DESIGN AND IMPLEMENTATION OF SAFETY CHANNELS FOR THE IDAHO STATE UNIVERSITY AGN-201m RESEARCH REACTOR CONTROL CONSOLE

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ABSTRACT

The purpose of the work described in this paper is to design, implement, and install new safety channels for the control console of the Idaho State University (ISU) AGN-201m Research 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. Due to the aging issues associated with this technology an entirely new control console is needed. There are 3 safety channels which serve as the monitors and safety systems for adequately shutting down the reactor should any limits be broken. These 3 safety channels work harmoniously with other systems within the new control console to ensure appropriate operation of the reactor. The safety channel replacements are composed of three complementary signal processing systems whose circuits monitor the operating parameters of the 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 ISU AGN-201m Research Reactor. The interconnections between each of these systems ensure that if any Channel fails or otherwise breaks a limit the entire system will initiate a scram and the reactor will become adequately sub-critical.

Key Words: Safety, Design, Channel, Research, University

1 INTRODUCTION

The work presented in this paper 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 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 and gauged by operating personnel at the control console. In addition, 3 radiation detectors monitor the flux near the core of reactor and display this data on the 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 active elements used in electronic circuitry. Consequently, the current reactor control console runs several systems including the safety channels off of 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 reactor.

Channel 2 is the safety channel responsible for displaying the entire operating range of current readings from 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 indication of the current output from its radiation detector. This means that detector current from multiple 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 power level equivalent to 6-Watts, then a high level scram will occur on both channels.

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 concludes the work performed on the control console for the AGN-201m.

2 CHANNEL 1 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. These readings are then displayed on a logarithmic count rate meter, M1. To calibrate the channel and test the trip circuit, two pushbutton test frequencies are available on the control console front panel. Figure 1 consists of a block diagram showing each of the interconnections.

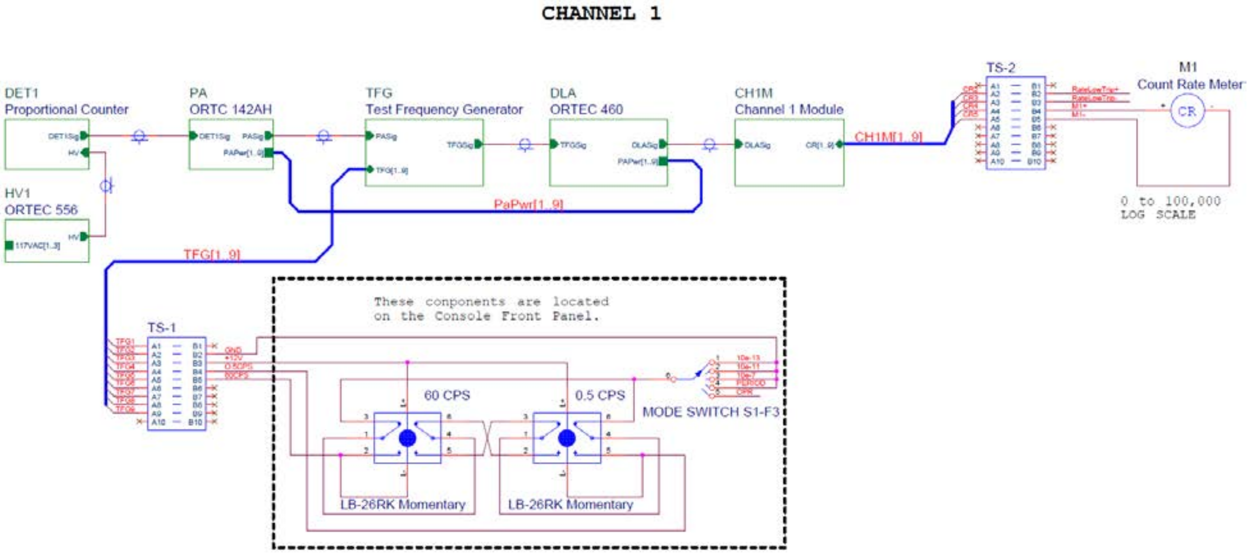

Figure 1. Channel 1 Block Diagram

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) BNC connector on the front panel 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 selectable 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. During normal operation the pushbuttons have no effect on injecting a test frequency.

The 60 CPS signal is used to verify that 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 meter M1. The 0.5 CPS signal is used to test the required low-level trip circuitry. This 0.5 CPS low-level trip is a part of the R-110 Licensed functions. If both pushbuttons are depressed at the same time, then no signal will generate. A diagram of the console front panel for Channel 1 is shown in Figure 2.

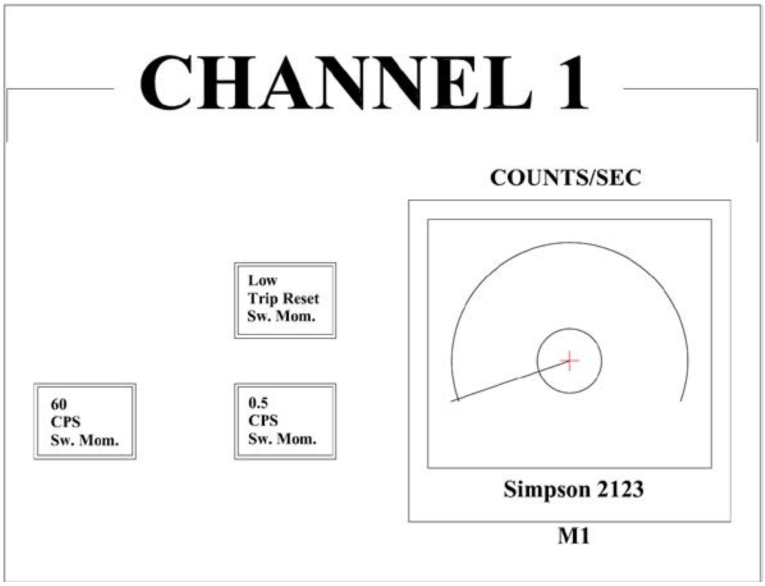

Figure 2. Channel 1 Console Front Panel

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2.2.1 Test frequency generator circuitry

The circuitry of the Test Frequency Generator consists of a 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 independent frequency adjustors capable of changing the frequency if they should alter over time. These adjustors, or potentiometers, are labeled as R1 for the 0.5 hertz and R2 for the 60 hertz.

Each of the pushbuttons triggers a relay when depressed. When the 0.5 CPS pushbutton is depressed relay K1 closes and the closure of these contacts determines 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 is depressed. K1, K2, and K3 are normally open during standard operation. Regardless of which test signal is selected all are run through the Unity Gain Buffer (A1). This buffer is responsible for converting the 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. This pulse is shown in Figure 3. Over time the tail-pulse shape may change so adjustments can become necessary. R5 is adjusted to set the output pulse baseline to zero volts and R4 is adjusted to set the amplitude of the generated tail-pulse to a level typical of a neutron.

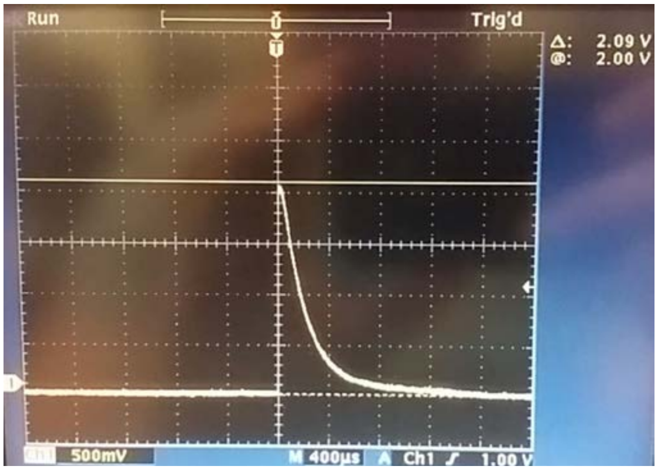

Figure 3. Channel 1 Test Pulse

2.3 Channel 1 Module

The Channel 1 module provides several discrete circuits, each serving a different function. 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 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 output of discriminator A1 drives U1 which is configured as a monostable multivibrator (single shot) whose output is a 0.7 microsecond’s wide, positive pulse, which is approximately 12-volt amplitude. This 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 logarithm 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 offset can be manually adjusted using potentiometers R7 and R4, respectively. This need only be performed if the tolerances of M1, R4, and R5 drift over time.

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. Table I further illustrates this relationship.

Table I. Voltage V. Count Rate

VDC	CPS
-0.5	1
-1.0	10
-1.5	100
-2.0	1,000
-2.5	10,000
-3.0	100,000

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 on the modules front panel, is adjusted either up or down depending on the application. R6 is used to calibrate any drift within R5 so a trip point of 0.5 CPS is guaranteed.

3 CHANNEL 2 SAFETY CHANNEL

3.1 Introduction

The logarithmic current level and reactor period of 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 reactor period. Figure 4 consists of a block diagram showing all the interconnections between these components.

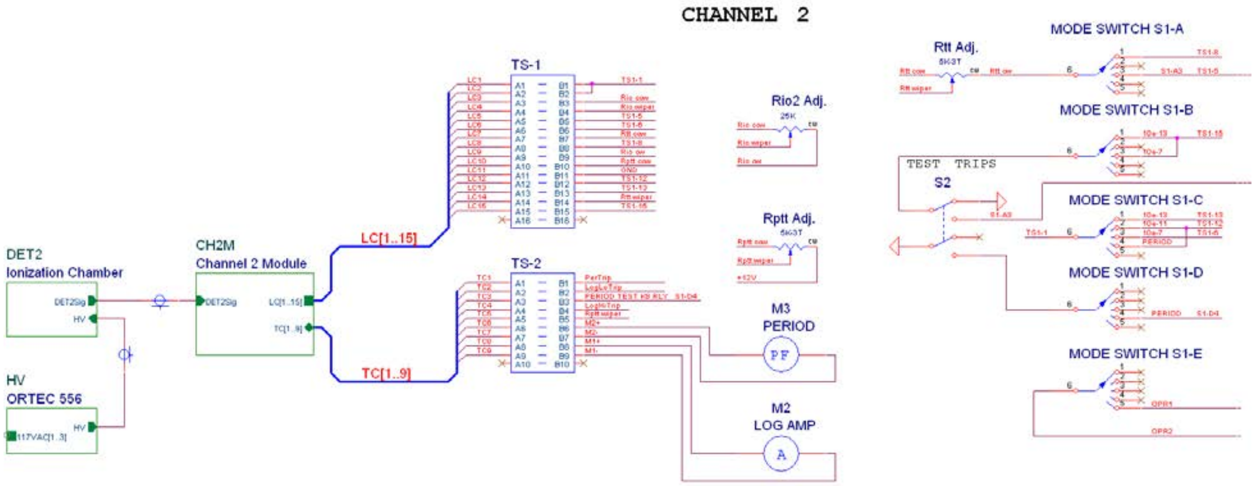

Figure 4. Channel 2 Block Diagram

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. 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.

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. This 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.

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 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 for the internal circuitry. As many as 1.5 amperes may be required to power the component if ambient temperatures are low. Since so much current is required by the component, the + 6 VDC power supply is used solely 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 a Rio2 potentiometer is used during the pre-operational check. The external Rio2 potentiometer parallels to a coarse adjustment potentiometer R7, which is located on the front panel of the Channel 2 module. This R7 potentiometer 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 amplifiers A4 & 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 amplifier A3 which determines reactor period, and 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 drives period meter M3 and period trip A6.

Amplifier A2 is configured as a unity gain buffer whose output in 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. This +1 volt offset exists because the logarithmic amplifier is rated for currents between 10^{-14} and 10^{-7} amperes. However, due to system noise within the 10^{-14} range it was not included in the final safety channel design.

3.2.2 Logarithmic test circuitry

During normal operation, the current from the ionization chamber drives this 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, and 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. 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.

Relays K1, K2, and K3 work in conjunction with 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 potentiometer 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. The variable current allows the trip threshold to be set and tested. The setting of the rotary switch S1, in conjunction with potentiometers Rtt, Rptt, and Rio2, and Pushbutton S2 allows the testing of all 3 Channel 2 trips: high current, low current, and reactor period. The front panel layout of Channel 2 is shown in Figure 5.

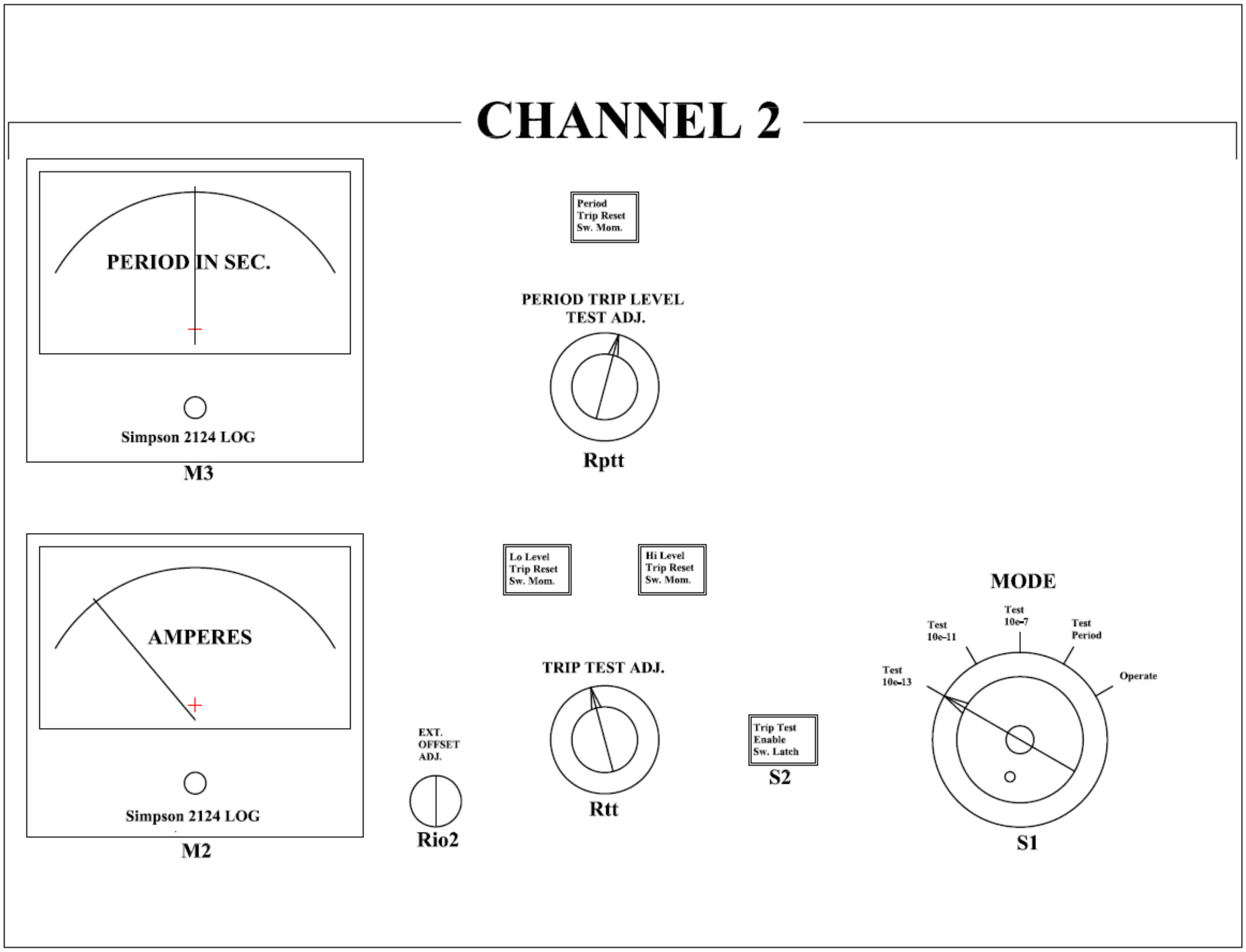

Figure 5. Channel 2 Console Front Panel

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

3.2.3 10^{-13} position

The 10^{-13} position energizes relays K1, K2, and K4 to disconnect the ionization chamber from the input of the logarithmic amplifier component and instead applies a test current to the logarithmic amplifier component via relay K4 & K2. Potentiometer Rio2 provides the amplifier offset current. When pushbutton S2 is depressed, the potentiometer Rtt can be adjusted to test the low trip threshold setting.

3.2.4 10^{-11} position

The 10^{-11} position applies a test current via relay K2 & 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 issue is resolved.

3.2.5 10^{-7} position

The 10^{-7} position applies a test current via relay K3 & 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.

3.2.6 Test period position

The test period position applies an input current designed to generate a period. Rptt adjusts this current so that a period of anywhere between a few seconds and infinity can be generated. Rptt is primarily used to test the reactor period trip point.

3.2.7 Period trip and circuitry

The period trip circuit is comprised of a simple comparator A6 and its associated circuitry. The trip point is readily adjusted with potentiometer R10. The comparator is driven by the differentiator circuitry present in the logarithmic amplifier output. 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.

4 CHANNEL 3 SAFETY CHANNEL

4.1 Introduction

The linear safety channel system begins with the output current from ^{10}B Uncompensated Neutron Ionization Chamber near the reactor core tank. Channel 3 consists of the Channel 3 Linear Amplifier module, ORTEC Model 556 High-Voltage Power Supply, Channel 3 Integrator module, and the Range Switch Module. The Channel 3 block diagram is shown in Figure 6.

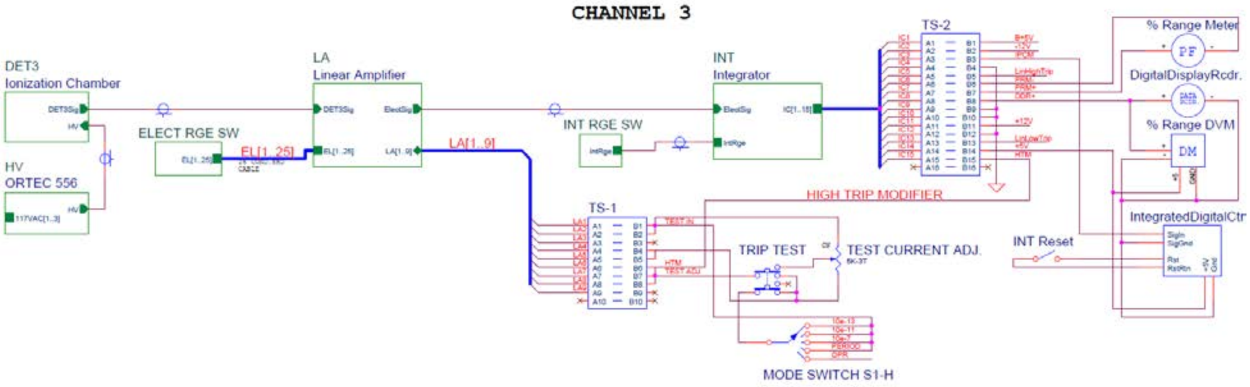

Figure 6. Channel 3 Block Diagram

This 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 these results, 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 usable pulse rate scaled for proportionality to the reactor's power level. This scaling results in the creation of 15 individual ranges and a voltage range from 0 to +1.00 volts (signifying 0 to 100% of the range power). The integrated power counts output pulses from the converter using a panel mounted digital counter, M6. In addition, the Channel 3 Integrator module drives a digital voltmeter M4, and an analog % of range meter, M5.

4.2 Channel 3 Amplifier Module

The 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 7 shows the layout of the Chanel 3 front panel including the placement of the Range Switch module.

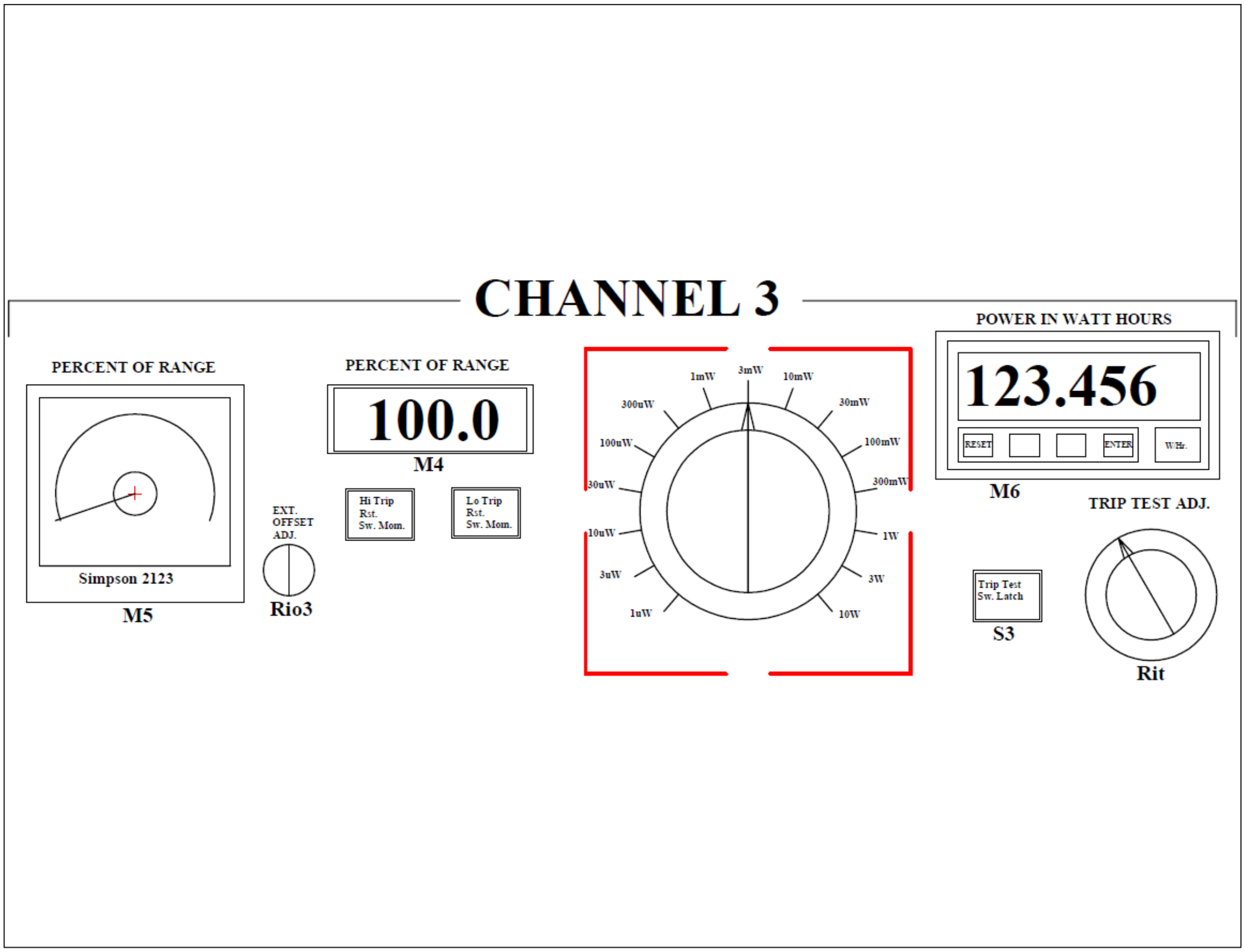

Figure 7. Channel 3 Console Front Panel

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. S3 creates the connection between the potentiometer Rit and the Channel 3 Linear Amplifier module. S1-F energizes the test relay K3, K4, and K5 within the 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 potentiometer to the linear amplifier is made via connector JR1 on the range switch module.

4.2.1 Logarithmic test circuitry

The input current to the Channel 3 Linear Amplifier module is fed to the input terminal of operation amplifier A1 (a LMC6001A). This operational amplifier has a specified input offset current of 2 femto-amperes at 25 degrees Celsius and is very suitable for our application, given that the minimum expected current from the ionization chamber is 0.1 pico-amperes.

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

$$V_o(A1) = Input\ Current * Feedback\ Resistor\ Value \qquad (1)$$

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 maximum. 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 A1's input limits that amplifiers protective diode current to approximately 6 mA.

The Channel 3 Linear Amplifier module feedback resistors R3, R4, and R5 were selected based on their capability to cover the modules input current ranges. The input current ranges for each of these resistors is shown in Table II.

Table II. Input Current V. Resistor Value

Amplifier A1 Feedback Resistor	Reactor Power Range	Corresponding Input Current (Amperes)
R3	1 μW	4.4×10^{-14}
R3	3 μW	1.33×10^{-13}
R3	10 μW	4.4×10^{-13}
R3	30 μW	1.33×10^{-12}
R3	100 μW	4.4×10^{-12}
R3	300 μW	1.33×10^{-11}
R4	1 mW	4.4×10^{-11}
R4	3 mW	1.33×10^{-10}
R4	10 mW	4.4×10^{-10}
R4	30 mW	1.33×10^{-9}
R4	100 mW	4.4×10^{-9}
R4	300 mW	1.33×10^{-8}
R5	1 W	4.4×10^{-8}
R5	3 W	1.33×10^{-7}
R5	10 W	4.4×10^{-7}

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.

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 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 NIM 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. Access to potentiometer Rio3 is made by the way of the 25 pin connector JR1 which is mounted on the Range Switch module.

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, its resolution is still much too coarse to simulate currents responding to reactor power levels below 100 milliWatts. To solve this issue, relay K4 and K5 are actuated 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 off the NIM bin +12 and -12 volt supplies. This +12-volt supply is used to actuate relays K1 through K5. This +12-volt 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.

4.3 Channel 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 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 selects the solid state switches U1, U2, and U3. The 15 pin make-before-break switch wafer (S1-B) is used to enable solid state switches U4 and U5 that determine the linear amplifiers response time. In addition, the associated range resistors of the integrator circuitry are mounted on switch wafer S1-D.

There is one switch contact within the module used to lower the high trip level when the 10-Watt range is selected. The high level trip is lowered to 6-Watts on this 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 Circuitry

The input signal to the Channel 3 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 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 integrators, 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.

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 relays of contact 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 in the Range Switch module. Potentiometer R7 is adjusted to calibrate the voltage to frequency converter

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 J1, pin1, in the event that an external +5-volt logic level might have application

5 CONCLUSIONS

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 circuitry there was no rationale for continuing operations with the original AGN-201m safety channels. The new safety channels were made to emulate the original circuits with a focus on improving key characteristics.

The upgraded safety channels 1, 2, and 3 provide numerous improvements. With increased signal processing speed each of the safety channels can provide a trip to scram the reactor quickly enough to meet all NRC standards. 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 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 improvements have opened up. This future work can take place on both the reactor and control sides of the equation. With all of these options there is no reason for the AGN-201m to not continue operating for many years into the future.

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