U.S. NUCLEAR REGULATORY COMMISSION

REGULATORY GUIDE 1.180, REVISION 2

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GUIDELINES FOR EVALUATING ELECTROMAGNETIC AND RADIO-FREQUENCY INTERFERENCE IN SAFETY-RELATED INSTRUMENTATION AND CONTROL SYSTEMS

A. INTRODUCTION

Purpose

This regulatory guide (RG) describes methods and procedures that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for demonstrating compliance with the NRC's regulations on design, installation, and testing to address the effects of electromagnetic and radio-frequency interference (EMI/RFI), power surges, and electrostatic discharge on safety-related instrumentation and control (I&C) systems.

Applicability

This RG applies to licensees and applicants subject to Title 10 of the *Code of Federal Regulations*, Part 50, "Domestic Licensing of Production and Utilization Facilities" (10 CFR Part 50) (Ref. 1), and 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" (Ref. 2).

Applicable Regulations

- 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," requires that structures, systems, and components that are important to safety in a nuclear power plant must be designed to accommodate the effects of environmental conditions (i.e., remain functional under postulated design-basis events (DBEs)).
    - 10 CFR 50.55a(h) states that protection systems must meet the requirements of the Institute of Electrical and Electronics Engineers (IEEE) standard (Std.) 603-1991, "Criteria for Safety Systems for Nuclear Power Generating Stations" (Ref. 3), or IEEE Std. 279-1971, "Criteria for Protection Systems for Nuclear Power Generating Stations" (Ref. 4), contingent on the date of construction permit issuance. The design basis criteria identified in those standards, or for plants with construction permits issued before January 1, 1971, the criteria identified in the licensing basis for such facilities, include the range

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of transient and steady state environmental conditions during normal, abnormal, and accident conditions during which the equipment must perform its safety functions.

- Criterion III, "Design Control," Criterion XI, "Test Control," and Criterion XVII, "Quality Assurance Records," of Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants" to 10 CFR part 50 require design control measures to verify the adequacy of the design, a test program to assure that all testing required to demonstrate that structures, systems, and components will perform satisfactorily in service is performed in accordance with written procedures, and the maintenance of sufficient records as evidence of quality assurance activities.

- 10 CFR 50.49 and 50.55(a) address validation measures such as testing that can be used to check the adequacy of design. Related requirements are contained in General Design Criteria 1, 2, 4, 13, 21, 22, and 23 of Appendix A, "General Design Criteria for Nuclear Power Plants" to 10 CFR part 50 and Part 50, Appendix B, Criterion III.

- 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants" governs the issuance of early site permits, standard design certifications, combined licenses, standard design approvals, and manufacturing licenses for nuclear power facilities.

  - Subpart B, "Standard Design Certifications," of 10 CFR part 52 addresses verification requirements for advanced reactor designs.

  - 10 CFR 52.47(a) requires that an application for design certification must identify the tests, inspections, analyses, and acceptance criteria that are necessary and sufficient to provide reasonable assurance that a plant has been constructed and will operate in conformity with the design certification.

Related Guidance

- NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Chapter 7, "Instrumentation and Controls," identifies electromagnetic compatibility among the acceptance criteria for safety-related I&C systems (Ref. 5).

- RG 1.89, "Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants" (Ref. 6), describes an acceptable method for demonstrating environmental qualification for safety-related electric equipment.

- RG 1.204, "Guidelines for Lightning Protection of Nuclear Power Plants" (Ref. 7), describes an acceptable method for establishing lightning protection at nuclear power facilities, which contributes to controlling the lightning-induced surge environment.

- RG 1.209, "Guidelines for Environmental Qualification of Safety-Related Computer-Based Instrumentation and Control Systems in Nuclear Power Plants" (Ref. 8), describes an acceptable method for demonstrating environmental qualification for digital I&C systems, which addresses service conditions that include electromagnetic and power surge environments.

Purpose of Regulatory Guides

The NRC issues RGs to describe to the public methods that the staff considers acceptable for use in implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated events, and to provide guidance to applicants. Regulatory guides are not substitutes for regulations and compliance with them is not required. Methods and solutions that differ from those set forth in RGs will be deemed acceptable if they provide a basis for the findings required for the issuance or continuance of a permit or license by the Commission.

Paperwork Reduction Act

This RG provides guidance for implementing the mandatory information collections in 10 CFR Parts 50 and 52 that are subject to the Paperwork Reduction Act of 1995 (44 U.S.C. 3501 et. seq.). These information collections were approved by the Office of Management and Budget (OMB), under control numbers 3150-0011 and 3150-0151. Send comments regarding this information collection to the Information Services Branch, U.S. Nuclear Regulatory Commission, (T6-A10M) Washington, DC 20555-0001, or by e-mail to Infocollects.Resource@nrc.gov, and to the Desk Officer, Office of Information and Regulatory Affairs, NEOB-10202 (3150-0011, 3150-0151), Office of Management and Budget, Washington, DC 20503.

Public Protection Notification

The NRC may not conduct or sponsor, and a person is not required to respond to, a collection of information unless the document requesting or requiring the collection displays a currently valid OMB control number.

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B. DISCUSSION

Reason for Revision

This revision of the guide (Revision 2) updates the guidance on EMC practices and test methods that the staff of the NRC considers acceptable for qualifying safety-related I&C systems for the expected electromagnetic environment in nuclear power plants. The revised RG endorses the current versions of previously endorsed standards, incorporates additional guidance for evaluating the effects of electrostatic discharge, and accounts for the evolution of the operational environment at nuclear power plants arising from the increased use of digital technology, including wireless communication for both personal (laptops, tablets, and smartphones) and industrial (remote I&C) applications.

Background

Existing I&C equipment in nuclear power plants is currently being replaced with digital I&C systems or advanced analog I&C systems. However, the electronic architecture used with these technologies may be more sensitive to the nuclear power plant EMI/RFI environment than existing I&C systems. This RG provides an acceptable method for qualifying digital and advanced analog I&C systems for the projected electromagnetic environment in nuclear power plants.

The typical environment in a nuclear power plant includes many sources of electrical noise. Examples include hand-held two-way radios, smartphones, industrial wireless devices, arc welders, switching of large inductive loads, high fault currents, and high-energy fast transients associated with switching at the generator or transmission voltage levels. The increasing use of advanced analog- and digital-based I&C systems in reactor protection and other safety-related plant systems has introduced concerns with respect to the creation of additional noise sources and the susceptibility of this equipment to the electrical noise already present in the nuclear power plant environment.

Manufacturers of digital systems are continually incorporating increasingly higher clock frequencies and lower logic level voltages into their designs. However, these performance advancements can have an adverse impact on the operation of digital systems because of the increased likelihood of extraneous electromagnetic noise being misinterpreted as legitimate logic signals. With advances in analog electronics, many of the functions currently being performed by several analog circuit boards could be combined into a single analog circuit board operating at reduced voltage levels, thereby making analog circuitry more susceptible to EMI/RFI, power surge, and electrostatic discharge as well. Hence, treatment of operational and functional issues related to safety in the nuclear power plant environment must address the possibility of upsets and malfunctions in I&C systems caused by EMI/RFI, power surge, and electrostatic discharge.

This RG endorses design, installation, and testing practices acceptable to the NRC staff for identifying and addressing the effects of EMI/RFI, power surge, and electrostatic discharge on safety-related I&C systems in a nuclear power plant environment. The guidance applies to both safety-related I&C systems and non-safety-related I&C systems whose failure can affect safety functions. The endorsed practices are also acceptable for identifying and evaluating the EMI/RFI effects of non-safety-related equipment that are intended for installation in close proximity to safety-related equipment. Thus, the endorsed practices can be applied for the control of electromagnetic emissions from non-safety-related I&C and electrical systems to ensure that nearby safety-related I&C systems can continue to perform properly in the nuclear power plant environment.

The changes implemented in this revision of this RG include endorsing current versions of the previously endorsed EMC standards. This RG revision extends the guidance to endorse updates in the test methods, adds a test method for electrostatic discharge (ESD), adjusts frequency ranges when appropriate, and relaxes operating envelopes (test levels) where experience and confirmatory research warrants. Conditions under which specific test criteria may be omitted are also offered based on technical considerations.

The updated standards that are endorsed in this RG include:

- MIL-STD-461G, "Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment," (Ref. 9),

- Parts of the commercial International Electrotechnical Commission (IEC) 61000 series on EMC:
    - IEC 61000-3, "Electromagnetic Compatibility (EMC) - Part 3: Limits" (Ref. 10);
    - IEC 61000-4, "Electromagnetic Compatibility (EMC) - Part 4: Testing and Measurement Techniques" (Ref. 11); and
    - IEC 61000-6, Electromagnetic Compatibility (EMC) - Part 6: Generic Standards" (Ref. 12).

- Institute of Electrical and Electronics Engineers (IEEE) standards:
    - IEEE Standard (Std.) 1050-2004, "IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations" (Ref. 13);
    - IEEE Std. C62.41.1-2002, "IEEE Guide on the Surge Environment in Low-Voltage (1000 V and Less) AC Power Circuits" (Ref. 14);
    - IEEE Std. C62.41.2-2002, "IEEE Recommended Practice on Characterization of Surges in Low-Voltage (1000 V or Less) AC Power Circuits" (Ref. 15); and
    - IEEE Std. C62.45-2002, "IEEE Recommended Practice on Surge Testing for Equipment Connected to Low-Voltage (1000 V or Less) AC Power Circuits." (Ref. 16).

The rationale for the selection of the methods and practices endorsed in this RG is that they provide a well-established, systematic approach for ensuring EMC and mitigating the effects of EMI/RFI, power surge, and electrostatic discharge on I&C equipment within their operational environment. The technical basis for selecting these particular methods and practices can be found in:

- NUREG/CR-5941, "Technical Basis for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related I&C Systems." (Ref. 17)

- NUREG/CR-6431, "Recommended Electromagnetic Operating Envelopes for Safety-Related I&C Systems in Nuclear Power Plants." (Ref. 18)

- NUREG/CR-5609, "Electromagnetic Compatibility Testing for Conducted Susceptibility Along Interconnecting Signal Lines." (Ref. 19)

- NUREG/CR-6782, "Comparison of U.S. Military and International Electromagnetic Compatibility Guidance." (Ref. 20)

- ORNL/SPR-2015/485, "Task 2–Limits for High-Frequency Conducted Susceptibility Testing–CS114 (NRCHQ6014D0015)" (Ref. 21).

- ORNL/SPR-2015/254, “Task 4–EMI/RFI Issues Potentially Impacting Electromagnetic Compatibility of I&C Systems (NRCHQ6014D0015)” (Ref. 22)

- ORNL/SPR-2016/108, “Task 5–Technical Basis for Electromagnetic Compatibility Regulatory Guidance Update (NRCHQ6014D0015)” (Ref. 23)

Finally, the above reports include documentation of the basis for the general operating envelopes cited in this RG. Of particular note is that ORNL/SPR-2015/485 documents the technical basis for the significantly revised operating envelope for the high-frequency conducted susceptibility test (CS114) associated with the U.S. Department of Defense test standard. Overall, the operating envelopes are applicable for locations within a nuclear power plant where safety-related I&C systems either are, or are likely to be, installed. These locations include control rooms, remote shutdown panels, cable spreading rooms, equipment rooms, relay rooms, auxiliary instrument rooms, and other areas (e.g., the turbine deck) where safety-related I&C system installations are planned. A comparable technical basis should be established to support the use of modified or different electromagnetic operating envelopes (e.g., lower site-specific envelopes).

Harmonization with International Standards

It is the NRC’s policy to harmonize with international standards, particularly documents from the International Atomic Energy Agency (IAEA). The NRC staff reviewed guidance from the IAEA and did not identify any standards that provided useful guidance to NRC staff, applicants, or licensees. The NRC staff reviewed guidance from the International Electrotechnical Commission (IEC). The review identified the following standards that include relevant EMC test methods for evaluating the impact of conducted and radiated EMI/RFI, power surge, and electrostatic discharge for safety-related I&C systems. For the reasons set forth in detail below in Section C of this RG, the staff concludes that portions of these IEC test standards are adequate, and endorses them, in part, in this RG (see Table 1 below.) This RG incorporates similar design and performance guidelines and is consistent with the safety principles provided in these publications. These IEC standards include:

- IEC 61000-3, “Electromagnetic Compatibility (EMC) - Part 3: Limits,”

- IEC 61000-4, “Electromagnetic Compatibility (EMC) - Part 4: Testing and Measurement Techniques,” and,

- IEC 61000-6, “Electromagnetic Compatibility (EMC) - Part 6: Generic Standards.”

Documents Discussed in Staff Regulatory Guidance

This RG endorses, in whole or in part, the use of one or more codes or standards developed by external organizations, and other third party guidance documents. These codes, standards and third party guidance documents may contain references to other codes, standards or third party guidance documents (“secondary references”). If a secondary reference has itself been incorporated by reference into NRC regulations as a requirement, then licensees and applicants must comply with that standard as set forth in the regulation. If the secondary reference has been endorsed in an RG as an acceptable approach for meeting an NRC requirement, then the standard constitutes a method acceptable to the NRC staff for meeting that regulatory requirement as described in the specific RG. If the secondary reference has neither been incorporated by reference into NRC regulations nor endorsed in an RG, then the secondary reference is neither a legally-binding requirement nor a “generic” NRC approved acceptable approach for meeting an NRC requirement. However, licensees and applicants may consider and use the information in the secondary reference, if appropriately justified, consistent with current regulatory practice, and consistent with applicable NRC requirements.

C. STAFF REGULATORY GUIDANCE

1. General

Establishing and continuing an EMC program for safety-related I&C systems in nuclear power plants contributes to the assurance that safety-related structures, systems, and components are designed to accommodate the effects of, and to be compatible with, the environmental conditions associated with nuclear power plant service. Application of consensus standard practices regarding the design, testing, and installation of safety-related I&C system modifications or new installations constitutes an important element of such a program. This guidance recommends design and installation practices to limit the impact of electromagnetic effects, testing practices to assess the emissions and susceptibility of equipment, testing practices to evaluate the power surge withstand capability (SWC) of equipment, and testing practices to evaluate the electrostatic discharge withstand capability of equipment. Operating envelopes characteristic of the electromagnetic environment in nuclear power plants are cited in this guidance as the basis for establishing acceptable testing levels.

Table 1 lists the specific positions on EMC that are set forth below in the Staff Regulatory Guidance. This guidance is applicable to all new safety-related systems or licensee-initiated modifications to existing safety-related systems that include analog, digital, or hybrid systems and components (i.e., analog and digital electronics equipment). Existing installed systems and equipment are not required to undergo additional testing. The emissions control aspects of this guidance also apply to non-safety-related systems and components whose operation can affect safety-related system or component functions. The endorsed test methods for evaluating the electromagnetic emissions, EMI/RFI susceptibility, power surge and electrostatic discharge withstand capabilities of safety-related equipment are intended for application in test facilities or laboratories before installation.

The electromagnetic conditions at the point of installation for safety-related I&C systems should be assessed to identify any unique EMI/RFI or power surge sources that may generate local interference. The EMI/RFI sources could include both portable and fixed equipment (e.g., portable transceivers, remote wireless I&C devices, arc welders, power supplies, and generators). In accordance with the EMC practices endorsed herein, the EMI/RFI immunity of safety-related I&C systems should be demonstrated with a minimum of an 8 decibel (dB) margin provided above expected exposure levels from all identified sources under any plant mode of operation (e.g., applied susceptibility operating envelopes provide an 8-dB margin above the anticipated highest exposure levels at the point of installation).

To ensure that the operating envelopes are being used properly, equipment should be tested in a physical configuration that is representative of its actual installation. However, rather than requiring that every variation of cabinet configuration be tested, testing should be performed on bounding configuration(s) that reasonably represent the worst-case interference exposure and emissions conditions. For example, a sparse configuration of modules in a cabinet might represent the bounding interference exposure condition (e.g., limited self-shielding among cards) for susceptibility testing. Conversely, a fully loaded configuration of modules in a cabinet might represent the bounding emissions condition for emissions testing. Therefore, testing should be performed with the equipment under test configured in a bounding configuration for the phenomena of interest (e.g., conducted or radiated emissions, conducted or radiated susceptibility, and surge). A justification that the tested configuration reasonably bounds the expected worst case should be provided as part of the test plan to document the basis for the configuration.

The as-tested physical configuration of the safety-related I&C system should be documented as part of test results so that EMC-specific configuration considerations can be implemented during installation and then maintained, and controlled. The design specifications that should be maintained and controlled include wire and cable separations, shielding techniques, shielded enclosure integrity, apertures, gasketing, grounding techniques, EMI/RFI filters, circuit board layouts, and the values of other design parameters that may impact the EMC qualification testing results.

The equipment being tested should be in its normal mode of operation (i.e., performing its intended function) during the testing. For software-based systems, the system should have functioning software and diagnostics that are representative of those used in actual operation.

Table 1 Specific Regulatory Positions for EMC Guidance

Regulatory Position	EMC Issue Addressed	Standards Endorsed	Comments/Conditions
1	General EMC program		Scope and applicability of guidance defined. Key considerations identified for confirming operating envelopes, configuring and conducting testing, and treating portable emitters.
2	EMI/RFI limiting practices	IEEE Std. 1050-2004	Endorsed.
3, 4	EMI/RFI emissions and susceptibility (radiated, conducted power line and conducted signal line) testing	MIL-STD-461G IEC 61000-3 IEC 61000-4 IEC 61000-6	Selected MIL-STD-461G and IEC 61000 test methods endorsed. Operating envelopes specified. Clarifications on application and conditions for omission provided.
5	SWC testing	IEEE Std C62.41.1-2002 IEEE Std C62.41.2-2002 IEEE Std C62.45-2002 IEC 61000-4	Selected IEEE Std C62.41.2-2002 surge test waveforms endorsed. Related IEEE Std C62.45-2002 test methods endorsed. Selected IEC 61000-4 surge test waveforms and test methods endorsed. SWC withstand levels specified with exception[1] taken to level in IEEE Std C62.41.2-2002.
6	Electrostatic discharge testing	IEC 61000-4	IEC 61000-4-2 test method endorsed. Test levels specified.
7	Documentation		Essential EMC documentation identified.

Exclusion zones should be established through administrative controls to prohibit the activation of portable EMI/RFI emitters (e.g., welders and handheld communication devices) in areas where safety-related I&C systems have been installed. An exclusion zone is defined as the minimum distance between the point of installation of safety-related I&C equipment and the location of portable EMI/RFI emitters. The size of the exclusion zones should be site-specific and depend on the effective radiated power and antenna gain of the portable EMI/RFI emitters used within a particular nuclear power plant.

[1] If the NRC staff does not endorse part of standard, it denotes that matter as an "exception" to the NRC staff endorsement of the standard.

The size of exclusion zones should also depend on the allowable electric field emission levels designated for the area in the vicinity of the installed safety-related I&C system. To establish the size of an exclusion zone, an 8 dB difference between the susceptibility operating envelope and the allowed emissions level should be maintained. For the operating envelope of 10 V/m (140 dB μV/m) associated with radiated electric field susceptibility, the size of the exclusion zones should be set such that the radiated electric fields emanating from the portable EMI/RFI emitters are limited to 4 V/m (132 dB μV/m) in the vicinity of safety-related I&C systems.

The minimum distance of an exclusion zone (d) in meters should be calculated by the following equation derived from the free space propagation model:

$$d = \frac{\sqrt{30 P_t G_t}}{E} (meters)$$

where:

P_t = the peak radiated power of the EMI/RFI emitter (in Watts);
G_t = the gain of the EMI/RFI emitter; and
E = the allowable radiated electric field strength of the EMI/RFI emitter (in Volts/meter) at the point of installation.

Note that unintentional transmitters (welders, motors, etc.) will typically have a gain that is less than or equal to 1 (the gain of an isotropic emitter), and the gain for intentional transmitters (two-way radios, cell phones, etc.) will typically be greater than 1. Typical values for the gain of intentional transmitters might vary from 1.5 for a short dipole antenna to 3 for a monopole antenna, and to 6 for a horn antenna.

2. IEEE Std. 1050-2004

IEEE Std. 1050-2004 describes design and installation practices that are acceptable to the NRC staff to limit EMI/RFI and power surge-related effects on safety-related I&C systems employed in nuclear power plants.

3. EMI/RFI Emissions Testing

The NRC staff concludes that specific test methods from MIL-STD-461G and IEC 61000-6 are acceptable for performing emissions testing of both safety-related I&C systems and non-safety-related I&C systems intended for installation in nuclear power plants. These test methods are identified in the guidance below and may be applied in the indicated combinations subject to the clarifications and conditions specified. Acceptable limits are given for each test in the form of identified operating envelopes.

MIL-STD-461G contains test practices that can be applied to characterize EMI/RFI emissions. IEC 61000-6 also specifies test practices that can be applied to characterize EMI/RFI emissions for industrial environments. The specific test methods acceptable to the NRC staff for performing emissions testing are presented in Tables 2 and 3. Table 2 lists the EMI/RFI emissions test methods in MIL-STD-461G, while Table 3 lists the corresponding criteria in IEC 61000-6-4, "Electromagnetic Compatibility (EMC) – Part 6: Generic Standards – Section 4: Emission standard for industrial environments" (Ref. 24). Either set of test methods should be applied in its entirety or in specified combinations subject to the clarifications and conditions identified in the guidance below. These test methods cover conducted (along power leads) and radiated interference emitted from equipment under test.

Table 2 MIL-STD-461G Test Methods for EMI/RFI Emissions

Method	Description
CE101	Conducted emissions, low-frequency, 30 Hz to 10 kHz
CE102	Conducted emissions, high-frequency, 10 kHz to 10 MHz
RE101	Radiated emissions, magnetic field, 30 Hz to 100 kHz
RE102	Radiated emissions, electric field, 2 MHz to 10 GHz

C = conducted, R = radiated, and E = emissions

Table 3 IEC 61000-6-4 Test Methods for EMI/RFI Emissions

Method	Description
None	Conducted emissions, low-frequency, 30 Hz to 10 kHz
CISPR 16	Conducted emissions, high-frequency, 150 kHz to 30 MHz
None	Radiated emissions, magnetic field, 30 Hz to 100 kHz
CISPR 16	Radiated emissions, electric field, 30 MHz to 6 GHz

MIL-STD-461G provides the latest revision of domestic guidance for emissions test methods, thus it represents current U.S. practice. IEC 61000-6-4 provides the most recent international guidance for emissions test practices and incorporates by reference the emissions test methods established by the Comité International Spécial des Perturbations Radioélectriques (CISPR) of the IEC. These emissions test methods are defined in parts 2-1 and 2-3 of CISPR 16, "Specification for radio disturbance and immunity measuring apparatus and methods" (Ref. 25 and Ref. 26) while guidance on measurement equipment is given in other specified CISPR16 parts.

Because of the non-intrusive nature of emissions measurement, the test methods from either the MIL-STD-461G or IEC 61000-6-4 can be applied in combination based on the emissions phenomenon of interest (e.g., high-frequency or low-frequency, conducted or radiated) without affecting the equipment under test. The individual MIL-STD and IEC emissions test methods are designed to be complementary in frequency range coverage within themselves. If emissions test methods from different standards are used and full coverage of frequency ranges is not provided, then supplemental testing should be undertaken to address the gaps or justification for the omission of testing in any frequency range should be documented as part of the test plan. Since the IEC standard does not provide for low-frequency emissions testing, the MIL-STD test methods should be applied for emissions testing in the low-frequency band unless test omissions are justified. When using a combination of IEC and MIL-STD emissions tests (e.g., MIL-STD for low frequency testing and IEC for high-frequency testing), it is necessary to ensure frequency range coverage is maintained.

The MIL-STD-461G test methods listed in Table 2 have associated operating envelopes that serve to establish test levels. General operating envelopes that are acceptable to the NRC staff are given below in the guidance on the listed MIL-STD-461G test methods. Likewise, operating envelopes for the IEC 61000-6-4 test methods have been identified that are comparable to their corresponding MIL-STD counterparts and are given below in the IEC emissions testing guidance. These operating envelopes are acceptable for locations where safety-related I&C systems either are, or are likely to be, installed and include control rooms, remote shutdown panels, cable spreading rooms, equipment rooms, auxiliary instrument rooms, relay rooms, and other areas (e.g., the turbine deck) where safety-related I&C system installations are planned. The operating envelopes are acceptable for analog, digital, and hybrid system installations. Where applicable, these standards also describe conditions under which specific test methods may be omitted.

3.1 CE101—Conducted Emissions, Low Frequency

The CE101 test measures the low-frequency conducted emissions on power leads of equipment and subsystems in the frequency 30 Hz to 10 kHz. For AC power leads, the frequency range over which the test is performed starts at the second harmonic of the power line frequency. This test may be omitted for equipment that meets the following two conditions.

1. The power quality requirements[2] of the equipment are consistent with the existing power supply and design changes include power quality controls.

2. The equipment will not impose additional harmonic distortion on the existing power distribution system that exceed 5% total harmonic distortion (THD) or other power quality criteria established with a valid technical basis.

When the CE101 test is to be performed, it is applicable to ac and dc power leads, including grounds and neutrals that obtain power from other sources not part of the equipment under test. Conducted emissions on power leads should not exceed the applicable root mean square (rms) values shown in Figure 3.1, "Low-Frequency Emissions Envelopes."

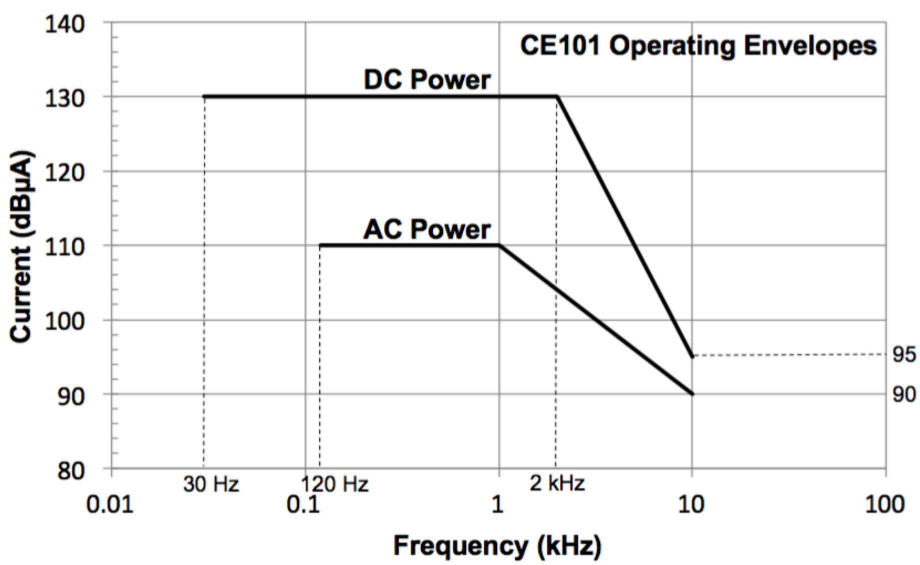

Figure 3.1 Low-Frequency Emissions Envelopes

3.2 CE102—Conducted Emissions, High Frequency

The CE102 test measures the high-frequency conducted emissions on power leads of equipment and subsystems in the frequency range 10 kHz to 10 MHz. The test is applicable to ac and dc power leads, including grounds and neutrals that obtain power from other sources that are not part of the equipment under test. Conducted emissions on power leads should not exceed the applicable rms values shown in Figure 3.2. The values are specified according to the voltage of the power source

[2] The term "requirements" in this context does not refer to legal requirements; rather, it refers to the characteristics of the design ("design requirements") that are necessary to perform the design function credited in the Final Safety Analysis Report.

feeding the equipment under test. Conduct of the CE102 test in the frequency range 10 kHz to 150 kHz may be omitted if the nuclear power plant has power quality controls in place (see the conditions for omission of the CE101 test above). Otherwise, the CE102 test should be performed over the full frequency range 10 kHz to 10 MHz.

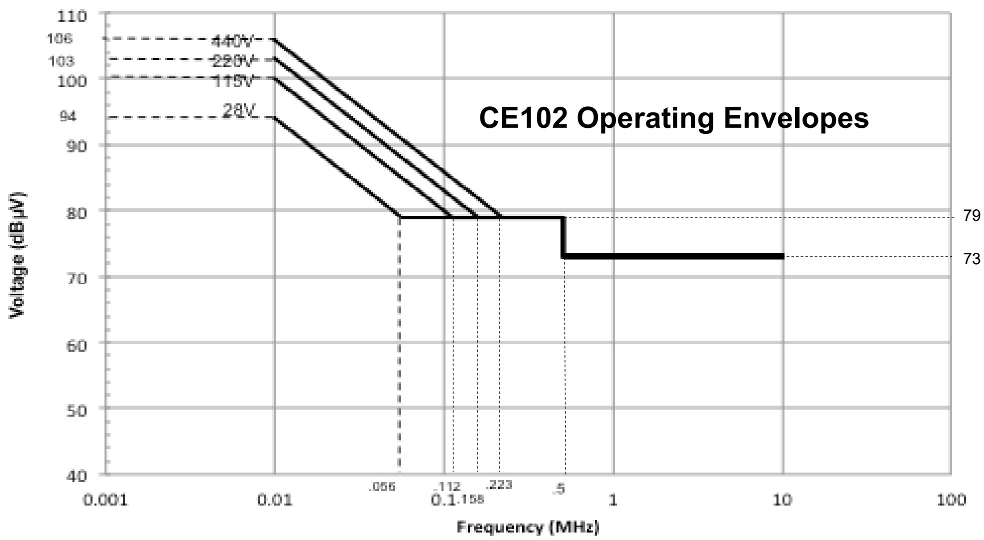

Figure 3.2 High-Frequency Conducted Emissions Envelopes

3.3 RE101—Radiated Emissions, Magnetic Field

The RE101 test measures radiated magnetic field emissions in the frequency range 30 Hz to 100 kHz. The RE101 test may be omitted for equipment not intended to be installed in areas with other equipment sensitive to magnetic fields. The test is applicable for emissions from equipment and subsystem enclosures, as well as all interconnecting leads. The test does not apply at transmitter fundamental frequencies or to radiation from antennas. Magnetic field emissions should not be radiated in excess of the levels shown in Figure 3.3. Magnetic field emissions are measured at the specified distances of 7 cm and compared against the corresponding envelope.

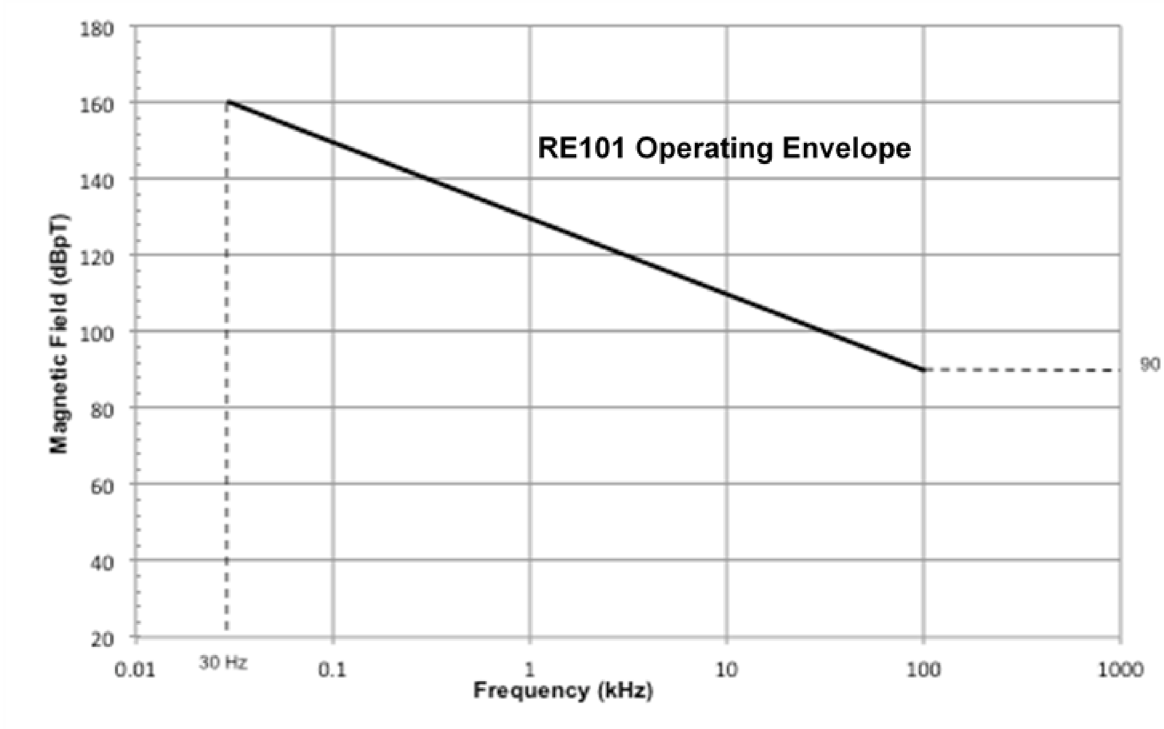

Figure 3.3 Magnetic-Field Radiated Emissions Envelope

3.4 RE102—Radiated Emissions, Electric Field

The RE102 test addresses the measurement of radiated electric field emissions in the frequency range from 2 MHz to 10 GHz. It is applicable for emissions from equipment and subsystem enclosures, as well as all interconnecting leads. The test does not apply at transmitter fundamental frequencies or to radiation from antennas.

Electric field emissions should not be radiated in excess of the rms values shown in Figure 3.4. At frequencies above 30 MHz, the test method should be performed for both horizontally and vertically polarized fields.

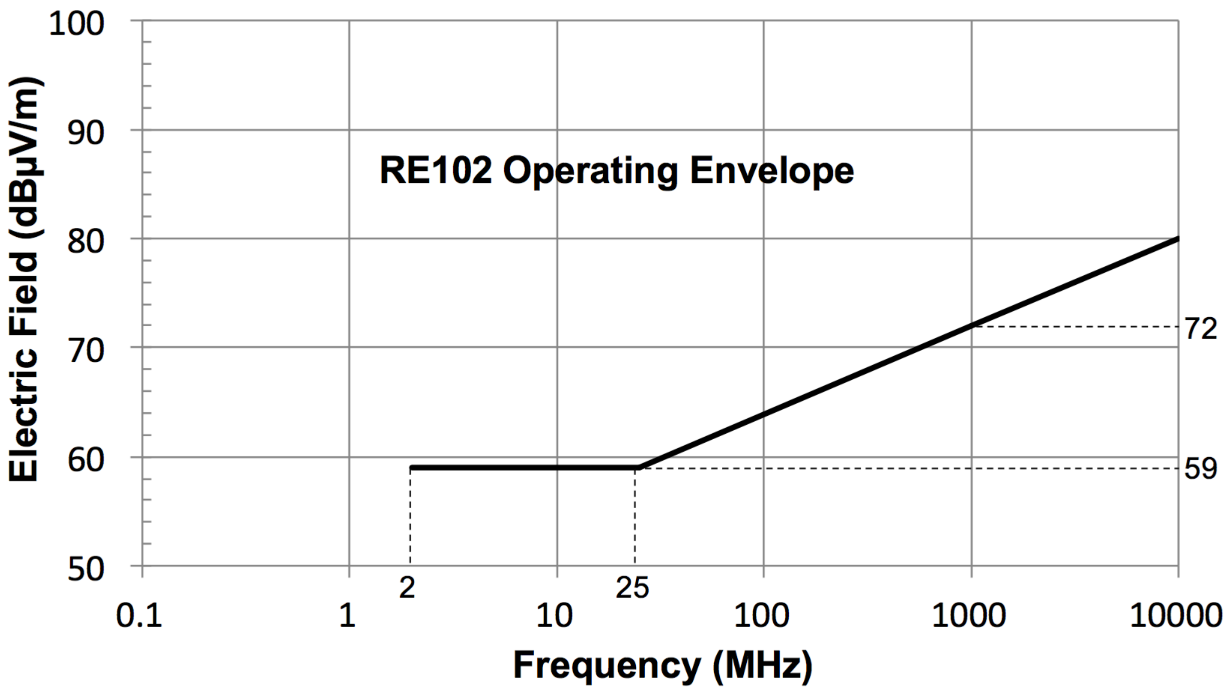

Figure 3.4 Electric-Field Radiated Emissions Envelopes

3.5 IEC Emissions Tests

The IEC 61000-6-4 tests address measurement of emissions for electrical and electronic equipment intended for use in industrial environments in the frequency range from 150 kHz to 6 GHz. IEC 61000-6-4 incorporates the test methods of CISPR 16 by reference. Conducted emissions testing covers the frequency range from 150 kHz to 30 MHz. Radiated emissions testing covers the frequency range from 30 MHz to 6 GHz. The IEC test methods are acceptable to the NRC staff for demonstrating emissions compliance in the high-frequency band for safety-related I&C systems and non-safety-related I&C systems intended for installation in nuclear power plants. However, since no test methods are provided by IEC to measure low-frequency conducted or radiated emissions, the application of these tests is limited to two options, which are described below.

The first option under which the application of the IEC emissions tests is acceptable involves the following two conditions that justify the omission of low-frequency emissions testing. First, power quality controls are in place, which eliminates the need to perform the CE101 test and the lower frequency band of the CE102 test. Second, separation from equipment that is sensitive to magnetic fields is maintained, making it is unnecessary to perform the RE101 test. These conditions for omission are discussed in the endorsement of CE101, CE102, and RE101.

The second option under which the application of the IEC emissions tests is acceptable involves supplementing the IEC emissions testing with MIL-STD-461G testing to account for the gaps in coverage across the low-frequency band. Specifically, the CE101 test should be performed to evaluate conducted emissions from 30 Hz to 10 kHz, the CE102 test should be performed across the lower range of its frequency band to evaluate conducted emissions from 10 kHz to 150 kHz, and the RE101 test should be performed to evaluate radiated emissions from 30 Hz to 100 kHz.

The specifications for the IEC 61000-6-4 test call for employing the CISPR 16 measurement techniques. These techniques are similar to those used in the MIL-STD-461G CE102 and RE102 tests, with some differences. Nevertheless, the tests have been shown to yield similar results per ORNL/TM-2002/257, "Conducted Susceptibility Tests on an Artifact Using IEC and MIL-STD Test Methods," dated July 2002, (Ref. 27). Values for the IEC 61000-6-4 conducted emissions envelopes comparable to those for CE102 are given in Table 4. Values for the IEC 61000-6-4 radiated emissions envelopes comparable to RE102 are given in Table 5.

Table 4 IEC 61000-6-4 Conducted Emissions Envelopes

Frequency Range	Test Level (dB µV/m)
150 kHz to 500 kHz	79 quasi-peak
500 kHz to 30 MHz	73 quasi-peak

Table 5 IEC 61000-6-4 Radiated Emissions Envelopes

Frequency Range	Test Level (dB µV/m)
30 MHz to 230 MHz	40 quasi-peak @ 10 m
230 MHz to 1 GHz	47 quasi-peak @ 10 m
1 GHz to 3 GHz	76 peak @ 3m
3 GHz to 6 GHz	80 peak @ 3m

3.6 EMI/RFI Emissions Test Summary

The CE101, CE102, RE101, and RE102 tests from MIL-STD-461G represent the baseline emissions testing program acceptable to the NRC staff. The CE101 test may be omitted if the nuclear power plant has power quality controls in place and the equipment won't impose more than 5% THD (see conditions in the CE101 test guidance). The CE102 test in the frequency range 10 kHz to 150 kHz may be omitted if power quality controls are in place. The RE101 test may be omitted for equipment not intended to be installed in areas with other equipment sensitive to magnetic fields.

As an alternative, the application of IEC 61000-6-4 tests is acceptable to the NRC staff in the form of two options. In the first option, the identified IEC emissions tests are acceptable as a standalone program if the two conditions for omitting low frequency emissions testing are met: 1) power quality controls are in place, eliminating the need to perform the CE101 test and the lower frequency band of the CE102 test and 2) separation from equipment that is sensitive to magnetic fields is maintained, eliminating the need to perform the RE101 test (Alternative #3 in Figure 3.5). In the second option, the IEC emissions tests should be supplemented by complementary MIL-STD-461G tests to evaluate emissions in the low-frequency band. Specifically, the CE101 test, CE102 test (from 10 kHz to 150 kHz), and RE101 test should be performed (Alternative #1 in Figure 3.5).

Figure 3.5 shows the acceptable emissions testing programs and indicates the conditions under which the alternative test suites can be applied. It should be noted that the use of specific MIL-STD-461G emissions tests to supplement the frequency range coverage of the IEC emissions tests does not constitute endorsement of unrestrained mixing and matching of test methods among the suites of tests. The absence of low-frequency emissions test guidance from the IEC, the non-intrusive nature of the test methods themselves, and the comparability of emissions measurement data justifies the specific combination of test methods to ensure acceptable frequency range coverage when the low-frequency emissions test omission criteria identified above are not satisfied.

Finally, Federal Communications Commission (FCC) certification for Class A or Class B devices under 47 CFR Part 15, "Radio Frequency Devices," (Ref. 28) may be credited over the frequency ranges covered by certification testing in lieu of additional testing for non-safety-related I&C systems. In order to take credit for FCC certification for safety-related I&C systems, test data and documentation equivalent to the information identified in Regulatory Position C.7 should be maintained and be available for review.

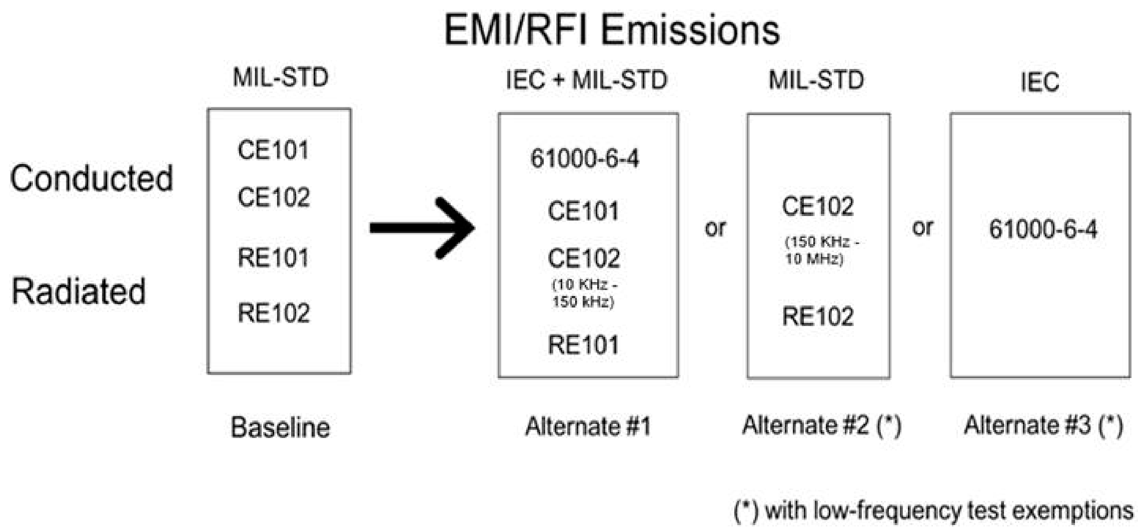

Figure 3.5 Acceptable Alternatives for EMI/RFI Emissions Testing

4. EMI/RFI Susceptibility Testing

Specific test methods from MIL-STD-461G and IEC 61000-4 are acceptable to the NRC staff for performing susceptibility testing of safety-related I&C systems intended for installation in nuclear power plants. These test methods are identified in the guidance below and may be applied in the indicated combinations subject to the clarifications and conditions specified. Acceptable limits are given for each test in the form of identified operating envelopes.

MIL-STD-461G contains test methods that can be applied to address EMI/RFI susceptibility for a selection of environments. IEC 61000-4 also specifies test methods that can be applied to characterize equipment susceptibility to conducted and radiated EMI/RFI. The test methods acceptable to the NRC staff with regard to susceptibility testing for safety-related I&C systems in nuclear power plants are presented in Tables 6 and 7. Table 6 lists the EMI/RFI test methods in MIL-STD-461G while Table 7 lists the corresponding test methods in IEC 61000-4 (Refs. 29-38). Regardless of which susceptibility testing program is chosen, either set of test methods should be applied in its entirety, without selective application of individual methods (i.e., no mixing and matching of test methods). These methods cover susceptibility to conducted and radiated interference resulting from exposure to electric and magnetic fields and noise coupling through power and signal leads.

Table 6 MIL-STD-461G EMI/RFI Susceptibility Test Methods

Method	Description
CS101	Conducted susceptibility, low frequency, 30 Hz to 150 kHz
CS114	Conducted susceptibility, high frequency, 10 kHz to 30 MHz
CS115	Conducted susceptibility, bulk cable injection, impulse excitation
CS116	Conducted susceptibility, damped sinusoidal transients,10 kHz to 100 MHz
RS101	Radiated susceptibility, magnetic field, 30 Hz to 100 kHz
RS103	Radiated susceptibility, electric field, 30 MHz to 10 GHz

C = conducted, R = radiated, and S = susceptibility

Table 7 IEC 61000-4 EMI/RFI Susceptibility Test Methods

Method	Description
61000-4-4	Conducted susceptibility, electrically fast transients/bursts
61000-4-5	Conducted susceptibility, surges
61000-4-6	Conducted susceptibility, disturbances induced by RF fields, 150 kHz to 80 MHz
61000-4-12	Conducted susceptibility, 100 kHz ring wave
61000-4-13	Conducted susceptibility, low frequency, 16 Hz to 2.4 kHz
61000-4-16	Conducted susceptibility, low frequency, 0 Hz to 150 kHz
61000-4-8	Radiated susceptibility, magnetic field, 60 Hz
61000-4-9	Radiated susceptibility, magnetic field, 60 Hz to 50 kHz
61000-4-10	Radiated susceptibility, magnetic field, 100 kHz and 1 MHz
61000-4-3	Radiated susceptibility, electric field, 26 MHz to 6 GHz

The MIL-STD-461G test methods listed in Table 6 have related operating envelopes that serve to establish test levels. General operating envelopes acceptable to the NRC staff are given below in the discussion of the MIL-STD 461G test methods. Likewise, operating envelopes for the IEC 61000-4 test methods have been identified that are comparable to their corresponding MIL-STD counterparts. A discussion on these is also given below. These operating envelopes are acceptable for locations where safety-related I&C systems either are or are likely to be installed and include control rooms, remote shutdown panels, cable spreading rooms, equipment rooms, auxiliary instrument rooms, relay rooms, and other areas (e.g., the turbine deck) where safety-related I&C system installations are planned. The operating envelopes are acceptable for analog, digital, and hybrid system installations.

The MIL-STD-461G and IEC 61000-4 test methods that demonstrate EMI/RFI susceptibility compliance are discussed below. These methods are acceptable to the NRC staff for accomplishing EMI/RFI susceptibility testing for safety-related I&C systems intended for installation in nuclear power plants. Where applicable, these standards also describe conditions under which specific test methods may be omitted.

4.1 EMI/RFI Conducted Susceptibility Testing—Power Leads

The MIL-STD-461G test methods that are acceptable to the NRC staff in addressing conducted EMI/RFI susceptibility along power leads are listed in Table 8. The comparable IEC 61000-4 test methods acceptable to the NRC staff to characterize equipment susceptibility to conducted EMI/RFI along power leads are listed in Table 9. These test methods cover susceptibility to conducted interference resulting from noise coupling through the power leads of safety-related I&C systems in nuclear power plants. Guidance on the test methods and operating envelopes follow below.

Table 8 MIL-STD-461G Conducted Susceptibility Test Methods—Power Leads

Method	Description
CS101	Conducted susceptibility, low-frequency, 30 Hz to 150 kHz
CS114	Conducted susceptibility, high-frequency, 10 kHz to 30 MHz

C = conducted and S = susceptibility

Table 9 IEC 61000-4 Conducted Susceptibility Test Methods—Power Leads

Method	Description
61000-4-6	Conducted susceptibility, disturbances induced by radio-frequency fields, 150 kHz to 80 MHz
61000-4-13	Conducted susceptibility, low-frequency, 16 Hz to 2.4 kHz
61000-4-16	Conducted susceptibility, low-frequency, 0 Hz to 150 kHz

4.1.1 CS101—Conducted Susceptibility, Low Frequency

The CS101 test ensures that equipment and subsystems are not susceptible to EMI/RFI present on power leads in the frequency range 30 Hz to 150 kHz. The test is applicable to ac and dc input power leads, not including grounds and neutrals. If the equipment under test is dc operated, this test is applicable over the frequency range 30 Hz to 150 kHz. If the equipment under test is ac operated, this test is applicable starting from the second harmonic of the power line frequency and extending to 150 kHz.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to a test signal with the rms voltage levels specified in Figure 4.1. Alternative envelopes are given for equipment with nominal source voltages at or below 28 V and those operating above 28 V. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

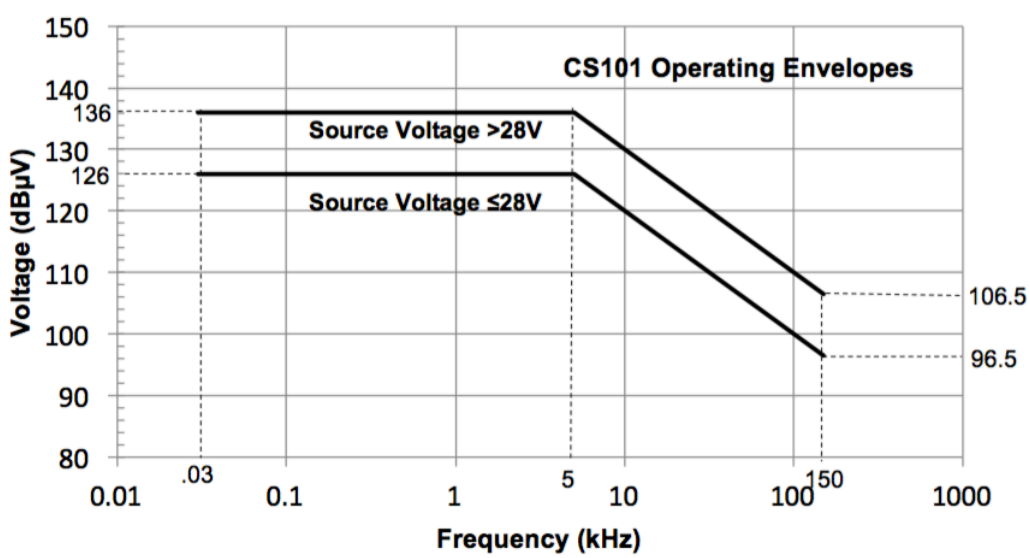

Figure 4.1 Low-Frequency Conducted Susceptibility Operating Envelopes

4.1.2 CS114—Conducted Susceptibility, High Frequency

The CS114 test simulates currents that will be developed on leads as a result of EMI/RFI generated by antenna transmissions. The test covers the frequency range 10 kHz to 30 MHz and is applicable to all interconnecting leads, including the power leads of the equipment under test. Although the CS114 test can be applied to assess both power line and signal line susceptibility, the guidance on test levels given in this section is specific to power leads.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to a test signal with the rms levels shown in Figure 4.2. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

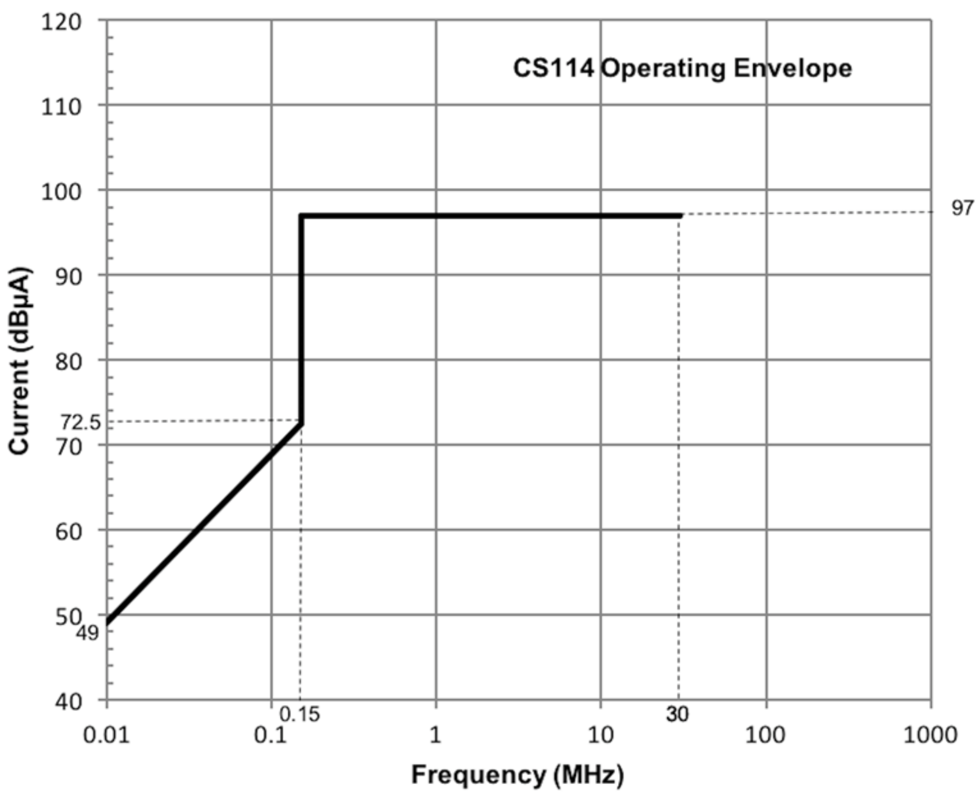

Figure 4.2 High-Frequency Conducted Susceptibility Operating Envelopes for Power Leads

4.1.3 IEC Conducted Susceptibility Tests—Power Leads

The IEC counterparts to the CS101 and CS114 tests are IEC 61000-4-13, IEC 61000-4-16, and IEC 61000-4-6. Operating envelopes for IEC 61000-4-13 correspond to the test levels for Class 2 devices and are shown in Tables 10 and 11. For the IEC 61000-4-16 test, operating envelopes correspond to the Level 3 test levels and are shown in Table 12. The operating envelope for IEC 61000-4-6 corresponds to the Level 3 test level of 140 dBμV. The test levels established by these envelopes are acceptable to NRC staff for evaluating conducted susceptibility along power leads.

Table 10 Harmonics Operating Envelope for IEC 61000-4-13

Harmonic No. (n)	Level (% of supply voltage)
2	3
3	8
4	1.5
5	9
7	7.5
9	2.5
11	5
13	4.5
17	3
19	2
23	2
25	2
29	1.5
31	1.5
35	1.5
37	1.5

Table 11 Interharmonics Operating Envelopes for IEC 61000-4-13

Frequency Range (Hz)	Level (% of supply voltage)
20 - 120	2.5
120 - 600	5
600 - 900	3.5
900 - 1200	2
1200 - 2400	1.5

Table 12 Operating Envelopes for IEC 61000-4-16

Disturbance	Test level
dc and power line frequency, continuous disturbance	10 Vrms
dc and power line frequency, short-duration disturbance	100 Vrms
Conducted disturbance, 15 Hz to 150 kHz	10-1 Vrms (15-150 Hz)* 1 Vrms (150-1.5 kHz) 1-10 Vrms (1.5-15 kHz)* 10 Vrms (15-150 kHz)

* Applied at 20 dB/decade slope

4.2 EMI/RFI Conducted Susceptibility Testing—Signal Leads

MIL-STD-461G contains test methods that can be applied to address conducted EMI/RFI susceptibility for interconnecting signal leads. In addition, IEC 61000-4 specifies test methods that can be applied to characterize equipment susceptibility to conducted EMI/RFI along interconnecting signal leads.

The test methods acceptable to the NRC staff with regard to conducted susceptibility testing for signal leads in safety-related I&C systems in nuclear power plants are presented in Tables 13 and 14. Table 13 lists the EMI/RFI test methods for signal leads in MIL-STD-461G, while Table 14 lists the corresponding methods in IEC 61000-4. These test methods are acceptable to test for susceptibility to conducted interference resulting from noise coupling through interconnecting signal leads.

Table 13 MIL-STD-461G Conducted Susceptibility Test Methods-Signal Leads

Method	Description
CS114	Conducted susceptibility, high-frequency, 10 kHz to 30 MHz
CS115	Conducted susceptibility, bulk cable injection, impulse excitation
CS116	Conducted susceptibility, damped sinusoidal transients, 10 kHz to 100 MHz

C = conducted and S = susceptibility

Table 14 IEC 61000-4 Conducted Susceptibility Test Methods-Signal Leads

Method	Description
61000-4-4	Electrical fast transient/burst immunity test
61000-4-5	Surge immunity test
61000-4-6	Immunity to conducted disturbances, induced by radio-frequency fields, 150 kHz to 80 MHz
61000-4-12	Oscillatory waves immunity test
61000-4-16	Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz

The MIL-STD-461 test methods listed in Table 13 have related operating envelopes that serve to establish test levels for signal leads. General operating envelopes that are acceptable to the NRC staff are shown in Table 15. Likewise, acceptable signal lead operating envelopes for the IEC 61000-4 test criteria listed in Table 14 have been identified in Table 16 and are comparable to their corresponding MIL-STD counterparts. Note that the operating envelope is based on the location of signal lines; in this context, the maximum EMI/RFI field strength postulated for a specific location is called the “withstand level” at that location. Most locations in the interior of a facility, which are typical for signal leads, correspond to the *Category B* surge withstand classification described in IEEE Std C62.41.2-2002 and discussed in Regulatory Position C.5. The vast majority of signal leads are expected to be located in limited surge activity environments that correspond to low withstand levels (see Regulatory Position C.5). However, for those few I&C systems that may be implemented in plant areas characterized by surge environments with significant switching transients and lightning activity (e.g., in very close proximity to the service entrance from the switchyard), elevated withstand levels would be necessary (see Regulatory Position C.5). Consequently, for the IEC tests, the operating envelopes in Table 17 should be used as a special case for those few I&C systems that may be implemented in plant areas that are characterized by the elevated surge environments.

Table 15 MIL-STD-461G Conducted Susceptibility Operating Envelopes—Signal Leads

Method	Description
CS114	Apply Figure 4.2
CS115	5 A
CS116	Apply damped sinusoidal waveform using frequency-dependent peak current specified in Figure CS116-2 of the MIL-STD

Table 16 IEC 61000-4 Conducted Susceptibility Operating Envelopes-Low Withstand-Signal Leads

Method	Description
61000-4-4	Level 3: 1 kV test voltage
61000-4-5	Level 3: 2 kV open circuit test voltage and 1 kA short circuit current
61000-4-6	Level 3: 140 dBμV test voltage
61000-4-12	Level 2: 1 kV test voltage
61000-4-16	Level 3: see Table 12

Table 17 IEC 61000-4 Conducted Susceptibility Operating Envelopes-Moderate Withstand-Signal Leads

Method	Description
61000-4-4	Level 4: 2 kV test voltage
61000-4-5	Level 4: 4 kV open circuit test voltage and 2 kA short circuit current
61000-4-6	Level 3: 140 dBμV test voltage
61000-4-12	Level 3: 2 kV test voltage
61000-4-16	Level 3: see Table 12

4.3 EMI/RFI Radiated Susceptibility Testing

The MIL-STD-461G test methods that are acceptable to the NRC staff for addressing the radiated EMI/RFI susceptibility of safety-related I&C systems in nuclear power plants are listed in Table 18. The comparable IEC 61000-4 test methods acceptable to characterize equipment susceptibility to radiated EMI/RFI are listed in Table 19. If wireless communication devices operating above 6 GHz are expected to be used at the site of installation, then the IEC test for high-frequency susceptibility should be applied up to 10 GHz. These test methods cover susceptibility to radiated interference resulting from electromagnetic emissions in nuclear power plants. Guidance on the test methods and operating envelopes follow below.

Table 18 MIL-STD-461G EMI/RFI Radiated Susceptibility Test Methods

Method	Description
RS101	Radiated susceptibility, magnetic field, 30 Hz to 100 kHz
RS103	Radiated susceptibility, electric field, 30 MHz to 10 GHz

R = radiated and S = susceptibility

Table 19 IEC 61000-4 EMI/RFI Radiated Susceptibility Test Methods

Method	Description
61000-4-8	Radiated susceptibility, magnetic field, 50 Hz and 60 Hz
61000-4-9	Radiated susceptibility, magnetic field, 50/60 Hz to 50 kHz
61000-4-10	Radiated susceptibility, magnetic field, 100 kHz and 1 MHz
61000-4-3	Radiated susceptibility, electric field, 26 MHz to 6 GHz

4.3.1 RS101—Radiated Susceptibility, Magnetic Fields

The RS101 test ensures that equipment and subsystems are not susceptible to radiated magnetic fields in the frequency range 30 Hz to 100 kHz. The RS101 may be omitted for equipment that is not intended to be installed in areas with strong sources of magnetic fields (e.g., CRTs, motors, cable bundles carrying high currents) and that follows the limiting practices endorsed in this guide (see Regulatory Position C.2). The test is applicable to equipment and subsystem enclosures and all interconnecting leads. The test is not applicable for electromagnetic coupling via antennas.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the rms magnetic field levels shown in Figure 4.3. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

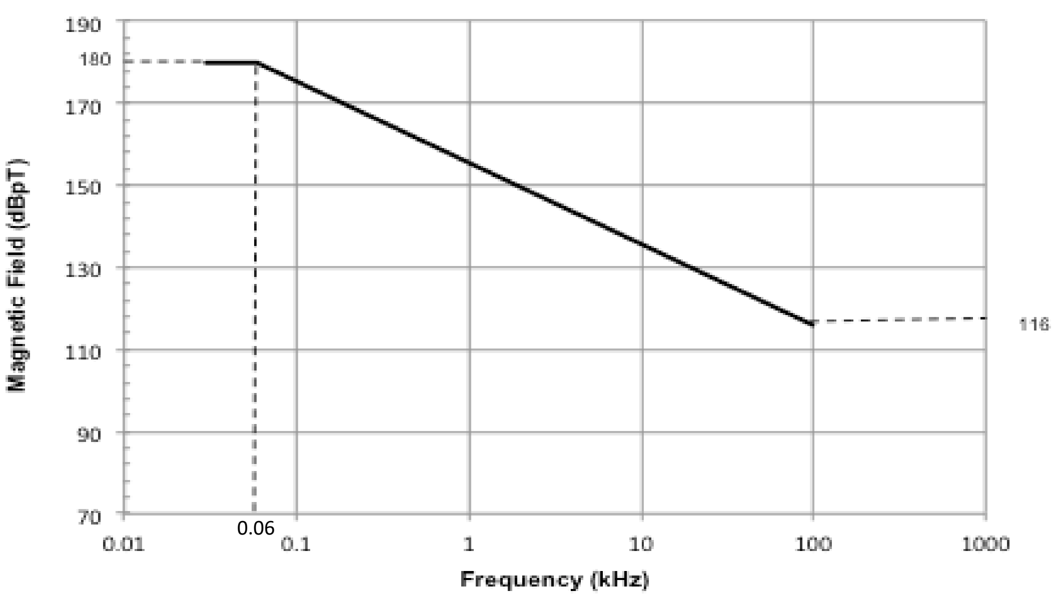

Figure 4.3 Low-Frequency Radiated Susceptibility Envelopes

4.3.2 RS103—Radiated Susceptibility, Electric Fields

The RS103 test ensures that equipment and subsystems are not susceptible to radiated electric fields in the frequency range from 30 MHz to 10 GHz. The test is applicable to equipment and subsystem enclosures and all interconnecting leads. The test is not applicable at the tuned frequency of antenna-connected receivers unless otherwise specified.

The equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the radiated electric fields. The applied electric field level should be 10 V/m (rms), measured in accordance with the techniques specified in the RS103 test method. The test method should be performed for both horizontally and vertically polarized fields. As described in MIL-STD-461G, circularly polarized fields are not acceptable because radiated electric fields are typically linearly polarized. Acceptable performance should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

4.3.3 IEC Radiated Susceptibility Tests

The IEC counterparts for the RS101 test are IEC 61000-4-8, IEC 61000-4-9, and IEC 61000-4-10. Operating envelopes corresponding to the Class 4 test level for each IEC test method are shown in Table 20. The IEC counterpart for the RS103 test is IEC 61000-4-3 and its frequency range is from 26 MHz to 6 GHz. The IEC 61000-4-3 operating envelope corresponding to Level 3 in the standard specifies a test level of 10 V/m. These levels are acceptable to NRC staff for the IEC radiated susceptibility tests.

Table 20 IEC 61000-4-8, -4-9, and -4-10 Operating Envelopes

Method	Test Level
IEC 61000-4-8	30 A/m (152 dBpT) 300 A/m (172 dBpT)
IEC 61000-4-9	300 A/m (172 dBpT)
IEC 61000-4-10	30 A/m (152 dBpT)

4.4 EMI/RFI Susceptibility Test Summary

The CS101 and CS114 tests for power leads, the CS114, CS115, and CS116 tests for signal leads, and the RS101 and RS103 tests represent the baseline susceptibility testing program. There is an alternative susceptibility testing program based on IEC 61000-4 is that is acceptable to the NRC staff for establishing susceptibility characteristics of safety-related I&C systems. Figure 4.4 shows the two acceptable susceptibility testing programs. Regardless of which susceptibility testing program is chosen, either should be applied in its entirety, without selective application of individual methods (i.e., no mixing and matching of test methods) for susceptibility testing.

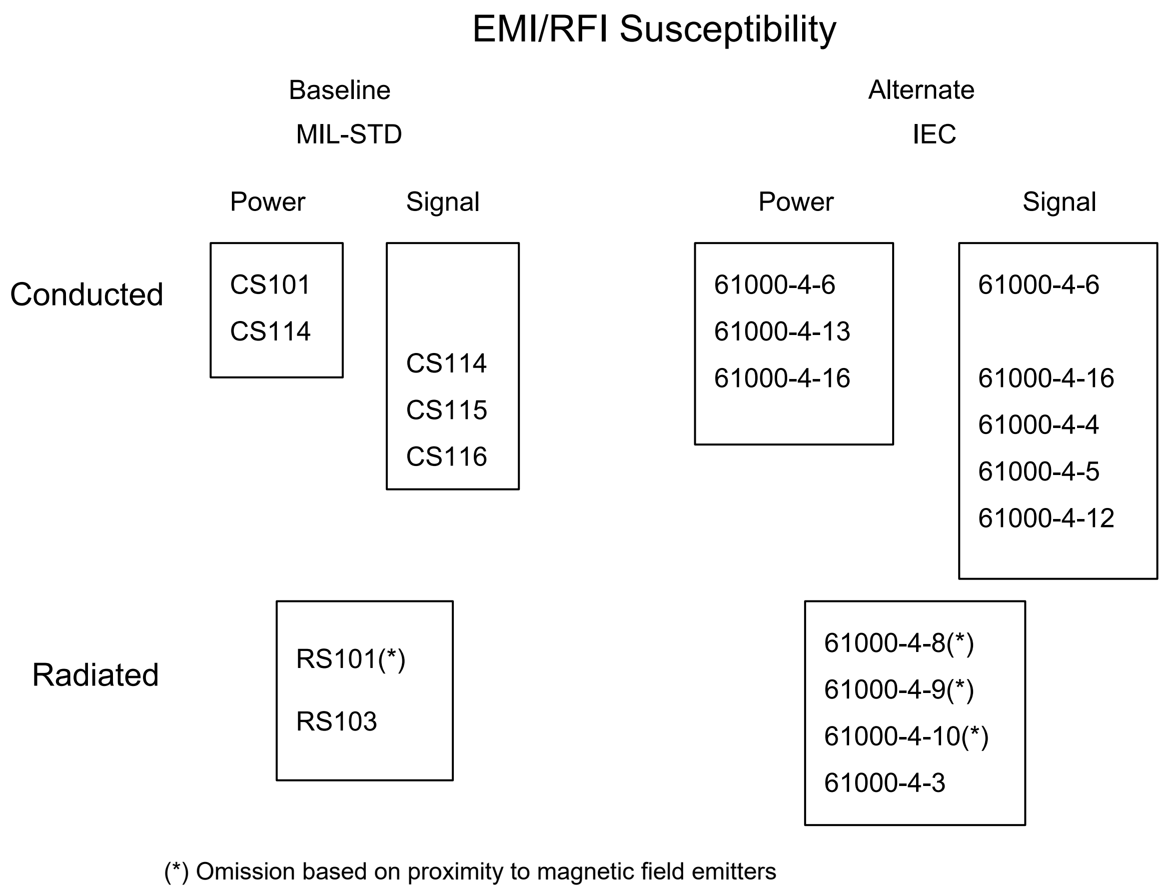

Figure 4.4 Acceptable Alternatives for EMI/RFI Susceptibility Testing

5. Surge Withstand Capability (SWC)

Specific SWC test waveforms and test methods from IEEE Std. C62.41.1-2002, IEEE Std. C62.41.2-2002, IEEE Std. C62.45-2002 and IEC 61000-4 are acceptable to the NRC staff for evaluating the effect of power surges on safety-related I&C systems intended for installation in nuclear power plants. These waveforms and test methods are identified in the guidance below and may be applied for SWC testing subject to the clarifications and conditions specified. Acceptable limits are given for each test in the form of identified operating envelopes.

The IEEE Std. C62.41.2-2002 defines a set of surge test waveforms that has manageable dimensions and represents a baseline surge environment. As discussed below, the NRC staff takes exception to the single withstand level specified in this standard to represent the surge environment in all locations. Typical environmental conditions for power surges in a nuclear power plant can be represented by the waveforms given in Table 21. These waveforms are acceptable to serve as the basis for SWC testing. IEEE Std. C62.45-2002 describes the associated test methods and equipment to be employed when performing the surge tests. These test methods are acceptable to NRC staff.

Table 21 IEEE Std. C62.41.2-2002 Power Surge Waveforms

Parameter	Ring Wave	Combination Wave		EFT Burst
Waveform	Open-circuit voltage	Open-circuit voltage	Short-circuit current	Pulses in 15-ms bursts
Rise time	0.5 µs	1.2 µs	8 µs	5 ns
Duration	100 kHz ringing	50 µs	20 µs	50 ns

The IEC 61000-4 tests comparable to the IEEE Std. C62.41.2-2002 tests are listed in Table 22. The test waveforms are the same and the test procedures are very similar. Hence, a direct interchange of the test methods is acceptable to the NRC staff.

Table 22 Comparable SWC Test Methods

IEEE Std. C62.41-1991	IEC Method
Ring Wave	61000-4-12
Combination Wave	61000-4-5
EFT	61000-4-4

IEEE Std C62.41.2-2002 describes location categories and withstand levels for the surge waveforms that should provide an appropriate degree of SWC. Location categories depend on the proximity of equipment to the service entrance and the associated line impedance. *Category* C covers the exterior and service entrance. *Category B* covers feeders and short branch circuits extending to interior locations from the service entrance. *Category A* covers outlets and branch circuits in interior locations. The indicated withstand level at all locations is 6 kV peak voltage for all of the SWC tests, while the peak current varies according to location.

The withstand levels presented in this regulatory position are based on *Category B* locations. The NRC staff has concluded that imposition of the 6 kV level on all tests without regard to location is overly conservative so an exception in the endorsement of the standard is taken to the specified withstand level. A determination of the withstand level classification that characterizes a particular location is more suitable for selecting applicable withstand levels than the application of a single conservative level as specified in the standard. This is a continuation of prior guidance, and the levels endorsed in Revision 1 of the guide for *Category B* locations remain acceptable to the NRC staff. Low withstand levels are appropriate for plant areas known for little load or capacitor switching and limited power surge activity, while elevated withstand levels are appropriate for locations where primary power is provided through connection to external lines or there are sources of significant switching transients present. Table 23 lists the withstand levels that are acceptable for nuclear power plant application. Interior locations where safety-related I&C systems either are or are likely to be installed include control rooms, remote shutdown panels, cable spreading rooms, equipment rooms, auxiliary instrument rooms, relay rooms, and other areas (e.g., the turbine deck). Most locations where safety-related I&C systems are likely to be installed can be characterized as having low surge conditions. However, locations where primary power is provided through direct connection to external lines or there are sources of significant switching transients present (e.g., switchgear, large motors) should be treated as being subject to elevated surge conditions. A determination of the exposure conditions that characterize a location is necessary to select instances where the elevated withstand level should be met.

Table 23 Surge Withstand Levels for Power Lines

Surge Waveform	Low Withstand Level	Elevated Withstand Level
Ring Wave	2 kV	4 kV
Combination Wave	2 kV / 1 kA	4 kV / 2 kA
EFT	2 kV	4 kV

5.1 IEEE Std. C62.41 Ring Wave and IEC 61000-4-12

The Ring Wave simulates oscillatory surges of relatively high frequency on the ac power leads of equipment and subsystems and is represented by an open-circuit voltage waveform. The waveform, a 100-kHz sinusoid, has an initial rise time of 0.5 µs and continually decaying amplitude. A plot of the waveform is shown in Figure 5.1. The rise time is defined as the time difference between the 10% and 90% amplitude points on the leading edge of the waveform. The amplitude of the waveform decays with each peak being 60% of the amplitude of the preceding peak of the opposite polarity.

The peak voltage value of the Ring Wave is given in Table 23. For the IEC test, the withstand levels correspond to Level 3 and Level 4 for the low and elevated surge conditions, respectively. During the performance of the test, the equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the Ring Wave. Acceptable performance of the equipment under test should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

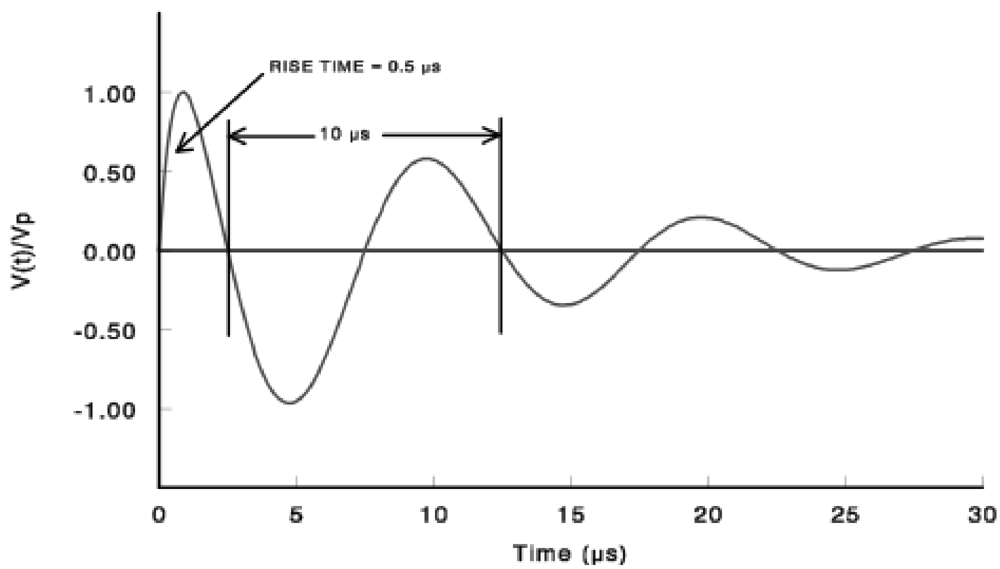

Figure 5.1 100-kHz Ring Wave

5.2 IEEE Std. C62.41 Combination Wave and IEC 61000-4-5

The Combination Wave involves two exponential waveforms, an open-circuit voltage and a short-circuit current. It is intended to represent direct lightning discharges, fuse operation, or capacitor switching on the ac power leads of equipment and subsystems. The open-circuit voltage waveform has a 1.2-µs rise time and an exponential decay with a duration (to 50% of initial peak level) of 50 µs. The short-circuit current waveform has an 8-µs rise time and a duration of 20 µs. Plots of the waveforms are shown in Figures 5.2 and 5.3.

The rise time is defined as the time difference between the 10% and 90% amplitude points on the leading edge of the waveform. The duration is defined as the time between virtual origin and the time at the 50% amplitude point on the tail of the waveform. Virtual origin is the point where a straight line between the 30% and 90% points on the leading edge of the waveform intersects the V=0 line for the open-circuit voltage and the i=0 line for the short-circuit current.

The peak value of the open-circuit voltage of the Combination Wave and the peak value of the short-circuit current are given in Table 23. For the IEC test, the withstand levels correspond to Level 3 and Level 4 for the low and elevated surge conditions, respectively. During the performance of the test, the equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the Combination Wave. Acceptable performance of the equipment under test should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

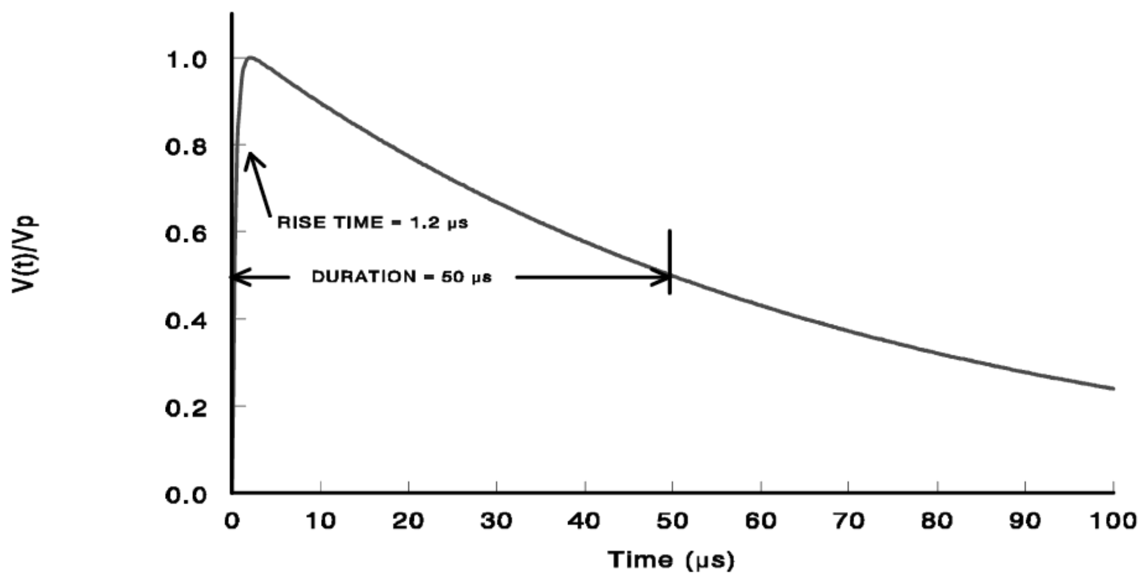

Figure 5.2 Combination Wave, Open-Circuit Voltage

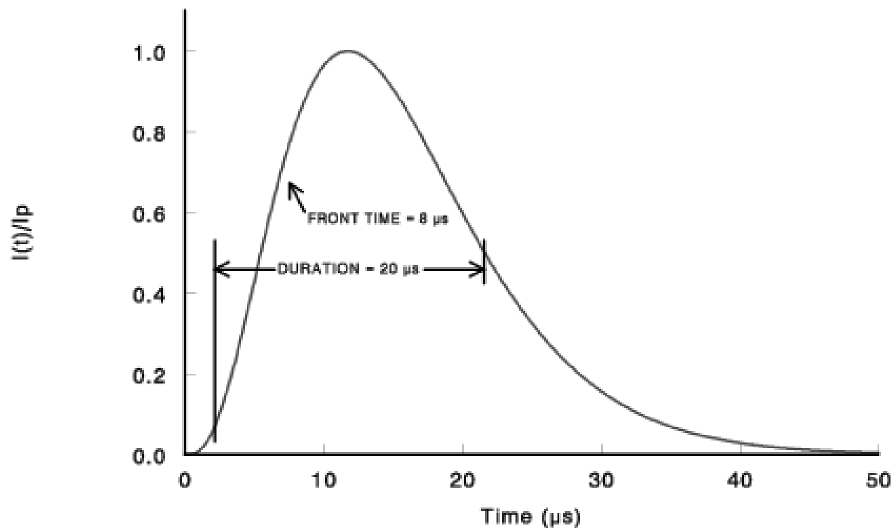

Figure 5.3 Combination Wave, Short-Circuit Current

5.3 IEEE Std. C62.41 Electrically Fast Transients and IEC 61000-4-4

The EFT waveform consists of repetitive bursts, with each burst containing individual unidirectional pulses, and is intended to represent local load switching on the ac power leads of equipment and subsystems. The individual EFT pulses have a 5-ns rise time and a duration (width at half-maximum) of 50 ns. Plots of the EFT pulse waveform and the pattern of the EFT bursts are shown in Figures 5.4 and 5.5. The number of pulses in a burst is determined by the pulse frequency. The pulse frequency is 5 kHz±1 kHz. For testing under IEC 61000-4-4, the 100 kHz±20kHz option for pulse frequency, with the associated 0.75 ms burst duration, can be alternately selected. The selection of pulse frequency of 2.5 kHz±0.5 kHz for peaks greater than 2 kV, as specified in IEEE C62.41.2-2002, is not necessary.

The rise time is the time difference between the 10% and 90% amplitude points on the leading edge of the waveform. The duration is the time between the 50% amplitude points on the leading and trailing edges of each individual pulse. Individual pulses occur in bursts of 15 ms duration.

The peak value of the individual EFT pulses is given in Table 23. For the IEC test, the withstand levels correspond to Level 3 and Level 4 for the low and elevated surge conditions, respectively. During the performance of the test, the equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the EFT pulses. Acceptable performance of the equipment under test should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

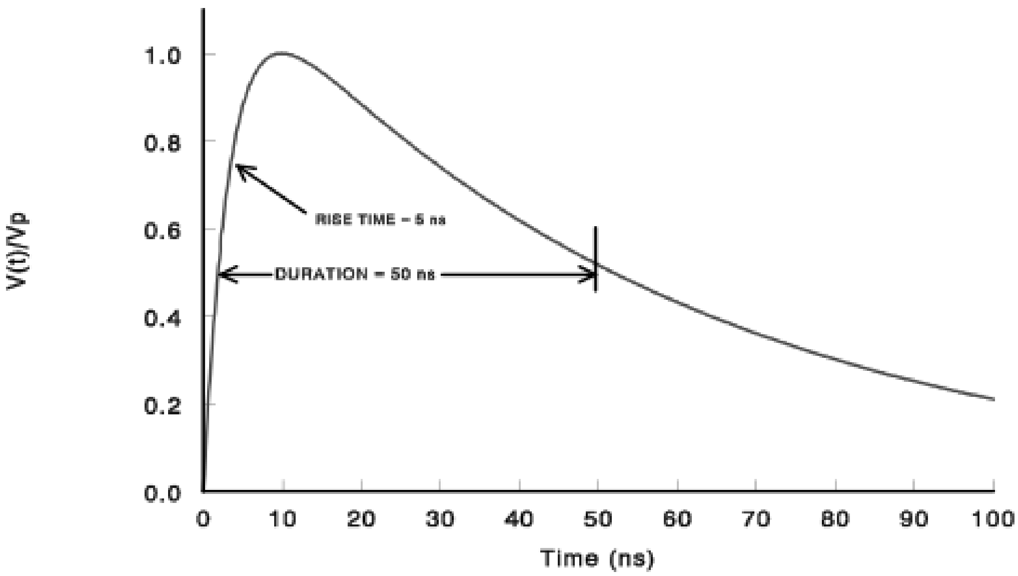

Figure 5.4 Waveform of the EFT Pulse

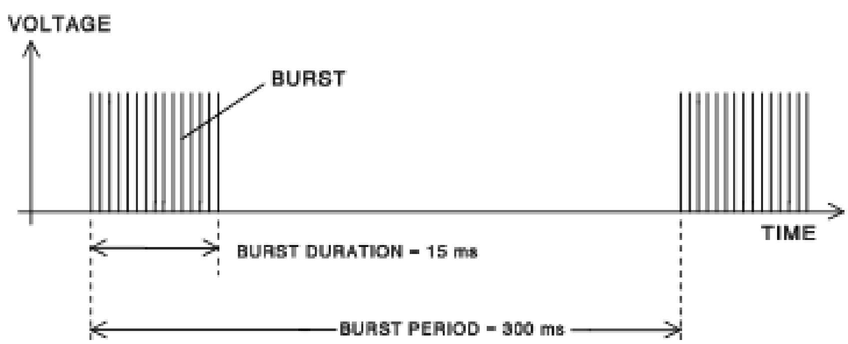

Figure 5.5 Pattern of EFT Bursts

6. Electrostatic Discharge Testing

The electrostatic discharge (ESD) immunity test method IEC 61000-4 is acceptable to the NRC staff for performing ESD withstand testing of safety-related I&C systems intended for installation in nuclear power plants. Acceptable limits are given for the test in the form of identified operating envelopes.

IEC Std. 61000-4-2, “Testing and Measurement Techniques - Electrostatic Discharge Immunity Test” (Ref. 39), provides a test method that can be used to establish the withstand capability of electrical and electronic equipment subjected to static electricity discharges, i.e., the sudden transfer of charge between two objects at differing electrostatic potential. It addresses the test levels, setup, equipment, and procedures for testing electrical and electronic equipment to assure their immunity to electrostatic discharge.

The test voltage to be applied depends on the environment and installation conditions. Contact discharge refers to the method of testing in which the electrode of the test generator comes into contact with the equipment under test and the discharge is actuated by the discharge switch within the generator. By contrast, air discharge refers to the method of testing in which the charged electrode of the test generator is moved towards the equipment under test until it discharges on it without actually touching the equipment. The test levels acceptable to NRC staff are 8 kV for direct contact discharge and 15 kV for indirect air discharge. These conditions correspond to environments with very low humidity and extensive use of synthetic fabrics (which promote generation of higher electrostatic charges by personnel).

The focus for the test should be centered on discharges that may occur during normal operation and the test points should be based on accessibility. For example, components such as panel displays, keyboards and control/input devices are touched frequently during operational activities and, thus, should be tested. Specifically, touch points that are electrically isolated from ground should be tested. Cables that are accessible during normal operations or are in close proximity to touch points should be tested at their entry point to equipment or cabinets. During the performance of the test, the equipment under test should not exhibit any malfunction or degradation of performance beyond specified operational tolerances when subjected to the electrostatic discharges. Acceptable performance of the equipment under test should be defined in the test plan by the end user or testing organization according to the applicable equipment, subsystem, or system specifications.

7. Documentation

Electromagnetic compatibility documentation should demonstrate that safety-related I&C equipment meets its specifications and is compatible with the projected electromagnetic environment, that the user adheres to acceptable installation practices, and that administrative controls have been established covering the allowable proximity of portable EMI/RFI sources. Data used to demonstrate the compatibility of the equipment with its projected environment should be pertinent to the application and be organized in a readily understandable and traceable manner that permits independent auditing of the conclusion presented.

The content of electromagnetic compatibility documentation should include the information listed below, as well as any additional information specified in the standards cited by this RG. These items, as a minimum, could be included as part of a qualification or dedication file.

1. Identification of the equipment
2. Specifications on the equipment
3. Identification of safety functions to be demonstrated by test data
4. Test plan
5. Test results, including
    - 5.1 Objective of the test
    - 5.2 Detailed description of test item
    - 5.3 Description and photographs of test setup, instrumentation, and calibration data
    - 5.4 Test procedure
    - 5.5 Summary of test data, accuracy, and anomalies
    - 5.6 Resolution of anomalies
6. The installation practices employed and administrative controls established to alleviate potential EMI/RFI and power surge exposure
7. Summary and conclusions

8. Approval signature and date.

D. IMPLEMENTATION

The NRC staff may use this regulatory guide as a reference in its regulatory processes, such as licensing, inspection, or enforcement. However, the NRC staff does not intend to use the guidance in this regulatory guide to support NRC staff actions in a manner that would constitute backfitting as that term is defined in 10 CFR 50.109, "Backfitting," and as described in NRC Management Directive 8.4, "Management of Backfitting, Forward Fitting, Issue Finality, and Information Requests," (Ref. 40), nor does the NRC staff intend to use the guidance to affect the issue finality of an approval under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." The staff also does not intend to use the guidance to support NRC staff actions in a manner that constitutes forward fitting as that term is defined and described in Management Directive 8.4. If a licensee believes that the NRC is using this regulatory guide in a manner inconsistent with the discussion in this Implementation section, then the licensee may file a backfitting or forward fitting appeal with the NRC in accordance with the process in Management Directive 8.4.

REFERENCES[3]

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3. Institute of Electrical and Electronics Engineers (IEEE) Standard (Std.) 603-1991, "Criteria for Safety Systems for Nuclear Power Generating Stations," 1991, New York, NY.[4]

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5. NRC, NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," Chapter 7, "Instrumentation and Controls," Washington, DC.

6. NRC, RG 1.89, "Environmental Qualification of Certain Electric Equipment Important to Safety for Nuclear Power Plants," Washington, DC.

7. NRC, RG 1.204, "Guidelines for Lightning Protection of Nuclear Power Plants," Washington, DC.

8. NRC, RG 1.209, "Guidelines for Environmental Qualification of Safety-Related Computer-Based Instrumentation and Control Systems in Nuclear Power Plants," Washington, DC.

9. MIL-STD-461G, "Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment," available free from: http://everyspec.com/MIL-STD/MIL-STD-0300-0499/MIL-STD-461_8678/. [5]

10. International Electrotechnical Commission (IEC) 61000-3, "Electromagnetic Compatibility (EMC) - Part 3: Limits," 2017 Geneva, Switzerland.[6]

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3 All NRC documents listed herein are available electronically through the NRC Library or Electronic Reading Room on the NRC's public Web site at http://www.nrc.gov/reading rm/doc collections/cfr/. Copies are also available for inspection or copying for a fee from the NRC's Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the mailing address is USNRC PDR, Washington, DC 20555; telephone 301-415-4737 or 800-397-4209; fax 301 415 3548; and e-mail pdr.resource@nrc.gov.

4 Copies of Institute of Electrical and Electronics Engineers (IEEE) documents may be purchased from the Institute of Electrical and Electronics Engineers Service Center, 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855 or through the IEEE's public Web site at http://www.ieee.org/publications_standards/index.html.

5 Copies of Military, DoD, Federal, NASA, DOE, and Government specifications, standards, handbooks, and publications are available free from www.EverySpec.com.

6 Copies of International Electrical Commission (IEC) documents may be obtained through their Web site: http://www.iec.ch/ or by writing the IEC Central Office at P.O. Box 131, 3 Rue de Varembé, 1211 Geneva, Switzerland, Telephone +41 22 919 02 11.

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