXING DIODES V 35
CATHODE FOLLOWER V 36
RELAY TUBE V 33B
RE 9
PT. A
MIXING DIODES V 54
REGULATOR CONTROL TUBE V 31, 37, 38
ϕ INV. V14A
END OF PUL. LENGTH PULSER V 15
PG 11
50 V. 10 μs.
END OF PULSE LENGTH
150 V. ADJ.
D.C. CURRENT TRANS. ADJ.
REGULATED BUCKING SUPPLY V 32
PG 2 FROM D. C. I TRANS.
MAG. CUR. TURN-OFF SIG.
CURRENT TURN OFF SCHMITT TRIGGER V 16
CUT OFF BIAS FOR 815
815 BIAS ADJ.
815 SERIES REGS V 20-24
815 SCREEN SUPPLY V 24-30
PT. "A"
0 V.
+50 V.
V13 PIN 1
240 V.
100 V.
V 50 PIN 6
240 V.
100 V.
V 51 PIN 6
240 V.
100 V.
V 34 PIN 6
240 V.
100 V.
RE 17
OFF
OPER.
B
A
PG 15
+130 V.
CUST. BIAS + M. G. CHANGE OVER
B
A
PG 17
RE 9
+130 V.
CUST. BIAS
RESET DECK
1 2 3 4 5 6 7 8 9 10 11
INTERVAL TIMER SWITCH
S 5A
1 2 3 4 5 6 7 8 9 10 11
SIGNAL DECK
INTERVAL TIMER C. F. V 18
INTERVAL TIMER RESET V 19
RESET
GATE
TO INTERVAL TIMER
0 V.
SIG.
-30 V.
ON
OFF
EXT. INPUTS TO INTERVAL TIMER
PG 3
PG 4
PRE-PULSE
SCOPE TRIG.
CUST. BIAS ON
PULSE LENGTH
M.G. CHANGE OVER DELAY
FILTER T. D.
SYNCH. TURN-OFF
PG 17 1ST CUST. BIAS OFF

23948-3

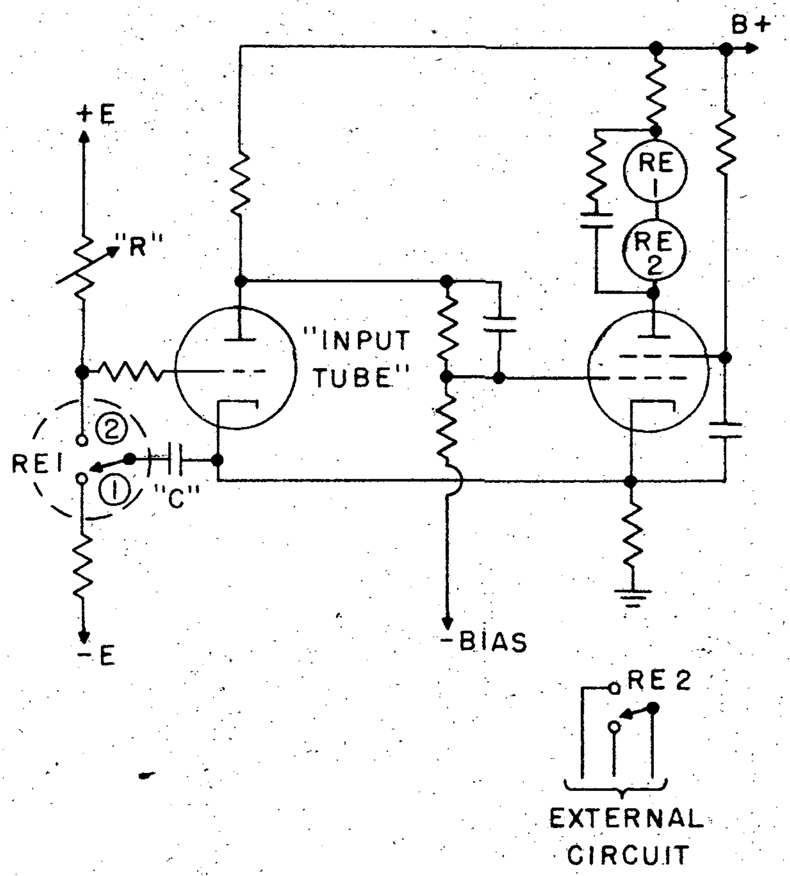


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Fig 4

[redacted]

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[redacted]

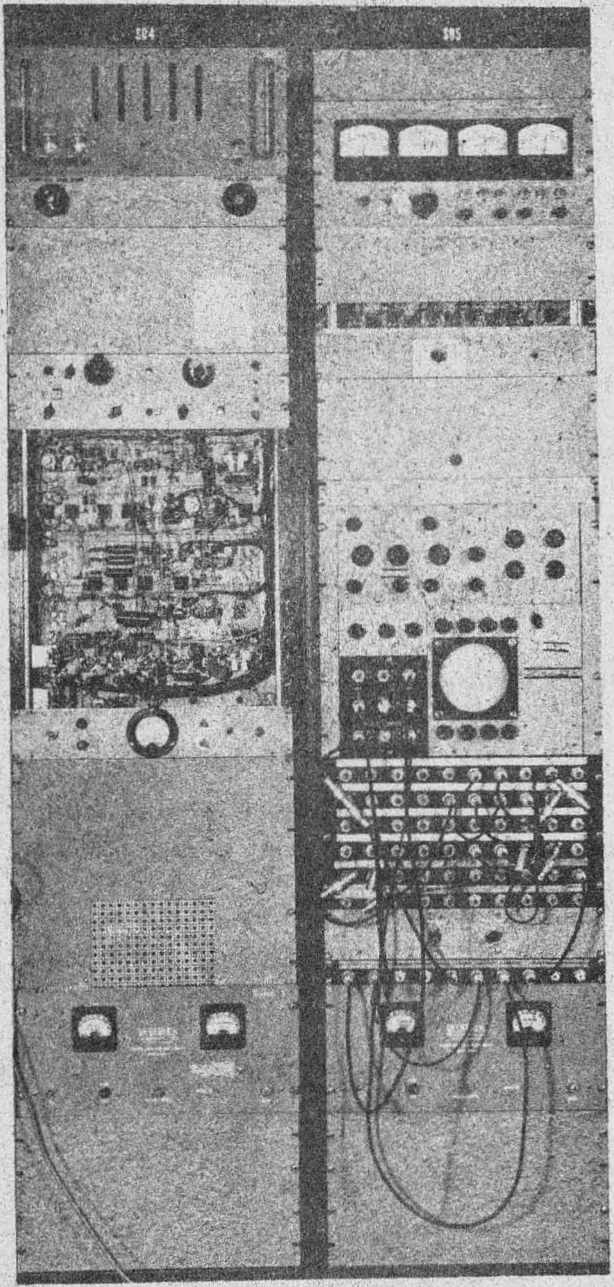

Fig. 7

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