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INSTRUCTION MANUAL FOR THE MODULATOR-KLYSTRON PROTECTION UNIT

1.0 INTRODUCTION

Operating experience with the modulators and high-power klystron amplifiers has indicated the following:

1. The number of recurrent faults may be minimized by interrupting the trigger to the modulator for at least a 1.0 second interval following detection of a fault.
2. Klystron life may be extended by interrupting the trigger to the modulator until after minimum r.f. drive has been achieved following loss of average klystron current for more than 3.5 seconds.
3. Operating time and available klystron population may both be maximized by minimizing attenuation of the r.f. drive, except when recurrent or prolonged faults result in loss of average klystron current for more than 3.5 seconds.

As a result of the foregoing considerations, a need is established for a unit external to the modulator whose primary functions are the following:

1. To sense "fast" faults such as reflected r.f. energy faults, or overvoltage faults due to high voltage breakdown in either the klystron or pulse transformer.
2. To interrupt the trigger train from the sector trigger generator to a faulted Modulator-Klystron.
3. To adjust the level of the r.f. drive applied to the klystron by means of on-off control of an attenuator drive motor.
4. To originate status information for the Central Control Room and control signals for the Sector Trigger Generator and the Automatic Klystron Replacement Systems.

The functions listed above are achieved in a unit called the Modulator-Klystron Protection Unit (MKPU).

2.0 FUNCTIONAL OPERATION

The MKPU accomplishes its primary protective functions as shown in the simplified semi-schematic block diagram of Figure 1. Operation is initiated when the interlocks are all closed and the attenuator is set to the position of minimum r.f. drive. Application of trigger pulses will result in an average flow of klystron current which actuates the MOD ON relay in the modulator. Once the MOD ON repeat relay K4 is closed, an actuation signal is applied to the MOD ON hold relay K1 via a transistor amplifier. Closure of the MOD ON hold relay energizes the attenuator motor provided that the R.F. DRIVE relay K12 is closed. The motor then removes attenuation slowly over an adjustable period of from 5 to 15 seconds. When the motor has driven the attenuator to a position of minimum attenuation, a microswitch is closed completing an actuating circuit for the ATTENUATOR OUT relay K8. When the Forward Energy Monitor indicates a satisfactory level of output power and the ATTENUATOR OUT relay is closed, a closed circuit is established indicating R.F. OK provided that the maintenance lockout switch is in its normal operating position.

If a fault occurs, relay K10 is de-energized and high voltage is removed from the gated trigger amplifier. Transistorized gating is used to effect inhibiting action in less than one interpulse period for overvoltage, overcurrent, or reflected energy faults. In addition, the FAULT-STRETCHER interrupts the actuating current to the NO-FAULT RELAY K2 and consequently opens K10. The Fault-Stretcher inhibit pulse has a duration of approximately 1.0 second.

After clearing of a fault, relays K7 and K10 are actuated. Klystron current flow closes the MOD ON switch. Relay K4 then closes and provides a charging path for an electrolytic capacitor in the MOD ON HOLD circuit while simultaneously providing a gating signal for the transistorized driver actuating relay K1. The MOD ON HOLD circuit allows relay K1 to remain closed for an additional 3 seconds following initial sensing of a fault. Consequently the attenuator motor continues its operation of either removing attenuation or keeping the attenuator in a position of minimum attenuation for at least 3.0 seconds following the occurrence of a single fault.

Overcurrent, overvoltage and reflected power faults will result in an outage of approximately 1 second. Since the MOD ON HOLD circuit actuates relay K1 for approximately 3 seconds after a fault occurs, there exists a nominal 2-second interval during which operation can be restored without attenuation being inserted. If more than two successive faults occur within 3 seconds, or if a single fault persists for over 3.0 seconds, attenuation will be reinserted.

Remote trigger ON-OFF control is restricted to applying or removing the trigger signal to all klystrons in one sector. Actual control is accomplished via the Sector Trigger Generator. Selection of the undelayed (accelerate) trigger or the delayed (standby) trigger is individual to each klystron. Selection is accomplished by means of a mode selection relay in the Sector Trigger Generator; however, control of this relay is exercised at the MKPU. For wide spectrum high-energy beams it is possible to leave recycling modulators in the accelerate mode and to disable control at the MKPU.

During r.f. phasing, provisions are made to select the standby mode. Indication is provided to the automatic phasing system when the modulator is unavailable for phasing. In addition, an output is provided to the r.f. phasing system when the r.f. power level is not satisfactory due to a temporary outage of the klystron.

While maintenance is being performed, the following provisions are made:

1. All remote controls to the unit are locked out by manually switching the MKPU to either the maintenance or external trigger mode.
2. A signal is presented to the Central Control Room (CCR) to indicate that the modulator is not available. All other signals to CCR are cancelled.
3. The mode switch is locked to standby so that any r.f. tests made will not affect the beam.

3.0 OPERATING REQUIREMENTS AND CIRCUIT REALIZATION

The major subunits of the MKPU have been mentioned briefly in Section 2. Before proceeding with a detailed description of each subunit, it is perhaps worthwhile to examine the general requirements of the MKPU as a whole and to simply list the subunits. Rather than presenting a detailed examination of inter-relations between subunits, it is simpler to follow through a given signal flow from input to output on a "single-thread" basis in the detailed description of each subunit. Despite the emphasis on signal flow, however, an attempt will be made to present the description on the basis of a division into the following subunits:

1. The Mod-On-Hold Circuit
2. The Gated Trigger Amplifier and Delay Circuit
3. The R.F. Drive Monitor
4. The Forward Energy Monitor
5. The Reflected Energy Monitor
6. The Overvoltage Monitor
7. The Overcurrent Monitor
8. The Fault Stretcher
9. The Low Speed Logic, Indication, and Control Circuitry
10. The De-Q'ing Reference Voltage Filter
11. The Dual MKPU Power Supply

A circuit diagram of the MKPU not including a schematic diagram of its dual power supply is shown in Figure 2.

Ordinarily, malfunctioning of the klystron may give evidence of a fault condition in terms of a change in the operating point of the klystron. Similarly, evidence of fault conditions in the waveguide or accelerator may be observed in the presence of an abnormally large reflected energy seen at the waveguide output. In the former case, the malfunction is evidenced by either an increase in beam current with a possible decrease of beam voltage, or by an increase of beam voltage with a possible decrease of beam current. The MKPU is equipped with three "fast-fault" detectors for detecting conditions of overvoltage, overcurrent, and excessive reflected energy. In addition to providing evidence of malfunctioning by means of the "fast-fault" detectors, the MKPU also incorporates a Forward Energy Monitor to indicate when the energy per pulse is at a satisfactory level. For the sake of simplicity, the "fast-fault" detectors and the Forward Energy Monitor each incorporate a screw-driver adjustment to set a fixed threshold sensitivity. However, one could also implement a simple automatic tracking system in which the threshold voltages are derived from the De-Q'ing Reference Voltage.

The MKPU must operate in the severe noise environment of the Klystron Gallery over the temperature range from 0 to $60^{\circ}C$. Pulse repetition rates for the R.F. Drive Monitor, the Forward Energy Monitor, and the fault detector circuits vary over the range from 60 pps to 360 pps.

3.1 MOD-ON-HOLD CIRCUIT

The MOD-ON signal originating as a relay closure in the modulator indicates that the modulator is pulsed and that the klystron is drawing average current. This signal is repeated in the MKPU low-speed logic section by Relay K4 to provide multiple contact closures. When relay K4 is closed, a +30 volt signal is applied to the base of transistor Q1. Capacitors C5 and C6 charge slowly through R13 with a charging time constant given by

$$\tau_1 = (C5 + C6)\ (R13) \approx 5 \text{ seconds}$$

As long as the contacts of K4 are closed, a 30 volt signal is applied to the base of Q1 and sufficient current flows through resistor R16 into the base of Q2 to saturate the transistor driving Relay K1. When the relay contacts of K4 open, capacitors C5 and C6 continue to provide base current to transistor Q1. The voltage at the base of Q1 decays exponentially with a time constant given approximately by

$$\tau_2 \cong \frac{(R14 + R15)\ (\beta)\ (R16)}{(R14) + (R15) + (\beta)\ (R16)}$$

and transistor Q2 remains saturated for approximately τ_2 seconds. Current continues to flow until the voltage at the base of Q1 falls below 6.5 volts. When Relay K4 opens after having been closed for at least 30 seconds, Relay K1 drops out after a time $T_d \approx 1.5\ \tau_2$. The holding time T_d can be adjusted over a range of from 0.5 to 3.5 seconds by varying the setting of R15.

Closure of Relay K1 results in application of -24 volts through contact K1-3 to the attenuator drive-motor controller as shown in Figures 1 and 2. Closure of contact K1-2 provides a parallel path around K9-2 for driving relays K7 and K10.

Finally, closure of K1-1 provides status information for both local and remote use. Local information is displayed by Lamp DS-5. Closure of K1-1 completes a path to -24 volts, lighting lamp DS-5. If switch S12, the Maintenance Lockout Switch, is in the normal operating position, closure of K1-1 also applies a -24 volt signal to J6-H.

3.2 TRIGGER GATE AND DELAY CIRCUIT

The Trigger Gate and Delay Circuit accepts negative trigger pulses from the

Sector Trigger Generator. The input triggers have a magnitude of 10 volts and a duration equal to or slightly greater than 0.4 µseconds. The trigger must be amplified by means of a gated amplifier to deliver a delayed positive pulse into a 50 ohm load at a voltage level of 50 volts. The pulse duration must be equal to or greater than 0.8 µseconds and have a rise time less than 40 nanoseconds. The circuitry does not contribute more than 10 nanoseconds to the total jitter. The gating levels are less than 1 volt for inhibiting the pulse and greater than 25 volts for enabling the trigger output.

The operation of the trigger gate and delay circuitry can be understood with the aid of the circuit diagram shown in Figure 2. Negative trigger pulses are applied across either of the voltage divider networks R6 and R8 or R7 and R9 from either an external portable test set or the Sector Trigger Generator, respectively. Negative 5 volt trigger pulses at the input of transformer T1 are stepped up by a ratio of 2:5 and match the load seen looking into the switched delay line composed of L1, L2, L3, L4, and L5. By means of switches S1 through S5 one can set up delays of up to 775 nanoseconds in increments of 25 nanoseconds. The Spiradel* delay lines are terminated in their characteristic impedance of 300 ohms by resistor R92.

The delay line output is applied to the input of transformer T2 through gating diode CR2 and the blocking capacitor C1. During fault conditions, diode CR2 is back biased by 29 volts since its anode voltage is +30 volts and the gate input voltage applied to the cathode from the collector of Q13 is only +1 volt. Thus, the 12.5 volt pulse signal is inhibited. However, under no-fault conditions the gate input is +28 volts. Thus, a trigger pulse of approximately 10 volts can be applied across the input of T2. For slow faults, opening of K10-1 removes the +30 volt supply from the collector of Q3.

Transformer T2, transistor Q3, and the associated circuitry form a series regenerative blocking oscillator. When a 10 volt pulse appears across the input of transformer T2, a 1.6 volt pulse appears between terminals 5 and 6 to transformer T2. Base current then flows in transistor Q3 and current is applied to the 50 ohm load through capacitor C3. As a result of regenerative action, Q3 is saturated and the small voltage drop across terminals 3 and 4 of T2 is inductively coupled across terminals 5 and 6. Thus, a 50 volt pulse is applied to the load. Diode CR3 is used to prevent spurious high-frequency oscillations and to facilitate reset of the transformer core at the termination of the positive pulse.

* Beckmann Instrument trademark

3.3 R.F. DRIVE MONITOR

The R.F. Drive Monitor serves the function of providing status information regarding the adequacy of the power level delivered by the rf drive sub-booster. The monitor is primarily a threshold detection device which provides a two-state output signal in the form of a relay closure when the rf drive is present at a power level greater than or equal to the set nominal power level. Only one monitor per sector is required since its output can be repeated to all FIAT racks in the sector.

3.3.1 DESIGN REQUIREMENTS

The R.F. Drive Monitor is intended to be a relatively crude measuring instrument designed to detect the absence or presence of adequate rf drive. That is, the device should be capable of detecting gross changes from a nominally acceptable power level. To meet this requirement, it is reasonable to demand a sensitivity sufficient to detect a 3 db drop in operating power level from the nominally acceptable power level set to effect relay closure under normal operating conditions. The monitor is used in conjunction with the low-speed logic; therefore, the demands on transit time between two output states is not a critical factor. For a step input, an operating speed of 0.1 seconds to effect a change of state is entirely satisfactory. The actuating signal for the relay has the fail-safe feature that the unactuated relay provides an "off" output signal. An "off" signal is then indicated whenever the monitor loses its required power input from either the dc power supply or the rf drive line.

3.3.2 CIRCUIT DESCRIPTION

The main sections of the monitor are the rf signal sampler, a monostable stage, and a relay driver.

The input signal to the monitor is derived from the pulsed rf drive signal being supplied to the sector. Since the rf drive signal has a nominal power level of from 4 to 6 kw peak, it is convenient to derive the sampled signal through a direction coupler having a loss of 30 db and an attenuator having a loss of 30 db.

A high-burnout crystal diode is used as the detector. The crystal diode is forward-biased through R98. Sensitivity of the monitor can be adjusted over a limited range by potentiometer R103 which controls the voltage applied to the emitter of transistor Q21.

Signal developed across R98 is coupled through capacitor C8 to the base of transistor Q21 which is normally off. When a sufficiently large signal is available, Q21 conducts and a plus voltage appears across R102. The change in voltage across R102 is coupled to the base of Q22 through capacitor C10 and R118. A regenerative action then begins since the collector of Q22 is dc coupled back to Q21 through resistor R101. Thus, Q21 and Q22 are part of a monostable circuit. It should be noted that both Q21 and Q22 are normally off. Initially, capacitor C11 is uncharged. However, when Q21 conducts, Q22 also conducts and charges capacitor C11. The conduction period depends principally on the time constant (C10) (R118), the β of transistor Q22, the initial charge on capacitor C11, the current limiting resistor R108 and the β of transistor Q23. The charge delivered to the base of Q22 during discharge of C10 is given approximately by

$$\Delta Q_{dis} = \int_0^{\Delta t} \frac{29}{R118} e^{-t/\tau_1} dt$$

where τ_1 = (C10) (R118) = 160 μsec and prf = 360 pps.

The charging time, Δt, is a complicated function depending heavily on the β of Q22 and to a lesser extent, on the β of Q23. As a result of the negative feedback at low frequencies, the charge on C11 builds up to some average steady-state value such that Δt adjusts itself to a value large enough to restore the charge lost by C11 during the discharge period. After the conduction period, capacitor C10 discharges towards the voltage across capacitor C11 with a time constant,

$$\tau_2 = (R102 + R118 + R107)(C10) = .80 \text{ msec}$$

Since the maximum pulse repetition rate is 360 pps, approximately three time constants are avilable to assure that C10 is discharged adequately to permit regenerative action. However, in the unlikely case that Q22 has an exceptionally high β (β 200), the monostable could count down the incoming pulse train since C11 would not discharge sufficiently to permit regenerative action to occur for each incoming pulse. Such action would only occur at the 360 pps rate and would not be objectionable since C11 would retain sufficient charge to keep Q23 saturated. To compensate for changes in threshold sensitivity due to temperature, a diode is inserted in the collector circuit of Q22. Current is drawn through diode CR3 via resistor R110. Voltage changes due to temperature variation are dc coupled to the base of Q21 through R106 and R101 and compensate for corresponding changes in voltage drop between the emitter and base of Q21.

Capacitor C11 is dc coupled to the base of Q23, which serves as a current amplifier. When capacitor C11 is charged to its peak value, the current flowing into the base of Q23 is sufficient to cause saturation so that the current through the relay coil is approximately

$$i = \frac{30}{R_L + R112}$$

where R_L is the resistance of the relay coil. After the conduction period of Q21 and Q22 terminates, i_L decays exponentially with a compound time constant determined by C11, R108, R109, the β of Q23, and R112. During the period during which Q3 is saturated, the decay time constant is given by

$$\tau_{sat} \cong (R108 + R112)(C11).$$

When the current flowing in the base of Q3 is insufficient to keep Q3 saturated, the time constant is approximately

$$t_{uns} \cong (R108 + \beta R112)(C11).$$

In terms of the actual values employed in the circuit, the relay will be actuated for about 30 milliseconds after the last conduction period of Q21 and Q22. If the monostable has not been triggered back to its "on" state in that 30 millisecond period (as a result of loss of rf drive signal), the relay releases. The drop out time is therefore long enough to allow for continuous closure of the relay for an input video pulse rate of 60 pps from the signal sampler.

The operating level of the device is set by adjusting potentiometer R103. A self-testing feature is incorporated in the form of a test switch. The switch is normally closed, thus shorting out R104. When the switch is opened, R104 is inserted in the circuit and the voltage level appearing at the emitter of Q21 is decreased by approximately 0.5 volts. A low impedance path to ground for pulse signal is provided by C12. When R103 has been set, depressing the test switch should result in a sufficient decrease in signal level to assure that relay K12 opens. If not, the sensitivity must be decreased. If depressing the test switch then results in opening the relay, the device is in its proper operating range. Of course, the relay must close when the test switch is not depressed and the rf drive is at an acceptable operating level.

3.3.3 OUTPUT SIGNALS

The output signals of the R.F. Drive Monitor appear as contact closures of Relay K12. A short circuit is observed across terminals J6-N and J6-P upon closure of relay contact K12-1. This contact closure is repeated at the Sector Alcove and distributed back to the Model No. 2 MKPU's which are not equipped with an R.F. Drive Monitor. Closure of the R.F. Drive Repeater Relays at the Sector Alcove results in application of -24 volts at J5-M. In the case of Model No. 1 MKPU's, the equivalent voltage is obtained upon closure of K12-2 which applies -24 volts to point X. The presence of a -24 volt level at point X (or JM-5) lights Lamp DS4. When relay contacts K1-2 are closed and -24 volts appears at point X, a -24 volt signal is applied to the drive motor of the Motor-Driven Attenuator. In addition to the primary functions described previously, an additional contact closure is available for diagnostic tests; namely, relay contact K12-3 supplies a switch closure between J16-H and J16-J when K12 is actuated.

3.4 FORWARD ENERGY OUTPUT MONITOR

3.4.1 REQUIREMENTS

In the MKPU, a monitoring device is required to indicate when the klystron output has reached a satisfactory operating level. The output information, presented as the state of a relay contact, is monitored at Central Control. When automatic klystron population management is implemented, the output information may also be used as a control signal. The instrument stability shall assure that the threshold sensitivity (in terms of energy per pulse) varies by less than $\pm$ 10% over the operating temperature range.

(1) An input circuit consisting of a stripline directional coupler (shared with other users)

(2) A crystal holder and microwave crystal detector

(3) A video amplifier and integrator

(4) A comparison voltage function generator and discriminator circuit

(5) An output amplifier

(6) A relay driver

The input to the stripline directional coupler consists of an rf pulse signal extracted from the waveguide directional coupler. The stripline directional coupler is located in close proximity to the R.F. Output Energy Monitor to minimize ground-loop induced noise problems. The output of the stripline directional coupler provides an rf input to an untuned crystal holder and a parallel 50 ohm terminating resistor at an rf pulse power per pulse nominally 90 db below the klystron rf output. A "high burnout" microwave crystal diode detects the rf signal and produces video pulses as large a 0.7 volt at maximum operating power levels. Since the diode is operated at a relatively high pulse power, simple amplifiers are required, and pulse noise problems are minimized.

After preliminary amplification, the video signal from the crystal is integrated. The integration provides a voltage output monotonically related to the energy per pulse assuming a fixed pulse width.* The integrated pulse is then compared with a dc threshold voltage corresponding to the minimum acceptable rf power output. When the peak of the integrated pulse is greater in amplitude than the comparison voltage, a pulse passes through the comparator. This pulse is amplified and then applied to a pulse stretcher low pass filter, and relay driver as shown in Figure 2.

In order to provide uniform output characteristics and temperature independence from the crystal detectors, a dc forward bias scheme is used. This bias voltage is regulated by the diode CR21. The video output of the crystal, a negative pulse between 0.2 and 0.7 volt in amplitude, drives the preamplifier consisting of Q15 and Q6. This preamplifier incorporates heavy negative feedback to insure adequate gain and operating point stability.

The integrator consists of the 3.3K load resistor, R75 and the 0.005 uf capacitor, C47. Its time constant is 6.5 times the nominal pulse width of 2.5 μsec, so that its output has an integration error of less than 8%. An additional amplifier and inverter, Q17, develops a negative pulse up to 13 volts in peak amplitude suitable for the comparison circuit.

The comparison reference voltage, variable from 0 to + 15 volts dc, is derived from the regulated 30 volts supply through the network centered around potentiometer R97. The potentiometer control is provided to adjust the comparator reference voltage to a selected threshold level. Identical

*Actually, the integrator produces a voltage output $V \simeq \int_0^T (P)^{1/2}\, dt$ rather than $\int_0^T P\, dt$ where P is the instaneous power output.

diodes, CR22 and CR23, are placed back to back in the comparator to minimize temperature threshold drifts. A test switch is provided to give an indication of proper functioning of the forward energy monitor. Test switch S_1 increases the reference level of the forward energy channel comparator. As a result, the output pulses from the integrator will be less than the reference threshold voltage and pulses will not be passed through the comparator. Release of switch S_1 should result in the appearance once again, for properly operating modulator klystrons, of pulses signifying rf-OK. The actual bias voltage is brought out to the Diagnostic Plug J16-U. Transistors Q18, Q19 and Q20 function as a one-shot and relay driver very similar to those employed in the R.F. Drive Monitor previously described in Section 3.3.2 When the negative voltage pulse applied to the base of Q19 exceeds some 0.7 volts, current will flow through R84, thereby impressing a voltage on the base of Q18 through R85 and C53. Regenerative action then follows. As a result, capacitor C54 is charged by current pulses whose duration is approximately 1 millisecond. The charge on capacitor C54 is applied to the base of relay driver transistor Q20 through resistor R89 so that adequate filtering is obtained. The current applied to the relay is sufficiently large throughout a cycle of operation to assure that the relay is held in reliably even at the 60 pps repetition rate.

The output signals of the Forward Energy Monitor appear as contact closures of Relay K3. Closure of contact K3-1 completes a path from -24 volts to ground through indicator lamp DS 7. In addition, a short circuit appears across terminals L and M of J6 when K3-2 and K8-2 are both closed and switch S-12(H) is in the Normal Operating position. The short circuit across LM indicates that the r.f. output from the klystron exceeds some specified threshold level, that the attenuator is completely out, and that the Maintenance Lockout switch is in the normal operating position.

3.5 REFLECTED ENERGY MONITOR

The purpose of the Reflected Energy Monitor is to detect conditions of excessive reflected energy due to voltage breakdown in the waveguide and possibly even breakdown in the accelerator tube. The instrument stability shall be such that the threshold sensitivity in terms of peak reflected power varies by less than $\pm$ 10% over operating temperature range. The threshold will normally be set to detect reflected power levels in the range .5MW to 2.0MW.

3.5.1 CIRCUIT DESCRIPTION

The input of the Reflected Energy Monitor consists of an r.f. pulse signal extracted from a stripline directional coupler. The stripline coupler receives its input from a waveguide directional coupler at a nominal level 55 db below the power observed at the waveguide. The stripline coupler and connecting cabling further reduce the signal level by an additional 20 db so that the signal at the output of the directional coupler is nominally 75 db below that at the input to the waveguide coupler. To minimize groundloop induced noise problems, the stripline coupler is located in close proximity to the Reflected Energy Monitor. An untuned crystal detector shunted by a 50 ohm terminating resistor is connected at the output of the stripline coupler.

As in the case of the Forward Energy Monitor described in 3.4.2, the crystal detector is forward biased through the network consisting of R40, R41 and CR10. The signal appearing across R41 is capacitively coupled through C22 to the base of Q8. Transistors Q8 and Q9 form a noninverting amplifier whose gain is stabilized at G = 4.8 by resistors R47 and R48. The amplified video pulse is compared with an analog of the maximum allowable reflected energy. When the peak of the amplified pulse is greater in amplitude than the comparison voltage appearing across R53, a pulse passes through diode CR11.

The regulated dc power supply provides a fixed voltage to drive the network centered around CR12. A front panel sensitivity control, R1, is provided to adjust the comparator reference level. Identical diodes, CR11 and CR12 are placed back to back in the comparator to minimize temperature threshold drifts.

A test switch is provided to give an indication of proper functioning of the reflected energy monitor. Depressing test switch S8 discharges capacitor C64 through R143 and R144 and generates a negative pulse across R144. The short exponential pulse is applied at the video input through CR30, simulating a reflected energy fault.

When the signal level across R52 exceeds the threshold voltage, a negative pulse appears across R119. The signal is then coupled to the base of Q12 through coupling capacitor C28 and the low pass filter consisting of R56 and C29. Transistor Q12 amplifies and inverts the signal which is then applied to diode CR16. A second signal channel from the collector of Q12 applies a sample of the voltage pulse to the gate input of the SCR Q11. The sensitivity of the SCR gate is controlled by potentiometer R5. When Q11 is fired, lamp DS16 on the front panel will indicate that a Reflected Energy Fault has occurred. The lamp remains on until reset switch S11(C) is closed. The output signal at the collector of Q12 is available after passing through Resistor R114 to J16-M for diagnostic purposes such as fault totalization.

The output stage of the R.E. Monitor applies a signal to an "OR" gate consisting of diodes CR14, CR15, and CR16 and resistor R61. The "OR" gate combines the output of the R.E. Monitor with output signals from the Overvoltage and Overcurrent Monitors to be described in Sections 3.6 and 3.7. The resultant signal is then applied to the Fault Stretcher described in Section 3.8.

3.6 OVERVOLTAGE MONITOR

The overvoltage monitor detects conditions of excessive voltage appearing at the klystron cathode. A threshold level is set so that the possibility of arcing due to excessive klystron beam voltage is minimized. The overvoltage monitor is designed to respond to voltages in excess of 10% above the maximum rated beam voltage of 250KV.

The beam voltage signal is scaled down by a 5000:1 capacitor divider network located in the pulse transformer tank and connected to the secondary side of the transformer. To preserve the shape of the beam voltage waveform at the output of the divider network, any load impedance connected at this output should be as large as possible. It is reasonable to specify that droop due to the loading presented by the overvoltage monitor shall be limited to less than 3%. If a more accurate beam voltage measurement must be made, one can disconnect the monitor from the divider network output. Normally, the momitor will be connected, and any distortion created by its input circuit will be less than 3% of the peak voltage.

3.6.1 CIRCUIT DESCRIPTION

The output of the capacitive voltage divider network is applied at input J1 as a negative voltage pulse whose magnitude ordinarily is less than 50 volts. The signal is coupled capacitively to R17 and R18 which are biased to a threshold voltage appearing across R19. The threshold level for the comparator is set by potentiometer R2 which is supplied from the regulated 30 volt supply. R17 and R18 serve as a voltage divider to reduce the signal level. The main effect of the input impedance of R17 and R18 is to cause a droop of approximately 2.5% in the input waveform.

A discriminator level for the comparator stage is provided by a resistor-diode network consisting of CR6, CR7 and R19. This network provides a scaled analog of the maximum klystron voltage. The voltage at the anode of diode CR6 is compared with the voltage appearing across resistor R18. If the amplitude of the voltage pulse is equal or less than the threshold voltage across C14 no forward current flows through CR7 and no voltage appears across R20 (assuming CR7 is an ideal diode). However, when the pulse voltage exceeds the comparison reference voltage, a fault is indicated. Diode CR6 is used to compensate for the forward voltage drop through CR7. Capacitor C14 provides a low impedance path to ground for pulse signals. Resistor R2 is a front panel sensitivity control.

When the signal level across R18 exceeds the threshold voltage, a negative pulse appears across R20. The voltage appearing across R20 **is** capacitively coupled to the base of Q4 through a low-pass R-C filter consisting of R22 and C17. Since the time constant (R22)(C17) = .05 Microseconds, only very sharp noise spikes are affected. Transistor Q4 is normally biased off. When the mitter-base drop exceeds approximately .7 volts, collector current flows resulting in a positive pulse being applied through CR14.

An operation testing feature is built into the monitor allowing from gross testing of the comparison circuit and associated circuitry. Normally, resistor R21 is shorted out of the beam voltage comparator circuit. When the O.V. test switch S9 is depressed, placing R21 in the circuit, the reference level is decreased by approximately 80%. Thus a pulse is produced across R20 on the next input pulse. The monitor then generates an output pulse which can be used for testing pusposes. Actually, a string of output pulses could be generated by keeping the O.V. test switch depressed, as long as the pulses were not used to disable the modulator, thus turning the klystron off.

The signal flow is split into two channels at the base of Q4. The first channel leads from the collector of Q4 to diode CR14 as described previously. The second channel leads from the collector of Q4 to the gate input of the SCR Q5. Resistors R25 and R113 serve as a voltage divider which applies a positive gate signal to Q5. When Q5 is fired, lamp DS17 on the front panel will indicate that a fault has occurred until reset switch S11(A) is closed. The channel through diode CR14 continues to function in its normal fashion even after Q5 is fired. Operation can continue even though lamp DS17 indicates an overvoltage fault.

The output stage of the O.V. Monitor applies a signal from the collector of Q4 to the "OR" gate through diode CR14. In addition, the output signal is also available through R117 for application to J16-N.

3.7 OVERCURRENT MONITOR

The overcurrent monitor detects conditions of excessive current appearing at the output of the pulse forming network. The O.C. Monitor derives its signal from a current transformer coupled to the drive line on the primary side of the pulse transformer, supplying the high voltage pulse to the Klystron cathode. The voltage developed across the leads of the current transformer is proportional to the drive line current which is proportional under no-fault conditions to the klystron current. The low output impedance of the current transformer does not place a severe restriction on the size of the input impedance of the beam current portion of the monitor. The O.C. Monitor shall reliably detect overcurrent conditions in excess of 10% above the maximum rated current of 262 amperes.

3.7.1 CIRCUIT DETAILS

A current transformer in the Modulator produces a voltage analog of the pulse current scaled to 0.25 volts per ampere.

The voltage analog of the measured current appears as a voltage V_I at Input J2 where

$$V_I = (0.25 \text{ volts/amp})\ I$$

When $V_I \geq 70.5$ volts, the current monitor must generate a fault signal. Circuit details are shown in Figure 2.

The comparison operation for the beam current can be described in a manner similar to that for the overvoltage monitor. A reference voltage proportional to the maximum allowable value of beam current is compared with the amplitude of the voltage pulse appearing across the secondary of T3 a 2:1:1 pulse transformer. The reference voltage is derived through R3, CR9, and R31.

Capacitor C38 provides a low impedance to ground for pulse signals. Diode CR9 is used to offset the voltage drop across CR8. A front panel sensitivity control is provided by R3.

A test feature similar to that provided for the overvoltage comparator is provided by the O.C. test switch S10 and R32.

When the signal level across R29 exceeds the threshold voltage, a negative pulse appears across R30. The voltage appearing across R30 passes through a low-pass filter consisting of R33 and C34 and is then impressed across resistor R34 through diode CR13. The signal is then coupled through C35 to a second stage of low-pass filtering and then applied to the base of Q6. The signal is amplified and inverted by Q6. At the collector of Q6, signal is applied to CR15. A second signal channel from the collector of Q6 applies a sample of the voltage pulse to the gate input of the silicon controlled rectifier Q7. The sensitivity of the SCR gate is controlled by potentiometer R4. When Q7 is fired, lamp DS18 on the front panel will indicate that a fault has occurred until reset switch S11(B) is closed.

The functions of the Fault Stretcher are to provide a 1-second opening of a relay incorporated in the low-speed logic and to provide a suitable gating signal to the trigger gate circuit (described in section 4.2) when a fault is sensed. Since the relay contact is in the interlock chain driving K10, the duration of the fault signal should be approximately 1 second. The gating signal levels are either less than 1 volt for the "inhibit" condition or greater than 27 volts for the "enable" condition. The circuitry provides an inhibit signal in much less than one interpulse period after the detection of a fault.

3.8.1 FAULT STRETCHER CIRCUITRY

As shown in Figure 2, the pulse stretcher is a variation of a conventional monostable circuit. A fault signal appears as a positive voltage pulse at the base of Q13, which is normally cut off. Q14 is normally saturated since its base is d-c coupled to the collector of Q13 through R66 and CR18. When Q13 is triggered by a signal sufficiently large to reduce the collector voltage to less than 2 volts, transistor Q14 becomes unsaturated and the current relay winding in the collector circuit of Q14, the voltage at the collector of Q14 increases rapidly. Thus, current is steered through diode

CR24 into the base of Q13, resulting in regenerative action. The collector current of Q13 continues to increase until Q13 is saturated and Q14 cut off. After an initial rapid decay, the charging current through C41 decreases exponentially with a time constant given approximately by

$$\tau_C = R_L + R68 + \frac{(R63)\ (R64)\ C41}{(R63 + R64)}$$

where R_L is the resistance of the relay coil.

The actual pulse width of the monostable will depend not only on the time constant τ_C but also on the β of transistor Q13. For $\beta \geq 40$, the charging period $T_C \geq 2\tau_C$. Consequently, even a low-β transistor will allow release of the relay which remains open for 1.0 seconds. Diode CR20 is used to to assure rapid discharge of capacitor C41. Diode CR19 is used to prevent the generation of a large inductive voltage across the actuating coil of K2 when the current through Q14 is interrupted.

It should be noted that the Fault Stretcher provides two outputs. The trigger gate output enables the trigger gate during no-fault conditions. Thus, a fault signal produces an inhibiting voltage level of less than 1.0 volts at the trigger gate; under no-fault conditions, the trigger gate enabling voltage is approximately 28 volts. The second output consists of a relay actuation of K2. As a fail safe feature, the relay is normally actuated under no-fault conditions. The occurrence of a fault, loss of d-c voltage or presence of a faulty connector interrupts the flow of actuating current and opens relays K7 and K10.

3.9 LOW SPEED LOGIC, INDICATION, AND CONTROL CIRCUITRY

Operation of the low-speed logic circuitry has already been described in considerable detail in the preceding sections (especially in Section 2.0). Consequently, this section will concentrate on those circuits which received inadequate attention previously. To facilitate the presentation, the devices external to the MKPU connected to J5, J6, J7, J8 and J13 are replaced by equivalent switches, relay coils, or voltage sources as shown in Figure 3.

The MOD AVAILABLE signal appears as an equivalent switch closure of S-03 across J5-A and J5-B. Since J6-F is connected to the minus side of the battery supply, display lamp DS3 will light when switch S-03 is closed.

The voltage across DS-3 will also appear at J6-E.

The MOD ON signal appears as a switch closure S-04 across J5-C and J5-D. Since J5-C is connected to the minus side of the 24 volts battery, relay K4 is actuated.

The water flow indication circuitry sees an equivalent interlock chain containing switches S-05, S-06, S-07, S-08, and S-09. Minus 24 volts from the battery is applied to J5-E through S13, the WATER FLOW TEST SWITCH. Switch S13 is normally closed. When flow conditions are satisfactory, the interlock chain is closed through to J5-Z so that -24 volts will be applied to one of the display lamps DS11, DS14, or DS22. For example, if both S-06 and S-09 are open, DS21 will light. Depressing switch S13 breaks the circuit to J5-E, interrupting current flow to either the display lamps or relay K5. For example, if K5 were closed, depressing S13 would interrupt the current to the relay coil and K5-1 would open, extinguishing DS1. A second contact pair K5-2 is available as an output across J16-K and J16-L. A third contact pair, K5-3, is available as an output across J6-A and J6-B.

The R. F. Drive Monitor has been described in detail in Section 3.3. In summary, closure of K12-1 with outputs at J6-N and J6-P is sensed at the sector alcove and used to close a repeater relay. The repeater relay provides a contact closure equivalent to S-010 for each Model No. 2 MKPU. Closure of S-010 across J5-L and J5-M connects -24 volts to point X, causing DS4 to light. For Model No. 1MKPU's, point X is connected to -24 volts through K12-2. Closure of either K12-2 or S-010 together with closure of K1-3 results in application of -24 volts at J13-E and causes the attenuator motor to remove attenuation in the 1FA package. A third contact pair, K12-3, is available as an output across J16-J.

The RECYCLE SUMMARY output appears as a closure of relay contacts K7-3 across J6-C and J6-D. Relay K7 is connected to the -24 volts side of the d-c battery through K2-1 and through an equivalent switch closure S-011 across J7-A and J7-C. If -24 volts is available at J7-A and either K9-2 or K1-2 is closed, current will be applied to the actuating coil of K7. An additional relay output for local diagnostic purposes is avilable at K7-2.

Relay coil K-10 is connected in parallel with the coil of K7. The status of relay K1 is sensed at the Sector Alcove by applying a -24 volt signal at J6-G. If K1-1 is closed, 24 volts is applied across DS-5. If the Maintenance Lockout Switch S-12 is in its normal operating position and K1-1 is closed, -24 volts appears at J6-H as an output signal to the Sector Alcove.

The status of switch S12 is sensed through S12-G across J6-J and J6-K.

The R.F. OK signal is observed as a short circuit across terminals J6-L and J6-M. This signal depends on the simultaneous closure of K3-2, K8-2 and S12(H).

The status of the MOD ON relay, K4, is sensed by observing the status of contacts K4-1 across J6-Q and J6-R.

When a vacuum fault occurs, the vacuum gauge opens the interlock chain through equivalent switch S-011, as described previously. In addition, a vacuum fault closes switch S-012 which connects J7-B to J7-C. Consequently, if K2-1 is closed, -24 volts is applied through S-012 and diode CR25 to DS19 and the relay coil of K6. Contact K6-1 seals the relay so that DS19 continues to indicate that a vacuum fault has occurred even after S-12 opens. Depressing the VACUUM HOLD RESET switch breaks the path to -24 volts through K6-1 allowing relay K6 to open provided that S-012 is open. Indication Lamp DS12 indicates a vacuum fault only when S-012 is actually closed. The voltage appearing at J7-C is also available at J16-C for diagnostic purposes. A -24 volt level appears at J16-C for the duration of a vacuum fault.

The d-c battery voltage is applied across J8-A and J8-B. Terminal J8-B is connected to ground and J8-A is at a potential of approximately -24 volts with respect to that at J8-B. When the battery is connected and provides a continuous path, lamp DS13 is illuminated.

J13 is connected the the motor-driven attenuator called the IFA package. Terminal J13-D is connected to -24 VDC. Switch S-013 connects J13-D to J13-A when the motor-driven attenuator has reached its minimum attenuation limit. Switch S-014 connects J13-D to J13-B when the maximum attenuation limit has been reached. Closure of S-013 and S-014 actuates K8 and K9 respectively. The status of K8 is indicated by lamp DSG, Lamp DS10 indicates the status of K9. If K9 is not closed and contact K1-2 is open, -24 VDC will be applied to DS9 to indicate an attenuation fault, provided that -24 VDC is available at J7-A.

3.10 DE-Q'ING REFERENCE VOLTAGE FILTER

Although the De-Q'ing Reference Voltage would only be required in the event that the MKPU were designed to incorporate automatic tracking, it is routed through the MKPU only to provide for a possible future design modification. The input reference voltage is applied to J14-A and J14-B with the voltage at J14-B positive with respect to that at J14-B. Resistor R136, the leakage inductance of transformer of T4, capacitor C60, and Z137 form a low-pass filter which effectively attenuates all narrow pulses whose duration are less than 10 μseconds. In addition, transformer T4 serves as a line-balancing transformer which cancels out lower frequency ground-loop induced noise voltages. The output of the De-Q'ing Reference Voltage Filter is applied to J4 and is then routed via a coaxial cable to the Modulator. In its present design, the reference voltage is not actually used in the MKPU itself.

3.11 POWER SUPPLIES

The MKPU makes use of two power supplies; namely, the 24 volt battery power supply and a dual, electronically regulated power supply. The d-c battery is shared with other users in the sector. Consequently, the MKPU uses this source of power for lamp and relay loads only. The electronic portion of the MKPU is provided with a separate regulated voltage power supply to avoid interference from noise present on the battery supply.

The dual regulated power supply is a modular supply produced by Power Designs, Inc. The unit designated PS136-032 supplies + 30 VDC rated at 1 ampere and -24 VDC rated at 1 ma. The a-c input at J15 is fused by slow-blo fuses F4 and F5. The supply itself limits d-c output current to approximately 1.3 amperes and 5 milliamperes for the +30 VDC and -24 VDC outputs repectively. Indicating lamp DS20 is connected to the +30 volt output in series R120. Thus, when the a-c input voltage is applied at J15, DS20 will light, provided that the +30 volt supply is operating into a normal load. If the output were short-circuited somehow, DS20 would fail to light.

4.0 TURN-ON AND TURN-OFF PROCEDURE

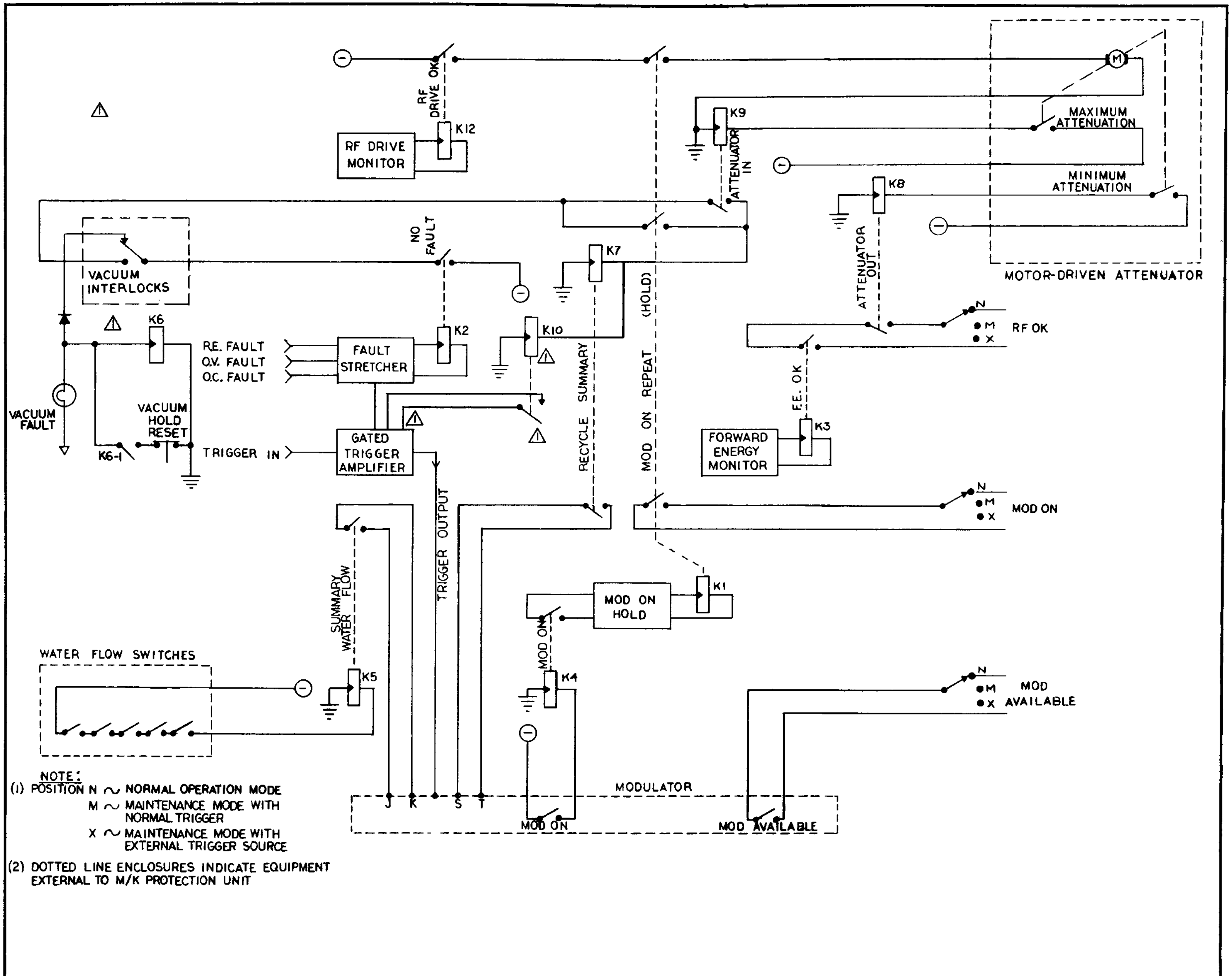
After assuring that all cabling, with the exception of the 120 VAC line cord has been properly connected, the line cord is inserted in J15. Lamp DS20 then indicates that 30 VDC is being applied to the remainder of the MKPU. The Maintenance Lockout Switch is thrown to the OPERATE position.

To turn off a unit, one need only remove a-c power. If one merely wants to disable the trigger output to the modulator, it is only necessary to place the Maintenance Lockout Switch to the External Trigger Position and then not provide any External Trigger.

5.0 OPERATIONAL MAINTENANCE

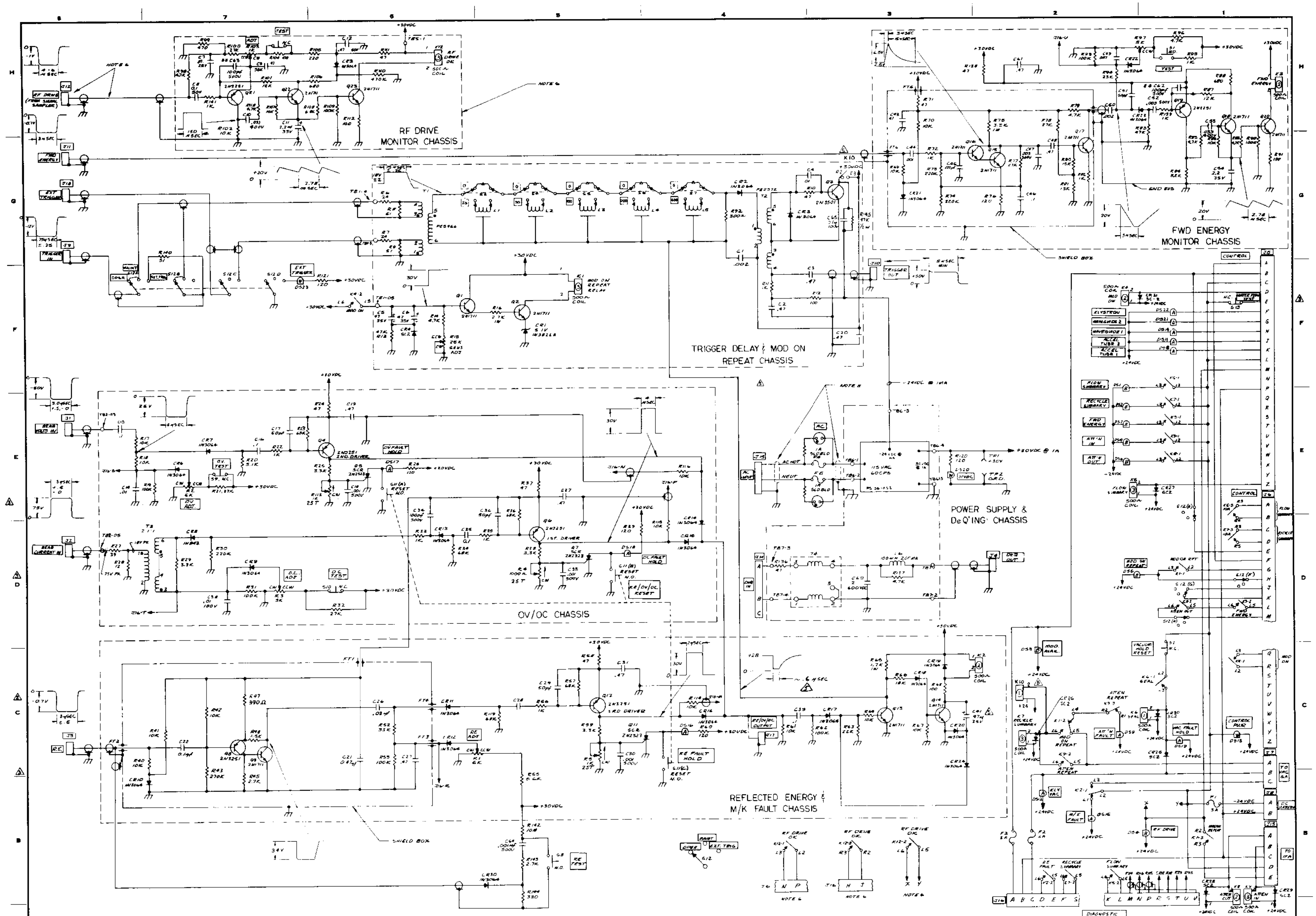
Operational maintenance will consist principally of frequent checks to assure that no change has occurred in the sensitivity settings. This can be accomplished using the M/K Diagnostic Test Set. Periodically, the sensitivity settings will be checked using an external calibrator unit.

If a unit fails, it will be replace with a checked out unit unless the trouble is trivial and simple to eliminate.



RF DRIVE OK
K12
RF DRIVE MONITOR
K9
MAXIMUM ATTENUATION
ATTENUATOR IN
MINIMUM ATTENUATION
K8
MOTOR-DRIVEN ATTENUATOR
NO FAULT
K7
(HOLD)
VACUUM INTERLOCKS
ATTENUATOR OUT
K6
R.F. FAULT
O.V. FAULT
O.C. FAULT
FAULT STRETCHER
K2
K10
RF OK
SUMMARY
RECYCLE
MOD ON REPEAT
F.E. OK
VACUUM FAULT
VACUUM HOLD RESET
K6-1
TRIGGER IN
GATED TRIGGER AMPLIFIER
FORWARD ENERGY MONITOR
K3
MOD ON
TRIGGER OUTPUT
SUMMARY WATER FLOW
MOD ON HOLD
K1
MOD ON
WATER FLOW SWITCHES
K5
K4
MOD AVAILABLE
MODULATOR
J K S T
MOD ON
MOD AVAILABLE
NOTE:
(1) POSITION N ~ NORMAL OPERATION MODE
M ~ MAINTENANCE MODE WITH NORMAL TRIGGER
X ~ MAINTENANCE MODE WITH EXTERNAL TRIGGER SOURCE
(2) DOTTED LINE ENCLOSURES INDICATE EQUIPMENT EXTERNAL TO M/K PROTECTION UNIT

Fig. 1



NOTES

1. ALL RESISTORS ½ W, 5% & OHMS UNLESS OTHERWISE NOTED.
2. ALL CAPACITORS 50VDC & MICROFARADS UNLESS OTHERWISE SPECIFIED.
3. △ = SHORT LEAD LENGTH
4. ✱✱ MOUNT C62, C63 DIRECTLY FROM Q19, Q21 BASE TO EMITTER.
5. (3) RELAY COIL WITH NUMBER INSIDE INDICATES NUMBER OF FORM C CONTACTS USED.
6. RF DRIVE MONITOR CHASSIS ON MODEL ONE ONLY.
7. ALL WAVEFORMS AT 360 PPS. WAVEFORMS SHOWN NOMINAL VALUE.
8. AC CIRCUITS USE TWIN CONDUCTOR, #16 SHIELDED WIRE.
9. ALL COAX CABLE RG196A/U.

Fig. 2

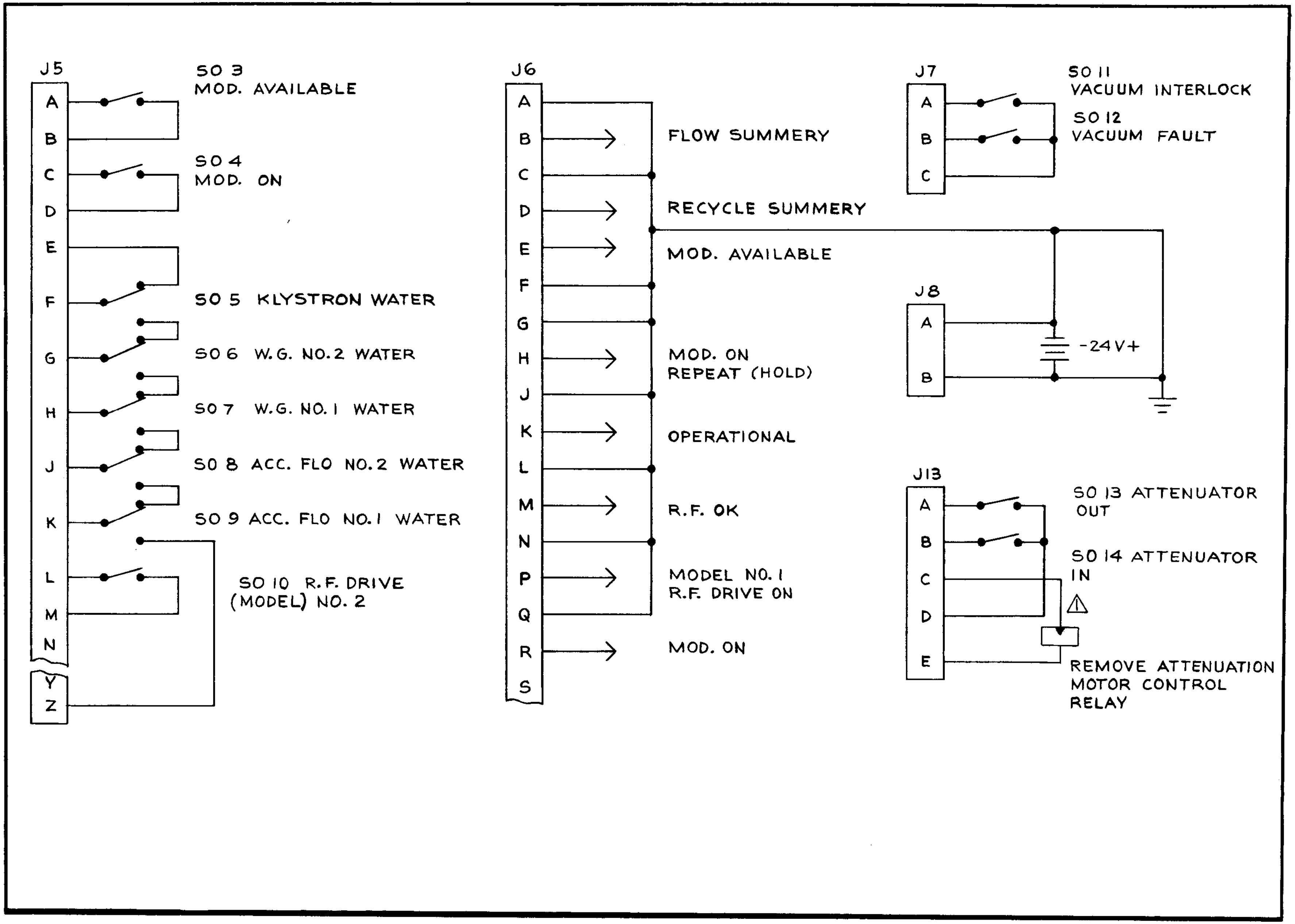

J5
SO 3
MOD. AVAILABLE
SO 4
MOD. ON
SO 5 KLYSTRON WATER
SO 6 W.G. NO. 2 WATER
SO 7 W.G. NO. 1 WATER
SO 8 ACC. FLO NO. 2 WATER
SO 9 ACC. FLO NO. 1 WATER
SO 10 R.F. DRIVE
(MODEL) NO. 2
J6
FLOW SUMMERY
RECYCLE SUMMERY
MOD. AVAILABLE
MOD. ON
REPEAT (HOLD)
OPERATIONAL
R.F. OK
MODEL NO. 1
R.F. DRIVE ON
MOD. ON
J7
SO 11
VACUUM INTERLOCK
SO 12
VACUUM FAULT
J8
-24V+
J13
SO 13 ATTENUATOR
OUT
SO 14 ATTENUATOR
IN
REMOVE ATTENUATION
MOTOR CONTROL
RELAY

Fig. 3