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# ISOLATION CAPABILITES OF BOP ISOLATORS

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## 1.0 SCOPE

This report provides an overview of the isolation capability of isolators currently used in Class 1E analog loops.

## 2.0 GENERAL

### 2.1 DEFINITIONS & TERMS

a. Common Mode Voltage. "The voltage common to all conductors of a group as measured between that group of a given location and an arbitrary reference (usually earth)." Refer. 7.5.5

b. Differential (Transverse) Mode Voltage. "The voltage at a given location between two conductors of a group." Refer. 7.5.5

c. Common Mode Input Impedance. The impedance common between all input terminals of a device and an arbitrary reference. Usually measured between input terminal and output common.

d. Differential Input Impedance. The impedance between the input signal terminals or between signal common and any other input terminal.

e. Common Mode Source Impedance. The impedance common between all source leads and an arbitrary reference (Usually earth).

f. Differential Mode Source Impedance. The impedance between the source leads or between source common and any other source lead.

## 3.0 APPLICABLE FAULT CONDITIONS

### 3.1 Credible Fault Voltages and Currents

As a general rule, instrumentation cables, power cables and control cables are each routed in separate raceways. In enclosures, Class 1E instrument and control cables may be routed together. Furthermore, non-Class 1E instrument cables connected to Class 1E tap points may be routed with Class 1E in the same channel/division as the respective tap point. (Ref. 7.5.6, Para. IV.A.H.8

<u>Direct Current Fault</u>: The maximum direct current fault is established at 250 VDC. △1

<u>Bases</u>: The maximum DC voltage in cables available at a location common with instrumentation cables is 250 VDC control cables routed in the PGCC Floor Sections. The 250 VDC control cables are fused at 10 amperes in the Control Center or source.

<u>Alternating Current Fault</u>: The maximum alternating current fault is established at 120 VAC. △1

<u>Bases</u>: The maximum AC voltage in cables available at locations common with instrumentation cables is 120 VAC control cables routed in the PGCC Floor Sections and in panels, and 120 VAC utility cables in panels. The 120 VAC control and utility cables have current limiting devices in the Control Center or the distribution panel.

3.2 Application of Faults (Fault Modes)

The following paragraph from IEEE Std 384-1981 provides a general summary of the fault modes that apply to isolation devices.

"7.2.2.1 General. A device is considered an electrical isolation device for instrumentation and control circuits if it is applied so that (a) the maximum credible voltage or current transient applied to the device's non-Class 1E side will not degrade the operation of the circuit connected to the device Class 1E or associated side below an acceptable level; and

(b) shorts, grounds, or open circuits occurring in the non-Class 1E side will not degrade the circuit connected to the device Class 1E or associated side below an acceptable level."

The maximum credible fault voltages that could be applied to the output and power supply terminals of the non-Class 1E side of the isolator is stated in Paragraph 4.1 above. These faults could either be applied transverse or common mode, and are listed as follows:

a. Common Mode Fault on Signal Output:
Fault voltages are 120VAC and 250 VDC. Refer to Figure 3.2-1.

b. Transverse Mode Fault on Signal Output:
Fault voltages are 120VAC and 250 VDC. Refer to Figure 3.2-2.

c. Common Mode Fault on Power Supply Input:
Fault voltages are 120VAC and 250 VDC. Refer to Figure 3.2-3.

d. Transverse Mode Fault of Power Supply Input:
Fault voltages are 120VAC and 250 VDC. Refer to Figure 3.2-4.

In addition to voltage and current faults, faults could occur as a result of shorts and opens on the non-Class 1E side. These faults are listed as follows:

e. Short on Signal Output.

f. Short on Power Supply Input.

1

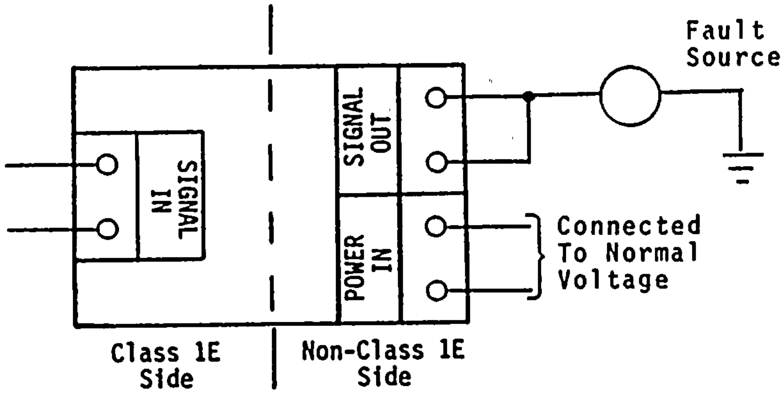
g. Opens on Signal Outputs.

h. Opens on Power Supply Inputs.

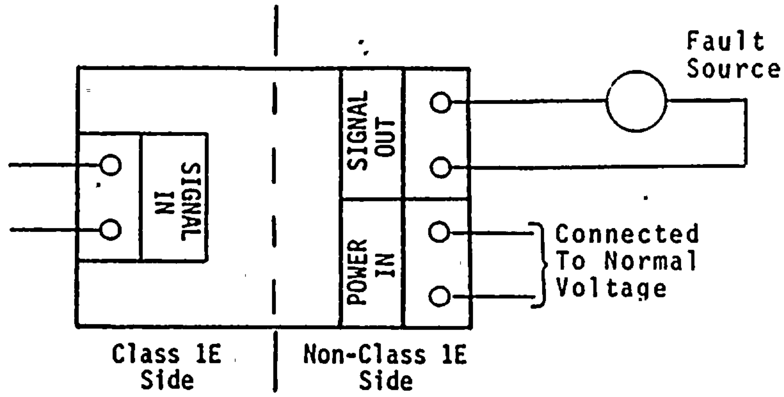
i. Grounded Signal Outputs.

j. Grounded Power Supply Inputs.

For all fault modes, the isolator should be considered operating under normal conditions, that is, Class 1E input side connected and power supply inputs connected and energized.

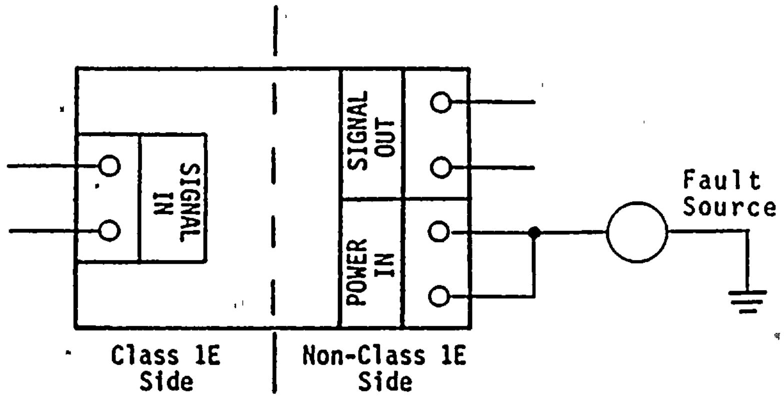



Common Mode Fault on Signal Output
Figure 3.2-1



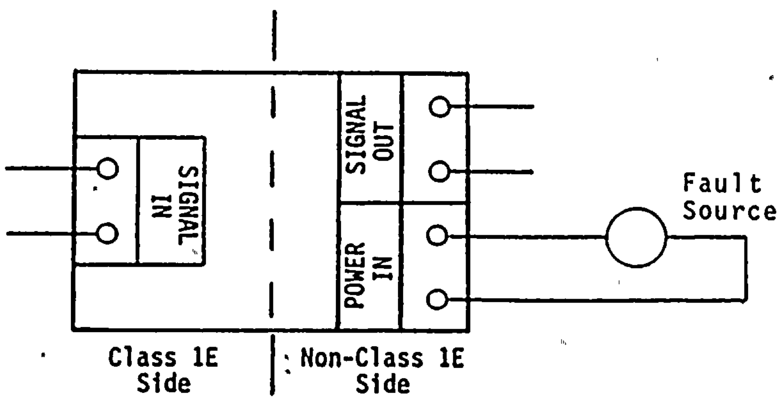

Transverse Mode Fault on Signal Output

Figure 3.2-2




Common Mode Fault on Power Supply Input

Figure 3.2-3




Transverse Mode Fault on Power Supply Input

Figure 3.2-4

## 4.0 Isolators in Current Use

### 4.1 Bailey Millivolt Converter

#### 4.1.1 Brief Description

The Bailey Type 740 millivolt converter is designed to convert millivolt or resistance input signals to a 1-5 VDC or 4-20 mA output signal. The DC input signal is transformed to an AC signal by the "chopper" circuit. The chopped input signal is fed to the output circuit through a transformer. The output demodulator, synchronized with the input-circuit chopper, reproduces the signal at the output. The 24VDC power drives an oscillator circuit to feed power across a transformer to the input and output circuits through separate windings. The output terminals and the power input terminals are isolated from the Class 1E input terminals by transformers.

#### 4.1.2 Application & Installation

The Bailey Type 740 millivolt converters are used as isolators in various systems. The Type 740 provides signal isolation between Class 1E systems and the BOP DCS Computer, and indicators, alarms and controllers of several systems. The millivolt converters are installed in the same panel as the signal source. The output signal of each isolator is 4-20 mA. The cabling from the Type 740 millivolt converters are non-Class 1E low energy circuits that are routed in cable trays of this voltage category, except when routed in the PGCC Floor Sections where they may be routed with 250 VDC cables.

#### 4.1.3 Summary of Testing

Although no specific test data or reports can be referenced, a letter from Bailey Controls Company to PP&L (Ref. 7.1.1) states that the isolation capability of the Bailey Model 740 Millivolt Converter is

300 VAC. Although not specifically stated, the isolation capability is assumed to be between the input terminals bused and the output terminals bused.

## 4.2 Simmonds-Precision IMUX

### 4.2.1 Brief Description

The Simmonds Precision IMUX is a stand-alone piece of equipment consisting of the Electronics Unit and Local Control Panel. The unit is microprocessor based and contains the following subassemblies: power supplies, analog and digital baskets; analog to digital converter card; analog interface card; Z80A processor card; memory card; non-isolated communications card; at least one isolated communications card; fault isolation card; and the analog and digital input cards required by its location in the plant. Figure 4.2 is a block diagram of the IMUX. (Ref. 7.2.5, Page 2-1)

The Class 1E IMUXs use both digital and analog input modules.

The Digital Input Modules are used to isolate and condition up to 16 similar inputs. Each input is protected from surges and overvoltages through zener diodes and fusible (fail open) resistors. The fusible resistors are mounted on terminal posts for easy replacement. Each input is optically isolated to 300 VDC from the data bus and from chassis. Inputs on the Digital Voltage Input Module are isolated from each other, as well. (Ref. 7.2.5, Page 2-13).

The Analog Input Module consists of : one test channel, seven isolated, two-wire input channels, which include circuitry for protection from surge voltages and overvoltages on the input lines; and an isolating multiplexer and decoder circuit for placing any one input signal on the output lines. (Ref. 7.2.5, Page 2-25).

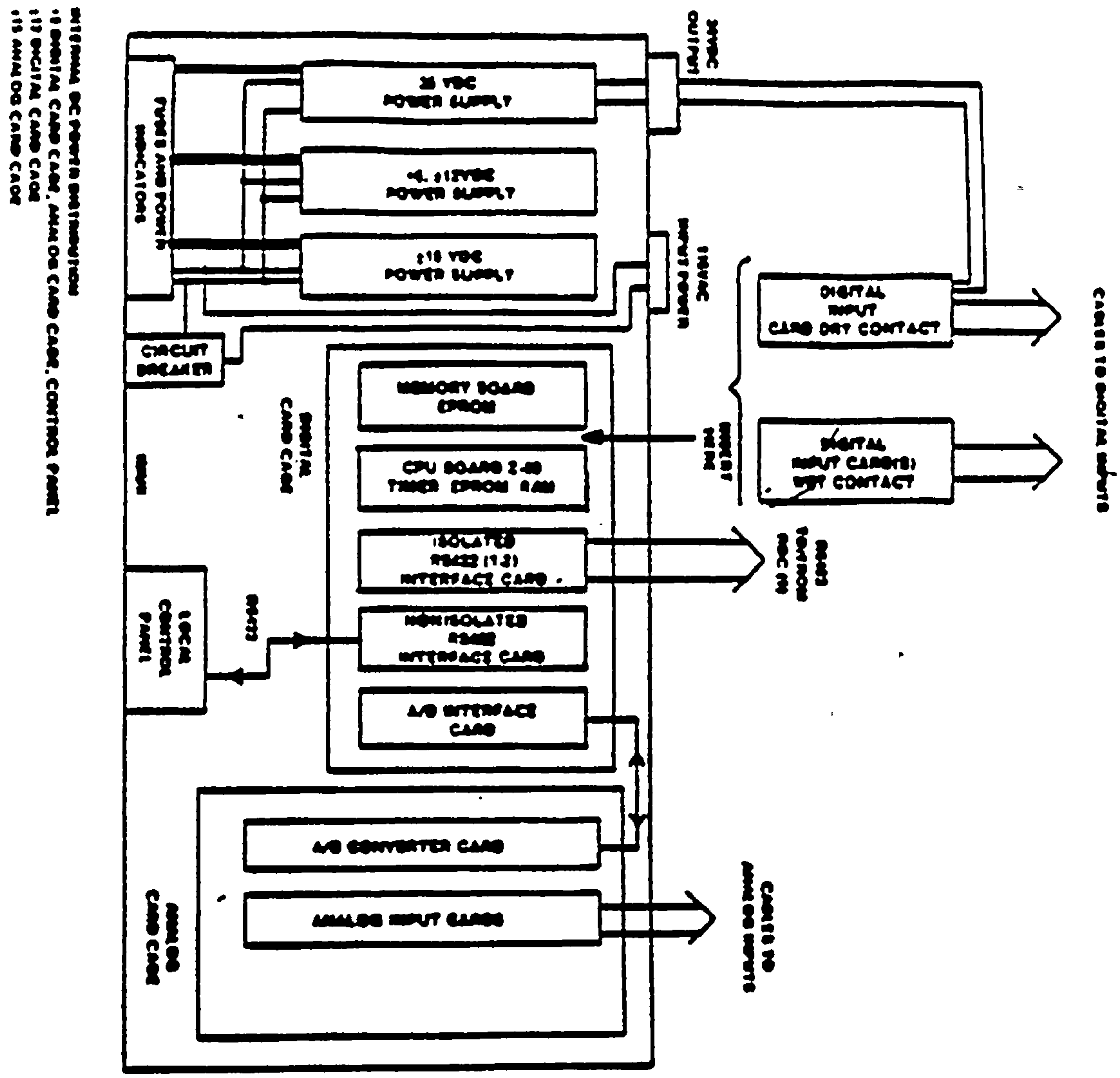



FIGURE 4.2  INTELLIGENT MULTIPLEXER BLOCK DIAGRAM

4.2.2 Application & Installation

The Simmonds Precision IMUXs are used to provide Class 1E signal interface with SPDS. The IMUXs converters analog and digital signals to a digital format then multiplexes these signals and transmits them serially to the SPDS Computer. Separate IMUXs in separate cabinets are used for each Class 1E Division, and separate IMUXs are used for non-Class 1E SPDS inputs. Divisional separation is maintained from the signal tap point to the IMUXs.

4.2.3 Summary of Testing

Simmonds Precision Report No. ICD-E-0227 (Ref. 7.2.2) describes fault isolation testing performed on the IMUX. This report describes the results of applying 277 VAC and 250 VDC faults both in the transverse and common mode to the input power cable and RS422 communication link. A review of this test was documented in correspondence PLI-46588 (Ref. 7.2.4) that concluded, "There were no catastrophic failures of associated or adjacent channels, and no failures propagated to external loop driven equipment as a result of the fault testing."

Simmonds Precision Report No. ICD-E-0205 (Ref. 7.2.1) describes the Surge Withstand Capability testing performed on the IMUX. Testing was conducted to the requirements of IEEE Std 472. The surge waveform was applied both in the transverse and common mode to all inputs and output groups. The IMUX fully recovered after each test and no damage was incurred; however, false data resulted from the applied surge.

Simmonds Precision Report No. ICD-E-0204 (Ref. 7.2.6) provides the results of applying 250 VAC and 250 VDC faults both in the transverse and common mode to the field inputs and multiplexed output. This report together with ICD-E-0222 (Ref. 7.2.7) verified the capability of the input and output circuits to limit fault propagation. These tests concluded that a fault applied to any single input (output) will not cause damage to propogate beyond that input (output) and will not permanently affect the performance of the IMUX.

Simmonds Precision Report No. ICD-E-0206 (Ref. 7.2.6) states that the IMUX system was subjected to EMI testing in accordance with CS01, CS02, RS03 test methods of MIL-STD-461A and MIL-STD-462. The IMUX passed every segment of the referenced tests. There were no anomalies during the test that were caused by the EMI test signals.

## 4.3 TEC Model 156 Isolators

### 4.3.1 Brief Description

The TEC (Technology for Energy Corporation) Model 156 Analog Signal Isolator Module was specifically designed to provide electrical isolation between Class 1E electronic circuits and non-Class 1E electronic circuits. The isolator is intended to provide isolation to permit circuits to meet the isolation criteria set forth in IEEE 279-1971, Par. 4.7.2, and IEEE 384-1981, Par. 7.2.2.1.

The design of the Model 156 is a commercially available isolation amplifier module with augmenting circuitry. Refer to Figure 4.3 on the following page. The amplifier uses a standard technique of modulating the input signal and then transformer coupling the modulator output to the demodulator to produce the output signal. The single 24 VDC source on the output side drives both the input and output circuitry. Separation and isolation is maintained using an oscillator in the output circuitry to drive the power transformer to the input power circuitry.

The output terminals and the power supply terminals are isolated from the input terminals by the transformers. The output signal is 4-20 mA for a 1-5 Vdc, 4-20 mA or 0-1 Vdc input signal.

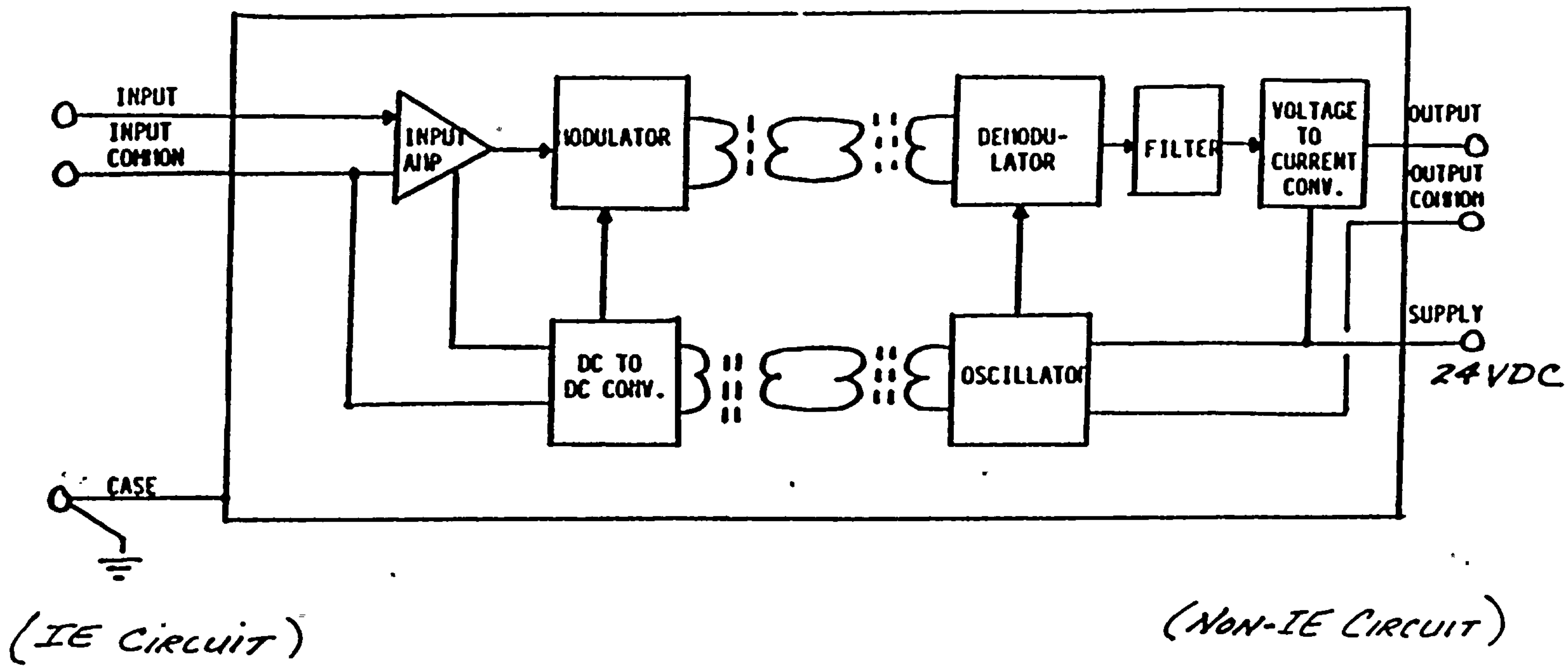



Figure 4.3 Model 156 Analog Isolator Block Diagram

4.3.2 Application and Installation

The TEC Model 156s are used as signal conditioners or isolators in various systems. The Model 156 provides signal conditioning or signal isolation between Class 1E systems and BOP DCS Computer, between the APRMs and the SPDS, between redundant channels of the Containment Instrument Gas System, and within the Containment Radiation Monitoring System. The Model 156s are installed in the same panel as the tap point location. The output cabling, including the power supply conductors, has a maximum voltage of 5 VAC from the signal and 24 VDC for the power source. The cabling from Model 156s (used as isolators between Class 1E and non-Class 1E circuits) are non-Class 1E low energy circuits and are routed in cable trays of this voltage category, except when routed in the PGCC Floor Sections where they may be routed with 250 VDC cables.

4.3.3 Summary of Testing

TEC Test Report No. 156-TR-02 (Ref. 7.3.5) provides the results of isolation testing and are summarized below.

a. Common mode input impedance at 2000 VDC from bused input terminals to the output common was greater than $5 \times 10^{10}$ ohms.

b. When the output terminals were opened, shorted and shorted to ground, voltages at the input terminals were measured between the inputs and between the input common and ground. The tests used 1000 ohms as the differential source impedance and the common mode source impedance. The acceptance criteria was voltages of less than 10 mV at the input terminals after an initial transient period of 10 mS. Test results indicate that the unit met this criteria.

c. When 120 VAC @ 60 Hz was applied across the power supply terminals and across the output terminals, voltages at the input terminals were measured as in b, above. The acceptance criteria was the same as above. The unit did not function as an amplifier after each test; however, the unit functioned as an isolator as was determined by a common mode input impedance test as described in a, above.

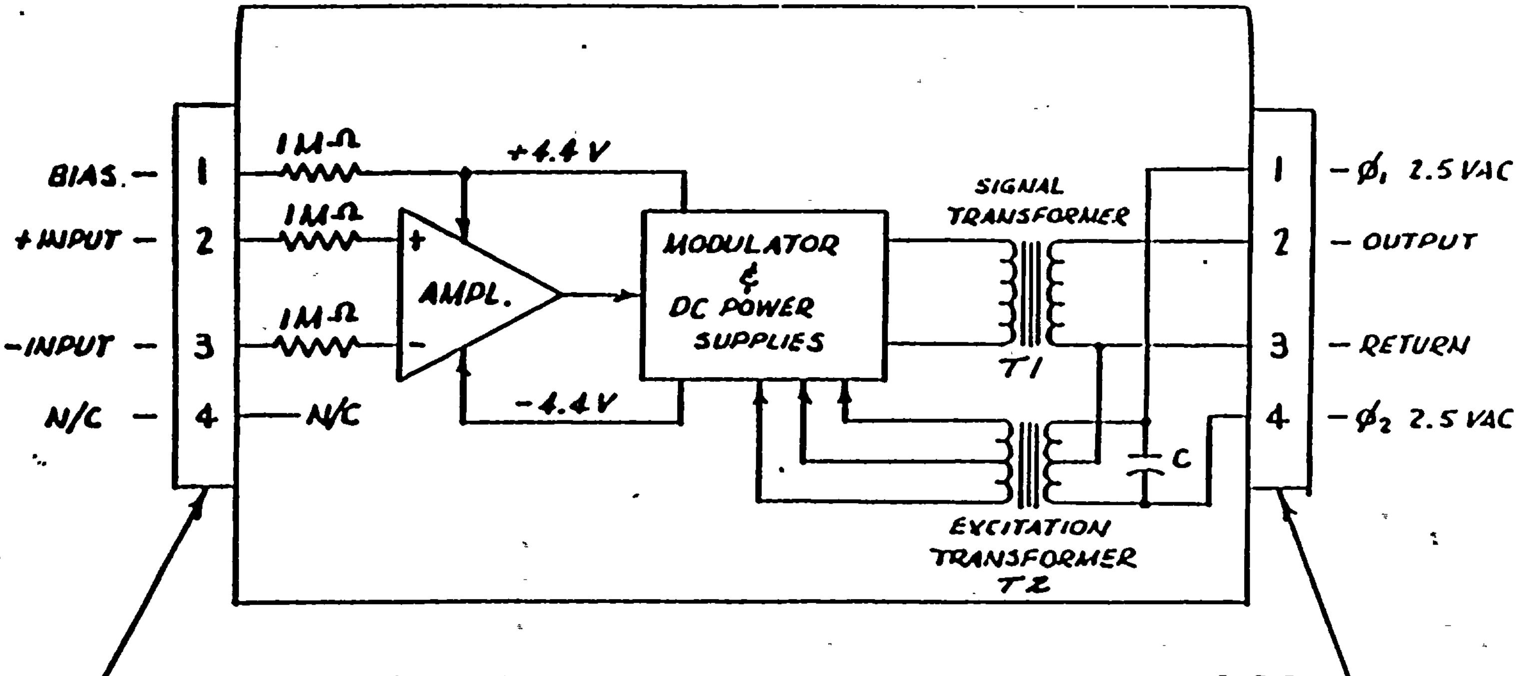
## 4.4 Validyne CM249 Isolators

### 4.4.1 Brief Description

The Validyne Model CM249 is a remote signal conditioner or more descriptively a signal modulator. Refer to Figure 4.4 on the following page. The externally generated carrier signal is transformer coupled to the input of the CM249. The power for the input and modulator circuit is derived from this carrier signal. The modulated input signal is transformer coupled to the output terminals of the CM249. The output terminals and the excitation terminals are isolated from the input or Class 1E terminals by the transformers. The carrier/excitation signal is 5 Vrms @ 3kHz and the output signal will be 35 mV for a 5 Vrms input signal.

### 4.4.2 Application & Installation

The Validyne Model CM249s are used as signal conditions and isolators at the front-end of the Transient Monitoring System (TMS), a non-safety system. The CM249 provides isolation between the Class 1E signal tap point and the non-Class 1E TMS and are installed in the enclosure or panel where the tap points is located. The cabling on the output side of the CM249 carries the carrier/excitation signal and the output signal. These cables are non-Class 1E low energy circuits and are routed in cable trays of this voltage category, except when routed in the PGCC Floor Sections where they may be routed with 250 VDC cables.



BIAS
+INPUT
-INPUT
N/C
1
2
3
4
1MΩ
1MΩ
1MΩ
N/C
+4.4V
-4.4V
AMPL.
+
-
MODULATOR & DC POWER SUPPLIES
SIGNAL TRANSFORMER
T1
EXCITATION TRANSFORMER
T2
C
$\phi_1$ 2.5 VAC
OUTPUT
RETURN
$\phi_2$ 2.5 VAC
INPUT TERMINAL STRIP
(1E Circuit)
OUTPUT TERMINAL STRIP
(Non-1E Circuit)


FIGURE 4.4

4.4.3 Summary of Testing

Wyle Test Report No. 58390 (Ref. 7.4.3) provides the results of functional tests performed as part of seismic and environmental qualification tests. The functional tests performed which are applicable to isolation capability are described in the report and are summarized below.

a. "hi-pot" testing verified the insulation between bused inputs and bused output terminals, between bussed inputs and chassis, and between bused outputs and chassis will stand-off 2000 VDC. (Ref. 7.4.3, Para. 4.2.1)

b. Common mode input impedance at 500 VDC from each input terminal to the output common was greater than 3 x $10^{12}$ ohms. (Ref. 7.4.3, Para. 4.2h)

c. Output to input noise rejection over the frequency range of 60 Hz to 20 kHz was measured to be less than 1mV across a 50 ohm source impedance when 200 mA was flowing through the output terminal. (Ref. 7.4.3, Para. 4.2j & k)

d. Differential input impedance was measured with 5 VDC applied to the input. When the output terminals were opened, shorted, shorted to ground (chassis), and connected to the demodulator, the input impedance remained 1.913 megohms. (Ref. 7.4.3, Para. 4.2c,d,e & f).

Validyne's MTBF analysis, Appendix A to Qualification Plan NDQ 783015 (Ref. 7.4.4) concludes that given a transformer failure the common mode input impedance would not be less than 1 megohm and that the differential input impedance would not be less than 2 megohm if a common mode voltage of 220 VAC @ 60 Hz was applied to the CM249.

# 5.0 EVALUATION OF ISOLATOR CAPABILITIES

## 5.1 Evaluation Criteria and Bases

Three of the four isolators in use utilize transformers to provide electrical isolation. The transformers provide a path for inducing some portion of an electrical fault from the non-Class 1E side to the Class 1E side of the isolators.

In order for the isolator to prevent the fault conditions from degrading the Class 1E circuit connected to the isolator inputs, 1) the isolator characteristic input impedance must be maintained and 2) the level of any signal propagated from the non-Class 1E output to the Class 1E circuit must be an acceptable level.

The acceptable level of any propagated signal was established as a variance equal to the loop accuracy tolerance. This criterion was selected so that the error introduced by the propagated signal would be no greater than the nominal loop tolerance. A survey of the NSSS analog loop accuracies was conducted and documented in Calculation J-CRR-245, Rev. 0. The accuracies of the analog loops were obtained from the GE Design Specification Data Sheets for the NSSS Systems. The survey determined that 17.1% of the total number of loops evaluated had a tolerance between 0% and 2%, and the 82.9% had a loop tolerance between 2.0% to 20%. Since the majority of the loops have a tolerance of 2.0% or greater, the maximum acceptable level of variance for any propagated signal at the input of the isolator was selected as 2% of the designed input range. Furthermore, each of those loops with a tolerance of less than 2% were evaluated to assess the effect of a 2% variance on the input of any isolator that may be installed. Most of these loops have no isolators installed and those that use isolators are "indication only" loops, that is, no associated automatic functions. It was concluded that because the 2% variance would be short term or transient and not destructive to the Class 1E circuits, then the variance would be acceptable for the 17.1% of the loops with a loop tolerance between 0% and 2%. 1

In addition to the analog loop survey, a review of the ECCS and RPS actuation loops was conducted. The ECCS and RPS functions are controlled by contact or digital loops, except the Neutron Monitoring System (NMS) and the Control Rod Drive (CRD) Discharge Volume Level signals. The propagation of low level signals (5 VDC) to 120 VAC and 125 VDC control relay circuits would not actuate or prevent actuation of those circuits; therefore, a review of the accuracies of contact or digital loops was not evaluated. No isolators are presently connected to the CRD Discharge Volume Level analog loops; however, the accuracies of the CRD analog loops was included in the survey for statistical purposes. The NMS was reviewed separately, because a significant number of isolators are connected to the NMS. Although the APRMs have a stated accuracy of 0.2%, the APRM analog loops were evaluated using the margin between the trip setpoint and the allowable value as listed in the Technical Specifications. The APRM RPS trip setpoint tolerance is calculated to be 1.6% of full scale. All the isolators connected to the APRM signals are connected through resistor divider networks. This results in a variance of the APRM signal equal to half or less of the variance at the input of the isolator. The proposed variance of 2% on the input of the isolator would therefore result in a 1% or less variance on the APRM signal. Since this value is less than the trip setpoint tolerance (1.6%), the selected value of 2% for isolator variance is acceptable for this application. As a result of the review, it is concluded that a 2% variance on either the analog or digital loops would not prevent the actuation of the ECCS and RPS functions within the specified tolerance.

In order to evaluate the level of fault signal propogation, the source impedance must be established, because the level of signal propogation is dependent on the source impedance of the Class 1E circuit. Instrument circuits are in general 4-20 mA loops that use a 250 ohm resistor to provide 1-5 VDC output signals; therefore, 250 ohms was selected as a typical source impedance for the signal connected to the isolation Class 1E input.

5.2 Bailey Millivolt Converter

Since no test procedures, test report or test data was presently available, no evaluation of the Bailey Model 740 Millivolt Converter can be made.

5.3 Simmonds Precision IMUX

The Simmonds Precision IMUX was tested to assure compliance to NUREG-0737 which states, "The SPDS shall be suitably isolated from electrical or electronic interference with equipment and sensors that are in use for safety systems." This testing was extensive, well documented, and included electrical fault testing as well as EMI testing.

The fault tests conducted included these defined in Section 3.2, except those identified in paragraphs 3.2e through 3.2j. Since the SPDS IMUX was capable of sustaining 277 VAC and 250 VDC transverse and common mode faults, it is reasonable to conclude that the IMUX is capable of isolating the Class 1E inputs from shorts, opens and shorts to ground of the 120 VAC power input or the communication link (IMUX output) to acceptable levels.

5.4 TEC Model 156 Isolator

The Model 156 was tested to and passed the 120 VAC, open and short fault conditions given in Section 3.2, but was not tested to 250 VDC fault conditions. The voltages at the input as a result of fault conditions was less than 0.2% of the full-range input signal. The tests used a source and common mode impedance of 1000 ohms instead on 250 ohms. Although the higher impedance resulted in higher voltages at the input, the isolator input impedance is sufficiently high that a lower source impedance would not significantly affect the test results.

5.5 Validyne CM249 Isolators

The functional testing of the Validyne CM249 established that when the output terminals were opened, shorted or shorted to ground, the input impedance was unchanged. Although the input was not monitored during the testing for generated or propogated voltages, any sustained voltages on the input would have been indicated as a change in the input impedance. The input impedance was unchanged throughout these functional tests. Open, shorted and shorted to ground of the isolator power input terminals were not conducted; however, since the power input terminals are directly connected to the power input transformer, these fault conditions would have no affect on the input circuit.

The analysis conducted concluded that the input impedance would not be degraded below 1 megohm common mode and 2 megohm differential mode. A source impedance of 250 ohms with 120 VAC and 250 VDC applied common mode. on the output will yield voltages at the isolation input of 30 mVAC (42 mVpk) and 62 mVDC. These voltage levels translate to 0.8% and 1.2% of the full range input signal.

## 6.0 CONCLUSIONS

6.1 Since no test isolation capability data is available for the Bailey Controls Company Model 740 millivolt Converter, it is recommended that tests be conducted for each of the fault conditions identified in Section 3.2 of this study to determine the isolation capability of the Model 740.

6.2 The numerous tests conducted on the Simmonds Precision IMUX verified that any of the fault condition identified would not result in a degradation of the Class 1E below an acceptable level.

6.3 The TEC Model 156 should be tested to fault condition identified in Section 3.2 to determine the isolation capability to 250 VDC faults. 1

6.4 The Validyne Model CM249 was determined, mainly by analysis, to be capable of mitigating the consequences of the identified faults to an acceptable level on the Class 1E input, but fault testing should be conducted to verify the analysis.

## 7.0 REFERENCES

7.1 Bailey Millivolt Converter References

1. EQDF Binder No. BB34 (BCN 2)

2. Letter from Bailey Controls Company (Erickson) to PP&L (Ballard) dated November 11, 1986. (See BCN #7 to Ref. 1, above)

7.2 Simmonds Precision IMUX References

1. Report of Surge Withstand Capability Qualification Testing performed in the Intelligent Multiplexer Portion of the PP&L Safety Parameter.

2. Report on Addition Isolation Testing Conducted on the IMUX portion of the PP&L SPDS, ICD-E-0227, Rev. A.

3. Technical Specification for Safety Parameter Display System Computer Systems, D1000.

4. PLI-46588, IMUX Test Analysis/Use for Class 1E Circuits.

5. Hardware Manual for Safety Parameter Display System (SPDS), ICD-D-0068-04.

6. Report on Isolation Qualification Testing Conducted on Intelligent Multiplexer (IMUX) Portion of PP&L Safety Parameter Display System, ICD-E-0204.

7. Report on Isolation Qualification Follow-up Testing Conducted on the Intelligent Multiplexer (IMUX) Portion of PP&L Safety Parameter Display System, ICD-E-0222.

8. Report on Electromagnetic Interference (EMI) Qualification Testing Performed on the IMUX Portion of the SPDX, ICD-E-0206.

7.3 TEC Isolator References

1. SQRT Binder No. J-49.

2. Qualification Plan for Verification of Performance and Environmental Characteristics of the TEC Model 156 Analog Signal Isolator by Type Testing, 31041-TR-01.

3. Testing Procedure for TEC Model 156 Analog Isolator, 156-QP-03.

4. Electromagnetic Interference (EMI) Test for TEC Model 156 Analog Signal Isolator Module, 156-QP-04.

5. Test Report on Isolation Testing and Measurements of the TEC Model 156 Series Isolators Including Shorts, Opens, and 120VAC Fault with fuses shorted, 156-TR-02.

6. 1E-Input Isolation (From Output Circuitry) - Analysis and Measurements for the TEC 156 Analog Isolator, 156-QP-07.

7.4 Validyne CM 249 Isolator References

1. SQRT Binder No. J-98.

2. Manual for Model CM249, IOM #414.

3. Wyle Laboratories Report No. 58390, Nuclear Environmental Qualification Analysis and Testing on Validyne C249 Remote Carrier Modulator for Commonwealth Edison Company.

4. Validyne Qualification Plan NDQ783015.

5. EQDF Binder No. BB47.

7.5 General References

1. SSES FSAR.

2. Regulatory Guide 1.75 - Physical Independence of Electric Systems.

3. IEEE Std 279-1971 - Criteria for Protection Systems for Nuclear Power Generating Stations.

4. IEEE Std 384-1981 - Criteria for Independence of Class 1E Equipment and Circuits.

5. IEEE Std 472-1974 - IEEE Guide for Surge Withstand Capability (SWC) Tests.

6. E-1012, Specification for Electrical Separation Criteria.

7. NUREG/CR-3453, Electronic Isolators Used in Safety Systems of U.S. Nuclear Power Plants.