PSNN-2014-0869

■Safety-related
□Non-Safety-related
□ASME CODE
□Others ( )

Document No.	FPG-TRT-C51-0101	Rev	1

NRW-FPGA-Based PRM System Qualification Project

Document Title Qualification Test Summary Report

CUSTOMER NAME	None
PROJECT NAME	NRW-FPGA-Based PRM System Qualification Project
ITEM NAME	PRM Equipment
ITEM NO.	C51
JOB NO.	FPG

TOSHIBA NED verified this Document;
Method : Design Verification & Qualification Test
Verification Report No. : DVR-E2-20160331-2
Verification Results Acceptable
Verified by T. Ito
Group Name Second Electrical System Design & Engineering Group
Date Mar 31, 2016
TOSHIBA

Date	Issued by	Approved by	Reviewed by	Prepared by	Document Filing No.
Mar 31, 2016	Second Electrical System Design &Engineering Group	N. Oda Mar 31, 2016	N. Oda Mar 31, 2016	T. Miyazaki Mar 31, 2016	RS-5125699

Rev No.	Date	History	Approved by	Reviewed by	Prepared by
0	Apr 16,2008	The first issue	N.Oda	T.Ito	H.Sakai
1	See Cover Page	Clarification of test configuration	N.Oda	N.Oda	T.Miyazaki

Table of Contents

1. Introduction

Qualification Test Summary Report Revision 1 incorporates the following:

- Clarification of hardware configuration in the Master Configuration List (Reference (29))
- Correction of description for design change of the AO module in Section 2.4
- Correction of reference errors
- Correction of minor errors
- Clarification of description

1.1. Background

Toshiba Nuclear Energy System & Service Division (NED) performed a generic qualification of the Non Re-writable Field Programmable Gate Array (NRW-FPGA) technology for safety-related Instrumentation and Control (I&C) systems. These systems use programmable logic in the FPGA for all functions and have neither central processing units (CPUs) nor operating systems. These systems have high testability and are designed for a long operational life. Toshiba is qualifying the NRW-FPGA-Based I&C systems for use in safety-related systems at nuclear power plants in the U.S.A.

The specific system to be qualified in this project is the BWR Power Range Monitor (PRM). The PRM system monitors the reactor power by measuring the neutron flux level, converting the measured flux to percent power, averaging many measured percent power readings, and issuing a trip signal when the average percent power exceeds the specified set point value. The PRM is a safety-related (Class 1E) systems. Figure 1-1 shows the overview of this project, which comes from Figure 9-1 of the Qualification Plan (Reference (11)).

The qualification of NRW-FPGA-Based systems was performed in based on the applicable guidance provided in EPRI TR-107330 (Reference (3)). The generic qualification approach described in EPRI TR-107330 includes both hardware qualification and software qualification. EPRI TR-107330 requires tests to be performed as part of the qualification process, under an 10 CFR 50 Appendix B nuclear

quality assurance program. This Qualification Test Summary Report documents Toshiba's Qualification Tests. The tests were performed according to the Master Test Plan (MTP) (Reference (12)) in which the applicable EPRI TR-107330 requirements are implemented.

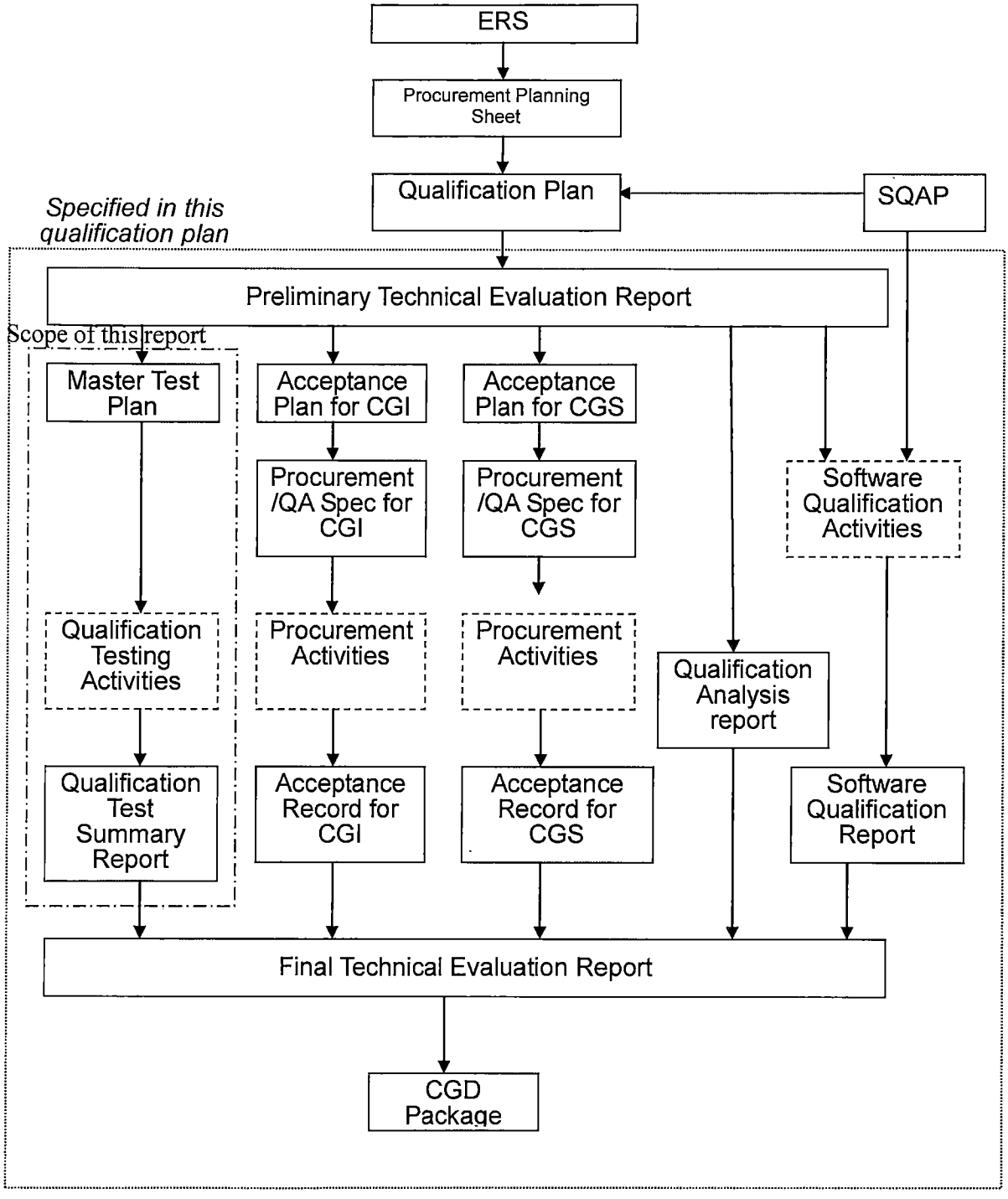

Figure 1-1 Relationship Between Project Documents
(Figure 9-1 of the Qualification Plan)

1.2. Scope of the Qualification Test

This Qualification Summary Report was issued to document the test results and evaluate the test results against the acceptance criteria provided in the MTP.

The PRM qualified in this project differs from PLC-based equipment typically qualified using EPRI TR-107330. The qualification tests were customized to eliminate unnecessary tests, including incorrect EPRI requirements for aging equipment installed in mild environments. Equipment Requirement Specification (ERS) (Reference (13)) specifies equipment requirements of the units to be qualified.

2. Description of Test Specimen and Test Equipment

The Test Specimen Units tested in this qualification project were designed and manufactured in accordance with the ERS, which was established to summarize the applicable requirements from the following three documents:

- EPRI TR-107330
- PRM System design specification provided for a typical Japanese plant
- Fuchu Complex vendor information

2.1. Description of Test Specimen

The Test Specimen was composed of all units needed to create a Test System which provides the typical PRM functions for a BWR-5. The Test Specimen for the project consisted of one LPRM Unit, one LPRM/APRM Unit, one Flow Unit, interconnecting cables, and the spare modules and the spare chassis that were provided for maintenance of the Test Specimen Units. Appendix 1 of the MTP provides a detailed description of the Test Specimen.

2.2. Description of Test Equipment

The Test Equipment was composed of equipment needed to generate input signals and to monitor the output signals of the Test Specimen during the Qualification Test. As described in Section 6.3 of MTP, this included data recording equipment, a variable power supply, and input simulators. The Test Equipment was provided and controlled based on the ERS Section 7.3.1.3, which satisfies the requirements of EPRI TR-107330 Section 6.2.3. The Preliminary Technical Evaluation Report (PTER) (Reference (14)) specified the Test Equipment requirements. Detailed Test Equipment specifications are described in MTP Section 6.3.

2.3. Test Configuration

The Qualification Tests were performed on a Test System, which contains the Test Specimen and Test Equipment. The configuration of the Test System used in this qualification project is shown in Figure 4-1 of the PTER.

2.4. Modifications

The Radiation Exposure Test was conducted in July 2006 with the hardware configuration identified by the date May 25th, 2006 in the Master Configuration List (Reference (29)).

The Environmental Test was performed during June 2006 through October 2006 with hardware configuration identified by the date May 25th, 2006 and August 7th, 2006 in the Master Configuration List. The Hardware configuration was changed during the environmental test due Test System failure caused by incorrect operation of the environmental chamber, condensing water on the top of the chamber that fell into the powered electronics. Detail of the hardware configuration change is described in Section 6.2.2.2 of this report.

The EMI/RFI, Surge Withstand Capability, EFT/B, ESD and Class 1E to Non-1E Isolation Tests, were performed from October 2006 through March 2007 with the hardware configuration identified by the date August 7th, 2006 in the Master Configuration List. However, the EMI Susceptibility Test failed. The hardware was re-designed to resolve the test failure. Therefore, for the second EMI/RFI, Surge Withstand Capability, EFT/B, ESD and Class 1E to Non-1E Isolation tests, the LPRM module HNS011 and the AO modules HNS511, HNS512, HNS513, and HNS514 were replaced with the LPRM module HNS013 and the AO modules HNS515, HNS516, HNS517 and HNS518. This test configuration is identified with the August 24th 2007 date in the Master Configuration List. The re-designed LPRM and AO modules had additional capacitors to enhance electric-noise-withstand-capability.

Two capacitors were added on the LPRM module. Those two capacitors are the same capacitors used in the other locations in the LPRM module.

Several changes were made to the multiple output channels on the AO board. The changes can be grouped into six categories as follows:

(1) Toshiba added 16 capacitors of the same type and capacity used in the LPRM module.
(2) Toshiba added 18 capacitors that are of the same type as those used in the LPRM module but have a different capacity.
(3) Toshiba replaced 16 capacitors with the same capacitor described in Item (2).
(4) Toshiba added 16 capacitors of the same type and capacity that were originally used in the same AO module in different locations.
(5) Toshiba enhanced the grounding connection in the module
(6) Toshiba moved some labels.

Because the same types of capacitors as the added capacitors had been used in other modules that passed the EQ tests (the environmental test and seismic test), Toshiba considered that the results of the environmental test and seismic test for the LPRM and AO modules without the additional capacitors were applicable to the LPRM and AO modules with the additional capacitors. Toshiba repeated the electromagnetic qualification tests with the revised modules.

After the second EMI/RFI, Surge Withstand Capability, EFT/B, ESD and Class 1E to Non-1E Isolation Tests, the replaced modules were removed and the original modules were re-installed on February 20th, 2008, as shown in the Master Configuration List.

Figure 2.4.1 [Deleted]

Figure 2.4.2 [Deleted]

3. Performance Specifications

3.1. Environmental Test

3.1.1. Test Conditions

3.1.1.1. Radiation Exposure

The Test Specimen Units were subjected to the total dose of 11 Gy +30%/- 9% gamma radiation (to satisfy the ERS section 5.5.1 of 10 Gy with 10% margin) using a ^{60}Co gamma ray source. The dose rate was measured at 4.27 Gy-air/hour.

3.1.1.2. Temperature and Humidity

The Test Specimen Units were subjected to the temperature and humidity conditions as shown in Figure 5-2 of ERS to evaluate the effects of temperature and humidity on Test Specimen operability.

3.1.2. Performance Requirements

After the test, the performance of the Test Specimen Units was compared to the baseline performance measured during the Pre-Qualification Test. The test demonstrated that the Test Specimen was not impacted by these tests.

3.2. Seismic Test

3.2.1. Test Conditions

Figure 5-3 of the ERS shows the Required Response Spectra (RRS) for the Operation Basis Earth Quake (OBE) and Safe Shutdown Earth Quake (SSE). The peak

amplitudes of this figure are shown in Table 3-1.

Table 3-1 Peak Amplitude of Seismic Test

Seismic Event	Amplitude Requirement from ERS Section 5.5.2 and EPRI TR-107330 Section 4.3.9
OBE	9.8 g
SSE	14 g

3.2.2. Performance Requirements

During the initial part of seismic testing, a resonance search was performed to verify that no resonances exist in the frequency range defined in the applicable standards. During the test, the Test Specimen Units performed normal processing of input data and produced the expected output data.

Following the Seismic Test, the Test Specimen Units were determined to be structurally intact. Specifically, the Test Specimen Units were examined to ensure no parts are damaged or loosened.

Following the Seismic Test, the Test Specimen Units were determined to be able to perform the safety functions as required in the ERS Section 4.1.2. Specifically, the Test Specimen Units met the acceptance criteria specified for the Operability Test following the SSE. ERS Section 7.2.2 provides the general acceptance criteria for the Operability Test.

The EPRI requirement for performing Prudency and Operability Tests during the seismic testing cannot be performed, as the seismic test would have to be extended from seconds to days to provide sufficient time to perform Prudency and Operability Tests. Since this is not reasonable, testing was performed during the seismic events to demonstrate that the equipment remained operable during application of seismic stressors. Additional testing was performed after the seismic events to demonstrate that the equipment was still operable.

Following the test, the performance of the Test Specimen was compared to the baseline performance (measured during the Pre-Qualification Test) to demonstrate that the test

did not impact the performance and operability of the Test Specimen.

3.3. Electromagnetic Compatibility (EMC) Test

The EMC Test includes the following tests:

(1) EMI/RFI Emission Test
(2) EMI/RFI Susceptibility Test
(3) Surge Withstand Capability Test
(4) Electrically Fast Transient and Burst (EFT/B) Test
(5) Electrostatic Discharge (ESD) Test
(6) Class 1E to Non-1E Isolation Test

All above Tests were performed in an anechoic chamber.

3.3.1. EMI/RFI Emission Test

3.3.1.1. Test Conditions

(1) Radiated Emissions

The tests followed the guidance of MIL-Std-461E (Reference (6)), RE101 and RE102. The emissions were measured from 30 Hz to 100 kHz (RE101) and 2MHz to 10 GHz (RE102).

(2) Conducted Emissions

The tests followed the guidance of MIL-STD-461E, CE101 and CE102. The emissions were measured from 120 Hz (the second harmonic of the power line frequency) to 10 kHz (CE101) and 10 kHz to 2MHz (CE102).

3.3.1.2. Performance Requirements

Conducted emissions were within the limits defined by Figure 5-7 of the ERS, complying with NRC Regulatory Guide 1.180 Revision1 (RG 1.180R1, Reference (1))

Figure 3.1, and Figure 5-8 of the ERS, complying with RG 1.180R1 Figure 3.2.

Radiated emissions were within the limits defined by Figure 5-9 of the ERS, complying with RG 1.180R1 Figure 3.3, and Figure 5-10 of the ERS, complying with RG 1.180R1 Figure 3.4.

3.3.2. EMI/RFI Susceptibility Test

3.3.2.1. Test Conditions

(1) Radiated Susceptibility, Magnetic Fields

The test followed the guidance of MIL-STD-461E, RS101. The applicable frequency range is 30 Hz to 100 kHz. Field strength is defined by Figure 5-6 of the ERS, complying with RG 1.180R1 Figure 4.3.

(2) Radiated Susceptibility, Electric Field

The test followed the guidance of MIL-STD-461E, RS103. The applicable frequency range is 30M Hz to 1 GHz. Field strength is 10 V/m defined by section 5.5.3.5 of the ERS, complying with RG 1.180R1 Section 4.3.2.

(3) Low-Frequency Conducted Susceptibility Test at AC Power Leads

The test followed the guidance of MIL-STD-461E, CS101. The applicable frequency range is 120 Hz (the second harmonic of the power line frequency) to 150 kHz. The test input signal amplitude is defined by Figure 5-4 of the ERS, complying with RG 1.180R1 Figure 4.1.

(4) High-Frequency Conducted Susceptibility Test at AC Power Leads

The test followed the guidance of MIL-STD-461E, CS114. The applicable frequency range is 10 kHz to 30 MHz. The test input signal amplitude is defined by Figure 5-5 of the ERS, complying with RG 1.180R1 Figure 4.2.

(5) High-Frequency Conducted Susceptibility (Signal Leads)

The test followed the guidance of MIL-STD-461E, CS114. The applicable frequency range is 10 kHz to 30 MHz. The test input signal amplitude is 91 dBμA defined by

Section 5.5.3.3 of the ERS, complying with RG1.180R1 Table 14.

(6) Conducted Susceptibility (Signal Leads, Bulk cable injection, impulse excitation)
The test followed the guidance of MIL-STD-461E, CS115. The test input signal amplitude is 2 amperes (A) defined by Section 5.5.3.3 of the ERS, complying with RG1.180R1 Table 14.

(7) Conducted Susceptibility (Signal Leads, Damped sinusoidal transients)
The test followed the guidance of MIL-STD-461E, CS116. The applicable frequency range is 10 kHz to 100 MHz. The test input signal amplitude is 5 amperes (A) defined by Section 5.5.3.3 of the ERS, complying with RG1.180R1 Table 14.

3.3.2.2. Performance Requirements

During the EMI/RFI Susceptibility Test, the Test Specimen performed the safety functions as required in ERS Section 4.1.2.

The performance of the Test Specimen Units after the test was compared to the baseline performance and demonstrated that the test did not impact the performance and operability of the Test Specimen Units.

3.3.3. Surge Withstand Capability Test

3.3.3.1. Test Conditions

The Surge Withstand Capability Test was performed at 2 kV for the AC power line to meet the requirements in the ERS Section 5.5.4, complying with RG 1.180 R1 Sections 5.1 and 5.2. The ring wave test was performed in accordance with IEC 61000-4-12 (Reference (10)). The Combination wave test was performed in accordance with IEC 61000-4-5 (Reference (9)).

3.3.3.2. Performance Requirements

During the surge application, the Test Specimen Units performed its safety functions as required in ERS Section 4.1.2.

The performance of the Test Specimen after the test was compared to the baseline performance and demonstrated that the test did not impact the performance and operability of the Test Specimen Units.

3.3.4. EFT/B Test

3.3.4.1. Test Conditions

The EFT/B Test was performed at 2 kV for the AC power lines to meet the requirements shown in the ERS Section 5.5.5, complying with RG1.180R1 section 5.3. The test was performed in accordance with IEC 61000-4-4 (Reference (8)).

3.3.4.2. Performance Requirements

During the EFT/B Application, the Test Specimen Units performed its safety functions as required in ERS Section 4.1.2.

The performance of the Test Specimen Units after the test was compared to the baseline performance and demonstrated that the test did not impact the performance and operability of the Test Specimen Units.

3.3.5. ESD Test

3.3.5.1. Test Conditions

The ESD Test was performed at 8 kV (Contact Discharge) and 15 kV (Air Discharge) to meet the requirements shown in the ERS Section 5.5.6, complying with EPRI TR-102323 (Reference (2)), Appendix B, Section 3.5. The test was performed in accordance with IEC 61000-4-2 (Reference (7)).

3.3.5.2. Performance Requirements

The ESD was applied to the test points which can be touched by persons during normal operation. During ESD Testing the Test Specimen Units performed its safety functions as required in the ERS Section 4.1.2.

The performance of the Test Specimen Units after the test was compared to the baseline performance and demonstrated that the test did not impact the performance and operability of the Test Specimen Units.

3.3.6. Class 1E to Non-1E Isolation Test

3.3.6.1. Test Conditions

The Class 1E to Non-1E Isolation Test was performed at 600 VAC and 250 VDC to meet the requirements shown in the ERS Section 5.5.7, complying with EPRI TR-107330 Section 4.6.4.

3.3.6.2. Performance Requirements

During the test level voltage application to the test points, the Test Specimen Units demonstrated the ability to perform safety functions as required in ERS Section 4.1.2.

The performance of the Test Specimen Units after the test was compared to the baseline performance and demonstrated that the test did not impact the performance and operability of the Test Specimen Units.

4. Description of Test Facility and Equipment

4.1. Test Facility

All Qualification Tests except the Radiation Exposure Test were conducted at [ ]^{a,c} [,]^{a,c} The Radiation Exposure Test was performed by [ ]^{a,c} personnel at the [ ]^{a,c} High Level Radiation Effects Facility in July 2006.

The Environmental Test was performed during June 2006 through October 2006. During August 2006, the test was suspended due an equipment fault caused by incorrect operation of the environmental chamber.

The other tests, EMI/RFI, Surge Withstand Capability, EFT/B, ESD and Class 1E to Non-1E Isolation Tests, were first performed during October 2006 through March 2007. However, the EMI Susceptibility Test failed. The LPRM and AO modules were

re-designed by adding capacitors on the printed circuit boards to enhance noise rejection. The re-designed modules were installed in the Test Specimen. The retest was performed during October 2007 to March 2008 and completed successfully.

After the completion of these tests, the replaced modules were removed and the original modules were installed. After installation of the original modules, the Performance Proof Test was performed to demonstrate that the safety functions required in the ERS Section 4.1.2 were still operable after testing.

4.2. Mounting

4.2.1. Environmental Test

For the Environmental and Radiation Exposure Tests, the Test Specimen Units were placed in a free-standing instrument rack. Figure 4-1 shows the mounting of the Test Specimen.

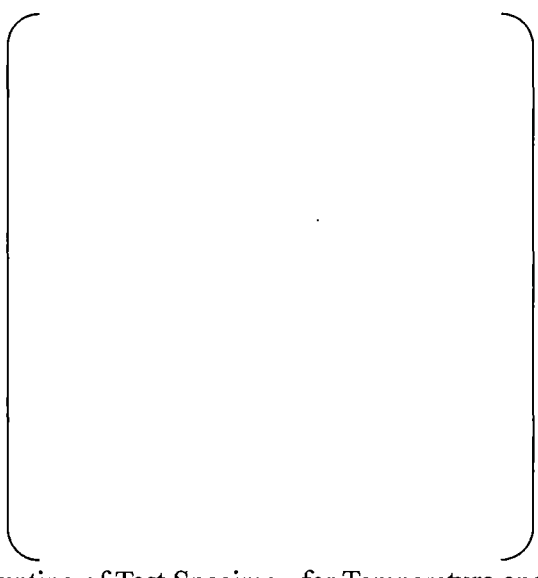

Figure 4-1 Mounting of Test Specimen for Temperature and Humidity Test

4.2.2. Seismic Test

Figure 4-2 shows the mounting of the Test Specimen. The Test Specimen Units were mounted on a structure that was sufficiently stiff. The mounting structure was constructed as follows:

- Two pieces of 6 inch x 3 inch x 3/8 inch steel tubing were welded to the test table with 3/16 inch fillet welds approximately 4 inch in length (two at each corner).
- The test fixture was constructed from 2 inch by 2 inch steel angle and was welded to the lower mounting tubes on each corner of the test fixture to form vertical 2 inch by 2 inch rails.
- The fixture was installed on the [ ]a,c Triaxial Seismic Simulator Table such that its horizontal axes were collinear with the horizontal axis of the table.
- The Test Specimen Units were mounted in the [ ]a,c provided test fixture using M5 mounting hardware located in the front of the chassis and M4 screws located in the rear of each unit. The three varistor panels were mounted horizontal to the test table using M5 mount hardware.


a,c

Figure 4-2 Mounting of Test Specimen for Seismic Test

4.2.3. EMI/RFI, Surge Withstand Capability, EFT/B, ESD and Isolation Tests

The Test Specimen Units were installed in the free-standing instrument rack used in the Environmental Test. This rack was designed not to shield emissions from the Test Specimen Units, and not to shield the applied fields used to evaluate the susceptibility of the Test Specimen Units.

The Test Specimen Units were installed in [ ]a,c anechoic chamber as shown in

Figures 4-3 and 4-4.

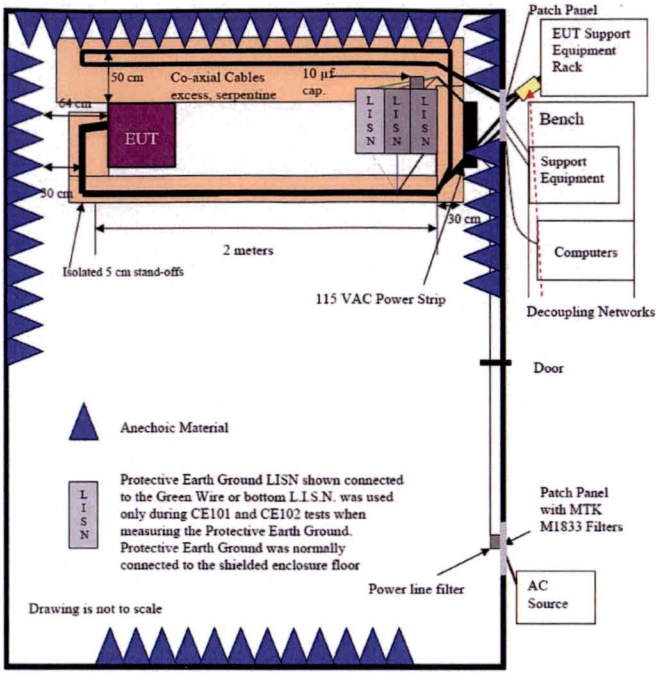

Figure 4-3 Layout in the test chamber

a,c

Figure 4-4 Picture in the test chamber

4.3. Test System Configuration and Electrical Connections

The Schematic Diagram (Reference (15)) shows the representative electrical

connections. The Schematic Diagram was developed according to the requirements provided in Figure 4-1 of the PTER, as described in Section 2.3 of this report.

The Schematic Diagram shows the representative configuration. The specific modifications required for the test conditions, such as penetrations through the EMC chamber walls, were implemented as required.

4.4. Instrumentation

The instrumentation measuring and test equipment used for this test was calibrated by equipment traceable to the National Institute of Standard and Technology (NIST) or the National Metrology Institute of Japan (NMIJ). Both NIST and NMIJ are signatories to the Bureau International des Poids et Mesures (BIPM). The test signal inputs and data acquisition system were located outside the anechoic chamber.

5. Test Procedures

Initial tests were performed for the assembled Test System in Japan. Then, the Test Specimen and some of the Test Equipment were shipped to the U.S for the test at the [ ]a,c. The tests performed were as follows:

- Pre-Qualification Tests, conducted prior to Qualification Test to determine that the system operates correctly and to provide baseline data on equipment performance. These tests were performed at the Toshiba Fuchu Complex, and repeated at the [ ]a,c test facility. The Pre-Qualification testing includes:

  - System Set-up and Check-out Test at Fuchu Complex, performed as a part of the System Validation Test for V&V activities
  - Burn-in Test at Fuchu Complex, performed as a part of the System Validation Test for V&V activities
  - System Set-up and Check-out Test at [ ]a,c (after shipping and re-assembly)
  - Operability Test
  - Prudency Test

- Qualification Tests, conducted to demonstrate compliance with the ERS requirements, and to demonstrate suitability of the Test Specimen while being subjected to stress conditions. The Qualification Tests were performed at [ ]a,c on the assembled Test System after the Test System has passed the Pre-Qualification Test acceptance criteria. The Qualification testing includes:

  - System Set-up and Check-out Test, after each Test System disassembly, reassembly, or relocation
  - Radiation Exposure Test
  - Environmental Test
  - Seismic Test
  - EMI/RFI Test
  - Surge Withstand Capability Test

- EFT/B Test
- ESD Test
- Class 1E to Non-1E Isolation Test
- Power quality Test (performed during other tests)

- Performance Proof Tests, conducted to confirm satisfactory operation after being subjected to Qualification Test conditions. The Performance Proof Tests are a repeat of the operability test and prudency test performed in the Pre-Qualification Tests to identify any changes in equipment performance. Performance Proof Tests were performed at [ ]^{a,c} and included:

  - System Set-up and Check-out Test
  - Operability Test (retest)
  - Prudency Test (retest)

The sequence of tests is shown in Table 5-1 and Figure 5-5 below.

Table 5-1. Qualification Test Overview

Test		ERS Ref. Para.	Toshiba Test Procedure Number	[a,c] Test Procedure Number
1. Pre-Qualification Test	1.1 System Set-up and Check-out Test	Not applicable	FPG-TPRC-C51-0001	Not applicable
	1.2 Burn-in Test	7.2.1G		Not applicable
	1.3 System Set-up and Check-out Test	Not applicable	FPG-TPRC-C51-1001	Not applicable
	1.4 Operability Test	7.2.2, 7.2.4	FPG-TPRC-C51-1009	Not applicable
	1.5 Prudency Test	7.2.3, 7.2.4	FPG-TPRC-C51-1010	Not applicable
2. Qualification Test	2.2 Environmental Test (Radiation Exposure)	7.3.2.4, 5.5.1	FPG-TPRC-C51-1002	FPG-VDN-C51-0200
	2.4 Environmental Test (Temperature and Humidity)	7.3.2.4, 5.5.1	FPG-TPRC-C51-1002	FPG-VDN-C51-0200
	2.6 Seismic Test	7.3.2.5, 5.5.2	FPG-TPRC-C51-1003	FPG-VDN-C51-0200
	2.8 EMI/RFI Test	7.3.2.2, 5.5.3	FPG-TPRC-C51-1004	FPG-VDN-C51-0201
	2.9 Surge Withstand Capability Test	7.3.2.7, 5.5.4	FPG-TPRC- C51-1005	FPG-VDN-C51-0201
	2.10 EFT / B Test	7.3.2.9, 5.5.5	FPG-TPRC- C51-1006	FPG-VDN-C51-0201
	2.11 ESD Test	7.3.2.10, 5.5.6	FPG-TPRC- C51-1007	FPG-VDN-C51-0201
	2.12 Class 1E to Non-1E Isolation Test	7.3.2.8, 5.5.7	FPG-TPRC- C51-1008	FPG-VDN-C51-0201
3. Performance Proof Test	3.2 Operability Test	7.2.2, 7.2.4	FPG-TPRC-C51-1009	Not applicable
	3.3 Prudency Test	7.2.3, 7.2.4	FPG-TPRC- C51-1010	Not applicable

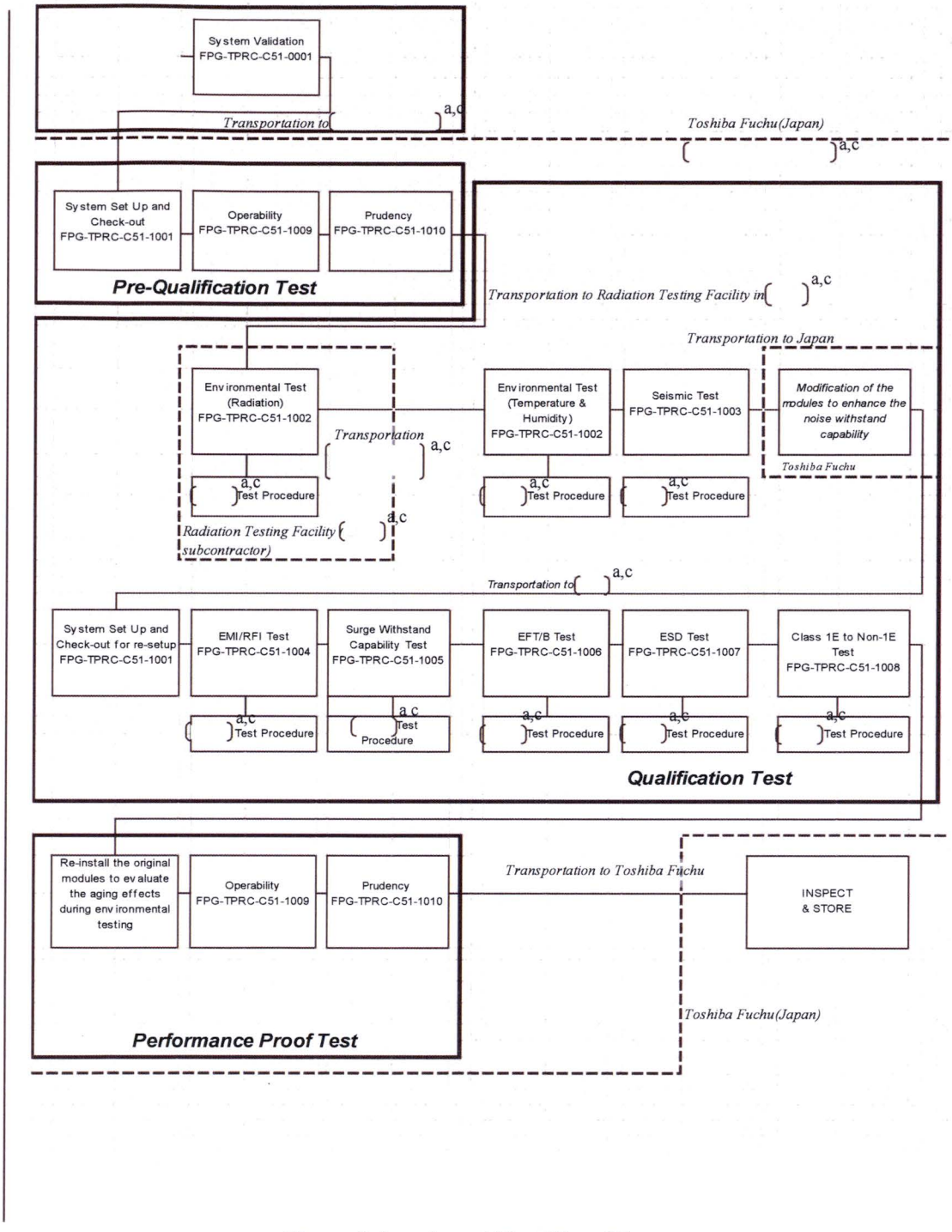

Figure 5-1. Actual Test Flow Diagram

5.1. Pre-Qualification Test

The Pre-Qualification Test was performed prior to the Qualification Test. The Pre-Qualification Test demonstrated that the Test Specimen operated as intended, and provided a performance baseline for the Qualification Test.

The NRW-FPGA-Based PRM Units were manufactured with the correct application logic, and thus required no application software objects testing.

All Test Specimen module parameters and switches were set and checked in the System Set-up and Check-out Test.

The Burn-in Test was carried out on the Test Specimen to detect any failures in early life that would corrupt the Qualification Test results. The Burn-in Test required 352 hours of continuous operation of the Test Specimen.

The Operability Test and the Prudency Test were performed to establish the baseline performance. The Operability Test was performed in order to demonstrate the functionality of the Test Specimen. The Prudency Test was performed to demonstrate the operability of the Test Specimen under highly dynamic conditions. The test requirements are provided in the ERS Section 7.2.

Table 5-1 and Figure 5-1 show the order for the Pre-Qualification Test, and the procedures used. The Pre-Qualification Test was performed as follows:

(1) **System Set-up and Check-out Test (FPG-TPRC-C51-0001).** This test verifies proper assembly, integration and operation of the assembled Test System for the Pre-Qualification Test in the Toshiba's facility. This test confirmed proper connection and operation of the Test System including the monitoring instruments, variable power supplies, and signal simulators. This test was performed as a part of the System Validation Test for V&V activities.

(2) **Burn-in Test (FPG-TPRC-C51-0001).** This test implemented a 352 hour burn-in of the assembled Test System, to detect any failures in early life that

might otherwise impact the subsequent Qualification Test activities. This test was performed as a part of the System Validation Test for V&V activities.

(3) **System Set-up and Check-out Test (FPG-TPRC-C51-1001).** After the Burn-in Test, the Test Specimen and Test Equipment were transported to the [ ]^{a,c} in the U.S. The System Set-up and Check-out Test was performed before the Operability Test. This test verified proper assembly, integration, and operation of the assembled Test System in [ ]^{a,c}. This test confirmed proper connection and operation of the Test System including monitoring instruments, variable power supplies, and signal simulators.

(4) **Operability Test (FPG-TPRC-C51-1009).** This test verified the Test System functions correctly before starting Qualification Tests. The initial performance confirmed in the Operability Test procedure also established the baseline Test System performance. The baseline performance was used for comparison to performance measured during the Qualification Tests.

(5) **Prudency Test (FPG-TPRC-C51-1010).** This test verified that the Test System functions correctly while being exercised in various ways to simulate potential in-service stresses. The initial performance of the Prudency Test procedure also established baseline performance of the Test System for comparison to performance measured during Qualification Tests.

5.2. Environmental Test

The Environmental Test was performed to demonstrate that the Test Specimen Units provide the performance required under the environmental conditions provided in ERS Section 5.5.1. The conditions in the ERS comply with the conditions in EPRI TR-107330.

The required conditions of temperature and humidity used for testing are provided in the ERS Section 5.5.1.

According to the requirements of ERS Section 7.3.2.11, a power quality tolerance test was performed, at the end of the elevated temperature test while still at high temperature. Input voltage ranges and frequency ranges of power supplies for connection to AC and DC sources are given in ERS Section 5.5.8, and the margin is given in IEEE Std 323 (Reference (5)).

Radiation Exposure Testing was included in the environmental evaluation in ERS Section 5.5.1. A 11 Gy gamma dose was applied, including a 10% margin above the requirement of 10 Gy. The 10 Gy exposure requirement is stated in the ERS Section 5.5.1 and satisfies the requirements of EPRI TR-107330 Section 4.3.6.1. The Radiation Exposure Test was performed in accordance with the guidance of IEEE Std 323.

Abnormal environmental conditions for each Environmental Test were defined by the abnormal environmental basic conditions provided in the ERS Section 5.5.1 considering the margins for each condition.

5.3. Seismic Test

The Seismic Test was performed to assure that the Test Specimen Units provide the performance and seismic withstand capability under the Seismic Test conditions provided in the ERS Section 5.5.2. These conditions in the ERS comply with the conditions in EPRI TR-107330 to the extent achievable at Wyle.

This test involved the following activities:

- Mounting of the Test Specimen Units on a vibration table,
- Setting up the Test System,
- Performing a System Set-up and Check-out Test to verify correct setup,
- Performing a Resonance Search Test,
- Performing five tri-axial Seismic Tests representative of an Operating Basis Earthquake (OBE) of the Test Specimen, followed by an inspection to verify structural integrity of the affected Test System components,

- Performing a Seismic Test representative of a Safe Shutdown Earthquake (SSE), followed by an inspection to verify structural integrity of the affected Test System components,
- Performing an Operability Test to compare the system performance to baseline performance.

Figure 5-3 of the ERS shows the Required Response Spectra (RRS) for the OBE and SSE. The peak amplitudes of this figure are shown in Table 3-1. Based on the information provided by [ ]^{a,c} Toshiba expected that the seismic test facility at [ ]^{a,c} would not be capable of performing a test according to the ERS spectra requirement. Toshiba negotiated with [ ]^{a,c} to determine the achievable spectra for the Test Specimen Seismic Qualification Test, which was performed to the table limits. Details of the results are provided in section 6.

5.4. EMI/RFI Test

This test demonstrates the suitability of the Test Specimen Units to withstand exposure to EMI/RFI and verifies that the Test Specimen does not emit more than acceptable levels of EMI/RFI. The EMI/RFI levels shown in the ERS comply with the levels shown in RG 1.180R1.

Note that the test levels specified were not the same as those specified in the EPRI TR-107330 requirements. Instead, the test levels used were obtained from RG1.180R1, which was issued in October 2003. Toshiba considered these new Regulatory Guide values were to better reflect the current requirements of US utilities. Note that EPRI TR-107330 was published in December 1996, prior to issuance of RG1.180R1.

The EMI/RFI susceptibility and emissions withstand capability given in NRC RG1.180R1 were tested using the following test methods from MIL-Std 461E:

Test Type	Test Method
(a) Low-Frequency Conducted Susceptibility (Power):	CS101
(b) High-Frequency Conducted Susceptibility (Power):	CS114
(c) High-Frequency Conducted Susceptibility (Signal):	CS114
	CS115
	CS116
(d) Radiated Susceptibility, Magnetic Field:	RS101
(e) Radiated Susceptibility, Electric Field:	RS103
(f) Low-Frequency Conducted Emissions:	CE101
(g) High-Frequency Conducted Emissions:	CE102
(h) Radiated Emissions, Magnetic Field:	RE101
(i) Radiated Emissions, Electric Field:	RE102

5.4.1. Conducted Susceptibility (Power Leads)

5.4.1.1. Low-Frequency Conducted Susceptibility (Power Leads)

This test was performed on the input power leads of the AC power sources. The test was performed according to MIL-Std-461E requirement CS101. The envelope is shown in ERS Figure 5-4. The test was performed from 120 Hz to 150 kHz.

5.4.1.2. High-Frequency Conducted Susceptibility (Power Leads)

This test was performed on the input power leads to the AC power sources. The test was performed according to MIL-Std-461E requirement CS114. The envelope is shown in ERS Figure 5-5. The test is performed from 10 kHz to 30 MHz.

5.4.1.3. Conducted Susceptibility (Signal Leads)

5.4.1.4. High-Frequency Conducted Susceptibility (Signal Leads)

This test was performed on all signal leads in accordance with MIL-Std-461E requirement CS114. The envelope was set from 10 kHz to 30 MHz, and 91 dBμA.

5.4.1.5. High-Frequency Conducted Susceptibility (Signal Leads – Impulse Excitation)

This test was performed according to MIL-Std-461E requirement CS115. The operating envelope was set to 2 amperes (A).

5.4.1.6. High-Frequency Conducted Susceptibility (Signal Lead – Damped Sinusoidal Transients)

This test was performed according to MIL-Std-461E requirement CS116. The operating envelope was set to 5 amperes (A). The test was performed from 10 kHz to 100 MHz.

5.4.2. Radiated Susceptibility

5.4.2.1. Radiated Susceptibility, Magnetic Field

This test was performed according to MIL-Std-461E requirement RS101. The Test Specimen Units were installed in close proximity (< 1 m) to sources of large magnetic fields (> 600 A/m). The frequency is set from 30 Hz to 100 kHz. The test level is shown in ERS Figure 5-6.

5.4.2.2. Radiated Susceptibility, Electric Field

This test was performed according to MIL-Std-461E requirement RS103. The test frequency was set from 30 MHz to 1 GHz, and the applied electric field level was 10 V/m for all frequencies. The test was performed with both vertical and horizontal polarized waves.

5.4.3. Conducted Emission

5.4.3.1. Low-Frequency Conducted Emissions

This test was performed on the power input leads, according to MIL-Std-461E requirement CE101. Envelope limits were the "envelope for less than 1kVA AC" limits shown in ERS Figure 5-7. Data is reported in dBμA. The frequency range was from 120 Hz to 10 kHz.

5.4.3.2. High-Frequency Conducted Emissions

This test was performed on the power input leads, according to MIL-Std-461E requirement CE102. The recommended emissions limits are shown in ERS Figure 5-8. The test frequency was set from 10 kHz to 2 MHz. Data was reported in dBμV.

5.4.4. Radiated Emission

5.4.4.1. Radiated Emissions, Magnetic Field

This test was performed according to MIL-Std-461E requirement RE101. The envelope limits are shown in ERS Figure 5-9. The test frequency was set from 30 Hz to 100 kHz. All measurements were performed at 7 cm, as specified by RE101.

5.4.4.2. Radiated Emissions, Electric Field

This test was performed according to MIL-Std-461E requirement RE102. The recommended emissions limits are shown in ERS Figure 5-10. The test frequency was set from 2 MHz to 10 GHz. This test was performed with both vertical and horizontal polarized waves.

5.5. Surge Withstand Capability Test

This test demonstrates the suitability of the Test Specimen Units as a safety-related device for lightning induced electrical perturbations, using surge withstand capability test protocols. As stated in ERS Section 5.5.4, IEC 61000-4-5 and IEC 61000-4-12 tests were performed.

The Surge Withstand Capability Test was performed to assure that the Test Specimen Units withstand the surge limits given in the ERS Section 5.5.4. The Surge Withstand Capability Test levels shown in the ERS comply with RG1.180R1.

The Surge Withstand Capability Test was performed in the same location as the EMI/RFI test.

5.6. EFT / B Test

This test demonstrates the suitability of the Test Specimen Units as a safety-related device for electrical perturbations from relay coil collapse, using the EFT/B withstand capability test. As stated in the ERS Section 5.5.5, IEC 61000-4-4 test was performed.

The EFT/B Test was performed to assure that the Test Specimen Units withstand the EFT/B waveforms provided in ERS Section 5.5.5. The EFT/B Test levels shown in the ERS comply with the levels shown in RG1.180R1. The EFT/B Test was performed in the same location as the EMI/RFI Test.

5.7. ESD Test

This test to demonstrates the ability of the Test Specimen Units to withstand Electro Static Discharge (ESD). IEC 61000-4-2 was performed.

The ESD Test was performed to assure that the Test Specimen withstands the ESD levels given in ERS Section 5.5.6. The ESD Test levels comply with the levels shown in EPRI TR-107330 Section 4.3.8.

The tests were performed according to EPRI TR-102323-R1 Appendix B Section 3.5. The ESD Test was performed in the same location as the EMI/RFI, Surge Withstand Capability and EFT/B Tests.

5.8. Class 1E to Non-1E Isolation Test

This test demonstrates the ability of the Test Specimen Units to provide electrical isolation from the Class 1E PRM to Non-1E field connections. The testing performed to demonstrate ERS Section 5.5.7 requirements demonstrates compliance to IEEE Std 384 (Reference (4)). The test levels shown in the ERS comply with the level shown in Section 4.6.4 of EPRI TR-107330 and IEEE Std 384.

The isolation device prevents any short, ground, or open circuits or application of the maximum credible voltage on the Non-Class 1E side from degrading the operation of the circuits on the Class 1E side.

The Class 1E to Non-1E Isolation Test was performed in the same location as the EMI/RFI, Surge Withstand Capability, EFT/B and ESD Tests. For the NRW-FPGA-Based PRM System, the AO module is required to have a Non-1E to Class 1E isolation capability. A high voltage was applied to the Non-1E side of the AO module, and the test confirmed that the safety-related functions which were performed in Class 1E side were not affected by this Non-Class 1E test.

5.9. Performance Proof Test

In the Pre-Qualification Test (section 5.1), the acceptable operation and baseline performance data of the Test Specimen Units were confirmed by conducting Operability and Prudency Tests. In the Qualification Tests (Sections 5.2 to 5.8), operability and performance of the Test Specimen under and after applying the environmental stressors were confirmed.

At the Performance Proof Tests, the Operability and Prudency Tests were performed repeated to confirm that the Test Specimen provided the required operability and performance even after being exposed to the environmental stress factors of the complete Qualification Test.

The Performance Proof Test was carried out as follows:

(1) **System Set-up and Check-out Test (Test Procedure: FPG-TPRC-C51-1001).** This test verified proper assembly, integration, and operation of the assembled Test System for the Performance Proof Test. This test confirmed proper connection and operation of the Test System peripherals including monitoring instruments, power supplies, signal simulators, and communication links.

(2) **Operability Test (Test Procedure: FPG-TPRC-C51-1009).** This test demonstrated acceptable system operability at the end of the Qualification Test.

(3) **Prudency Test (Test Procedure: FPG-TPRC-C51-1010).** This test demonstrated acceptable system performance at the end of the Qualification Test.

5.10. Testing Conclusion

Successful completion of these tests demonstrates that there are no common cause environmental stressors that could preclude operation, as long as the PRM is installed in accordance with Toshiba instructions, in an environment that complies with the assumptions made to generate the limits defined by the U.S. Nuclear Regulatory Commission in RG 1.180R1.

6. Test Data and Results

6.1. Baseline Performance of Test Specimen Units

Prior to the Environmental, Seismic, and EMC Tests, the Pre-Qualification Test described in Section 5.1 was performed to confirm the baseline performance of the Test Specimen Units. The Test Specimen Units passed all tests included in the Pre-Qualification Test, and the baseline performance was established.

After the Environmental, Seismic, and EMC Tests, the Performance Proof Test described in Section 5.9 was performed, and the test confirmed that the Test Specimen Units provided the required operability and performance even after being exposed to aging and stress factors of the complete Qualification Test. The Test Specimen Units passed all tests included in the Performance Proof Test, and the baseline performance was verified.

6.2. Environmental Test

6.2.1. Summary of Environmental Test

The Test Specimen Units were subjected to a radiation exposure, temperature and humidity tests.

The Test Specimen Units passed the Radiation Exposure Test with no signs of physical or functional degradation. The Test Specimen Units also passed the temperature and humidity test. In the first test opportunity, the Test Specimen Units stopped functioning in the high temperature and high humidity condition after incorrect operation of the chamber resulted in condensed water on the chamber ceiling dripping into the powered Test Specimen Units. By adding a condensation shield to the environmental chamber, a retest was performed and the Test Specimen Units passed all temperature and humidity tests.

6.2.2. Data Evaluation

6.2.2.1. Radiation Exposure

The irradiation was performed at [ ]^{a,c} High Level Radiation Effects Facility. For this irradiation, [ ]^{a,c} curies (Ci) ^{60}Co was used., at the exposure rate shown in the dosimetry data in Table 6.1.1

The Test Specimen Units were irradiated at a gamma dose rate of 4.27 Gy-air/hr for 3 hours for a total integrated dose of 12.81 Gy-air. Due to the size of the Test Specimen Units, the irradiation was conducted on half of the units at a time. All the Test Specimen Units were rotated 180 degrees at the midpoint of their radiation, to be exposed in a uniform dose.

At the end of the all Qualification Tests, the Performance Proof Test was performed, as described, and all safety functions were confirmed to be within the required tolerance provided in the ERS Section 4.1.2 post-exposure.

Table 6.1.1 Dosimetry test data

RADCAL INSTRUMENT MEASUREMENT FORM

Meter Model No. 2025, S/N: 2703	Probe Model No. 10X5-0.6 S/N: 9520
Calibration Date: 01-25-06	Calibration Date: 01-25-06

Probe Correction Factor (PCF): ^{137}Cs ^{60}Co 10.027 R/"R" rdg

Measured Exposure or Exposure Rate, in Roentgens (R) or R/hour

1.	6.
2.	7.
3.	8.
4.	9.
5.	10. AVG 46.3 R/hr

Temperature: 83 °F or 28 °C [(°F-32) 5/9 = °C]

Atmospheric Pressure: 29.08 in. Hg 739 mm Hg (1 inch = 25.4 mm)

Temperature & Pressure Correction Factor (TPCF):

$$TPCF = \frac{28\ ^{\circ}C + 273^{\circ}C}{295^{\circ}C} \times \frac{760\ mmHg}{739\ mmHg} = 1.049$$

Total Correction Factor = 10.027 x 1.049 = 10.52 (TPCF x PCF)

Actual Exposure or Exposure Rate, in R or R/hour

1.	6.
2.	7.
3.	8.
4.	9.
5.	10. AVG 427 R/hr

$rads = 0.877 \frac{rads}{R} \left(\frac{\mu_{ms} / \rho_{ms}}{\mu_{air} / \rho_{air}} \right)$ Reference: Cember, 1996 (Page 179 and Appendix F), 1 Gray = 100 rad

Actual Dose or Dose Rate, in rads or rads/hour

1.	6.
2.	7.
3.	8.
4.	9.
5.	10. AVG 427 rads/hr

Signature: Jerome Ozuk Date: July 17, 2006

6.2.2.2. Temperature and Humidity Exposure

The Test Specimen Units were placed in a free-standing instrument rack and installed in the temperature and humidity test chamber. For the Temperature and Humidity exposure, specific test patterns shown in Table 6.1.2 were applied, repeating the pattern throughout the test. The output data were monitored during the tests.

Table 6.1.2 Input and Expected Output Pattern

	Input		Expected Output						
Time (min)	LPRM Input Current (microampere)	Loop FLOW Input Current (mA)	LPRM CH 1 Output (Computer) (mV)	APRM/TPM*1) Output (Computer) (mV)	FLOW Output (Computer) (mV)	TPM (H) Set point (Computer) (mV)	APRM HH Trip Output	TPM H Trip DO	APRM INOP Trip DO
0 – 15	0	4	0	0	0	79.36	Not Occur*2)	Not Occur*3)	Not Occur
15- 30	200	14.24	64	128	128	147.2	Not Occur	Not Occur	Not Occur
30 – 45	350	14.24	112	177.79	128	147.2	Occur2)	Occur*3)	Not Occur
45 - 60	500	6.56	160	177.79	64	119.04	Occur	Occur	Not Occur

Note:
*1) TPM Output will be delayed from APRM Output with the time constant of 6 seconds.
*2) Status change of APRM HH will be made within about 40 ms after the change of LPRM Signal.
*3) Status change of TPM H will be made within about 40 ms from the TPM Output change.

(1) First Test

The Temperature and humidity profiles at the first exposure are shown in Figures 6.1.1 and 6.1.2.

The test started at 8:00 AM on Jul 28, 2006. The temperature and humidity were raised gradually, and at 2:00 PM on July 28, 2006, the temperature and humidity reached the expected values (140 degree-F and 95 %RH). The high-temperature and high-humidity conditions were kept for about 96 hours.

During the high-temperature and high-humidity conditions, the Test Specimen Units stopped functioning at 3:00 AM on Jul. 29, 2006. The trouble shooting performed at that timing found that some modules included in the Test Specimen Units were broken. Toshiba decided to interrupt the test and detailed cause investigation was performed. During the investigation, Toshiba personnel found marks which indicated water drops

from the ceiling of the chamber were falling on the top face of the Test Specimen Units. Toshiba analyzed the failed modules in Toshiba's laboratory, and found an electro-migration due to the water dropped on the IC pins, as shown in Figure 6.1.3. This electro-migration caused a short circuit between the IC pins and failures in the Test Specimen Units.

The test condition required was non-condensing environment and these results shows the environmental condition was deviated from the required conditions. By the discussion with[ ]^{a,c}, Toshiba determined to add a condensation shield, which prevents the water drop from the ceiling of the environmental chamber from falling into the Test Specimen Units, as shown in Figure 6.1.4 (b).

The broken modules were removed and spare modules which were also subjected to the radiation exposure were installed in the Test Specimen Units. After these corrective actions, the second exposure test was started and completed.

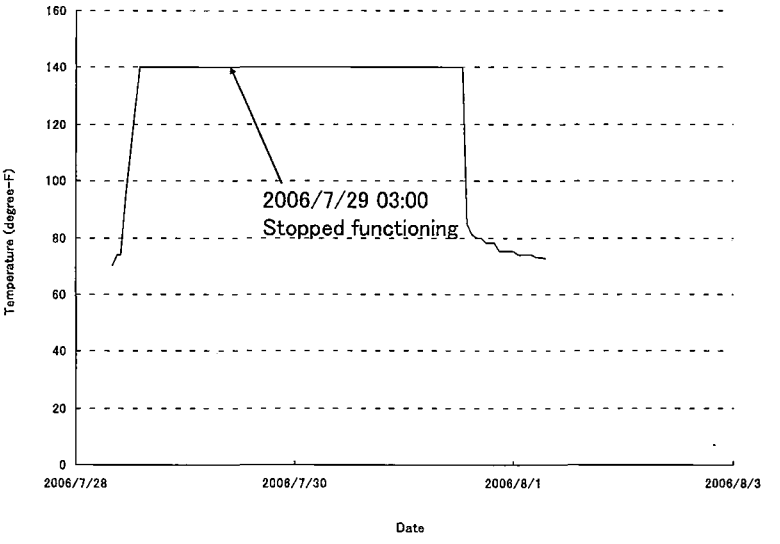

Figure 6.1.1 Temperature Profile in First Exposure Test

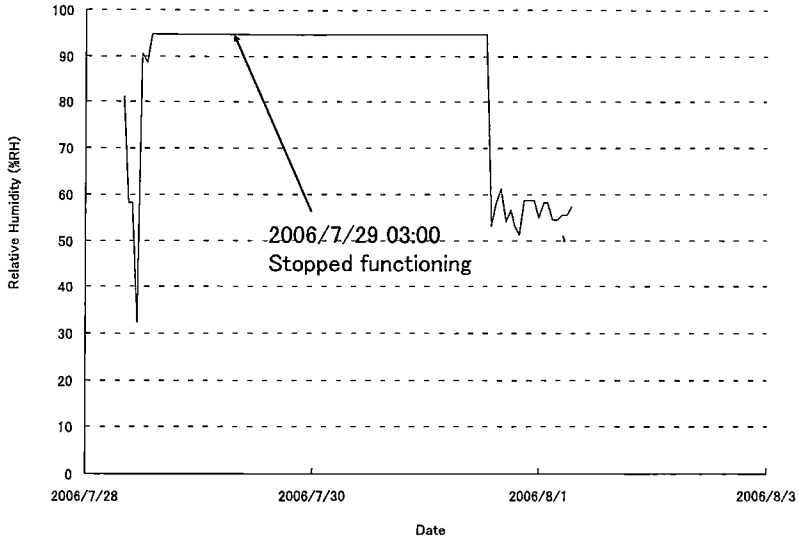

Figure 6.1.2 Humidity Profile in First Exposure Test

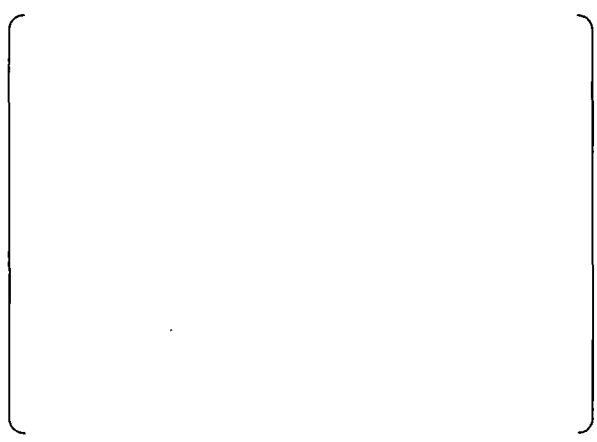

Figure 6.1.3 Results of the analysis of the IC chip.

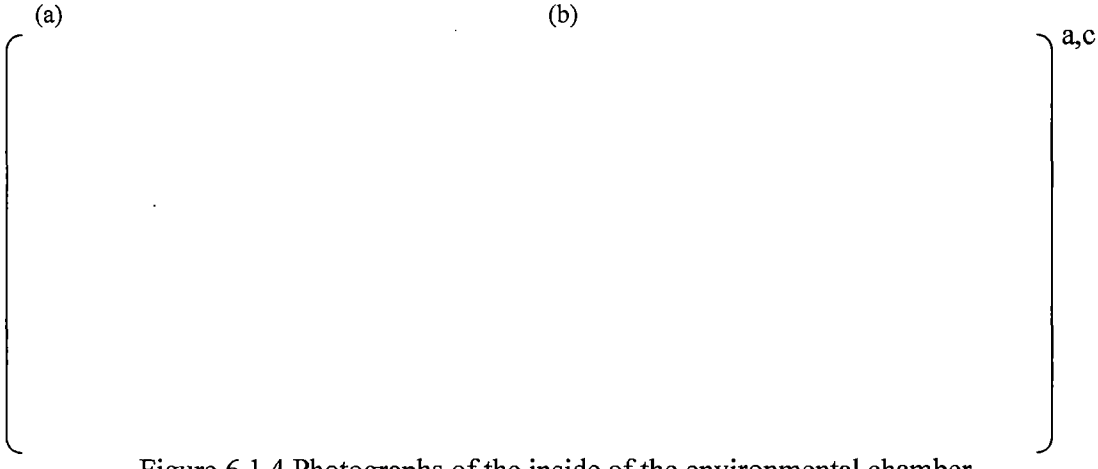

Figure 6.1.4 Photographs of the inside of the environmental chamber
(a) For First Exposure
(b) For Second Exposure

(2) Second Test (Retest)
The Temperature and humidity profiles for the second exposure are shown in Figures 6.1.5 and 6.1.6.

At 1:00 PM on Oct. 17, 2006, the test started. The temperature and humidity were raised gradually, and at 5:00 PM on Oct 17, 2006, the temperature and humidity reached the expected values, 140 degrees F and 95 %RH). The high-temperature and high-humidity conditions were maintained for about 90 hours.

After the 48 hours of exposure to high-temperature and high humidity condition, the Operability and Prudency Tests were performed and the Test Specimen Units passed the Operability and Prudency Tests under the following conditions.

- AC Power Supply: 81V, Frequency: 51Hz
- AC Power Supply: 81V, Frequency: 70Hz
- AC Power Supply: 165V, Frequency: 51Hz
- AC Power Supply: 165V, Frequency: 70Hz

After the high-temperature and high-humidity conditions, the temperature was lowered gradually, and at 3:00 PM on Oct. 21, 2006, the temperature reached the expected value, 35 degrees F. The low temperature conditions were kept for about 67 hours. During this period, the specified relative humidity could not be achieved. The low temperature test was performed independent of the low humidity test. After 8 hours of low temperature conditions, Operability and Prudency Tests were performed and the Test Specimen Units passed the Operability and Prudency Tests. The tests that require manual operation of Test Specimen switches and jumpers were skipped.

After the low-temperature conditions, the humidity was lowered gradually and at 11:00 PM on Oct. 24, 2006, the humidity reached the expected value, below 10 %RH. The low humidity conditions were kept for about 16 hours. After the first 8 hours of low humidity conditions, Operability and Prudency Tests were performed and Test Specimen Units passed the Operability and Prudency Tests. The tests require manual operation of Test Specimen switches and jumpers were skipped.

After the low-humidity conditions, the temperature and humidity were moved to ambient conditions and the Test Specimen Units passed the Operability Tests under the normal condition.

The period of high temperature and high humidity, low temperature, and low humidity conditions satisfied the required length shown in Figure 5-2 of the ERS, and the Test Specimen Units performed correctly as shown in Table 6.1.3.

At the end of the all Qualification Tests, the Performance Proof Test was performed, as described in Section 6.1, and all safety functions were confirmed that they were within the required tolerance provided in ERS Section 4.1.2 after the Test Specimen Units was exposed to the abnormal environmental conditions.

Table 6.1.3 Results of Temperature and Humidity Test

Condition	Required Period of Condition	Actual Period of Condition	Performance of Test Specimen
High Temperature and High Humidity	40 hours minimum	90 hours	Performed correctly
Low Temperature	8 hours minimum	67 hours	Performed correctly
Low Humidity	8 hours minimum	16 hours	Performed correctly

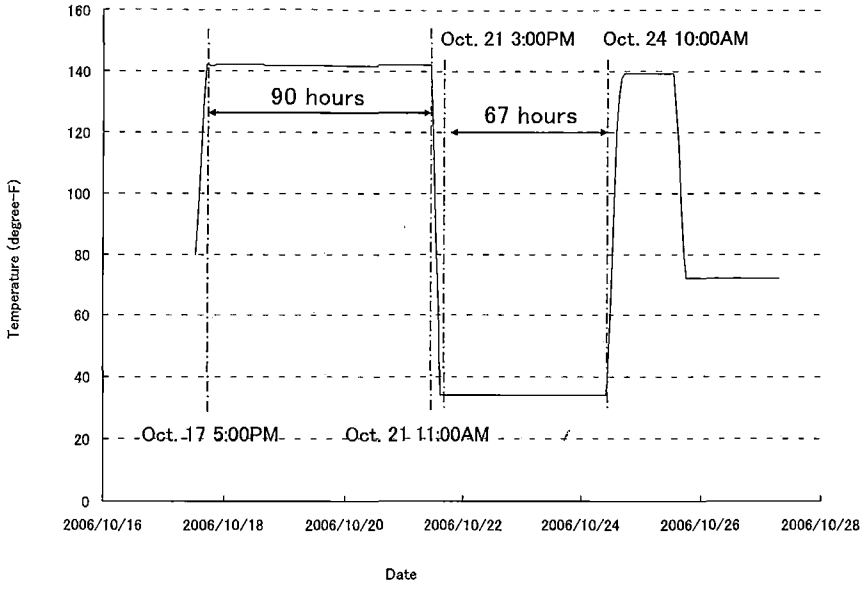

Figure 6.1.5 Temperature Profile in Second Exposure Test

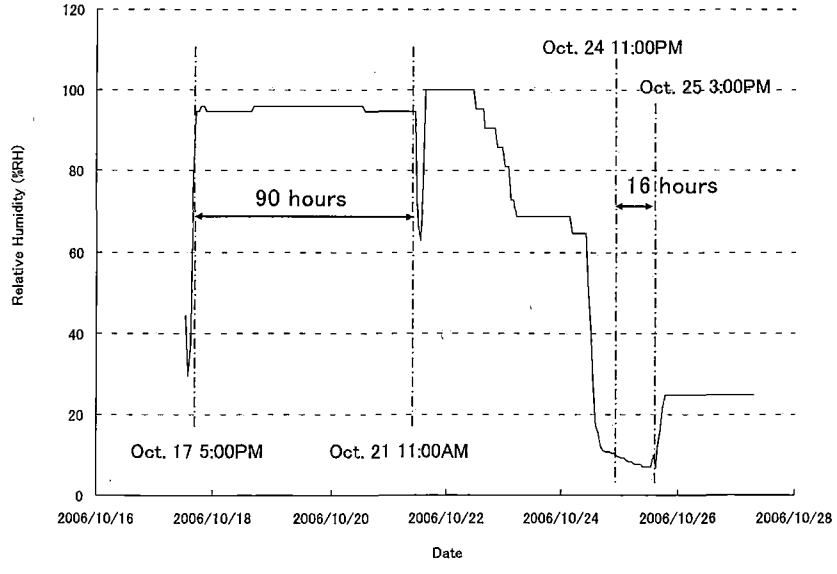

Figure 6.1.6 Humidity Profile in Second Exposure Test

6.3. Seismic Test

6.3.1. Summary of Seismic Test

In this test, the maximum level of acceleration in the SSE was limited to about 10 g, due to the limitation in [ ]^{a,c} vibration table. Other than this deviation, the tests successfully completed with no signs of physical or functional degradation of the Test Specimen Units.

Accelerometers are attached to the text fixture, the Test Specimen Units (LPRM, LPRM/APRM, and FLOW), the power line panel, and the test table. Appendix A provides the Seismic Tests results.

6.3.2. Data Evaluation

(1) Resonance Search

A low-level, approximately 0.2 g, single-axis sine sweep was performed in each of the three orthogonal axes to search for any major resonance of the Test Specimen Units in a defined frequency band. The sweep was performed at a sweep rate of one octave per minute.

Figures A.1.1 throughA.1.15 shows the results for the resonance search along vertical axis. Figures A.1.1, A.1.6, and A.1.11 are the spectra of the test fixtures. Compared to these spectra, other spectra which show the response of the Test Specimen Units and the power line panel do not show major resonance.

(2) Random Multifrequency Tests (5 OBEs and 1 SSE)

The Test Specimens were subjected to 30 second duration triaxial multifrequency random motion, which was amplitude-controlled in one-sixth octave bandwidth spaced one-sixth octave apart over the frequency range of 1 to 100 Hz. These simultaneous, but independent random signals were used as the excitation to produce phase-incoherent motions in the vertical and two horizontal axes. The amplitude of each

one-sixth octave bandwidth was independently adjusted in each of the three axes until the Test Response Spectra (TRS) enveloped the Required Response Spectra (RRS). The resulting table motion was analyzed by a response spectrum analyzer and plotted at one-sixth octave intervals over the frequency range of 1 to 100Hz.

The Test Specimen was subjected to five Operating Basis Earthquake (OBE) Tests and one Safe Shutdown Earthquake (SSE). The required peak amplitude of the SSE should be 14 g according to ERS Figure 5-3. Due to [ ]^{a,c} seismic table limits, the peak amplitude of SSE was approximately 10 g.

Figures in sections A.2.1 to A.2.5 show the TRS for OBE tests and Figures in Section A2.6 show Test Response Spectra for the SSE test. Figures A2.6.4 to A2.6.6 show the coherent plot of the SSE.

These test results show that the random multi frequency tests conditions were successfully applied to the Test Specimen Units, with the single exception of not meeting the peak loading for the SSE, based on table limits.

During the vibration application period, the Test Specimen Units were powered and their representative signals (Analog Outputs and Digital Outputs) were monitored. The results of the test confirmed that all signals were within the required tolerance during the vibration application period.

Following the seismic testing, the performance of the Test Specimen was compared to the baseline performance, measured during Pre-Qualification Test, to determine if the test impacted the performance and operability of the Test Specimen. There was no deviation from the baseline performance.

6.4. EMC Test

6.4.1. Summary of EMC Test

After the first series of EMC Tests (EMI/RFI, Surge Withstand Capability, EFT/B, ESD and Class 1E to Non 1E Isolation), modifications of the Test Specimen Units were performed as discussed in Section 2.4 of this report. The EMC tests were then repeated.

The EMC Test with modified modules was performed from October 18th 2007 to December 5th 2007 as shown in Table 6.4.1. The Test Specimen Units passed all tests except CE101 without any deviations from the requirements in Section 3.3. For CE101, some mitigation is required for the Test Specimen Units as shown in Section 6.4.2.1 (2).

Appendix B shows the detailed test results.

For all EMC Tests, specific test patterns were applied in repetition. For this purpose, system inputs were varied during the EMC Test as shown in Table 6.4.2. The pattern was repeatedly applied.

During the susceptibility tests, the output data were continuously compared to the expected values with the tolerance.

Table 6.4.1 Compliance Matrix for EMC Test

Test ID	Test Description	Test Completed On	Compliance with Specification
CE101	Conducted Emissions – Power Leads 60 Hz to 10 kHz	19 Oct. 2007	No (Mitigation needed)
CE102	Conducted Emissions – Power Leads, 10 kHz to 2MHz	7 Nov. 207	Yes
CS101	Low Frequency Conducted Susceptibility Test at AC Power Leads	5 Nov. 2007	Yes
CS114	High Frequency Conducted Susceptibility Test at AC Power Leads and Signal Leads	29 Oct. 2007	Yes
CS115	Conducted Susceptibility (Signal Leads, Bulk cable injection, impulse excitation)	1 Nov. 2007	Yes
CS116	Conducted Susceptibility (Signal Leads, Damped sinusoidal transients)	1 Nov. 2007	Yes
RE101	Radiation Emissions, Magnetic Field	9 Nov. 2007	Yes
RE102	Radiated Emissions, Electric Field	30 Oct. 2007	Yes
RS101	Radiated Susceptibility, Magnetic Field	24 Oct. 2007	Yes
RS103	Radiated Susceptibility, Electric Field	30 Oct. 2007	Yes
SWC	Surge Withstand Capability	28 Nov. 2008	Yes
EFT/B	Electrical Fast Transient/Burst	29 Nov. 2008	Yes
ESD	Electrical Discharge	26 Nov. 2007	Yes
Class 1E to Non-1E Isolation	Class 1E to Non-1E Isolation	05 Dec. 2007	Yes

Table 6.4.2 Input and Expected Output pattern

	Input		Expected Output							Internal Value				
Time (sec)	LPRM Input Current (μA)	Loop FLOW Input Current (mA)	HNS 511/515 LPRM (V)	HNS 514/518 LPRM (mV)	HNS 512/516 APRM (V)	HNS 514/518 APRM (mV)	HNS512/516 FLOW (V)	HNS513/517 FLOW (V)	APRM High High Trip*2	LPRM (%)	APRM (%)	FLOW (%)	TPM (%)*1	APRM High High Threshold
0	0 00	20 00	1 00	0 00	0 00	0 00	1 00	5 00	0	0 00	0 00	125 00	68 26	120 00
1	37 33	18 67	1 30	11 95	0 15	23 89	0 96	4 79	0	9 33	18 67	119 68	59 99	120 00
2	74 67	17 33	1 60	23 89	0 30	47 79	0 91	4 56	0	18 67	37 33	114 11	56 22	120 00
3	112 00	16 00	1 90	35 84	0 45	71 68	0 87	4 33	0	28 00	56 00	108 25	56 18	120 00
4	149 33	14 67	2 19	47 79	0 60	95 57	0 82	4 08	0	37 33	74 67	102 06	59 26	120 00
5	186 67	13 33	2 49	59 73	0 75	119 47	0 76	3 82	0	46 67	93 33	95 47	64 94	120 00
6	224 00	12 00	2 79	71 68	0 90	143 36	0 71	3 54	0	56 00	112 00	88 39	72 78	120 00
7	261 33	10 67	3 09	83 63	1 05	167 25	0 65	3 23	1	65 33	130 67	80 69	82 43	120 00
8	298 67	9 33	3 39	95 57	1 11	177 79	0 58	2 89	1	74 67	138 50	72 17	91 78	118 75
9	336 00	8 00	3 69	107 52	1 11	177 79	0 50	2 50	1	84 00	138 50	62 50	99 56	118 75
10	373 33	6 67	3 99	119 47	1 11	177 79	0 41	2 04	1	93 33	138 50	51 03	106 05	118 75
11	410 67	5 33	4 29	131 41	1 11	177 79	0 29	1 44	1	102 67	138 50	36 08	111 46	118 75
12	448 00	4 00	4 58	143 36	1 11	177 79	0 00	0 00	1	112 00	138 50	0 00	115 97	118 75
13	485 33	2 67	4 88	155 31	1 11	177 79	0 00	0 00	1	121 33	138 50	0 00	119 72	118 75
14	522 67	1 33	5 18	167 25	1 11	177 79	0 00	0 00	1	130 67	138 50	0 00	122 85	118 75
15	560 00	0 00	5 44	177 79	1 11	177 79	0 00	0 00	1	138 90	138 50	0 00	125 46	118 75
16	522 67	1 33	5 18	167 25	1 11	177 79	0 00	0 00	1	130 67	138 50	0 00	127 63	118 75
17	485 33	2 67	4 88	155 31	1 11	177 79	0 00	0 00	1	121 33	138 50	0 00	129 44	118 75
18	448 00	4 00	4 58	143 36	1 11	177 79	0 00	0 00	1	112 00	138 50	0 00	130 95	118 75
19	410 67	5 33	4 29	131 41	1 11	177 79	0 29	1 44	1	102 67	138 50	36 08	132 21	118 75
20	373 33	6 67	3 99	119 47	1 11	177 79	0 41	2 04	1	93 33	138 50	51 03	133 26	118 75
21	336 00	8 00	3 69	107 52	1 11	177 79	0 50	2 50	1	84 00	138 50	62 50	134 13	118 75
22	298 67	9 33	3 39	95 57	1 11	177 79	0 58	2 89	1	74 67	138 50	72 17	134 86	118 75
23	261 33	10 67	3 09	83 63	1 05	167 25	0 65	3 23	1	65 33	130 67	80 69	134 16	118 75
24	224 00	12 00	2 79	71 68	0 90	143 36	0 71	3 54	0	56 00	112 00	88 39	130 47	118 75
25	186 67	13 33	2 49	59 73	0 75	119 47	0 76	3 82	0	46 67	93 33	95 47	124 28	120 00
26	149 33	14 67	2 19	47 79	0 60	95 57	0 82	4 08	0	37 33	74 67	102 06	116 01	120 00
27	112 00	16 00	1 90	35 84	0 45	71 68	0 87	4 33	0	28 00	56 00	108 25	106 01	120 00
28	74 67	17 33	1 60	23 89	0 30	47 79	0 91	4 56	0	18 67	37 33	114 11	94 56	120 00
29	37 33	18 67	1 30	11 95	0 15	23 89	0 96	4 79	0	9 33	18 67	119 68	81 91	120 00
30	0 00	20 00	1 00	0 00	0 00	0 00	1 00	5 00	0	0 00	0 00	125 00	68 26	120 00

*1: After 2-3 cycles from the starting of pattern input

*2: 1: Trip, 0: Not Trip

*3: Threshold contains the hysteresis

6.4.2. Data Evaluation

6.4.2.1. EMI/RFI Emission Test

(1) Radiated Emissions, Magnetic Field

This test measured radiated magnetic field emissions in the frequency range 30 Hz to 100 kHz with the field applied 7 cm from the surface of test point, according to MIL-Std 461 requirements RE101. Table B1 summarized the test points and results. All emissions were below the allowable level specified in Section 5.4.2.1. Figures B.1.1 to B.1.5 shows the example of the emission data obtained.

(2) Radiated Emissions, Electric Field

Vertically and horizontally polarized emissions were measured with antenna placed one meter from the test boundary. A RF-survey was performed as a pre-scan to determine that the measurement at the front of the Test Specimen would be the worst case. The data documented in Appendix B Figures B2.1 and B2.2 show that the emissions were below the allowable level specified in Section 5.4.2.2.

(3) Low Frequency Conducted Emissions

The test setup followed the guidance of MIL-Std 461E requirement CE101. Table B.3.1 summarized the test points. Figures B.3.1 to B.3.9 are the Test plots. Table B3.2 to Table B3.6 show the detailed test results between 60 Hz to 1 kHz.

For the CE101 requirement, appropriate compensatory mitigation should be provided for the NRW-FPGA Based PRM Units. For example, Figure B.3.1 shows the emission from the power leads. From 100 Hz to 700 Hz, the emission exceeded the limit shown in RG1.180R1. This emission result from waveform distortion from the AC to DC converter included in the PRM Units. To suppress this emission, inserting a coil was effective, as shown in Figure B.3.4 through B.3.9. If the suppression is not applied, the distortion should be evaluated to ensure that the distortion will not affect any other equipment connected to the same power train.

(4) High Frequency Conducted Emissions

The test setup followed the guidance of of MIL-Std 461E requirement CE102. Figures B.4.1 to B.4.3 are the Test plots. Table B4 summarized the test points. All emissions were below the allowable level specified in Section 5.4.3.2.

6.4.2.2. EMI/RFI Susceptibility Test

(1) Radiated Susceptibility, Magnetic Fields

The Test Specimen Units were tested for susceptibility to radiated magnetic fields in accordance with MIL-461E requirement RS101. The test level is shown in ERS Section 5.5.3 Figure 5-6. The test frequency range was from 30 Hz to 100 kHz. The radiated magnetic fields were applied to the test points shown in Table B5 and the Test Specimen Units operated normally before, during, and after application of the radiated magnetic field .

(2) Radiated Susceptibility, Electric Field

This test confirmed that the Test Specimen is not susceptible to the radiated electric fields. The test applied an electric field at 10 volts/meter, with frequency ranging from 30 MHz to 1 GHz, as shown in ERS Section 5.5.3.

The radiated electric field was applied to the front panel of the Test Specimen Units rack according to MIL-Std 461E requirement RS103. The Test Specimen Units operated normally before, during, and after the application of the radiated electric field.

(3) Low-Frequency Conducted Susceptibility Test at AC Power Leads

This test was performed on the input power cable No. 10 of the AC power sources. The test was performed according to MIL-Std-461E requirement CS101. The envelope limits are shown in ERS Figure 5-4. The test was performed from 120 Hz, which is the second harmonic of Power Frequency (60 Hz) to 150 kHz.

The Test Specimen Units operated normally before, during, and after the testing.

(4) High-Frequency Conducted Susceptibility Test at AC Power Leads

This test was performed to the input power leads to the AC power sources. The test was performed according to MIL-Std-461E requirement CS114. The envelope limits

are shown in ERS Figure 5-5. Test was performed from 10 kHz to 30 MHz. The test signals were applied to the test points shown in Table B6.

The Test Specimen Units operated normally before, during, and after testing.

(5) High-Frequency Conducted Susceptibility (Signal Leads)

This test was performed on signal leads in accordance with MIL-Std-461E requirement CS114. The envelope was set from 10 kHz to 30 MHz, and 91 dBμA. The test signals were applied to the test points shown in Table B7.

The Test Specimen Units operated normally before, during, and after testing.

(6) Conducted Susceptibility (Signal Leads, Bulk cable injection, impulse excitation)

This test was performed according to MIL-Std-461E requirement CS115. The operating envelope is set to 2 amperes (A). The test signals were applied to the test points shown in Table B8.

The Test Specimen Units operated normally before, during, and after testing.

(7) Conducted Susceptibility (Signal Leads, Damped sinusoidal transients)

This test was performed according to MIL-Std-461E requirement CS116. The operating envelope was set to 5A. The test is performed from 10 kHz to 100 MHz. The test signals were applied to the test points shown in Table B9.

The Test Specimen Units operated normally before, during, and after testing.

6.4.2.3. Surge Withstand Capability Test

In this test, surges were applied to the Test Specimen Units in accordance with IEC 61000-4-12 (for Ring Wave) and IEC 61000-4-5 (for Combination Wave). Surges were applied to the leads of power cable No. 10. The combinations of the power leads to which the surges were applied were as follows:

- Line and Neutral
- Line and Ground
- Neutral and Ground
- [Line and Neutral] and Ground, only for Ring Wave

The Ring Wave test signals had the following requirements:

- Voltage:+/- 2kV
- Pulse Shape: 100kHz, 0.5 microsecond rise time, 10 microseconds pulse width
- Repetition at 1 per 5 second*
- Number of tests: Five positive and five negative at the selected points
- Phase:0 degree, 90 degree and 270 degree

*Note: The application of 1 repetition each second is in IEC 61000-4-12. However, [ ]^{a,c} equipment could not operate this rapidly. This is only the application period issue and this does not create any adverse effects on the equipment qualification envelope.

The Combination Wave had the following requirements:

- Voltage: +/- 2 kV
- Pulse Shapes:
  - Impulse of 1.2 microsecond (+/- 30 %) rise time, 50 microseconds pulse width, open circuit, double exponential
  - Impulse of 8 microseconds (+/- 20 %) rise time, 20 microseconds pulse width, short circuit, double exponential
- Repetition: 1 per minute
- Number of tests: Five positive and five negative at the selected points
  - Phase:0 degree, 90 degree and 270 degree

The surges were applied to the test points shown in Tables B10.1 and B10.2. The Test Specimen Units operated normally before, during, and after testing.

6.4.2.4. EFT/B Test

In this test, EFT/B transients were applied to the Test Specimen Units in accordance with IEC 61000-4-4 (Reference 2 (8)). The EFT/B transient was applied to the leads of power cable No. 10. The EFT/B was applied to the following cables, as follows:

- Line
- Neutral
- Ground
- Line, Neutral and Ground simultaneous

The specification for the EFT/B applied in this test was as follows:

- Limits (Applied peak voltage): Voltage = +/- 2 kVp-p
- Pulse Shape: Impulse of 5 nanoseconds (+/- 30 %) rise time, 50 nanoseconds (+/- 30 %) pulse width, double exponential
- Repetition rate: 5 kHz (+/- 1k Hz)
- Burst duration: 15 ms (+/- 20 %)
- Burst period: 300 ms (+/- 20 %)
- Test Signal Application Duration: Not less than 1 minute

The EFT/B transients were applied to the test points shown in Tables B11. The Test Specimen Units operated normally before, during, and after testing.

6.4.2.5. ESD Test

This test showed that the ESD features of the NRW-FPGA-Based PRM system conformed to IEC 61000-4-2 and the ESD levels complied with the levels shown in Section 6.4.2 of EPRI TR-107330 and EPRI TR-102323 Rev.1 Appendix B Section 3.5 ($\pm$8kV for contact discharge or $\pm$15kV for air discharge). Detailed results are shown in Table B.12.

No temporary degradation or loss of function or performance at the ESD application were shown when the ESD transients were applied to the front panels and the parts

placed on the front panels, which can all be touched by people during normal operation. In addition no temporary degradation, or loss of function or performance occurred with ESD transients applied to the side panels. Temporary degradation or recoverable loss of function were identified when the ESD transients were applied to the rear panels, or the parts placed on these panels, which will not likely be exposed to ESD during normal operation.

The cabinet in which the NRW-FPGA-Based PRM Units are installed should be placarded as containing ESD sensitive equipment, and plant administrative procedures written to limit access to the rear panels during normal plant operation. A notification that any person who accesses the rear panels of NRW-FPGA-Based PRM Units shall wear an anti-ESD wrist strap during normal plant operation should be added to the User's Manual.

6.4.2.6. Class 1E to Non-1E Isolation Test

The test levels applied were 600 VAC and 250 VDC at 25 amperes for 30 seconds.

These test level voltages were applied to the test points shown in Tables B13.1 and B13.2. The Test Specimen Units were not affected by the voltages, and the modules were not affected.

7. Conclusion

Table 7.1 summarizes the results of this testing. When the NRW-FPGA-Based PRM System is applied to actual plants, the following limitation should be considered:

(1) In the Seismic Test, due to the limitation of the [redacted]^{a,c} vibration table, the peak amplitude of SSE was approximately 10 g. The seismic withstand capability of the NRW-FPGA-Based PRM Units should be evaluated against the plant's maximum requirements. Retest may be required if the plant SSE maximum requirements are not enveloped by the testing.

(2) For conducted emissions (CE101), appropriate compensatory mitigation should be provided for the NRW-FPGA-Based PRM Units. To suppress the low frequency conducted emission, mitigations such as inserting a coil should be considered.

(3) The cabinet in which the NRW-FPGA-Based PRM Units were installed should be placarded to limit access to the rear panels during normal plant operation and plant administrative procedures written to limit access to the rear panels during normal plant operation. A notification that any person who accesses the rear panels of the NRW-FPGA-Based PRM Units during the normal plant operation shall wear an anti-ESD wrist strap should be added to the user's manual.

With the above considerations, the NRW-FPGA-Based PRM Units achieved the required performance shown in the ERS Section 5 in accordance with the test requirements given in the ERS Section 7.

Table 7.1 Summary of Qualification Test[a,c]

Test		ERS Ref. Para.	Toshiba Test Procedure Number	[ ] Test Procedure Number	Results
1. Pre-Qualification Test	1.1 System Set-up and Check-out Test	Not applicable	FPG-TPRC-C51-0001	Not applicable	Complied
	1.2 Burn-in Test	7.2.1G		Not applicable	
	1.3 System Set-up and Check-out Test	Not applicable	FPG-TPRC-C51-1001	Not applicable	
	1.4 Operability Test	7.2.2, 7.2.4	FPG-TPRC-C51-1009	Not applicable	
	1.5 Prudency Test	7.2.3, 7.2.4	FPG-TPRC-C51-1010	Not applicable	
2. Qualification Test	2.2 Environmental Test (Radiation Exposure)	7.3.2.4, 5.5.1	FPG-TPRC-C51-1002	FPG-VDN-C51-0200	Complied
	2.4 Environmental Test (Temperature and Humidity)	7.3.2.4, 5.5.1	FPG-TPRC-C51-1002	FPG-VDN-C51-0200	1st Test:Failed due to the problem of environmental Chamber 2nd Test: Comply
	2.6 Seismic Test	7.3.2.5, 5.5.2	FPG-TPRC-C51-1003	FPG-VDN-C51-0200	Complied (due to the limitation of the [ ]a,c vibration table, the peak amplitude of SSE was approximately 10 g.)
	2.8 EMI/RFI Test	7.3.2.2, 5.5.3	FPG-TPRC-C51-1004	FPG-VDN-C51-0201	Complied (Before this test, modifications of AO and LPRM modules to enhance the noise withstand capability were performed. For CE101 test, choke coil should be added for mitigation.)
	2.9 Surge Withstand Capability Test	7.3.2.7, 5.5.4	FPG-TPRC- C51-1005	FPG-VDN-C51-0201	Complied
	2.10 EFT / B Test	7.3.2.9, 5.5.5	FPG-TPRC- C51-1006	FPG-VDN-C51-0201	Complied
	2.11 ESD Test	7.3.2.10, 5.5.6	FPG-TPRC-C51 -1007	FPG-VDN-C51-0201	Complied (The some test points in back panel of the Test Specimen Units showed susceptibilities, but recovered without degradation. These results complied with the requirement of ESD Test)
	2.12 Class 1E to Non-1E Isolation Test	7.3.2.8, 5.5.7	FPG-TPRC-C51 -1008	FPG-VDN-C51-0201	Complied

Test		ERS Ref. Para.	Toshiba Test Procedure Number	a,c [ ] Test Procedure Number	Results
3. Performance Proof Test	3.2 Operability Test	7.2.2, 7.2.4	FPG-TPRC-C51-1009	Not applicable	Complied

8. References, Definitions and Acronyms

8.1. References

(1) U.S. NRC Regulatory Guide RG-1.180 Revision 1
Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems, revised October 2003. Chapters 3 and 4
(2) EPRI TR-102323-R2
Guidelines for Electromagnetic Interference Testing in Power Plant Equipment, Subsystems and Equipment, November 2000
(3) EPRI TR-107330
Generic Requirements Specification for Qualifying a Commercially Available PLC for Safety-Related Applications in Nuclear Power Plants, Final Report dated December 1996
(4) IEEE Std 384-1992
IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits
(5) IEEE Std 323-1983
Standard for Qualifying of Class 1E Equipment for Nuclear Power Generating Stations
(6) MIL-Std-461E
Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
(7) IEC61000-4-2: 1995, Amendment 1 (1998), Amendment 2 (2000)
Electrostatic discharge immunity test
(8) IEC61000-4-4: 1995, Amendment 1 (2000), Amendment 2 (2001)
Electrical fast transient / burst immunity test
(9) IEC61000-4-5: 1995, Amendment 1 (2000)
Surge immunity test
(10) IEC61000-4-12: 1996
Oscillatory Waves Immunity Tests

(11) FPG-PLN-C51-0003
NRW-FPGA-Based PRM System Qualification Project Qualification Plan, Rev.3
(12) FPG-PLN-C51-0005
NRW-FPGA-Based PRM System Qualification Project Master Test Plan, Rev.4
(13) FPG-RQS-C51-0001
NRW-FPGA-Based PRM System Qualification Project Equipment Requirement Specification of FPGA based Units, Rev.7
(14) FPG-DRT-C51-0002
NRW-FPGA-Based PRM System Qualification Project Preliminary Technical Evaluation Report, Rev.10
(15) FPG-VDN-C51-0047 Schematic Diagrams (PRM System for Qualification), Rev.9
(16) FPG-VDN-C51-0200 Radiation Exposure, Environmental, and Seismic Qualification Test Procedure for a Toshiba FPGA-Based PRM System, Rev.1
(17) FPG-VDN-C51-0201 EMI MIL-STD-461E Test Procedure on a new-FPGA-Based PRM System, Rev.5
(18) FPG-TPRC-C51-0001 System Validation Test Procedure, Rev.2
(19) FPG-TPRC-C51-1001 System Set-Up and Check-out Test Procedure, Rev.6
(20) FPG-TPRC-C51-1002 Environmental Test Procedure, Rev.3
(21) FPG-TPRC-C51-1003 Seismic Test Procedure, Rev.3
(22) FPG-TPRC-C51-1004 EMI/RFI Test Procedure, Rev.7
(23) FPG-TPRC-C51-1005 Surge Withstand Capability Test Procedure, Rev.4
(24) FPG-TPRC-C51-1006 EFT/B Test Procedure, Rev.4
(25) FPG-TPRC-C51-1007 ESD Test Procedure, Rev.5
(26) FPG-TPRC-C51-1008 Class 1E to Non-1E Isolation Test Procedure, Rev.5
(27) FPG-TPRC-C51-1009 Operability Test Procedure, Rev.5
(28) FPG-TPRC-C51-1010 Prudency Test Procedure, Rev.5
(29) FPG-CFM-C51-0001 Master Configuration List, Rev.4

8.2. Definitions and Acronyms

Test System, Test Specimen, and Test Equipment. The Qualification Project performs qualification of PRM Units installed in a Test System. Terms relating to the Test System are defined as follows:

- Test System means a system consisting of Test Specimen and Test Equipment.
- Test Specimen means NRW-FPGA-Based PRM Units, and the cable between the Units, to be tested for Qualification.
- Test Equipment means support equipment for the Qualification Test of the Test Specimen such as the simulator, cable, and data logger.

APRM:	Average Power Range Monitor
EFT/B:	Electrically Fast Transients and Burst
ERS:	Equipment Requirement Specification
ESD:	Electro Static Discharge
FPGA:	Field Programmable Gate Array (a programmable logic device).
LPRM:	Local Power Range Monitor
MTP:	Master Test Plan
NED:	Nuclear Energy Systems & Services Division
NRW-FPGA	Non-Rewritable-FPGA
OBE:	Operating Basis Earthquake
PRM:	Power Range Monitor
PTER:	Preliminary Technical Evaluation Report
SSE:	Safe Shutdown Earthquake

APPENDIX A Test results data for seismic tests

A.1 Resonance Search

<Vertical>

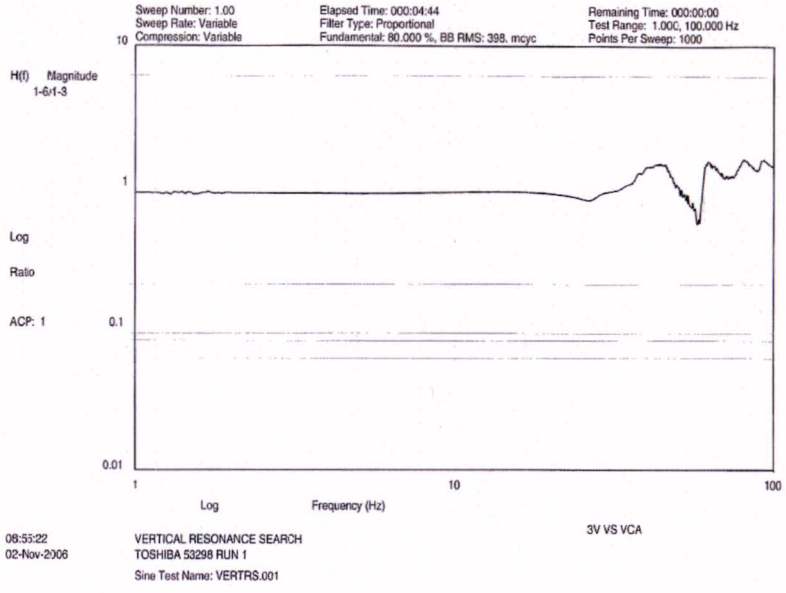

Figure A.1.1 Test Fixture's spectrum for Vertical vibration.

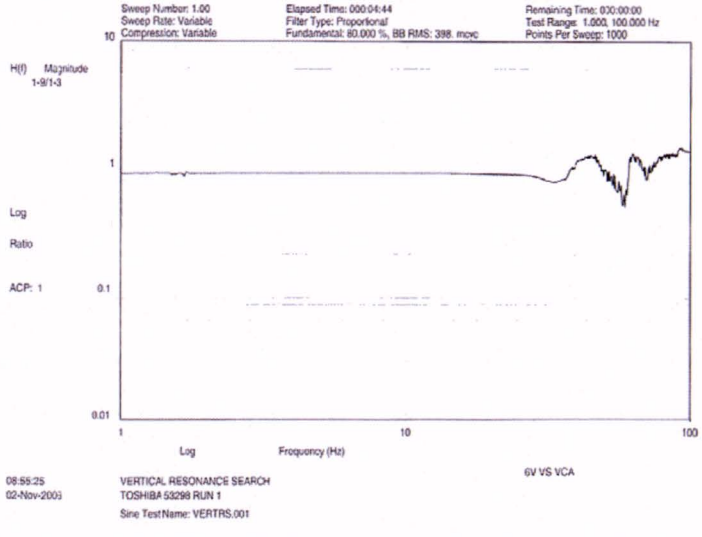

Figure A.1.2 Flow Unit's spectrum for Vertical vibration.

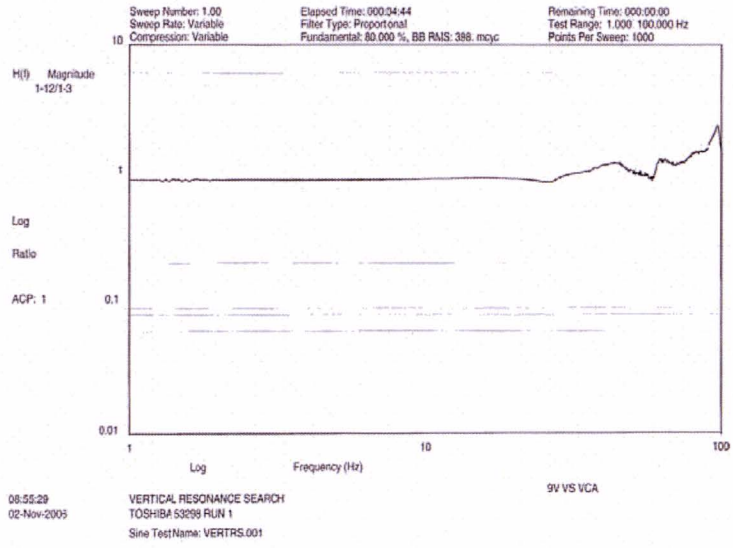

Figure A.1.3 Power Line Panel's spectrum for Vertical vibration.

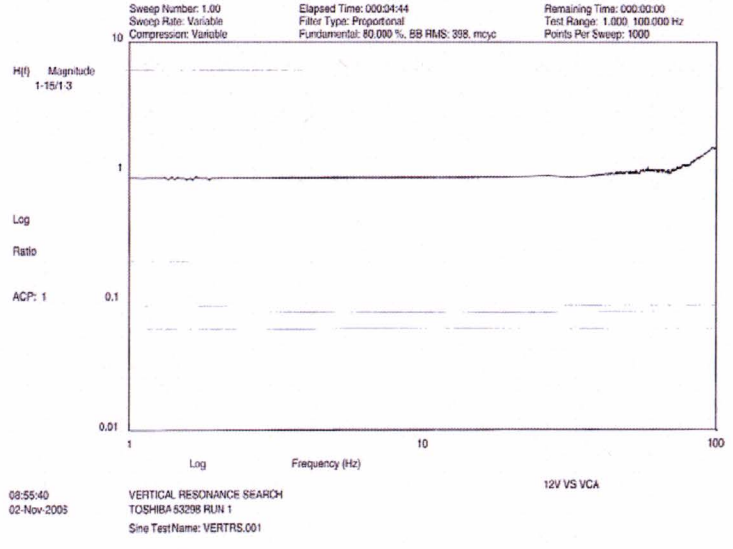

Figure A.1.4 LPRM/APRM Unit's spectrum for Vertical vibration.

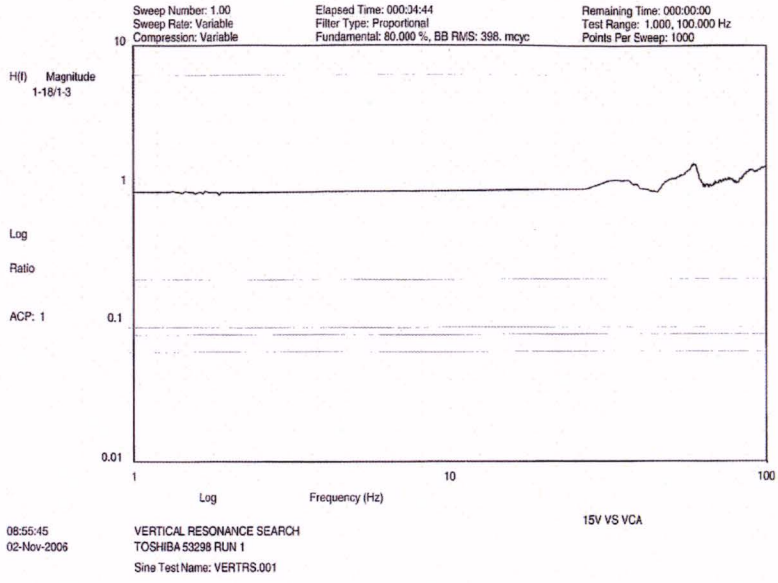

Figure A.1.5 LPRM/APRM Unit's spectrum for Vertical vibration

<North to South>

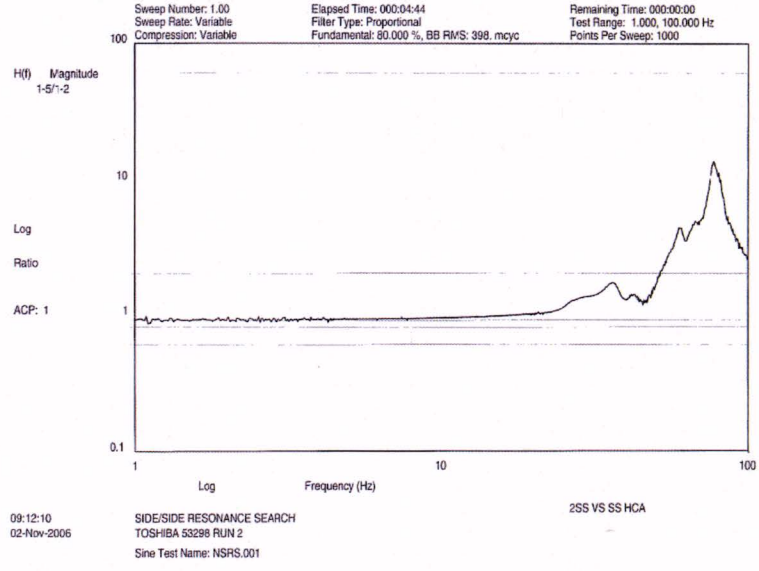

Figure A.1.6 Test Fixture's spectrum for Horizontal (North to South) vibration.

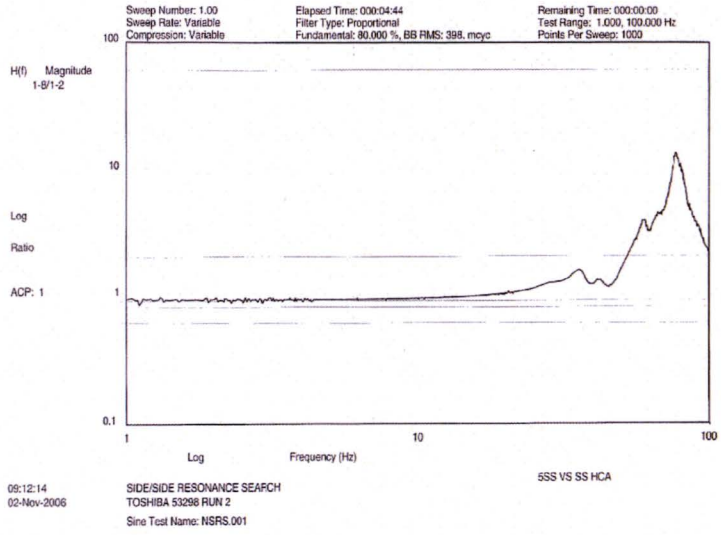

Figure A.1.7 Flow Unit's spectrum for Horizontal (North to South) vibration.

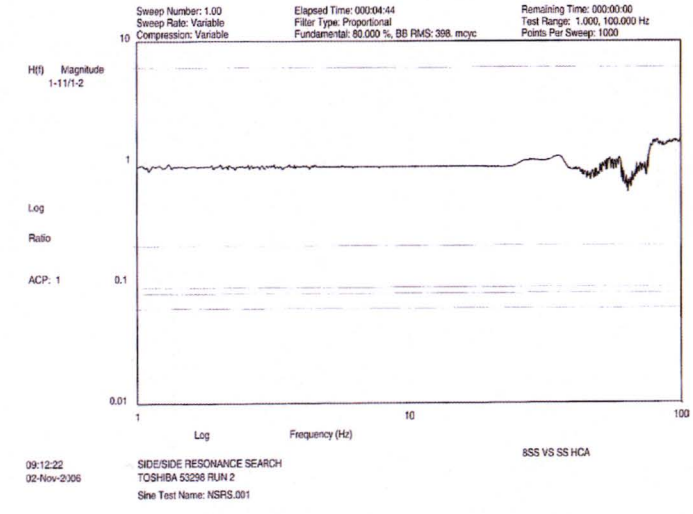

Figure A.1.8 Power Line Panel's spectrum for Horizontal (North to South) vibration.

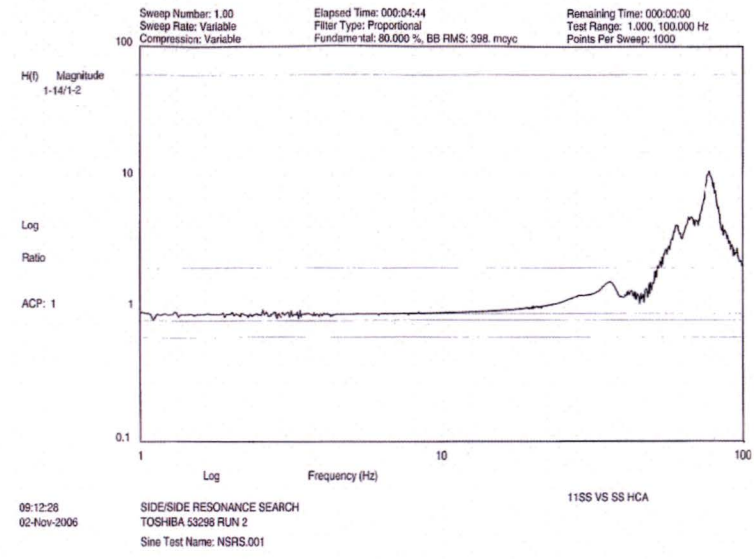

Figure A.1.9 LPRM/APRM Unit's spectrum for Horizontal (North to South) vibration.

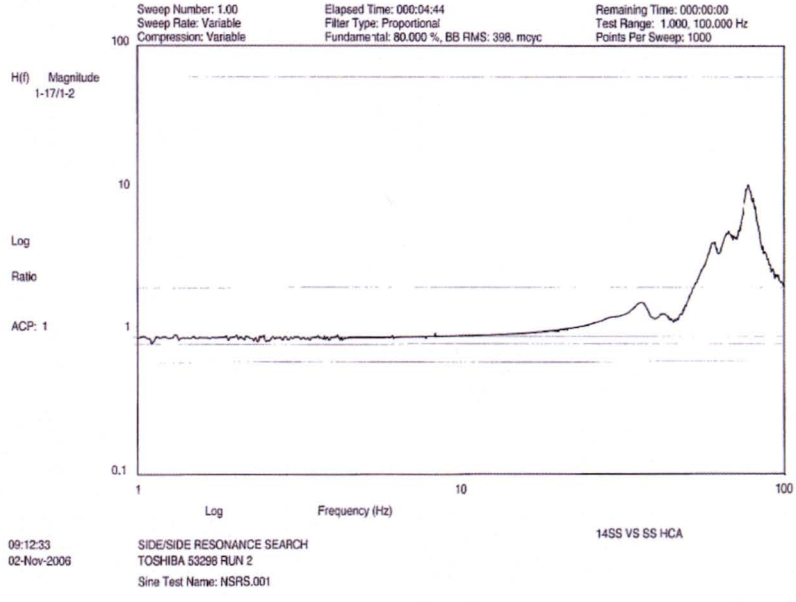

Figure A.1.10 LPRM Unit's spectrum for Horizontal (North to South) vibration.

<East to West>

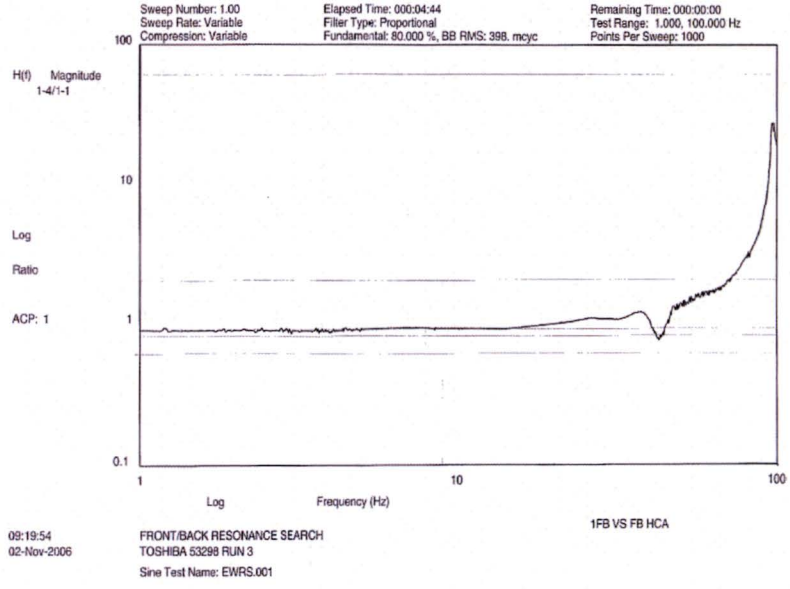

Figure A.1.11 Test Fixture's spectrum for Horizontal (East to West) vibration

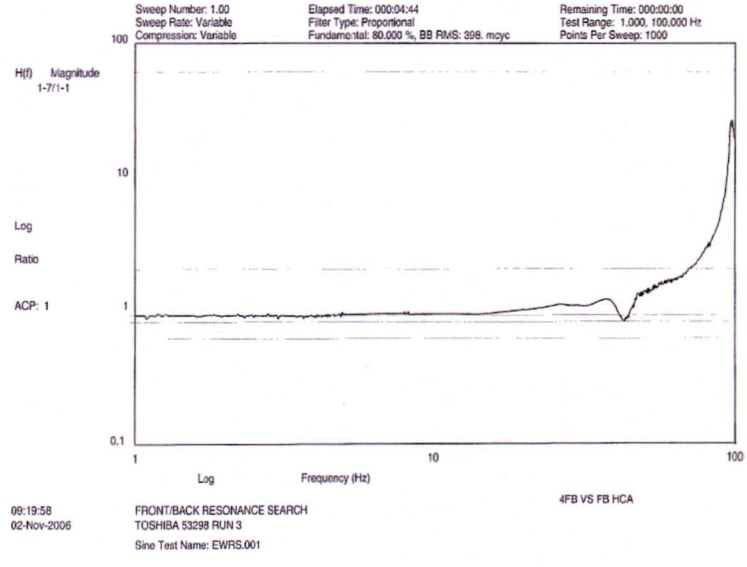

Figure A.1.12 Flow Unit's spectrum for Horizontal (East to West) vibration

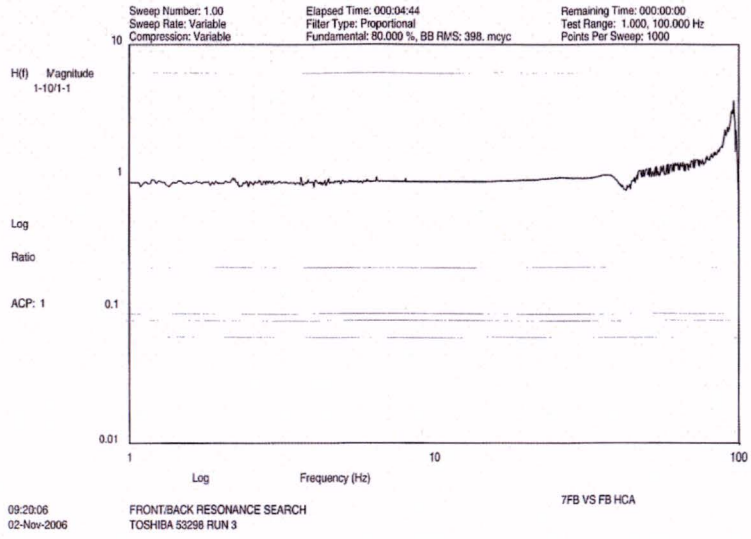

Figure A.1.13 Power Line Panel's spectrum for Horizontal (East to West) vibration

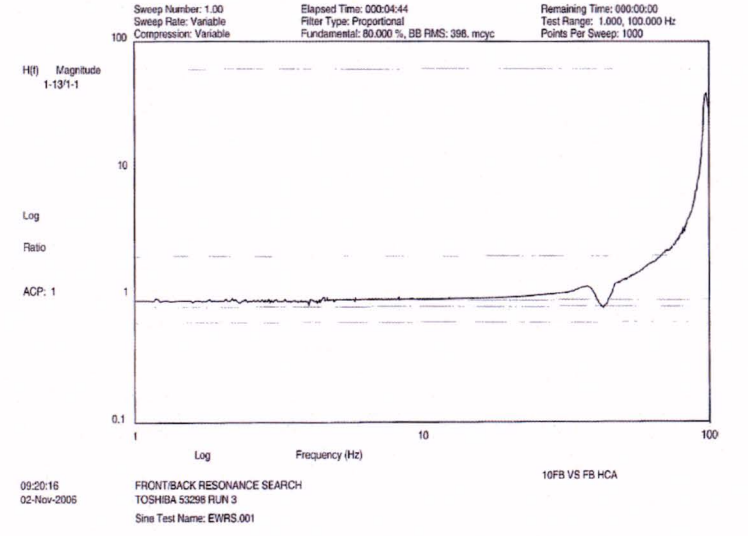

Figure A.1.14 LPRM/APRM Unit's spectrum for Horizontal (East to West) vibration

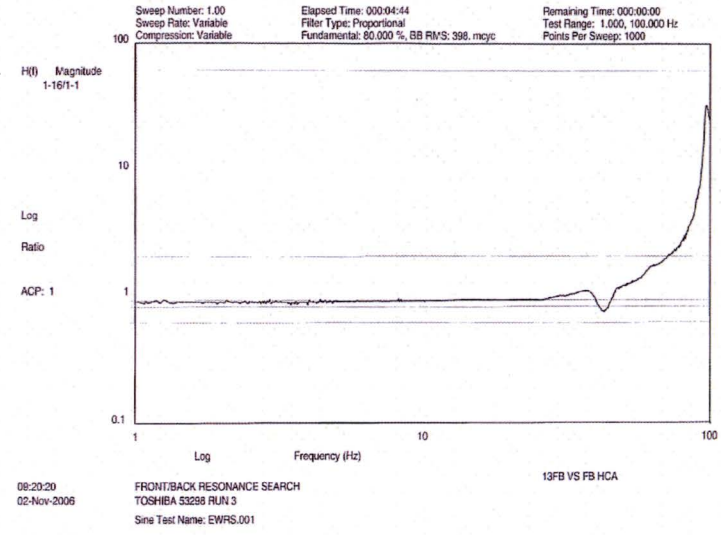

Figure A.1.14 LPRM Unit's spectrum for Horizontal (East to West) vibration

A.2 Random Multi Frequency Tests

A2.1 1st OBE

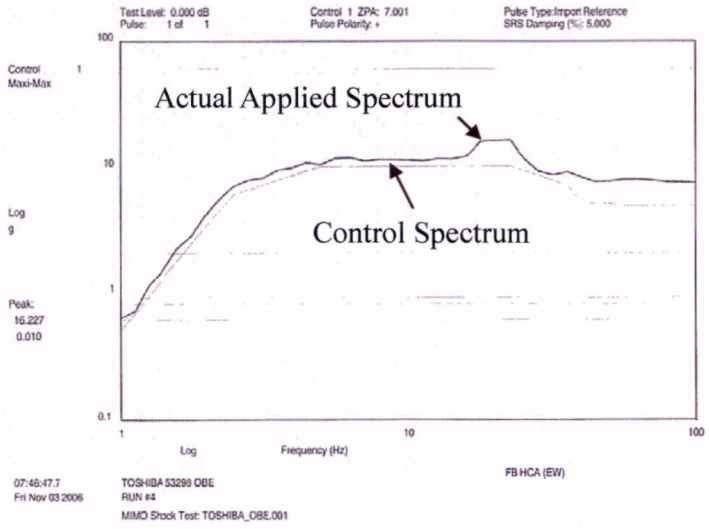

Figure A.2.1.1 TRS for 1st OBE for Horizontal Axis (East to West)

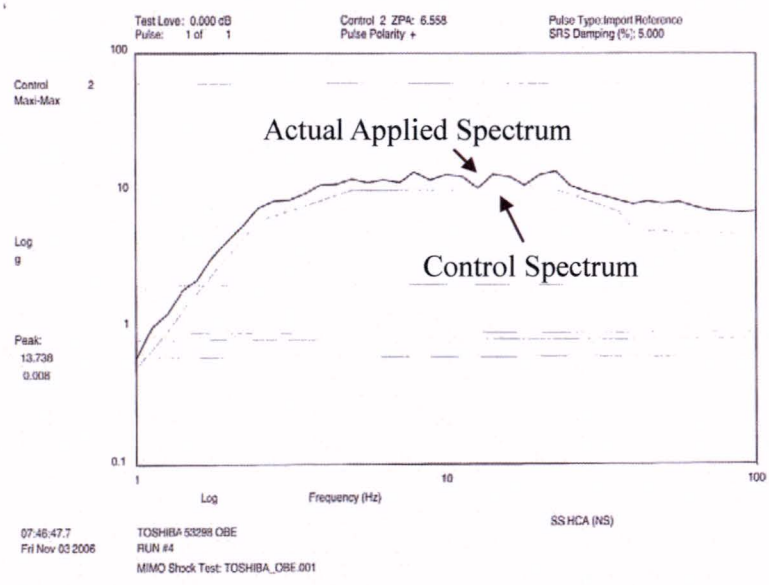

Figure A.2.1.2 TRS for 1st OBE for Horizontal Axis (North to South)

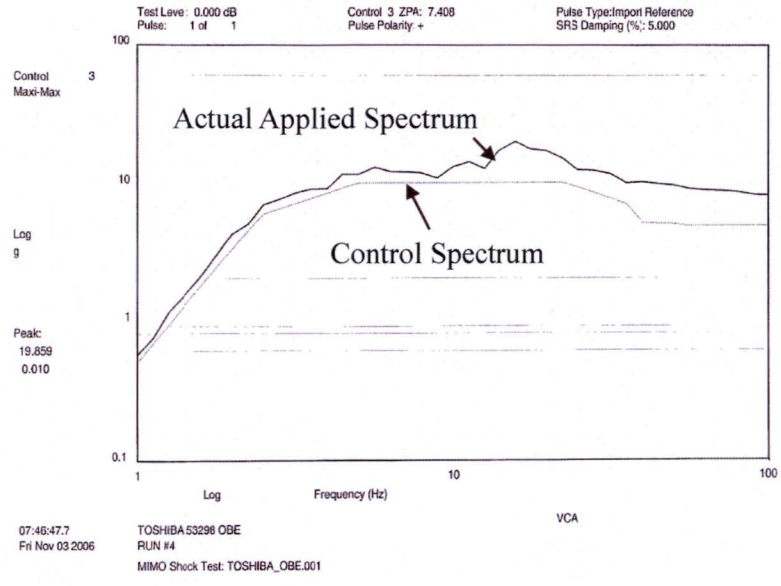

Figure A.2.1.3 TRS for 1st OBE for Vertical Axis

A 2.2 2nd OBE

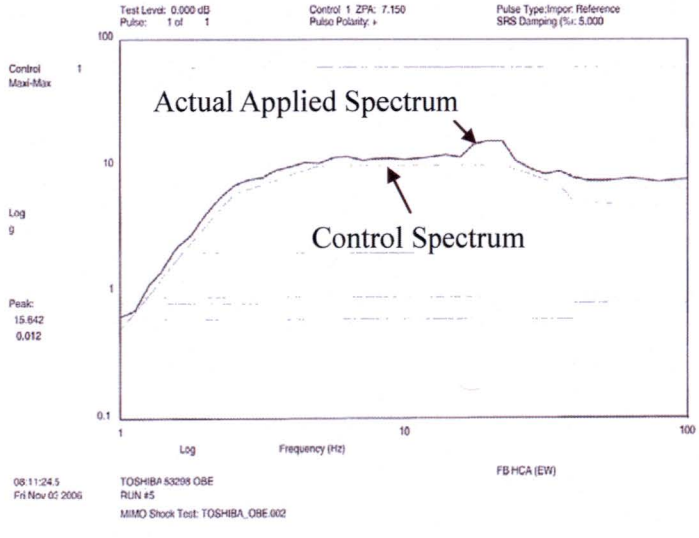

Figure A.2.2.1 TRS for 2nd OBE for Horizontal Axis (East to West)

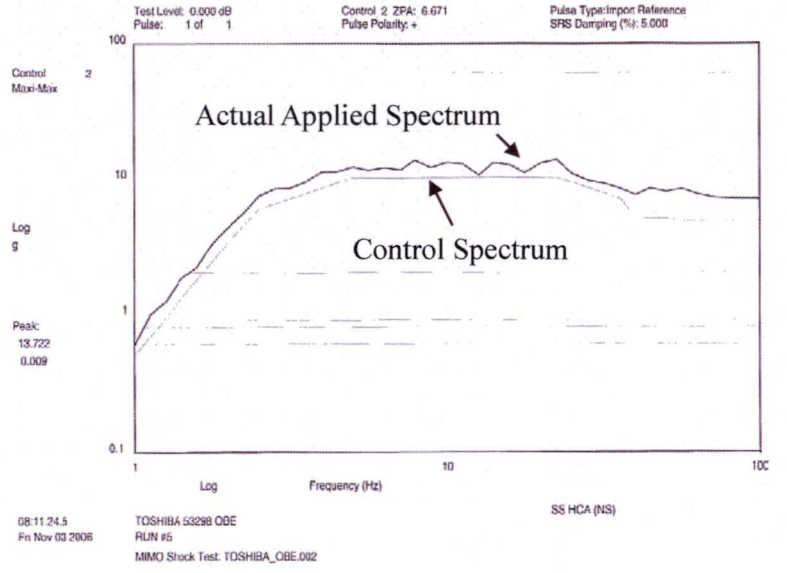

Figure A.2.2.2 TRS for 2nd OBE for Horizontal Axis (North to South)

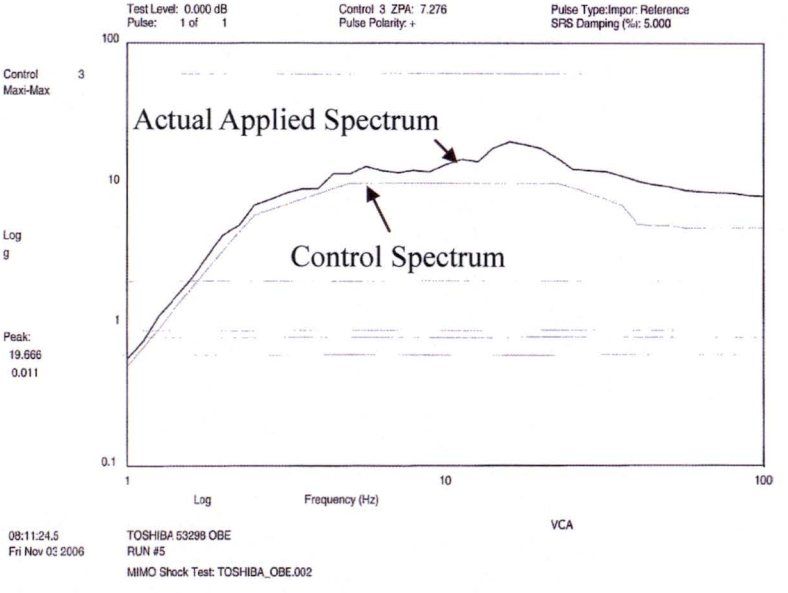

Figure A.2.2.3 TRS for 2nd OBE for Vertical Axis

A 2.3 3rd OBE

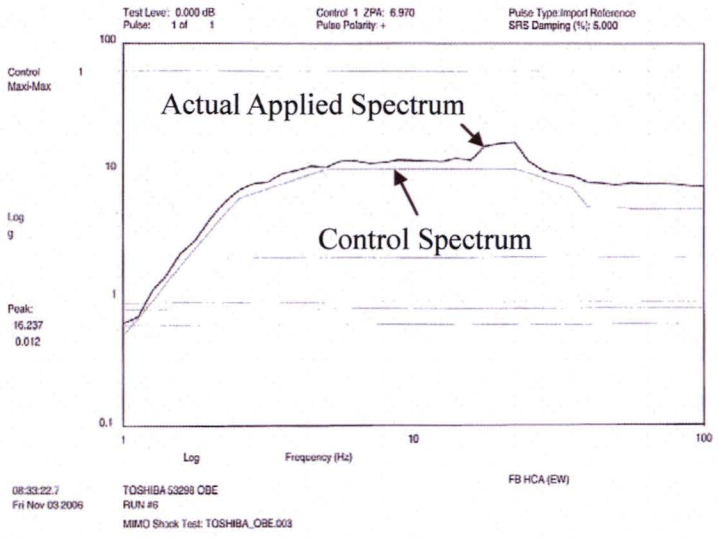

Figure A.2.3.1 TRS for 3rd OBE for Horizontal Axis (East to West)

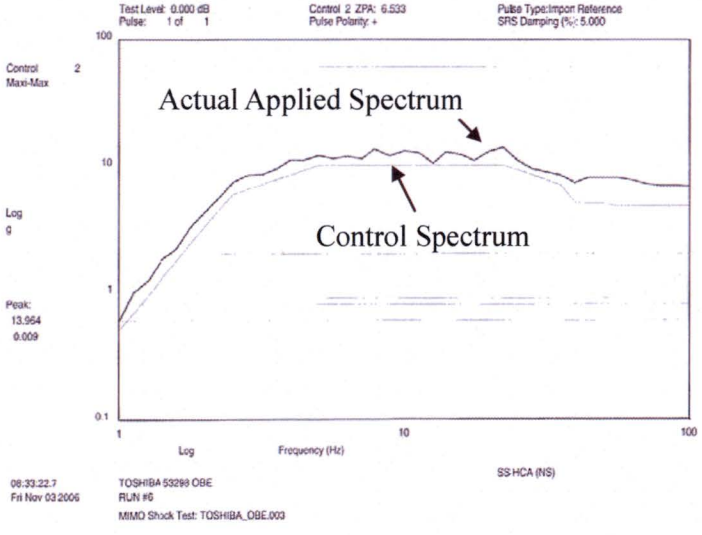

Figure A.2.3.2 TRS for 3rd OBE for Horizontal Axis (North to South)

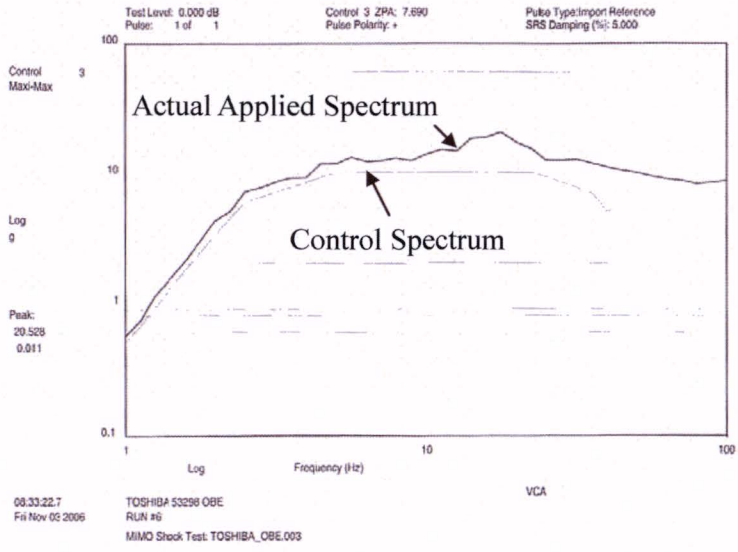

Figure A.2.3.3 TRS for 3rd OBE for Vertical Axis

A 2.4 4th OBE

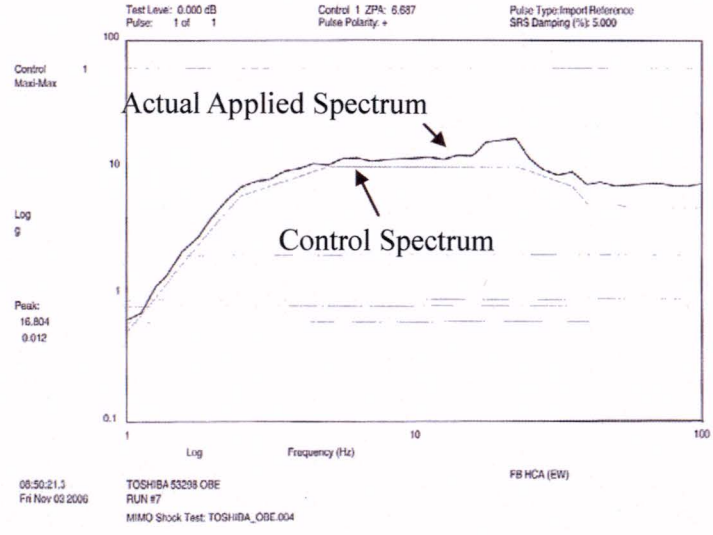

Figure A.2.4.1 TRS for 4th OBE for Horizontal Axis (East to West)

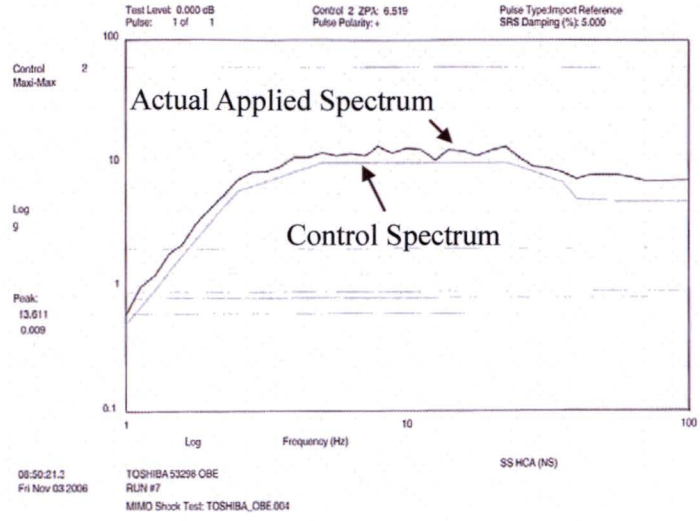

Figure A.2.4.2 TRS for 4th OBE for Horizontal Axis (North to South)

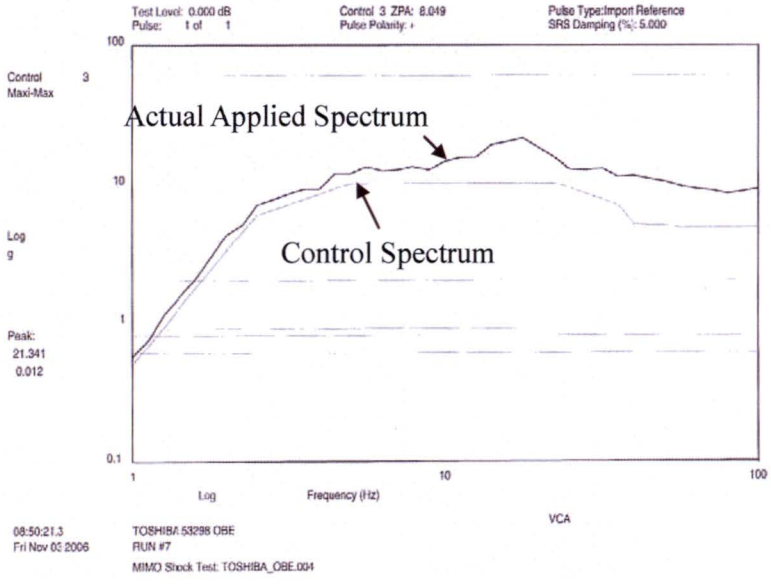

Figure A.2.4.3 TRS for 4th OBE for Vertical Axis

A 2.5 5th OBE

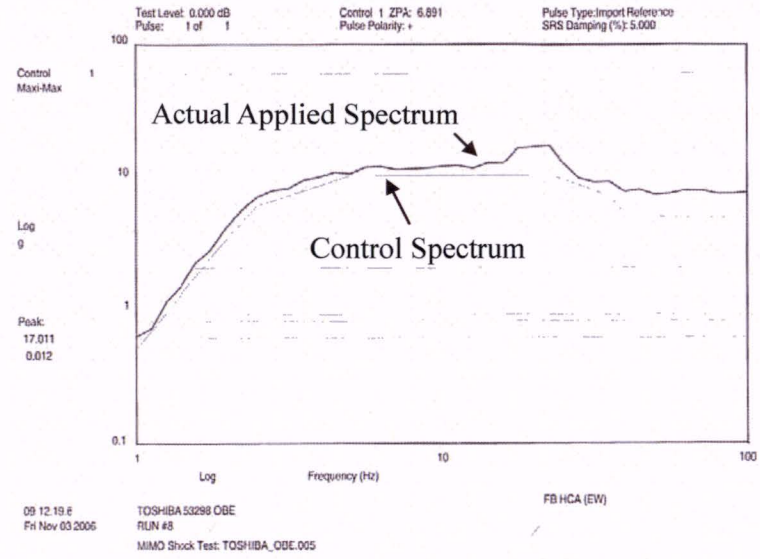

Figure A.2.5.1 TRS for 5th OBE for Horizontal Axis (East to West)

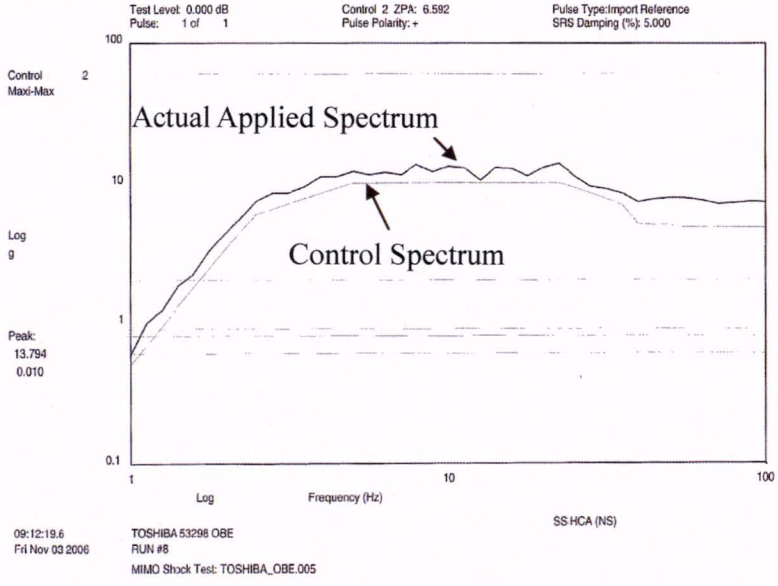

Figure A.2.5.2 TRS for 5th OBE for Horizontal Axis (North to South)

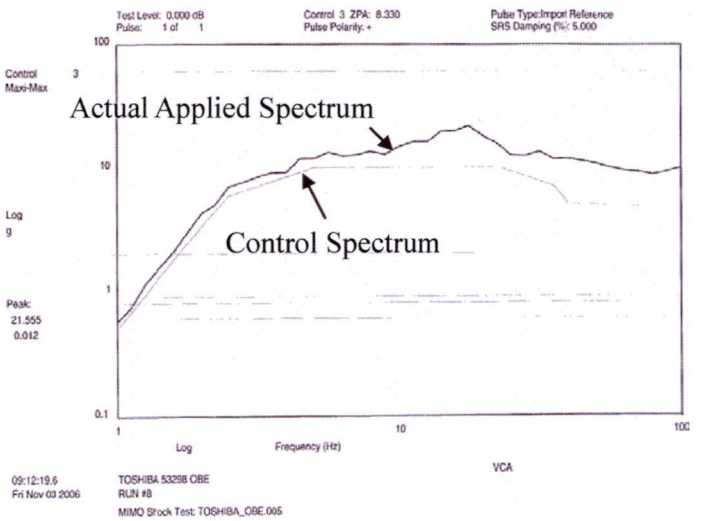

Figure A.2.5.3 TRS for 5th OBE for Vertical Axis

A 2.6 SSE

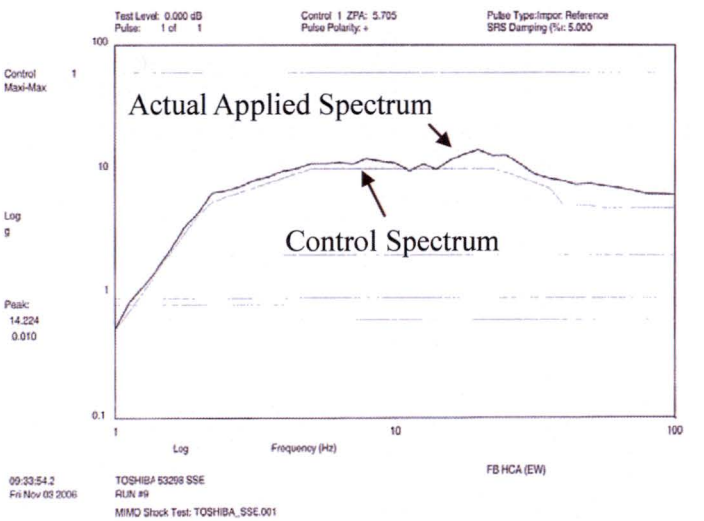

Figure A.2.6.1 TRS for SSE for Horizontal Axis (East to West)

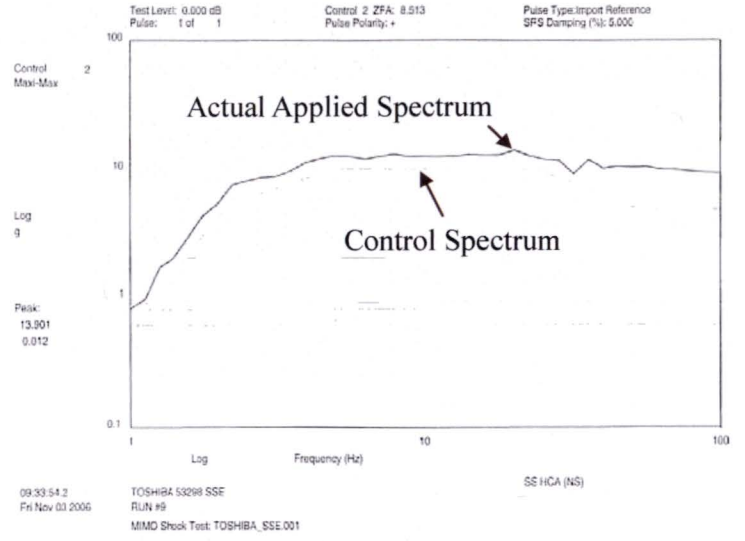

Figure A.2.6.2 TRS for SSE for Horizontal Axis (North to South)

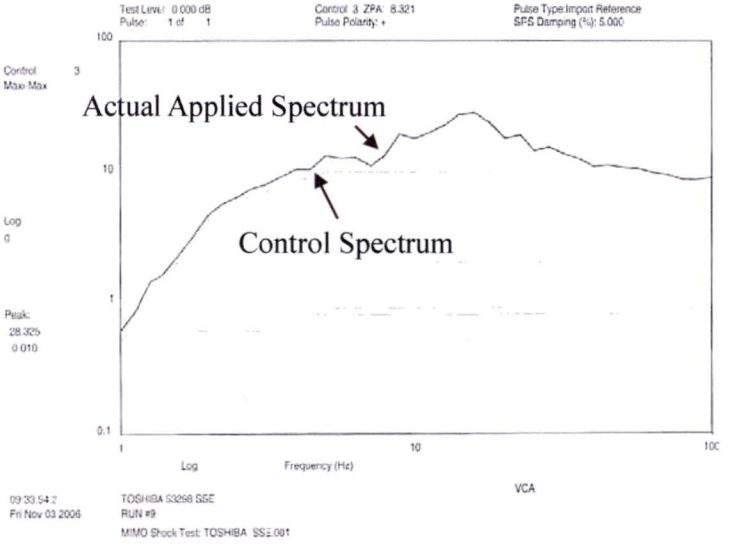

Figure A.2.6.3 TRS for SSE for Vertical Axis

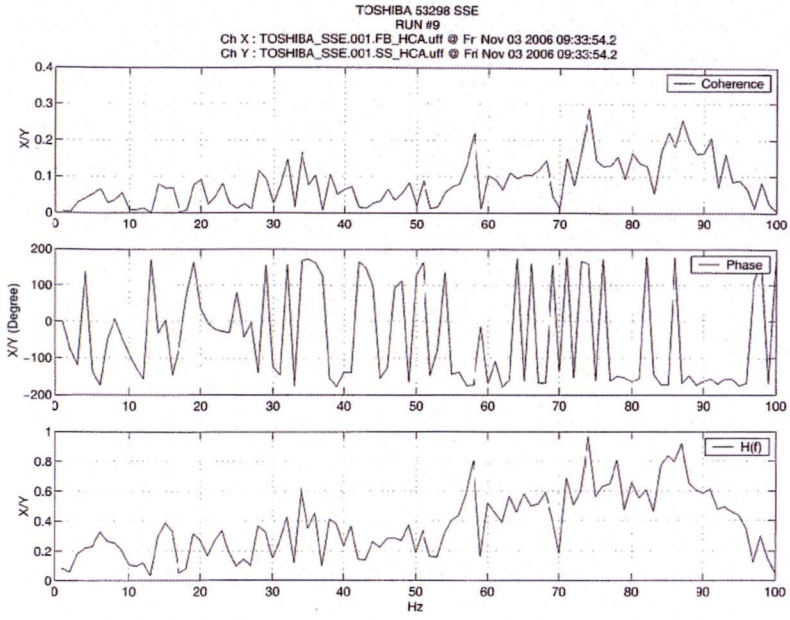

Figure 2.6.4 Coherent Plot between Horizontal Axes (East to West and North to South).

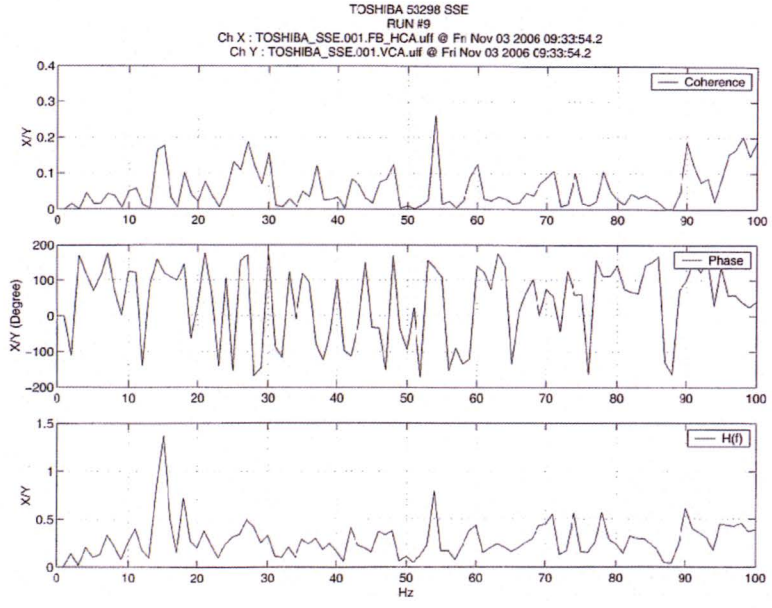

Figure 2.6.5 Coherent Plot for Horizontal Axis (East to West) and Vertical Axis.

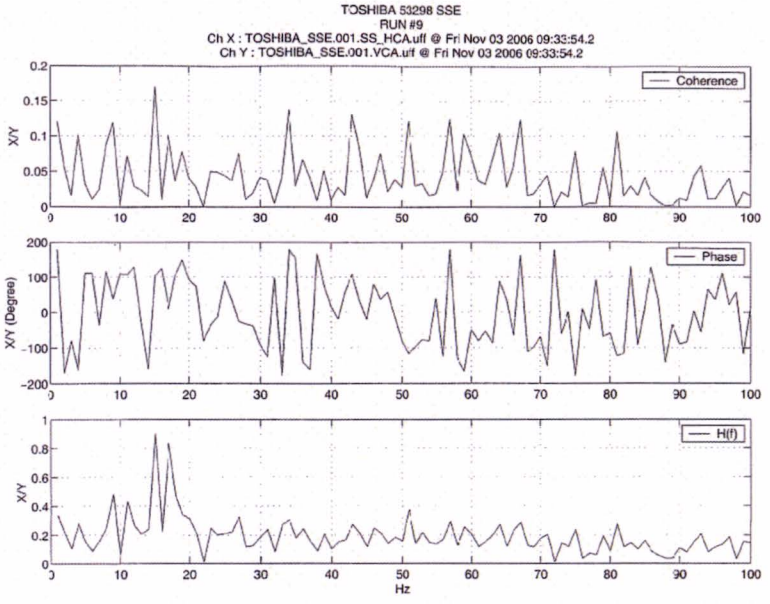

Figure 2.6.6 Coherent Plot for Horizontal Axis (North to South) and Vertical Axis.

APPENDIX B Test results data for EMC tests

B.1 Radiated Emission, Magnetic Field (RE101)

Table B.1 RE101 Test Matrix

Test Point	Compliant with Specification
Connector of LVPS Cable #18	Yes
Connector of LVPS Cable #34	Yes
Connector of LVPS Cable #47	Yes
Front Face of LPRM Unit	Yes
Back Face of LPRM Unit	Yes
Top Face of LPRM Unit	Yes
Bottom Face of LPRM Unit	Yes
Right Face of LPRM Unit	Yes
Left Face of LPRM Unit	Yes
Connector of LPRM Cable #128	Yes
Connector of AO Cable #169	Yes
Connector of AO Cable #182	Yes
Connector of DIO Cable #336	Yes
Front Face of LPRM/APRM Unit	Yes
Back Face of LPRM/APRM Unit	Yes
Top Face of LPRM/APRM Unit	Yes
Bottom Face of LPRM/APRM Unit	Yes
Right Face of LPRM/APRM Unit	Yes
Left Face of LPRM/APRM Unit	Yes
Connector of LPRM Cable #105	Yes
Connector of AO Cable # 195	Yes
Connector of AO Cable # 208	Yes
Connector of AO Cable # 215	Yes
Connector of DIO Cable #332	Yes
Front Face of FLOW Unit	Yes
Back Face of FLOW Unit	Yes
Top Face of FLOW Unit	Yes
Bottom Face of FLOW Unit	Yes
Right Face of FLOW Unit	Yes
Left Face of FLOW Unit	Yes
Connector of FLOW Cables(#139,140)	Yes
Connector of AO Cable # 228	Yes
Connector of AO Cable #234	Yes
Connector of AO Cable # 240	Yes
Connector of DIO Cable #333	Yes

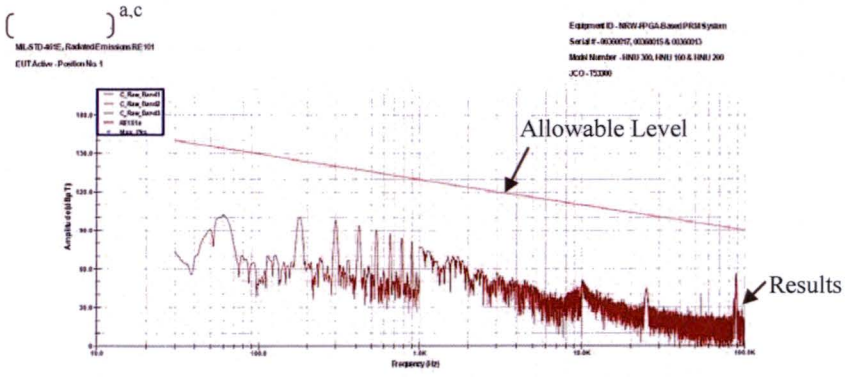

Figure B.1.1 RE101 Data for Connector of LVPS cable (No.18)

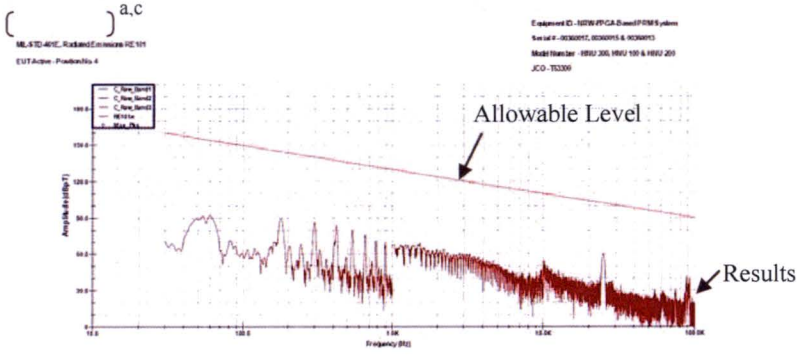

Figure B.1.2 RE101 Data for Front Face of LPRM Unit

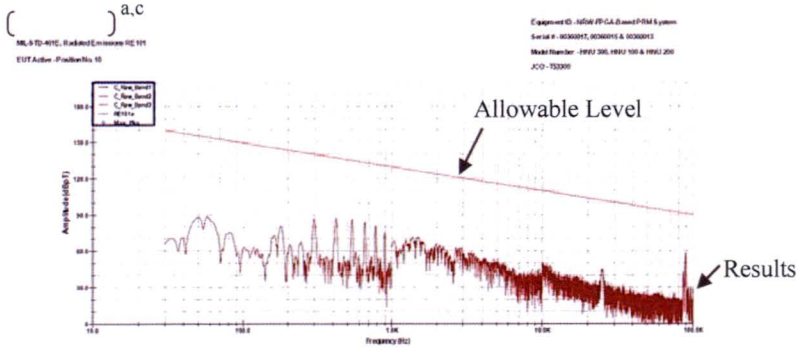

Figure B.1.3 RE101 Data for LPRM Unit Cable (No. 128)

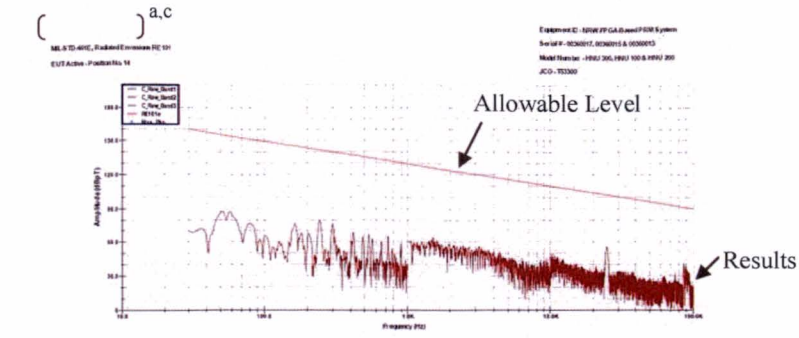

Figure B.1.4 RE101 Data for LPRM/APRM Unit Front Face

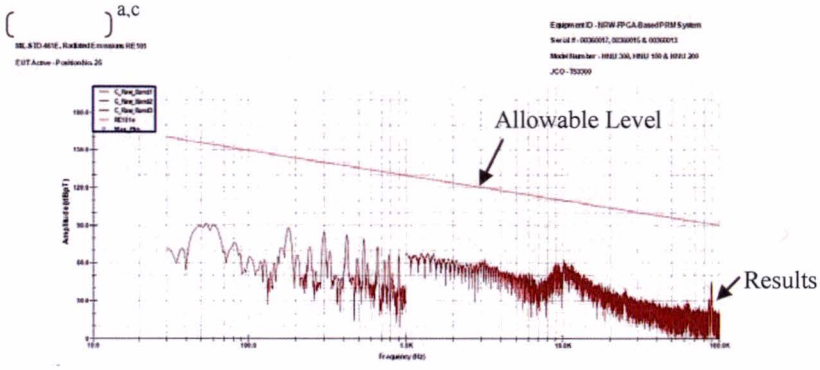

Figure B.1.5 RE101 Data for Flow Unit Front Face

B.2 Results of Radiated Emission, Electric Field (RE102)

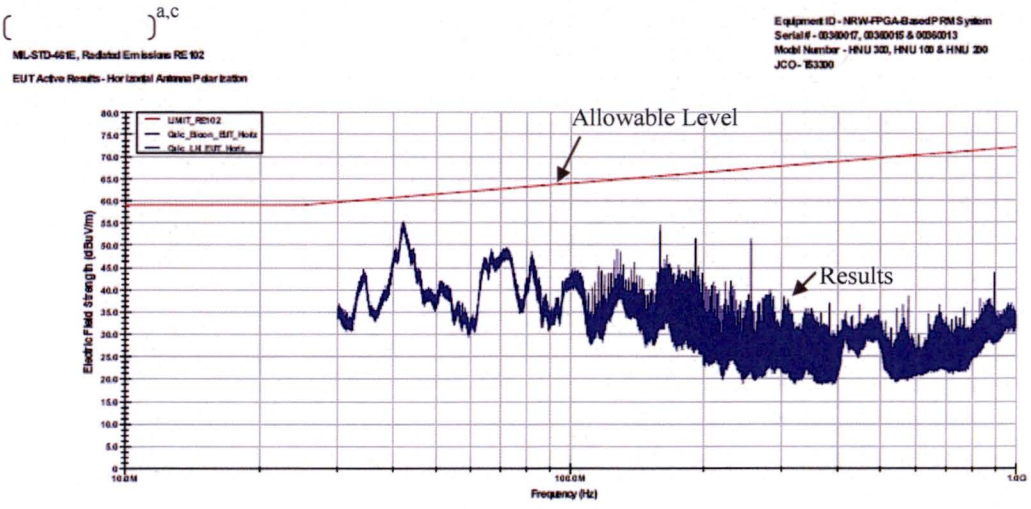

Figure B.2.1 Results of RE102 (Horizontal Antenna Position)

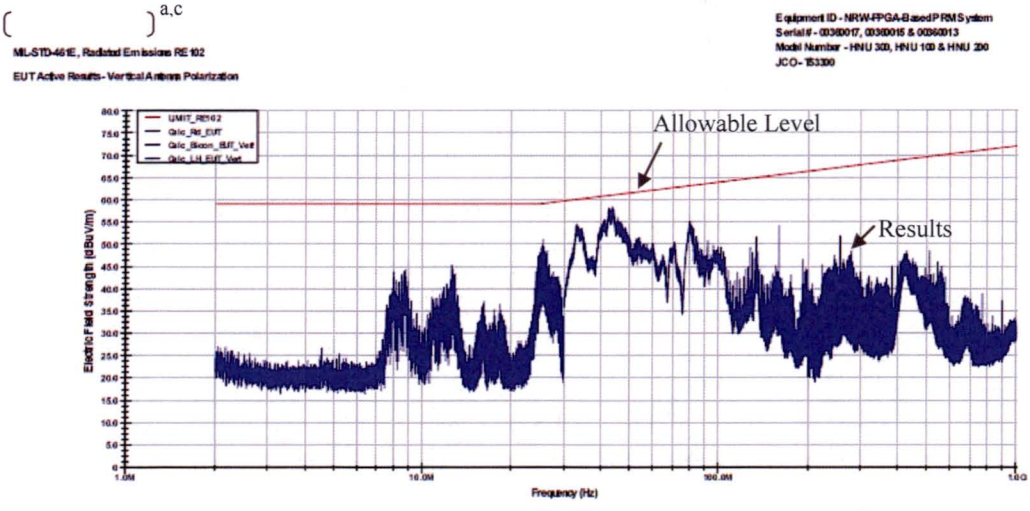

Figure B.2.2 Results of RE102 (Vertical Antennal Position)

B.3 Results of Low Frequency Conducted Emissions (CE101)

Table B.3.1 CE101 Test Matrix

Test Point	Compliant with Specification
Cable#10(Line)	No (approximately 100Hz to 700Hz, emission exceeds the limit)
Cable#10(Neutral)	No (approximately 100Hz to 700Hz, emission exceeds the limit)
Cable#10(Ground)	Yes
Cable#10(Line) with choke-coil (100 mH)	Yes (Note: Mitigation was re-calculated according to the peak amplitude at 60 Hz)
Cable#10(Neutral) with choke-coil (100 mH)	Yes (Note: Mitigation was re-calculated according to the peak amplitude at 60 Hz)
Cable#10(Ground) with choke-coil (100 mH)	Yes
Cable#10(Line) with choke-coil (120 mH)	Yes (Note: Mitigation was re-calculated according to the peak amplitude at 60 Hz)
Cable#10(Neutral) with choke-coil (120 mH)	Yes (Note: Mitigation was re-calculated according to the peak amplitude at 60 Hz)
Cable#10(Ground) with choke-coil (120 mH)	Yes

Table B.3.2 Results of Line without coil

Frequency (Hz)	Peak Amplitude (dB micro A)	CE101 Limit (Approximation) (dB micro A)	CE101 Limit (Corrected with actual amplitude at 60 Hz) (dB micro A)	Margin (dB micro A)	Compliant with Specification
60.499	122.9	119.9	122.9	-	-
180.614	122.1	108.8	111.8	10.2	**No**
299.465	120.3	103.7	106.7	13.6	**No**
419.315	177.5	100.2	103.2	74.3	**No**
540.810	113.4	97.7	100.7	12.7	**No**
660.572	107.2	95.6	98.6	8.5	**No**
780.040	98.6	93.9	96.9	1.7	**No**
899.038	96.6	92.5	95.5	1.1	**No**

Table B.3.3 Results of Line with 100 mH coil

Frequency (Hz)	Peak Amplitude (dB micro A)	CE101 Limit (Approximation) (dB micro A)	CE101 Limit (Corrected with 60 Hz actual Data) (dB micro A)	Margin (dB micro A)	Compliant with Specification
60.764	122.4	119.9	122.5	-	-
74.188	72.1	117.8	120.4	-48.32	**Yes**
75.304	66.1	117.7	120.3	-54.176	**Yes**
76.949	65.8	117.5	120.1	-54.34	**Yes**
78.095	68.1	117.3	119.9	-51.832	**Yes**
82.061	65.6	116.8	119.4	-53.832	**Yes**
84.088	69.4	116.6	119.2	-49.749	**Yes**
86.496	67.7	116.3	118.9	-51.218	**Yes**
88.729	66.0	116	118.6	-52.637	**Yes**
90.609	66.3	115.8	118.4	-52.065	**Yes**
111.230	67.4	113.7	116.3	-48.941	**Yes**
128.326	68.7	112.3	114.9	-46.2244	**Yes**
180.438	111.2	108.8	111.4	-0.213	**Yes**
299.876	101.5	103.7	106.3	-4.817	**Yes**
419.403	94.5	100.2	102.8	-8.341	**Yes**
530.000	66.3	97.9	100.5	-34.219	**Yes**
540.927	88.1	97.7	100.3	-12.189	**Yes**
660.396	81.8	95.6	98.2	-16.397	**Yes**
779.805	75.7	93.9	96.5	-20.776	**Yes**
899.273	68.7	92.5	95.1	-26.429	**Yes**

Table B.3.4 Results of Neutral with 100 mH coil

Frequency	Peak Amplitude	CE101 Limit (Approximation) (dB micro A)	CE101 Limit (Corrected with 60 Hz actual Data)	Margin	Compliant with Specification
60.6	122.7	119.9	122.7	-	-
180.4	111.3	108.8	111.6	-0.3	**Yes**
299.9	101.5	103.7	106.5	-5.0	**Yes**
419.4	94.3	100.2	103.0	-8.7	**Yes**
540.9	87.8	97.7	100.5	-12.7	**Yes**
550.5	81.3	95.6	98.4	-17.0	**Yes**
780.0	74.9	93.9	96.7	-21.8	**Yes**
899.5	67.6	92.5	95.3	-27.7	**Yes**
530.0	66.0	97.9	100.7	-34.7	**Yes**
192.7	71.8	108.1	110.9	-39.1	**Yes**
125.7	67.1	112.5	115.3	-48.2	**Yes**
129.1	65.6	112.2	115.0	-49.4	**Yes**
132.6	65.1	111.9	114.7	-49.6	**Yes**
110.8	66.7	113.8	116.6	-49.9	**Yes**
75.0	69.6	117.7	120.5	-50.9	**Yes**
82.5	68.3	116.8	119.6	-51.3	**Yes**
86.5	67.2	116.3	119.1	-51.9	**Yes**
90.3	66.6	115.8	118.6	-52.0	**Yes**
77.6	66.5	117.4	120.2	-53.7	**Yes**
84.1	64.7	116.6	119.4	-54.7	**Yes**

Table B.3.5 Results of Line with 120 mH coil

Frequency	Peak Amplitude	CE101 Limit (Approximation) (dB micro A)	CE101 Limit (Corrected with 60 Hz actual Data)	Margin	Compliant with Specification
60.6	122.4	119.9	122.5	-	-
74.6	65.4	117.8	120.4	-55.0	**Yes**
76.8	66.6	117.5	120.1	-53.4	**Yes**
80.9	66.6	117	119.6	-53.0	**Yes**
85.3	67.0	116.4	119.0	-51.9	**Yes**
87.2	68.0	116.2	118.8	-50.7	**Yes**
89.9	65.6	115.9	118.5	-52.9	**Yes**
93.6	65.7	115.5	118.1	-52.3	**Yes**
110.7	66.9	113.8	116.4	-49.5	**Yes**
114.2	66.4	113.5	116.1	-49.6	**Yes**
124.3	65.4	112.6	115.2	-49.8	**Yes**
131.2	66.1	112.0	114.6	-48.5	**Yes**
180.4	109.3	108.8	111.4	-2.0	**Yes**
299.9	99.8	103.7	106.3	-6.4	**Yes**
419.5	92.4	100.2	102.8	-10.3	**Yes**
530.0	65.3	97.9	100.5	-35.2	**Yes**
540.9	85.9	97.7	100.3	-14.4	**Yes**
660.4	79.3	95.6	98.2	-18.9	**Yes**
779.9	73.0	93.9	96.5	-23.4	**Yes**
899.3	66.4	92.5	95.1	-28.6	**Yes**

Table B.3.6 Results of Neutral with 120 mH coil

Frequency	Peak Amplitude	CE101 Limit (Approximation) (dB micro A)	CE101 Limit (Corrected with 60 Hz actual Data)	Margin	Compliant with Specification
60.8	122.4	119.9	122.4	-	-
74.3	70.0	117.8	120.3	-50.283	**Yes**
75.2	64.7	117.7	120.2	-55.484	**Yes**
77.4	69.5	117.4	119.9	-50.446	**Yes**
79.0	64.7	117.2	119.7	-55.034	**Yes**
80.7	63.7	117.0	119.5	-55.869	**Yes**
83.7	67.1	116.6	119.1	-51.978	**Yes**
87.6	65.8	116.2	118.7	-52.93	**Yes**
125.3	66.4	112.5	115.0	-48.603	**Yes**
132.1	64.2	112.0	114.5	-50.308	**Yes**
166.9	64.0	109.6	112.1	-48.082	**Yes**
180.4	109.3	108.8	111.3	-2.012	**Yes**
299.9	99.7	103.7	106.2	-6.555	**Yes**
419.4	92.0	100.2	102.7	-10.696	**Yes**
530.0	63.3	97.9	100.4	-37.082	**Yes**
540.9	85.3	97.7	100.2	-14.938	**Yes**
660.3	78.5	95.6	98.1	-19.602	**Yes**
780.0	71.8	93.9	96.4	-24.605	**Yes**
899.3	65.0	92.5	95.0	-30.066	**Yes**

( )[a,c]

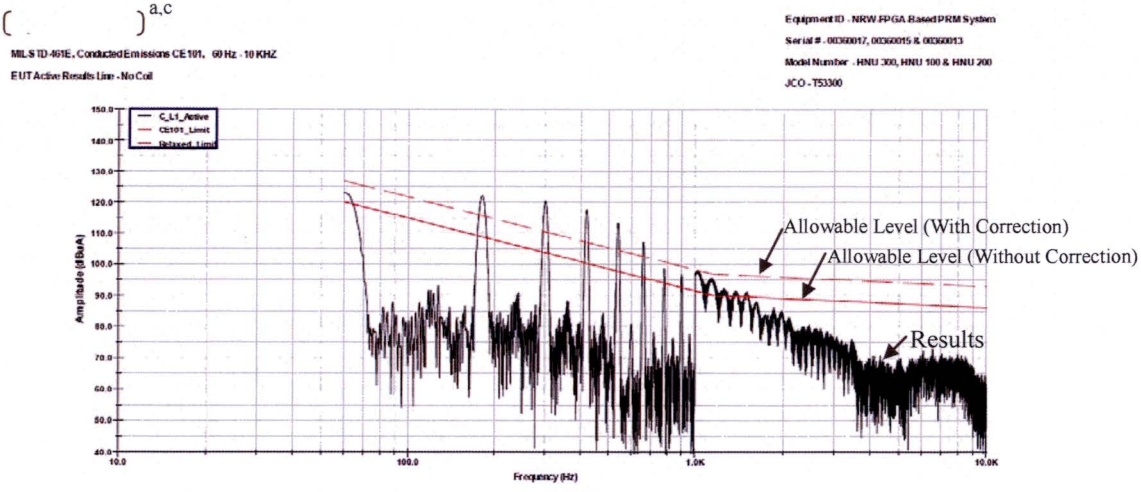

Figure B.3.1 Results of CE101 (Line, No coil)

( )[a,c]

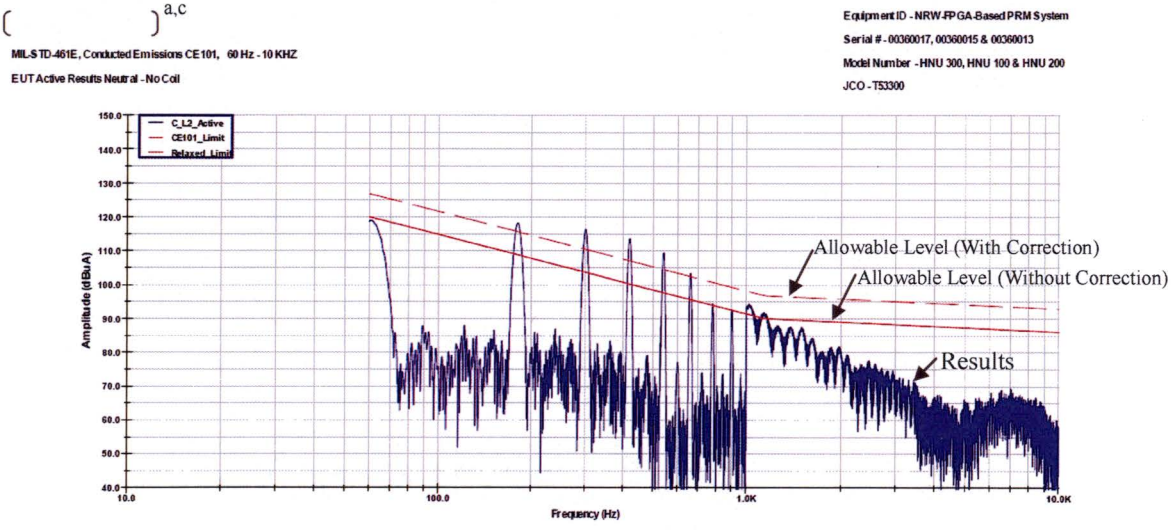

Figure B.3.2 Results of CE101 (Neutral, No coil)

( )a,c

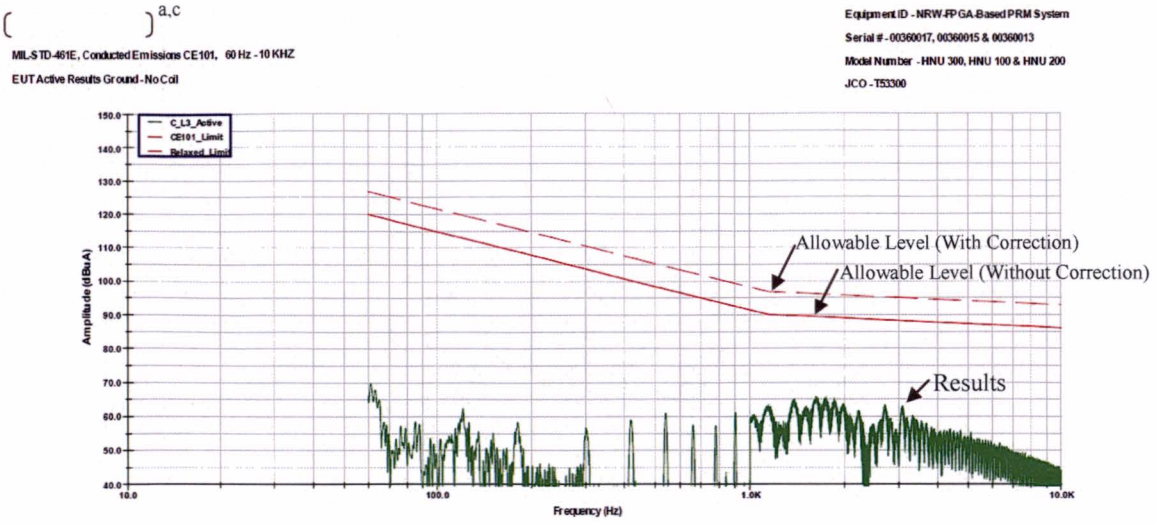

Figure B.3.3 Results of CE101 (Ground, No coil)

( )a,c

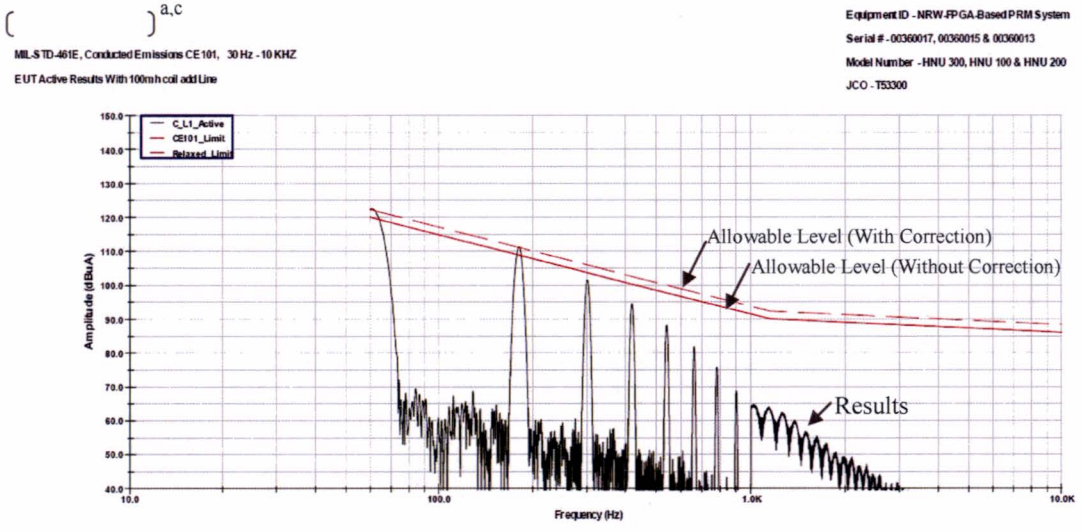

Figure B.3.4 Results of CE101 (Line, with 100 mH coil addition)

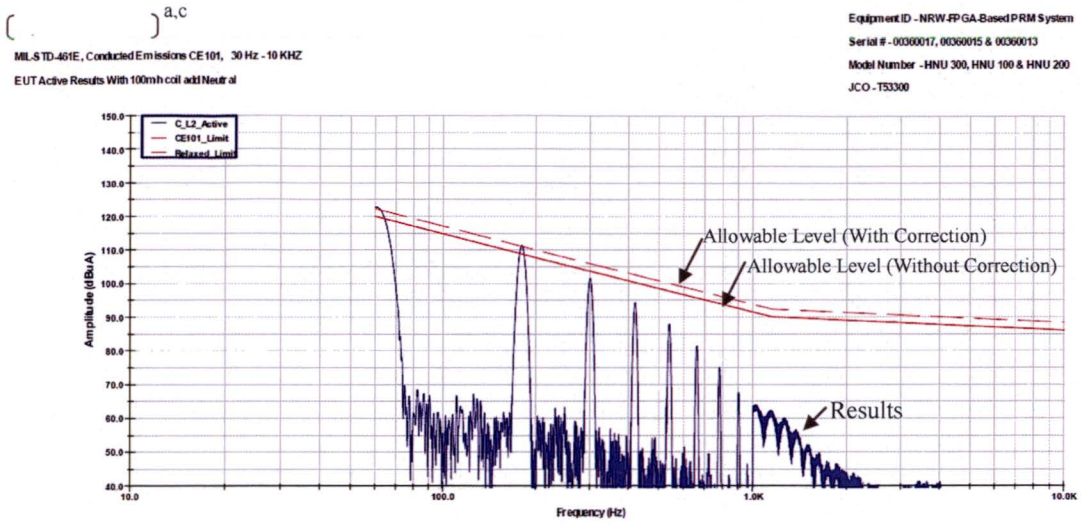

Figure B.3.5 Results of CE101 (Neutral, with 100 mH coil addition)

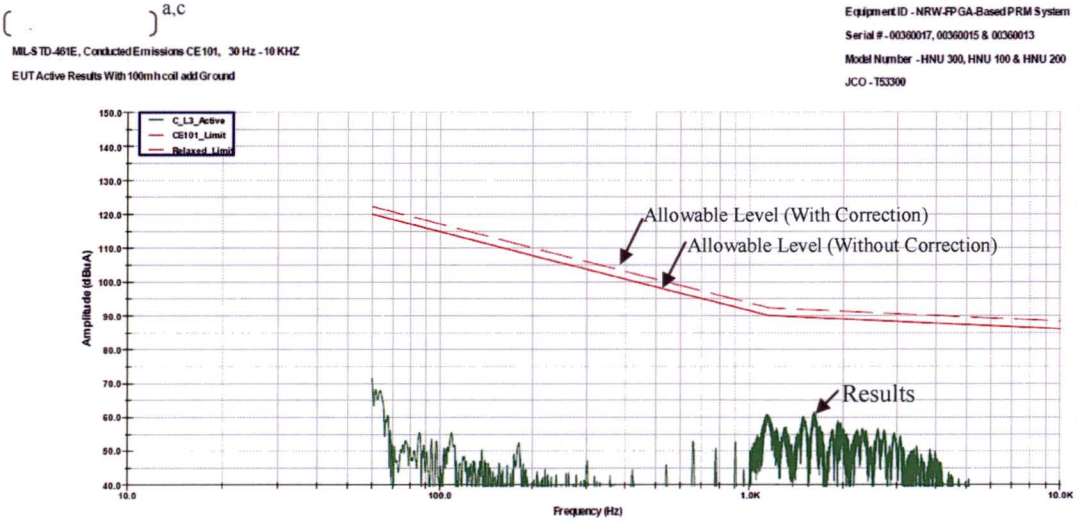

Figure B.3.6 Results of CE101 (Ground, with 100 mH coil addition)

( )[a,c]

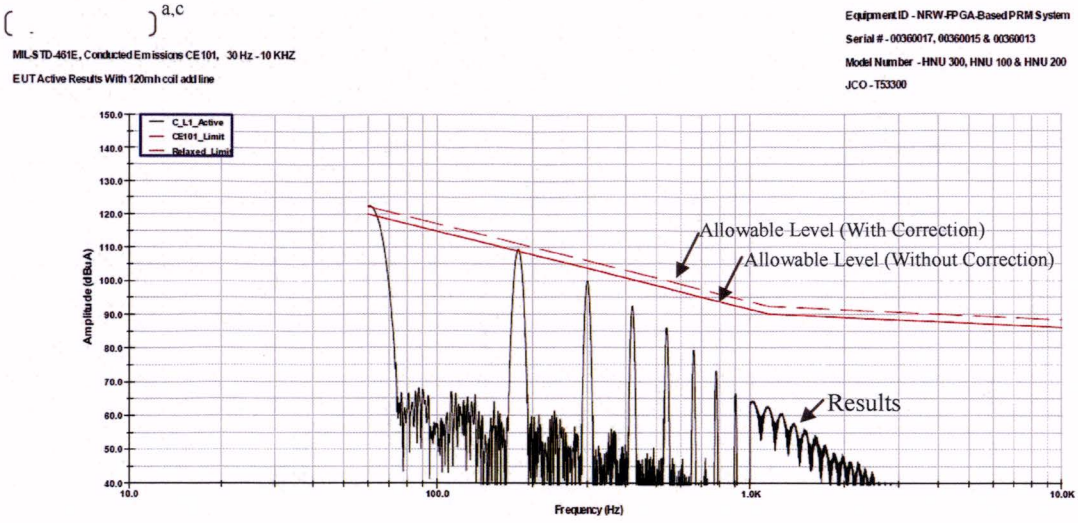

Figure B.3.7 Results of CE101 (Line, with 120 mH coil addition)

( )[a,c]

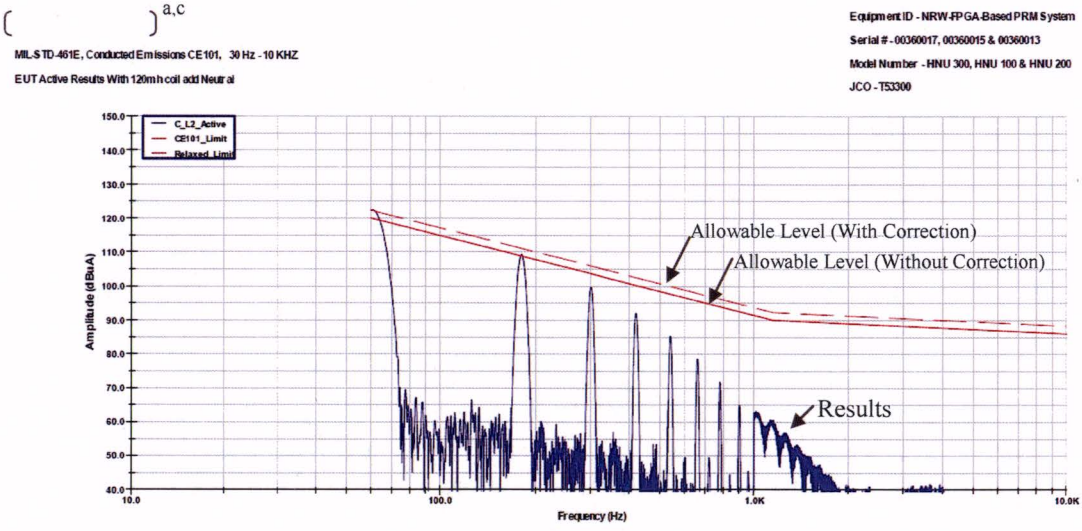

Figure B.3.8 Results of CE101 (Neutral, with 120 mH coil addition)

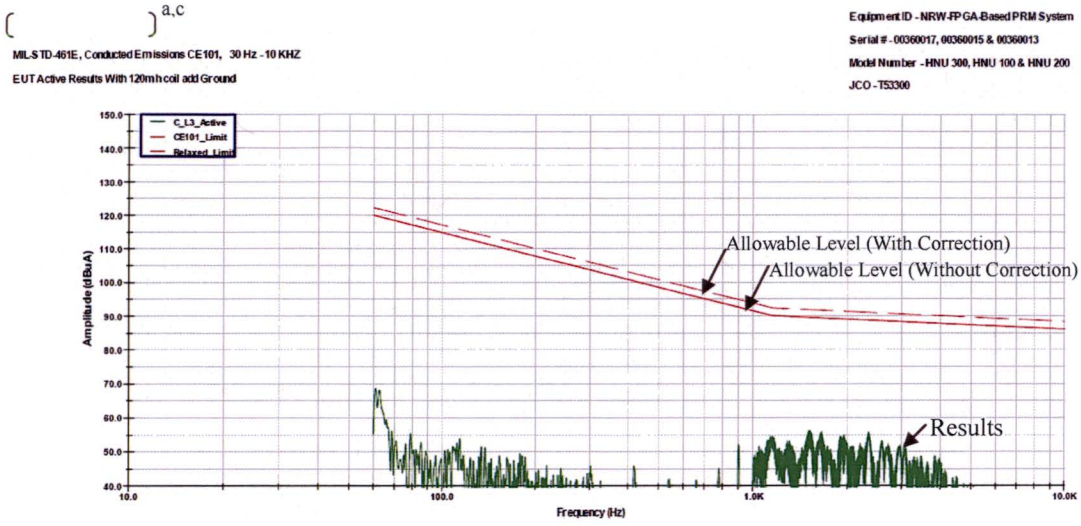

Figure B.3.9 Results of CE101 (Ground, with 120 mH coil addition)

B.4 Results of High Frequency Conducted Emissions (CE102)

Table B4 CE102 Test Matrix

Test Point	Compliant with Specification
Cable#10(Line)	Yes
Cable#10(Neutral)	Yes
Cable#10(Ground)	Yes

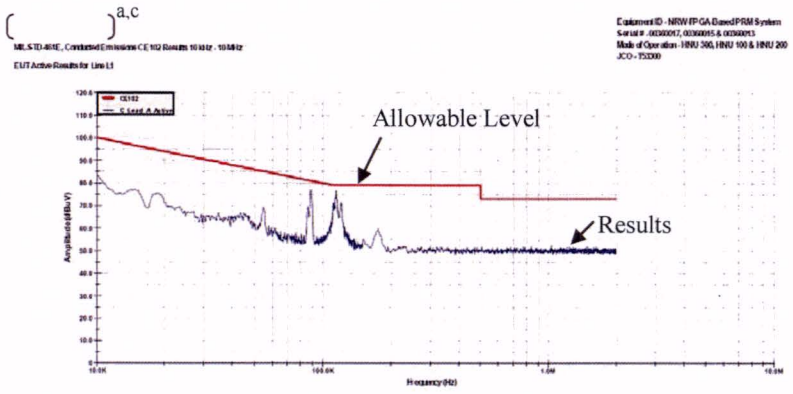

Figure B.4.1 Results of CE102 (Line)

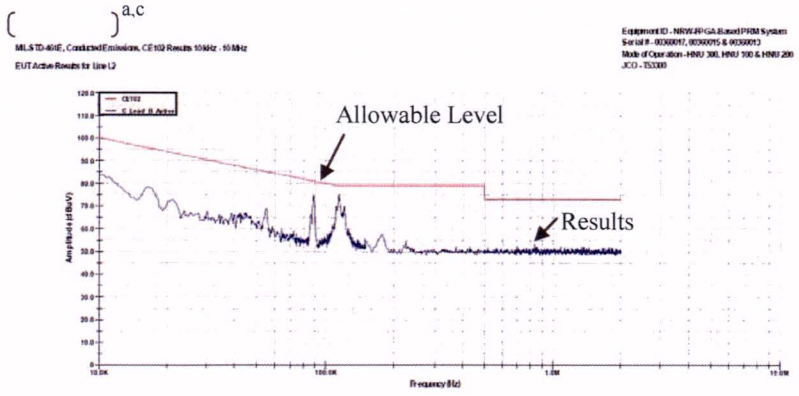

Figure B.4.2 Results of CE102 (Neutral)

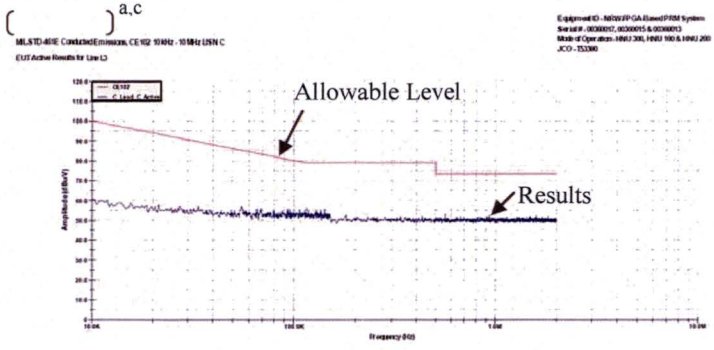

Figure B.4.3 Results of CE102 (Ground)

B.5 Results of Radiated Susceptibility, Magnetic Fields (RS101)

Table B5 Summary of test results for RS101

Test Points	Test Specimen Operation	Compliant with Specification
Connector of LVPS Cable #18	Within the required tolerance of the normal operation	Yes
Connector of LVPS Cable #34	Within the required tolerance of the normal operation	Yes
Connector of LVPS Cable #47	Within the required tolerance of the normal operation	Yes
116mm from the left edge and 89 mm from bottom edge on the front Panel of LPRM Unit	Within the required tolerance of the normal operation	Yes
116mm from the right edge and 89 mm from bottom edge on the front panel of LPRM Unit	Within the required tolerance of the normal operation	Yes
116mm from the left edge and 89 mm from bottom edge on the back Panel of LPRM Unit	Within the required tolerance of the normal operation	Yes
116mm from the right edge and 89 mm from bottom edge on the back panel of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 89 mm from the bottom edge on the right side wall of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 89 mm from the bottom edge on the right side wall of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 89 mm from the bottom edge on the left side wall of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 89 mm from the bottom edge on the left side wall of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the right side wall on the upper surface of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the left side wall on the upper surface of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the right side wall on the upper surface of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the left side wall on the upper surface of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the right side wall on the bottom surface of LPRM Unit	Within the required tolerance of the normal operation	Yes

Test Points	Test Specimen Operation	Compliant with Specification
111 mm from the front panel and 116 mm from the left side wall on the bottom surface of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the right side wall on the bottom surface of LPRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the left side wall on the bottom surface of LPRM Unit	Within the required tolerance of the normal operation	Yes
Connector of LPRM Cable #128	Within the required tolerance of the normal operation	Yes
Connector of AO Cable #169	Within the required tolerance of the normal operation	Yes
Connector of AO Cable #182	Within the required tolerance of the normal operation	Yes
Connector of DIO Cable #336	Within the required tolerance of the normal operation	Yes
116mm from the left edge and 89 mm from bottom edge on the front Panel of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
116mm from the right edge and 89 mm from bottom edge on the front panel of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
116mm from the left edge and 89 mm from bottom edge on the back Panel of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
116mm from the right edge and 89 mm from bottom edge on the back panel of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 89 mm from the bottom edge on the right side wall of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 89 mm from the bottom edge on the right side wall of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 89 mm from the bottom edge on the left side wall of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 89 mm from the bottom edge on the left side wall of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the right side wall on the upper surface of LPRM /APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the left side wall on the upper surface of LPRM /APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the right side wall on the upper surface of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes

Test Points	Test Specimen Operation	Compliant with Specification
111 mm from the back panel and 116 mm from the left side wall on the upper surface of LPRM /APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the right side wall on the bottom surface of LPRM /APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the left side wall on the bottom surface of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the right side wall on the bottom surface of LPRM/APRM Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the left side wall on the bottom surface of LPRM /APRM Unit	Within the required tolerance of the normal operation	Yes
Connector of LPRM Cable #105	Within the required tolerance of the normal operation	Yes
Connector of AO Cable # 195	Within the required tolerance of the normal operation	Yes
Connector of AO Cable # 208	Within the required tolerance of the normal operation	Yes
Connector of AO Cable # 215	Within the required tolerance of the normal operation	Yes
Connector of DIO Cable #332	Within the required tolerance of the normal operation	Yes
116mm from the left edge and 89 mm from bottom edge on the front Panel of FLOW Unit	Within the required tolerance of the normal operation	Yes
116mm from the right edge and 89 mm from bottom edge on the front panel of FLOW Unit	Within the required tolerance of the normal operation	Yes
116mm from the left edge and 89 mm from bottom edge on the back Panel of FLOW Unit	Within the required tolerance of the normal operation	Yes
116mm from the right edge and 89 mm from bottom edge on the back panel of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 89 mm from the bottom edge on the right side wall of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 89 mm from the bottom edge on the right side wall of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 89 mm from the bottom edge on the left side wall of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 89 mm from the bottom edge on the left side wall of FLOW Unit	Within the required tolerance of the normal operation	Yes

Test Points	Test Specimen Operation	Compliant with Specification
111 mm from the front panel and 116 mm from the right side wall on the upper surface of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the left side wall on the upper surface of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the right side wall on the upper surface of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the left side wall on the upper surface of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the right side wall on the bottom surface of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the front panel and 116 mm from the left side wall on the bottom surface of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the right side wall on the bottom surface of FLOW Unit	Within the required tolerance of the normal operation	Yes
111 mm from the back panel and 116 mm from the left side wall on the bottom surface of FLOW Unit	Within the required tolerance of the normal operation	Yes
Connector of FLOW Cables(#139,140)	Within the required tolerance of the normal operation	Yes
Connector of AO Cable # 228	Within the required tolerance of the normal operation	Yes
Connector of AO Cable #234	Within the required tolerance of the normal operation	Yes
Connector of AO Cable # 240	Within the required tolerance of the normal operation	Yes
Connector of DIO Cable #333	Within the required tolerance of the normal operation	Yes

B.6 Results of High-Frequency Conducted Susceptibility Testing at AC Power Leads (CS114)

Table B6 Summary of test results for CS114 (Power)

Test Points	Test Specimen Operation	Compliant with Specification
Cable#9 and Cable#10 simultaneously	Within the required tolerance of the normal operation	Yes
Cable #10 only	Within the required tolerance of the normal operation	Yes
'L' lead of Cable #10 only	Within the required tolerance of the normal operation	Yes

B.7 Results of High-Frequency Conducted Susceptibility (Signal Leads) (CS114)

Table B7 Summary of test results for CS114 (Signal)

Test Points	Test Specimen Operation	Compliant with Specification
Bundle of LPRM Cables (#123～#134)	Within the required tolerance of the normal operation	Yes
Bundle of LPRM Cables (#101 ～#110)	Within the required tolerance of the normal operation	Yes
Bundle of FLOW Cables (#139,140)	Within the required tolerance of the normal operation	Yes
DIO Cable #332	Within the required tolerance of the normal operation	Yes
DIO Cable #333	Within the required tolerance of the normal operation	Yes
DIO Cable #336	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#169, #195 and #228)	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#208 and #234)	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#182, #215 and #240)	Within the required tolerance of the normal operation	Yes

B.8 Results of Conducted Susceptibility (Signal Leads, Bulk cable injection, impulse excitation) (CS115)

Table B8 Summary of test results for CS115

Test Points	Test Specimen Operation	Compliant with Specification
Bundle of LPRM Cables (#123～#134)	Within the required tolerance of the normal operation	Yes
Bundle of LPRM Cables (#101～#110)	Within the required tolerance of the normal operation	Yes
Bundle of FLOW Cables (#139,140)	Within the required tolerance of the normal operation	Yes
DIO Cable #332	Within the required tolerance of the normal operation	Yes
DIO Cable #333	Within the required tolerance of the normal operation	Yes
DIO Cable #336	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#169, #195 and #228)	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#208 and #234)	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#182, #215 and #240)	Within the required tolerance of the normal operation	Yes

B.9 Results of Conducted Susceptibility (Signal Leads, Damped sinusoidal transients) (CS116)

Table B9 Summary of test results for CS116

Test Points	Test Specimen Operation	Compliant with Specification
Bundle of LPRM Cables (#123～#134)	Within the required tolerance of the normal operation	Yes
Bundle of LPRM Cables (#101 ～#110)	Within the required tolerance of the normal operation	Yes
Bundle of FLOW Cables (#139,140)	Within the required tolerance of the normal operation	Yes
DIO Cable #332	Within the required tolerance of the normal operation	Yes
DIO Cable #333	Within the required tolerance of the normal operation	Yes
DIO Cable #336	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#169, #195 and #228)	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#208 and #234)	Within the required tolerance of the normal operation	Yes
Bundle of AO Cables (#182, #215 and #240)	Within the required tolerance of the normal operation	Yes

B.10 Results of Surge Withstand Capability Testing

Table B10.1 Summary of test results for Surge Withstand Capability (Ringwave)

Test Points	Test Specimen Operation	Compliant with Specification
'Line' and 'Neutral'	Within the required tolerance of the normal operation	Yes
'Line' and 'Ground'	Within the required tolerance of the normal operation	Yes
'Neutral' and 'Ground'	Within the required tolerance of the normal operation	Yes
['Line' & 'Neutral'] and 'Ground'	Within the required tolerance of the normal operation	Yes

Table B10.2 Summary of test results for Surge Withstand Capability (Combination Wave)

Test Points	Test Specimen Operation	Compliant with Specification
'Line' and 'Neutral'	Within the required tolerance of the normal operation	Yes
'Line' and 'Ground'	Within the required tolerance of the normal operation	Yes
'Neutral' and 'Ground'	Within the required tolerance of the normal operation	Yes
['Line' & 'Neutral'] and 'Ground'	Within the required tolerance of the normal operation	Yes

B.11 Results of EFT/B Testing

Table B11 Summary of test results for EFT/B

Test Points	Test Specimen Operation	Compliant with Specification
'Line'	Within the required tolerance of the normal operation	Yes
'Neutral'	Within the required tolerance of the normal operation	Yes
Ground'	Within the required tolerance of the normal operation	Yes
Line', 'Neutral' and 'Ground' simultaneous	Within the required tolerance of the normal operation	Yes

B.12 Results of ESD Testing

Table B12 Test Results of ESD Test (1/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
LPRM Unit **Contact Discharge**			
On the right edge on the front surface of the chassis of LPRM Unit	+8kV −8kV	Yes	
On the left edge on the front surface of the chassis of LPRM Unit	+8kV −8kV	Yes	
On the top of the status module front panel	+8kV −8kV	Yes	
On the mode key switch of LPRM module in FSL-7	+8kV −8kV	Yes	
On the mode key switch of LPRM module in FSL-1	+8kV −8kV	Yes	
On the bottom of the status module front panel	+8kV −8kV	Yes	
On the mode key switch of LPRM module in FSL-12	+8kV −8kV	Yes	
On the surface of the connector of the signal cable (No. 123) connected to the LPRM Unit	+8kV −8kV	Yes	
On the surface of the connector or the optical cable (No. 328) connected to the LPRM Unit	+8kV −8kV	Yes	
On the fixing screw of the connector of the signal cable (No. 169) connected to the LPRM Unit	+8kV −8kV	Yes	
On the fixing screw of the connector of the signal cable (No. 182) connected to the LPRM Unit	+8kV −8kV	Yes	
On the fixing screw of the connector of the signal cable (No. 336) connected to the LPRM Unit	+8kV −8kV	Yes	

Table B12 Test Results of ESD Test (2/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
LPRM Unit **Air Discharge**			
On the "RESET" switch of the status module	+15kV −15kV	Yes	
On the upper side 3 digits LED indicator of LPRM module in FSL-1	+15kV −15kV	Yes	
On the lower side 3 digits LED indicator of LPRM module in FSL-1	+15kV −15kV	Yes	
On the mode "SELECT" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "+" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "-" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "▸" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "RESET" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "SET" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the upper side 3 digits LED indicator of LPRM module in FSL-7	+15kV −15kV	Yes	
On the lower side 3 digits LED indicator of LPRM module in FSL-7	+15kV −15kV	Yes	
On the mode "SELECT" switch of LPRM module in FSL-7	+15kV −15kV	Yes	
On the "+" switch of LPRM module in FSL-7	+15kV −15kV	Yes	
On the "-" switch of LPRM module in FSL-7	+15kV −15kV	Yes	
On the "▸" switch of LPRM module in FSL-7	+15kV −15kV	Yes	
On the "RESET" switch of LPRM module in FSL-7	+15kV −15kV	Yes	
On the "SET" switch of LPRM module in FSL-7	+15kV −15kV	Yes	
On the upper side 3 digits LED indicator of LPRM module in FSL-12	+15kV −15kV	Yes	
On the lower side 3 digits LED indicator of LPRM module in FSL-12	+15kV −15kV	Yes	

Table B12 Test Results of ESD Test (3/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
LPRM Unit **Air Discharge (Continued)**			
On the mode "SELECT" switch of LPRM module in FSL-12	+15kV −15kV	Yes	
On the "+" switch of LPRM module in FSL-12	+15kV −15kV	Yes	
On the "-" switch of LPRM module in FSL-12	+15kV −15kV	Yes	
On the "▸" switch of LPRM module in FSL-12	+15kV −15kV	Yes	
On the "RESET" switch of LPRM module in FSL-12	+15kV −15kV	Yes	
On the "SET" switch of LPRM module in FSL-12	+15kV −15kV	Yes	
On the surface of the connector of the power cable connected to the LVPS-1 module	+15kV −15kV	Yes	
On the surface of the connector of the power cable connected to the LVPS-2 module	+15kV −15kV	Yes	
LPRM Unit **Indirect Discharge**			
Left vertical side of the LPRM Unit	+8kV −8kV	Yes	
Right vertical side of LPRM Unit	+8kV −8kV	Yes	
Back vertical side of LPRM Unit	+8kV −8kV	Yes	
Front vertical side of LPRM Unit	+8kV −8kV	Yes	

Table B12 Test Results of ESD Test (4/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
LPRM/APRM Unit Contact Discharge			
On the right edge on the front surface of the chassis of LPRM/APRM Unit	+8kV −8kV	Yes	
On the left edge on the front surface of the chassis of LPRM/APRM Unit	+8kV −8kV	Yes	
On the top of the status module front panel	+8kV −8kV	Yes	
On the bottom of the status module front panel	+8kV −8kV	Yes	
On the mode key switch of LPRM module in FSL-1	+8kV −8kV	Yes	
On the mode key switch of LPRM module in FSL-10	+8kV −8kV	Yes	
On the mode key switch of APRM module in FSL-11	+8kV −8kV	Yes	
On the surface of the connector of the signal cable (No. 101) connected to the LPRM/APRM Unit	+8kV −8kV	Yes	
On the surface of the connector or the optical cable (No. 330) connected to the LPRM/APRM Unit	+2kV −2kV	Yes	Temporary Degradation was observed at +4/-4 kV levels
On the fixing screw of the connector of the signal cable (No. 195) connected to the LPRM/APRM Unit	+8kV −8kV	Yes	
On the fixing screw of the connector of the signal cable (No. 208) connected to the LPRM/APRM Unit	+8kV −8kV	Yes	
On the fixing screw of the connector of the signal cable (No. 215) connected to the LPRM/APRM Unit	+4kV −4kV	Yes	Temporary Degradation was observed at +6/-6 kV levels
On the fixing screw of the connector of the signal cable (No. 332) connected to the LPRM/APRM Unit	+0 kV −4kV	Yes	Temporary Degradation was observed at +2/-4 kV levels

Table B12 Test Results of ESD Test (5/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
LPRM/APRM Unit **Air Discharge**			
On the "RESET" switch of the status module	+15kV −15kV	Yes	
On the upper side 3 digits LED indicator of LPRM module in FSL-1	+15kV −15kV	Yes	
On the lower side 3 digits LED indicator of LPRM module in FSL-1	+15kV −15kV	Yes	
On the mode "SELECT" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "+" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "-" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "▸" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "RESET" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the "SET" switch of LPRM module in FSL-1	+15kV −15kV	Yes	
On the upper side 3 digits LED indicator of LPRM module in FSL-10	+15kV −15kV	Yes	
On the lower side 3 digits LED indicator of LPRM module in FSL-10	+15kV −15kV	Yes	
On the mode "SELECT" switch of LPRM module in FSL-10	+15kV −15kV	Yes	
On the "+" switch of LPRM module in FSL-10	+15kV −15kV	Yes	
On the "-" switch of LPRM module in FSL-10	+15kV −15kV	Yes	
On the "▸" switch of LPRM module in FSL-10	+15kV −15kV	Yes	
On the "RESET" switch of LPRM module in FSL-10	+15kV −15kV	Yes	
On the "SET" switch of LPRM module in FSL-10	+15kV −15kV	Yes	
On the upper side 3 digits LED indicator of APRM module in FSL-11	+15kV −15kV	Yes	
On the middle side 3 digits LED indicator of APRM module in FSL-11	+15kV −15kV	Yes	
On the lower side 3 digits LED indicator of APRM module in FSL-11	+15kV −15kV	Yes	
On the "mode SELECT" switch of APRM module in FSL-11	+15kV −15kV	Yes	

Table B12 Test Results of ESD Test (6/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
LPRM/APRM Unit Air Discharge (Continued)			
On the upper "SELECT" switch of APRM module in FSL-11	+15kV −15kV	Yes	
On the lower "SELECT" switch of APRM module in FSL-11	+15kV −15kV	Yes	
On the "+" switch of APRM module in FSL-11	+15kV −15kV	Yes	
On the "-" switch of APRM module in FSL-11	+15kV −15kV	Yes	
On the "▸" switch of APRM module in FSL-11	+15kV −15kV	Yes	
On the "RESET" switch of APRM module in FSL-11	+15kV −15kV	Yes	
On the "SET" switch of APRM module in FSL-11	+15kV −15kV	Yes	
On the surface of the connector of the power cable connected to the LVPS-1 module	+15kV −15kV	Yes	
On the surface of the connector of the power cable connected to the LVPS-2 module	+15kV −15kV	Yes	
LPRM/APRM Unit Indirect Discharge			
Left vertical side of the LPRM/APRM Unit	+8kV −8kV	Yes	
Right vertical side of LPRM/APRM Unit	+8kV −8kV	Yes	
Back vertical side of LPRM/APRM Unit	+8kV −8kV	Yes	
Front vertical side of LPRM/APRM Unit	+8kV −8kV	Yes	

Table B12 Test Results of ESD Test (7/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
FLOW Unit **Contact Discharge**			
On the right edge on the front surface of the chassis of FLOW Unit	+8kV −8kV	Yes	
On the left edge on the front surface of the chassis of FLOW Unit	+8kV −8kV	Yes	
On the top of the status module front panel	+8kV −8kV	Yes	
On the bottom of the status module front panel	+8kV −8kV	Yes	
On the mode key switch of FLOW module in FSL-12	+8kV −8kV	Yes	
On the surface of connector of the signal cable (No. 139 and No.140) connected to the FLOW Unit	+8kV −8kV	Yes	
On the surface of the connector of the optical cable (No. 330) connected to the FLOW Unit	+4kV −2kV	Yes	Temporary Degradation was observed at +6/-4 kV levels
On the fixing screw of the connector of the signal cable (No. 228) connected to the FLOW Unit	+8kV −8kV	Yes	
On the fixing screw of the connector of the signal cable (No. 234) connected to the FLOW Unit	+8kV −8kV	Yes	
On the fixing screw of the connector of the signal cable (No. 240) connected to the FLOW Unit	+8kV −8kV	Yes	
On the fixing screw of the connector of the signal cable (No. 333) connected to the FLOW Unit	+8kV −8kV	Yes	

Table B12 Test Results of ESD Test (8/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
FLOW Unit **Air Discharge**			
On the "RESET" switch of the status module	+15kV −15kV	Yes	
On the upper side 3 digits LED indicator of FLOW module in FSL-12	+15kV −15kV	Yes	
On the middle side 3 digits LED indicator of FLOW module in FSL-12	+15kV −15kV	Yes	
On the bottom side 3 digits LED indicator of FLOW module in FSL-12	+15kV −15kV	Yes	
On the "+" switch of FLOW module in FSL-12	+15kV −15kV	Yes	
On the "-" switch of FLOW module in FSL-12	+15kV −15kV	Yes	
On the "►" switch of FLOW module in FSL-12	+15kV −15kV	Yes	
On the "RESET" switch of FLOW module in FSL-12	+15kV −15kV	Yes	
On the "SET" switch of FLOW module in FSL-12	+15kV −15kV	Yes	
On the "SELECT" switch of FLOW module in FSL-12	+15kV −15kV	Yes	
On the "mode SELECT" switch of FLOW module in FSL-12	+15kV −15kV	Yes	

Table B12 Test Results of ESD Test (9/9)

Test Point	Test Levels without any temporary degradations	Compliant with Specification	Note
FLOW Unit Air Discharge(Continued)			
On the upper side 3 digits LED indicator of SQ-ROOT module in FSL-11	+15kV −15kV	Yes	
On the lower side 3 digits LED indicator of SQ-ROOT module in FSL-11	+15kV −15kV	Yes	
On the "RESET" switch of SQ-ROOT module in FSL-11	+15kV −15kV	Yes	
On the volume knob of SQ-ROOT module in FSL-11	+15kV −15kV	Yes	
On the surface of the connector of the power cable connected to the LVPS-1 module	+15kV −15kV	Yes	
On the surface of the connector of the power cable connected to the LVPS-2 module	+15kV −15kV	Yes	
FLOW Unit Indirect Discharge			
Left vertical side of the FLOW Unit	+8kV −8kV	Yes	
Right vertical side of FLOW Unit	+8kV −8kV	Yes	
Back vertical side of FLOW Unit	+8kV −8kV	Yes	
Front vertical side of FLOW Unit	+8kV −8kV	Yes	

B.13 Results of Class 1E to Non-1E Isolation Testing

Table B13.1 Summary of test results for Class 1E to Non-1E Isolation for 600VDC

Test Points	Test Specimen Operation	Compliant with Specification
Between pin D and pin K of the output connector [ ] [ ]a,c of HNS518 AO module installed in BSL1 of LPRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin N and pin T of the output connector [ ] [ ]a,c of HNS515 AO module installed in BSL3 of LPRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin JJ and pin PP of the output connector [ ] [ ]a,c of HNS518 AO module installed in BSL1 of LPRM/APRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin JJ and pin PP of the output connector [ ] [ ]a,c of HNS516 AO module installed in BSL2 of LPRM/APRM Unit	Within the required tolerance of the normal a,c operation	Yes
Between pin A and pin E of the output connector [ ] [ ]a,c of HNS515 AO module installed in BSL3 of LPRM/APRM Unit	Within the required tolerance of the normal a,c operation	Yes
Between pin JJ and pin PP of the output connector [ ] [ ]a,c of HNS518 AO module installed in BSL1 of LPRM/APRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin JJ and pin PP of the output connector [ ] [ ]a,c of HNS516 AO module installed in BSL2 of LPRM/APRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin A and pin E of the output connector [ ] [ ]a,c of HNS515 AO module installed in BSL3 of LPRM/APRM Unit	a,c Within the required tolerance of the normal operation	Yes

Table B13.2 Summary of test results for Class 1E to Non-1E Isolation for 250VAC

Test Points	Test Specimen Operation	Compliant with Specification
Between pin D and pin K of the output connector [[ ]] [ ]a,c of HNS518 AO module installed in BSL1 of LPRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin N and pin T of the output connector [[ ]] [ ]a,c of HNS515 AO module installed in BSL3 of LPRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin JJ and pin PP of the output connector [[ ]] [ ]a,c of HNS518 AO module installed in BSL1 of LPRM/APRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin JJ and pin PP of the output connector [[ ]] [ ]a,c of HNS516 AO module installed in BSL2 of LPRM/APRM Unit	Within the required tolerance of the normal a,c operation	Yes
Between pin A and pin E of the output connector [[ ]] [ ]a,c of HNS515 AO module installed in BSL3 of LPRM/APRM Unit	Within the required tolerance of the normal a,c operation	Yes
Between pin JJ and pin PP of the output connector [[ ]] [ ]a,c of HNS518 AO module installed in BSL1 of LPRM/APRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin JJ and pin PP of the output connector [[ ]] [ ]a,c of HNS516 AO module installed in BSL2 of LPRM/APRM Unit	a,c Within the required tolerance of the normal operation	Yes
Between pin A and pin E of the output connector [[ ]] [ ]a,c of HNS515 AO module installed in BSL3 of LPRM/APRM Unit	a,c Within the required tolerance of the normal operation	Yes