DESIGN AND IMPLEMENTATION OF SAFETY CHANNELS FOR THE IDAHO STATE UNIVERSITY AGN-201M NUCLEAR REACTOR MODERN CONTROL CONSOLE

by

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A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Science in the Department of Nuclear Engineering

Idaho State University

Spring 2017

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The members of the Committee to examine the thesis of Maxwell J. Daniels find it satisfactory and recommend it be accepted.

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To my wife

Acknowledgements

I would like to acknowledge and thank Dr. Jay Kunze, Mr. Jim Larson, and Mr. Craig Shull for their encouragement, support, and expertise throughout this work. I would also like to thank the Institute of Nuclear Power Operations for sponsoring this work, as well as the committee members for their insights into the research scope and thoughtful comments on the thesis.

I would like to offer a heartfelt thanks to my wife, Crystal, for her unwavering support throughout this process. I would also like to acknowledge and thank Dr. Mary Lou Dunzik-Gougar, Matthew Beatty, John Mulvaney, and David Munson for their willingness to provide meaningful suggestions and aid in qualifying this circuitry.

Abstract

The purpose of the work described in this thesis is to design, implement, and install new safety channels for the control console of the Idaho State University (ISU) AGN-201m Reactor. These channels will replace the current vacuum-tube driven system, which has been in operation for over 50 years at the ISU nuclear engineering laboratory. The safety channels are composed of three complementary signal processing systems whose circuits monitor the operating parameters of the nuclear reactor. The key reactor information is shown on several independent meters corresponding to each of the three safety channels. Finally, the reactor trip points are set to correspond with the standards promulgated by the Nuclear Regulatory Commission (NRC) to ensure safe operation of the reactor.

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Nomenclature

A – Operational Amplifier (Opamp), including but not limited to: unity gain buffer, comparator, differential, voltage, and output.

C – Capacitor, including but not limited to: ceramic, film, tantalum, and sliver mica.

D – Diode, including but not limited to: zener, signal, and light emitting.

K – Relays, including but not limited to: latching, reed, and solid-state contactor.

M – Meters, including but not limited to: digital, analog, and logarithmic.

R – Resistor, variable resistors (potentiometers) or set resistors.

U – Integrated Circuits (excluding operational amplifiers). Including but not limited to: CMOS hex inverter and solid-state switches.

1. Introduction

The work presented in this thesis concerns the design, construction, and installation of three solid-state safety channel systems for the Idaho State University AGN-201m research reactor. This reactor system is a Nuclear Regulatory Commission (NRC) licensed training reactor under license # R-110. The AGN-201m has a maximum licensed power of 5-Watts thermal and contains a uranium core enriched to approximately 20%. The reactor uses equivalently enriched fuel rods to control the nuclear reaction. The movement and position of the control rods is performed by operating personnel at the control console. In addition, 3 radiation detectors monitor the flux near the core tank of the reactor and display this data on the reactor control console.

The reactor and associated control systems were created in the 1950s by Aerojet General Nucleonics (AGN). At that point in time vacuum tubes were the active elements used in electronic circuitry. Consequently, the current reactor control console runs several systems, including the safety channels using vacuum tubes and vintage electrical components. The prevalence of vacuum tubes has decreased radically as modern solid-state transistor circuitry became the standard, making replacement parts for the current safety channels difficult to obtain. To ease this difficulty, new solid-state safety channels have been built and qualified to serve as replacements.

Each of the safety channels links to a separate radiation detector and as such serves a different function. Channel 1 is the safety channel responsible for ensuring an adequate neutron population for start-up. Without an adequate neutron population Channel 1 will trip resulting in the scram of each of the control rods. Channel 2 is the safety channel responsible for display of the entire operating range of current measured by its radiation detector, as well as measuring its rate of change, or reactor period. If the period should rise above a pre-determined limit or if the current reading on Channel 2 should get too high or too low, then Channel 2 will trip resulting in a scram. Channel 3 is the safety channel responsible for very fine measurements of the current output from its radiation detector. This means that detector current from multiples sources is available for display and as such several independent trips can occur. If the current reading should dip below 5% or go above 95% of the full scale, then a trip will occur causing a scram. If the current output of either the Channel 2 or Channel 3 detectors should reach a magnitude equivalent to a power level of 6-Watts, then a high level scram will occur.

The three new solid-state safety channels are designed to emulate the original design. The benefits of these new systems include increased signal processing speed, easy-to- replace components, and simple diagnostics. This paper follows the chronological order in which these components were designed and built. Chapters 2-4 outline the work that has been performed to create these solid-state safety channels. These chapters include specifics on the choice of circuitry, calibration of this circuitry, and an overall idea of their purpose. Chapter 5 addresses the control console as a whole, including any future work that is to be performed in order to ensure a successful completion of a new reactor control console for the ISU AGN-201m.

2. Start-Up Safety Channel

2.1 Introduction

The Channel 1 Circuitry consists of the following: An ORTEC model 556 High-Voltage Power Supply, an ORTEC model 460 Delay Line Amplifier, an ORTEC model 142AH preamplifier, a Test Frequency Generator module, and a Channel 1 module. These modules gather and interpret readings from the Channel 1 dedicated radiation detector; a ^{10}B-lined proportional counter. This counter requires a nominal voltage of 760 volts, provided by the ORTEC model 556 High-Voltage Power Supply and can detect more neutron radiation then gamma radiation. Each of these components work together to make the Start-Up Safety Channel. The readings are displayed on a logarithmic count rate meter, M1. To calibrate the Channel and test the trip circuit, two pushbutton enabled test frequencies are available on the control console front panel. Figure 2.1 consists of a block diagram showing each of the interconnections.

CHANNEL 1

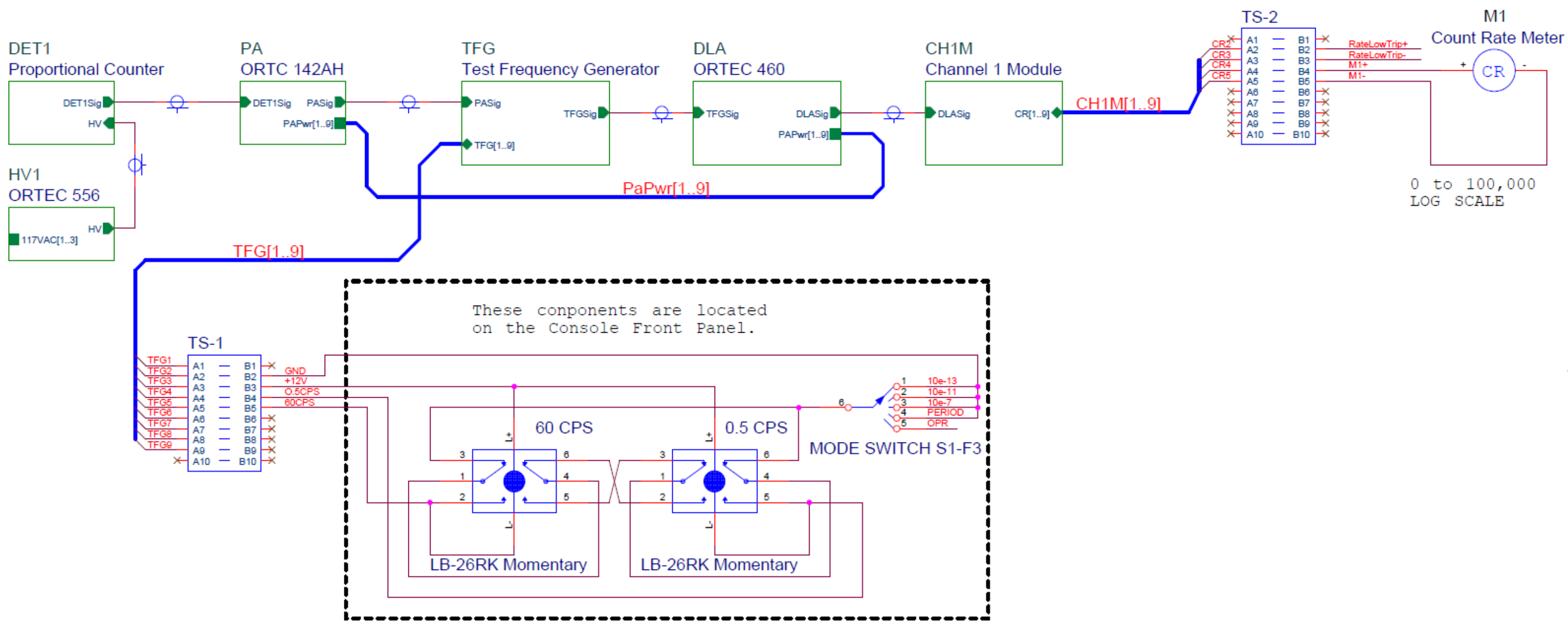

Figure 2.1 Channel 1 Block Diagram

2.2 Test Frequency Generator

The test frequency generator module is a non-commercial unit designed to work with and receive power from the standard Nuclear Instrumentation Module (NIM) Bins. The preamplifier output runs directly into this module via a (Bayonet Neill–Concelman) panel mount BNC connector on the front of the module. The primary function of the test frequency generator module is to provide selectable 0.5 counts per second (CPS) and 60 CPS signal pulses to test the functionality of the Channel 1 count rate processing circuitry, meter M1, and trip circuitry located in the Channel 1 module.

Each of the individual test frequencies are selected via corresponding pushbuttons on the reactor control console front panel. When either pushbutton is depressed the test frequency generator module opens a path between the output of the preamplifier and the input of the ORTEC 460 delay line amplifier. With this pathway open the selected test signal is injected into the ORTEC 460 delay line amplifier. The pushbuttons are not depressed during normal operation.

The 60 CPS signal is used to verify that the meter M1 is reading properly and that the logarithmic count rate circuitry is calibrated and functioning correctly. 60 CPS was chosen simply because it is an easily verifiable number on the front panel meter M1 associated with Channel 1. The 0.5 CPS signal is used to test the required low-level trip circuitry. The 0.5 CPS low-level trip is a part of the R-110 license and thus it must be ensured before any operation. No signal is generated if both pushbuttons are depressed at the same time. A diagram of the console front panel for Channel 1 is shown in Figure 2.2.

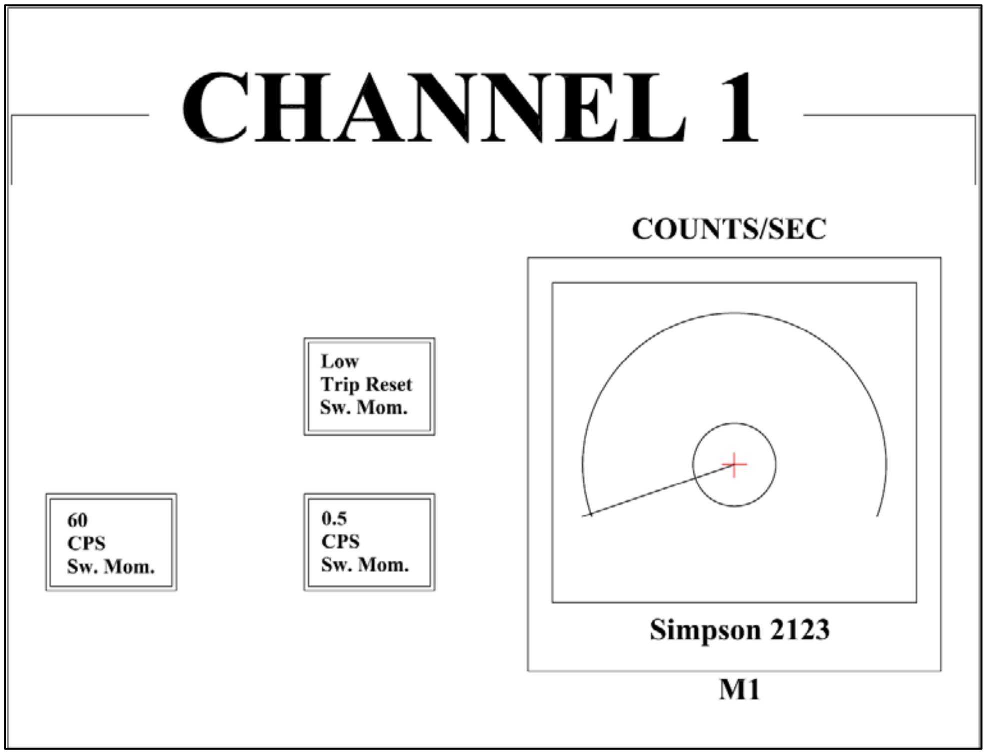

Figure 2.2 Channel Console Front Panel

2.2.1 Test Frequency Generator Circuitry

The circuit diagram of the Test Frequency Generator is shown in Figure 2.3. The frequency generating circuitry of the module consists of two separate LMC555 integrated circuits responsible for generating 0.5 hertz and 60 hertz square waves. When either the 0.5 CPS or 60 CPS pushbuttons are depressed the square waves are counted and displayed as CPS on meter M1. The 0.5 hertz circuitry is built around integrated circuit U1 and the 60 hertz circuitry is built around integrated circuit U2. Both U1 and U2 have test points named TP1 and TP2 respectively to verify their functionality. U1 and U2 each have independent frequency adjustors capable of modifying their frequency if either should alter over time. These adjustors, or potentiometers, are labeled as R1 for the 0.5 hertz and R2 for the 60 hertz.

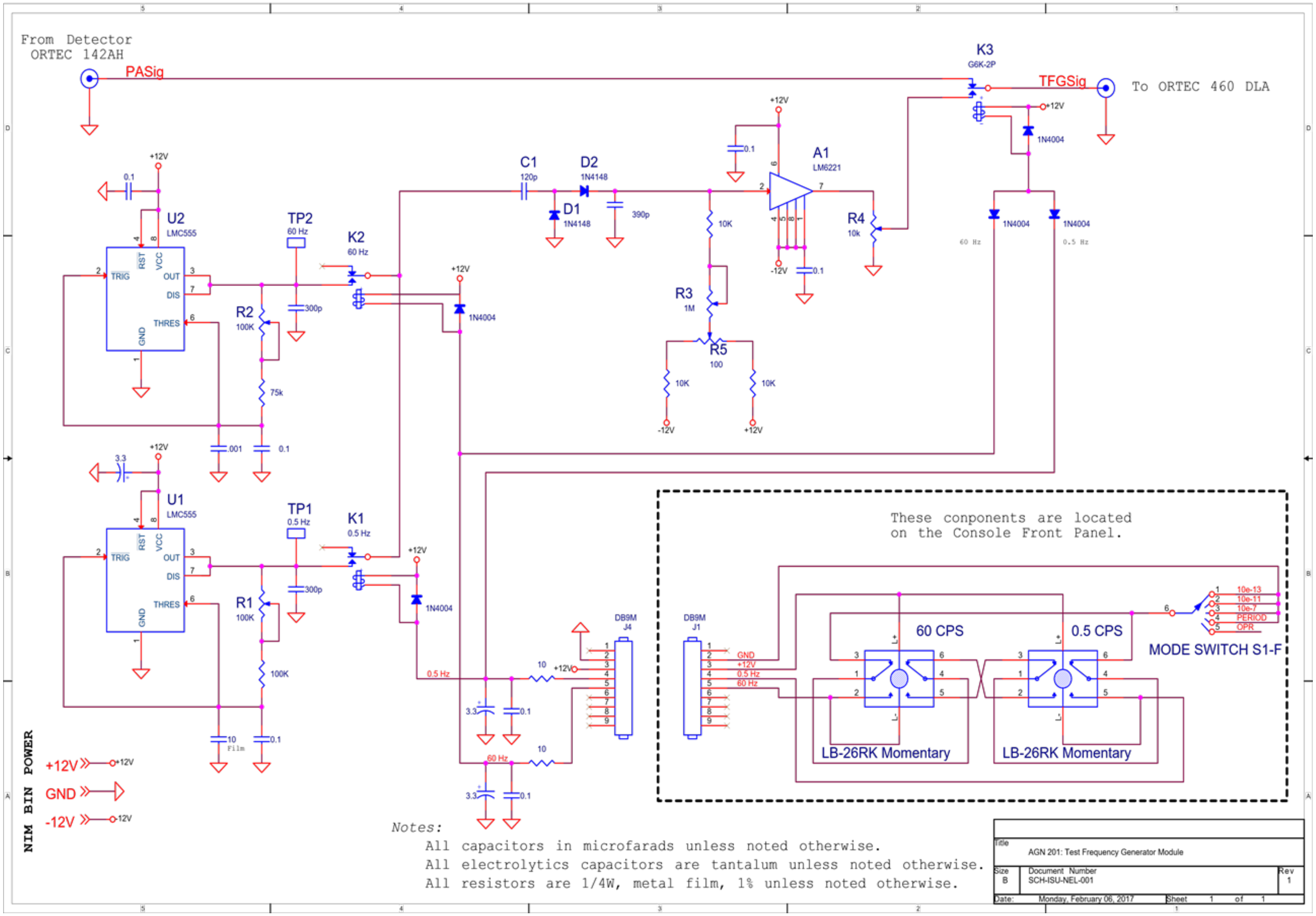

Figure 2.6 Test Frequency Generator Module Schematic

Each of the pushbuttons energize a relay when depressed. When the 0.5 CPS pushbutton is depressed relay K1 closes and the closure of these contacts selects the output of U1 for as long as the pushbutton is depressed. Relay K2 is energized in the same manner by the 60 CPS pushbutton, which selects the output of U2. Relay K3 is energized when either of these pushbuttons are depressed. The contacts of K1, K2 and K3 are normally open during standard operation. Regardless of which test signal is selected, all test signals are run through the Unity Gain Buffer (A1). This buffer is responsible for converting the shaped high impedance tail pulses to low impedance without actually changing their peak amplitude.

When either the 0.5 or 60 hertz square wave is selected, the test frequency will drive diodes D1, D2, and capacitor C1 to develop a tail pulse that can be adjusted by R3 to have the same shape as that produced by the output of the ORTEC 142AH. The pulse given off by the ORTEC 142AH and emulated within the Test Frequency Generator is shown in Figure 2.4.

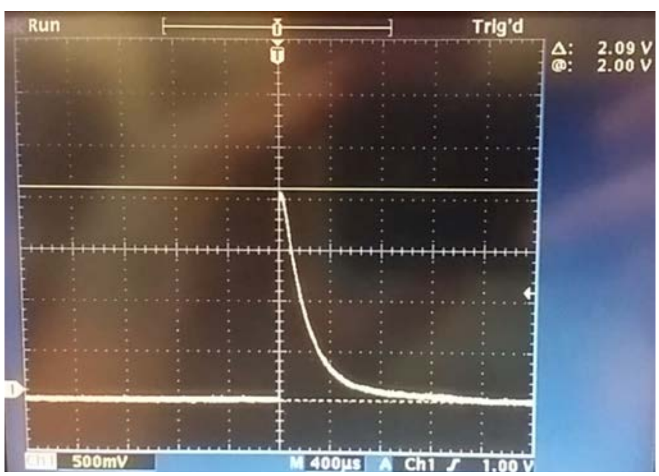

Figure 2.4 Channel 1 Test Pulse

Over time the required tail-pulse shape may change so adjustments can be made to the pulse generated by the Test Frequency Generator. R5 is adjusted to set the output pulse baseline to zero volts. R4 is adjusted to set the amplitude of the generated tail-pulse to a level typical of a neutron generated pulse from the preamplifier. The potentiometer locations in the Test Frequency Generator module are shown in Figure 2.5.

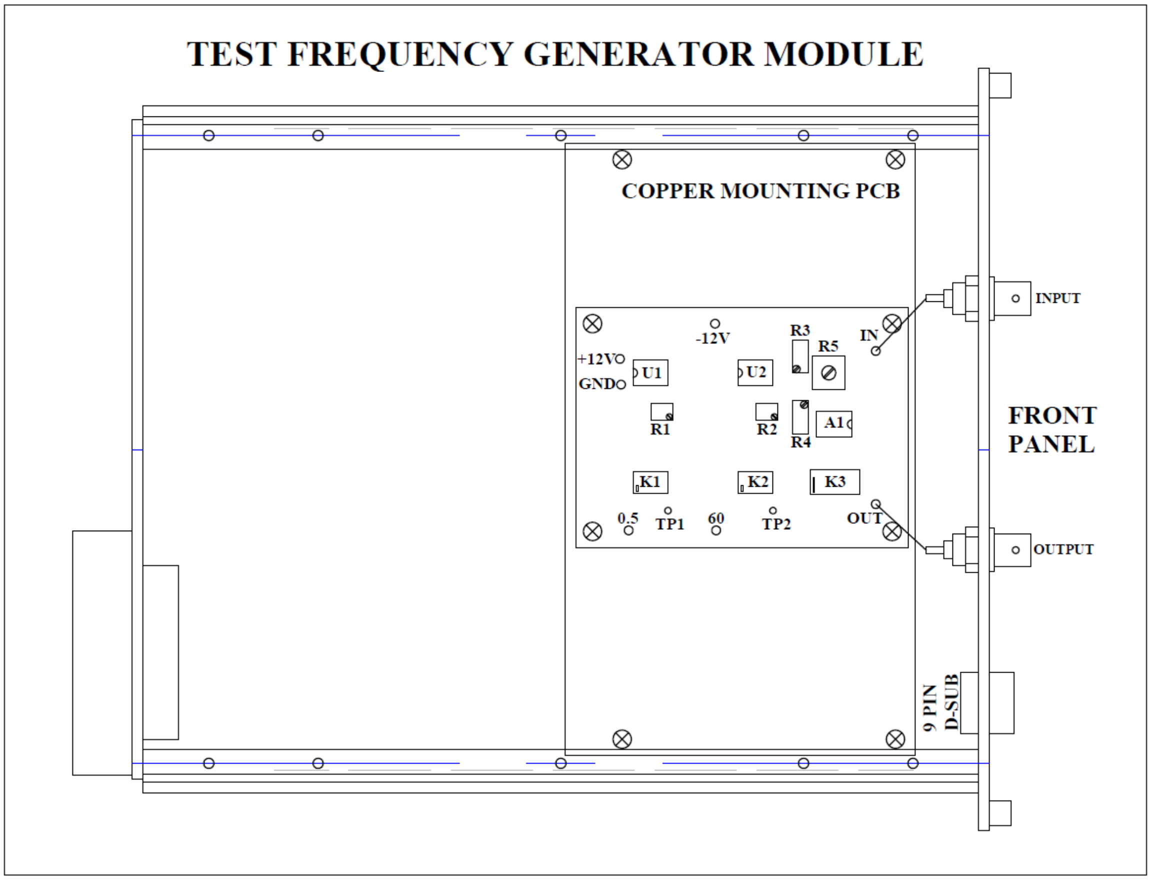

Figure 2.5 Potentiometer Locations in Test Frequency Generator

2.3 Channel 1 Module

The Channel 1 module provides several discrete circuits serving different functions. This module contains the log rate circuitry designed to drive the 0.1 to 100,000 CPS logarithmic scale meter M1 located on the front panel of the reactor control console. This module contains a separate circuit designed to trip a relay and scram the reactor at rates equal to or less than 0.5 CPS. This low-level trip is verified in daily operations via the introduction of the 0.5 CPS test frequency. When the trip occurs the lamp within the "Low-Trip Reset" momentary pushbutton will activate signifying to the operator a trip has occurred.

2.3.1 Channel 1 Module Circuitry

The circuit diagram of the Channel 1 module is shown in Figure 2.6. The circuitry of the module consists of a pulse height discriminator (A1) having a fixed 0.6-volt discrimination level designed to eliminate gamma background. This number was chosen based on simple experimentation to check for system noise. Adjustment of the discriminator threshold is made by simply adjusting the gain of the ORTEC 460 delay line amplifier, the output of which drives the module.

The ORTEC 460 delay line amplifier has a variety of settings available to shape the pulse, invert it, and change the integration time. After some testing of the system set-up, it was determined that the best settings for the ORTEC 460 delay line amplifier were non-inverting, bipolar, with a 40 nanosecond integrating time constant. Non-inverting is required since the discriminator requires a positive pulse. Bipolar was chosen to minimize baseline shift and the effect of pulse pileup at high counting rates. The 40 nanosecond integrating time constant was selected to ensure fast resolution of the presence of an input pulse. This 40 nanosecond integrating time constant is also the smallest amount of integration available on the ORTEC 460 delay line amplifier.

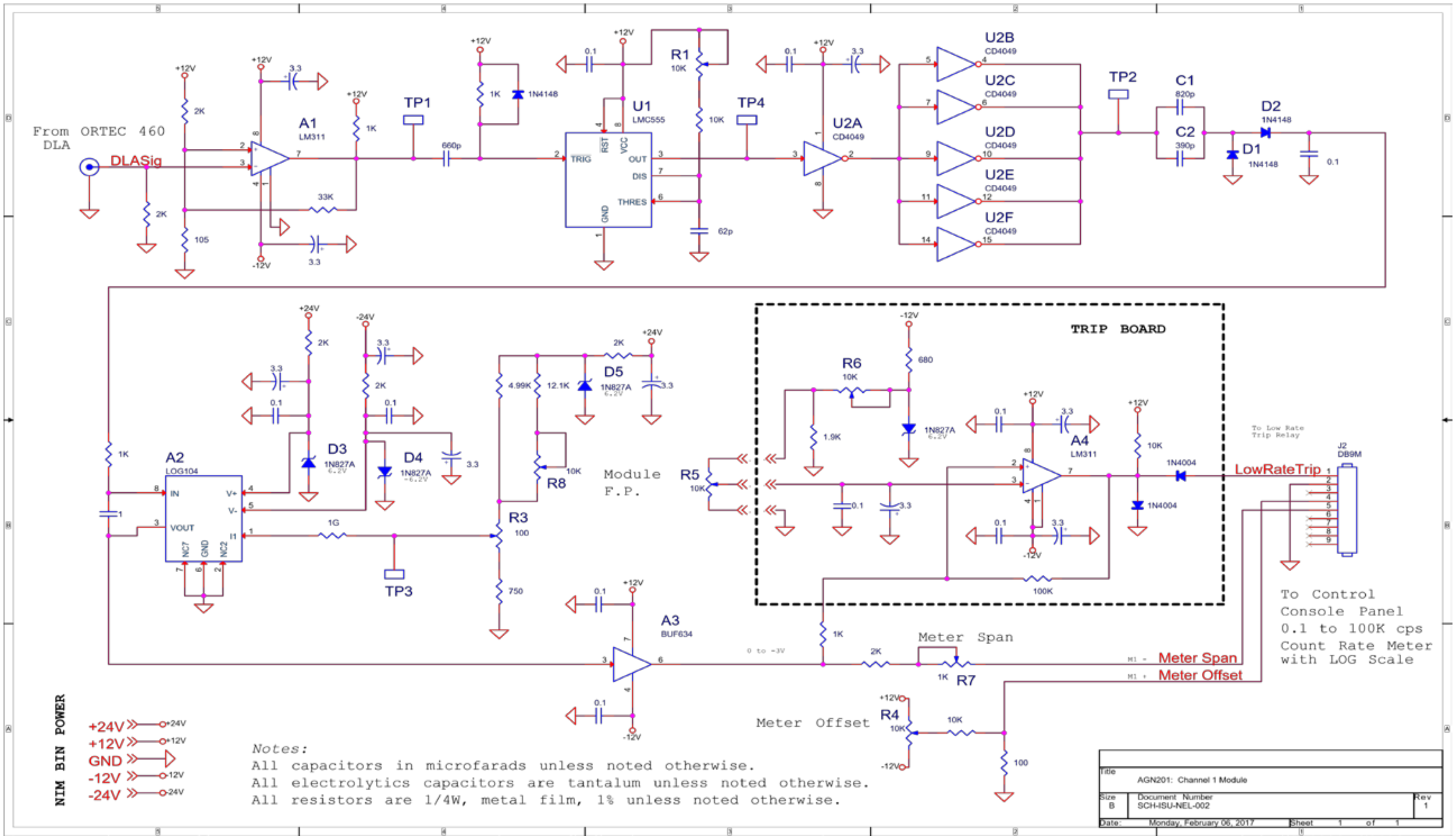

Figure 2.6 Channel 1 Module Schematic

The output of discriminator A1 drives U1 which is configured as a monostable multivibrator (single shot) whose output pulse is approximately 0.7 microseconds wide, positive, with a 12-volt amplitude. The pulse width can be varied as needed by adjusting R1. The output of U1 drives a static CMOS Hex Inverter, (U2). This part is configured as a non-inverting buffer. U2 drives a charge pump comprised of C1, C2, D1 and D2. The charge pump develops an output current which is proportional to the pulse rate of the input signal applied to the module.

The output current from the charge pump is applied to the input of the logarithmic amplifier (A2), which in turn, develops an output voltage proportional to the log of the input count rate. Diodes D3, D4, and D5 are 6.2 volt Zener reference diodes that regulate the logarithmic amplifiers supply and reference voltage. The 1 gigohm resistor provides a 1 nanoampere reference current for the logarithmic amplifier, thus calibrating the logarithmic amplifier to yield 0 volt out for a 1 nanoampere output from the charge pump. Potentiometers R3 and R8 provide coarse and fine adjustment of the reference current. Capacitors C1 and C2 are sized to deliver 1 nanoampere of input current to the logarithmic amplifier at a count rate of 0.1 CPS. In addition, the meter span and meter offset can be manually adjusted using potentiometers R7 and R4 respectively. This need only be performed if the tolerances of M1, R4, or R5 drift over time. The location of all Channel 1 module potentiometers are shown in Figure 2.7.

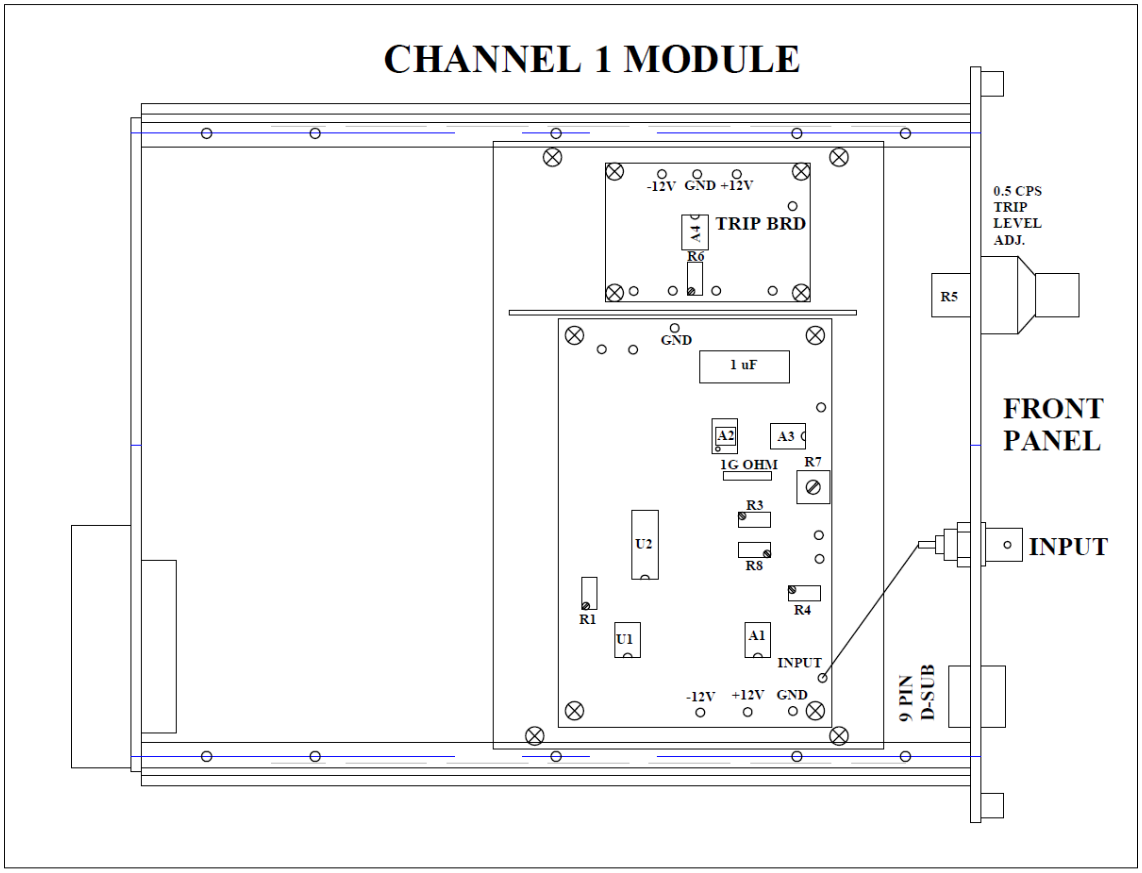

Figure 2.7 Potentiometer Locations in Channel 1 Module

The logarithmic amplifier is inverting, and its output increases in the negative direction by -0.5 volts for each decade increase of pulse rate at the input of the charge pump. The output voltage of the log amplifier drives the logarithmic count rate meter M1, which displays 6 decades of count rate, (0.1 CPS to 100,000 CPS). Output voltage from the logarithmic amplifier, by decade, increases in intervals of 0.5 volts DC as shown in Table 1.1.

Voltage (Direct Current) V. Count Rate	
-0.5 VDC	1 CPS
-1.0 VDC	10 CPS
-1.5 VDC	100 CPS
-2.0 VDC	1,000 CPS
-2.5 VDC	10,000 CPS
-3.0 VDC	100,000 CPS

Table 2.1 Voltage (Direct Current) V. Count Rate

The output of log amplifier A2 is buffered by the unity gain buffer amplifier A3, which in turn drives the logarithmic count rate meter M1 and comparator A4. Comparator A4 drives the Channel 1 0.5 CPS low-level count rate trip relay. To adjust the count rate low-level trip point, potentiometer R5 located on the modules front panel, is adjusted either up or down depending on the requirements. R6 is adjusted to calibrate the dial setting of R5 to correspond to the trip point of 0.5 CPS.

3. Logarithmic and Period Safety Channel

3.1 Introduction

The logarithmic current level and reactor period information combine to make safety Channel 2. Channel 2 consists of a ^{10}B-Lined Uncompensated Neutron Ionization Chamber near the reactor core tank, a Channel 2 NIM module and an ORTEC Model 556 High-Voltage Power Supply. This channel serves two discrete functions: to interpret and display the detector output current on a logarithmic scale and to analyze this output current to generate a. period. Figure 3.1 consists of a block diagram showing all the inter-connections between these components.

3.2 Channel 2 Module

The Channel 2 module drives 2 separate meters: Meter M2 indicates detector current over the full operational range and meter M3 shows changes in reactor period. This reactor period is the rate of change for the logarithmic signal. The module includes the three following trips: High Current, Low Current, and a High Reactor Period. Each of these trips will trigger a scram of the reactor. The circuit diagram of the Channel 2 module is shown in Figure 3.2.

Reactor power is determined by measuring the magnitude of the ionization chamber's output current with a logarithmic amplifier. This amplifier has a logarithmic transfer function and dynamic range of input current from 10^{-13} to 10^{-6} amperes. The measured ionization chamber current is displayed on an equivalent range analog meter (M2), which has a seven-decade scale with logarithmic spacing. The logarithmic amplifier drives both the high and low trips, (A4 & A5), and a differentiating amplifier, (A3). Each of these is driven directly by the output of the logarithmic amplifier via unity gain buffer amplifier, (A1).

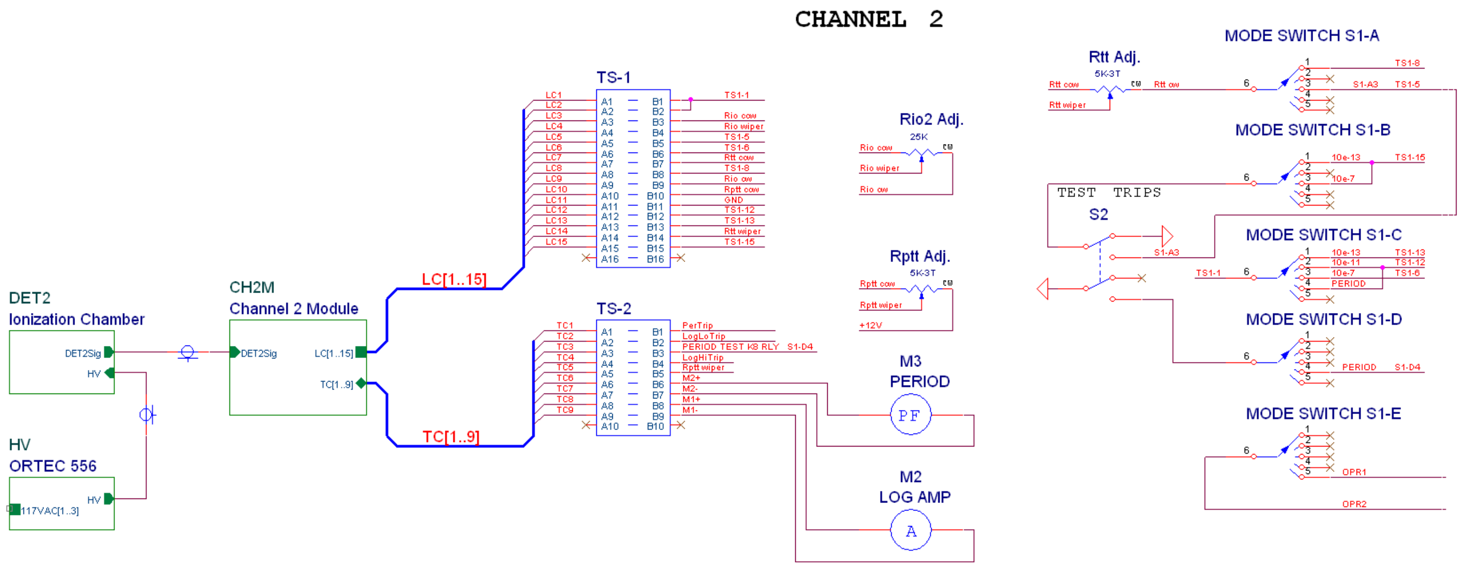

Figure 3.1 Channel 2 Block Diagram

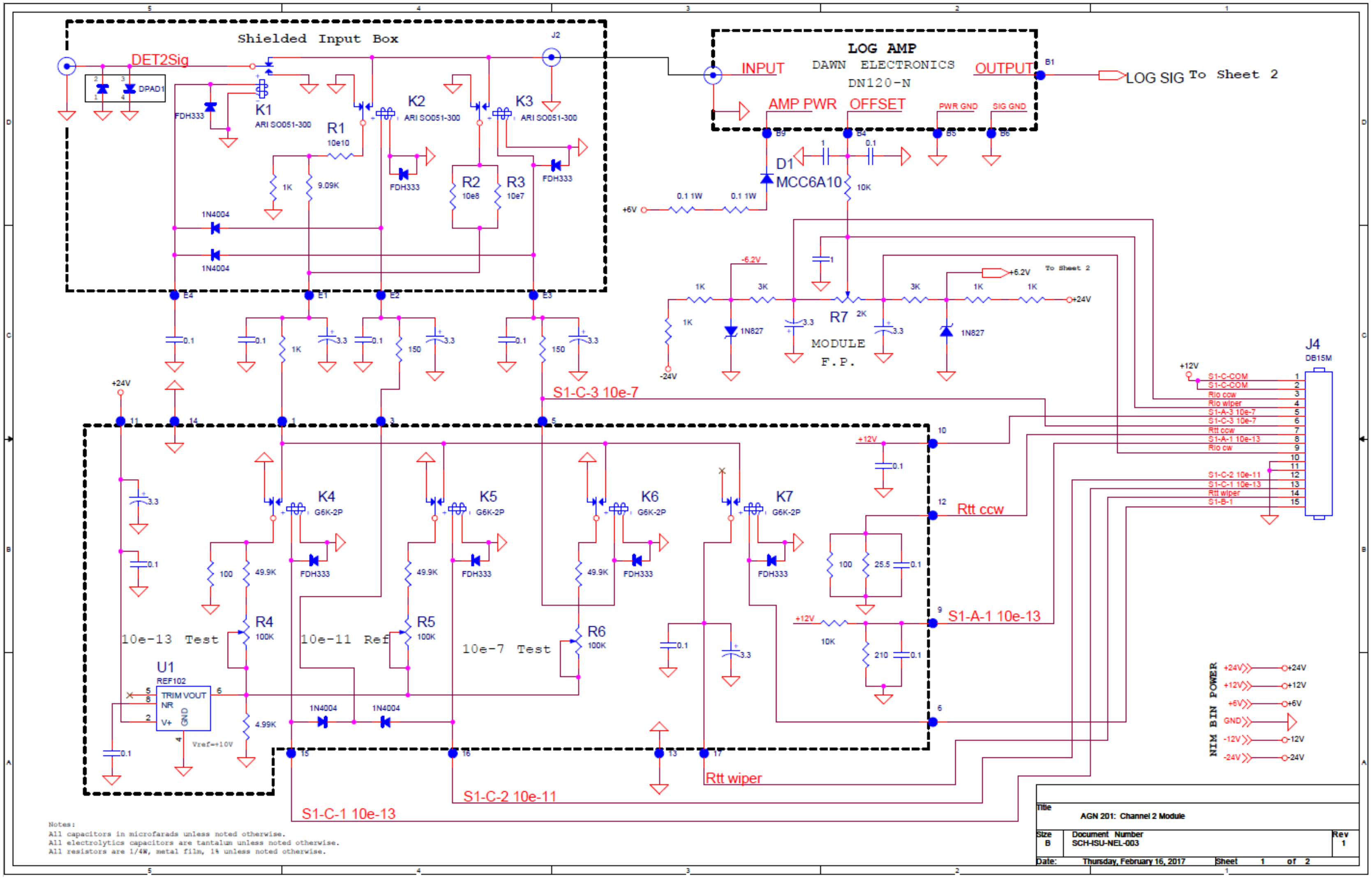

Figure 3.2 Channel 2 Module Schematic

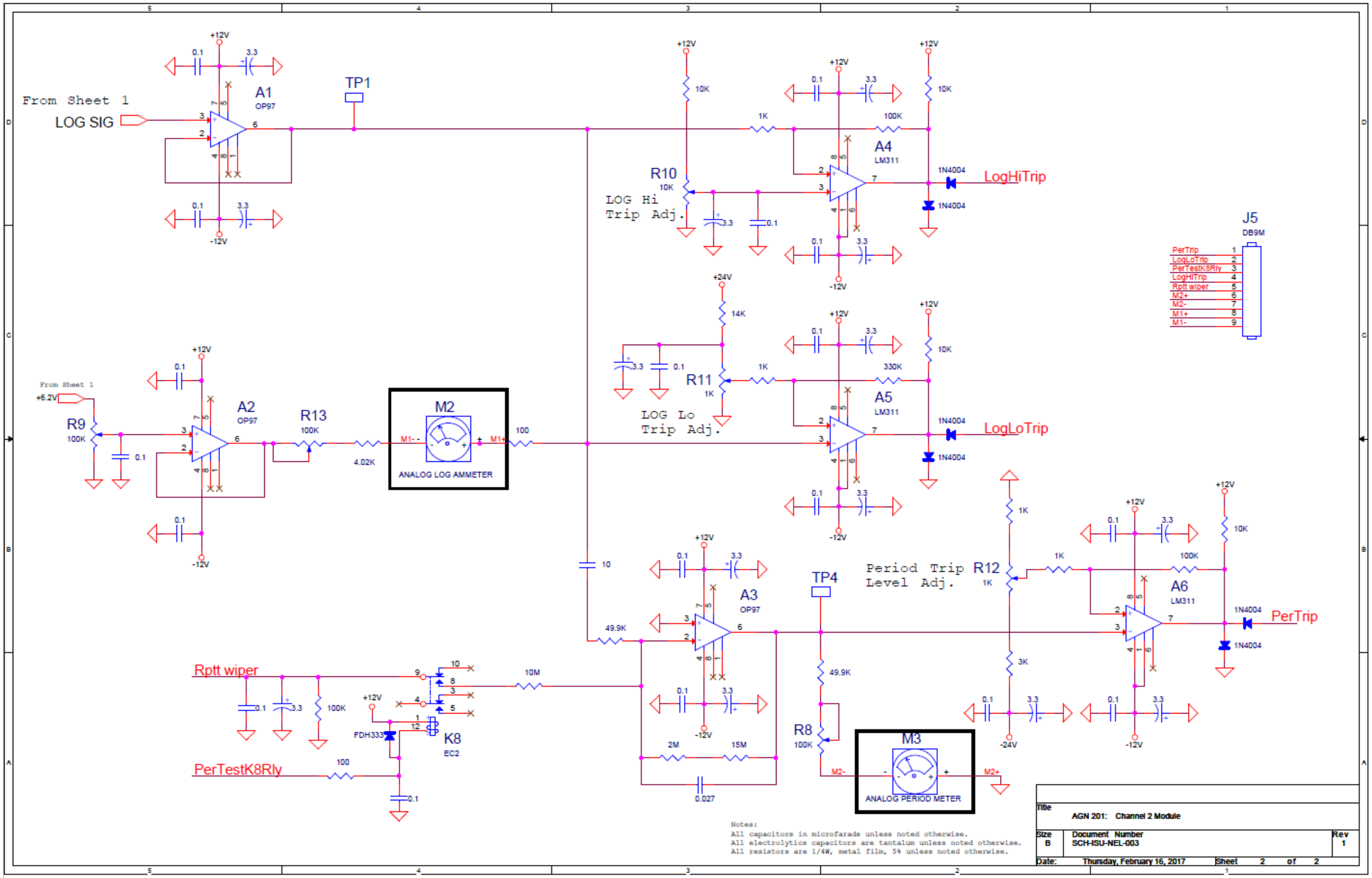

Figure 3.2 Channel 2 Module Schematic

The period is measured by a differentiating amplifier which drives both the period meter and the period trip circuit. The period meter (M3) measures both positive and negative values of period as power levels fluctuate. The period trip point is adjustable via potentiometer R12.

3.2.1 Logarithmic Amplifier

The logarithmic amplifier is a commercially built component mounted in the Channel 2 module. The logarithmic amplifier is powered from the NIM bin +6 VDC supply via two 0.1 ohm resistors in series with a MCC6A10 diode, (D1). This set-up serves as a voltage divider that drops the +6 VDC power to +5 VDC +/- 0.25 VDC as required by the logarithmic amplifier component. The logarithmic amplifier has an internal oven that maintains temperature stability holding the components internal circuitry at a constant temperature. Without this temperature stability, drift (especially in the 10^{-12} and 10^{-13} ranges) becomes more apparent. As many as 1.5 amperes may be required to power the module if ambient temperatures are low. Because so much current is required by this component, it is powered specifically from the NIM Bins + 6 VDC power supply, and this output connection is only used for the logarithmic amplifier component.

The logarithmic amplifier has some minor drift in the range between 10^{-13} and 10^{-12}. The drift fluctuates every time that the Channel 2 module is powered on, which occurs every time the reactor is energized for operation. To offset this drift potentiometer Rio2 (located on the console front panel) is used during the pre-operational check. The external Rio2 potentiometer parallels a coarse adjustment potentiometer R7, which is located on the front panel of the Channel 2 module. R7 will be calibrated on an annual basis.

The logarithmic amplifier output is buffered by the operational amplifier A1, which is configured as a unity gain buffer. The output of buffer amplifier A1 drives A4 and A5. A4 is the comparator responsible for the high trip of Channel 2 and this trip point can be adjusted by accessing the R10 potentiometer. The A5 comparator drives the low trip and can be adjusted by accessing the R11 potentiometer. A1 also drives the differentiating amplifier A3 which determines reactor period, and the log scale meter M2. A3, in conjunction with feedback elements C1, R14, and R15, develops the output voltage that is proportional to period. The output of A3 drive period meter M3 and the period trip comparator A6.

Amplifier A2 is configured as a unity gain buffer whose output is nominally set at +1 VDC by potentiometer R9. The output voltage of A2 is applied to the negative terminal of the logarithmic meter to cancel the +1 volt offset that exists at the output of the logarithmic amplifier component. This +1 volt offset exists because the logarithmic amplifier has a zero output for an input current of 10^{-15} amperes, and a log response of 0.5V per decade. Thus, the logarithmic amplifiers output voltage for 10^{-13} amperes input is +1 VDC.

3.2.2 Logarithmic Test Circuitry

During normal operation, the current from the ionization chamber drives the logarithmic amplifier via the normally closed contacts of relay K1. In addition, the normally open contacts of relays K2 and K3 are connected to the logarithmic amplifier input. Relays K2 and K3 are de-energized when the console is in normal operation. These relays only become energized during the pre-operational checks, where the channels calibration and trip points are tested on 3 separate values of current.

Relays K1, K2, & K3 at the input stage of the module have been selected for their high-degree of isolation to ensure that no leakage current is introduced to the signal path. This isolation is absolutely essential given the small currents associated with the ionization chamber (i.e. 10^{-13},10^{-12}, etc.). To increase isolation from other stages of the Channel 2 module these relays are placed in a shielded compartment that is only accessed by the input BNC connector of the module, the input connection of the logarithmic amplifier, and filtered feedthrough terminals through which test currents may be generated. These filtered feedthrough terminals provide a means of carrying a signal through the enclosure without compromising its shielding properties.

Relays K1, K2, and K3 work in conjunction with the Mode switch S1, located on the front operator panel of the console, and also in conjunction with relays K4, K5, K6, and K7 to develop channel test signals through potentiometers R1 or R2/R3 to verify logarithmic amplifier function and the high and low trip points. Relays K4, K5, K6, and K7 apply calibration voltages to R1 or R2/R3. These voltages are adjustable via potentiometers R4, R5, and R6, which, in turn are driven by the 10-volt reference supply U1. K7 is energized by the trip test pushbutton S2, on the front operator panel of the console, which adds a test current that may be varied by potentiometer Rtt, which is also on the console's front panel. The variable current allows the trip threshold setting to be tested. The setting of the rotary switch S1, in conjunction with potentiometers Rtt, Rptt, Rio2, and pushbutton S2 allows testing of all Channel 3 trips: high current, low current, and period. The front panel layout of Channel 2 is illustrated in Figure 3.3.

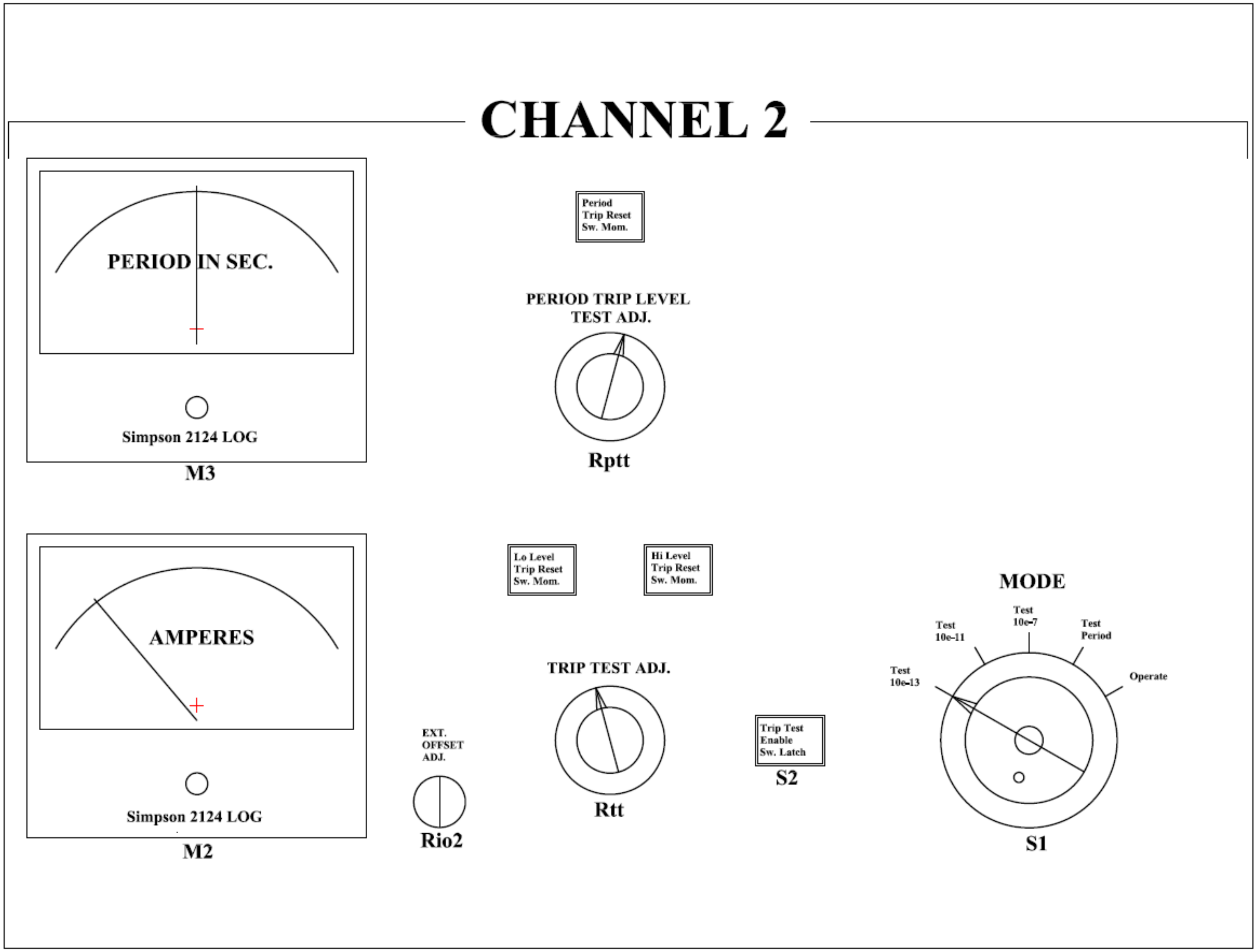

Figure 3.3 Channel 2 Console Front Panel

Switch S1 (Mode Switch) has 5 positions as illustrated in Figure 3.3. The function of each position is as follows:

3.2.2.1 10^{-13} Position

The 10^{-13} position energizes Relay K1, K2, & K4 to disconnect the ionization chamber from the input of the log amplifier and applies a test current to the log amp via relay K4 & K2. Potentiometer Rio2 provides amplifier offset current. When the front panel Trip Test Enable (pushbutton S2) is depressed, the potentiometer Rtt can be adjusted to test the low trip threshold setting.

3.2.2.2 10^{-11} Position

The 10^{-11} position applies a test current via relay K2 and K5. This current in non-adjustable. It merely serves as an independent verification of the logarithmic amplifier functionality. If the meter reads outside the range of 10^{-11}, operations will not commence until the cause is found and the problem resolved.

3.2.2.3 10^{-7} Position

The 10^{-7} position applies a test current via relay K3 and K6. This current may be adjusted via potentiometer Rtt. When pushbutton S2 is depressed, the potentiometer Rtt can be adjusted to test the high trip threshold setting.

3.2.2.4 Test Period Position

The test period position applies an input current to A3, via Rptt so that a simulated period of anywhere between a few seconds and infinity can be generated. Rptt can be adjusted to test the period trip point.

3.2.2.5 Operate Position

The operate (OPR) position locks out all test features described in 3.2.2.1, 3.2.2.2, 3.2.2.3, and 3.2.2.4. In the operate position the connection between the ionization chamber and the Channel 2 Module is made via the normally closed contact of K1.

3.2.3 Period Circuitry and Trip

The period trip circuit is comprised of comparator A6 and its associated circuitry. The trip point is readily adjusted with potentiometer R12. The comparator is driven by the differentiator circuitry, A3 and associated components. Period meter M3 is driven by A3 via a meter calibration potentiometer R8. Relay K8 connects Rptt to the period circuitry and is energized by depressing pushbutton S2 on the control console panel. Energizing K8 allows potentiometer Rptt to vary the output voltage of A3 to simulate a wide range of period when testing or setting the period trip point. Each of the potentiometer locations within the Channel 2 module are shown in Figure 3.4.

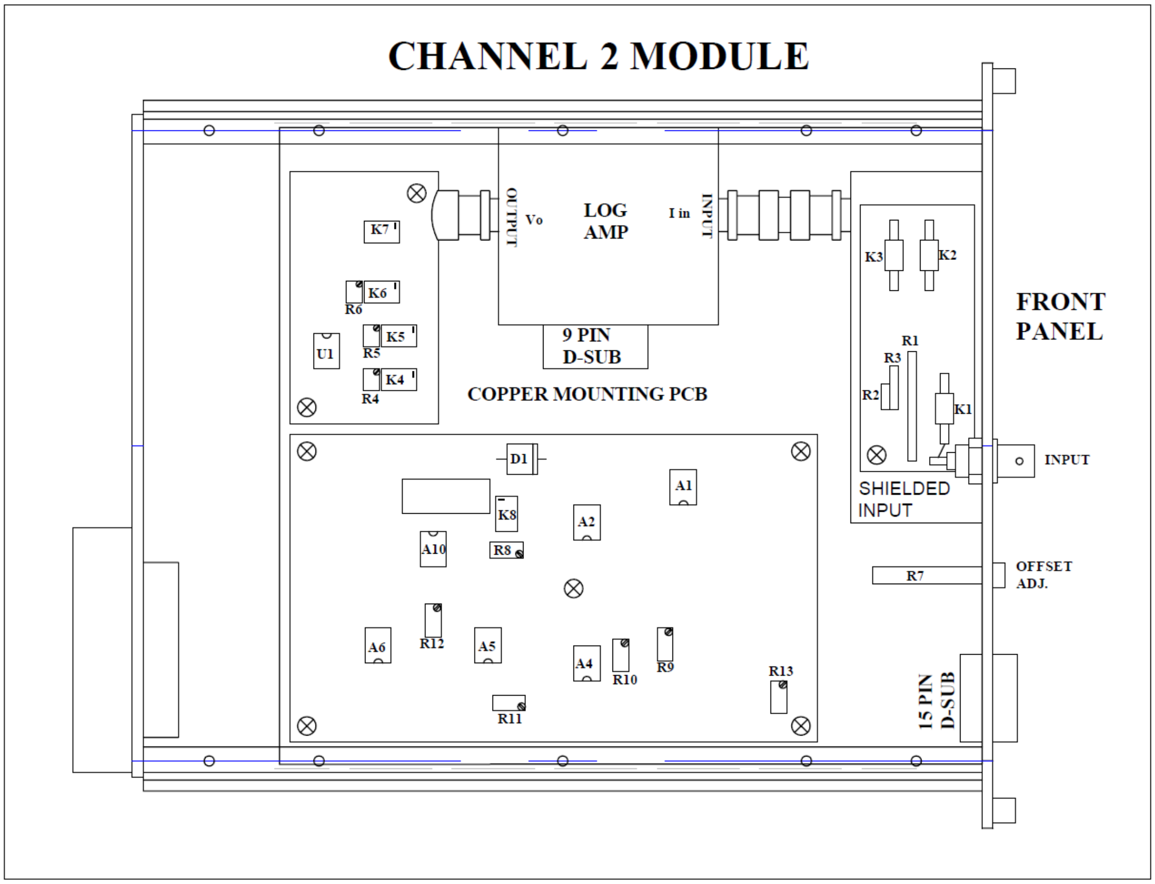

Figure 3.4 Potentiometer Locations in Channel 2 Module

4. Linear Safety Channel

4.1 Introduction

The linear safety channel system begins with the output current from ^{10}B-Lined Uncompensated Neutron Ionization Chamber near the reactor core. This detector output is fed into the Channel 3 Linear Amplifier module which in turn connects to the Channel 3 Integrator module and Range Switch Module. The linear safety channel is shown in the block diagram below Figure 4.1.

The linear safety channel serves 3 major functions as follows. (1) The safety channel provides a precise indication of the ionization chambers current reading, which is proportional to reactor power. (2) Using the results of these precise measurements, the linear safety channel calculates the integrated thermal power generated for each operation. (3) The linear channel contains both high and low trips on every range to ensure safe operations. Both the high and low trips are contained in the Channel 3 Integrator module.

The Channel 3 Integrator module contains voltage to frequency conversion circuitry capable of converting output voltage from the Channel 3 Linear Amplifier module into a pulse rate scaled for proportionality to the reactor's power level. The output pulses from the voltage to frequency converter circuitry are counted using a panel mounted digital counter (M6). In addition, the Channel 3 Integrator module buffers the output of the linear amplifier to drive a digital voltmeter (M4), analog panel meter (M5), and the chart recorder which displays and records the reactors power level.

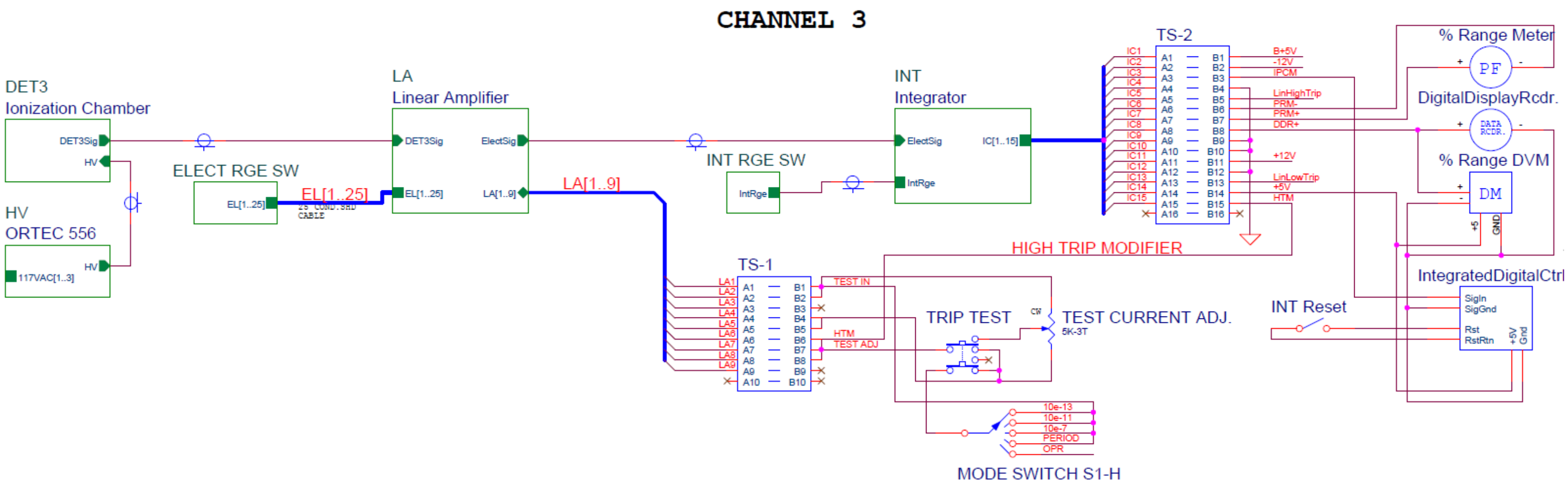

Figure 4.1 Channel 3 Block Diagram.

4.2 Channel 3 Linear Amplifier Module

The Channel 3 Linear Amplifier module is an ultra-sensitive electrometer. Its range of input currents goes from 10^{-14} amperes to $4.4*10^{-7}$ amperes. The ranges of the Channel 3 Linear Amplifier module include the following levels: 1, 3, 10, 30, 100 & 300 microWatts; 1, 3, 10, 100, & 300 milliWatts; and 1, 3, & 10-Watts. The Channel 3 Linear Amplifier module contains all the active circuitry needed to accurately measure and amplify the small signal currents from the Channel 3 ionization chamber. The Range Switch for the Channel 3 Linear Amplifier module is located on the right front panel of the control console. Figure 4.2 shows the layout of the Chanel 3 front panel including the placement of the Range Switch module.

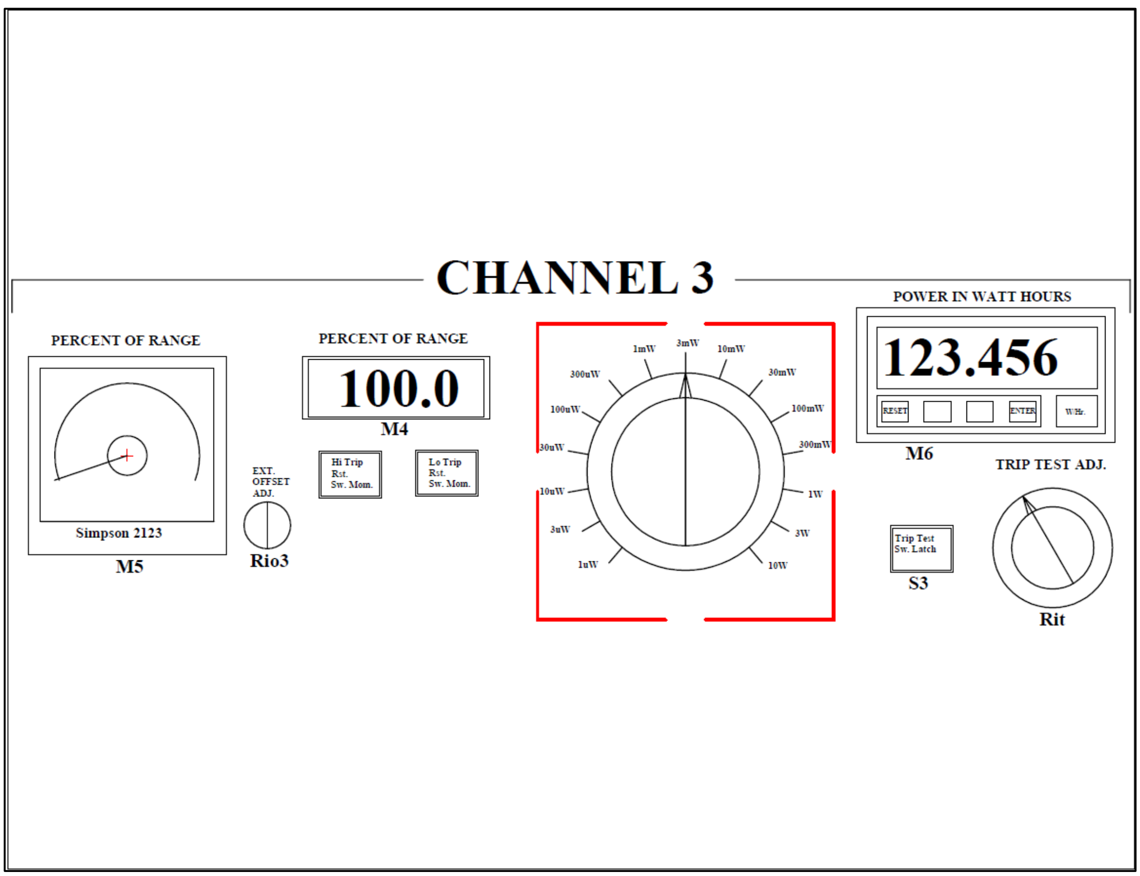

Figure 4.2 Channel 3 Front Panel Layout (Range Switch Module in Red)

Switches S1-F and S3, located on the front panel of the control console enable test currents from potentiometer Rit to be applied to the Channel 3 Linear Amplifier module to generate the required test currents for verifying trip points. Trip Test pushbutton switch S3 creates the connection between the potentiometer Rit and the Channel 3 Linear Amplifier module. S1-F energizes the test relays K3, K4, and K5 within the Channel 3 Linear Amplifier.

Each of the three major systems (Channel 3 Integrator Module, Channel 3 Linear Amplifier Module, and the Range Switch module) are connected with simple prefabricated cables. The Range Switch module is connected directly to the linear amplifier via a 25-pin D-Subminiature connector and cable. The front panel Rio3 potentiometer allows minor adjustment of the linear amplifiers offset current prior to start-up. The connection of Rio3 to the linear amplifier is made via connector JR1 on the range switch module. The Channel 3 Linear Amplifier module output connects directly to the input of the Channel 3 Integrator module via a RG-62 cable with coaxial connectors.

4.2.1 Channel 3 Linear Amplifier Module Circuitry

The Channel 3 Linear Amplifier Module schematic is shown in Figure 4.3. The input current to the Channel 3 Linear Amplifier module is fed to the input terminal of operational amplifier A1 (LMC6001A). This amplifier has a typical input offset current of less than $10*10^{-15}$ amperes at 25 degrees Celsius and is very suitable for our application, given that the minimum expected current from the ionization chamber is $100*10^{-15}$ amperes.

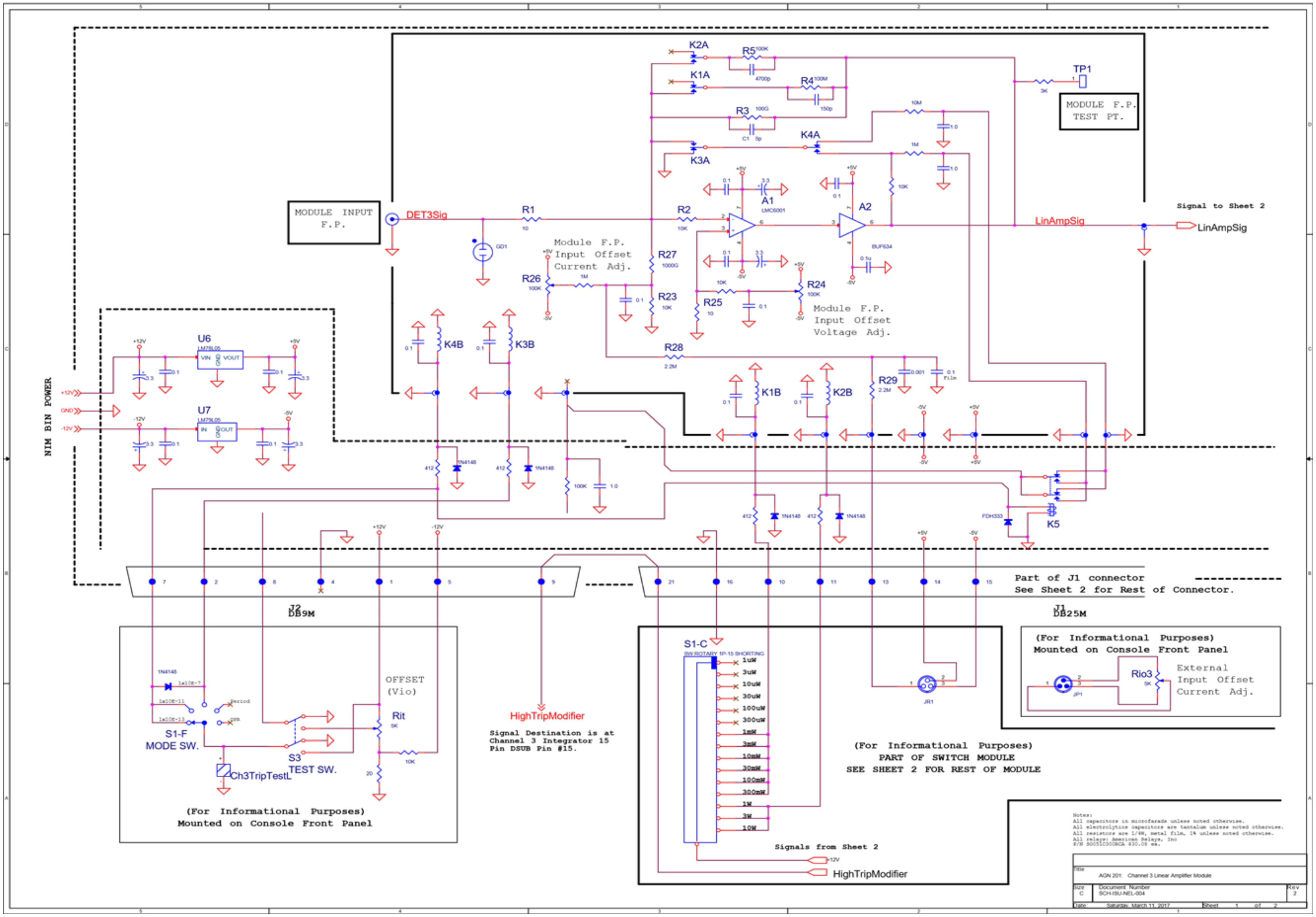

Figure 4.3 Channel 3 Linear Amplifier Module Schematic

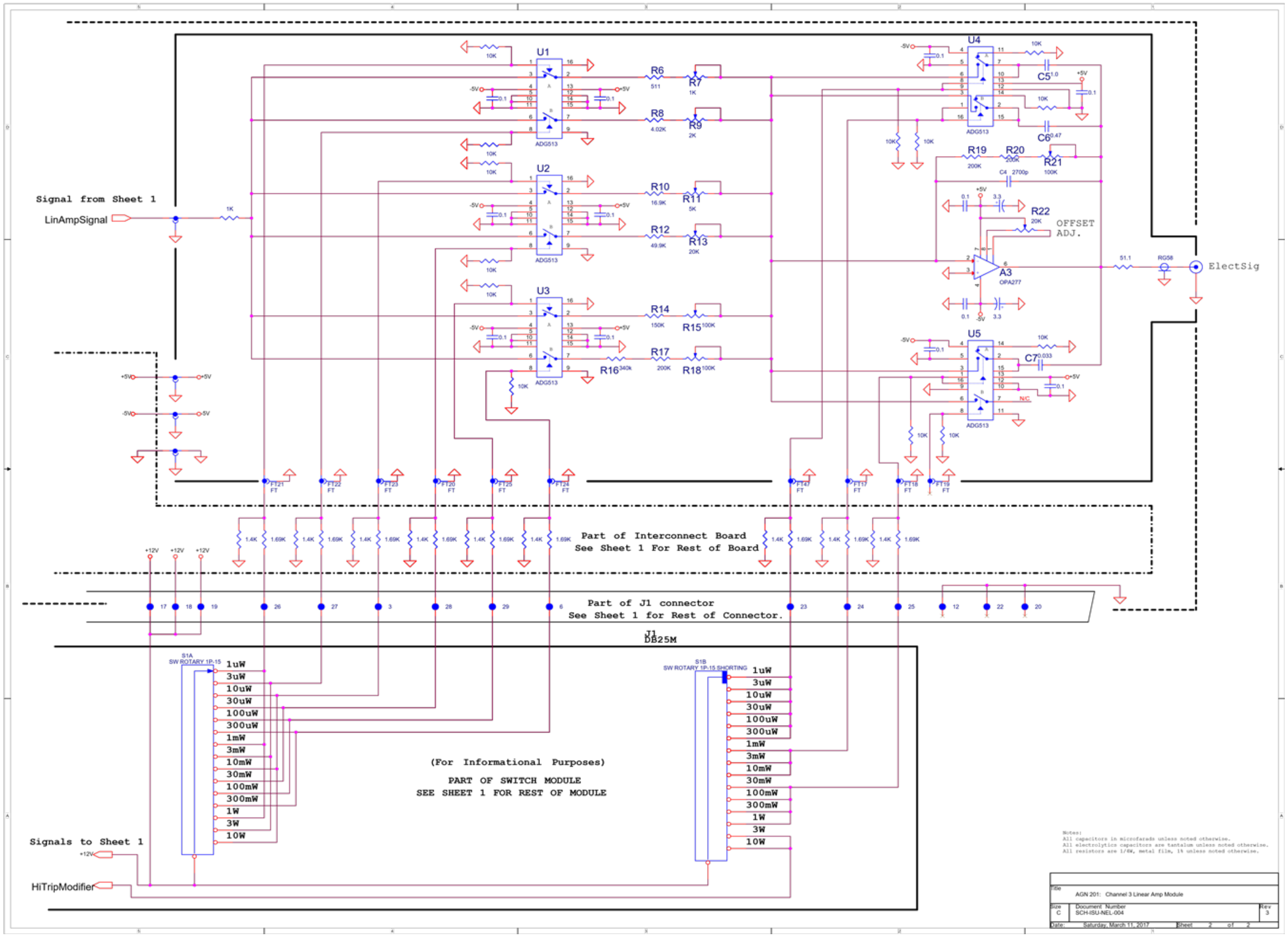

Figure 4.3 Channel 3 Linear Amplifier Module Schematic

Range switching in the input stage of the Channel 3 Linear Amplifier is accomplished using reed relays to select specific range resistors in the feedback loop of A1. The voltage developed at the output of A1 may be expressed as follows:

$$Vo(A1) = Input\ Current * Feedback\ Resistor\ Value$$

A1 is followed by A2, which is an operational amplifier which acts as a unity gain buffer used to isolate the output of A1 from loading by the external output circuitry.

It should be noted that Amplifier A1 must be protected from excessive voltage that might be developed on the cable connecting the linear amplifier to the ionization chamber, should that cable be in a charged state prior to its connection to the module. Amplifier A1 has internal diode protection on its input, however the diode current must not exceed 10 mA. Diode overcurrent protection is provided by the gas discharge surge protector GD1 connected directly between the modules input terminal and ground. This device limits the maximum voltage that can be developed on the modules input terminal to approximately 90 volts. The series resistance, (15k), provided by R2 in series with the A1 input will limit A1’s protective diode current to approximately 6 mA maximum.

The resistance values of the Channel 3 Linear Amplifier module feedback resistors R3, R4, and R5 were selected to cover the modules input current ranges. The input current ranges for each of these resistors is shown in Table 4.1.

Amplifier A1 Feedback Resistor	Reactor power Range	Corresponding Input Current in AMPERES	Output Stage Solid-State Switch Contact
R3	1 μW	4.4×10^{-14}	U1-A
R3	3 μW	1.33×10^{-13}	U1-B
R3	10 μW	4.4×10^{-13}	U2-A
R3	30 μW	1.33×10^{-12}	U2-B
R3	100 μW	4.4×10^{-12}	U3-A
R3	300 μW	1.33×10^{-11}	U3-B
R4	1 mW	4.4×10^{-11}	U1-A
R4	3 mW	1.33×10^{-10}	U1-B
R4	10 mW	4.4×10^{-10}	U2-A
R4	30 mW	1.33×10^{-9}	U2-B
R4	100 mW	4.4×10^{-9}	U3-A
R4	300 mW	1.33×10^{-8}	U3-B
R5	1 W	4.4×10^{-8}	U1-A
R5	3 W	1.33×10^{-7}	U1-B
R5	10 W	4.4×10^{-7}	U2-A

Table 4.1 Reactor Power Range V. Current Range

The input stage of the linear amplifier (A1 / A2), is followed by amplifier A3 which is connected to the following feedback elements: R6 – R21, & C4 - C7. Each of these feedback elements are selected by the solid-state switches U1-U5. Each of these switches are used with the feedback elements to determine the Channel 3 Linear Amplifiers overall gain and time response for the selected range. The calculated time response of each of the power ranges is shown in Table 4.2.

Reactor power Range	Corresponding Time Constant in MILLISECONDS
1 uW	510
3 uW	510
10 uW	510
30 uW	510
100 uW	510
300 uW	510
1 mW	450
3 mW	450
10 mW	450
30 mW	21
100 mW	21
300 mW	21
1 W	21
3 W	1.31
10 W	1.1

Table 4.2 Reactor Power Range V. Response Time

Each of these time constants are capable of providing a sufficiently fast response time for its corresponding power range. R21 provides the means to calibrate the overall gain of the linear amplifier to match power levels to the output current given off by the Channel 3 ionization chamber.

A3 is an operational amplifier and as such it has an input offset voltage. To negate this offset voltage potentiometer R22 is used. To cancel the input offset current of A1 potentiometer R26 is used in conjunction with R23 and R27. To cancel the input offset voltage of A1 potentiometer R24 is used in conjunction with R25. The potentiometers R24 and R26 are located on the front panel of the Channel 3 Linear Amplifier module. The front panel of the Channel 3 Linear Amplifier module is shown in Figure 4.4.

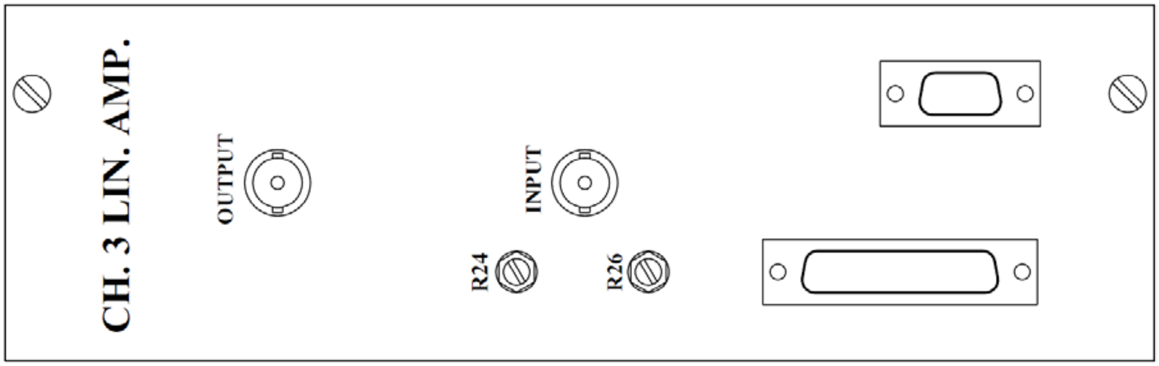

Figure 4.4 Front Panel of Channel 3 Linear Amplifier Module

In order to externally adjust the current offset, resistors R28 and R29 are used. The series connection of these resistors terminates on the wiper of potentiometer Rio3 which is mounted on the console front panel as shown in Figure 4.2 (External Offset Adjust). Access to potentiometer Rio3 is made by way of JR1, which is mounted on the Range Switch Module This connects to the Channel 3 Linear Amplifier module via its 25 pin connector.

The contacts of reed relay K3 provide a path to inject the test currents directly into the input of amplifier A1 as a means to test the Channel 3 Linear Amplifier modules function and associated high and low trips. Test current is generated by placing the front panel mode switch to the 10^{-7} position, then depressing the front panel mounted test pushbutton S3. The test current is then adjusted via potentiometer Rit to any value between 10^{-8} and 10^{-6} amperes. Even though Rit is a ten turn pot, it's resolution is still much too coarse to simulate currents responding to reactor power levels below 100 milliWatts. To increase resolution on the bottommost ranges, relay K4 and K5 are actuated along with K3 at ranges below 100 milliWatts (10, 3, 1 milliWatt, 10, 3, 1 microWatt) by placing the mode switch S1-F to its 10^{-13} or 10^{-11} position. Either of these two positions reconfigure the input amplifier, (A1, A2), as a voltage follower whose output voltage is independent of input current but proportional to the setting of Rit.

The Channel 3 Linear Amplifier module is powered directly by the NIM bin +12 and -12 volt supplies. The +12-volt supply is used to actuate relays K1 through K5. This supply also provides input voltage for the +5-volt regulator U6, and for the front panel potentiometer Rit. The -12-volt supply is used to provide input voltage for the -5-volt regulator U7, and used to develop a small negative offset bias for potentiometer Rit. Amplifiers A1, A2, and A3 and their associated offset and null circuitry are powered by the outputs of voltage regulators U6 and U7. The potentiometer locations for the Channel 3 Linear Amplifier module are shown in Figure 4.5

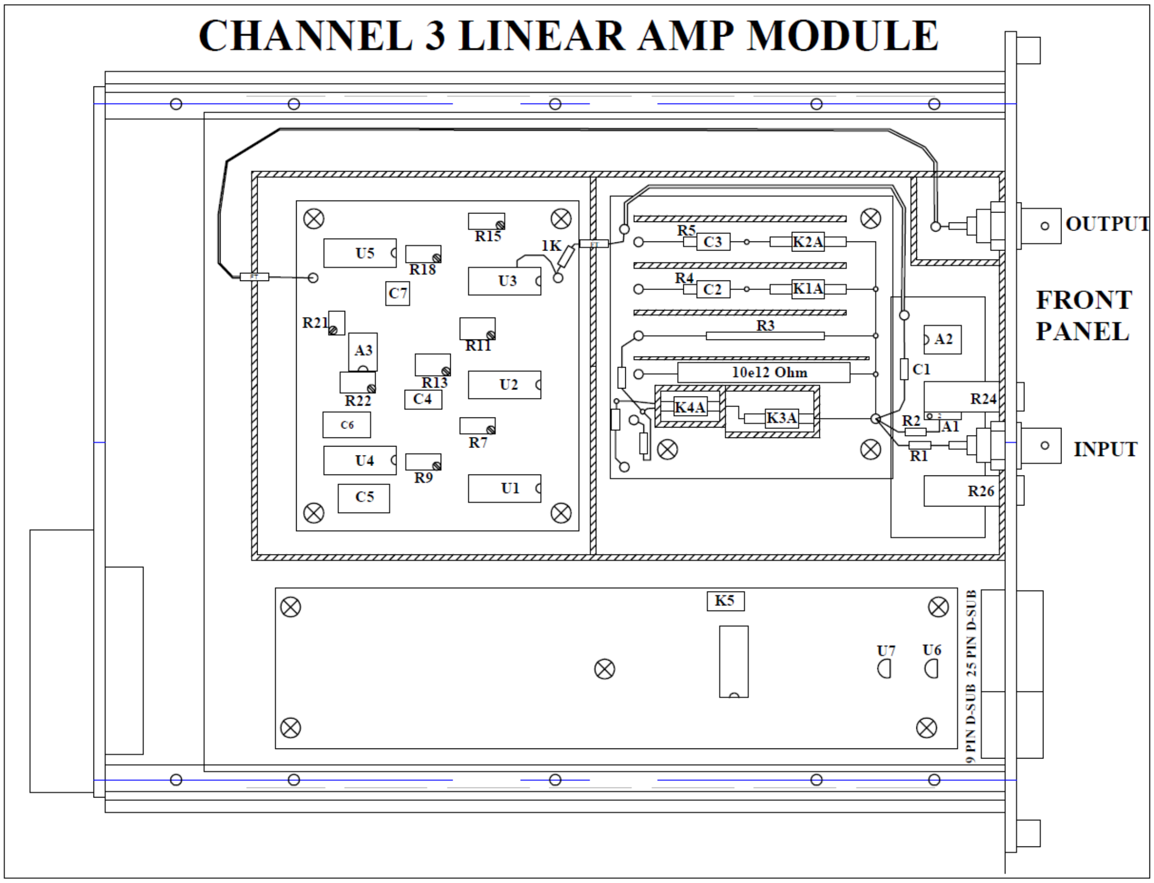

Figure 4.5 Potentiometer Locations for Channel 3 Linear Amplifier

4.3 Range Switch Module

The Range Switch module provides the range switches used by the Channel 3 Linear Amplifier module and the voltage to frequency converter circuitry located in the Channel 3 Integrator module. The range switch contains 4 individual wafers (S1-A, S1-B, S1-C, and S1-D) all mounted on a single switch shaft with a 15 position detent. One 15 pin make-before-break switch wafer, (S1-C), and one break-before-make switch wafer, (S1-A), are used to select the desired power range of the Linear Amplifier module. S1-C is used to enable the gain selecting reed relays and S1-A enables the solid state switches of IC's U1, U2, and U3. The 15 pin make-before-break switch wafer (S1-B) is used to enable the solid state switches in U4 and U5 that determine the linear amplifiers response time. The associated range resistors of the integrator circuitry are mounted on wafer S1-D.

There is one switch contact within the Range Switch module used to lower the linear high trip level when the 10-Watt range is selected. The high level trip is lowered to 6-Watts on the 10-Watt range to meet the standards set forward in the facility documentation. This lowering is accomplished by activating relay K5 inside the Channel 3 Integrator module which lowers the high level trip from 95% to 60% when the Range Switch is on the 10-Watt range.

4.4 Channel 3 Integrator Module

The Channel 3 Integrator module is driven directly by the output of the Channel 3 Linear Amplifier module. The Channel 3 Integrator module provides the integration circuitry, the output metering circuitry, and trip level circuits that are driven by the output of the Channel 3 Linear Amplifier module.

4.4.1 Channel 3 Integrator Module Circuitry

The Channel 3 Integrator module circuit diagram is shown in Figure 4.6. The input signal to the Channel 3 Integrator module is buffered by operational amplifier A1, which is configured as a unity gain buffer. Potentiometer R1 adjusts the output offset of A1 to zero VDC when the input to the module is shorted to ground. The output of A1 drives the external panel meters, the strip chart recorder, the high and low level trip circuits and the input to the power integrator circuit. The inputs to the integrator, panel mounted digital voltmeter (M4), and the strip chart recorder are driven directly, whereas the panel mounted analog meter (M5) is driven via two potentiometers. Potentiometer R2 is a meter span adjustment and potentiometer R3 is a meter zero adjustment.

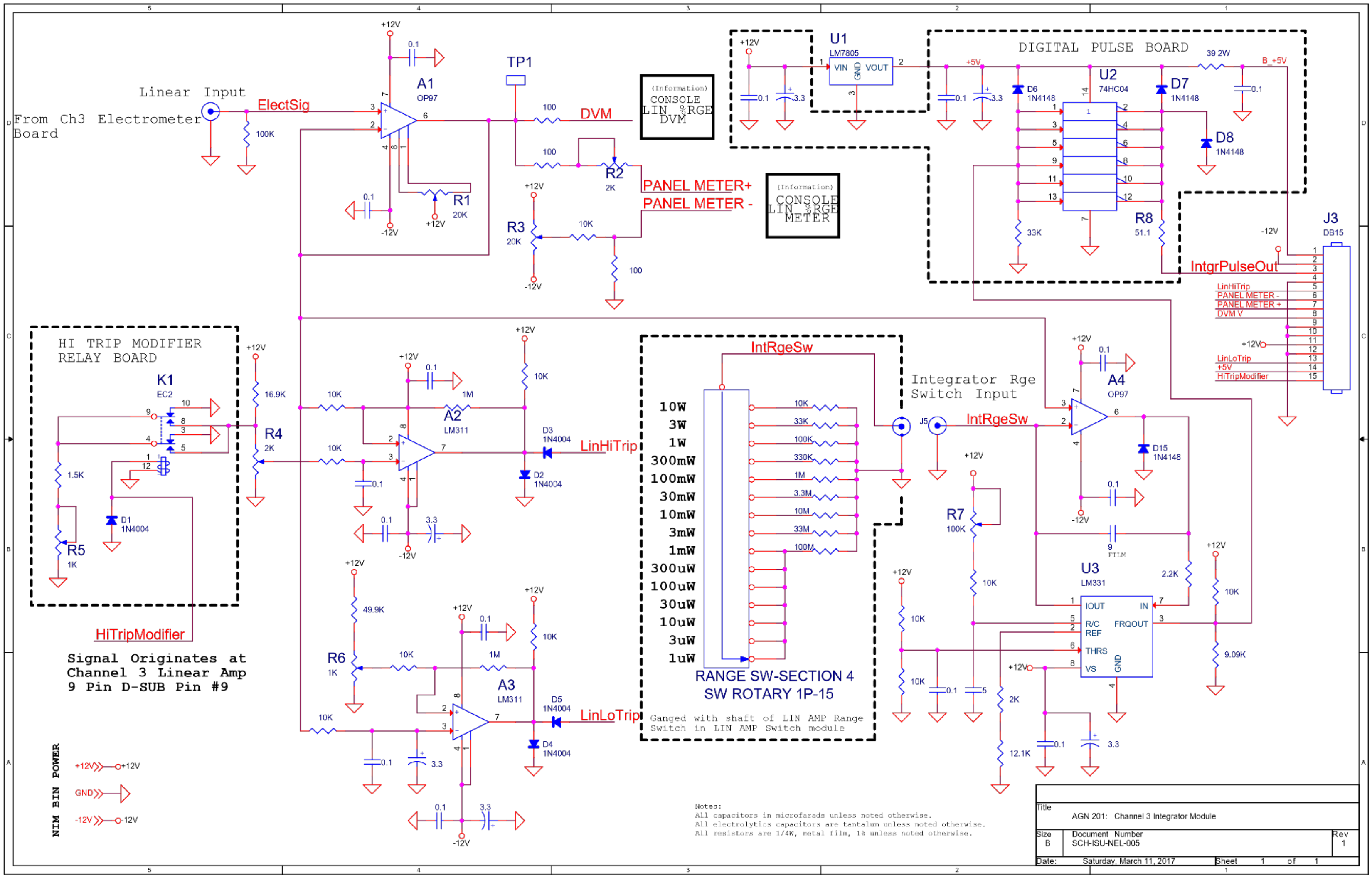

Figure 4.6 Channel 3 Integrator Module Schematic

A3 and its associated components make up the low level trip circuit. The trip point of this circuit is adjusted via Potentiometer R6. A2 and its associated components comprise the high level trip circuit. Two different potentiometers are associated with the high level trip circuit. Potentiometer R4 is used on all ranges except the 10-Watt range. This potentiometer is nominally set to initiate a trip at 95% on those ranges. On the 10-Watt range, potentiometer R5 is paralleled with potentiometer R4 via the contacts of realy K1, which is enabled by the Range Switch module at its 10-Watt setting. R5 is adjusted to lower the trip on this range to 60% of full scale.

A4 and U3 and their associated components comprise the power integration circuit. This circuitry is essentially a voltage to frequency converter whose output pulse frequency is proportional to the magnitude of the Channel 3 Linear Amplifier module output voltage, scaled by an appropriately sized resistor selected by the integrators range switch S1-D in the Range Switch module. Potentiometer R7 is adjusted to calibrate the voltage to frequency converter. The location of all potentiometers for the Channel 3 Integrator module is shown in Figure 4.7.

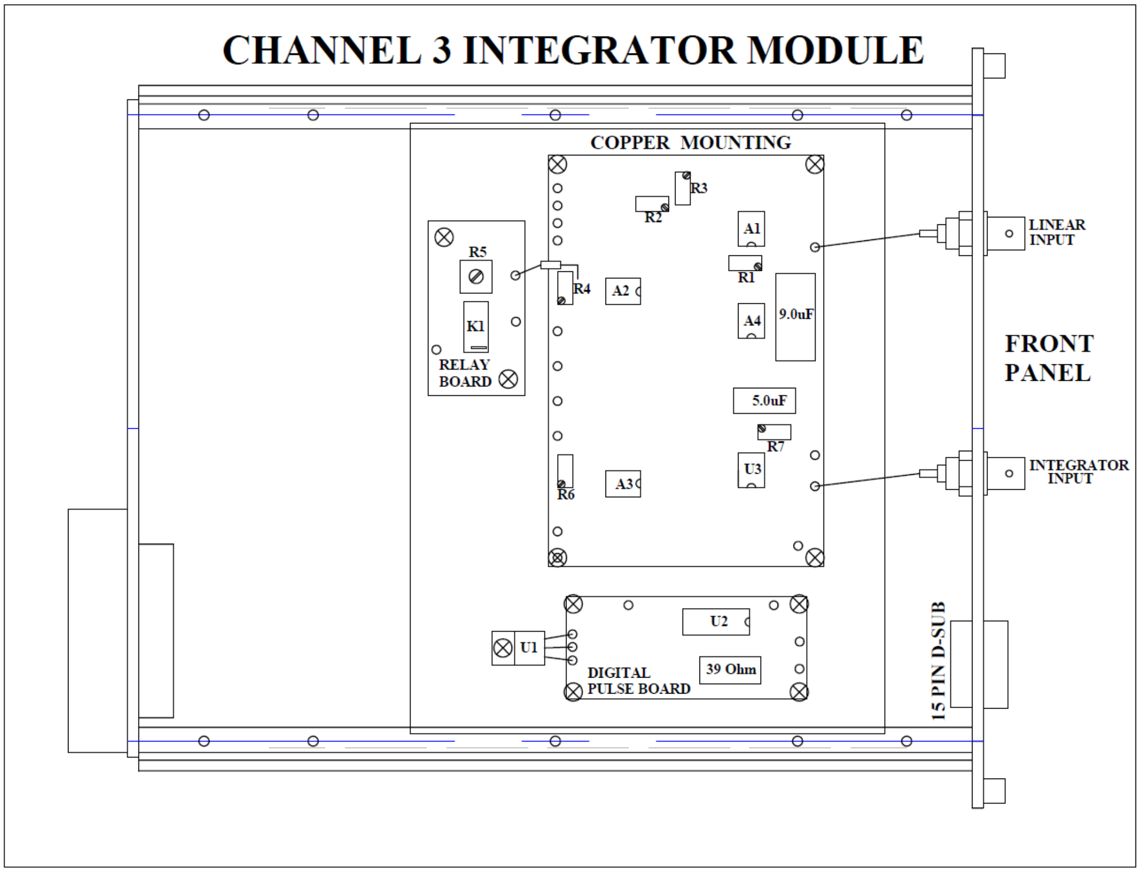

Figure 4.7 Potentiometer Locations in Channel 3 Integrator Module

The integrator output pulse amplitude is TTL compatible and drives the paralleled inputs of U2, (a 74HC04 CMOS Hex inverter). The paralleled outputs of U2, (in series with R8, and protected by diodes D7 and D8), drives the external panel mounted digital counter (M6).

U1 is a +5-volt regulator powered from the + 12-volt NIM BIN supply. The +5-volt output of U1 is also routed to J3, pin1, in the event that an external +5-volt logic level might have application relative to use of an external counter or digital voltmeter.

5. Future Work

5.1 Introduction

The AGN-201m has operated for over 50 years at Idaho State University. With new electronic technologies entering the market daily and a decrease in vacuum tube availability there was an imperative need to replace the original AGN-201m console with one using solid-state technology. The new safety channels were made to emulate the function of the original circuits with a focus on improving key characteristics. The upgraded safety channels 1, 2, and 3 provide numerous improvements. With improved response times each of the safety channels can provide a trip to scram the reactor quickly enough to meet all NRC standards, and the Technical Specifications requirements for the AGN-201. Several separate systems have been added within the modules and to the front panel of each of the channels. These new systems will ease operations, improve safety and reliability, and gather more information than the original system is able to. The improved signal processing has led to benefits in uncertainty quantification and analysis for each of the safety channels.

The new safety channels are only a part of the new control console for the AGN-201m. With the upgraded safety channels the options for other new systems within the console has expanded. This future work can take place on both the reactor body and reactor control console. Notable future work is expected to include improvements to the rod position circuitry and replacement of the original relay chassis within the current AGN-201 control console.

5.2 Rod Position Circuitry

The rod position circuitry currently in use is a series of connections beginning at the control rod drive assembly within the reactor body and continuing into the reactor control console. The position circuitry is responsible for indication of position for the four safety control rods. These four safety rods are the Coarse Control Rod (CCR), Fine Control Rod (FCR), Safety Rod #1, and Safety Rod #2. Safety Rod #1 and Safety Rod #2 only have position indicators for when the control rod is fully inserted or fully removed. These positions indicators are driven by micro-switches which attach to the magnet on the control rod drive. The control rod drive assembly (with micro-switch locations highlighted in yellow) is shown in Figure 5.1.

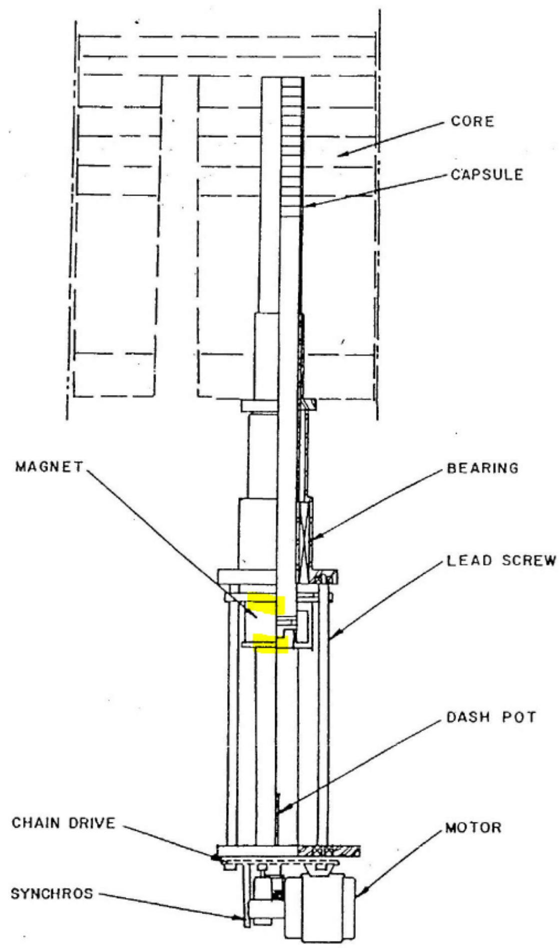

Figure 5.1. Control Rod Drive Assembly

The CCR and the FCR include these micro-switches to indicate “up” or “down” just as Safety Rod #1 and Safety Rod #2 do. In addition to these micro-switches, the definitive position of the CCR and FCR is determined via lead screws, a reversible DC motor, and synchronous generators. Each of these systems work together to drive two independent rod position indicators. This system has worked adequately, but various drawbacks both within the individual components and of the entire system have led to ideas for a replacement.

The replacement system will consist of several subsystems designed to work in harmony with the control rod drive assembly. An absolute multi-turn encoder connected to the control rod drive assemblies of the Coarse Control Rod and the Fine Control Rod will measure the turns of the lead screw. This data will be sent to a microprocessor which will convert the number of rotations to the exact vertical position of the control rods. This microprocessor system will be responsible for continuously plotting the information provided by the encoder both in the positive (as the rod is inserted into the core) and negative (as the rod is with-drawn from the core) positions.

5.3 Relay Chassis Replacement

The original relay chassis is shown in Figure 5.2. This module is responsible for various functions as they relate to drive logic and drive positions. This relay chassis specifically is responsible for the reverse drive logic of the rod motors in the event of a scram. If any of the trip points are violated, then the reactor will be placed into a scram condition. When this happens the current will be cut to each of the control rod drive magnets and the fuel rods will be ejected from the core quickly. As soon as the magnet connection is broken a component within the relay chassis will energize. This component connection will reverse the DC motors causing each of the control rod drive magnets to proceed to the fully “out” position.

Figure 5.2 Relay Chassis Physical Layout

A simple replacement for this system will include updated relays and new wiring. The current relays are either open-faced (no protection of contacts) or no longer made. Open-faced relays have no coverage over their contacts which can cause electrical malfunctions if the relays become covered in dust or other residue. The other relays are near impossible to find for replacement. The wiring of this system is overly complex (with several modifications made over the decades), and the connector types are non-standard which makes them difficult to work with. New wiring and new contacts will simplify the system and reduce any risk associated with outdated technology. Both of these improvements will decrease the size of the module and reduce the possibility for compatibility problems between the new safety channels and the control rod drive assemblies.

5.4 Control Console Body

The current control console body is effectively built to house all the components necessary. With the creation of new safety channels, it has become clear that a new control console body will have to be made. However, a spare control console exists. It contains no circuitry as shown in the Figure 5.3.

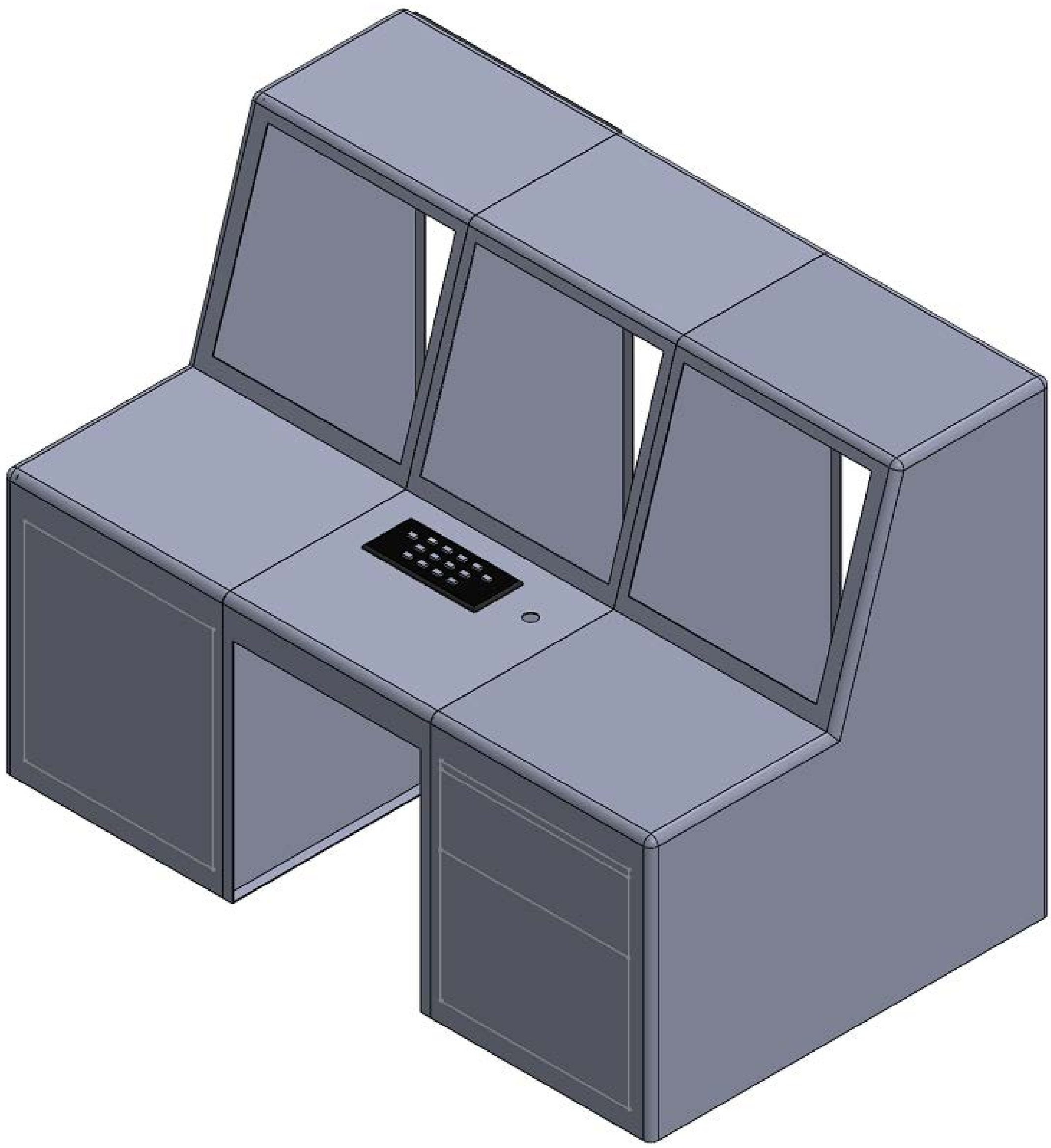

Figure 5.3 Control Console Model

This control console has adequate space for each of the new safety channels with additional space available for any other safety systems which may be put into place. In fact, the new safety channels can currently fit in a standard NIM bin with additional space available for any other modules. The position of each of the new safety channels within a standard NIM bin is shown in Figure 5.4.

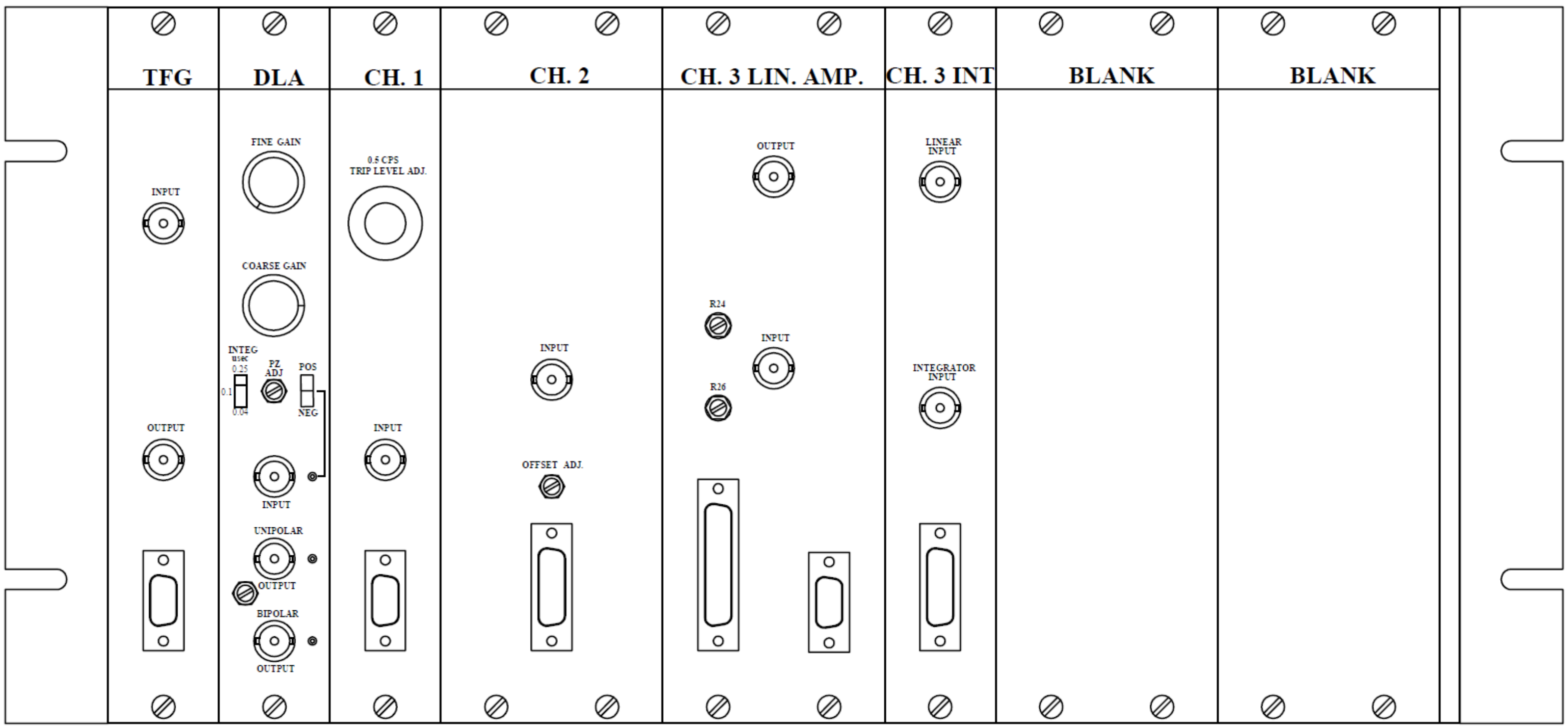

Figure 5.4. NIM BIN Safety Channel Position / Front Panels

6. Conclusions

The appropriate mating of several systems within the new AGN-201m reactor control console is an absolute requirement for safe and effective operation. The continued use of parts that are no longer commercially available has made repairs of the current safety channels difficult and costly. The safety channels outlined in this thesis serve as the primary system for signal processing, reactor condition monitoring, and as the first link in the scram protection system. The creation of these channels yield several benefits over the current safety systems. Improved component reliability and the elimination of obsolete parts are two major benefits associated with this upgrade. Each of the components used within these safety channels are commercially available and each component manufacturer has stringent quality assurance measures in place. The design and implementation of the new safety channels within the AGN-201m lends itself to the overall creation of a more effective nuclear reactor control console.

Appendix A

CHANNEL 1 MODULE CALIBRATION PROCEDURE

A. Logarithmic Amplifier Calibration

1. Extend and power-up the module.
2. Verify that all input signal cables are in place and that the Ortec 460 Delay Line Amplifier gain and pulse shaping controls are properly set.
3. Disconnect the preamplifier output from the input to the Test Frequency Generator module.
4. Connect the output of a tail pulse generator, (Berkley Nucleonics or equivalent), to the modules input.
5. Configure the pulse generators output for a fast rising positive pulse, (0.1 microsecond or faster), and 100 microsecond tail.
6. Set the generator frequency to 1000 pulses/sec as verified with an oscilloscope. Set the pulse height from the generator so that the peak pulse height from the delay line amplifier is approximately 5 volts.
7. Adjust potentiometer R7 until the consoles meter M1 indicates 1,000 CPS.
8. Depress the console 0.5 CPS test pushbutton. Allow 30 seconds for the channel 1 logarithmic circuitry to settle, then adjust potentiometer R8 until the channel 1 panel meter indicates 0.5 CPS.
9. Repeat steps 3 through 5 until the meter indicates correctly for both the 0.5 and 1000 CPS count rates.

B. Trip Level Calibration

1. Set the Channel 1 module front panel potentiometer to its 0.5 position.
2. Depress the console panel 0.5 CPS pushbutton. Allow 30 seconds settling time.
3. Adjust potentiometer R6 in the direction that causes the 0.5 CPS trip relay to drop out, then adjust the potentiometer until the 0.5 CPS trip relay to pick up.
4. Very slowly adjust R6 in the direction to cause a trip, stopping adjustment at the point where trip occurs.
5. Verify the trip point by releasing the 0.5 CPS push button momentarily, then depressing it again so that the modules output again approaches the trip level. Repeat as necessary with fine adjustment of R6 until the trip point is accurately set, then release the 0.5 CPS pushbutton.

C. 60 CPS Check

1. Depress the 60CPS pushbutton. The modules Channel 1 count rate meter should indicate 60 pps +/- 5%.

CHANNEL 1 TEST FREQUENCY GENERATOR CALIBRATION PROCEDURE

A. **Calibrating 0.5 and 60 Hz generators.**
    1. Extend and power up the module. (Refer to the modules circuit board layout drawing to identify adjustment potentiometers and test points)
    2. Configure a counter to measure period to an accuracy of 0.1 msec.
    3. Connect the counters input to the modules test point #1 on the modules circuit board. Connect the counters ground to the modules circuit board ground.
    4. Adjust R1 for a measured period of 2.000 +/- 0.001 seconds.
    5. Connect the counters input to test point #2 on the modules circuit board.
    6. Configure the counter to measure period to an accuracy of 0.001 msec.
    7. Adjust R2 for a measured period of 16.666 +/- 0.001 msec.

B. **Adjusting pulse amplitude and shape.**
    1. DC couple an oscilloscope to the modules OUTPUT connector. Depress the 60 CPS pushbutton on the consoles front panel. Observe a positive going tail pulse with a 60 PPS repletion rate.
    2. Adjust R4 for a pulse amplitude of 2 Volts peak.
    3. Adjust R3 until the decay rate of the tail of the pulses is approximately the same as those from the preamplifier.
    4. Adjust R5 until the output pulses decay to 0 volts +/- 10.0 mvolt.
    5. Depress the 0.5 CPS pushbutton on the consoles front panel. Observe a positive going tail pulse with a 0.5 PPS repletion rate.

CHANNEL 2 MODULE CALIBRATION PROCEDURE

A. Verify the functionality and accuracy of the ThermOptics DN120-N Logarithmic Amplifier.

1. Extend and power-up the Channel 2 module. Allow the module to warm-up for at least 30 minutes prior performing the following procedures.
2. Connect a digital voltmeter (DVM), (Fluke 8060A or equivalent), between test point TP1 and ground. Set the DVM to measure DC voltage, (0 to 20 VDC)
3. Connect the output of a calibrated current source, (Keithley model261 or equivalent), to the Input BNC connector of the module.
4. Set the current sources output current to $1x10^{-13}$ amperes.
5. Place the console front panel MODE switch (S1) to its OPR position.
6. Adjust the console front panel EXT OFFSET ADJ (Rio2) control to its exact center position.
7. Adjust the modules Offset Adjust potentiometer, (R7), located on the modules front panel until the DVM indicates +0.500 +/- 0.001 VDC.
8. Set the current source output to $1x10^{-13}$ Amperes. The DVM should indicate +1.000 +/- 0.050 VDC.
9. Set the current source output to $1x10\text{-}^{12}$ Amperes. The DVM should indicate +1.500 +/- 0.020 VDC.
10. Set the current source output to $1x10^{-11}$ Amperes. The DVM should indicate +2.000 +/- 0.010 VDC.
11. Set the current source output to $1x10^{-10}$ Amperes. The DVM should indicate +2.500 +/- 0.010 VDC.
12. Set the current source output to $1x10^{-9}$ Amperes. The DVM should indicate +3.000 +/- 0.010 VDC.
13. Set the current source output to $1x10^{-8}$ Amperes. The DVM should indicate +3.500 +/- 0.010 VDC.
14. Set the current source output to $1x10^{-7}$ Amperes. The DVM should indicate +4.000 +/- 0.010 VDC.
15. Set the current source output to $1x10^{-6}$ Amperes. The DVM should indicate +4.500 +/- 0.010 VDC.

B. Calibrate 10^{-13}, 10^{-11} and 10^{-7} test currents.

1. Set the current source output to zero.
2. Place the console front panel MODE switch (S1) to its 10^{-13} position.
3. Adjust potentiometer R4 until the DVM indicates+1.000 +/- 0.001 VDC.
4. Depress the console front panel Channel 2 trip test pushbutton (S2) and observe that the console front panel Channel 2 trip test adjust potentiometer (Rtt) is capable of adjusting the measured voltage from a value < 1.0 VDC to > 1.5 VDC.
5. Release the pushbutton.
6. Place the console front panel MODE switch (S1) to its 10^{-11} position.
7. Adjust potentiometer R5 until the DVM indicates+2.000 +/- 0.001 VDC.

8. Place the console front panel MODE (S1) switch to its 10^{-7} position.
9. Adjust potentiometer R6 until the DVM indicates+4.000 +/- 0.001 VDC.
10. Depress the console front panel Channel 2 trip test pushbutton (S2) and observe that the console front panel Channel 2 trip test adjust potentiometer (Rtt) is capable of adjusting the measured voltage from a value < 4.0 VDC to > 4.5 VDC. Release the pushbutton.

C. Calibrate the Channel 2 console Log Scale panel meter

1. Place the console front panel MODE switch (S1) to its 10^{-13} position.
2. The DVM should indicate 1.000 +/- 0.001 VDC.
3. Adjust pot R9 until the console front panel log scale meter (M2) indicates 10^{-13}.
4. Place the console front panel MODE switch (S1) to its 10^{-7} position.
5. Adjust potentiometer R13 until the log scale panel meter (M2) indicates 10E-7.
6. Repeat steps 1 and 2 until the meter (M2) reads correctly at both currents.

D. Calibrate the Channel 2 Period meter

1. Disconnect the current source from the modules Input connector.
2. Connect the current output of the Period Calibrator to the Channel 2 modules input connector.
3. Set the RUN/RESET switch on the front panel of the Period Calibrator unit to its RESET position.
4. Place the console front panel MODE switch (S1) to its OPR position.
5. The Channel 2 front panel log scale meter (M2) should indicate approximately 10^{-9}
6. Allow the console front panel period meter (M3) to settle to infinite period
7. Set the calibrator RUN/RESET switch to its RUN position.
8. The Period meter should respond with a period indication.
9. Adjust R8 until the meter (M3) settles at 5 seconds.
10. The output signal from the Period Calibrator saturates after a run time of approximately 30 seconds; consequently, it may be necessary to cycle the calibrator through numerous reset/run cycles before the Channel 2 modules period calibration is completed.

E. Calibrate the Channel 2 Period Trip Level

1. Place the console front panel MODE switch (S1) to its PERIOD position.
2. Adjust the console front panel PERIOD TRIP LEVEL TEST ADJ. potentiometer (Rptt) until the Period Meter reads exactly 5 Seconds.
3. Adjust potentiometer R12 until a Period trip occurs, then adjust the potentiometer in the opposite direction until the Period Trip can be cleared with the console front panel Period Trip reset pushbutton.
4. Once the Period trip has been reset, slowly adjust R12 in the direction to cause a trip, stopping the adjustment at the point where the trip just occurs. Verify

the trip adjustment by increasing the period with the PERIOD TRIP LEVEL TEST control, then slowly decreasing period with that control until the period trip occurs.

F. Calibrating the HI and LO Level Trips

1. Place the console front panel MODE switch (S1) to its 10^{-7} position.
2. Depress the front panel Channel 2 Trip Test pushbutton (S2). Adjust the console Channel 2 TRIP TEST ADJ. (Rtt) control until the DVM connected at Test Point TP1 indicates 4.21 VDC, corresponding to a 6 Watt power level when the 10 Watt chamber current has been calibrated at 4.4×10^{-7} amperes.
3. Adjust the high level trip potentiometer R10 until the high level trip just occurs.
4. Place the console front panel MODE switch to its 10^{-13} position.
5. Depress the front panel Channel 2 Trip Test pushbutton (S2).
6. Adjust the console Channel 2 TRIP TEST ADJ. (Rtt)control until the DVM connected at Test Point TP1 indicates 1.24 VDC, corresponding to a chamber current of 3×10^{-13} amperes.
7. Adjust the LO level trip potentiometer R11 until the LO level trip just occurs.

CHANNEL 3 LINEAR AMPLIFIER CALIBRATION PROCEDURE

A. ZEROING THE INPUT OFFSET VOLTAGE OF OUTPUT AMPLIFIER A3.

(Note: The DVM used in this procedure should be able to resolve a near zero DC level to 0.01 mV or better.)

1. Remove the input signal cable from the input BNC connector on the front panel of the Channel 3 Linear amplifier module. Place the BNC Cap attached to the modules front panel onto the modules input BNC connector. Disconnect the coax cable from the OUTPUT BNC connector on the modules front panel.
2. Remove the module from the BIN, then remove the modules Left side cover. Place the module in an extender, then re-insert the module and extender back into the BIN slot vacated by the module. Place the console front panel MODE switch (S1) to its OPR position.
3. Remove the 4 screws from the cover of the rear enclosure. Lift the cover out of the enclosure and completely out of the way of the circuit board within the enclosure.
4. Tape the cover to the modules frame so that it remains out of the way for the duration of the following procedures. (Note: the cover is attached to the enclosure by a grounding strap. DO NOT remove this strap).
5. Allow the module to warm-up for five minutes before continuing the procedure.
6. Configure a DVM to read DC volts on its most sensitive scale. Connect the negative lead of the DVM to the terminal of the feed thru mounted on the side of the enclosure that separates the rear enclosure from the front enclosure. (Note: A 1K ohm resistor is connected to this terminal and goes directly to its termination on the circuit board).
7. Connect the positive lead of the DVM to the signal terminal of the OUTPUT BNC connector on the modules front panel.
8. Place the Linear Amplifier range switch to its 1 Watt position.
9. Adjust R22, (refer to the Linear Amplifier schematic and circuit board parts placement drawing to identify this potentiometer), until the DVM reads 0.0000 +/- 0.0001 VDC. Disconnect the DVM after the adjustment is made.

B. ZEROING THE INPUT OFFSET VOLTAGE AND CURRENT OF AMPLIFIER A1.

Note: Procedure **A** should always be performed prior to doing this procedure.

1. Verify that the Linear Amplifier range switch is in its 1 Watt position and that the console front panel mode switch is at its OPR position.

2. Adjust the console front panel Channel 3 Offset Adjust pot to its mid position. (Note: this is a 3 turn potentiometer; mid position is 1 ½ turns from either end of full rotation).
3. Verify that the coax cable normally attached to the front panel OUTPUT BNC connector is disconnected,
4. Allow the module to warm-up for 30 minutes.
5. Adjust the modules input amplifier A1 voltage offset pot R24, (located on the modules front panel and labeled with the number 1), until the DVM reads 0.0000 +/- 0.0005 VDC.
6. Place the Linear Amplifier range switch to its 30 microwatt position.
7. Adjust the modules input A1 current offset pot R26, (located on the modules front panel and labeled with the number 2), until the DVM reads 0.0000 +/- 0.0005 VDC.
8. Place the Linear Amplifier range switch to its 1 microwatt position.
9. Adjust the console front panel Channel 3 Offset Adjust potentiometer full clockwise. The DVM should read a voltage between +0.20 and +0.35 VDC
10. Adjust the console front panel Channel 3 Offset Adjust potentiometer full counter-clockwise. The DVM should indicate a voltage between -0.20 and -0.35 VDC.
11. Return the Zero Adjust control to its center position 1 ½ turns from either end of full rotation.

C. CALIBRATING THE MODULES RANGE POTENTIOMETERS R7, R9, R11, R13, R15, & R18.

Note: Procedures **A** and **B** should always be performed prior to doing this procedure**.**

1. Remove the cap from the front panel INPUT BNC connector. Connect the output of a Keithley model 261 or equivalent precision current source to the input connector using a short length of coaxial cable.
2. Set the Linear Amplifier range switch to its 1 Watt position and the output current of the current source to +4.4 x 10-8 amps.
3. Adjust R7, (refer to the Linear Amplifier schematic and circuit board parts placement drawing to identify this potentiometer), until the DVM reads 1.000 +/- 0.001 VDC.
4. Set the Linear Amplifier range switch to its 3 Watt position and the output current of the current source to +1.33 x 10-7 amps.
5. Adjust R9, (refer to the Linear Amplifier schematic and circuit board parts placement drawing to identify this potentiometer), until the DVM reads 1.000 +/- 0.001 VDC.
6. Set the Linear Amplifier range switch to its 10 Watt position and the output current of the current source to +4.4 x 10-7 amps.

7. Adjust R11, (refer to the Linear Amplifier schematic and circuit board parts placement drawing to identify this potentiometer), until the DVM reads 1.000 +/- 0.001 VDC.
8. Set the Linear Amplifier range switch to its 30 mili-watt position and the output current of the current source to +1.33 x 10-9 amps.
9. Adjust R13, (refer to the Linear Amplifier schematic and circuit board parts placement drawing to identify this potentiometer), until the DVM reads 1.000 +/- 0.001 VDC.
10. Set the Linear Amplifier range switch to its 100 mili-watt position and the output current of the current source to +4.4 x 10-9 amps.
11. Adjust R15, (refer to the Linear Amplifier schematic and circuit board parts placement drawing to identify this potentiometer), until the DVM reads 1.000 +/- 0.001 VDC.
12. Set the Linear Amplifier range switch to its 300 mili-watt position and the output current of the current source to +1.33 x 10-8 amps.
13. Adjust R18 , (refer to the Linear Amplifier schematic and circuit board parts placement drawing to identify this potentiometer), until the DVM reads 1.000 +/- 0.001 VDC.

D. GLOBAL GAIN ADJUSTMENT.

Potentiometer R21 provides a means to adjust the modules gain in a global fashion should the channels ionization chamber be replaced with a different chamber whose output current differs from the original chamber at the reactors calibration wattage. R21 allows the modules gain to be shifted up or down by approximately 10% without the need to re-adjust the values of the range pots of calibration procedure **C.** Chamber current variation greater than 10% would require a change in resistor value of R19 or R20, in which case the resistor would have to be removed and replaced with another having the new required value.

E. VERIFYING FUNCTIONALITY OF LINEAR CHANNEL TEST CURRENT CIRCUITRY.

1. Place the console front panel Mode switch to its 10-13 position.
2. Place the Channel 3 range switch to its 3 Watt position
3. Depress the front panel Channel 3 Test Current pushbutton and while holding the pushbutton depressed note that the button illuminates and that adjustment of the Channel 3 current test potentiometer on the consoles front panel varies the current indicated by the channels % of Range meter.
4. Verify that the meter indicates zero current when the test current potentiometer is full CCW.
5. Verify that the meter indicates >100% when the test current potentiometer if full CW.

6. Place the Channel 3 range switch to its 10 Watt position and depress the test current pushbutton.
7. Verify that the meter indicates zero current when the test current potentiometer is full CCW.
8. Verify that the meter indicates >100% when the test current potentiometer is full CW.
9. Verify that the measurements of steps 2 through 8 above may be repeated when the consoles front panel mode switch is at its 10-11 and 10-7 positions.

CHANNEL 3 INTEGRATOR CALIBRATION PROCEDURE

A. ZEROING THE INPUT OFFSET VOLTAGE OF INPUT AMPLIFIER A1, AND CALIBRATING THE CONSOLE MOUNTED PANEL METERS.

(Note: The DVM used in this procedure should be able to resolve a near zero DC level to 0.01 mv or better.)

1. Disconnect the coax cable from the input connector of the module, Remove the module from the NIM BIN, remove the left side cover from the module, place the module in an extender and re-insert the module and extender into the slot vacated by the module. Allow the module to warm-up for 5 minutes before proceeding with its calibration.
2. Connect a BNC 50 Ohm terminator onto the modules Input BNC connector. Connect the DVM between the terminal of the input BNC connector and Test Point 1, (TP1), at the output of A1. Adjust trimpot VR1 until the DVM indicates 0.00 +/- 0.01 mVDC.
3. Adjust the console front panel mounted Channel 3 DVM for a reading of 0.000 VDC.
4. Remove the 50 ohm terminator from the modules input and connect a coaxial cable between the output of the Channel 3 Linear Amplifier and the input of the integrator module.
5. Place the range switch of the Channel 3 linear amp module to its 3 Watt position.
6. Remove the input cable to the Channel 3 Linear amplifier module. Connect a precision current source, (Keithley 261 or equivalent), to the input of the Channel 3 Linear amp.
7. Set the current source output to zero. (The panel mount DPM should indicate 0.00 VDC.) Adjust the manual zero screw on the front of the Simpson panel meter for a zero reading on that meter.
8. Set the output of the current source to the level that generates a reading of 1.000 +/- 0.001 Vdc on the console panel mounted DPM. (The current source current will be approximately 1.33 X 10-7 amp, but is a function of the current

reactor power calibration). Adjust the span pot VR2 in the integrator module until the Simpson panel meter indicates 100 %.

9. Set the output of the current source to zero and adjust the offset pot VR3 in the integrator module until the Simpson panel meter indicates zero.
10. Repeat steps 8 and 9 until the Simpson panel meter reads correctly at zero and at full scale.

B. SETTING THE HI AND LO TRIP LEVELS.

1. Connect the DVM across terminals 4 (-) and 5(+) of the Channel 3 Integrator modules terminal strip. Verify that the Channel 3 Linear amplifier range switch is at its 3 Watt position.
2. Adjust the output of the current source until the console panel DPM indicates 0.950 VDC.
3. Adjust the HI trip level by adjusting pot VR4 CW until the DVM across terminals 4 and 5 indicates approximately -11 VDC, then slowly adjusting the pot CCW until the DVM voltage jumps to approximately +0.7 VDC.
4. Test the setting by lowering the output from the current source to reset the trip, then slowly increasing the current source until the trip occurs. Repeat the trip adjustment as necessary until the trip point is within the desired tolerance about the 95% level.
5. Adjust the output of the current source until the DVM indicates +0.500 VDC.
6. Place the range switch of the Channel 3 Linear amp to its 10 Watt position.
7. Adjust trimpot VR5 CW until the DVM indicates approximately -11 VDC, then slowly adjust VR5 until the DVM reading jumps to approximately +0.7 VDC.
8. Test the setting by lowering the output from the current source to reset the trip, then slowly increasing the current source until the trip occurs. Repeat the trip adjustment as necessary until the trip point is within the desired tolerance about the 50% level.
9. Connect the DVM across terminals 12 (-) and 13(+) of the Channel 3 Integrator modules terminal strip.
10. Adjust the output of the current source until the console panel DPM indicates 0.050 VDC.
11. Adjust the LO trip level by adjusting trimpot VR6 CCW until the DVM indicates approximately -11 VDC, then slowly adjust VR6 CW until the DVM reading jumps to approximately +0.7 VDC.
12. Test the setting by raising the output from the current source to reset the trip, then slowly lowering the current source output until the trip occurs. Repeat the trip adjustment as necessary until the trip point is within the desired tolerance about the 5% level.

C. CALIBRATING THE CHANNEL 3 INTEGRATOR.

1. Set the output of the current source to the level that generates a reading of 1.000 +/- 0.001 Vdc on the console panel Linear Channel DPM. Set the Channel 3 Range switch to its 10 Watt level.
2. Connect the input of a counter to terminal 3 of the Channel 3 Integrator modules terminal strip. Connect the counters ground to terminal 4 of that strip. Set the counter to measure period with a resolution of 0.1 msec.
3. Adjust trimpot VR7 until the counter indicates a pulse period of 360.0 +/- 0.1 msec.
4. Set the range switch to its 3 Watt position. The pulse period should be 1.20 +/- 0.024 sec.
5. Set the range switch to its 1 Watt position. The pulse period should be 3.6 +/- 0.072 sec.
6. Set the range switch to its 0.3 Watt position. The pulse period should be 12 +/- 0.24 sec.
7. Set the range switch to its 0.1 Watt position. The pulse period should be 36 +/- 0.72 sec.
8. Set the range switch to its 0.03 Watt position. The pulse period should be 120 +/- 2.4 sec.
9. Set the range switch to its 0.01 Watt position. The pulse period should be 360 +/- 7.2 sec.
10. Set the range switch to its 0.003 Watt position. The pulse period should be 1200 +/- 24 sec.
11. Set the range switch to its 0.001 Watt position. The pulse period should be 3600 +/- 72 sec.
12. Set the range switch to is 10 Watt range. Set the output of the current source to the level that generates a reading of 0.100 +/- 0.0001 Vdc on the console panel Linear Channel DPM. The pulse period should be 3.60 +/- 0.01 sec.