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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Front-end Electronics for Unattended Measurement (FEUM): Prototype Test Plan

Revision 1

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August 2015

Pacific Northwest NATIONAL LABORATORY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Revision Log and Approvals

Front-end Electronics for Unattended Measurement (FEUM): Prototype Test Plan

Rev. No.	Date	Describe Changes	Pages Changed
0	11/25/14	Original Issue	
1	5/20/15	Removed references to use of charge injector – Arbitrary Waveform Generator (AWG) to be use instead Removed quantitative aspects of Test 3 (Pulse Shape). Added reference AWG waveforms to Section 3. Removed ground loop noise susceptibility test (Test 22) Various edits for clarity Removed Test 9 (impedance measurements) Performance targets recalculated and updated in section 1.2 Deleted references to performing NGAM verification Added Appendix B (original IAEA specifications for FEUM) in place of original appendix B (Charge Injector Technical Specifications) Updated the digital summing test procedure Removed Test 21, Conducted EMI Susceptibility	Various

Name and Title	Approvals	Date
PNNL		

Acronyms and Abbreviations

ADAM	Advanced Data Acquisition Module from Bot Eng.
AWG	arbitrary waveform generator
CANDU	CANada Deuterium Uranium
COTS	commercial off the shelf
CZT	cadmium zinc telluride
DAQ	data acquisition
DUT	device under test
ECP	Engineering Change Proposal
ESD	electrostatic discharge
EMI	electromagnetic interference
FEUM	Front-end Electronics for Unattended Measurements
GRAND	Gamma Ray and Neutron Detector from Canberra Ind.
IAEA	International Atomic Energy Agency
LED	light-emitting diode
MCA	multichannel analyzer
NGAM	Next Generation ADAM Module
NGSI	Next Generation Safeguards Initiative
RFI	radio frequency interference
SCA	Single channel analyzer
TTL	transistor-transistor logic
UMS	Unattended monitoring system(s)
UNAP	Universal NDA Data Acquisition Platform
UNDA	Unattended Non-Destructive Assay

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1.0 Introduction

1.1 Background

The International Atomic Energy Agency (IAEA) deploys unattended monitoring systems (UMS) in facilities around the world to provide continuous monitoring of nuclear movements within safeguarded facilities. As the number of unattended monitoring instruments increases, the IAEA is challenged to become more efficient in the implementation of those systems. In 2010, the IAEA initiated development of the Front-end Electronics for Unattended Measurement (FEUM) project with the goals of a) greater flexibility in terms of the interfaces to various sensors and data acquisition systems, and b) improved capabilities for remotely located sensors (e.g., where sensor and front-end electronics might be separated by 10s of meters) (Figure 1.1).

The majority of the IAEA's UMS are counting, rather than spectroscopic systems, where the measurement needs are more qualitative than quantitative. IAEA's UMS instruments are designed with simplicity, durability, and ease of maintenance in mind. The classes of detectors typically used in IAEA UMS instruments include

- gas-filled neutron detectors: predominantly pulse-mode fission ion chambers (U-235) and He-3 proportional counters, but also boron-lined proportional counters;
- gas-filled gamma-ray detectors: generally current-mode ion chambers but also Geiger-Mueller tubes;
- semiconductor gamma-ray detectors: predominantly Si PIN diodes used in gross-counting mode (no spectroscopy) or CZT diodes operated in spectroscopic mode;
- medium- and low-resolution gamma-ray spectrometers: NaI(Tl) and plastic scintillators, typically coupled to photomultiplier tubes.

The IAEA issued technical specifications for FEUM devices in 2012 [Appendix B], and the first FEUM prototype was delivered to the IAEA in May 2013. Basic functional testing of these devices were performed by the IAEA, but the IAEA does not have the resources to perform a comprehensive evaluation of FEUM characteristics, strengths, and limitations over the broad range of important parameters that includes sensor types, cable types, and the spectrum of industrial electromagnetic noise that can degrade signals from remotely located detectors. The IAEA indicated the need for a comprehensive and objective evaluation of FEUM in representative environments (e.g., high industrial noise, high radiation, widely varying temperatures) in order to define where and how FEUM should be implemented in the field. The Next Generation Safeguards Initiative (NGSI) FEUM project, a collaboration between Pacific Northwest National Laboratory (PNNL), Idaho National Laboratory and Los Alamos National Laboratory, is performing this evaluation on behalf of and in close consultation with the IAEA. The gas-filled neutron detector and gross-counting gamma-ray sensors account for the vast majority of deployed detectors, and therefore were the original focus of the IAEA's FEUM project, and the testing described in this document.

To help guide the FEUM development and constrain the scope to a manageable level, three scenarios have been defined to be representative of IAEA's UMS deployments around the world:

- Scenario 1: He-3 and B-lined proportional counters (used for variety of qualitative and quantitative applications)
- Scenario 2: U-235 fission chamber (representative of the neutron portion of IAEA's Core Discharge Monitor for heavy-water reactors)
- Scenario 3: NaI(Tl) spectrometer sensor (e.g., for verification of mixed-oxide fuel rods).

In each of these scenarios, it will be assumed that the detector is physically separated from FEUM by a distance ranging from a few meters to ~100 meters. A nominal configuration for FEUM's deployment in the field is depicted in Figure 1.1. In general, this device is required to provide pulse amplification, pulse shaping, and single-channel analyzer functionality for a range of radiation detector types, and interface with existing and new IAEA data acquisition (DAQ) systems.

This test plan documents methods used to provide testing and characterization of prototype FEUM modules to verify compliance with the core set of IAEA requirements, and to assess predicted performance of the FEUM devices in controlled as well as more challenging environments. The testing described in this report will inform IAEA's decision about whether to move forward with the current FEUM prototypes (e.g., by requesting modifications by the vendor) or to pursue alternative paths to the same end.

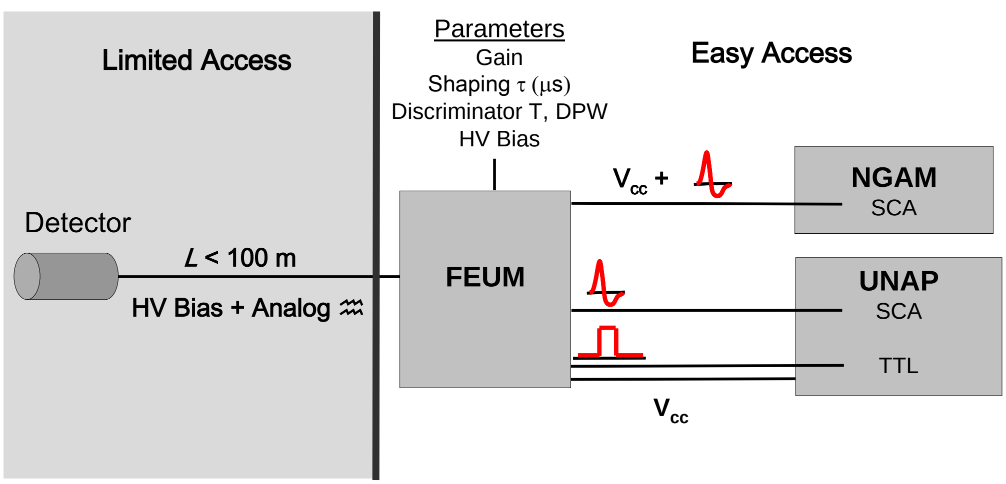


Figure 1.1. IAEA FEUM Concept

1.2 Test Objectives

1. Verify compliance with a core set of the full requirements for the FEUM procurement [Appendix B]. The full set of requirements and selected test requirements are listed in Appendix A. A summary of items for testing or excluded from testing is listed in Table 1.

Table 1. Summary of Requirements for Evaluation in Initial Test Phase

Requirement	**Initial Test Applicability**
Functional Attributes	TESTED
Compatibility with UMS DAQ	NOT TESTED AT THIS STAGE
Environmental – EMI/RFI Susceptibility	TESTED
Environmental – Other	NOT TESTED AT THIS STAGE

2. Measure performance of the FEUM prototype and compare against against the performance targets provided by the IAEA in the original FEUM specifications for ^{3}He detectors [Appendix A and Appendix B]. Those performance targets are founded on the use of an integral pulse height spectrum (IPHS) for data display and reduction, described by previous analysis[1]. Illustrative examples of IPHSs for various FEUM scenarios (i.e., cable length, shaping time, noise threshold) are shown qualitatively in Figure 1.2 for “easy” (green), “medium” (blue) and “difficult” (red) FEUM scenarios.

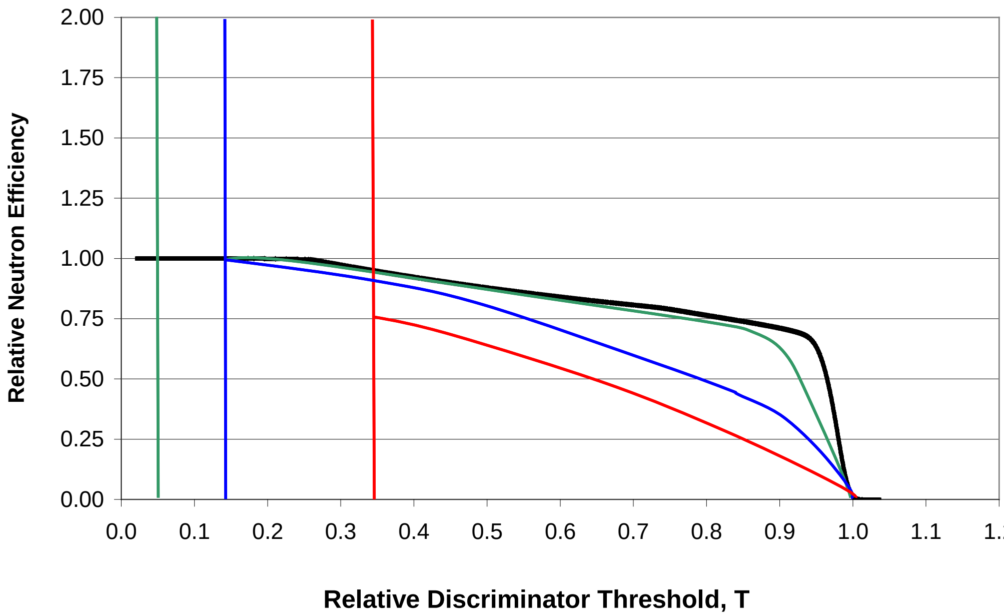


Figure 1.2. Graphical Representation of FEUM Performance Targets

[1]LE Smith et al., “Evaluation of Front-end Electronics for Unattended Safeguards Instruments”, IEEE Nuclear Science Symposium, 2011

The IAEA then calculated quantitative performance targets for the relative neutron efficiency from the ^{3}He, $\varepsilon_{neutron}$, for a set of representative scenarios using the following methodology:

- T_{noise} *is the discrimination threshold* where $R_{noise} < 5$ cps with no neutron source present;
- $\varepsilon_{neutron}(T)$ is the relative neutron efficiency defined to be $R_{net}(T) / R_{ideal}$
- R_{ideal} = net neutron count rate for $T = T_{noise}$ under assumptions of $L \sim 0$, $\tau \sim 2.0$;
- $R_{net}(T)$ = net neutron count rate after subtraction of $R_{noise}(T)$

The IAEA's original table of performance targets is shown in Appendix A. PNNL believes, however, that the IAEA had an error in its calculational methodology-- R_{ideal} was not held as a constant throughout the scenarios. Therefore, PNNL has developed a revised table using approximate target valuels for $\varepsilon_{neutron}(T)$ drawn from Figure 1.2. Table 2 tabulates these PNNL-calculated performance targets for relative neutron efficiencyas a function of discriminator threshold, cable length (capacitance), pulse shaping time, and noise-based minimum threshold. Additional discussion with the IAEA is needed to resolve the performance target question, but the values in Table 2 provide at least some context for the results of the FEUM prototype performance testing.

Table 2. Nominal FEUM Performance

***L* (*m* RG-71), τ (µs)**	T_{noise}	T, $\varepsilon_{neutron}$
(1, 2) (50, 2)	0.05	(0.20, 0.80) (0.50, 0.45) (0.80, 0.15)
(1, 0.1) (50, 0.5) (100, 0.5) (100, 2)	0.15	(0.20, 0.70) (0.50, 0.0.40) (0.80, 0.10)
(50, 0.1) (100, 0.1)	0.35	(0.35, 0.40) (0.50, 0.20) (0.80, 0.05)

Nominal FEUM Performance Targets for T_{noise} and $\varepsilon_{Neutron}(T)$ for a Variety of Cable Lengths and Shaping Constants, assuming a ^{3}He neutron detector and RG-71 cable. Relative neutron efficiency targets are given for three notional classes of implementation scenario: "easy" (green), "medium" (blue) and "difficult" (red). *Note: These values were calculated by PNNL and differ from original IAEA targets due to a possible error in IAEA calculations.*

2.0 Testing Overview

This section describes an overview of the testing approach and setups to be used. Specific procedures and data collection are located in the procedures, Appendix C. Tests will be conducted with the FEUM prototype configured for charge-sensitive mode, and where applicable, current-sensitive mode as well. Tests which are expected to be run in in charge-sensitive and current-sensitive mode are called out in each section. Several tests were added in revision 1 of this document but still apply to the functional testing section, and therefore some test numbering may be out of order.

2.1 Conformance Verifications

[TEST 1] Feature Conformance Verification

Conformance verifications typically take the form of a visual inspection or circuit analysis to note gaps between the FEUM requirements and FEUM prototype and to provide a first-order inspection of the FEUM prototype. There is no associated test procedure. General items to be evaluated are listed below but are not all-inclusive.

Preamplifier

Amplifier design variants and gain range

Shaping Amplifier

Shaping filter design and shaping-constant ranges

Bias Supply

High-voltage power supply design, range and isolation

High-voltage transient protection

Enclosure

Size and material of enclosure

Ease of access

Interfaces

Type of Connectors

Type of isolation employed

2.2 Functional Tests

The following tests are intended to verify individual electrical characteristics of the FEUM and that required functions of the FEUM are met. The FEUM prototype is the device under test (DUT) and will be connected to various test equipment (shown in gray) as notionally depicted in Figure 2.1. The test signal generator will typically be connected to the detector input port, but will alternatively be connected to the test input port in some tests to verify that port's functionality.

The FEUM prototype will be tested to the IAEA-defined ranges where possible, or to the extent of the as-built prototype ranges, for cases where the IAEA-defined ranges cannot be achieved.

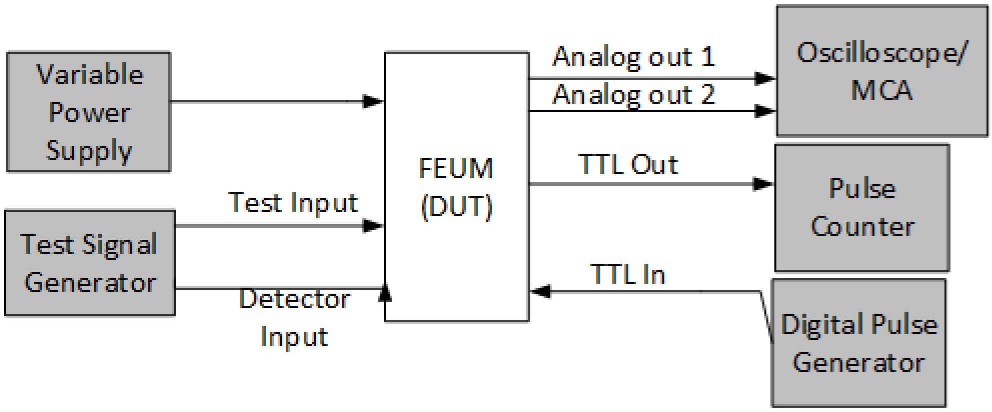


Figure 2.1. Generic Test Setup for Functional Tests

2.2.1 Preamplifier

[TEST 2] Pulse Rise Time

Test Removed. This test will not be pursued because it would require access to an internal test point that is not readily available in the FEUM prototypes.

2.2.2 Shaping Amplifier

[TEST 3] Shaping Amplifier – Gain and Charge Calibration

Measure the output pulse amplitude with various discrete gain settings. The target gain range is from 0.001 pC/V to 5000 pC/V. Measurements will be performed in both charge-sensitive and current-sensitive mode. An absolute charge calibration will be performed as a part of this test.

[TEST 4] Analog Shaping Constant

Verify the pulse shape of output pulses using all variants for FEUM prototype shaping time constants. The target time constant range is from 0.05 µs to 2.0 µs. Measurements will be performed in both charge-sensitive and current-sensitive mode.

This test will verify on an oscilloscope that the output pulses are consistent with bipolar pulse shaping and that the output pulse widths are consistent with the shaping time constant selected. This test is a semi-quantitative confirmation.

2.2.3 Discriminator

[TEST 5] Discriminator - Threshold

Measure the output pulse height spectra on a multichannel analyzer (MCA) over the range of discrete discriminator thresholds from 0 V to 3.825 V. This test will verify that the low level discriminator cutoff is consistent with the discriminator setting selected and the pulse injected and that it behaves in a linear manner. Visual verification will be performed using the oscilloscope and triggering on the TTL output. Measurements will be performed in both charge-sensitive and current-sensitive mode.

[TEST 6] TTL Pulse Width

Measure the TTL output pulse width for the FEUM prototype settable values. The target range is 50–500 ns. This test will verify on an oscilloscope that 50% of peak at the rising edge to 50% of peak at the falling edge is consistent with the pulse width selected. Measurements will be performed in both charge-sensitive and current-sensitive mode.

2.2.4 High-Voltage Bias Supply

[TEST 7] Bias Supply – Voltage

Measure the DC bias voltage for each discrete high-voltage setting. The target range is from 200 V to 2000 V. This test will verify that the bias voltage as measured by a DC voltmeter is consistent with the bias voltage selected over a range of settings.

[TEST 8] Bias Supply - Stability

Sample the DC output bias voltage for four bias voltages incrementally spaced over the range of the detector for a period of hours and days at millisecond and second time resolution. This test will verify that the instantaneous bias supply voltage is within 50 mV of nominal by periodically sampling voltage with a data acquisition system (DAQ).

2.2.5 Interfaces

[TEST 9] Input/Output Port Resistance

Test Removed. The original test methods were not practical for all input/output ports. Some ports require the FEUM to be energized and measured in reference to test points which are not available on the FEUM prototype. Appropriate test points could be determined with detailed schematics, however these results are a lower priority and the outputs performed as expected with an oscilloscope input impedance set to 50Ω,

[TEST 10] Count-Rate Indicator - LED Pulse

Measure the light-emitting diode (LED) blink rate when the FEUM is stimulated with a low pulse-rate input and visually verify that the blink rate is at least approximately representative of the input count rate. This test is purely qualitative—no effort is devoted to quantitatively comparing the blink rate to the actual count rate.

[TEST 11] Isolated Input Power

For input voltage levels ranging from 9 V to 13.8 V in steps of ~0.5 V, verify basic FEUM functionality: correct bias voltage by digital voltmeter, and analog output pulse amplitude and shape using the oscilloscope.

[TEST 12] Digital Input - Logic Voltage Levels

Verify 5-V TTL input levels on the digital input, with V_{IH} = 2.4 V. This test will measure the input voltage level at which logic high and logic low is registered (V_{IH} and V_{IL}) to ensure compatibility with typical 5-V TTL logic.

[TEST 13] Digital Input – Digital Summing

Verify the digital pulse summing functionality by measuring digital output pulses when stimulating the detector input and the TTL input simultaneously and sequentially. This test will use the AWG connected to the detector input port and the digital pulse generator connected to the digital input port. The output pulse is expected to be a logical OR or XOR of the two input pulses.

[TEST 14] V_{cc} Grounded Input Power

This test will analyze the device operation with the external, non-isolated power supply input on analog port #2, and compare against the isolated power supply on the standard power input. This quality comparison will be made by monitoring the low-voltage supply average voltage and noise, internal to the FEUM.

[TEST 15] Analog Output 1 & 2

Measure the output pulse on amplifier output #1 and output #2 with the AWG input. This test will verify that the output #1 and #2 pulse shape and amplitude are consistent with the charge injected input and that #1 is completely decoupled from the input power supply while #2 is superimposed on the Vcc Supply. This test will also verify that the two outputs are identical except for the DC offset.

[TEST 16] Digital Output- Logic Voltage Levels

Verify that the digital TTL output is compatible with 5-V TTL logic, with V_{OH} = 2.4 V. This test will measure the output voltage level for a logic high and low (V_{OH} and V_{OL}) to ensure compatibility with typical 5-V TTL logic.

[TEST 17] Ground Isolation

Measure the port-to-port resistance and the port-to-ground resistance to determine how well the ports and ground are isolated. If the FEUM prototype supports multiple ground isolation configurations, test each configuration.

2.2.6 Deadtime and Intrinsic Noise Characteristics

[TEST 23] Deadtime

The deadtime of the prototype FEUM device will be evaluated across different analog shaping times and discriminator output pulse widths. Three measurement methods will be utiilized: 1) Random pulse generator intended to be generically representative of IAEA UMS sensors, and 2) "two-source method" using a NaI(Tl) detector and gamma-ray sources to represent gamma-ray sensors, and 3) . a "time-interval histogram" method applied to a 3He detector, to represent UMS neutron sensors that must often operate in high gamma-ray fields.

[TEST 24] Equivalent Noise Charge

The equivalent noise charge (ENC) is a basic measure of instrument noise levels and will be measured in a manner consistent with open-literature protocols[2].The ENC characterization test will use the AWG as the signal generator and will vary the shaping time and input capacitance across a wide range of values representative of IAEA UMS scenarios.

2.2.7 UMS DAQ Standards Compatibility

[TEST 18] NGAM Compatibility

Test Removed. This test was a lower priority and removed due to schedule and budget constraints.

Verify that an NGAM type DAQ is compatible with the FEUM and that the NGAM operates as expected. This is accomplished by taking count rate and peak channel measurements with both an MCA and an NGAM, with several different input amplitudes and varying the discriminator threshold on the FEUM prototype. This test will verify that the discriminator cutoff energies are similar for the MCA and the NGAM, and that the count rates also are consistent. This test is optional for this phase of testing (as schedule and budget permits).

2.3 Performance Tests

[TEST 19] Baseline FEUM Performance

The baseline FEUM performance will first be evaluated in controlled conditions, and this baseline will provide a reference for performance in more challenging environments. The basic setup depicted in Figure 2.2 will used for this test. Ideally, the baseline performance will be measured in the "quiet" atmosphere of an anechoic chamber but if the chamber is not available, testing will be performed in a standard laboratory environment. The MCA will be used to record the differential pulse height spectra which can then be analyzed to produce the integral pulse height spectra, as specified by the IAEA (see Section 1.2 and Appendix A for more discussion). The MCA-based integral pulse-height spectra will be spot-checked using the discriminator of the

[2] IEEE Standard 301-1976 *IEEE Standard Test Procedures for Amplifiers and Preamplifiers for Semiconductor Radiation Detectors for Ionizing Radiation*

FEUM device and a digital counter. These tests will be performed on the FEUM in both charge-sensitive and current-sensitive modes, as supported by the FEUM prototype and the detector to be measured. Not all detector types are compatible with current sensitive mode of operation.

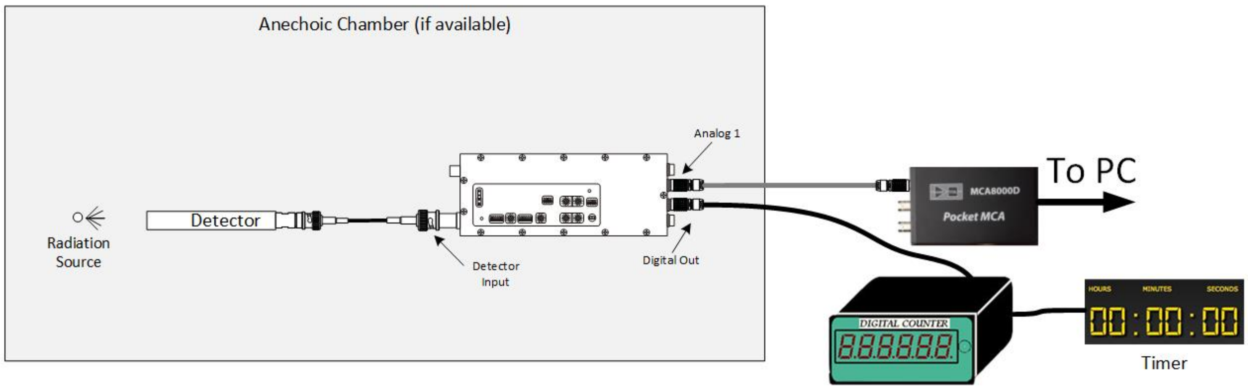


Figure 2.2. Baseline Performance Test Setup

The baseline FEUM performance will be studied over the range of detector, cabling and pulse-shaping parameters recommended by the IAEA's FEUM specifications, as detailed in Table 3. The detector types are listed in order of descending priority.

Table 3. Detection Parameters to Vary for Performance Testing

Detector Type	Cable/Length	Pulse Shaping Time	Output Port
AWG	RG-71/1 m	0.1 µs	Isolated
He-3	RG-71/50 m	0.4 µs	Ground-Coupled (Vcc Coupled)*
Fission Chamber	RG-71/100 m**	2.4 µs	
NaI (TI)	RG-174/100 m		

*Fewer measurements will be taken with the ground-coupled output, since the two outputs should be similar.

**If reasonable results with 100m cable are not achievable, shorter length cables such as 10m and 25m may be used

2.4 Stress Performance Tests

2.4.1 EMI/RFI Susceptibility

Because EMI/RFI susceptibility is an important implementation issue for FEUM devices in the anticpated operating environments, this testing will explore FEUM prototype performance under varying EMI/RFI conditions. These tests will consist of radiated RF resistance at higher frequencies (30 MHz to 2.45 GHz) and conducted RF resistance at lower frequencies (10 kHz to 30 MHz), based on analysis per NUREG/CR-6782, *Comparison of U.S. Military and International Electromagnetic Compatibility Guidanc*e. Conducted susceptibility is performed at the lower frequencies because it is generally accepted that typical cable lengths are not adequately long for testing radiated susceptibility at low frequencies (long wavelengths). Test methods are based on MIL-STD-461E. While not an exhaustive test for EMI/RFI susceptibility, these tests should inform IAEA planning for additional evaluation.

[TEST 20] Radiated EMI/RFI Susceptibility

The test setup in Figure 2.3 will be used for radiated susceptibility tests. The same set of detector, cable and shaping time parameters used in the baseline performance tests will be applied. Because the double-shielded RG-71 cabling is the most prevalent cable used in new IAEA deployments and is expected to provide more robust performance in noisy environments, priority will be placed on testing with this cable type (and less on the RG-174). Typical test methods require 10 V/m field strength; however 5 and 20 V/m may also be tested to explore the bounds of FEUM performance in RF fields. Table 4 summarizes the parameters and parameter variants to be considered during EMI/RFI susceptibility testing. Detector types are listed in order of descending priority.

Table 4. Detection Parameters to Vary for Performance Testing

Detector Type	Cable/Length	Pulse Shaping Time	Radiated Field Strength	Output Port
AWG	RG-71/1 m	0.1 us	10 V/m	Isolated
He3	RG-71/50 m	0.5 us	(5 V/m)*	Ground-coupled
Fission Chamber	RG-71/100 m**	2 us	(20 V/m)*	
NaI (TI)	RG-174/100 m*			

* To be tested if time permits and initial results warrant

**If reasonable results with 100m cable are not achievable, shorter length cables such as 10m and 25m may be used

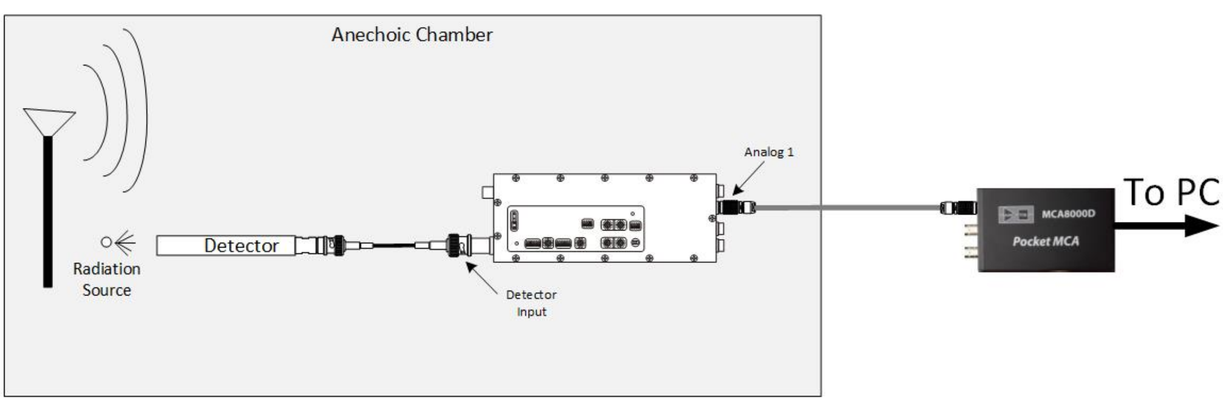


Figure 2.3. **Radiated EMI/RFI Test Setup**

[TEST 21] Conducted EMI/RFI Susceptibility

Test Removed. This test was removed because conducted EMI susceptibility can be considered a system-level test, while the FEUM evaluation is focused on component-level tests. The results are highly dependent on the power supply chosen for use, and as such have limited value for practical FEUM use.

The test setup in Figure 2.4 will be used for conducted susceptibility tests. The tests will focus on the standard RG-71 cable, using setup permutations shown in Table 5. (Detector variants shown in order of descending priority) MIL-STD-461E allows for both power source injection and signal injection. Signal noise injection is chosen for this test as it is expected to be more consistent with the industrial noise experienced in IAEA's UMS deployments. The arbitrary waveform generator will be coupled to the detector input either by inductive injection or direct injection.

Table 5. Detection Parameters to Vary for Conducted Susceptibility Tests

Detector Type	Cable/Length	Pulse Shaping Time	Noise Amplitude	Output Port
AWG	RG-71/1 m	0.1 µs	(110 dBuV)*	Isolated
He3	RG-71/50 m	0.5 µs	(120 dBuV)*	Ground-coupled
Fission Chamber	RG-71/100 m**	2 µs	130 dBuV	
NaI (TI)	RG-171/100 m*			

* To be tested if time permits and initial results warrant

**If reasonable results with 100m cable are not achievable, shorter length cables such as 10m and 25m may be used

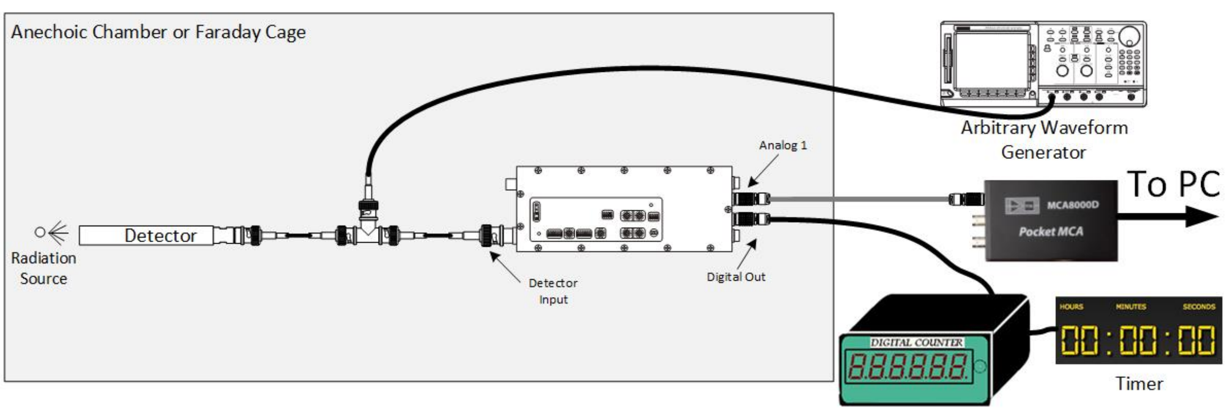


Figure 2.4. Conducted EMI/RFI Test Setup

[TEST 25] High Radiation Field Susceptibility

IAEA's unattended monitoring systems are often deployed in high radiation fields. A particular concern is the ability of neutron counting systems to sufficiently discriminate high gamma-ray fields. In these tests, the setup described in Figure 2.2 will be deployed at a PNNL facility where intense neutron and gamma-ray sources are available. ^{3}He and fission chambers operating at representative neutron detection rates will be subjected to increasing gamma-ray fields. MCA spectra at each field intensity will allow study of gamma-ray pileup effects on both the differential and integral pulse height spectra. These tests will be limited to RG-71 cable at varying lengths as shown in Table 6.

Table 6. Detection Parameters to Vary for High Radiation Field Test

Detector Type	**Cable/Length**	**Pulse Shaping Time**	**Output Port**
Fission Chamber	RG-71/1 m	0.1 μs	Isolated
He3	RG-71/50 m	0.5 μs	
	RG-71/100 m	2 μs	

2.4.2 Ground Loop Noise Susceptibility

[TEST 22] Ground Loop Susceptibility

Test Removed. IAEA has indicated that ground-loop noise can be a significant degrading issue in field deployments, but because ground-loop effects are highly dependent on the specific conditions of the facility (e.g., frequency and voltage of supply power, ground quality) and IAEA deployment (e.g., sensor types, collimator contact to the sensor), the effects in question cannot be reproduced for meaningful quantitative testing. Any qualtitative testing does not adequately prove the FEUM is free of specific noise issues observed from ground loops.

3.0 Equipment and Configuration

This section describes the applicable test equipment, settings, and documentation.

3.1 Device Under Test (DUT)

3.1.1 FEUM Prototype

In the test procedures, the devices under test (DUTs) are assumed to be the FEUM v1.0 or 1.1 from BOT Engineering unless otherwise explicitly stated.

3.2 Test Equipment

3.2.1 Variable Power Supply

The power supply will be a standard commercial-off-the-shelf (COTS) supply, 0–24 V+/-100 mV, 3 A or greater.

3.2.2 Oscilloscope

The oscilloscope for testing will be a standard COTS unit, >500 MHz bandwidth, >1 GSa/s, capable of 2000 V with a high voltage probe for high-voltage measurements. .

3.2.3 Pulse Counter

An Ortec 773 timer counter Nuclear Instrumentation Module (NIM) will be used for counting digital pulses.

3.2.4 Multi-channel Analyzer

The MCA used for testing will have at least 16k channels of resolution, Amptek Pocket MCA 8000 or similar.

3.2.5 Charge Injector

This test component has been removed. All uses of the charge injector have been replaced with the arbitrary waveform generator..

3.2.6 Arbitrary Waveform Generator

The arbitrary waveform generator (AWG) to be used will be a 30 MHz, Agilent 33522A AWG or equivalent. General settings were a sawtooth output at a frequency of 1 KHz. The output impedance was set to high-Z.

3.2.7 He-3 Detector

The He-3 detector to be used will be a Reuter-Stokes RS-P4-0825-203, 1” x 25” (Dia x L) He-3 proportional counter at 10 atm.

3.2.8 Fission Chamber

RS-P6-0805-134 used by the IAEA or equivalent, in a similar moderation configuration.

3.2.9 NaI (Tl) Detector

The NaI detector for performance measurements will be a Ludlum Measurements, Inc. Model 44-2, scintillator, 2.5 x 2.5 cm (1 x 1 in.) (Dia x L) thick NaI(Tl).

3.2.10 Multimeter

Multimeter measurements will be made using COTS digital voltmeters CAT III or CAT IV rated, Fluke 87 or equivalent. For higher voltage measurements a 1000:1 high-voltage probe may be used.

3.2.11 Data Acquisition System

For long term data acquisition, a National Instruments 0–10 V, 100 ms data logger will be used, in conjunction with a voltage divider for higher voltage measurements.

3.2.12 High Voltage, Precision Capacitor

Connecting a capacitor in series with the an AWG will produce a charge pulse. The charge generated is determined by the voltage change from the AWG and the size of the capacitor. The shape of the pulse is determined by the rate of voltage change. Two precision capacitors were used with nominal values of 15 pF and 2 nF. They were placed inside an aluminum box with a BNC connector on one side and a SHV connector on the other. Reference waveforms form the AWG and precision capacitor outputs are shown in the following figures.

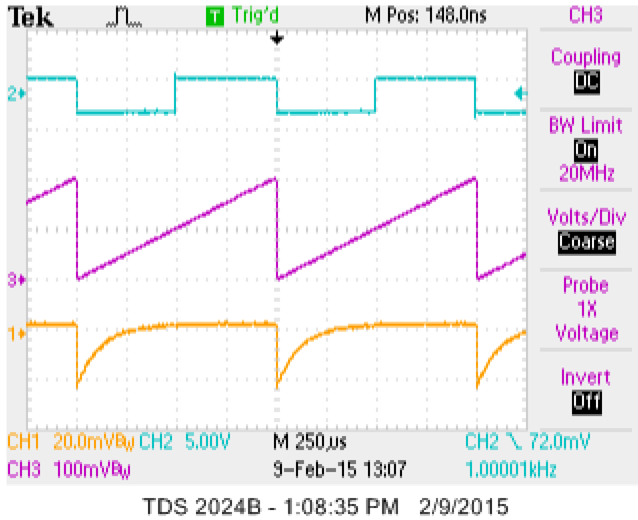


Figure 3.1 Reference AWG and capacitor waveforms.
Yellow(1)-Capacitor Output, Blue(2)-AWG Sync Signal, Magenta(3)-AWG Waveform Output

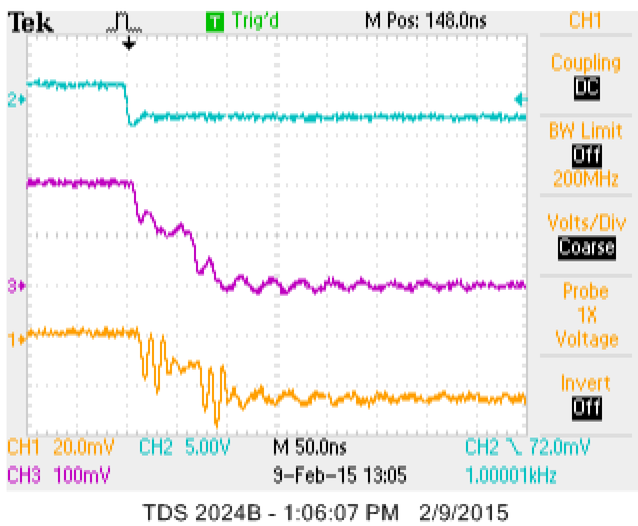


Figure 3.2 Reference AWG and capacitor waveform edges with reduced time scale.
Yellow(1)-Capacitor Output, Blue(2)-AWG Sync Signal, Magenta(3)-AWG Waveform Output

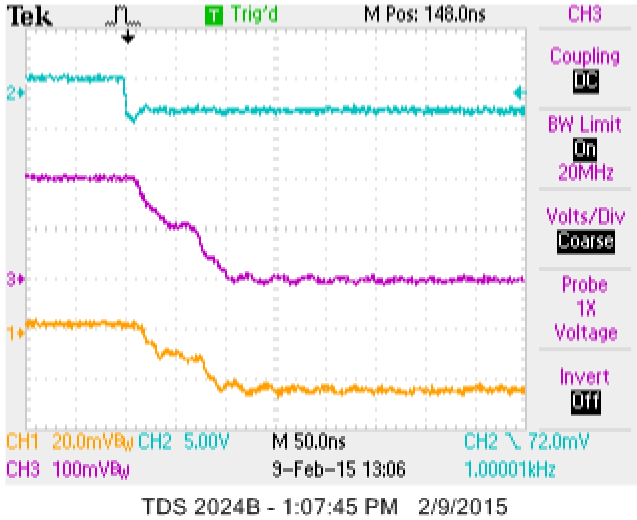


Figure 3.3 Reference AWG and capacitor waveforms with 20 MHz bandwidth.
Yellow(1)-Capacitor Output, Blue(2)-AWG Sync Signal, Magenta(3)-AWG Waveform Output

3.3 Configuration

Figure 3.4 shows the configurable settings available on the FEUM v1.x devices. Nominal settings for the device are all switches set at the median setting. Specific procedures will direct settings different from the nominal settings.

Test equipment configuration settings will be set as directed by specific procedures.

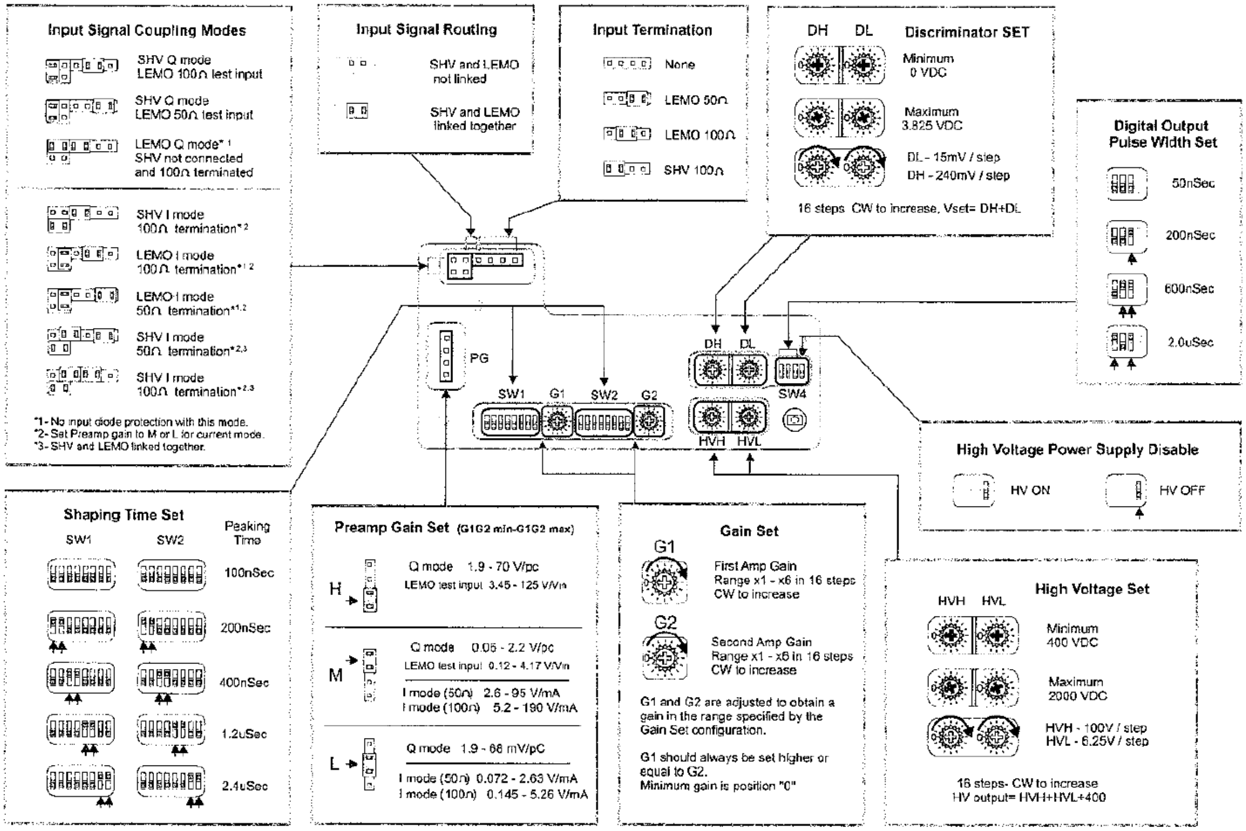


Figure 3.4. FEUM Prototype Configuration Settings

4.0 Reporting Requirements

4.1 Interim Reporting

The data to be collected for post-test analysis consist of primarily:pulse waveforms as collected on the oscilloscope;pulse height spectra collected by the MCA;series of data points used to characterize the variable of interest (e.g., linearity of gain, discriminator threshold).

The primary analysis will be processing spectral data into integral pulse height spectra, which will lead into reporting on relative FEUM neutron detection efficiency as a function of cable length, discriminator threshold, and environmental noise.

Interim test results will be provided to project stakeholders after initial phases of performance testing, and compared to those reported from previous IAEA testing relevant to the FEUM prototypes ("Evaluation of Front-End Electronics for Unattended Safeguards Instruments", 2011 IEEE Nuclear Science Symposium Conference Record, L.E. Smith et al.). Interim results will also include any results from tests already completed which provide early input to the IAEA in regards to the FEUM prototype suitability.

4.2 Vendor Feedback

PNNL will compile a list of comments for the FEUM prototype vendor. These items will be logged during testing and FEUM prototype review, and submitted to the vendor during or at the completion of testing, as appropriate.

4.3 Final Test Report

The final test report will be generated at the end of testing and after all analysis has been completed. The report is to include completed data sheets from the test procedures, and analysis of all data collected per the descriptions in this document and additional methods as defined after testing has begun.

The final content of the test report will be determined after all data have been collected and analyses have been performed. Table 7 provides a summary of the data to be collected and the expected analyses and/or metrics expected to be used for each test conducted.

Table 7. Summary of Tests, Data Collected, and Analyses

Test #	Section	Data Collected	Analysis/Metric
Test 1 – Feature Conformance Verification	N/A	Engineering analyses of design	Various
Test 2 – Pulse Rise Time	Test Removed	N/A	N/A
Test 3 – Gain and Charge Calibration	C.1	Input/output waveforms, data tables of gain vs. gain setting	Quantitative linearity

Test #	**Section**	**Data Collected**	**Analysis/Metric**
Test 4 – Analog Shaping Constant	C.1	Output Waveforms, Data Tables of pulse width and amplitude	Qualitative-pulse shape, Qualitative - pulse width and amplitude
Test 5 – Discriminator Threshold	C.2	Data tables of threshold vs. threshold setting	Quantitative linearity
Test 6 – TTL Pulse Width	C.3	Data tables of pulse width vs. settings	50% to 50% pulse width vs. expected
Test 7 – Bias Supply Voltage	C.4	Data tables of average voltage versus expected	Quantitative linearity.
Test 8 – Bias Supply Stability	C.5	Data plots of voltage over short periods on order of days or less	Verify all voltages are +/- 50 mV of expected
Test 9 – Input/Output Port Resistance	Test Removed	N/A	N/A
Test 10 – LED Count Rate	C.3	N/A	Visually verify 10-Hz count rate ~ as expected
Test 11 – Isolated Input Power	C.6	Data tables of high voltages vs. input voltage Data tables of output amplitude vs expected gain	Plot measured high voltage vs. expected Compute linearity of gain for each voltage input
Test 12 – Digital Input Logic Voltage Levels	C.7	Data tables of input voltage required to trigger output	Calculate V_{IH} and V_{IL} and compare to spec and TTL
Test 13 – Digital Summing	C.7	Pulse width and separation	Verify two discrete output pulses for independent and coincident inputs
Test 14 – Grounded Input Power	C.6	Data tables of high voltages vs. input voltage Data tables of output amplitude vs expected gain	Compare measured high voltage vs. expected Compute linearity of gain for each voltage input
Test 15 – Analog Output #1 and #2	C.8	DC offset with grounded power input Data tables of pulse width and height with grounded power input	Verify offset is 0 and Vcc Verify pulse shapes are similar Compare input amplitude to output amplitude and gain

Test #	**Section**	**Data Collected**	**Analysis/Metric**
Test 16 – Digital Output Logic Voltage Levels	C.3	Voltages at which output is logic 1 or 0 (V_{OH} and V_{OL})	Verify voltages are within spec and TTL norms
Test 17 – Ground Isolation	C.9	Data tables of port ground isolation	Verify isolation and note abnormal impedance
Test 18 – NGAM Compatibility (Optional)	Test Removed	N/A	N/A
Test 19 – Baseline FEUM Performance	C.10	MCA pulse height spectra Limited comparison to discriminator/SCA response	Construct integral pulse height curves, as a function of cable length and shaping time per IAEA performance targets
Test 20 –Radiated EMI/RFI Susceptibility	C.11	MCA pulse height spectra Limited comparison to discriminator/SCA response	Construct integral pulse height curves, as a function of cable length and shaping time per IAEA performance targets
Test 21 - Conducted EMI/RFI Susceptiblity	Test Removed	N/A	N/A
Test 22 –Ground Loop oise	Test Removed	N/A	N/A
Test 23 – Deadtime	C.13	Count rates from detector based on known input rates and/or time interval histograms	Fitting of measured count rate vs. input count rate to determine dead time values and characteristics (paralyzableor non-paralyzable), and investigation of leading edges in the time-interval histogram
Test 24 – Equivalent Noise Charge	C.14	Centroid and FWHM of calibrated pulser peaks	Calculation of ENC and construction of input capacitance vs ENC and shaping time vs ENC graphs
Test 25 – High Radiation Field Susceptibility	C.15	MCA pulse height spectra Limited comparison to discriminator/SCA response	Construct integral pulse height curves, as a function of cable length and shaping time per IAEA performance targets

Appendix A

Requirements Compliance Matrix

Requirement	Source of Requirement		Verification	Comments
Preamplifier				
Charge- or Current-Sensitive	Specifications	Ver 1	Various	
Rise Time < 20 ns	Specifications	Ver 1	Test 2	
Shaping Amplifier				
Bipolar Shaping	Specifications	Ver 1	Test 1	
τ = 0.05, 0.1, 0.25, 0.5, 1.0, 2.0 μs	Specifications	Ver 1	Test 3	
Gain 0.001 – 5000 pC/V	Specifications	Ver 1	Test 4	
Vout 0 to 0.9 Vcc	Specifications	Ver 1	Test 4	
1 Vout superimposed on Vcc	Specifications	Ver 1	Test 14, Test 15	
1 Vout decoupled from Vcc	Specifications	Ver 1	Test 15	
Discriminator				
Adjustable 0–0.9 Vcc	Specifications	Ver 1	Test 5	
> 100 settings	Specifications	Ver 1	Test 1	
TTL pulse width 50–500 ns	Specifications	Ver 1	Test 6	
Bias Supply				
Adjustable 200–2000 V	Specifications	Ver 1	Test 7	
Vbias increments of 50 V	Specifications	Ver 1	Test 7	
Noise < 0.02 V over entire range	Specifications	Ver 1	Test 7	
Stability ±0.05 V over entire range	Specifications	Ver 1	Test 8	
Bias protection network for HV transients	Specifications	Ver 1	Test 1	This is verified by visual inspection/design analysis because testing would likely be destructive
Detector Input				
Zin = 93 Ω	Specifications	Ver 1	Test 9	
SHV type connector	Specifications	Ver 1	Test 1	
Input NEMA rated	Specifications	Ver 1	Test 1	
Test Input				
Zin = 50 Ω	Specifications	Ver 1	Test 9	
Connector LEMO (HGP.00.250)	Specifications	Ver 1	Test 1	

Requirement	Source of Requirement		Verification	Comments
Vcc Input				
Nominal voltage 12 VDC, rated for 9 to 13.8 VDC	Specifications	Ver 1	Test 11	
Connector LEMO (HGP.00.302)	Specifications	Ver 1	Test 1	
Digital TTL Input (Summing)				
Zin = 50 Ω	Specifications	Ver 1	Test 9	
Logic: 2.4 V to 4 V (high); maximum of 5.5 V	Specifications	Ver 1	Test 13	
Connector LEMO (HGP.00.250)	Specifications	Ver 1	Test 1	
Shaping Amplifier #1				
Superimposed on Vcc Supply	Specifications	Ver 1	Test 14	
Zout = 50 Ω	Specifications	Ver 1	Test 9	
Connector LEMO (HGP.00.250)	Specifications	Ver 1	Test 1	
Shaping Amplifier #2				
Zout = 50 Ω	Specifications	Ver 1	Test 9	
Connector LEMO (HGP.00.250)	Specifications	Ver 1	Test 9	
Discriminator Digital Output				
Logic: 2.4 V to 4 V (high); maximum of 5.5 V	Specifications	Ver 1	Test 16	
Zout = 50 Ω	Specifications	Ver 1	Test 9	
Connector LEMO (HGP.00.250)	Specifications	Ver 1	Test 1	
LED count-rate indicator				
Blinks once for each TTL output pulse	Specifications	Ver 1	Test 10	
Form Factor				
Stainless Steel	Specifications	Ver 1	Test 1	
100 cm3 volume, >2 ratio	Specifications	Ver 1	Test 1	
< 4 fasteners access	Specifications	Ver 1	Test 1	
Discriminator threshold externally visible	Specifications	Ver 1	Test 1	
Ground Isolation				
Input ground isolated from output ground and chassis ground	Specifications	Ver 1	Test 17	DUT may not have all of the configurable options listed in specification
Input ground connected to output ground, isolated from chassis ground	Specifications	Ver 1	Test 17	

Requirement	**Source of Requirement**		**Verification**	**Comments**
Input ground connected to chassis ground but isolated from output ground	Specifications	Ver 1	Test 17	
Output ground connected to chassis ground but isolated from input ground	Specifications	Ver 1	Test 17	
UMS DAQ Compatibility				
Compatible with NGAM	Desired Functionality Pg 5	Ver 1	Test 18	Optionally tested
Compatible with UNAP	Desired Functionality Pg 5	Ver 1	N/A	Test equipment is not readily available. TTL output tests check part of functionality.
Compatible with ADAM	Desired Functionality Pg 5	Ver 1	N/A	Demonstration of NGAM functionality suffices for ADAM.
Compatible with mini-GRAND	Desired Functionality Pg 5	Ver 1	N/A	Test equipment is not readily available. TTL output tests check part of functionality.
Environmental				
Operating Temp -10 °C to 50 °C	Specifications	Ver 1	N/A	Environmental not tested at this stage
Storage Temp -40 °C to 80 °C	Specifications	Ver 1	N/A	Environmental not tested at this stage
Radiation Resistance Class 3 per NRTP 1.0	Specifications	Ver 1	N/A	Environmental not tested at this stage
Vibration per MIL-STD 810F	Specifications	Ver 1	N/A	Environmental not tested at this stage
Shock per MIL-STD-810F	Specifications	Ver 1	N/A	Environmental not tested at this stage
High Temp per MIL-STD-810F	Specifications	Ver 1	N/A	Environmental not tested at this stage
Low Temp per MIL-STD-810F	Specifications	Ver 1	N/A	Environmental not tested at this stage
Humidity per MIL-STD-810F	Specifications	Ver 1	N/A	Environmental not tested at this stage
Moisture per IP-62	Specifications	Ver 1	N/A	Environmental not tested at this stage
Seismic per MIL-STD-461E	Specifications	Ver 1	N/A	Environmental not tested at this stage

Requirement	Source of Requirement		Verification	Comments
Radiated Emissions per MIL-STD-461E	Specifications	Ver 1	N/A	Environmental not tested at this stage
Radiated Susceptibility per MIL-STD-461E, 10 V/m field strength 14 kHz to 18 GHz	Specifications	Ver 1	Test 20	Partial testing Performed to verify concerning EMI issues
Electrostatic Discharge per EN61000-4-2, 15 kV	Specifications	Ver 1	N/A	Environmental not tested at this stage
Performance Targets	Specifications Pg 20	Ver 1	Test 19, 20, 21	

* References in the source column refer to the FEUM Work Plan Version 1, 2/20/14

Appendix B

IAEA's Technical Specifications for FEUM

Revised 17 February 2012

Definitions

L	Length of coaxial cable (typically RG-71B/U) between detector and FEUM
C_{ext}	External capacitive loading on the preamplifier (e.g. cable + detector)
V_{cc}	DC supply voltage for FEUM
HV Bias	High-voltage bias provided to detector (e.g. He-3 or fission chamber)
$\tau_{CR} = \tau_{RC} = \tau$	Shaping time constant for differentiator-integrator pulse shaping
T	Lower-level discriminator threshold
DPW	Digital pulse width (ns) of discriminator TTL output signal
R	Count rate (counts per second, cps) above the discriminator threshold
Z	Characteristic impedance of input and output interfaces (Ohm, Ω)
DAQ	Data acquisition instrumentation
SCA	Single channel analyzer with lower and upper discriminator thresholds

Architecture and General Specifications

A schematic overview of FEUM deployment is given in Figure 1. The text that follows provides additional detail about the system architecture and technical specifications.

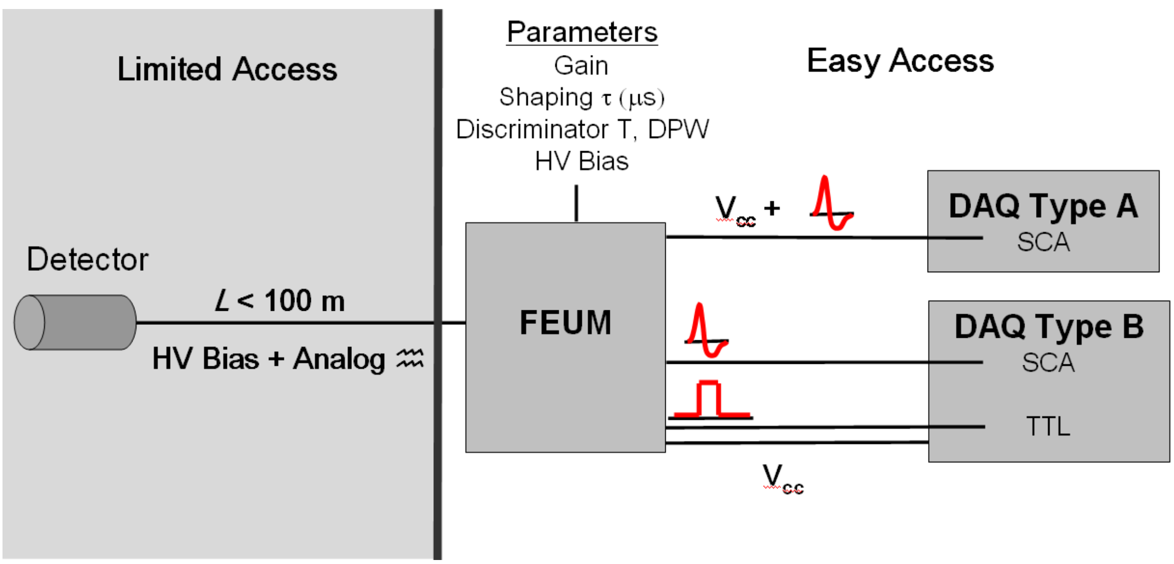


Figure 1. Conceptual overview of FEUM implementation. FEUM will be separated from the detector by distances up to 100 m (dependent on facility and instrument constraints) so that it can be located in easily accessible areas. FEUM will be coupled to one of two different data acquisition (DAQ) instruments currently utilized by the IAEA.

Preamplifier

- Charge-sensitive and/or current-sensitive
- Rise time < 20 ns at C_{ext} = 0 pF, < 50 ns at C_{ext} = 100 pF

Shaping Amplifier

- Bipolar (CR^2-RC) shaping
- τ : internally adjustable to discrete settings. The nominal range and values are τ = 0.05, 0.1, 0.25, 0.5, 1.0, 2.0 μs
- Gain: internally adjustable to discrete settings with a range to accommodate sensors ranging from U-235 fission chambers (~1x10^{-3} pC per event) to NaI(Tl) with photomultiplier tubes (~5000 pC per event). The nominal range and discrete values are 0.001, 0.005, 0.01, 0.05, 0.1, 0.25, 0.5, 1, 5, 10, 50, 100, 500, 1000, 5000 pC/ V_{out}.
- Output amplitude range: 0 to ~0.9*V_{cc}
- Output is delivered in two different forms for compatibility with DAQ instruments:
    - Superimposed on V_{cc}
    - Decoupled from V_{cc} (i.e. referenced to ground)

Discriminator

- Lower level discriminator (LLD): External adjustable from 0 to ~0.9*V_{cc}, with controls that allow a high number of discrete (e.g. >100) settings.
- TTL output pulse width: internally adjustable to discrete settings. The nominal range and values are 50, 100, 200, 500 ns.

Bias Supply

- Adjustable from +200 V to +2000 V: internal discrete settings, nominally in increments of 50 V.
- Noise: ~ 0.02 V over operating range
- Stability per hour: ~ 0.05 V over operating range
- Bias protection network for HV transients

Detailed Specifications

Input

- From detector
    - Z_{in} = 93 Ω
    - Connector: SHV type consistent with NEMA Standard IP-62 (see Quality Specifications section)
- Test Input
    - Z_{in} = 50 Ω
    - Connector: LEMO type coaxial connector (nominal HGP.00.250)
- V_{cc} Input
    - +12 VDC (+9 to 13.8 VDC)
    - Connector: LEMO type coaxial connector (nominal HGP.00.302)
- Digital (TTL) summing
    - Z_{in} = 50 Ω
    - Logic: 2.4 V to 4 V (high); maximum of 5.5 V
    - Connector: LEMO type coaxial connector (nominal HGP.00.250)

Output

- Shaping Amplifier #1
    - Superimposed on V_{cc} supply
    - Z_{out} = 50 Ω
    - Connector: LEMO type coaxial connector (nominal HGP.00.250)
- Shaping Amplifier #2

- Z_{out} = 50 Ω
- Connector: LEMO type coaxial connector (nominal HGP.00.250)

- Discriminator Digital (TTL)
  - Z_{out} = 50 Ω
  - Logic: 2.4 V to 4 V (high); maximum of 5.5 V
  - Connector: LEMO type coaxial connector (nominal HGP.00.250)
- LED count-rate indicator
  - Blinks once for each Discriminator digital output pulse

Note: To reduce the complexity and size of the field-prototype enclosures, the inputs and outputs can take the form of short cables rather than bulkhead connectors. Cable types and connectors should be compatible with the requirements stated above.

<u>Form Factor</u>

- Polished stainless steel enclosure with nominal volume of ~100 cm^3 and nominal aspect ratio of > 2 (i.e. length to cross-sectional dimension). Significant departures from this enclosure size or shape need to be negotiated with the IAEA.
- Enclosure should be capable of being opened with fewer than four fasteners
- Numerical discriminator threshold value must be externally visible

<u>Ground Isolation</u>

To provide flexibility in the deployment of FEUM at facilities where ground loop problems may arise, specific ground isolation options are required. The design should allow for the following options via internal jumper settings:

- Input ground isolated from output ground and FEUM chassis ground;
- Input ground connected to output ground but isolated from FEUM chassis ground;
- Input ground connected to FEUM chassis ground but isolated from output ground;
- Output ground connected to FEUM chassis ground but isolated from input ground.

Environmental and Quality Targets

The following environmental and quality information is given to inform FEUM development, not as strict requirements for the initial field prototypes. The initial prototypes do not need to be tested to these requirements before delivery to the IAEA.

The list below indicates the range and types of tests that will likely be required of future production versions of FEUM. Therefore, design choices for the FEUM field prototypes should be consistent with these targets.

- Operating Temperature: -10^{o}C to 50^{o}C;
- Storage Temperature: -40^{o}C to 80^{o}C;
- Radiation Resistance
  - Reference Nuclear Radiation Test Procedures for IAEA Safeguards Systems NRTP 1.0;
  - Should meet Special Applications Class 3 (use 50 mSv/hr for 7 years as the ambient dose equivalent).
- Vibration Test per Military Standard 810F, Method 514.5, Procedure II-Loose Cargo Transportation, 5 hour test;
- Shock Testing per Military Standard 810F, Method 516.5, Procedure IV-Transportation Drop;
- High Temperature Test per Military Standard 810F, Method 501.4, Procedure I (storage), test under condition HOT, 7 cycles, 4 hours per cycle;
- Low Temperature Test per Military Standard 810F, Method 502.4; Procedure I (storage), test under condition COLD, 24 hour soak;
- Humidity Tests per Military Standard 810F, Method 507.4 (30^{o}C, 95% Relative Humidity);
- Moisture Intrusion per NEMA Standard IP-62;
- Seismic (Earthquake) Testing per IEEE Standard 344-2004, Zone 4, 2 G vertical, 3 G horizontal;
- Radiation Emissions per Military Standards 461E, technique RE102, 14KHz to 18 GHz, equipment classification for Navy Fixed/Air Force, or equivalent European Norm Standard;
- Radiation Emissions per Military Standards 461E, technique RS103, 10 Volts/meter field strength, 14 KHz to 18 GHz, equipment classification for Navy Ground, or equivalent European Norm Standard;
- Electrostatic Discharge per European Norm Standard EN61000-4-2, 15KV.

Performance Targets

The integral pulse-height spectrum (PHS) [1] is the basis of the FEUM performance targets (additional discussion of the integral PHS can be found in Appendix A). These performance targets are intended to ensure that FEUM can support the wide range of radiation detection scenarios where IAEA Unattended Monitoring Systems (UMS) are applied. In this context, a "scenario" is defined by a number of factors that include the detector type (e.g. He-3, B-lined, fission chamber), distance between the detector and front-end electronics and the type of cable used (e.g. 50 m of RG-71 cable), and maximum event rate (e.g. 400,000 cps).

The performance targets have been defined in a way that can be tested in typical radiation detection laboratory using the following components:

- He-3 proportional counter (2.54-cm diameter, poly-moderated);
- Neutron source (e.g. Cf-252, tens of μCi);
- FEUM prototype;
- RG-71B/U cables with lengths of 1, 50, and 100 meters;
- Counter/timer.

FEUM Performance Requirements are shown qualitatively in Figure 2 and quantitatively in Table 1. There are two primary metrics in these requirements, $\varepsilon_{neutron}$ and T_{noise} where:

- T_{noise} *is the threshold* where R_{noise} < 5 cps with no neutron source present;
- $\varepsilon_{neutron}(T)$ is the relative neutron efficiency defined to be $R_{net}(T) / R_{ideal}$
- R_{ideal} = net neutron count rate for $T = T_{noise}$ under assumptions of $L \sim 0$, $\tau \sim 2.0$;
- $R_{net}(T)$ = net neutron count rate after subtraction of $R_{noise}(T)$

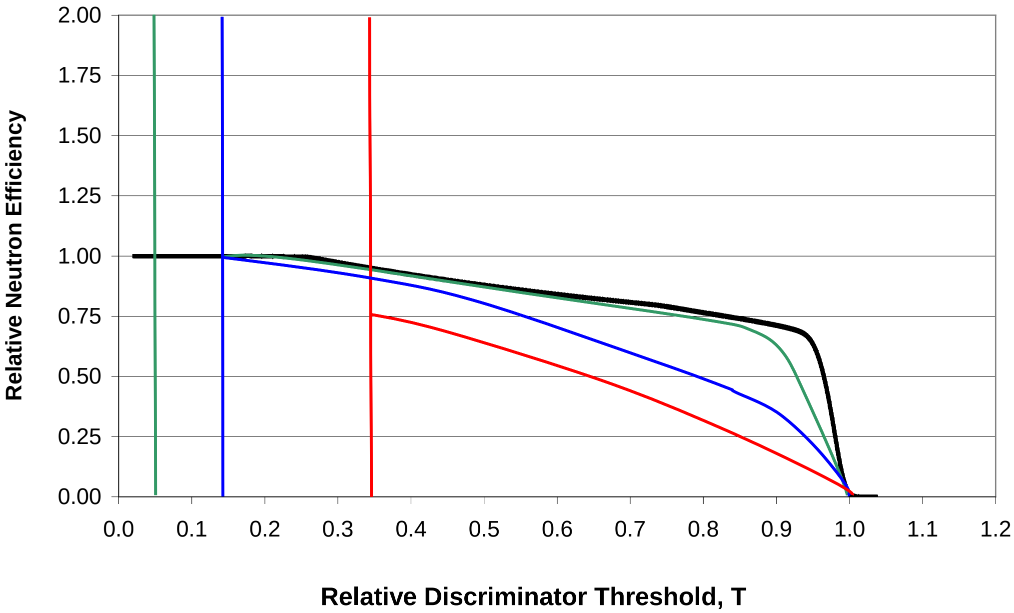


Figure 2. Qualitative depiction of the FEUM performance metrics, T_{noise} and $\varepsilon_{neutron}(T)$ in an integral PHS form. Quantitative target values for the three scenarios are given in Table 1.

Table 1. Quantitative FEUM performance targets for T_{noise} and $\varepsilon_{neutron}(T)$ for a variety of cable length and shaping constant.

***L (m RG-71)*, τ (μs)**	T_{noise}	$T, \varepsilon_{neutron}$
(1, 2) (50, 2)	0.05	(0.20, 1.00) (0.50, 0.85) (0.80, 0.75)
(1, 0.1) (50, 0.5) (100, 0.5) (100, 2)	0.15	(0.20, 0.90) (0.50, 0.75) (0.80, 0.50)
(50, 0.1) (100, 0.1)	0.35	(0.35, 0.75) (0.50, 0.60) (0.80, 0.30)

References
[1] G.F. Knoll, *Radiation Detection and Measurement*, 3rd Edition, 2000.

Appendix C

Procedures

C.1 TEST 3, TEST 4 – Output Gain/Charge Calibration and Shaping Time Constant

C.1.1 Purpose:

This test is to measure the gain and the pulse shaping time constant to verify they are as expected and suitable for a FEUM. This test will also measure/calculate the absolute charge calibration.

C.1.2 Required Equipment:

Power supply for DUT

AWG Multi-Channel Analyzer

Oscilloscope

Testing cable to connect DUT digital input to BNC jack

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

High Voltage, Precision Capacitor

C.1.3 References:

DUT documentation provided by vendor

C.1.4 Preparation:

Ensure that the testing surface is ESD safe.

C.1.5 Procedure:

C.1.5.1 Gain

1. Connect the AWG and precision capacitor to the detector input port and the oscilloscope to the analog output ports #1 and #2 as shown in
2. Figure C**.1**.
3. Connect a 12V DC power supply to the DUT isolated power input (not shown).
4. Configure the DUT for nominal operation (charge-sensitive).
5. Record the DUT settings if different than nominal.
6. Set the AWG to output pulses suitable for the DUT in the low gain range. Record the setting selected (input pulse amplitude) in Table C.1.

7. Select five gain settings and set the DUT to each setting. Measure each output pulse amplitude and record the gain setting, output pulse amplitude and calculated gain for each.
8. Verify the expected gain for all gain settings by comparing the calculated and measured amplitudes.
9. Repeate steps 1-7 for current sensitive mode.
10. Disconnect the oscilloscope and connect the MCA to the isolated analog output as shown in Figure C.2. (This can alternatively be done in parallel with the preceding steps using a T coupler to connect both the MCA and Oscilloscope).
11. Repeat steps 5–7 with the MCA, instead recording the peak channel from the MCA for each gain setting. Record the data in Table C.2 through Table C.7. These data will be used to construct linearity plots and charge calibration for the amplifier.
12. Repeat steps 5–10for the mid-gain and high-gain range.
13. Calculate the absolute charge calibration for each gain setting, by dividing the amount of known input charge to measured peak channel on the MCA.

C.1.5.2 Shaping Time Constant

14. Return all DUT settings to the nominal settings.
15. Cycle through all the shaping time constant settings and verify the pulse shape is consistent with bipolar output pulses.
16. Save the oscilloscope waveforms for each test and MCA spectra.
17. Repeat all steps for the DUT in current-sensitive mode.

C.1.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

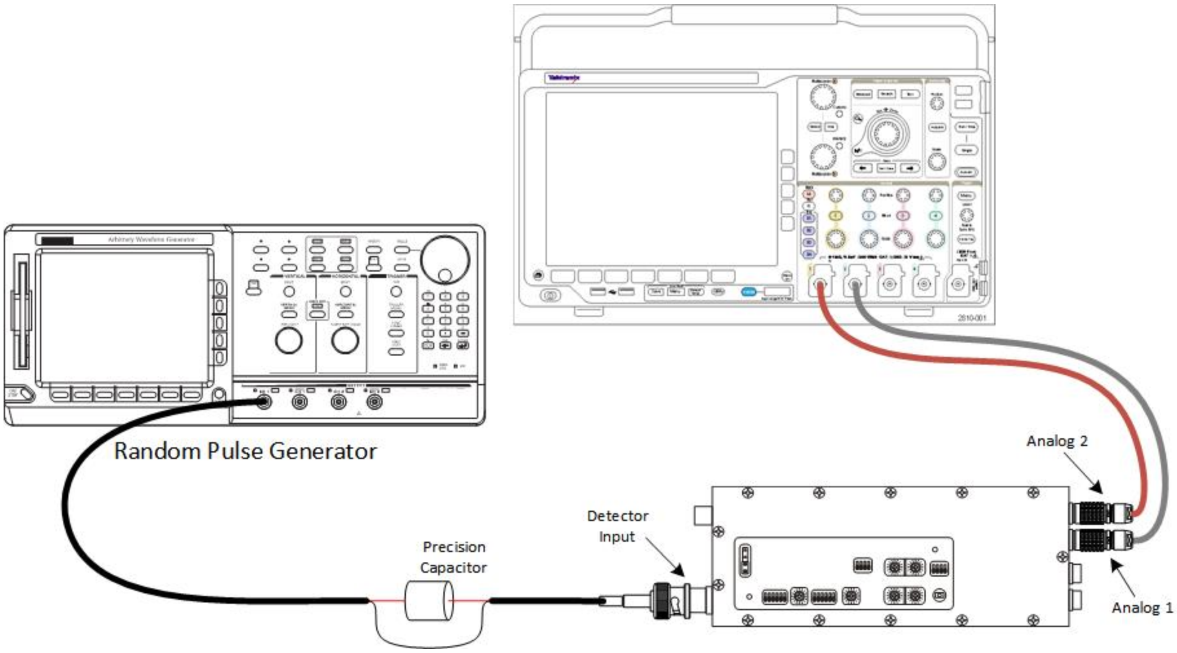


Figure C**.**1. Using O-Scope to Measure Gain Linearity

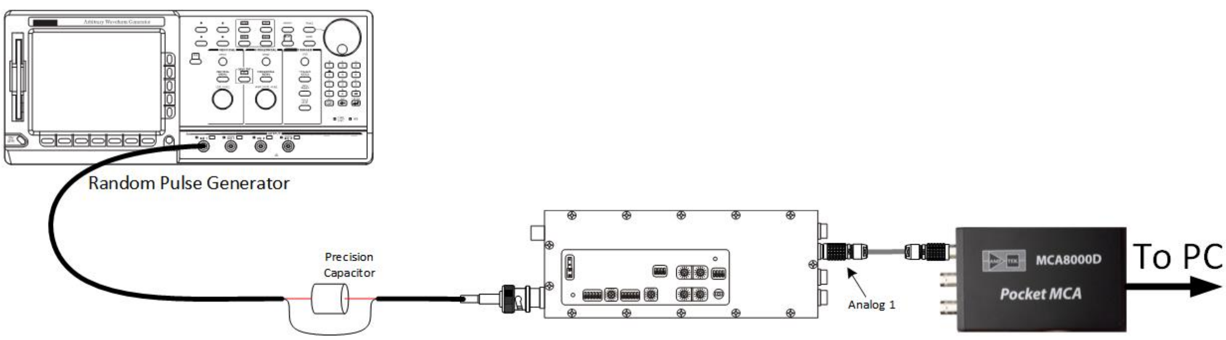


Figure C.2. Using MCA to Measure Gain Linearity and Charge Calibration

C.1.6.1 Data Tables:

Table C.1. DUT Configuration

Parameter	Setting
Input Signal Mode (Q or I)	
Input Termination	
Charge Gain (range)	
G1 – Gain	
G2 – Gain	
HVH - High Voltage	
HVL - High Voltage	
SW1 - Shaping Time	
SW2 - Shaping Time	
DH – Discriminator High	
DL – Discriminator Low	
Digital Ouput Pulse Width	

Table C.2. Gain Results for Low-Range Gain (Charge Sensitive)

Test #	Input Pulse Charge	Gain	Output Pulse Amplitude	Calculated Gain	Peak Channel
1					
2					
3					
4					
5					

Table C.3. Gain Results for Mid-Range Gain (Charge Sensitive)

Test #	Input Pulse Charge	Gain	Output Pulse Amplitude	Calculated Gain	Peak Channel
1					
2					
3					
4					
5					

Table C.4. Gain Results for High-Range Gain (Charge Sensitive)

Test #	Input Pulse Charge	Gain	Output Pulse Amplitude	Calculated Gain	Peak Channel
1					
2					
3					
4					
5					

Table C.5. Gain Results for Low-Range Gain (Current Sensitive)

Test #	Input Pulse Amplitude	Gain	Output Pulse Amplitude	Calculated Gain	Peak Channel
1					
2					
3					
4					
5					

Table C.6. Gain Results for Mid-Range Gain (Current Sensitive)

Test #	Input Pulse Amplitude	Gain	Output Pulse Amplitude	Calculated Gain	Peak Channel
1					
2					
3					
4					
5					

Table C.7. Gain Results for High-Range Gain (Current Sensitive)

Test #	Input Pulse Amplitude	Gain	Output Pulse Amplitude	Calculated Gain	Peak Channel
1					
2					
3					
4					
5					

C.2 TEST 5 – Discriminator Threshold

C.2.1 Purpose:

This test is to evaluate the functionality and linearity of the discriminator threshold over the full range of operation.

C.2.2 Required Equipment:

Power supply for DUT

AWG

Multi-channel Analyzer

Oscilloscope

Testing cable to connect DUT digital input to BNC jack

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

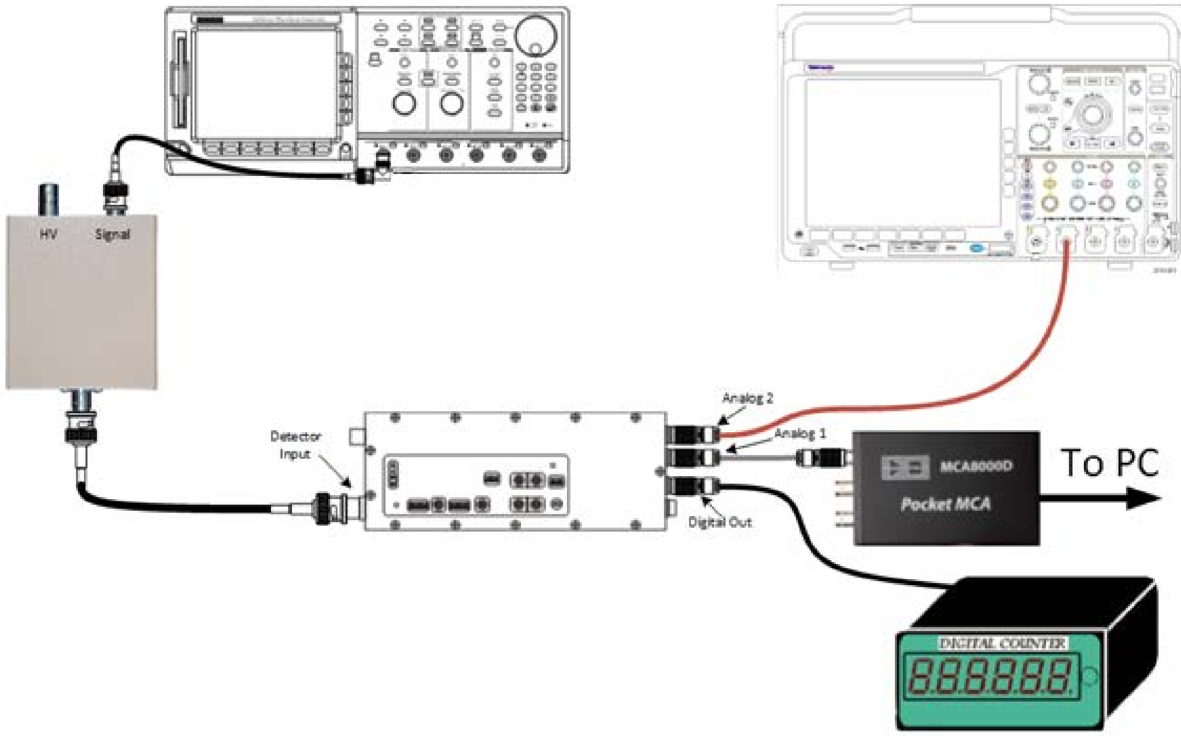
C.2.3 References:

DUT documentation provided by vendor

C.2.4 Preparation:

Ensure that the testing surface is ESD safe.

C.2.5 Procedure:



1. Figure C.3.
2. Configure the DUT for nominal operation (charge-sensitive).
3. Record the DUT settings used in Table C.8 if different than nominal.
4. Set the discriminator setting on the DUT to 0V.
5. Set the AWG output and the DUT gain to the lowest setting possible.
6. Adjust the DUT output pulse height to measure the LLD (lower level discriminator). This is accomplished by raising the AWG amplitude in the smallest increment possible until the discriminator no longer filters out the pulse and the digital output begins to provide pulses.
7. Record the AWG setting and output pulse amplitude from the oscilloscope and the peak energy from the MCA for this discriminator setting in Table C.9.
8. Adjust the discriminator setting on the DUT up four steps (60mV).
9. Repeat steps 5–9 63 times until the highest discriminator setting is tested.
10. Repeat all steps for the DUT in current sensitive mode and record results in Table C.10.

C.2.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

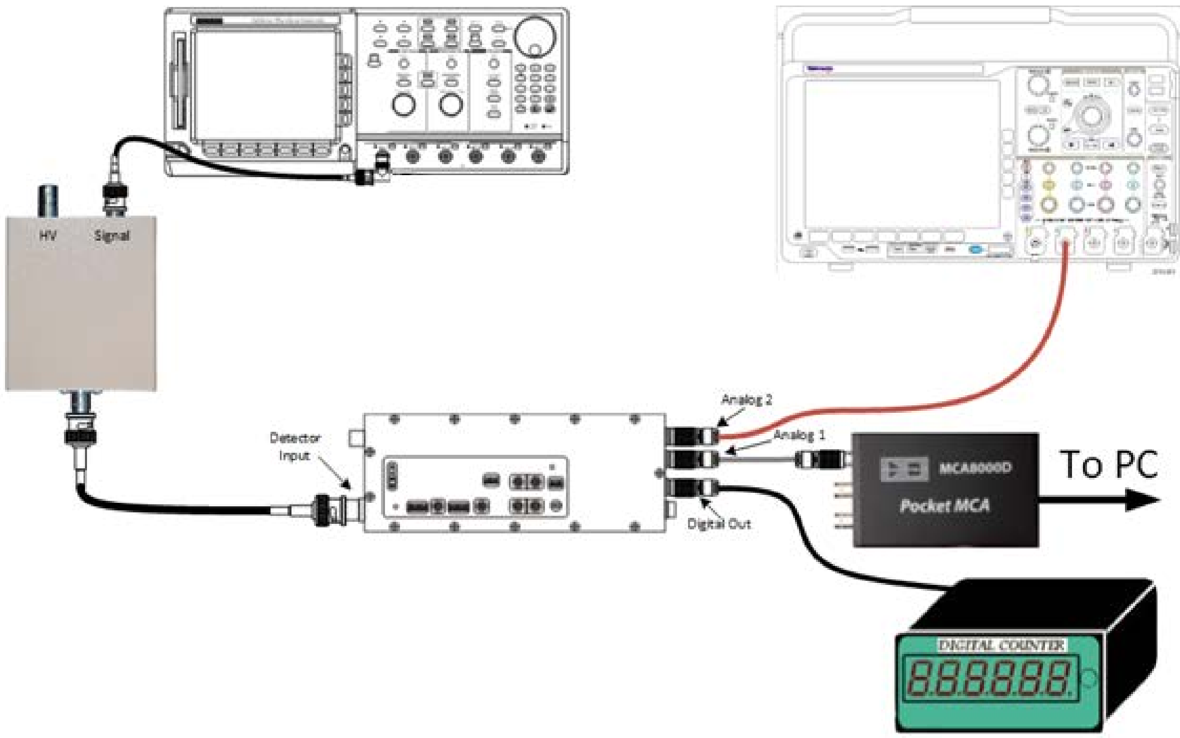


Figure C.3. Discriminator Threshold Test Setup

C.2.6.1 Data Tables:

Table C.8. DUT Configuration

Parameter	Setting
Input Signal Mode (Q or I)	
Input Termination	
Charge Gain (range)	
G1 – Gain	
G2 – Gain	
HVH - High Voltage	
HVL - High Voltage	
SW1 - Shaping Time	
SW2 - Shaping Time	
DH – Discriminator High	
DL – Discriminator Low	
Digital Ouput Pulse Width	
HV Power Switch	Off

Table C.9. Discriminator Measurement Results (Charge Sensitive)

Test #	Discriminator Threshold	Measured LLD Voltage	AWG Voltage Amplitude	MCA LLD Energy
1	60 mV			
2	120 mV			
3	180 mV			
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				
37				
38				
39				
40				
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				
51				
52				
53				
54				

Test #	Discriminator Threshold	Measured LLD Voltage	AWG Voltage Amplitude	MCA LLD Energy
55				
56				
57				
58				
59				
60				
61				
62				
63				
64	3825 mV			

Table C.10. Discriminator Measurement Results (Current Sensitive)

Test #	Discriminator Threshold	Measured LLD Voltage	AWG Voltage Amplitude	MCA LLD Energy
1	60 mV			
2	120 mV			
3	180 mV			
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				
21				
22				
23				
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34				
35				
36				

Test #	Discriminator Threshold	Measured LLD Voltage	AWG Voltage Amplitude	MCA LLD Energy
37				
38				
39				
40				
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				
51				
52				
53				
54				
55				
56				
57				
58				
59				
60				
61				
62				
63				
64	3825 mV			

C.3 TEST 6, TEST 10, TEST 16 – TTL Pulse Width, LED Blink Rate Output Logic Levels

C.3.1 Purpose:

This test is to verify that the logic output is compatible with interfacing devices by inspecting the output voltage levels and the signal's pulse width.

This test also verifies that the LED blinks at an appropriate rate.

C.3.2 Required Equipment:

Power supply for DUT

Oscilloscope with one scope probe (0-5V) and single shot functionality

AWG

Testing cable to connect DUT digital input to BNC jack

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.3.3 References:

DUT documentation provided by vendor

C.3.4 Preparation:

Ensure that the testing surface is ESD safe.

C.3.5 Procedure:

1. Configure the DUT for nominal operation (charge-sensitive)
2. Record the DUT settings in Table C.11.
3. Set the DUT TTL pulse width to 2.0 µs.
4. Select a AWG output amplitude and record
5. Connect the AWG to the detector input and an oscilliscope to the digital output as shown in Figure C.4.
6. Connect the power supply to the DUT.
7. Power on the DUT.
8. Measure and record at least three pulses from the digital output using the oscilloscope's single shot function. Record the rise time, fall time, pulse width, low voltage, high voltage, and ending low voltage in Table C.12 to Table C.17 as appropriate.
9. Repeat measurements with the DUT's pulse width set to:
   a. 600 ns
   b. 200 ns
   c. 50 ns

10. For several of the tests previous, visually verify that the LED blinks at the rate of the AWG input pulse (10 Hz).

C.3.6 Test Data

UUT Serial Number:
UUT Part Number:
Tested By:
Test Date:

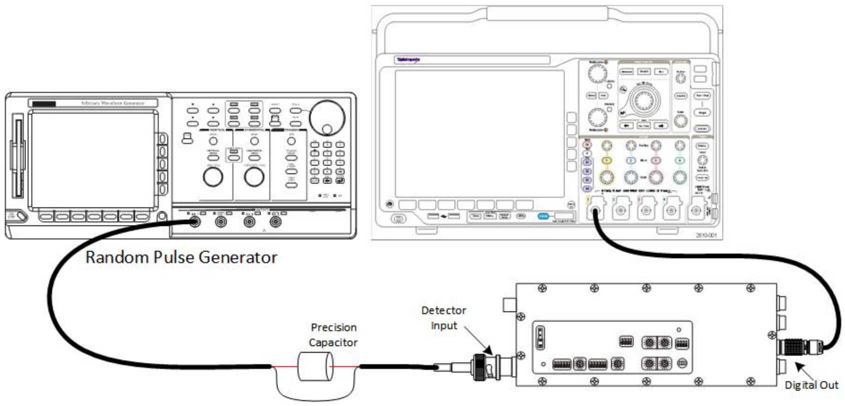


Figure C.4. Using O-Scope to Measure Output Logic Levels Triggered by Pulse Generator

C.3.6.1 Data Tables:

Table C.11. DUT Configuration

Parameter	Setting
Input Signal Mode (Q or I)	
Input Termination	
Charge Gain (range)	
G1 – Gain	
G2 – Gain	
HVH - High Voltage	
HVL - High Voltage	
SW1 - Shaping Time	
SW2 - Shaping Time	
DH – Discriminator High	
DL – Discriminator Low	
Digital Ouput Pulse Width	

Table C.12. Output Logic Characteristics, pulse width 2.0 µs

Test #	Rise Time	Fall Time	Pulse Width	Low 1 (V)	High (V)	Low 2 (V)
1						
2						
3						

Rise time (the time required for the signal to rise from 10% to 90% of pulse height)

Fall time (the time required for the signal to fall from 90% to 10% of pulse height)

Pulse width (the time interval from the rising edge to falling edge of pulse where the amplitude is 50% of pulse height)

Low 1 - stable voltage prior to the pulse

High - stable voltage at high logic level

Low 2 - stable voltage prior to the pulse

Table C.13. Output Logic Characteristics, pulse width to 1.8 µs

Test #	Rise Time	Fall Time	Pulse Width	Low 1 (V)	High (V)	Low 2 (V)
1						
2						
3						

Table C.14. Output Logic Characteristics, pulse width to 1.2 µs

Test #	Rise Time	Fall Time	Pulse Width	Low 1 (V)	High (V)	Low 2 (V)
1						
2						
3						

Table C.15. Output Logic Characteristics, pulse width to 800 ns

Test #	Rise Time	Fall Time	Pulse Width	Low 1 (V)	High (V)	Low 2 (V)
1						
2						
3						

Table C.16. Output Logic Characteristics, pulse width to 400 ns

Test #	Rise Time	Fall Time	Pulse Width	Low 1 (V)	High (V)	Low 2 (V)
1						
2						
3						

Table C.17. Output Logic Characteristics, pulse width to 200 ns

Test #	Rise Time	Fall Time	Pulse Width	Low 1 (V)	High (V)	Low 2 (V)
1						
2						
3						

C.4 TEST 7- Bias Supply Output Voltage

C.4.1 Purpose:

This test is to determine operational range of the detector bias voltage and ensure that minimal noise is present

C.4.2 Required Equipment:

Power supply for the DUT

Multimeter with a HV probe (rated to at least $2000V_{DC}$)

Oscilloscope

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.4.3 References:

DUT Documentation Provided by Vendor

C.4.4 Preparation:

Ensure that the testing surface is ESD safe.

C.4.5 Procedure:

1. Set the DUT high-voltage setting to the minimum value.
2. Connect the DUT to the power supply.
3. Power on the DUT.
4. Measure and record the bias voltage using the multimeter and the 1000:1 HV probe. (see Figure C.5). Multiply the value read by 1000, and record the voltage in Table C.18.
5. Power off the DUT.
6. Increment the high-voltage bias supply by eight units (50 V).
7. Repeat steps 3–7 until testing has completed measurements at the maximum voltage output and all 32 high-voltage settings have been measured.

C.4.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

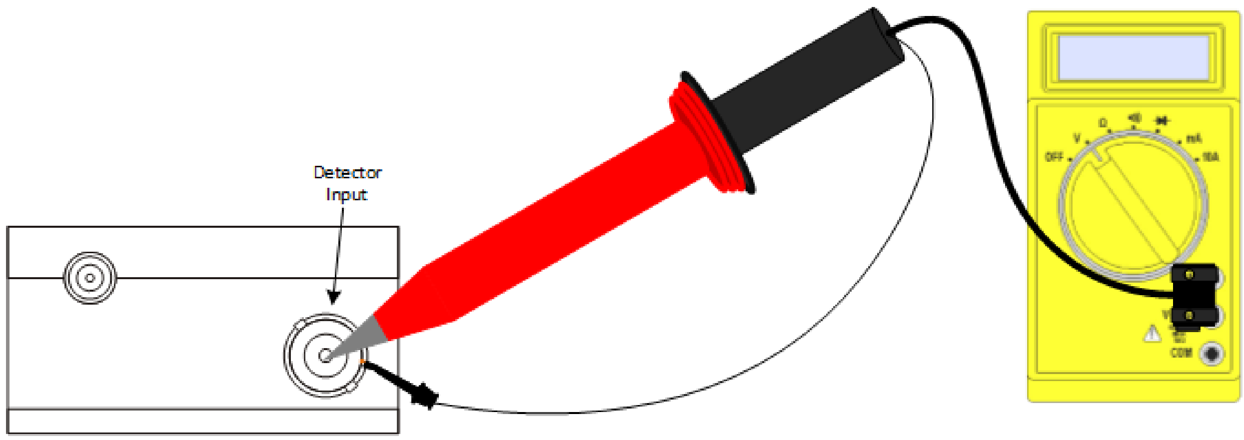


Figure C.5. Using Multimeter to Measure Bias Voltage

C.4.6.1 Data Table:

Table C.18. HV Bias Characteristics

Test #	Setting (V)	Measured (V)
1	Minimum 400 V	
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		

Test #	Setting (V)	Measured (V)
20		
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		
32	Maximum 1993.75V V	

C.5 TEST 8 - Bias Supply Stability

C.5.1 Purpose:

This test is to determine the stability of the detector's bias voltage. Measurements will be taken, starting at the minimum output voltage, for an hour and then for several days. After each hour the voltage output will be incremented by ¼ of the operating range till the maximum output voltage is reached.

C.5.2 Required Equipment:

Power supply for the DUT

DAQ /Data logger capable of:

- Measuring up to 10 V with divide by 500 voltage divider to achieve 2000 V_{DC}
- Accuracy to at least 2.5 significant figures
- Resolution high enough to measure 50 mV
- Logging once every 100 ms and every 1 s

Testing cable to connect from the DUT's detector input to the DAQ

Jeweler's screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.5.3 References:

DUT documentation Provided by Vendor

C.5.4 Preparation:

Ensure that the testing surface is ESD safe.

C.5.5 Procedure:

1. Set the DUT high-voltage bias to the minimum value.
2. Configure the power supply for 12V DC and connect it to the DUT.
3. Connect the test cable from the DUT detector input to the DAQ (see Figure C.6). Insert a 500:1 voltage divider in series with the DAQ in order to measure up to a 2000 V signal (resistors should be as large as possible to reduce the loading effect on HV power supply).
4. Power on the DUT.
5. Configure the DAQ to log once every 100ms, and log the bias supply voltage for 1 hour.
6. Configure the DAQ to log once every 1 s and log the bias supply voltage for several days as allowed by the DAQ.
7. Calculate and record the average, minimum, maximum, and standard deviation for the data set in Table C.19 Verify that the minimum and maximum do not exceed 50mV of the average voltage.
8. Power off the DUT.

9. Increase the high-voltage bias supply ¼ of the interval from minimum to maximum voltage. Repeat steps 4–8 for the remaining voltages.

C.5.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

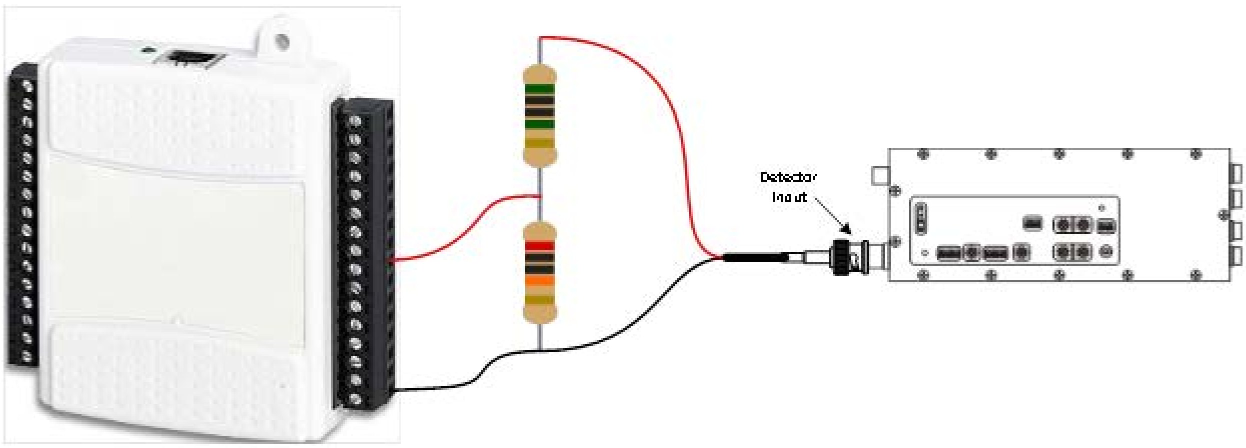


Figure C.6. Using DAQ with Data Logger to Measure Bias Voltage

C.5.6.1 Data Table:

Table C.19. HV Stability Characteristics

Test #	Voltage (V)	Mean (V)	Max (V)	Min (V)	Std Dev. (V)
1 (min) 100ms					
2					
3					
4					
5 (max)					
6 (min) 1s					
7					
8					
9					
10 (max)					

C.6 TEST 11, Test 14 – Isolated and Grounded Power Input Ranges

C.6.1 Purpose:

This test is to verify that the DUT will function as expected over a variety of input voltages: +8 to +15 V DC on the isolated power input and +10.5 V to +15 V DC on the analog output #2 port.

This test also verifies that the power input on analog output #2 functions equivalently to the isolated power input.

C.6.2 Required Equipment:

Variable power supply

Oscilloscope

AWG

Voltmeter

High-Voltage Probes up to 2000 V DC.

C.6.3 References:

DUT documentation provided by vendor

C.6.4 Preparation:

Ensure that the testing surface is ESD safe.

C.6.5 Procedure:

High-Voltage Bias

1. Configure the DUT for nominal settings. If other settings are necessary for the test, record the settings used in Table C.20.
2. Connect the variable power supply to the isolated power input port.
3. Configure the power supply for 8 V DC and power on the DUT.
4. Set the DUT high-voltage bias to the minimum value.
5. Measure the high-voltage bias as shown in Figure C.7 using 1000:1 high-voltage probes.
6. Set the DUT high-voltage bias to the maximum value.
7. Measure the high-voltage bias as shown in Figure C.7 using 1000:1 high-voltage probes.
8. Multiply the values measured by 1000 and record in Table C.21.
9. Increase the supply voltage by 0.5 V and repeat steps 4–8 for the entire input voltage range.
10. Repeat steps 4–9 for the power supply connected to analog output #2.
11. Turn off power and disconnect the power supply.

Pulse Verification

12. Return the DUT to nominal settings.
13. Connect the variable power supply to the isolated power input port. Connect the AWG to the detector input port, and analog output #1 to the oscilloscope.
14. Configure the power supply for 8V DC and power on the DUT.
15. Configure the AWG for pulses with amplitude in the mid-range of the DUT.
16. Verify on the oscilloscope that the output pulse shape is reasonable.
17. Measure the output amplitude and record it in Table C.22
18. Repeat steps 15–17 with the gain at the maximum and minimum setting.
19. Repeat steps 14–19 for each voltage in Table C.22.
20. Connect the power supply to analog output port #2.
21. Repeat steps 14–20 for each voltage in
22. Table C.23.
23. If any anomalies are noted repeate measurements for more voltages in the specified range for each input.

C.6.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

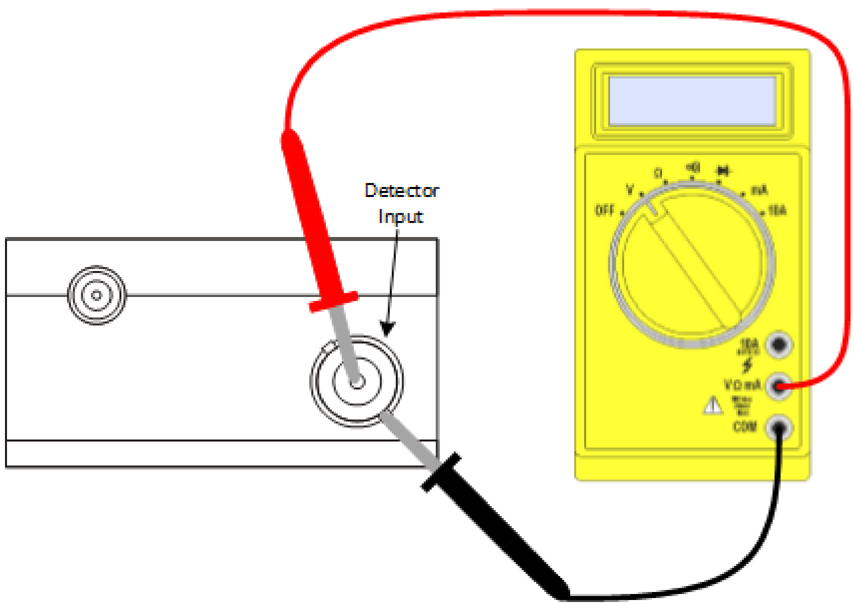


Figure C.7. Measuring Detector Bias Voltage on the DUT

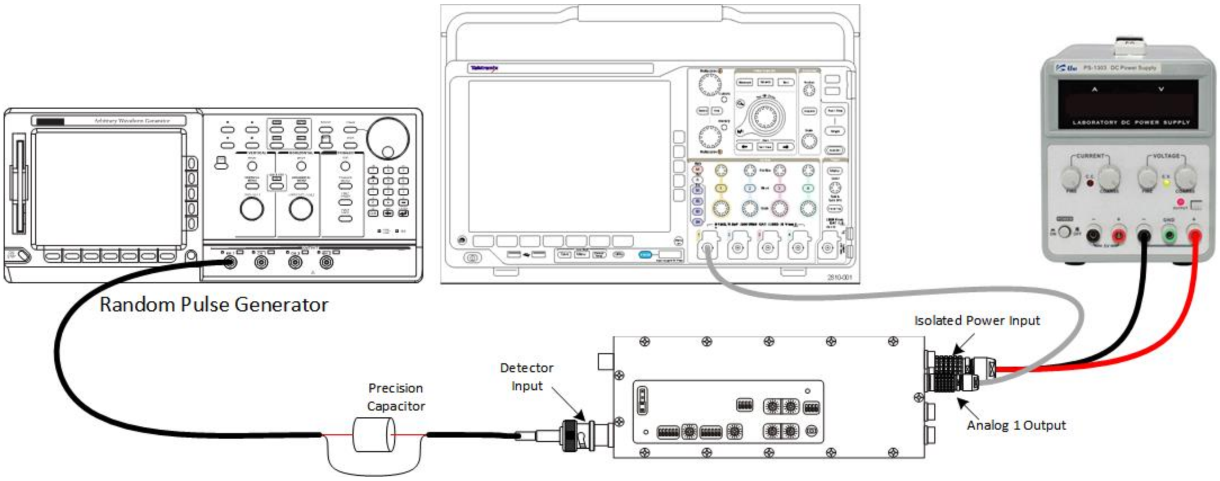


Figure C.8. Using a Variable Power Supply to Verify DUT at Multiple Voltage Inputs

C.6.6.1 Data Table:

Table C.20. DUT Configuration

Parameter	Setting
Input Signal Mode (Q or I)	
Input Termination	
Charge Gain (range)	
G1 – Gain	
G2 – Gain	
HVH - High Voltage	
HVL - High Voltage	
SW1 - Shaping Time	
SW2 - Shaping Time	
DH – Discriminator High	
DL – Discriminator Low	
Digital Ouput Pulse Width	

Table C.21. Variable Supply Voltage HV Characteristics

Test #	Supply Voltage (V)	Isolated Supply HV Bias Min (V)	Isolated Supply HV Bias Max (V)	Grounded Supply HV Bias Min (V)	Grounded Supply HV Bias Max (V)
1	8.0			N/A	N/A
2	10.5				
3	15				

Table C.22. Gain Response for Isolated Power at Various Voltages

Test #	Supply Voltage (V)	Output Amplitude Nominal Gain	Output Amplitude Max Gain	Output Amplitude Min Gain
1	8.0			
2	15			

Table C.23. Gain Response for Grounded Power Input at Various Voltages

Test #	Supply Voltage (V)	Output Amplitude Nominal Gain	Output Amplitude Max Gain	Output Amplitude Min Gain
1	10.5			
2	15			

C.7 TEST 12, TEST 13 – Digital Input Logic Levels & Summing

C.7.1 Purpose:

This test is to verify that the DUT recognizes valid 5V TTL logic inputs. This test also verifies that the digital summing function works correctly, such that a pulse from either the digital input or the detector input produce pulses on the digital output, and that coincident pulses produce two separate digital pulses. Required Equipment:

Power supply for DUT

Oscilloscope with one scope probe and single shot functionality

Pulse generator (AWG or BNC pulser) capable of:

- Dual channel, random pulses
- Generating pulse with rise time of 100 ns and fall time of several microseconds

Three 50 Ω BNC cable (e.g. RG-58)

One 50 Ω BNC-T

Testing cable to connect the DUT digital input to BNC jack

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.7.2 References:

DUT documentation provided by vendor

C.7.3 Preparation:

Ensure that the testing surface is ESD safe.

C.7.4 Procedure:

Logic Levels

1. Configure the DUT for nominal operation with the pulse generator
2. Record the DUT settings in Table C.24.
3. Set the DUT digital pulse width to 2.0 µs.
4. Configure the equipment per Figure C.9and set the AWG output as follows:
    a. Output wave set to square
    b. Frequency set to 25 kHz (wavelength = 40 µs)
    c. Duty Cycle set to 5% (0.05*40 µs = 2 µs)
    d. Amplitude set to 5 V
5. Enable the waveform output and verify that AWG output is from 0 to 5 V.
6. Disable the waveform output.
7. Connect the BNC-T to the DUT's digital input.

8. Connect the power supply to the DUT and configure for 12 V DC.
9. Power on the DUT.
10. Enable the waveform output (verify output using the oscilloscope).
11. Using the oscilloscope's single shot function, verify that input pulses match the output pulses (see Figure C.9)
12. Begin adjusting the AWG output, maintaining the signal minimum at 0 V while reducing the maximum voltage by increments of 0.1V until output pulses stop being generated. Record the last voltage at which a logic high is recognized in Table C.25.
13. Return signal to 0 to 5 V.
14. Begin adjusting the AWG output, maintaining the signal maximum at 5 V while increasing the minimum voltage by 0.1-V increments until the output becomes a constant logic high). Record the last voltage at which a logic low is recognized in Table C.25.

Digital Summing

15. Return the DUT to nominal settings.
16. Connect the test equipment to the DUT as shown in Figure C.10.
17. Configure the digital input pulse generator to output a pulse width of approximately 50 ns width.
18. Configure the detector input pulse generator to output a pulse with several ns of fall time and several microseconds of rise time and a voltage in the middle of the DUT range.
19. Set the random pulse generators to output count rates of approximately 1 kcps.
20. Measure the input and output count rates for the 1) digital input only, 2) detector input only, and 3) both the digital and detector inputs.
21. Verify that the measured count rates match the expected count rates. Record the count rates in Table C.26.
22. Repeate steps 19 through 22 for each of the count rates listed in Table C.26.

C.7.5 Test data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

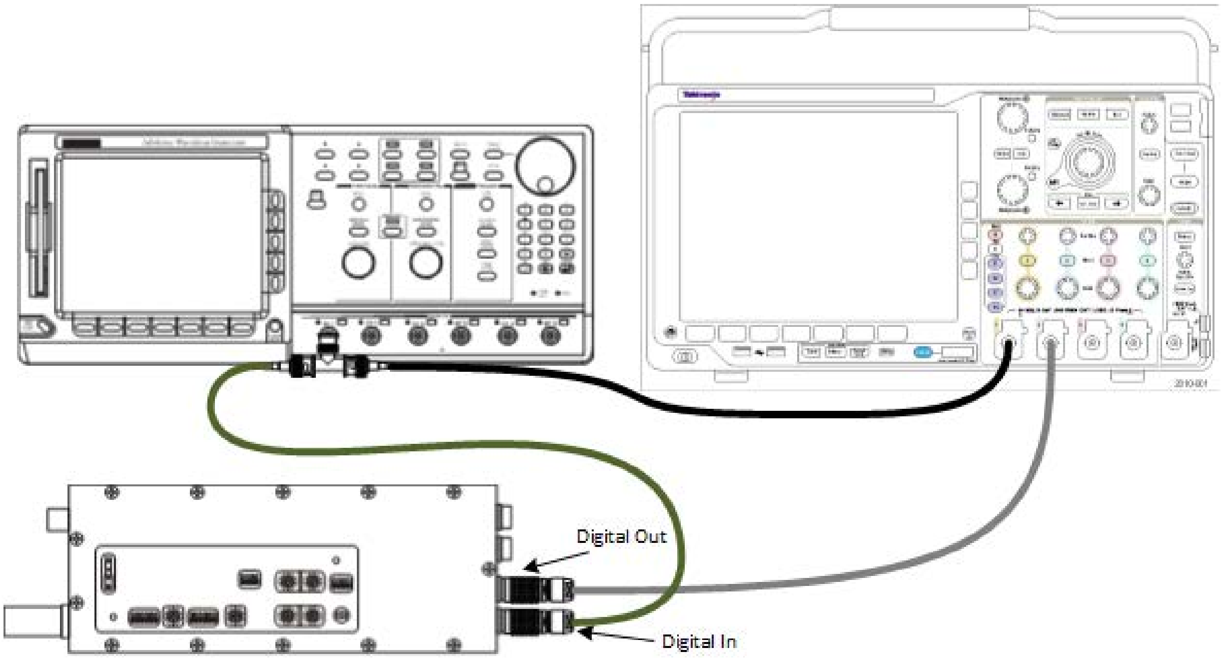


Figure C.9. Logic Voltage Levels Test Setup

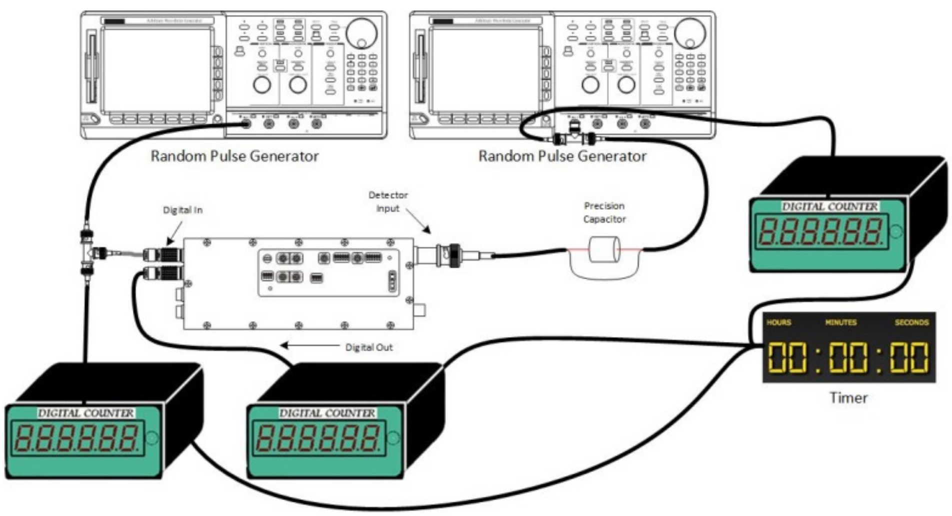


Figure C.10. Digital Summing Test Setup

C.7.5.1 Data Table:

Table C.24. DUT Configuration

Parameter	Setting
Input Signal Mode (Q or I)	
Input Termination	
Charge Gain (range)	
G1 – Gain	
G2 – Gain	
HVH - High Voltage	
HVL - High Voltage	
SW1 - Shaping Time	
SW2 - Shaping Time	
DH – Discriminator High	
DL – Discriminator Low	
Digital Ouput Pulse Width	

Table C.25. Input Logic High Characteristics

Input (V)	
Logic Low (V_{IL})	**Logic High (V_{IH})**

Table C.26. Summed Digital Output Results

	Detector Only		Digital Input Only		Simultaneous Inputs			
Average Counts (kcps)	Input rate (kcps)	Output rate (kcps)	Input rate (kcps)	Output rate (kcps)	Detector input rate (kcps)	Digital input rate (kcps)	Ideal summed rate (kcps)	Output summed rate (kcps)
0.1667								
1.67								
10								
100								
1000								

C.8 TEST 15 - Analog Output #1 and #2 Functionality

C.8.1 Purpose:

This test is to verify that the shaping amplifier's output is compatible with interfacing devices by inspecting the output voltage levels and pulse shape and to verify outputs are decoupled or superimposed on V_{cc}.

C.8.2 Required Equipment:

Variable Power supply

Multimeter

Banana jack to BNC adapter

Oscilloscope with two scope probes or two 50 Ω BNC cables (e.g. RG-58)

AWG

Precision Capacitor

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.8.3 References:

DUT documentation provided by vendor

C.8.4 Preparation:

Ensure that the testing surface is ESD safe.

C.8.5 Procedure:

1. Configure the DUT as necesary for nominal operation.
2. Record the DUT settings in Table C.27 if different than nominal settings.
3. Configure the power supply for 12 V DC and turn it on while disconnected from the DUT.
4. Measure and record in Table C.28 the power supply's output with the multimeter.
5. Turn off the power supply.
6. Connect the 12 V power supply and the oscilloscope channel 1 to the DUT V_{cc} superimposed output via a BNC-T as shown in Figure C.11. Connect the oscilloscope channel 2 to the DUT isolated output as shown in Figure C.11.
7. Power on the DUT.
8. Measure and record the stable output voltages from analog output #1 and #2 with the multimeter or oscilloscope and record the values in Table C.28.
9. Configure the AWG to output pulses at a mid-range voltage.

10. Measure and record at least ten pulses using the oscilloscope's single shot function.. Record values in Table C.29.
11. Verify output #1 and #2 have similar pulse shapes and amplitudes.

C.8.6 Test data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

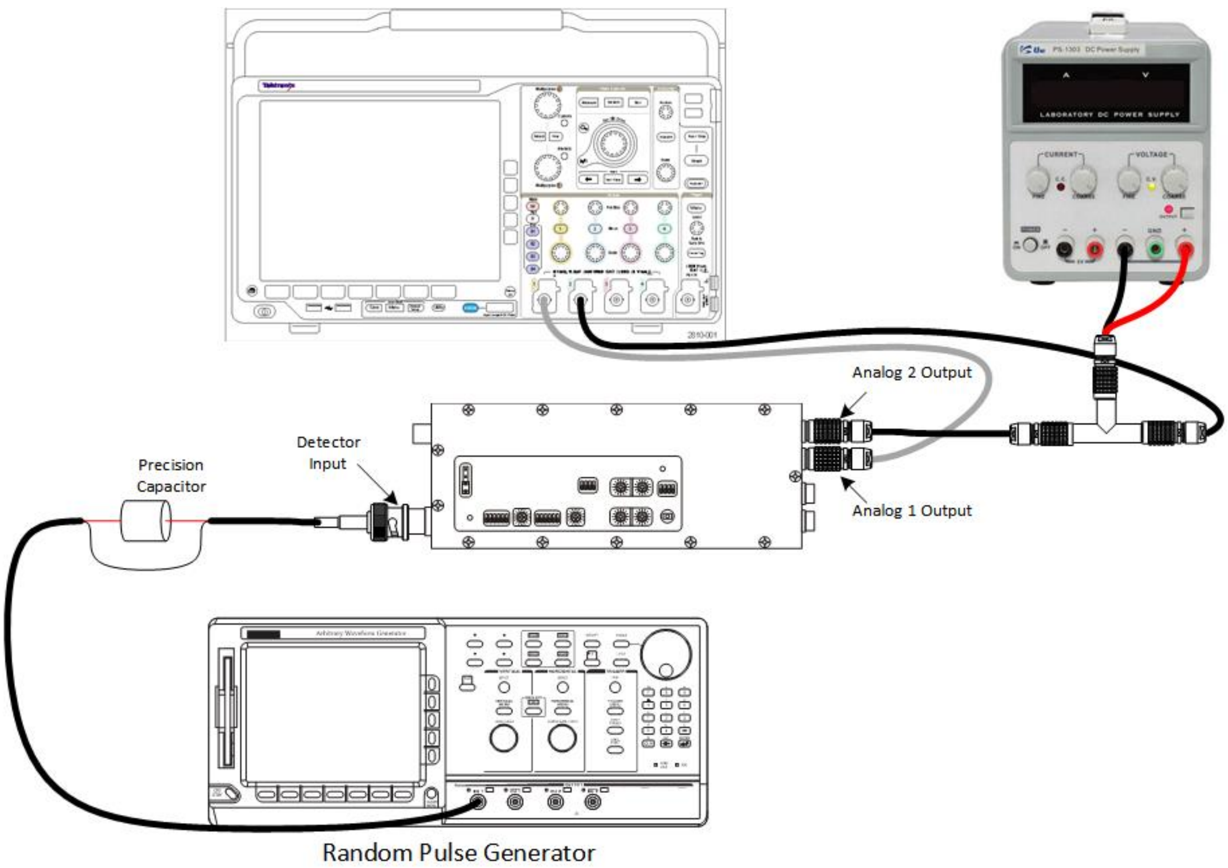


Figure C.11. Using O-Scope to Measure Output Logic Levels

C.8.6.1 Data Table:

Table C.27. DUT Configuration

Parameter	Setting
Input Signal Mode (Q or I)	
Input Termination	
Charge Gain (range)	
G1 – Gain	
G2 – Gain	
HVH - High Voltage	
HVL - High Voltage	
SW1 - Shaping Time	
SW2 - Shaping Time	
DH – Discriminator High	
DL – Discriminator Low	
Digital Ouput Pulse Width	

Table C.28. DUT Power and Signal Voltages

Power Supply Voltage	Baseline Output #1 Voltage	Baseline Output #2 Voltage

Table C.29. DUT Analog Output Characteristics

Test #	AWG Setting	Output #1 Amplitude	Output #1 Pulse Width	Output #2 Amplitude	Output #2Pulse Width
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

C.9 TEST 17 – Ground Isolation

C.9.1 Purpose:

It desirable to have sufficient isolation from signal to ground and between various signal grounds in order to reduce noise issues that propagate via the ground and formed by ground loops. The resistance between the input grounds, output grounds and chassis ground will be checked to determine how well they are isolated. Also, if the DUT provides the ability to configure grounding isolation, those configurations will be confirmed.

This test also measures impedance of the ports for proper impedance matching.to connected equipment, both at DC and at standard impedance reporting frequency of 1KHz.

C.9.2 Required Equipment:

2 Ohm-Meters or multimeters

Impedance Analyzer (if not available AWG and fixed resistor)

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.9.3 References:

None

C.9.4 Preparation:

Determine if device grounding isolation is configurable

- Create a new data table for each configuration
- Caption each table with the configuration name from the manual or a similar descriptor Ensure that the testing surface is ESD safe.

Don personal grounding equipment (e.g. wrist or shoe straps)

C.9.5 Procedure:

1. If grounding isolation is configurable, configure for the first setting.
2. If using a multimeter, set it to measure resistance.
3. Measure the DC resistance between each point listed in the Table C.30 (see Figure C.12).
   a. Port 1 ground conductor to Port 2 ground conductor
   b. Input ground conductor to chassis ground
   c. Output ground conductor to chassis ground
4. Measure the DC resistance from signal to ground reference for each port in Table C.30. (See Figure C.13 for example measurement setup)

C.9.5.1 Test Data:

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

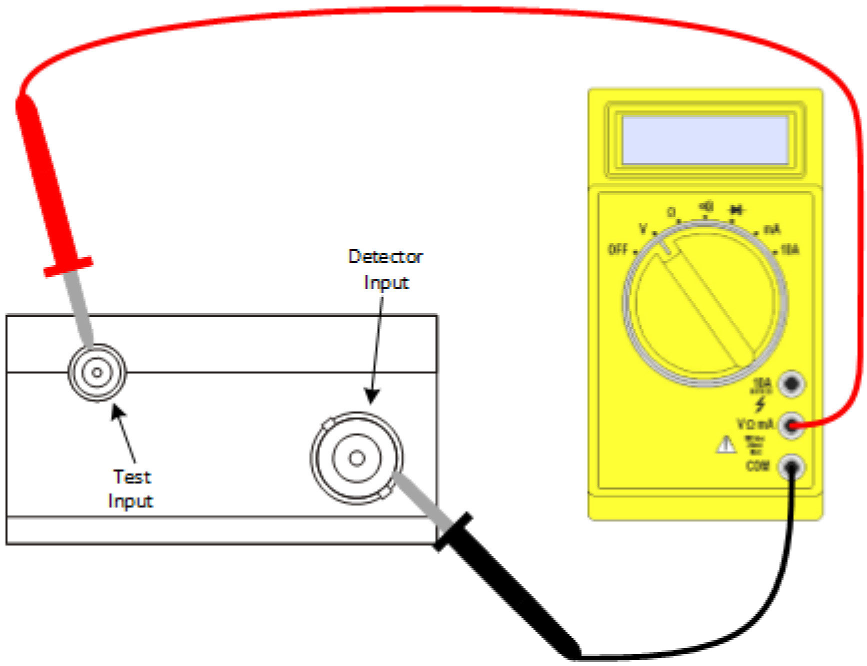


Figure C.12. Measuring Between Grounding Points

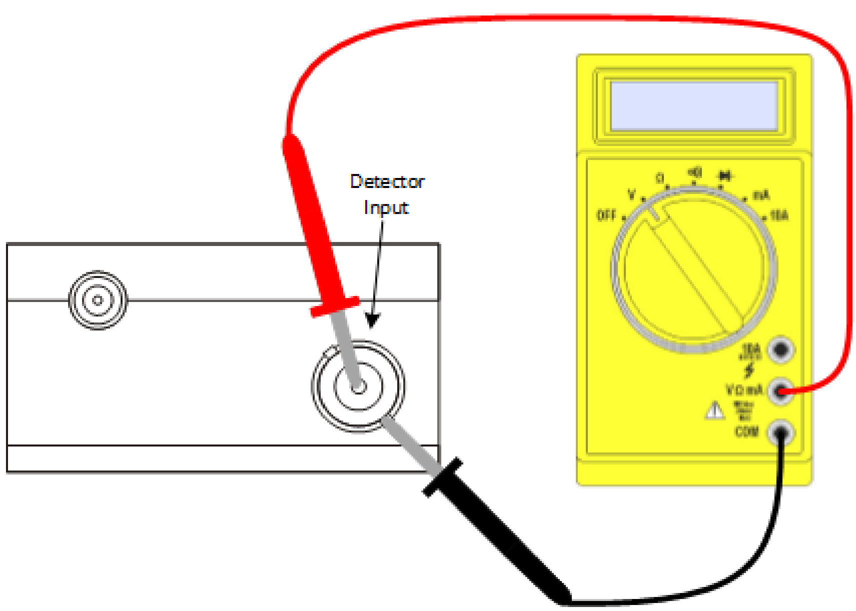


Figure C.13. Measuring DC Port Input/Output Resistance

C.9.5.2 Data Table:

Table C.30. Grounding Schema: Record actual resistance measured, short or open

	Test In	Power In	Analog1 Out	Analog2 Out	Digital In	Digital Out	Chassis
Detector In							
Test In							
Power In							
Analog1 Out							
Analog2 Out							
Digital In							
Digital Out							

C.10 TEST 19- Baseline FEUM Performance

C.10.1 Purpose:

This test will examine how well the DUT performs in a standard environment, relative to the detector efficiency versus cable length and intrinsic noise. The setup in

Figure C.14 and various configurations in Table C.31 will be used.

C.10.2 Required Equipment:

AWG

Precision Capacitor

12V DC Power Supply

He3 detector

Fission Chamber

NaI (TI) Detector

Multi-channel Analyzer

Digital Pulse Counter

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.10.3 References:

DUT documentation provided by vendor

C.10.4 Preparation:

Gather the test equipment and setup the equipment as shown in
Figure C.14.

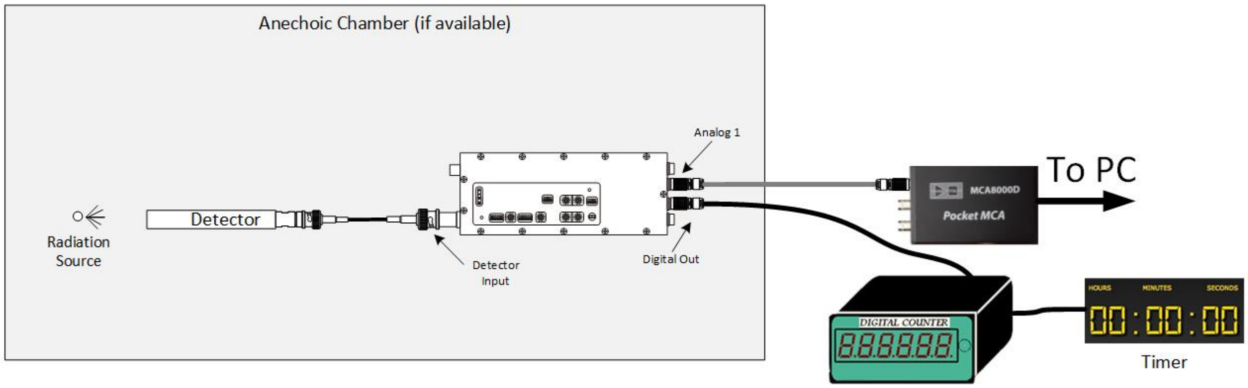


Figure C.14. Baseline Performance Testing Setup

Prepare equipment and setup for variations in test setup per Table C.31.

Table C.31. Configurations for Baseline Performance Testing

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
1	Pulse Generator	RG-71/12cm	0.1 µs	Isolated
2	Pulse Generator	RG-71/12cm	0.1 µs	Ground-Coupled
3	Pulse Generator	RG-71/12cm	0.4 µs	Isolated
4	Pulse Generator	RG-71/12cm	2.4 µs	Isolated
5	Pulse Generator	RG-71/1m	0.1 µs	Isolated
6	Pulse Generator	RG-71/1m	0.4 µs	Isolated
7	Pulse Generator	RG-71/1m	2.4 µs	Isolated
8	Pulse Generator	RG-71/10m	0.1 µs	Isolated
9	Pulse Generator	RG-71/10m	0.4 µs	Isolated
10	Pulse Generator	RG-71/10m	2.4 µs	Isolated
11	Pulse Generator	RG-71/50m	0.1 µs	Isolated
12	Pulse Generator	RG-71/50m	0.4 µs	Isolated
13	Pulse Generator	RG-71/50m	2.4 µs	Isolated
14	Pulse Generator	RG-71/100m	0.1 µs	Isolated
15	Pulse Generator	RG-71/100m	0.4 µs	Isolated
16	Pulse Generator	RG-71/100m	2.4 µs	Isolated
17	Pulse Generator	RG-174/100m	0.1 µs	Isolated
18	Pulse Generator	RG-174/100m	0.4 µs	Isolated
19	Pulse Generator	RG-174/100m	2.4 µs	Isolated

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
20	He3	RG-71/12cm	0.1 µs	Isolated
21	He3	RG-71/12cm	0.1 µs	Ground-Coupled
22	He3	RG-71/12cm	0.4 µs	Isolated
23	He3	RG-71/12cm	2.4 µs	Isolated
24	He3	RG-71/1m	0.1 µs	Isolated
25	He3	RG-71/1m	0.4 µs	Isolated
26	He3	RG-71/1m	2.4 µs	Isolated
27	He3	RG-71/10m	0.1 µs	Isolated
28	He3	RG-71/10m	0.4 µs	Isolated
29	He3	RG-71/10m	2.4 µs	Isolated
30	He3	RG-71/50m	0.1 µs	Isolated
31	He3	RG-71/50m	0.4 µs	Isolated
32	He3	RG-71/50m	2.4 µs	Isolated
33	He3	RG-71/100m	0.1 µs	Isolated
34	He3	RG-71/100m	0.4 µs	Isolated
35	He3	RG-71/100m	2.4 µs	Isolated
36	He3	RG-174/100m	0.1 µs	Isolated
37	He3	RG-174/100m	0.4 µs	Isolated
38	He3	RG-174/100m	2.4 µs	Isolated
39	Fission Chamber	RG-71/12cm	0.1 µs	Isolated
40	Fission Chamber	RG-71/12cm	0.1 µs	Ground-Coupled
41	Fission Chamber	RG-71/12cm	0.4 µs	Isolated
42	Fission Chamber	RG-71/12cm	2.4 µs	Isolated
43	Fission Chamber	RG-71/1m	0.1 µs	Isolated
44	Fission Chamber	RG-71/1m	0.4 µs	Isolated
45	Fission Chamber	RG-71/1m	2.4 µs	Isolated
46	Fission Chamber	RG-71/10m	0.1 µs	Isolated
47	Fission Chamber	RG-71/10m	0.4 µs	Isolated
48	Fission Chamber	RG-71/10m	2.4 µs	Isolated
49	Fission Chamber	RG-71/50m	0.1 µs	Isolated
50	Fission Chamber	RG-71/50m	0.4 µs	Isolated
51	Fission Chamber	RG-71/50m	2.4 µs	Isolated

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
52	Fission Chamber	RG-71/100m	0.1 µs	Isolated
53	Fission Chamber	RG-71/100m	0.4 µs	Isolated
54	Fission Chamber	RG-71/100m	2.4 µs	Isolated
55	Fission Chamber	RG-174/100m	0.1 µs	Isolated
56	Fission Chamber	RG-174/100m	0.4 µs	Isolated
57	Fission Chamber	RG-174/100m	2.4 µs	Isolated
58	NaI	RG-71/12cm	0.1 µs	Isolated
59	NaI	RG-71/12cm	0.1 µs	Ground-Coupled
60	NaI	RG-71/12cm	0.4 µs	Isolated
61	NaI	RG-71/12cm	2.4 µs	Isolated
62	NaI	RG-71/1m	0.1 µs	Isolated
63	NaI	RG-71/1m	0.4 µs	Isolated
64	NaI	RG-71/1m	2.4 µs	Isolated
65	NaI	RG-71/10m	0.1 µs	Isolated
66	NaI	RG-71/10m	0.4 µs	Isolated
67	NaI	RG-71/10m	2.4 µs	Isolated
68	NaI	RG-71/50m	0.1 µs	Isolated
69	NaI	RG-71/50m	0.4 µs	Isolated
70	NaI	RG-71/50m	2.4 µs	Isolated
71	NaI	RG-71/100m	0.1 µs	Isolated
72	NaI	RG-71/100m	0.4 µs	Isolated
73	NaI	RG-71/100m	2.4 µs	Isolated
74	NaI	RG-174/100m	0.1 µs	Isolated
75	NaI	RG-174/100m	0.4 µs	Isolated
76	NaI	RG-174/100m	2.4 µs	Isolated

C.10.5 Procedure:

1. Connect the equipment for configuration #1.
2. Place an appropriate source (e.g., Cf-252 for neutron sensors and Cs-137 for gamma sensors) at a fixed distance from the detector. Record the source type, strength and geometry relative to the detector in Table C.32.
3. Configure the DUT as appropriate for the detector type and parameters to be varied. Record the settings selected in Table C.32.

   a. If applicable to the detector, adjust the HV Setting to be appropriate for typical operation (e.g., for He-3, above the knee of the counting plateau). Record the HV setting used.
   b. Adjust the DUT gain settings to be appropriate for the detector pulse height spectrum, DUT amplifier output voltage range, and the MCA voltage range. Record the setting used.
   c. Using the longest pulse shaping time, and a short cable (~10cm) measure the peak efficiency in this configuration. Record the value in Table C.32. Save the pulse height spectrum. This value will be used as a reference for 100% relative efficiency for the remaining measurements taken.
4. Power on the DUT, using the standard isolated power port, and test equipment.
5. For just a few of the configurations, adjust the discriminator threshold in uniform increments over the full range of the DUT amplifier output and record the corresponding digital output count rate, each discriminator value, and the MCA-calculated count rate in Table C.33. For the other configurations, leave the discriminator at a sufficiently low level such that unwanted noise is not introduced, but the full spectral data can be captured on an MCA.
6. Save the MCA pulse height spectrum for subsequent integral pulse height spectrum analysis (post processing).
7. Repeat steps 3–6 for the rest of the configurations in Table C.31. Make copies of Table C.33 as necessary.
8. Repeat all steps for the current-sensitive mode of operation.

C.10.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

C.10.6.1 Data Table:

Table C.32. DUT and Test Configuration

Parameter	AWG Settings	He-3 Settings	Fission Chamber Settings	NaI (TI) Settings
AWG Setting		NA	NA	NA
Input Signal Mode (Q or I)				
Input Termination				
Charge Gain (range)				
G1 – Gain				
G2 – Gain				
HVH - High Voltage				
HVL - High Voltage				
DH – Discriminator High				
DL – Discriminator Low				
Digital Ouput Pulse Width				
Source Type				
Source Strength				
Source Geometry				
Peak Efficieny				

Table C.33. Baseline FEUM Performance Data

Config #	Discriminator Threshold	Digital Counter Count Rate	MCA-Calculated Count Rate	Config #	Discriminator Threshold	Count Rate	MCA-Calculated Count Rate

C.11 TEST 20- Radiated EMI/RFI Susceptibility

C.11.1 Purpose:

This test examines how well the FEUM performs under stress from radiated EMI/RFI. RS103 from MIL-STD-461E is referenced and used as a base document for the RF field setup and measurement. The base range of MIL-STD-461E, RS103 are used (30 MHz – 2.45 GHz), but larger frequency steps are utilized to minimize the amount of data collected. The number of frequencies used and variations in Table C.38 may be reduced to accommodate schedule.

C.11.2 Required Equipment:

Pulse Generator

He3 detector

Fission Chamber

NaI Detector

Anechoic Chamber

Antenna

RF Generator

Digital Pulse Counter

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.11.3 References:

DUT documentation provided by vendor MIL-STD-461E, RS103

C.11.4 Preparation:

Gather the test equipment and arrange the equipment as shown in Figure C.15.

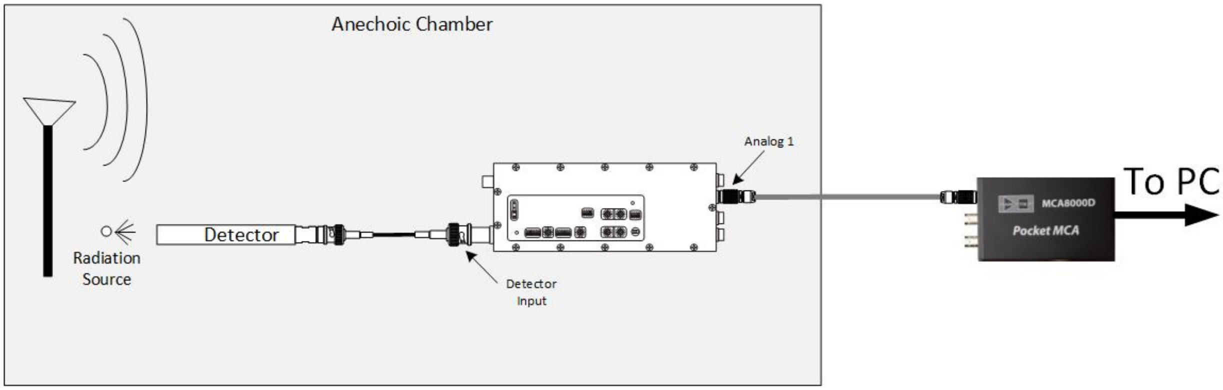


Figure C.15. Radiated EMI/RFI Performance Testing Setup

Prepare equipment and arrange for variations in test setup per Table C.34.

Table C.34. Configurations for EMI/RFI Performance Testing

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
1	Pulse Generator	RG-71/1m	0.1 µs	Isolated
2	Pulse Generator	RG-71/1m	0.4 µs	Isolated
3	Pulse Generator	RG-71/1m	2.4 µs	Isolated
4	Pulse Generator	RG-71/10m	0.1 µs	Isolated
5	Pulse Generator	RG-71/10m	0.4 µs	Isolated
6	Pulse Generator	RG-71/10m	2.4 µs	Isolated
7	Pulse Generator	RG-71/50m	0.1 µs	Isolated
8	Pulse Generator	RG-71/50m	0.4 µs	Isolated
9	Pulse Generator	RG-71/50m	2.4 µs	Isolated
10	Pulse Generator	RG-71/100m	0.1 µs	Isolated
11	Pulse Generator	RG-71/100m	0.4 µs	Isolated
12	Pulse Generator	RG-71/100m	2.4 µs	Isolated
13	Pulse Generator	RG-174/100m	0.1 µs	Isolated
14	Pulse Generator	RG-174/100m	0.4 µs	Isolated
15	Pulse Generator	RG-174/100m	2.4 µs	Isolated
16	He3	RG-71/1m	0.1 µs	Isolated
17	He3	RG-71/1m	0.4 µs	Isolated
18	He3	RG-71/1m	2.4 µs	Isolated

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
19	He3	RG-71/10m	0.1 µs	Isolated
20	He3	RG-71/10m	0.4 µs	Isolated
21	He3	RG-71/10m	2.4 µs	Isolated
22	He3	RG-71/50m	0.1 µs	Isolated
23	He3	RG-71/50m	0.4 µs	Isolated
24	He3	RG-71/50m	2.4 µs	Isolated
25	He3	RG-71/100m	0.1 µs	Isolated
26	He3	RG-71/100m	0.4 µs	Isolated
27	He3	RG-71/100m	2.4 µs	Isolated
28	He3	RG-174/100m	0.1 µs	Isolated
29	He3	RG-174/100m	0.4 µs	Isolated
30	He3	RG-174/100m	2.4 µs	Isolated
31	Fission Chamber	RG-71/1m	0.1 µs	Isolated
32	Fission Chamber	RG-71/1m	0.4 µs	Isolated
33	Fission Chamber	RG-71/1m	2.4 µs	Isolated
34	Fission Chamber	RG-71/10m	0.1 µs	Isolated
35	Fission Chamber	RG-71/10m	0.4 µs	Isolated
36	Fission Chamber	RG-71/10m	2.4 µs	Isolated
37	Fission Chamber	RG-71/50m	0.1 µs	Isolated
38	Fission Chamber	RG-71/50m	0.4 µs	Isolated
39	Fission Chamber	RG-71/50m	2.4 µs	Isolated
40	Fission Chamber	RG-71/100m	0.1 µs	Isolated
41	Fission Chamber	RG-71/100m	0.4 µs	Isolated
42	Fission Chamber	RG-71/100m	2.4 µs	Isolated
43	Fission Chamber	RG-174/100m	0.1 µs	Isolated
44	Fission Chamber	RG-174/100m	0.4 µs	Isolated
45	Fission Chamber	RG-174/100m	2.4 µs	Isolated
46	NaI	RG-71/1m	0.1 µs	Isolated
47	NaI	RG-71/1m	0.4 µs	Isolated
48	NaI	RG-71/1m	2.4 µs	Isolated
49	NaI	RG-71/10m	0.1 µs	Isolated
50	NaI	RG-71/10m	0.4 µs	Isolated
51	NaI	RG-71/10m	2.4 µs	Isolated

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
52	NaI	RG-71/50m	0.1 µs	Isolated
53	NaI	RG-71/50m	0.4 µs	Isolated
54	NaI	RG-71/50m	2.4 µs	Isolated
55	NaI	RG-71/100m	0.1 µs	Isolated
56	NaI	RG-71/100m	0.4 µs	Isolated
57	NaI	RG-71/100m	2.4 µs	Isolated
58	NaI	RG-174/100m	0.1 µs	Isolated
59	NaI	RG-174/100m	0.4 µs	Isolated
60	NaI	RG-174/100m	2.4 µs	Isolated

C.11.5 Procedure:

1. Setup the anechoic chamber and antenna in accordance with MIL-STD-461E, RS103.
2. Set the RF field to 50 V/m. Do not turn on yet.
3. Connect the equipment for configuration #1, frequency #1.
4. Place an appropriate source (e.g., Cf-252 for neutron sensors and Cs-137 for gamma sensors) at a fixed distance from the detector. Record the source type, strength and geometry relative to the detector in Table C.35.
5. Configure the DUT as appropriate for the detector type and parameters to be varied. Record the settings selected in Table C.32.
   a. If applicable to the detector, adjust the HV Setting to be appropriate for typical operation (e.g., for He-3, above the knee of the counting plateau). Record the HV setting used.
   b. Adjust the DUT gain settings to be appropriate for the detector pulse height spectrum, amplifier output voltage range, and the MCA voltage range. Record the setting used.
6. Turn on the RF antenna and verify 50 V/m at the face of DUT.
7. Sweep through the frequencies from 700 MHz – 2.00 GHz by decade.
8. Repeat steps 4– for the rest of the configurations in Table C.34

9. Table C.36 as necessary.
10. Repeat all steps for the current-sensitive mode of operation.

C.11.6 Test data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

C.11.6.1 Data Table:

Table C.35. DUT and Test Configuration

Parameter	**AWG Settings**	**He-3 Settings**	**Fission Chamber Settings**	**NaI (TI) Settings**
AWG Setting		NA	NA	NA
Input Signal Mode (Q or I)				
Input Termination				
Charge Gain (range)				
G1 – Gain				
G2 – Gain				
HVH - High Voltage				
HVL - High Voltage				
DH – Discriminator High				
DL – Discriminator Low				
Digital Ouput Pulse Width				
Source Type				
Source Strength				
Source Geometry				
Peak Efficieny				

Table C.36. Performance Data for Radiated EMI/RFI

Config #	Frequency	Discriminator Threshold	Digital Counter Count Rate	MCA-Calculated Count Rate

C.12 TEST 21- Conducted EMI/RFI Susceptibility

C.12.1 Purpose:

This test examines how well the FEUM performs under stress from conducted EMI/RFI. CS114 from MIL-STD-461E is referenced and used as a base document for the conducted RFI setup and measurement. The base range of MIL-STD-461E, CS114 is used (10 kHz – 30 MHz), but larger frequency steps are utilized to minimize the amount of data collected. The number of frequencies used and variations in Table C.41 may be reduced to accommodate schedule.

C.12.2 Required Equipment:

He3 detector

Fission Chamber

NaI Detector

AWG

Noise injector probe (Induction or Direct)

Digital Pulse Counter

Jewelers’ screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.12.3 References:

DUT documentation provided by vendor MIL-STD-461E, CS114

C.12.4 Preparation:

Gather the test equipment and arrange the equipment as shown in Figure C.16.

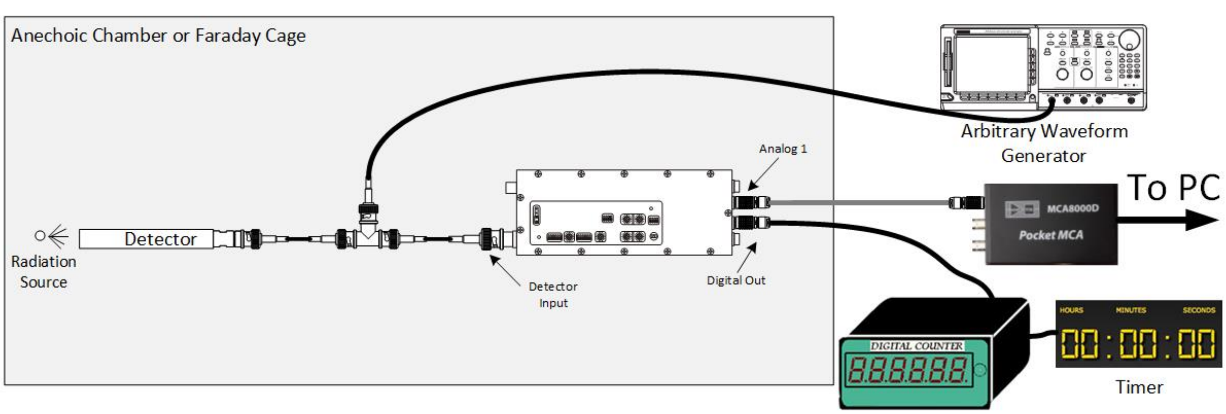


Figure C.16. Conducted EMI/RFI Performance Testing Setup

Prepare equipment and arrange for variations in test setup per Table C.37.

Table C.37. Configurations for Conducted EMI/RFI Performance Testing

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
1	Pulse Generator	RG-71/1m	0.1 µs	Isolated
2	Pulse Generator	RG-71/1m	0.4 µs	Isolated
3	Pulse Generator	RG-71/1m	2.4 µs	Isolated
4	Pulse Generator	RG-71/10m	0.1 µs	Isolated
5	Pulse Generator	RG-71/10m	0.4 µs	Isolated
6	Pulse Generator	RG-71/10m	2.4 µs	Isolated
7	Pulse Generator	RG-71/50m	0.1 µs	Isolated
8	Pulse Generator	RG-71/50m	0.4 µs	Isolated
9	Pulse Generator	RG-71/50m	2.4 µs	Isolated
10	Pulse Generator	RG-71/100m	0.1 µs	Isolated
11	Pulse Generator	RG-71/100m	0.4 µs	Isolated
12	Pulse Generator	RG-71/100m	2.4 µs	Isolated
13	Pulse Generator	RG-174/100m	0.1 µs	Isolated
14	Pulse Generator	RG-174/100m	0.4 µs	Isolated
15	Pulse Generator	RG-174/100m	2.4 µs	Isolated
16	He3	RG-71/1m	0.1 µs	Isolated
17	He3	RG-71/1m	0.4 µs	Isolated
18	He3	RG-71/1m	2.4 µs	Isolated
19	He3	RG-71/10m	0.1 µs	Isolated
20	He3	RG-71/10m	0.4 µs	Isolated
21	He3	RG-71/10m	2.4 µs	Isolated
22	He3	RG-71/50m	0.1 µs	Isolated
23	He3	RG-71/50m	0.4 µs	Isolated
24	He3	RG-71/50m	2.4 µs	Isolated
25	He3	RG-71/100m	0.1 µs	Isolated
26	He3	RG-71/100m	0.4 µs	Isolated
27	He3	RG-71/100m	2.4 µs	Isolated
28	He3	RG-174/100m	0.1 µs	Isolated
29	He3	RG-174/100m	0.4 µs	Isolated
30	He3	RG-174/100m	2.4 µs	Isolated

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
31	Fission Chamber	RG-71/1m	0.1 µs	Isolated
32	Fission Chamber	RG-71/1m	0.4 µs	Isolated
33	Fission Chamber	RG-71/1m	2.4 µs	Isolated
34	Fission Chamber	RG-71/10m	0.1 µs	Isolated
35	Fission Chamber	RG-71/10m	0.4 µs	Isolated
36	Fission Chamber	RG-71/10m	2.4 µs	Isolated
37	Fission Chamber	RG-71/50m	0.1 µs	Isolated
38	Fission Chamber	RG-71/50m	0.4 µs	Isolated
39	Fission Chamber	RG-71/50m	2.4 µs	Isolated
40	Fission Chamber	RG-71/100m	0.1 µs	Isolated
41	Fission Chamber	RG-71/100m	0.4 µs	Isolated
42	Fission Chamber	RG-71/100m	2.4 µs	Isolated
43	Fission Chamber	RG-174/100m	0.1 µs	Isolated
44	Fission Chamber	RG-174/100m	0.4 µs	Isolated
45	Fission Chamber	RG-174/100m	2.4 µs	Isolated
46	NaI	RG-71/1m	0.1 µs	Isolated
47	NaI	RG-71/1m	0.4 µs	Isolated
48	NaI	RG-71/1m	2.4 µs	Isolated
49	NaI	RG-71/10m	0.1 µs	Isolated
50	NaI	RG-71/10m	0.4 µs	Isolated
51	NaI	RG-71/10m	2.4 µs	Isolated
52	NaI	RG-71/50m	0.1 µs	Isolated
53	NaI	RG-71/50m	0.4 µs	Isolated
54	NaI	RG-71/50m	2.4 µs	Isolated
55	NaI	RG-71/100m	0.1 µs	Isolated
56	NaI	RG-71/100m	0.4 µs	Isolated
57	NaI	RG-71/100m	2.4 µs	Isolated
58	NaI	RG-174/100m	0.1 µs	Isolated
59	NaI	RG-174/100m	0.4 µs	Isolated
60	NaI	RG-174/100m	2.4 µs	Isolated

C.12.5 Procedure:

1. Setup the noise injector and auxiliary equipment in accordance with MIL-STD-461E, CS114.

2. Set the noise stimulus to 130 dbµV. Do not turn on yet.
3. Connect equipment for configuration #1.
4. Place an appropriate source (e.g., Cf-252 for neutron sensors and Cs-137 for gamma sensors) at a fixed distance from the detector. Record the source type, strength and geometry relative to the detector in Table C.38.
5. Configure the DUT as appropriate for the detector type and parameters to be varied. Record the settings selected in Table C.38.
   a. If applicable to the detector, adjust the HV Setting to be appropriate for typical operation (e.g., for He-3, above the knee of the counting plateau). Record the HV setting used.
   b. Adjust the DUT gain settings to be appropriate for the detector pulse height spectrum, amplifier output voltage range, and the MCA voltage range. Record the setting used.
6. Turn on the noise injection system and check noise induced per CS114 of MIL-STD-461E.
7. Sweep through the frequencies from 10 kHz – 30 MHz by decade.
8. Repeat steps 4–7 for the rest of the configurations in Table C.37. Make copies of Table C.39 as necessary.
9. Repeat all steps for the current-sensitive mode of operation.

C.12.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

C.12.6.1 Data Table:

Table C.38. Configuration Settings for Conducted EMI/RFI Testing

Parameter	AWG Settings	He-3 Settings	Fission Chamber Settings	NaI (TI) Settings
AWG Setting		NA	NA	NA
Input Signal Mode (Q or I)				
Input Termination				
Charge Gain (range)				
G1 – Gain				
G2 – Gain				
HVH - High Voltage				
HVL - High Voltage				
DH – Discriminator High				
DL – Discriminator Low				
Digital Ouput Pulse Width				
Source Type				
Source Strength				
Source Geometry				
Peak Efficieny				

Table C.39. Conducted Susceptibility Performance Data

Config #	Frequency	Discriminator Threshold	Digital Counter Count Rate	MCA-Calculated Count Rate

Config #	Frequency	Discriminator Threshold	Digital Counter Count Rate	MCA-Calculated Count Rate

C.13 TEST 23- Deadtime

C.13.1 Purpose:

This test performs basic investigation of the deadtime of the prototype FEUM device under a number of shaping time and output pulse width settings. This procedure details three methods for deadtime calculation: 1) random pulse-generator, 2) two- source, and 3) time interval histogram.

C.13.2 Required Equipment:

Arbritrary Waveform Generator (AWG)

Random Pulse Generator

Variable Power Supply

BNC, SHV and Lemo Connectors and Cables

2 Digital Pulse Counters

Timer Module

Precision Capacitor (2.2 nF)

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

2 Cs-137 sources with a combined activity to exceed 20% dead time of the DUT

NaI detector

He3 detector

Digital pulse time acquisition instrument(s)

C.13.3 References:

DUT documentation provided by vendor

C.13.4 Preparation:

Gather the test equipment and arrange the equipment as shown in Figure C.17.

Setup AWG to trigger off of pulse from the random pulse generator

Prepare equipment and arrange for variations in test setup per **Error! Reference source not found.**.

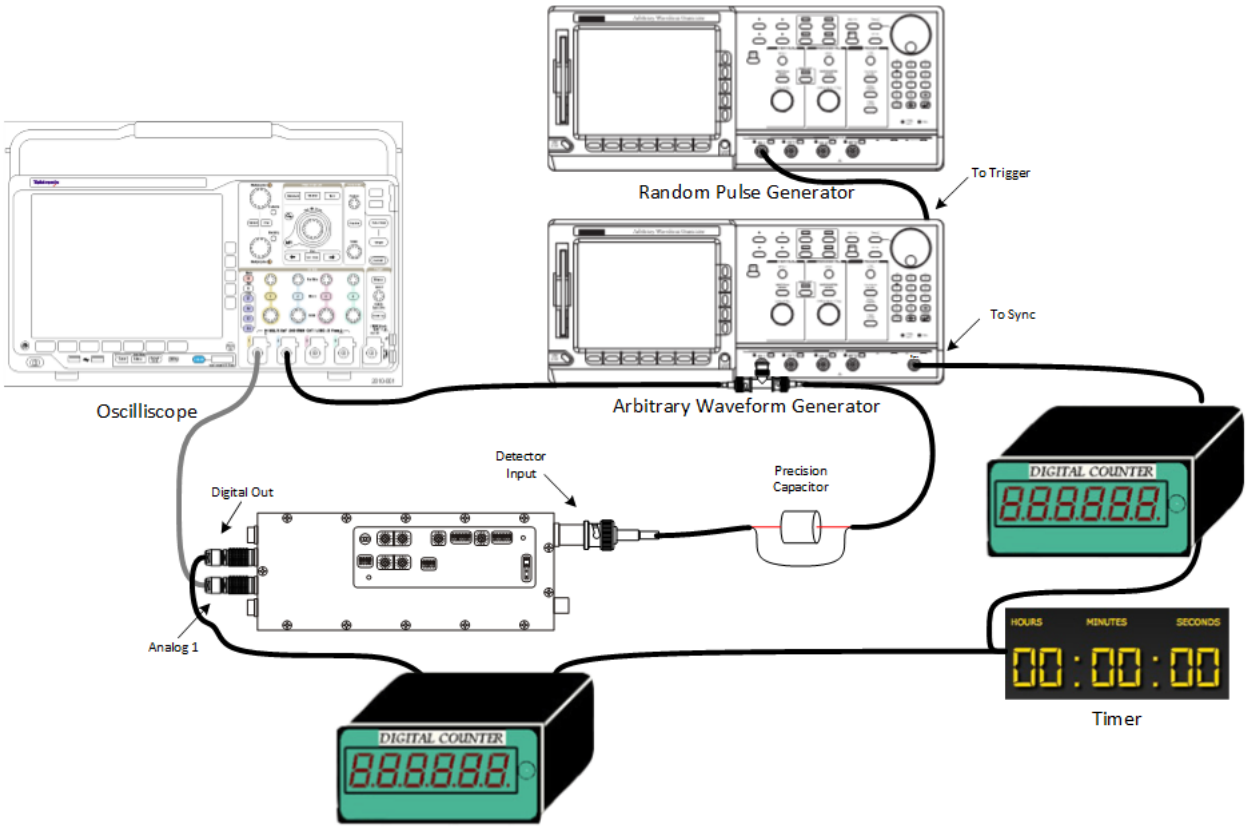


Figure C.17. Performance Testing Setup for Dead Time, using Pulse Generator Method

Table C.40. Configurations for Deadtime Performance Testing with the Pulse Generator Method

#	Pulse Shaping Time (us)	Output Pulse Width (us)	RPG Avg. Rate (cps)
1	0.08	0.2	1
2	0.08	0.2	10 K
3	0.08	0.2	100 K
4	0.08	0.2	200 K
5	0.08	0.2	500 K
6	0.08	0.2	750 K
7	0.08	0.2	1 M
8	1.8	0.2	1
9	1.8	0.2	10 K
10	1.8	0.2	100 K
11	1.8	0.2	200 K
12	1.8	0.2	500 K

#	Pulse Shaping Time (us)	Output Pulse Width (us)	RPG Avg. Rate (cps)
13	1.8	0.2	750 K
14	1.8	0.2	1 M
15	0.08	2.0	1
16	0.08	2.0	10 K
17	0.08	2.0	100 K
18	0.08	2.0	200 K
19	0.08	2.0	500 K
20	0.08	2.0	750 K
21	0.08	2.0	1 M
22	1.8	2.0	1
23	1.8	2.0	10 K
24	1.8	2.0	100 K
25	1.8	2.0	200 K
26	1.8	2.0	500 K
27	1.8	2.0	750 K
28	1.8	2.0	1 M

C.13.5 Procedure for Random Pulse Generator Method:

1. Connect the equipment for configuration #1.
2. Configure the DUT and AWG according to Figure C.17
3. Power on the DUT, using the standard isolated power port, and test equipment.
4. Set RPG to the tested rate.
5. Clear both counters.
6. Start timer.
7. Record real events and measured events in Table C.42.
8. Repeat steps for the rest of the configurations in Table C.40.

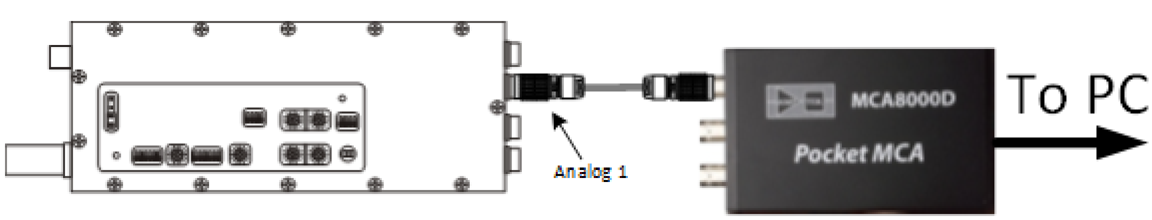


Figure C.18 Test Setup for Two-Source Deadtime Method

C.13.6 Procedure for Two-Source Method:

9. Connect the NaI to the detector input port as shown in Figure C.18. Connect the digital output to the digital counter.
10. Connect a 12V DC power supply to the DUT isolated power input.
11. Configure the DUT for nominal operation (charge-sensitive).
12. Record the DUT settings if different than nominal.
13. Place the 1st Cs-137 source into position and acquire counts for X hours
14. Record the number of counts (m_1) and clear counter
15. Place the 2nd Cs-137 source into position and acquire counts for X hours
16. Record the number of counts (m_{12}) and clear counter
17. Remove the 1st Cs-137 source and acquire counts for X hours
18. Record the number of counts (m_2) and clear counter
19. Remove the 2nd Cs-137 source and acquire counts for X hours
20. Record the number of counts (m_b) and clear counter
21. Calculate dead time using the following formula (non-paralyzable model):
22. Record real events and measured events in Table C.42.
23. Repeat steps for the rest of the configurations in Table C.40.

$$\tau = \frac{X\left(1 - \sqrt{1 - Z}\right)}{Y}$$
$$X \equiv m_1 m_2 - m_b m_{12}$$
$$Y \equiv m_1 m_2 (m_{12} + m_b) - m_b m_{12} (m_1 + m_2)$$
$$Z \equiv \frac{Y(m_1 + m_2 - m_{12} - m_b)}{X^2}$$
$$m_1 = Observed\ rate\ of\ source\ 1$$
$$m_2 = Observed\ rate\ of\ source\ 2$$
$$m_{12} = Observed\ rate\ of\ source\ 1\ \&\ 2$$
$$m_b = Observed\ rate\ of\ background$$

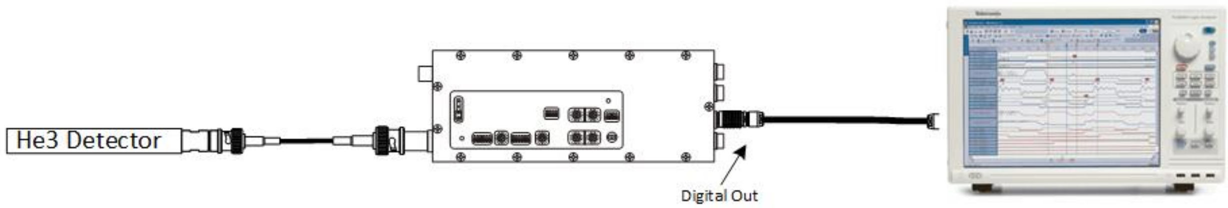


Figure C.19 Test Setup for Time Interval Histogram Deadtime Method

C.13.7 Procedure for Time Interval Histogram Method:

1. Connect the He3 to the detector input port as shown in Figure C.18. Connect the digital output to the digital pulse acquisition instrument.
2. Connect a 12V DC power supply to the DUT isolated power input.
3. Configure the DUT for nominal operation (charge-sensitive).

4. Record the DUT settings if different than nominal.
5. Acquire sufficient data to create a time interval histogram that has a peak greater than 1000 counts. This may be over 20 million counts.

C.13.8 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

C.13.8.1 Data Table:

Table C.41. FEUM and AWG Configuration

Device	Parameter	Setting
DUT	Input Signal Mode (Q or I)	
DUT	Input Termination	
DUT	Charge Gain (range)	
DUT	G1 – Gain	
DUT	G2 – Gain	
DUT	HVH - High Voltage	
DUT	HVL - High Voltage	
DUT	SW1 - Shaping Time	
DUT	SW2 - Shaping Time	
DUT	DH – Discriminator High	
DUT	DL – Discriminator Low	
DUT	Digital Ouput Pulse Width	
AWG	Pulse Type	Tail
AWG	Pulse Period	0.5 us
AWG	Pulse Low Voltage	
AWG	Pulse High Voltage	
AWG	Output Impedance	High-Z

Table C.42. Deadtime DUT Performance Data

Config #	Real Count Rate (cps)	Measured Count Rate (cps)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
21		
22		
23		
24		
25		
26		
27		
28		

Table 8. 2 Source Method Data

Config #	No Source	1st Source Only	2nd Source Only	Both Sources
1				

C.14 TEST 24- Equivalent Noise Charge

C.14.1 Purpose:

This test performs measures the Equivalent Noise Charge (ENC) under a variety of FEUM settings and input capacitance.

C.14.2 Required Equipment:

Arbritrary Waveform Generator (AWG)

Variable Power Supply

BNC, SHV and Lemo Connectors and Cables

Multi-Channel Analyzer

Precision Capacitor (X pF)

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.14.3 References:

DUT documentation provided by vendor

IEEE Standard Test Procedures for Amplifiers and Preamplifiers for Semiconductor Radiation Detectors for Ionizing Radition (1976)

C.14.4 Preparation:

Gather the test equipment and arrange the equipment as shown in Figure C.20.

Prepare equipment and arrange for variations in test setup per Table C.43.

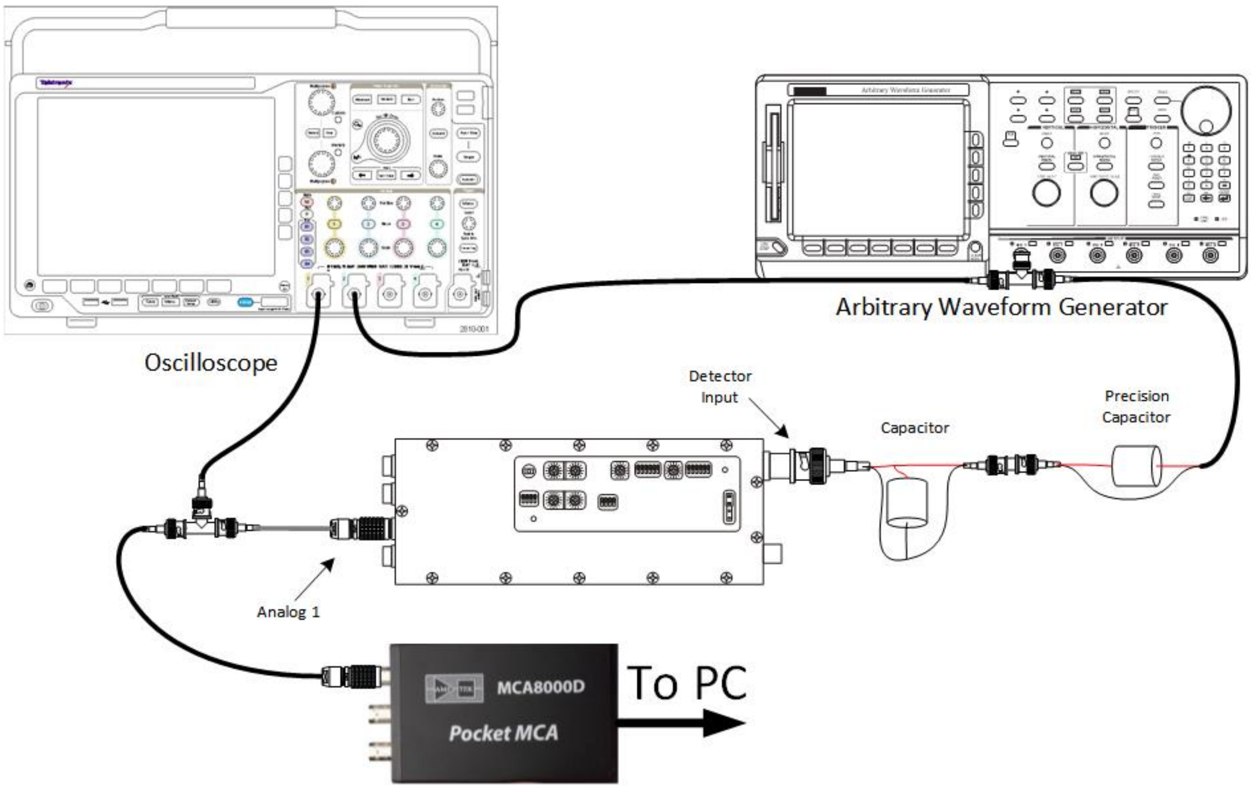


Figure C.20. Performance Testing Setup for ENC

Table C.43. Configurations for ENC Performance Testing

#	High Voltage (VDC)	Input Capacitance (pF)	Shaping Time (us)
1	400	Minimum	0.08
2	400	Minimum	0.3
3	400	Minimum	0.5
4	400	Minimum	0.8
5	400	Minimum	1.4
6	400	Minimum	1.8
7	2000	Minimum	0.08
8	2000	Minimum	0.3
9	2000	Minimum	0.5
10	2000	Minimum	0.8
11	2000	Minimum	1.4
12	2000	Minimum	1.8
13	400	100	0.08
14	400	560	0.08

#	High Voltage (VDC)	Input Capacitance (pF)	Shaping Time (us)
15	400	5000	0.08
16	400	10000	0.08
17	400	100	0.5
18	400	560	0.5
19	400	5000	0.5
20	400	10000	0.5
21	400	100	1.8
22	400	560	1.8
23	400	5000	1.8
24	400	10000	1.8

C.14.5 Procedure:

1. Connect the equipment for configuration #1.
2. Configure the DUT, AWG and MCA according to Table C.44.
3. Power on the DUT, using the standard isolated power port, and test equipment.
4. Configure the DUT and input capacitance for configuration #1.
5. Set the AWG to the high peak value
6. Acquire a spectra on the MCA
7. Determine the peak centroid and FWHM and record to Table C.45.
8. Set the AWG to the low peak value
9. Acquire a spectra on the MCA
10. Determine the peak centroid and FWHM and record to Table C.45.
11. Use the following formula to determine ENC and record in Table C.45.
    a. $\Delta_Q = \frac{V_{p1}-V_{p2}}{\hat{x}_1-\hat{x}_2} C_c \overline{\Delta_N}$, where V_{px} are high and low AWG voltage values, $\hat{x}_x$ are the high and low peak centroids, C_c is the precision capacitor value, $\overline{\Delta_N}$ is the average of the high and low peak FWHM values
12. Repeat steps for the rest of the configurations in Table C.44..

C.14.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

C.14.6.1 Data Table:

Table C.44. DUT, AWG and MCA Configuration

Device	Parameter	Setting
DUT	Input Signal Mode (Q or I)	
DUT	Input Termination	
DUT	Charge Gain (range)	
DUT	G1 – Gain	
DUT	G2 – Gain	
DUT	HVH - High Voltage	
DUT	HVL - High Voltage	
DUT	SW1 - Shaping Time	
DUT	SW2 - Shaping Time	
DUT	DH – Discriminator High	
DUT	DL – Discriminator Low	
DUT	Digital Ouput Pulse Width	
AWG	Pulse Type	Tail
AWG	Pulse Period	0.5 us
AWG	Pulse Low Voltage	
AWG	Pulse High Voltage	
AWG	Output Impedance	High-Z
MCA	Number of bins	Maximum (16384)
MCA	Voltage Range	5 V

Table C.45. ENC DUT Performance Data

Config #	High Peak Centroid (channel)	High Peak FWHM (channel)	Low Peak Centroid (channel)	Low Peak FWHM (channel)	ENC (FWHM pC)
1					
2					
3					
4					
5					
6					
7					
8					
9					

Config #	High Peak Centroid (channel)	High Peak FWHM (channel)	Low Peak Centroid (channel)	Low Peak FWHM (channel)	ENC (FWHM pC)
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					

C.15 TEST 25- High Radiation Fields

C.15.1 Purpose:

This test will examine how well the FEUM performs in a high neutron environment, relative to the detector efficiency versus cable length and intrinsic noise. The setup in Figure C.21 and various configurations in Table C.46 will be used.

C.15.2 Required Equipment:

12V DC Power Supply

He3 detector

Fission Chamber

Neutron well and detector shielding/moderator

Multi-channel Analyzer

Digital Pulse Counter

Jewelers' screwdriver (for toggling configuration dipswitches, if applicable)

Tweezers (for changing jumper settings, if applicable)

C.15.3 References:

DUT documentation provided by vendor

C.15.4 Preparation:

Gather the test equipment and setup the equipment as shown in Figure C.21.

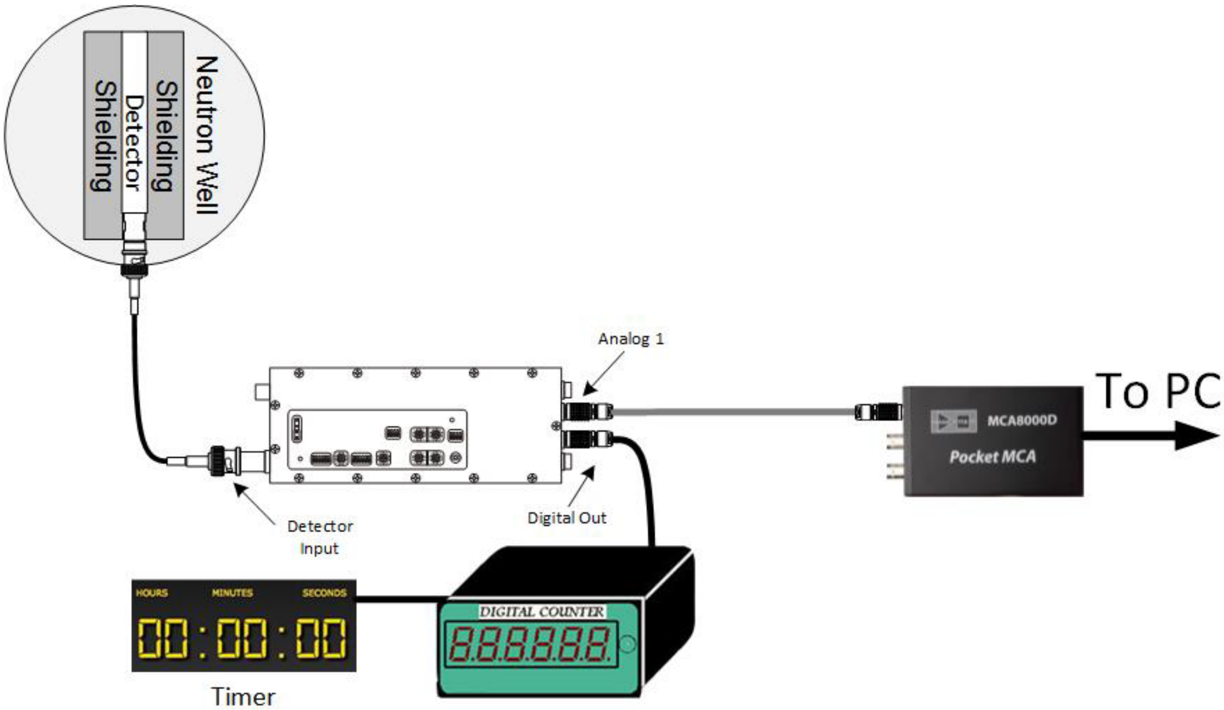


Figure C.21. Performance Testing Setup with Neutron Well

Prepare equipment and setup for variations in test setup per Table C.46.

Table C.46. Configurations for High Neutron Performance Testing

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
1	He3	RG-71/1m	0.1 µs	Isolated
2	He3	RG-71/1m	0.4 µs	Isolated
3	He3	RG-71/1m	2.4 µs	Isolated
4	He3	RG-71/10m	0.1 µs	Isolated
5	He3	RG-71/10m	0.4 µs	Isolated
6	He3	RG-71/10m	2.4 µs	Isolated
7	He3	RG-71/50m	0.1 µs	Isolated
8	He3	RG-71/50m	0.4 µs	Isolated
9	He3	RG-71/50m	2.4 µs	Isolated

#	Detector Type	Cable/Length	Pulse Shaping Time	Output Port
10	He3	RG-71/100m	0.1 µs	Isolated
11	He3	RG-71/100m	0.4 µs	Isolated
12	He3	RG-71/100m	2.4 µs	Isolated
13	He3	RG-174/100m	0.1 µs	Isolated
14	He3	RG-174/100m	0.4 µs	Isolated
15	He3	RG-174/100m	2.4 µs	Isolated
16	Fission Chamber	RG-71/1m	0.1 µs	Isolated
17	Fission Chamber	RG-71/1m	0.4 µs	Isolated
18	Fission Chamber	RG-71/1m	2.4 µs	Isolated
19	Fission Chamber	RG-71/10m	0.1 µs	Isolated
20	Fission Chamber	RG-71/10m	0.4 µs	Isolated
21	Fission Chamber	RG-71/10m	2.4 µs	Isolated
22	Fission Chamber	RG-71/50m	0.1 µs	Isolated
23	Fission Chamber	RG-71/50m	0.4 µs	Isolated
24	Fission Chamber	RG-71/50m	2.4 µs	Isolated
25	Fission Chamber	RG-71/100m	0.1 µs	Isolated
26	Fission Chamber	RG-71/100m	0.4 µs	Isolated
27	Fission Chamber	RG-71/100m	2.4 µs	Isolated
28	Fission Chamber	RG-174/100m	0.1 µs	Isolated
29	Fission Chamber	RG-174/100m	0.4 µs	Isolated
30	Fission Chamber	RG-174/100m	2.4 µs	Isolated

C.15.5 Procedure:

13. Connect the equipment for configuration #1.
14. Configure the DUT as appropriate for the detector type and parameters to be varied (see settings recorded in section C.10).
15. Record the settings selected in Table C.47.
    a. If applicable to the detector, adjust the HV Setting to be appropriate for typical operation (e.g., for He-3, above the knee of the counting plateau). Record the HV setting used.
    b. Adjust the DUT gain settings to be appropriate for the detector pulse height spectrum, amplifier output voltage range, and the MCA voltage range. Record the setting used.
16. Power on the DUT, using the standard isolated power port, and test equipment.
17. Set source to deliver desired dose rate and record in Table C.47.
18. Save the MCA pulse height spectrum for subsequent integral pulse height spectrum analysis (post processing).

19. Repeat steps for the rest of the configurations in Table C.46.

C.15.6 Test Data

DUT Serial Number:
DUT Part Number:
Tested By:
Test Date:

C.15.6.1 Data Table:

Table C.47. DUT and Test Configuration

Parameter	He-3 Settings	Fission Chamber Settings
Input Signal Mode (Q or I)		
Input Termination		
Charge Gain (range)		
G1 – Gain		
G2 – Gain		
HVH - High Voltage		
HVL - High Voltage		
DH – Discriminator High		
DL – Discriminator Low		
Digital Ouput Pulse Width		
SW1 - Shaping Time		
SW2 - Shaping Time		
Source Type		
Source Strength		
Source Geometry		
Peak Efficieny		

Table C.48. High Neutron DUT Performance Data

Charge Sensitive				Charge Sensitive			
Config #	Discriminator Threshold	Digital Counter Count Rate	MCA-Calculated Count Rate	Config #	Discriminator Threshold	Count Rate	MCA-Calculated Count Rate
1				16			
2				17			
3				18			
4				19			
5				20			
6				21			
7				22			
8				23			
9				24			
10				25			
11				26			
12				27			
13				28			
14				29			
15				30			

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