Guidelines for Electromagnetic Interference Testing of Power Plant Equipment

Revision 3 to TR-102323

This report describes research sponsored by EPRI and the U.S. Department of Energy under the Nuclear Energy Plant Optimization (NEPO) Program.

Technical Report

Guidelines for Electromagnetic Interference Testing of Power Plant Equipment

Revision 3 to TR-102323

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REPORT SUMMARY

To continue meeting safety and reliability requirements while controlling costs, operators of nuclear power plants must be able to replace and upgrade equipment in a cost-effective manner. One issue that has been problematic for new plant equipment and especially for digital instrumentation and control (I&C) systems in recent years is electromagnetic compatibility (EMC). The EMC issue usually involves testing to show that critical equipment will not be adversely affected by electromagnetic interference (EMI) in the plant environment. This guide will help nuclear plant engineers address EMC issues and qualification testing in a consistent, comprehensive manner.

Background
EMC received renewed attention in the early 1990s when nuclear power plants started replacing obsolete analog I&C systems with digital systems. Little guidance was available on EMC for nuclear plants, and the industry and the Nuclear Regulatory Commission (NRC) pursued the issue in a series of iterations that reflected the increasing knowledge base and evolution of testing standards. An earlier revision of this guideline received NRC approval through a safety evaluation report (SER) in 1996 and became a de facto standard within the U.S. nuclear industry. NRC published its guidance in a regulatory guide (1.180) in 2000 with a revision in 2003, and this is the third revision of the EPRI guidance. With each update, the two guidance documents have become better aligned with each other and with EMC standards used by the military and other industries.

Objectives
- To refine testing recommendations to make them more practical and consistent with standards used by the military and other industries and to remove excessive conservatism and customized tests where appropriate.
- To investigate CS114—a high-frequency conducted susceptibility test that has proven particularly problematic for most equipment—and develop new recommended test levels if appropriate.
- To provide technical justification for changes to the existing guidance and variances with Regulatory Guide 1.180, Revision 1.

Approach
This guidance was developed under the supervision of an EPRI Working Group comprising EMI experts from nuclear plants and other industries. The basic approach of this guideline and its predecessors has been to establish bounding emission limits based on plant measurements and use these bounds to establish susceptibility test limits that can be applied to new equipment in a laboratory environment to demonstrate adequate margin of safety. To ensure adherence to

bounding limits, the guide also recommends controlling emissions of systems/equipment in close proximity. In Revision 3, the existing guidance was reassessed and revised in light of the latest industry and standards information. To address the CS114 issue, the data and test methods were reviewed against the latest industry guidance, potential sources of error were identified, and a laboratory demonstration was used to confirm the results qualitatively.

Results

This guide defines recommended generic EMI susceptibility and emissions test levels for use in establishing equipment EMC for nuclear power plant applications. Specifically, the guide identifies emissions sources in nuclear power plants; recommends appropriate standards for equipment testing; defines plant and equipment emissions limits; and details proper grounding, cable separation, emissions control of portable transceivers, and restriction of EMI sources in the vicinity of EMI-sensitive equipment. Recommended tests are referenced in standards defined by the military and commercial sectors, and the levels are conservative based on the analyzed data. This revision of the EPRI guidance makes better use of EMC testing standards commonly used by equipment vendors and suppliers and generally reduces differences with the recommendations of NRC Regulatory Guide 1.180, Revision 1. Where differences remain, the bases for the Revision 3 position are provided. One issue of special note in Revision 3 is its treatment of CS114. The CS114 test levels recommended in previous revisions of this report and in Regulatory Guide 1.180, Revision 1, were based on plant data acquired by EPRI in the early 1990s. The latest results indicate that the early data were misapplied, and less conservative test levels are recommended.

EPRI Perspective

It is essential that nuclear utilities have a clear, practical, and technically defensible approach for ensuring EMC as they expand efforts to replace obsolete I&C equipment. From a practical standpoint, consistency with industry standards and regulatory guidance also are highly desirable. This revision accomplishes nearly all these goals, and agreement between EPRI and NRC guidance is now quite good. The one significant exception is the CS114 test levels, where the new recommended test levels represent a significant departure from those in Regulatory Guide 1.180, Revision 1. Further, utility experience and results of current investigation indicate that using the Regulatory Guide approach may lead plants to design and implement costly EMI filters that are actually unnecessary. EPRI recommends that the industry and NRC work together to resolve this final EMC issue to avoid regulatory confusion and unneeded hardware modifications in the future.

Keywords

Electromagnetic interference (EMI)
Electromagnetic compatibility (EMC)
Instrumentation and control
Digital systems

ABSTRACT

This study was undertaken to provide utilities with a more complete understanding of the electromagnetic interference (EMI) problem and to provide technically sound alternatives to demonstrate that EMI will not adversely affect the operation of sensitive electronic equipment. Emissions data acquired previously from two nuclear plants and data collected by the U.S. NRC in the 1980s from two plants in the operating and shutdown modes were analyzed. Based on the emissions levels and expected types and levels of interference in nuclear power plants, guidelines for equipment susceptibility tests were developed. The recommended tests are consistent with standards defined by military and commercial sectors, and the levels are conservative based on the analyzed data. The working group defined specifications to obtain additional emissions data to validate these guidelines, develop a basis for equipment emissions testing, bound highest observed emissions from nuclear plants, and eliminate the need for site surveys. Data were obtained from seven additional plants in 1993 and 1994. In addition, emissions data collected under NRC Regulatory Guide 1.180 (issued in January 2000) were integrated with EPRI data to define more pragmatic limits that removed excessive conservatism without compromising nuclear safety. This report includes recommended EMI limiting practices and guidance on equipment emission levels.

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1 INTRODUCTION

Background

Electromagnetic compatibility (EMC) of a system or component refers to the equipment's ability to perform its intended function without degradation or misoperation and without adversely affecting other equipment in the electromagnetic environment in which it is installed. Electromagnetic emissions are energy originating from various sources in the environment. They have the potential to create electromagnetic interference (EMI) with the equipment of concern. In the past, EMI was more narrowly referred to as radio frequency interference (RFI). However, today the term EMI is used to more broadly describe the conducted and radiated electromagnetic energy that can adversely affect the operation of plant equipment if it is susceptible.

When nuclear power plants began replacing obsolete analog instrumentation and control (I&C) systems with digital systems, the U.S. Nuclear Regulatory Commission (NRC) expressed concern about the effects of electromagnetic emissions on the safe and reliable operation of digital systems. Several utilities measured (or surveyed) the electromagnetic emissions at the location of the digital equipment installation to demonstrate that emission levels were below equipment EMI/RFI susceptibility levels. The need to perform EMI site surveys added to the cost and schedule for these analog to digital modifications. In addition, there are uncertainties in trying to characterize fully the electromagnetic environment for a particular plant location during an EMI site survey.

The industry and the NRC have addressed the issue of EMC in a series of iterations that reflect the increasing knowledge base and evolution of standards since the early 1990s. As a response to early plant experience with digital upgrades, EPRI first published TR-102323, *Guidelines for Electromagnetic Interference Testing in Power Plants* [1] in 1995. The NRC issued a Safety Evaluation Report (SER) in 1996, endorsing the guidelines with comments (see Appendix D). In January 1997 EPRI published TR-102323 Revision 1 to better align the document with the margins discussed in the NRC's SER. The EPRI guideline recommended testing safety-related equipment to ensure compatibility using common procedures described in the U.S. military standards (MIL-STDs) or the International Electrotechnical Commission (IEC) standards. The test levels were based on bounding limits established from plant emission measurements at representative plants.

In January 2000, the NRC published Regulatory Guide 1.180, *Guidelines for Evaluating Electromagnetic and Radio-Frequency Interference in Safety-Related Instrumentation and Control Systems* [2], which reflected the results of earlier NRC and EPRI investigations. In November 2000 EPRI published Revision 2 to TR-102323, which applied operating experience to justify removing excessive conservatism in the earlier guidelines and extended previous guidance to address emissions from devices operating at frequencies greater than 1 GHz. The NRC subsequently issued Regulatory Guide 1.180 Revision 1 in October 2003, which endorses several European Norm (EN) and International Electrotechnical Commission (IEC) EMC test standards and provides different test levels for signal and power lines. This revision of TR-102323 (Revision 3) makes use of the electromagnetic compatibility (EMC) testing standards commonly used by equipment vendors and suppliers and generally reduces differences with the recommendations of NRC Regulatory Guide 1.180, Revision 1. Where differences remain, the bases for the Revision 3 position are provided.

One issue of special note in Revision 3 is its treatment of CS114, a high frequency conducted susceptibility test that has proven particularly problematic for most equipment. The CS114 test levels recommended in previous revisions of this report were based on plant data acquired in support of the first release (Revision 0) of TR-102323 and were carried forward in later revisions. The plant data used to establish CS114 test levels in TR-102323 were also used as part of the basis for the test levels recommended in Regulatory Guide 1.180. As part of the TR-102323 Revision 3 effort, the basis for the CS114 test level was investigated, and the plant data were found to not be applicable to high frequency conducted susceptibility test levels. This finding resulted in a change in the basis for the test levels to match the basis used by MIL-STD-461E rather than using the plant measurements.

Applicability

This guidance is applicable to all new safety-related plant system-level modifications that include analog, digital, and hybrid systems and components (analog and digital electronics equipment). It applies to both safety-related systems and components and non-safety-related systems and components whose operation can affect safety-related system or component functions or are deemed important for power production. In addition, this guidance could be applied to other non-safety related systems and components, as appropriate.

Section 5, "Equipment Susceptibility and Emissions Testing Guidance," recommends susceptibility and emissions testing and limits. Recommended minimum EMI limiting practices to help ensure EMC are detailed in Section 4. These practices are applicable to all safety-related systems and components and non-safety-related systems and components whose operation can potentially affect safety-related system or component functions.

This report presents guidance on addressing electromagnetic compatibility (EMC) concerns for nuclear power plant equipment. There may be other ways to address specific electromagnetic interference concerns or threats than the approaches described in these guidelines; however, the user would have to either comply with current regulatory guidance (Regulatory Guide 1.180) or produce a separate, defensible technical basis for such methods.

The EPRI/Utility EMI Working Group

The EPRI/Utility EMI Working Group was organized by EPRI and interested utilities after an industry workshop [3]. The group was composed of EPRI personnel, utility engineers and managers, and recognized EMC industry experts. The working group's mission was to:

- Measure and evaluate nuclear plant EMI/RFI emissions and their levels
- Recommend an appropriate set of EMI/RFI equipment emissions levels and susceptibility tests to qualify safety-related equipment for use in nuclear plant installations
- Develop products for the nuclear power industry to minimize the effects of EMI on plant I&C equipment

A list of current and former members of the EPRI/Utility EMI Working Group (called the EMI Working Group in the remainder of this report) is provided in Appendix A.

Purpose

This report establishes appropriate EMC testing scope and limits for the nuclear power industry. It defines recommended generic EMI susceptibility and emissions testing levels to be used in establishing equipment EMC for nuclear power plant equipment. The bases of the recommendations are international and domestic standards, and analysis of EMI data collected at several U.S. nuclear power plants. The report also provides criteria by which an engineer can determine if special conditions requiring additional engineering evaluation exist (see Section 4).

Basics of EMC Testing and Standards

Standards for conducted and radiated emissions testing have been developed by the military and by commercial and instrument manufacturers. The MIL-STDs are comprehensive and have been used to ensure EMC since the 1960s [4]. Since then, standards in the commercial sector have evolved steadily. The IEC Standard EN 61000 series is presently utilized extensively in the commercial sector [5]. A list of applicable testing standards is included as Table 5-2.

Some nuclear plants have performed emissions mapping to support NRC evaluations of digital upgrades. Plant emissions measurements performed in conjunction with the EPRI/Utility EMI Work Group data collection effort were performed in accordance with the guidance provided in MIL-STD-462. The corresponding MIL-STD-461C and MIL-STD-461D standards specify limits on equipment emissions as a function of frequency. Figure 1-1 illustrates recommended equipment emissions levels for CE03 (MIL-STD-461C) and CE102 (MIL-STD-461D) tests from a prior revision of this document. Both of these test procedures deal with measuring the conducted current emissions on power from equipment over the frequency range of 10 kHz to 10 MHz. The units for CE03 are dBμA and dBμV for CE102. For comparison, the CE102 limits have been converted to dBμA.

When these measurements are performed in a controlled laboratory environment, the contribution from the power source (plant) must be eliminated, typically resulting in lower level emissions measured from the equipment. The emissions output from a single component should be appreciably less than normal expected levels in the plant, minimizing the probability that new equipment would make a significant increase in the EMI/RFI environment of the plant. Figure 1-1 illustrates a typical conducted equipment emissions limit and should not be confused with measured plant emissions data, which are a cumulative measurement of several devices local to the point of measurement and thus generally greater in amplitude.

Figure 1-1 also illustrates a typical conducted equipment susceptibility limit. In order to achieve EMC between equipment, susceptibility levels (EMI levels that can be tolerated) must be higher than emissions levels (levels of interference). Figure 1-2 also illustrates this concept for typical radiated equipment susceptibility and emissions limits. It is important to understand that these emissions limits are for one device or system. Measured plant data collected in accordance with an appropriate industry standard illustrate how plant emissions levels are generally higher, but all plant-measured emissions must also be below the corresponding equipment susceptibility level by an adequate margin to provide reasonable assurance of EMC.

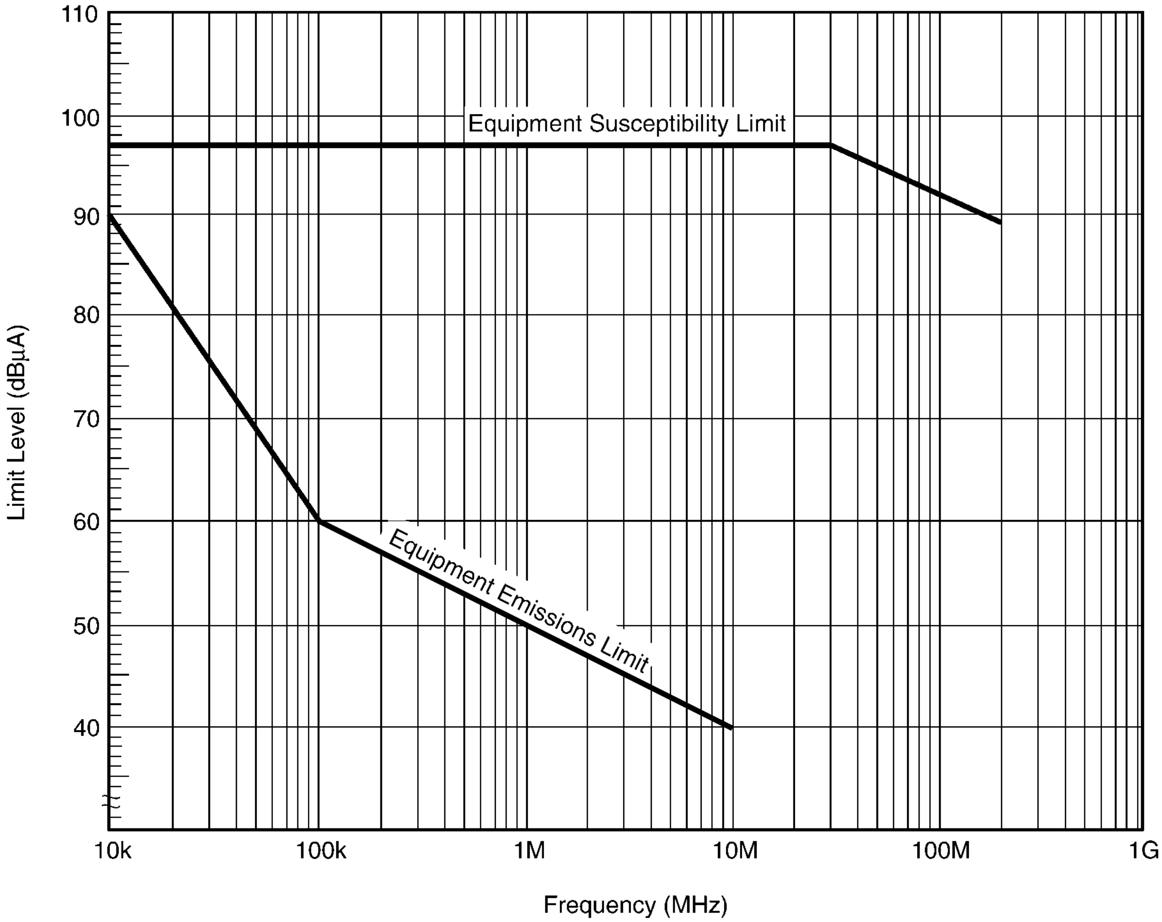

Figure 1-1
High-Frequency Conducted Testing Limits

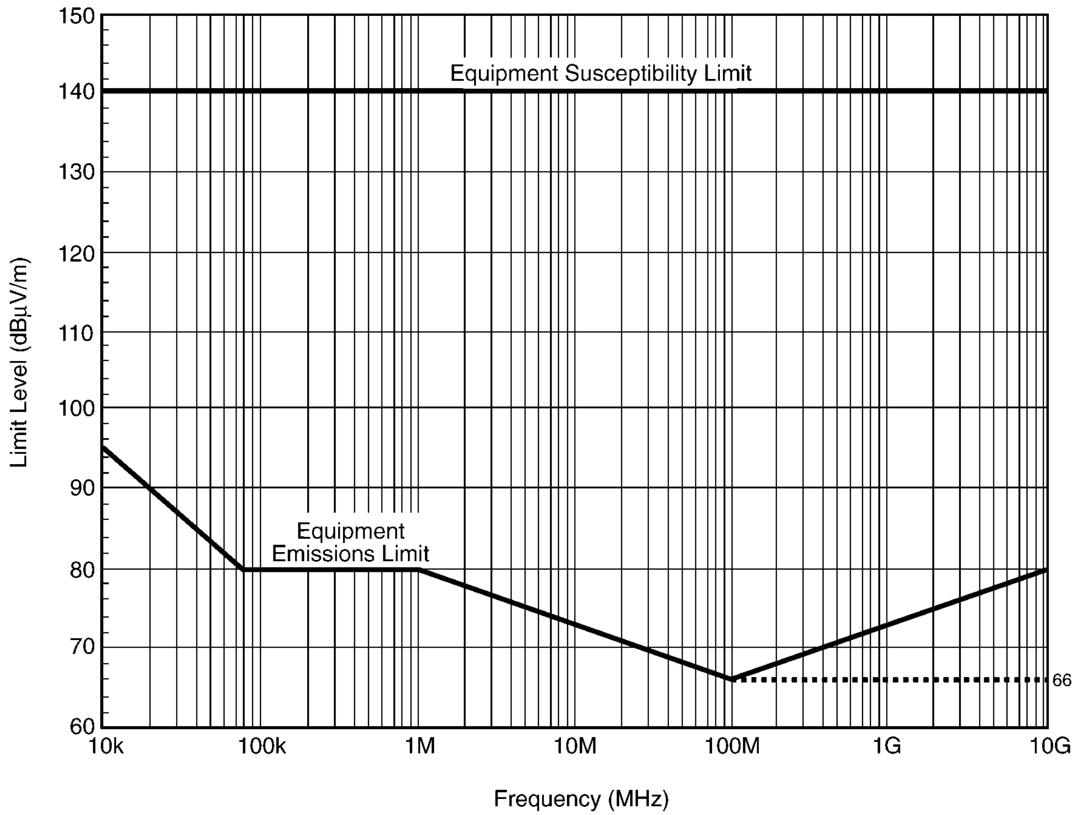

Figure 1-2
High-Frequency Radiated Testing Limits

Report Organization

The report is organized into nine sections of the body and ten appendices. Section 2 describes electromagnetic emissions data used to establish equipment emission and susceptibility limits, including discussion of procedures for measurement and results of testing at seven different plants. Section 3 provides an overview of emissions measurements and tests performed by the NRC, and their relationship to the evolution of NRC guidelines for EMC (Regulatory Guide 1.180). Section 4 defines recommended minimum EMI limiting practices utilities should comply with to ensure that plant emissions levels are bounded and the recommended susceptibility limits are not exceeded. Section 5 defines the scope, applicability, standards and limits for equipment susceptibility and emissions testing. Section 6 compares recommended emissions limits to plant emissions measurements and equipment susceptibility limits to show how the testing recommended in Section 5 supports EMC. Section 7 contains an overall summary and conclusions. Sections 8 and 9 are lists of definitions and references, respectively.

Members of the EMI Working Group are listed in Appendix A. Appendix B provides information on EMI sources in the power plant. Sample hard-copy plots of the emissions data obtained at nuclear plants are provided in Appendix C. Appendix D contains a copy of the

NRC SER issued for Revision 1 to TR-102323. Appendices E and F describe the information that should be included in an EMI test procedure and qualification report under U.S. Department of Defense documents DI-EMCS-80201B and DI-EMCS-80200B.

The technical bases for the changes in susceptibility and emission guidelines from Rev. 1 to Rev. 2 of this report are documented in Appendix G. The Technical Bases for the changes in susceptibility and emissions testing guidelines from Rev. 2 to Rev. 3 (the current revision) of this report are documented in Appendix H. Appendix I summarizes the differences between this report and NRC Regulatory Guide 1.180 Rev. 1 and documents the changes made to better align this report with NRC guidance and current industry EMC testing standards. Appendix J describes new testing performed to address the issue of using conducted emissions measurements as the basis for CS114 test levels, in particular to confirm that the plant data used to establish the test levels in previous revisions of TR-102323 and in Regulatory Guide 1.180 was misapplied.

Plant Modification Guidance

Most readers of this report will be referencing it to address or review the electromagnetic compatibility (EMC) qualification of plant equipment and systems in conjunction with a plant modification. The following guidance is provided to support that application of this report.

Previously Tested Equipment

Most equipment suppliers are familiar with the needs and benefits of EMC testing and many of the devices and systems available to plant licensees have been previously tested. Licensees should carefully review vendor EMC qualification tests and reported results, focusing on the scope, applied testing limits and any anomalies recorded during EMC equipment testing. The vendor’s testing scope, applied limits and results should be compared to the guidance and recommendations outlined in Section 5 of this report. Discrepancies in scope and/or applied testing limits should be identified and evaluated. Section 6 of this report may useful in assessing differences in applied emissions or susceptibility testing limits to determine if adequate EMC margin exists. Differences may require additional testing depending on the application. EMC qualification specifications should be incorporated into purchasing agreements to contractually document vendor requirements.

Equipment Not Previously Tested

For situations where devices or systems have not been previously tested for EMC, the guidance and recommendations outlined in Section 5 of this report can be used to develop an EMC testing specification. Reference [25] Volume 2 Appendix E provides an outlined for a sample testing specification. Note that Section 5 includes considerations for EMI testing of commercial grade equipment. EMC qualification specifications should be incorporated into purchasing agreements to contractually document vendor requirements. Final vendor testing and qualification reports should be reviewed for compliance and acceptability.

Practices to Ensure EMC

Section 4 of this report documents design and configuration control practices that should be managed to ensure electromagnetic compatibility (EMC). These practices are a set of design conditions that will help ensure that plant emissions levels remain bounded and that recommended equipment susceptibility testing levels are not exceeded. The recommendations and guidance of Section 4 should be incorporated into plant design change packages and other documents as appropriate. Focus should be placed on ensuring that installation instructions will result in a configuration that is consistent with the configuration used in the qualification testing.

2 PLANT EMISSIONS DATA

Introduction

This section contains descriptions of plant emissions data collected between 1983 and 2002. It provides background information that is useful in understanding the underlying bases of the recommended qualification tests. Readers interested primarily in recommendations on practices to ensure EMC compatibility and on susceptibility and emissions testing may wish to go directly to Sections 4, 5, and 6 and return to this section for reference as needed.

The EMI/RFI emissions data reported in this document were collected from a number of plants, using procedures based on the military standards (MIL-STDs) developed by the U.S. Department of Defense for measuring emissions from equipment. The MIL-STD procedures were adapted to allow defining an EMI/RFI emissions environment, rather than measuring and controlling emissions created by new equipment. In addition, it was necessary to perform measurements in a manner that did not interfere with normal plant operations. The standards used by EPRI researchers to collect the data were revisions C and D of MIL-STD-461 [4] and MIL-STD-462 [32].

The measurements selected for the plant emissions mapping consisted of the current on interconnecting cables and conductors, measured using a current probe, and radiated fields and waves, measured using electric and magnetic field antennae. The data were recorded and presented in accordance with standard industry practices and procedures. Measurements were focused on collecting data on known plant emissions sources. Appendix B provides information on typical EMI sources, coupling paths, and maximum expected plant emissions levels within the power plant electromagnetic emissions environment.

Appendix C contains sample plant emissions data collected to support digital equipment installations. The data plots include spectral distribution over ranges of frequency described along the abscissa. The conducted emissions amplitude is commonly expressed in decibel-microAmperes (dBμA), where 0 dBμA equals 1 microAmpere (1μA) and 120 dBμA indicates 1 ampere. Similarly, the radiated electric field is expressed in decibel microVolts (dBμV) and the radiated magnetic field in decibel picoTeslas (dBpT). The transient data are plotted as amplitude variation (amperes) against time in microseconds or nanoseconds.

Comparison of emissions data to equipment-tested susceptibility levels (described in Section 6) sometimes required conversion from voltage to current or vice-versa. In these cases, the first approach was to use the standard as a basis for conversion, where test limits were established for some definition of load current, peak voltage, or peak power level. In other cases, where the signals were typically above 10 kHz, the signal was assumed to be a traveling wave and the line impedance was assumed to be 50 ohms characteristic impedance.

Early Nuclear Plant Emissions Data

Plant emissions data taken prior to May 1992 were examined to determine if they described any patterns or general levels. While the data were useful in identifying desirable tests, they were not directly related from site to site and were not used by the EMI Working Group as bases for recommended test limits.

Plant Emissions Comparison between Operating and Shutdown Conditions

In 1983, the NRC conducted research to examine the level of EMI/RFI in commercial nuclear power plants. The data in NUREG/CR-3270 consist mainly of time domain data (pulses) of magnetic fields and currents on cables [6]. The approach used to collect the data was different from conventional EMI survey data [7], which made it difficult to analyze and compare the data. In addition, the test equipment that was available in 1983 limited the quality of the data. Therefore, it is not possible to directly compare these data with the more recent emissions data. However, it was worthwhile to review the approach and the findings and to examine the EMI data in the report.

The 1983 measurements were concentrated on 60-Hz systems, and the data were collected using equipment that filtered out the 60-Hz component. This enhanced the high-frequency harmonics and inverter switching noise. Circuit breaker operation switching transients as high as 377 milliAmperes were recorded. The ringdown frequency of the noise differed between the two plants as well as between the general levels. A significant observation was that high-frequency transients died out very quickly on power conductors. A difference of 15.6 dB was noted over a span of 10 feet. In general, the EMI levels at Plant A, a pressurized water reactor (PWR), were about 10 times higher than the levels at Plant B, a boiling water reactor (BWR). The incidence of EMI transients was higher on the BWR, which was shut down. These data did not allow development of generic conclusions regarding emissions at plants that were operating compared to plants that were shut down.

Procedure for Obtaining Data at Turkey Point and Zion

In 1991-92, data was collected at the Turkey Point and Zion nuclear plants. The data for Turkey Point comply with the SAMA Standard PMC 33.1-1978 [8] guidance for susceptibility testing over the frequency range of 20–1,000 MHz at levels of 3 and 10 V/m. The SAMA standard is now no longer active. Similar data were later obtained at Zion, but the NRC found them to be unacceptable because of the limited range, large error factor, and questions regarding the testing methodology.

The Zion plant applied the more rigorous MIL-STD-461C specifications to obtain conducted emission data according to CE01 and CE02, radiated emission data according to RE01 and RE02, and DC magnetic field data. While the general measurement procedures were followed in obtaining the data, note that MIL-STD-461 is intended to measure emissions from equipment under rigorous setup conditions using measurement probes located at precise distances and minimizing emissions from external sources, thus establishing a controlled environment for more accurate results. The emissions measurements in the MIL-STD therefore describe equipment levels and not plant levels. In addition, due to spatial constraints in the plant in setting up antennae for measurement of radiated fields, it was not always possible to follow the exact measurement procedure specified in the MIL-STD.

For instance, MIL-STD-461C radiated magnetic field measurement under RE01 calls for the probe to be 7 cm (~3 inches) from the surface of the equipment under test (EUT). Data collected at Zion indicate that the probe was 50 cm (20 inches) from cabinet surfaces. For the radiated electric field measurement under the RE02 standard, the antenna must be located 1 m from the EUT with no back reflections. The data acquired at Zion indicate that the antenna was located in the center of aisles (maximum clearance), which again does not comply with the standard.

In recognition of these differences, direct comparison of plant emissions data to MIL-STD-461 equipment emissions limits is not possible. MIL-HDBK-235 provides some guidance for determining the electromagnetic environment [9]. This handbook is general in nature; however, paragraph 4.3.2, "Conditions Precluding Exposure," mentions dimensional restrictions, which contribute to the metallic clutter in the power plant. This clutter (for example, racks and walls) makes measurement of the radiated fields very difficult and, as a benefit, significantly reduces the radiated environment.

Turkey Point

The site survey data for Florida Power & Light Co.'s Turkey Point plant, taken in September 1991, consisted of the following:

- ***Conducted current emissions.*** Data were recorded over two ranges: 30 Hz–15 kHz and 15 kHz–50 MHz. The emissions are on single conductors of AC and DC power cables. At 15 kHz, both data plots are in general agreement. Significant effort was made to document the equipment energized during the test. Over the range of 15 kHz to 50 MHz, there are recordings of both narrow-band and broad-band data.
- ***Radiated electric field.*** Radiated emissions data (in volts per meter) were recorded from 20 to 1,000 MHz in the switchgear room. Both vertical and horizontal antenna polarizations were included as well as narrow-band and broad-band data. One recording includes emissions from a site walkie-talkie (MTX-900S). No information is included on the location of the walkie-talkie relative to the E-field antenna.

Zion

The site survey data for Commonwealth Edison Co.'s Zion plant, taken in February 1992, consisted of the following:

- ***Conducted emissions.*** Data acquired at Zion were very similar to Turkey Point with two data plots: 30 Hz–15 kHz and 15 kHz–50 MHz. The 15 kHz to 50 MHz data consist of both narrow-band and broad-band data. At 15 kHz, the high-frequency data plot is 20 dB greater than the low-frequency plot; no information is provided to explain the difference. The low-frequency data appear to correlate to the measured 60 Hz current in the conductors.

- ***Radiated electric field.*** Radiated emissions data were collected over the frequency range of 14 kHz to 1,000 MHz at numerous locations in the auxiliary electric equipment room (AEER). Both narrow-band and broad-band data are provided.
- ***Radiated magnetic field***. DC magnetic fields were measured at many locations. In addition, AC magnetic field emissions were recorded over the frequency range of 30 Hz to 50 kHz at many locations.
- ***Radiated electric field emissions from portable transceivers.*** The portable transceiver is listed only as a site maintenance radio. Its location relative to the measurement antenna is noted, but actual distances are unavailable from the data package. The resolution bandwidth is defined as 30 kHz.

Evaluation of Early Emissions Data

This section contains an evaluation of the plant emissions data obtained at Commonwealth Edison Co.'s Zion plant and Florida Power & Light Co.'s Turkey Point plant. This analysis was performed prior to development of equipment susceptibility testing guidance by the EMI Working Group. The conclusions from this analysis formed the basis for determining preliminary susceptibility testing standards and levels and for defining generic plant emissions measurement activities at additional plants in order to obtain the highest observed plant emissions environment.

Conducted Emissions

Considerable data were taken on AC and DC power leads at Zion and Turkey Point in accordance with CE01 and CE03 as defined in MIL-STD-461C. The Zion data were taken only on AC power leads while Turkey Point data were taken on both AC and DC power leads. Both the AC and DC leads had data taken from 30 Hz to 50 MHz such that the AC power current shows as an emission when it should actually be considered an operating requirement. In addition, there appears to be a calibration error in the Zion data. An abnormal 20-dB gain is indicated when data are recorded in the range of 30 Hz to 15 kHz, as compared to the measurements in the 15-kHz to 50-MHz range. The Turkey Point data have only a minor shift on similar data plots—a difference that is not fully explained.

No attempt was made to differentiate between emissions coming from the load connected to the power leads and the emissions from the power distribution system. The emission limits should be relaxed for loads in excess of 1A, in accordance with MIL-STD-461C. The spectral energy below 5 kHz was principally related to the power frequency (60 Hz) and harmonics, including suspected switching EMI from inverters. The 60 Hz current ranged from ~100 mA on the DC lines to ~18 A on the AC power cable conductors. These signals fell off at ~ 20 dB per decade. Above 5 kHz, there were no signals above 3 mA. Above 15 kHz, the data fell off at ~40 dB per decade.

The conducted emissions data obtained at Turkey Point and Zion are comparable and well within the low-frequency conducted susceptibility limits defined in MIL-STD-461E [4] even though there are multiple sources on the tested power leads. The data are 15–20 dB below recommended limits, assuming a 50-ohm characteristic impedance.

The NRC-obtained data in the NUREG/CR-3270 report [6] indicate that the 60-Hz components are the result of the power drawn from the equipment and are not EMI. The higher frequency components (low kHz range) attenuate rapidly with distance. The EMI due to inverter noise described in the report was attenuated 15.6 dB over 10 feet (~3 m) with a maximum of 40 mA at plant "A" (at power) and 6 mA at plant "B" (shutdown). It appears that plant "B" had more spiking attributable to maintenance during shutdown.

Equipment cycled at remote locations does not appear to influence conducted emissions on the power cables at the local measurement point. This supports the evaluation of emissions on the basis of local point of installation.

Electric Fields

The radiated electric field emissions recorded at the Zion plant were very low, with the highest measured field of 0.16 V/m. The radiated electric field data recorded at both Turkey Point and Zion correlated well where comparisons could be made, with the exception of intentional transmitters at ~450 MHz (that is, portable transceivers). Although these levels are low, they represent elevated levels due to the limited clearance between equipment racks and receiving antennae. Metallic clutter tends to capture re-radiated energy, making the field more uniform throughout the room. The radiated emissions data follow the classical envelope presented in MIL-STD-461E [4], with an exception on the high end where they fall even further below the accepted levels. The low-frequency radiated emissions test of MIL-STD-461 applies to individual equipment or subsystems and not the plant as mapped. Again, the actual values were well below the susceptibility test limits. The NRC SER on the modification at Zion [13] incorrectly states, "at locations 1CB50 and 1CB26, the results indicate the values of 31.6 V/m (peak) and 29.8 V/m (peak) respectively." These measurements should be identified as V/m-MHz to denote broad-band data. The actual narrow-band levels are several orders of magnitude less than those reported. The susceptibility test levels are defined for narrow-band input signals; consequently, they should be compared to narrow-band emission limits.

The data obtained at Zion are likely not being properly interpreted in comparison to the susceptibility test levels specified in MIL-STD 461C or PMC 33.1 [8]. The broad-band data have been compared directly to susceptibility tests, causing NRC concern at that time that the equipment was not tested with at least a 6-dB margin for conservatism. However, MIL-STD-461C radiated susceptibility test RS02 imposes a narrow-band signal measured according to procedure with a narrow-band conventional voltmeter instrument, so the comparison to broad-band data was not appropriate.

The highest radiated narrow-band data measured at Zion were 104 dBμV/m, or 0.158 V/m, at location 1CB50. This is still 36 dB below the 10 V/m level (140 dBμV/m) normally used for the susceptibility test, providing adequate safety margin well above the 6-dB safety margin. This gives a 30-dB measure of uncertainty for variations between power plants. In support of this argument, revisions incorporated into MIL-STD 461D call for elimination of the broad-band emission measurements.

The Turkey Point electric field data are recorded only from 20 to 1,000 MHz. The peak narrow-band Turkey Point data are over 100 dBμV/m but 40 dB below the 140 dBμV/m (10 V/m) test level (except in the case of deliberate keying of portable transceivers, which can be avoided through administrative controls).

Portable Transceiver Emissions

Portable transceivers represent the greatest radiated continuous wave (CW) electric field threat at a plant. Large transceiver-induced electric field signals were recorded at both Zion and Turkey Point. At Zion, the field strength was measured with the portable transceiver outside the AEER, in accordance with site restrictions. Narrow-band measurements as high as 107.4 dBμV/m were recorded. The location of the portable transceiver at Turkey Point was not noted, and the narrow-band level was equal to or greater than 80 dBμV/m.

Intentional portable transceiver electric field emission levels are much higher than ambient levels and are a function of transceiver power, antenna gains, and distance. These sources are narrow-band in nature. Where transceiver communications were observed during mapping at Zion, the levels were low: ~93 dBμV/m at 160 MHz and ~87 dBμV/m at 450 MHz. Short duration spikes that relate to the intentional transmitters, at 0.022 V/m, are well below test standard levels. The steady-state EMI level at these frequencies was 60 dBμV/m or below. In contrast, the intentional transmitter levels at the emergency bus load sequencer at Turkey Point were recorded at 133.5 dBμV/m (that is, ~5 V/m) at 450 MHz. Portable transceivers are necessary for operation of the sequencer; consequently, the equipment susceptibility testing was performed with adequate margin. It can be concluded that for certain equipment, portable transceivers are operated in close proximity, and susceptibility testing should be performed with adequate margin. In most other cases where the use of portable transceivers is not required, stringent administrative controls are in effect. Portable transceivers are a known threat and the subject of NRC Information Notice (IN) 83-83 [14]. Using the restricted operating guidelines, the radiated EMI levels at the location of the digital equipment can be maintained well below a 10-V/m (140-dBμV/m) susceptibility test level. Mapping does not appear to add any useful information for this known problem area.

Radiated Magnetic Fields

Radiated magnetic fields are a near-field and localized phenomenon recorded only at Zion. While described as a radiated test in the MIL-STD, the MIL-STD-461C RE01 test is actually a measurement of near-field or inductive fields and should be performed 7 cm from the surface of the device under test. The data obtained at Zion were 50 cm (20 inches) from the surface and do not correlate directly with any emissions criteria, although at this distance the highest measurement (corresponding to 1CB76) is at least 20 dB below the MIL-STD-461 limit. The Zion data show that at 50 cm (20 inches) from equipment, there were no field strengths of concern, and the recorded levels were 20–50 kHz, 20 dB below low-frequency radiated susceptibility levels described in MIL-STD-461E [4]. Being in the near field, the level falls off as an inverse cube or inverse square of the distance from the source, that is, proportional to $1/R^3$ or $1/R^2$, where R is the distance. Because of the rapid decay of magnetic fields from the source, the main concern is high current power frequency conductors in close proximity to digital equipment. There were no significant levels found in the Zion data at 50 cm (20 inches).

Note that DC magnetic fields cannot couple into active circuitry and that there is no industry testing standard for this phenomenon. Only specialized equipment, such as a cathode-ray tube, would be affected.

Magnetic field strength is a local, installation area concern that is site specific. High-magnetic-field areas are located simply by locating AC power equipment and/or cables. Installation restraints are reflected in the EMI limiting practices detailed in Section 4.

Additional information can be found in standard practices and guidelines that have been developed by the Institute of Electrical and Electronic Engineers (IEEE) and documented in standards ANSI/IEEE C37.90.1 [15], IEEE-1050 [16], and IEEE-518 [17].

Emissions Data Used as Bases for Testing

In the early 1990's, the EMI Working Group recommended conducting additional plant emissions measurements in an effort to bound typical plant electromagnetic emissions at nuclear plants. Earlier tests required by the NRC could not capture transient events that are more likely to describe the bounding environment. In addition, the procedures for the NRC-required tests did not include differential modes, nor were the data collected individually from the power and signal leads. The EMI Working Group developed a set of measurement specifications, which are described in this section.

Data were obtained from seven nuclear plants, representing different geographical conditions, plant configurations, and nuclear steam supply system (NSSS) vendors. The strategy was to identify key safety systems and locations and to use existing standards to capture the bounding conditions. The measurements were used to:

- Bound or envelope the highest observed electromagnetic emissions environment at a nuclear power plant, thus eliminating the need for future EMI site surveys
- Validate guidelines for equipment susceptibility testing levels
- Provide a basis for recommending equipment emissions controls and testing guidelines and limits

Procedures for Generic Measurements to Establish Guidelines

The generic emissions measurement procedures developed by the EMI Working Group included collection of typical baseline data at predetermined locations within the plant. It was anticipated that the results of these tests would be comparable to site emissions data collected previously to support independent utility digital upgrades. Data collected so far indicate that to be the case. The highest measured level for each type of emissions test was to be compared to the recommended susceptibility guidelines. If adequate margin existed between the highest measured levels and the recommended susceptibility test levels, then the interfering signal emissions would have been successfully bounded. However, if the highest measured levels were too close to susceptibility tested levels, then the susceptibility levels were to be adjusted accordingly. The approach was intended to bound each type of emissions for a typical nuclear plant and to allow a shift from the current practice to a more practical approach that controls equipment emissions and susceptibility, instead of mapping levels as part of an equipment EMC qualification process.

Emissions Measurements Used to Establish Guidelines

The group recommended that the following measurements be made to describe the ambient environment in support of issuing the original TR-102323:

- Conducted emissions measurements in the frequency domain on power and signal[1] leads between 30 Hz and 15 kHz in common and differential[1] modes.
- Conducted emissions measurements in the frequency domain on power and signal[1] leads between 10 kHz and 30 MHz in common and differential modes. Data collected from these measurements should not be compared to the Section 5 limits for high-frequency conducted susceptibility testing from 10 kHz to 1 MHz due to differences in current testing standard methodologies.
- Conducted emissions measurements in the time domain[1] on power leads in common and differential modes for frequencies below 50 MHz. (Note: The measurements are taken using current probes, and the current values are converted to voltages for analysis.)
- Radiated emissions measurements of magnetic fields in the frequency domain between 30 Hz and 50 kHz.
- Radiated emissions measurements of electric fields in the frequency domain between 14 kHz and 1 GHz.
- Radiated emissions measurements of DC magnetic fields.
- The following general guidance was incorporated into the developed measurement procedure.
- Measurements will be strictly passive and nonintrusive.
- Conducted emissions measurements will be performed with current probes, frequency analyzers, oscilloscopes, and signal transient recorders.
- Radiated emissions measurements will be performed using radio antennae and frequency analyzers.
- Current probes will be wrapped around the cables being measured without de-terminating any connections.
- When performing common-mode signal cable conducted emissions measurements, an attempt should be made to wrap the current probe around as many conductors as possible in the cable bundle.
- When performing common-mode power cable conducted emissions measurements, an attempt should be made to wrap the current probe around as many conductors as possible, including the ground wire (where applicable).
- When performing differential-mode signal lead conducted emissions measurements, an attempt should be made to select the conductors in the cable bundle that are most exposed to electric and magnetic fields. Conductors that traveled the greatest distance from the cable bundle to a point of termination were previously considered the greatest EMI carriers. However, more recent data indicate that EMI threats are more common from nearby loads.
- Measurements must be taken for signal leads closest to the power leads and thus most exposed to potential EMI.

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1 Indicates features or measurements specified by the EMI Working Group but not previously requested by the NRC.

Collecting Emissions Data at EMI/RFI Sensitive Equipment

The EMI Working Group identified transient EMI sources (as opposed to steady-state or continuous sources) as being more likely to define the bounding emissions environment. Part of the generic emissions measurements requires energizing or cycling equipment during testing to identify the effects of transients on the measured emission levels.

Earlier sections of this report note the importance of distance in defining the amplitude of potential EMI sources. For conducted emissions, higher frequencies (low kHz range and above) attenuate rapidly. The EMI due to inverter emissions was attenuated 15.6 dB over 10 feet. Also noted is that equipment cycled at remote locations did not appear to influence conducted emissions measurements at the local measurement point. Radiated emissions share a similar relationship to distance. Electric field emissions levels (including portable transceivers) are a function of power and distance. Near-field emissions fall off as an inverse squared or inverse cubed function of the distance from the source. Field strengths from radio waves fall off as a linear function of distance.

EMI amplitudes are a function of the distance to the source(s). Because of the rapid fall-off rate of most high-frequency sources, the emissions levels at a point in space are primarily a function of equipment "local" to that point and not typically influenced by equipment at a distance. In simple terms, electromagnetic emissions levels are primarily a function of equipment local to the point of measurement.

For an analog component being replaced by a digital counterpart within an electrical enclosure, any equipment remaining within that enclosure after the digital equipment is installed should be considered a potential EMI source. Cables penetrating the enclosure should also be considered potential EMI sources. Nearby loads on these cables should be analyzed to determine if they represent potential EMI sources.

It is not necessary to cycle motors/generators and other power generation equipment in remote locations or for the plant to be in a particular mode of operation to collect electromagnetic emissions data. Emissions from power plant equipment are controlled by maintaining equipment separation, as described in Section 4, "Minimum EMI Limiting Practices." Data recently collected show no appreciable difference in EMI levels between plants that are shut down or at partial or full power.

The critical point of measurement is the connection point to the digital equipment. Figure 2-1 is a schematic representation of a remote component (a 460-volt motor) connected to a digital component via a temperature probe. The 460-volt 3-phase 60 Hz motor will generate EMI during its operation. Unless the motor is very close to the digital equipment (that is, less than 50 feet [~16 meters]), the emissions will be significantly attenuated at the input to the digital equipment. In this situation, the operation of the 460-volt motor will not create significant EMI at the digital equipment. Conversely, nearby equipment—although of lesser power—will have a short conductive path to the digital equipment and thus create higher levels of EMI. Equipment with less than 50 feet of conductive path from the digital equipment should be considered for energizing/cycling to create maximum EMI at the digital equipment connection points. It is especially important to operate inductive loads, such as relays, within the rack—even if they are not directly connected to the digital equipment.

The plant emissions measurement should always be made at the input to the digital equipment and not at the terminals of the EMI source. The input may be the cables feeding into the rack (if the rack is dedicated to the digital equipment) or individual cables connected to a module installed in an existing rack.

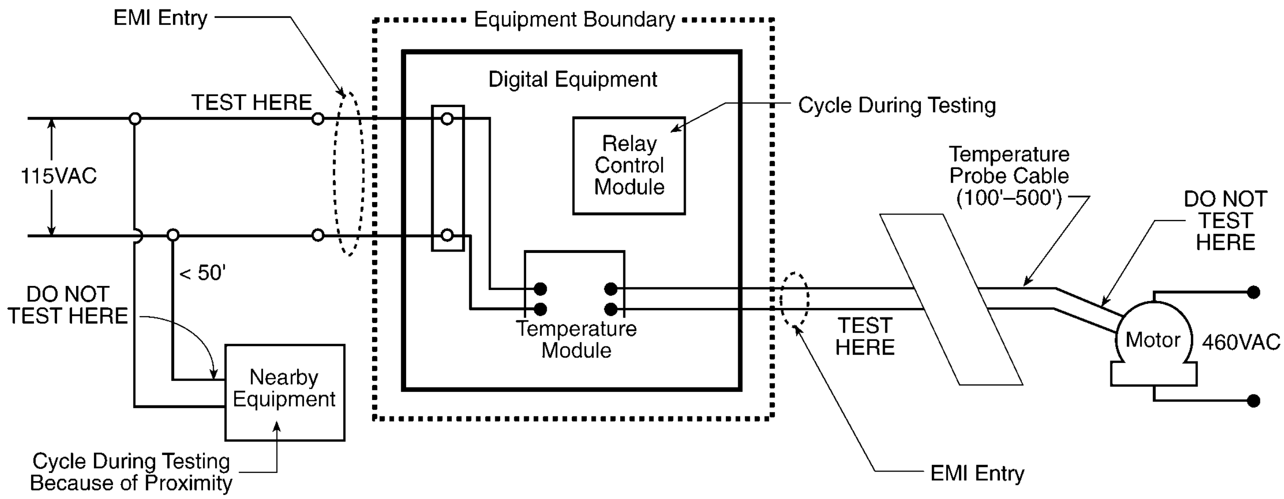


Figure 2-1
Schematic Illustration of EMI Sources from Surrounding Equipment and Measurement Locations

The utility should obtain clearances on equipment identified as a potential EMI source and energize or cycle that equipment during the emissions testing. The testing organization should capture those transients as outlined in the generic emissions measurements procedure.

Selecting Systems for the EMI Surveys

At the time the original TR-102323 was being developed, several plants were planning and implementing modifications to install digital equipment in safety-related systems. The NRC practice for evaluating equipment EMC at that time was to compare the vendor's EMI/RFI susceptibility tests to the on-site emissions survey. This comparison is based on demonstrating adequate margin between on-site levels and the vendor's tested susceptibility levels to demonstrate equipment EMC. These "point-of-installation" surveys were used by the EMI Working Group as opportunities to collect data according to the procedures described above. The group recommended that point-of-installation surveys performed to justify the modifications be included in the database to describe and bound the nuclear power plant environment.

The group also recommended that data be obtained from key safety systems to facilitate comparison of emissions levels at similar locations and systems across several plants. It was recommended that measurements be obtained for two independent channels of the reactor protection system. Each set of measurements was to be performed on the signal processing and relay logic portions of each channel. The group recommended that measurements also be obtained for two additional plant-selected safety systems. To characterize the radiated emissions environment, the group recommended that data be obtained from the control room, cable spreading rooms, turbine deck, switchgear rooms, battery rooms, diesel generator rooms, and remote shutdown panel areas.

Generic Emissions Measurements Data

In 1993, generic emissions data were obtained from seven plants. All seven plants performed emissions measurements to support the installation of digital modifications. This was viewed as an opportunity to collect additional emissions data to develop a generic profile and to validate the recommended susceptibility levels. Each plant was required to justify that the equipment susceptibility level provided adequate margin from the highest measured emissions environment. Each plant acquired emissions data according to the recommended guidelines.

Haddam Neck

Connecticut Yankee's Haddam Neck plant installed a digital feedwater control system in the control room [18]. This system is self-contained and replaces the existing system logic and controls. The digital system receives analog input signals for pressure, flow and level monitoring from the feedwater flow, steam flow, steam line break flow, steam generator narrow range level, and steam generator pressure. The digital system processes the information and provides isolated signals to the plant process computer and to displays on the control panel in the control room. It also provides trip signals to the plant protection system. Incoming and outgoing signals are carried on twisted shielded pairs with an overall protective jacket. The incoming signals have shields directly grounded to the digital system ground bus. Conducted and radiated emissions tests were performed at the point of installation in the control room. The purpose of the tests was to demonstrate that adequate margin exists between the vendor-conducted susceptibility tests on the digital feedwater control system and the highest measured plant emissions. The measurements were performed in June 1993.

Browns Ferry

Tennessee Valley Authority's Browns Ferry Plants Units 1, 2, and 3 installed a nuclear unit measurement and analysis control (NUMAC) system in the control room for use as a reactor building vent radiation monitor (RBVRM). The plant decided to measure electromagnetic emissions in the control room as well as on the refuel floor. The testing compared the site survey measured levels to the NUMAC system's conducted and radiated susceptibility levels to establish whether the system could adequately function in the RBVRM environment [19]. Measurements were performed in April and May 1993.

Brunswick

Carolina Power & Light Co.'s Brunswick nuclear plant installed a digital NUMAC system for use as a steam-leak detection system [20]. This upgrade was similar to other NUMAC installations. The testing verified adequate margin between laboratory-tested equipment susceptibility levels and the plant emissions environment. Emissions data were obtained in May 1993 at the point of installation, according to procedures developed by the working group.

Perry

FirstEnergy Nuclear Operating Company's Perry Plant upgraded their steam-leak detection modules with a digital NUMAC detection system, replaced obsolete data recorders with digital counterparts, and was considering an upgrade of the Neutron Monitoring System [21]. Emissions data were obtained in November 1993 from several locations, including the reactor protection system and turbine deck.

Vogtle

Southern Nuclear Operating Co.'s Vogtle Plant installed a new diesel generator digital controller system to replace their existing analog system [22]. The plant demonstrated EMC by comparing the site survey data to the system's conducted and radiated susceptibility measurement data. The site profile was developed in October 1993, according to group-recommended procedures.

Peach Bottom

PECO Energy Co.'s Peach Bottom Atomic Power Station upgraded several systems. Emissions maps were requested to support digital modifications, which included the high-pressure coolant injection (HPCI) and reactor coolant injection (RCIC) flow controllers and the containment air dilution (CAD) analyzer [23]. In addition, the plant requested that emissions data be collected at the alternate shutdown panel and the cable spreading room. Emissions data were acquired October through December 1993.

Palo Verde

Arizona Public Service Co.'s Palo Verde Nuclear Generating Station installed an 850-MHz trunk radio system to meet regulatory commitments and to ensure more reliable communication among plant personnel. Plant staff wished to assess potential EMI effects from the new radio system on existing plant equipment. EMI measurements were made in the control room in the vicinity of potentially sensitive equipment from the reactor protection system (RPS), the engineered safety features actuation system (ESFAS), and the diverse auxiliary feedwater actuation system (DAFAS). Measurements were taken during April and May 1994 [24].

Generic Plant Emissions Data Analysis

Plots of the highest observed composite spectra for each of the seven plants are shown in Figures 2-2 through 2-6 for MIL-STD-461C conducted emissions tests (CE01 and CE03), radiated emissions tests (RE01 and RE02), and transient emissions tests (CE07). The highest observed composite spectra or envelope for each plant's emissions was obtained by plotting the highest emissions level measured across all frequencies for all locations where data were collected. Each plant's highest measured composite plant emissions data are individually represented and labeled on each graph as Plant A through G, respectively. This illustration of each plant's data is a conservative representation of the typical EMI emissions environment and is not indicative of the actual emissions measured at any given location.

Also illustrated in Figures 2-2 through 2-6 is a highest composite plant emissions envelope. The highest composite plant emissions level is a plot of the highest emissions level measured across all frequencies for all locations where data were collected for all seven plants. For each test other than high-frequency conducted susceptibility, this plot is used in Section 6 to compare the highest measured plant emissions levels to equipment susceptibility testing limits in order to demonstrate margin and ensure that plant emissions are adequately bounded by the working group's equipment susceptibility testing limits.

Low-Frequency Conducted Emissions

Figure 2-2 shows the highest observed conducted emissions envelope for Plants A through G and the highest composite plant emissions levels, ranging from 30 Hz to 15 kHz. Data for this testing were collected in accordance with MIL-STD-461C CE01 and represent continuous-wave, steady-state low-frequency conducted plant emissions. Emissions levels were measured on power, signal, and neutral lines in both common- and differential-mode. The region from 30 Hz to 120 Hz is the device power consumption region and should not be viewed as plant emissions or interference. Consequently, that region generally had the highest observed emission levels due to the load-carrying current and its harmonics.

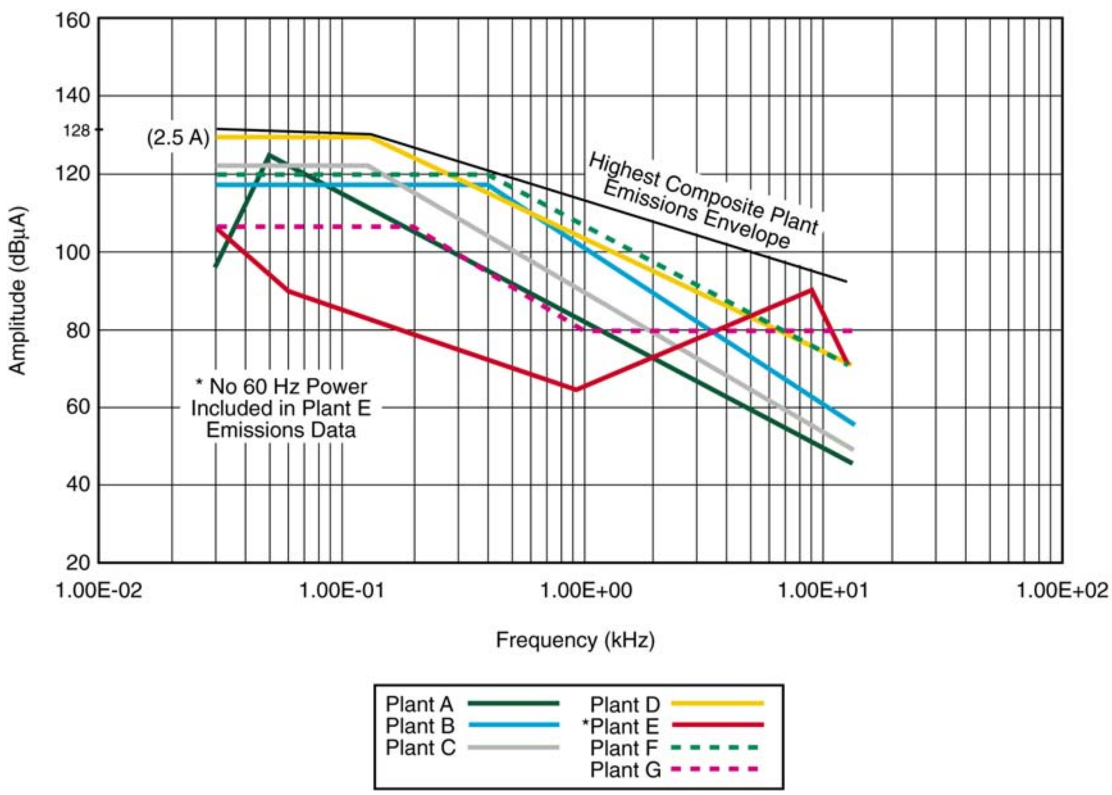


Figure 2-2
Composite Highest Observed Plant Conducted Emissions (CE01) Envelope at Seven Nuclear Power Plants

High-Frequency Conducted Emissions

Figure 2-3 shows the highest observed conducted emissions envelope for plants A through G and the highest composite plant emissions levels, ranging from 15 kHz through 50 MHz. Data for this test were collected in accordance with MIL-STD-461C CE03 in an effort to characterize the continuous-wave, steady-state high-frequency conducted plant emissions. Again, emissions were measured on power and signal lines in both common-and differential-mode.

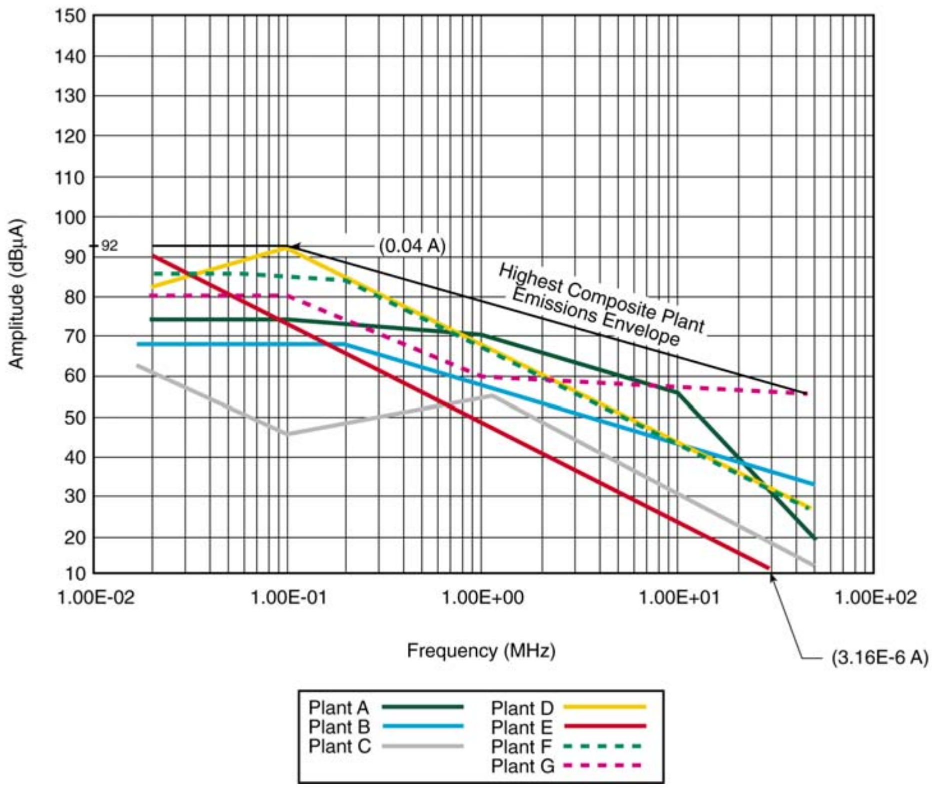


Figure 2-3
Composite Highest Observed Plant Conducted Emissions (CE03) Envelope at Seven Nuclear Power Plants

Several members of the EMI Working Group and engineers in the nuclear industry noted problems with the high frequency susceptibility test CS114 limit levels that were based on these emissions measurements. A more detailed review of these emissions measurements was performed to establish limits for high-frequency conducted susceptibility test CS114. EPRI published the report "Review of High Frequency Conducted Susceptibility Limits" [35], in December 2003. The review found several issues with the methods used to collect the data for these envelopes. These issues indicate that the CE03 measurements do not accurately characterize the continuous-wave, steady-state conducted emissions environment. The EMI Working Group concluded that conducted emissions data should not be used to establish high frequency conducted susceptibility testing limits because of the fundamental differences between the conducted emissions measurement method and the purpose and method of applying test signals for the standards endorsed for this test. See Appendix H, Technical Basis, for a summary of the technical basis for this conclusion.

In 2004, additional testing was performed at Tennessee Valley Authority (TVA) EMC labs to determine whether the CE03 testing described above may have captured and included transient events. The test used a 50-ohm load terminating a 10 m cable. The load was subjected to surge or EFT waveforms applied line to neutral (differential mode). Conducted emissions measurements were made using a FCC F-52 current probe and an Agilent E7404A Spectrum Analyzer. The testing found that if the surge or EFT event occurs in the time window of the spectrum analyzer, significant energy is recorded. During testing the surge energy was found to fall off (decrease) in the ~50MHz region, but EFT energy was recorded into the high MHz region. Should this test be duplicated using a common-mode emissions source, similar results would be expected. The conclusion based on the testing is that a spectrum analyzer will record transient energy during a measurement of conducted emissions and that energy recorded in this manner cannot be distinguished from continuous wave energy (see Appendix J for test results). The testing provides further support for the conclusions of the EMI Working Group that the early conducted emissions measurements captured transient emissions that are not meant to be addressed in conducted susceptibility test CS114.

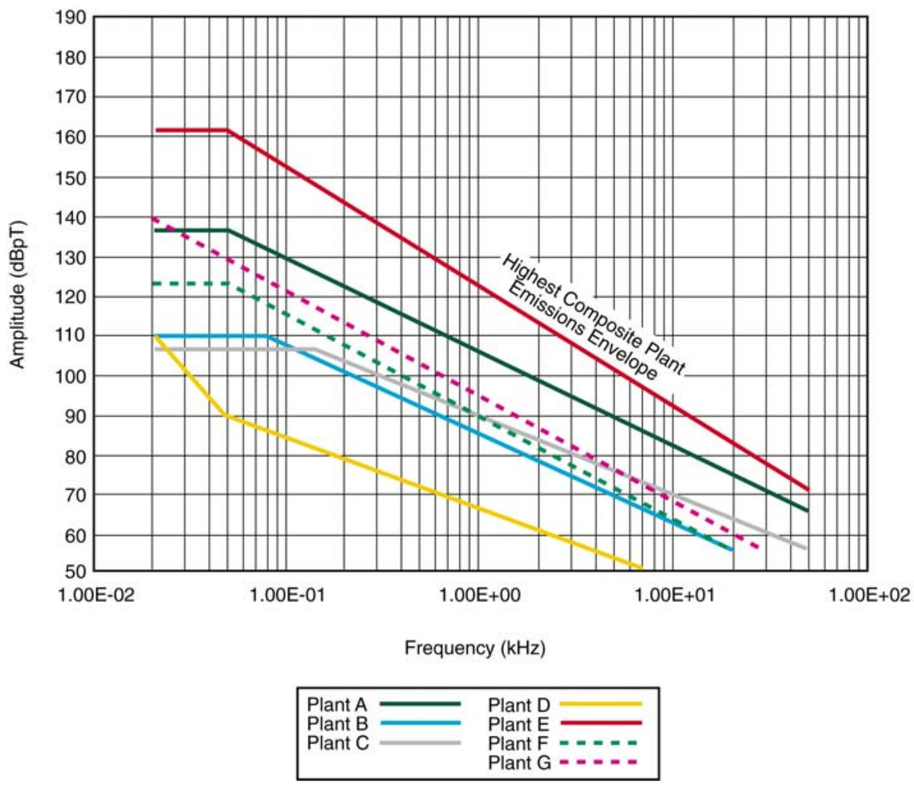


Figure 2-4
Composite Highest Observed Plant Radiated Emissions (RE01) Envelope at Seven Nuclear Power Plants

Radiated Magnetic Field Emissions

Figure 2-4 shows the highest observed radiated magnetic field emissions (RE01) envelope for plants A through G and the highest composite plant emissions levels, ranging from 30 Hz to 50 kHz. The AC magnetic fields in the 30 Hz–50 kHz range exhibit rapid fall-off in field strength at short distances from the equipment that generates the EMI. The highest magnetic fields displayed among the seven plants were recorded at the rear of a diesel control panel (162 dBpT) with the diesel generator operating. It is expected that a ferrous metal enclosure (such as the control panel cabinet) would reduce the measured radiated emissions level at least an additional 20 dBpT.

Radiated Electric Field Emissions

Figure 2-5 shows the highest observed radiated electric field emissions (RE02) envelope for plants A through G and the highest composite plant emissions levels, ranging from 14 kHz through 1 GHz. The large spikes at 200 MHz for plant B (144 dBmV/m) and at 450 MHz for several other plants (118 dBmV/m) are due to intentional keying of radio transmitters. Most plants place administrative controls on the use of portable transceivers near critical equipment. The working group recognizes that specific independent control of portable communications emissions is required to ensure that equipment susceptibility levels are not exceeded. Section 4, "Practices to Ensure EMC," provides guidance on the control of portable transceivers. Technological trends indicate that plants are migrating toward higher frequency devices operating at lower power levels, which should reduce the impact of these devices on future digital equipment.

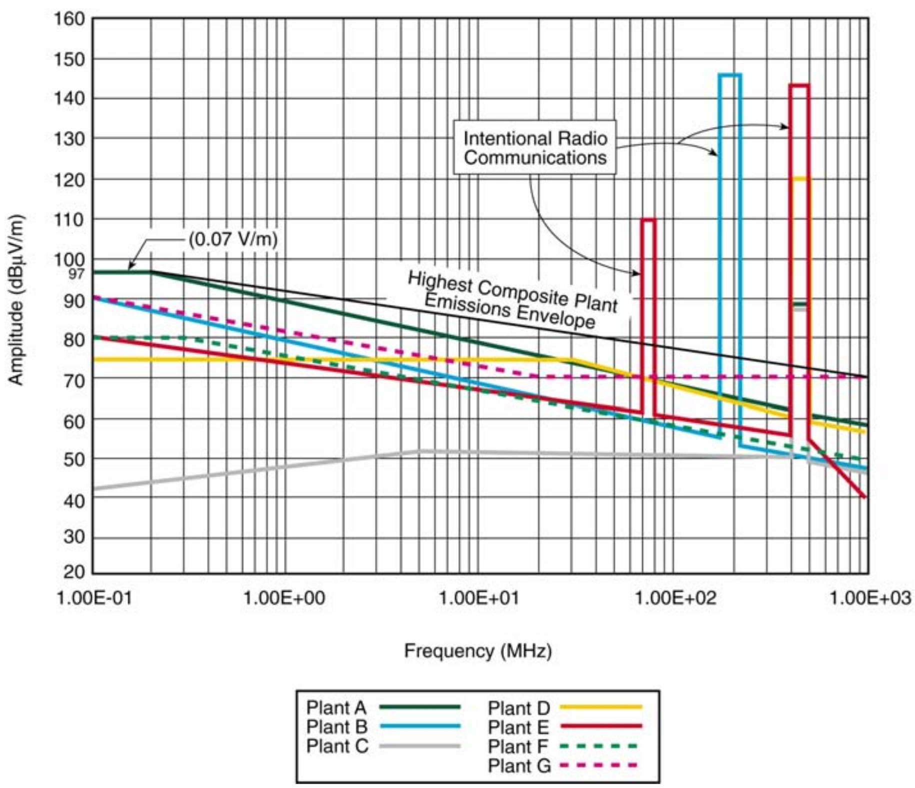


Figure 2-5
Composite Highest Observed Plant Radiated Emissions (RE02) Envelope at Seven Nuclear Power Plants

Radiated Electric Field Emissions above 1 GHz

In 2002, the EMI Working Group began to look at the effect of high frequency communication systems. These systems typically operate at frequencies above 1 GHz. It was noted that no nuclear plant data exists from which to base either emissions or susceptibility limits at frequencies greater than 1GHz. A plant emissions survey program was initiated by the group to measure the ambient EMI emissions above 1 GHz at 5 nuclear generating stations. The nuclear generating stations surveyed during this data collection period were: TXU's Comanche Creek Power Station, TVA's Brown's Ferry and Sequoyah Generating Stations and PSEG Nuclear's Salem and Hope Creek Stations. As can be seen in Figure 2-6, these results of the site surveys demonstrate that the emissions and susceptibility limits proposed in TR-102323-R1 were adequate at the frequency range from 1 GHz to 10 GHz. Note that the plants where these surveys were performed are different than the plants where surveys for other measurements were performed, so plants A-D in Figure 2-6 are not the same as plants A-D in other figures in this section. The highest level of narrowband emissions at the five generating stations was 108 dbµV/m at 7.2 GHz which is 32 dB below the recommended susceptibility limit of 140 dBµV/m. This signal was traced to a microwave wave-guide system in the communications room at the generating facility.

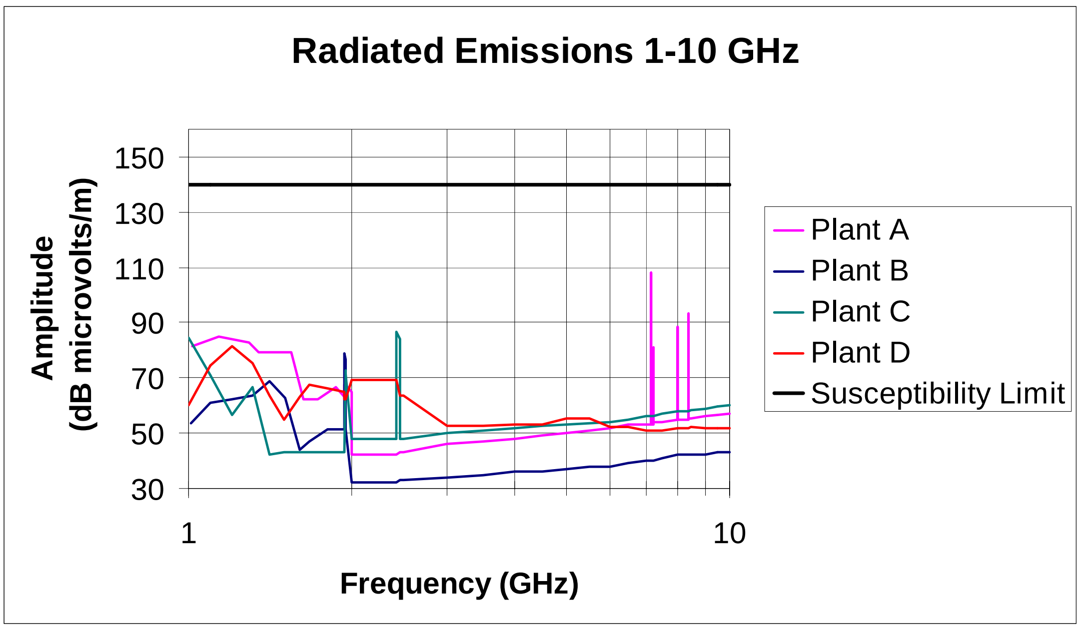


Figure 2-6
Composite Plant Emissions above 1 GHz at Four Nuclear Power Plants

Conducted Transient Emissions

Figure 2-6 shows the composite conducted transient emissions (CE07) envelope for Plants A through G and the highest composite plant emissions level for all seven plants. The transient emissions data were obtained at each plant by recording the highest observed time-domain signal on power leads in both common- and differential-mode over a 30-minute duration. The interfering signal is seen at the input of the equipment under test (EUT) as a ringing waveform at a single frequency. This is a typical resonant circuit response to an impulse. The plant emissions are graphically represented as the maximum peak-to-peak levels at approximated fundamental ringing frequencies of the recorded waveform. Typically, the maximum emission levels are observed as differential-mode signals on the power leads at a resonant frequency that is most likely a function of the length of the power leads.

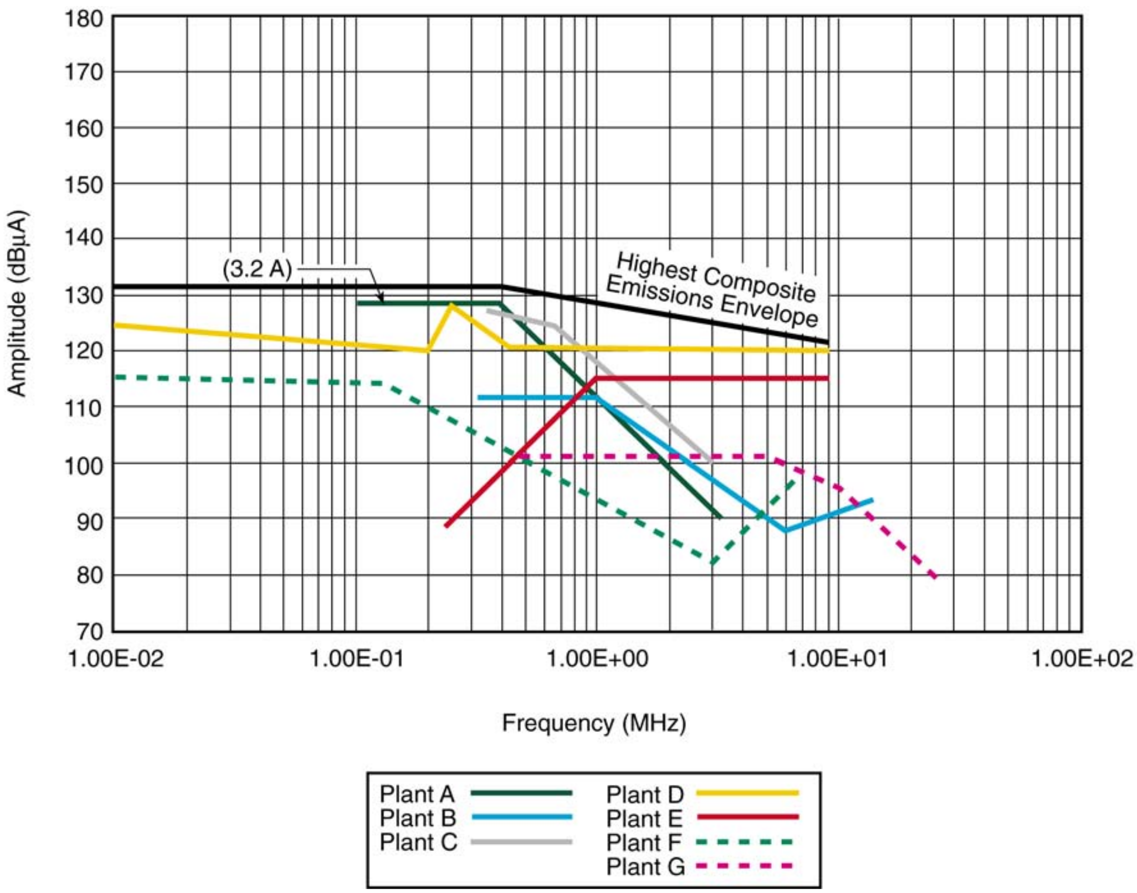


Figure 2-7
Composite Highest Observed Transient Plant Emissions (CE07) Envelope at Seven Nuclear Power Plants

3
NRC RESEARCH AND APPLICABLE GUIDANCE

NRC Emissions Measurements

NUREG/CR-6431 documents NRC-endorsed electromagnetic operating envelopes and testing limits for safety-related I&C systems in nuclear power plants [10]. It also includes a technical basis for the NRC-recommended envelopes and testing limits that is based primarily on the results of a measurement survey of nuclear power plant electromagnetic emissions data collected by Oak Ridge National Laboratory (ORNL) under contract to the NRC. A detailed analysis of the ORNL plant-measured EMI/RFI data is documented in NUREG/CR-6436 [11].

NUREG/CR-6436 documents radiated electric and magnetic field data and some conducted EMI data [11]. The data and results reported in NUREG/CR-6436 [11] are based on ORNL measurements from eight U.S. nuclear power plants. Measurements were taken over a 14-month period at one Combustion Engineering PWR, three Babcock & Wilcox PWRs, three Westinghouse PWRs, and one General Electric BWR. ORNL measured ambient electromagnetic conditions in a variety of plant locations and under various plant operating conditions. Measurements were taken in plant control rooms, cable penetration areas, cable spreading rooms, plant equipment rooms, and on plant turbine decks. Plant operating conditions during the data collection period included full power operation, plant startup and low power operation, and coast down and outage conditions.

Because of differences in test equipment used to measure the plant emissions and because the length of data collection was generally longer for the ORNL plant testing, there are some differences between the data reported by NUREG/CR-6431 [10] and this report. However, both data sets support the use of the equipment susceptibility testing limits originally recommended by TR-102323-R1 [1]. In NUREG/CR-6782 [33], the NRC evaluated MIL-STD-461E and IEEE C62.41 test methods and levels and compared them to the requirements of the IEC EN 61000 standards [5]. NUREG/CR-6782 [33] concluded the MIL-STD-461 and IEEE C62.41 test methods could be interchanged with the IEC EN-61000 test methods without loss of confidence that equipment could withstand the intended nuclear power plant environment. NUREG/CR-6782 [33] also acknowledged some differences between these standards and how they could be addressed.

In NUREG/CR-5609 [34], the NRC documented a review of statistics from the licensee event report (LER) database and concluded that signal line EMI/RFI is a potential problem that cannot be ignored and that should be adequately addressed. NUREG/CR-5609 [34] also concluded that MIL-STD-461E [4] and IEC EN 61000-4 [5] were appropriate to address susceptibility to conducted EMI/RFI and power surges along interconnecting signal lines. The applicable tests for addressing conducted susceptibility for signal lines from MIL-STD-461 [4] were CS114, CS115 and CS116. The applicable tests for addressing conducted susceptibility for signal lines from IEC EN 61000-4 were 61000-4-4, 61000-4-5, 61000-4-6, and 61000-4-12.

NRC Testing Guidance

The NRC used the technical bases of NUREG/CR-5941 [12] as well as *in situ* test data published in NUREG/CR-6436 [10] to develop Regulatory Guide 1.180 [2] Revision 0, which was issued in 2000. To support revisions to Regulatory Guide 1.180 [2], the NRC sponsored additional research described above. The NRC issued Regulatory Guide 1.180 [2] Revision 1 in October 2003. This revision endorsed the use of the IEC EN-61000 testing standards and methods, extended guidance covering signal lines testing and addressed testing at high frequencies where portable communication devices are experiencing increased usage.

The operating envelopes and testing limits endorsed in NUREG/CR-6431 [10] and Regulatory Guide 1.180 Revision 1 [2] are generally consistent with those recommended in this report. The data reported in NUREG/CR-6436 [11] are generally consistent with the data reported here and also support the use of the equipment susceptibility and emissions testing limits and other criteria and recommendations documented in this report. Where there are differences between the recommendations of this report and those of Regulatory Guide 1.180 Revision 1, a technical basis for these differences is provided in Appendix H.

Section 7 of the NRC Standard Review Plan, NUREG-0800 [42], provides guidance for review of the I&C portions of applications for nuclear reactor licenses and permits and for review of applications for license amendments. The Standard Review Plan was last revised in 1997, prior to the issuance of Regulatory Guide 1.180 or of Revision 2 of TR-102323. The Standard Review Plan endorses the use of TR-102323 Revision 1 along with its companion NRC Safety Evaluation Report (SER) (see Appendix D for a copy of the SER).

4
PRACTICES TO ENSURE EMC

This section describes design and configuration control practices that help ensure electromagnetic compatibility (EMC). The SER in Appendix D refers to these as “EMI eliminating practices.” They are intended to bound and control equipment emissions for new and existing EMI/RFI sources. These practices are a set of design conditions that should be satisfied to ensure that plant emissions levels remain bounded and that recommended equipment susceptibility testing levels are not exceeded. If these practices are satisfied, then an EMI/RFI site survey will generally not be necessary. If any of these practices detailed below is not satisfied, additional engineering evaluation may be needed and a documented basis should be provided to ensure that equipment susceptibility levels are not exceeded.

Purpose

Equipment tested according to the most rigorous equipment susceptibility tests is not guaranteed to be electromagnetically compatible with its environment unless equipment emissions from surrounding sources are controlled. These practices limit the generation and coupling of EMI, which would otherwise potentially invalidate the susceptibility testing levels established in this report. For further recommendations on limiting the effects of EMI, refer to the EPRI EMI Handbooks [25].

Applicability

The practices outlined in this section apply to all new safety-related plant modifications that include analog, digital, and hybrid systems and components (analog and digital electronics equipment). The guidance of this report applies to both safety-related and non-safety-related systems and components whose operation can affect safety-related system or component functions and to those deemed important for power production.

Recommendations

Recommendations are designated here by the use of the verb “should.” This document is a guideline, not a standard or code, and as such does not impose requirements. The responsible engineer should, as a minimum, assess each recommendation and determine whether it should be implemented based on the specific circumstances of the plant modification under consideration. However, implementation of the recommended limiting practices can significantly reduce the likelihood of EMC related problems, and it is recommended that they be considered for incorporation into the plant procedures as appropriate.

Controlling Emissions Sources

Portable Transceivers (Walkie-Talkies)

Proper administrative control of portable transceivers is necessary to protect EMI/RFI sensitive equipment. To provide at least an 8-dB margin between the transceiver emissions limit (4 V/m) and the recommended equipment susceptibility limit (10 V/m), a minimum transmitter exclusion distance should be maintained. The transceiver field intensity can be estimated knowing the device power level and assuming the highest antenna gain factor of 1, according to the equation:

$$V_d = \frac{(30PG)^{.5}}{d}$$ **Equation 4-1**

where

P is the effective radiated power of the transceiver in watts

G is the gain term and is dimensionless

d is the far-field distance in meters from the transceiver, where the far field begins at a distance greater than 1/6 wavelength from the transceiver

V_d is the field strength in volts per meter

In the far field, a portable transceiver with an effective radiated power of 0.53 Watts generates a field strength of 4 V/m at a distance of 1 m, 2 V/m at 2 m, and 0.4 V/m at 10 m. The field strength falls off linearly with distance. Alternatively, the transceiver field strength can be measured at 1 m by testing according to Electronic Industries Association (EIA), TIA/EIA 603 [26].

To determine the minimum transceiver exclusion distance:

1. Calculate the transceiver field strength for a distance (d) of 1 m using Equation 4-1.
2. Determine the minimum transceiver exclusion distance corresponding to the calculated transceiver field strength at 1 m (see Figure 4-1).

To determine the minimum transceiver exclusion distance by measurement:

1. Measure the field strength at various distances.
   - Gather data using a spectrum analyzer connected to a horn antenna inside an EMI-shielded room or enclosure.
   - Ensure the spectrum analyzer frequency range covers the transmitted frequency and is set to “peak-hold” so that it records the maximum field strength measured during the dwell time at each frequency step. This is particularly important for devices that use modern spread-spectrum and/or frequency-hopping protocols (e.g., IEEE 802.11b).

   - Some equipment will not transmit unless queried, so equipment used for the test should be set up to result in transmissions. The equipment should also be used in a mode that generates the maximum power level.

2. If the transmitter has different antennas that can be used, take measurements with each antenna in use.
3. Determine the transceiver radiated field strength profile by plotting the measured data and a best-fit line (e.g., using a logarithmic regression). Note the point at which the line crosses 4 V/m. Some equipment may not generate over 4 V/m at any distance.

The minimum exclusion distance is that required to ensure a margin of at least 8 dB between the transceiver emissions and the equipment susceptibility testing levels. It is acceptable to increase the minimum transceiver distance or to restrict use in rooms where EMI/RFI sensitive equipment is located. As a matter of practicality, there are instances where transceivers and EMI/RFI sensitive equipment must operate in a shared environment; the guidance here is intended to accommodate such cases.

An example of exclusion zones found by testing follows. A plant had a dosimeter system tested to validate the emitter exclusion zones for the mobile units (Electronic Personal Dosimeters) and the base station. The base station for this system has four antennas: 9 dB omnidirectional (omni), 9 dB directional, 14 dB directional, and 6 dB omni. The base station emissions were measured in an EMI shielded enclosure using an HP 8566 Spectrum Analyzer fed by a horn antenna. The analyzer was set up to sweep from 2.4 to 2.5 GHz and the peak-hold setting was used to measure and record the maximum emission level. The horn antenna was set up at various distances (from 0.5 to 4 meters) from the transmitter antenna and in the center of the beam for directional antennas. The measured field strength was plotted and a logarithmic regression used to obtain a best-fit line. For each antenna available, the test report provides the distance beyond which field strength will be below 4 V/m. The test also found that during testing of the mobile units, emissions in the test chamber did not vary significantly. This result indicated that the mobile units had emissions of minimal signal strength. The test results are used at the plant as part of the design process to identify exclusion zones of equipment prior to deployment of that equipment at the site and ensure EMC between the tested equipment and installed equipment.

Arc Welding

Arc welding should be avoided to the extent possible (and prohibited if possible) in rooms containing in-service EMI/RFI sensitive safety equipment. Arc welding that is necessary in areas with potentially EMI/RFI sensitive equipment in service should be controlled using shielded enclosures around the welding equipment and power line filters on power cables.

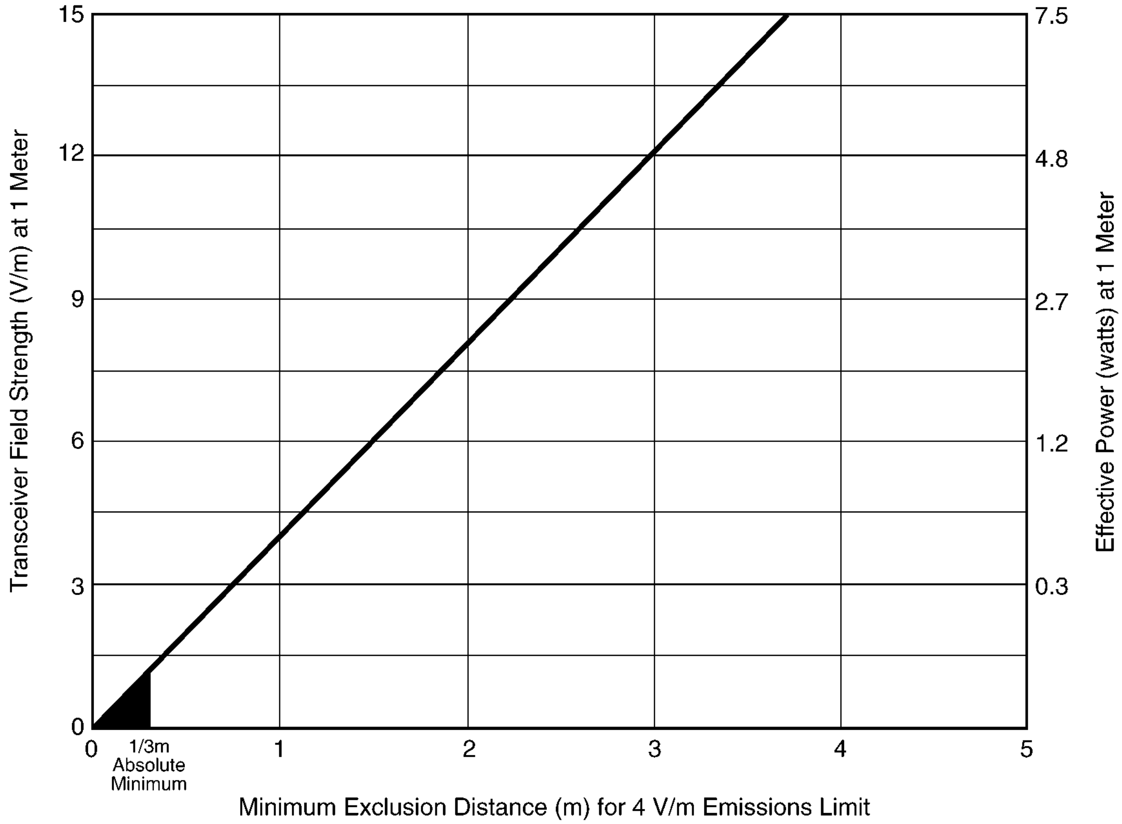


Figure 4-1
Recommended Minimum Exclusion Distance (in Meters) as a Function of Transceiver Field Strength (V/m) at 1 Meter

Grounding

The shields of EMI/RFI sensitive cables and conductors longer than 2 m should be terminated to the chassis ground using a 360-degree connector body for new equipment with operating frequencies above 10 MHz. At operating frequencies below 10 MHz, an acceptable alternative is to use low-impedance jumper connections no greater than 0.15 m (6 inches) in length.

EMI/RFI sensitive equipment should be installed with a grounding design in accordance with the IEEE standard 1050-1996 description for a central distribution frame ground bus [16]. Isolation or separation of ground connections for EMI/RFI sensitive equipment and other equipment grounds is not recommended at the lowest level distribution point, such as the rack or cabinet ground point. This guidance corresponds to the description of the local signal reference grid described in IEEE Standard 1100 [27]. Refer to IEEE 1050-1996 for additional recommendations and installation practices for grounding techniques to limit the effects of sources of EMI/RFI [16].

Equipment and Cable Separation

Switching inductive loads can create transients that couple to EMI/RFI sensitive equipment. The amplitude of the transients (as measured at the EMI/RFI sensitive equipment) is controlled by maintaining equipment and cable separation between the power generation EMI/RFI emitter and EMI/RFI sensitive equipment. Equipment and cable separation for new digital equipment should be maintained as described in Table 4-1. Figure 4-2 illustrates equipment and cable separation recommendations.

Table 4-1
Equipment and Cable Separation for Power Generation EMI/RFI Emitters

EMI/RFI Emitter Operating Voltage (V)	Equipment Separation Distance (m)	Cable Separation Distance (m)
>125 V	3 m with no shielding between devices; 1 m if the emitter or sensitive equipment is within a shielded enclosure[1]	0.6 m if the emitter and sensitive cables are located in the same cable tray; 0.3 m if either the emitter or sensitive cables are located in a rigid steel conduit or if both are in a separate cable trays
≤125 V	No separation requirement	0.1 meters in trays[2, 3]

Note: The minimum separation distances shown in Table 4-1 were conservatively calculated to ensure negligible capacitive or inductive coupling between equipment and cables. Typical wire sizes recommended by the National Electrical Code Handbook [28] over a wide range of noise frequencies were considered. At these distances, both near-field and far-field electric and magnetic field effects will be attenuated several decades or more (see EPRI EMI Handbook [25], Vol. 1, Section 1.2.2 and Vol. 2, Section 8.6.2). Separation distances equal to 1/4 of the wavelength of the EMI should also be avoided. The minimum separation distances shown in Table 4-1 are not meant to supercede the separation distances or criteria specified in IEEE 384-1992.

[1] An industry standard metal enclosure surrounding the EMI emitter or EMI sensitive equipment qualifies as a shielded enclosure.

[2] Where possible, this separation distance should also be maintained at the back of the equipment where the 120 VAC or 125 VDC supply and signal lead connections are terminated.

[3] This requirement can be waived if either the EMI/RFI emitter cables or EMI/RFI sensitive cables are routed within rigid steel conduits.

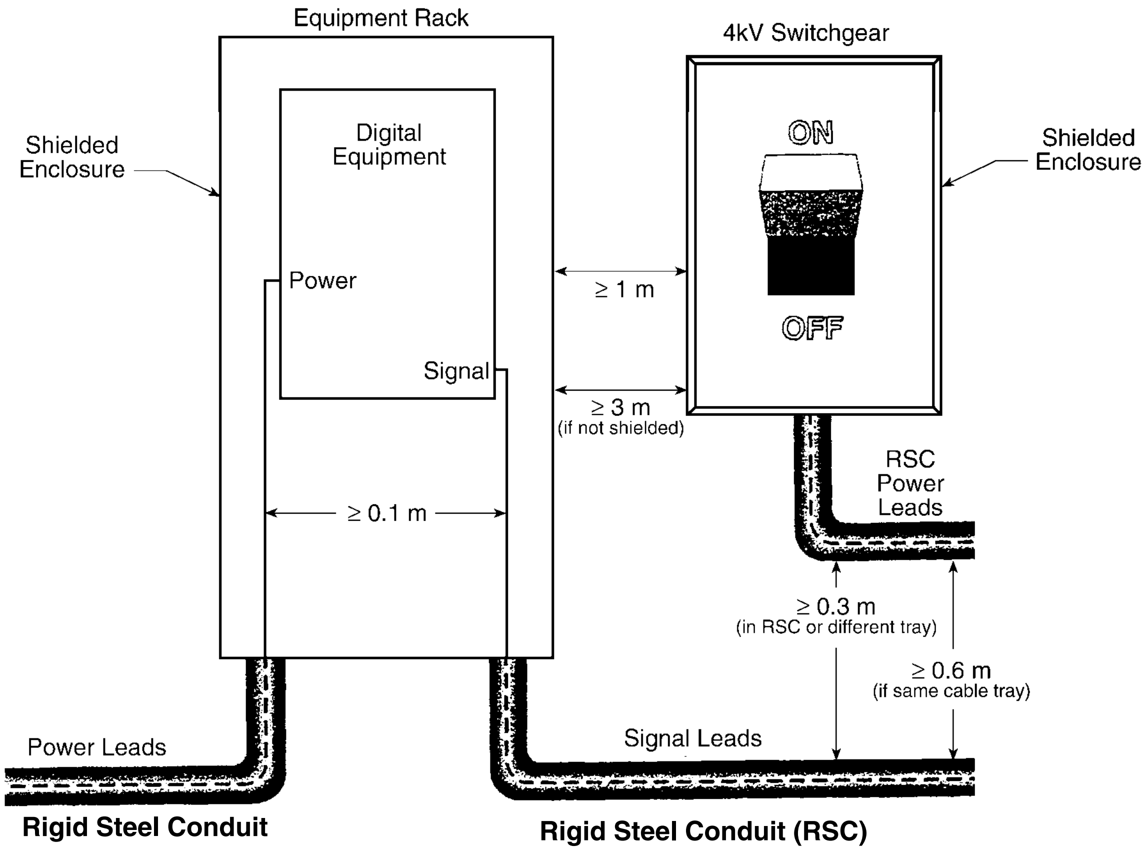


Figure 4-2
Illustration of Equipment and Cable Separation Recommendations for Power Generation EMI/RFI Emitters

Power Distribution Design Practices

The switching of inductive loads is the primary cause of transients on power distribution lines. The effects of these transients can be reduced by installing surge suppression on relays and other inductive loads or by maintaining minimum conducted path distances (cable lengths) between the inductive loads and EMI/RFI sensitive equipment. EMI/RFI sensitive equipment should not be connected to the same power source as relays or other inductive loads without surge suppression unless a minimum conducted path of 15 m exists between the unsuppressed inductive loads and the EMI/RFI sensitive equipment. Power sources are considered different if they originate from different transformers.

The practice of bringing twisted three-conductor power cables into the rack and then using untwisted single conductor jumpers inside the rack may cause increased coupling and interference. These leads should remain twisted as close as possible to their point of termination.

Electrostatic Discharge

ESD should be controlled by ensuring that plant personnel working on sensitive equipment use antistatic mats and wrist straps as defined in equipment O&M manuals.

Design Configuration Control Practices

The laboratory-tested and final installed system and equipment configurations should be as close to identical as practical. This includes consideration of the following:

- Printed circuit boards floated (not grounded) during the test should also be floated for the installed system or equipment.
- Equipment tested in the laboratory with power line filters and radio-frequency chokes should use the same components for the installed system or equipment configuration.
- If multiple derived sources are to be used for the installed configuration, then multiple derived sources should be used during laboratory testing.
- Equipment grounding designs for the installed system or component should be the same during laboratory testing.
- External cables and termination hardware used during laboratory testing should be the same as those in the installed configuration.

Internal distribution of power and signal cabling during the test should be documented to ensure that special routing or termination practices followed in the test specimen can be mirrored in the field installation, including shield terminations and power cable twisting retained during internal cabinet wire routing.

5
EQUIPMENT SUSCEPTIBILITY AND EMISSIONS TESTING GUIDANCE

Purpose

This section provides guidance for performing susceptibility and emissions testing for equipment to be installed in a power plant environment. EMI testing ensures EMC between existing and new electrical and electronic power plant equipment. Testing new equipment for susceptibility to EMI reasonably ensures that it will function and operate as designed when installed in the industrial electromagnetic environment of a power plant. Testing and using design practices to control emissions from new equipment ensure that the new equipment will not interfere with the operation of existing power plant equipment.

Applicability

The testing guidance of this report is applicable to all new safety-related plant system-level modifications that include analog, digital, and hybrid systems and components (analog and digital electronics equipment). It applies to safety- and non-safety-related systems and components whose operation can affect safety-related system or component functions or those deemed important for power production.

Electromagnetic interference testing should be addressed for all analog and digital electronic equipment with DC operating voltages (for example, 3-, 5-, 12-, and 15- VDC supply systems) or equipment with clock frequencies greater than 9 kHz. The recommended scope of applicable testing is defined in Table 5-1. Acceptable testing standards are listed in Table 5-2.

Table 5-1
Testing Applicability

	Susceptibility Tests							Emissions Tests			
	Conducted		Radiated		Surge	EFT	ESD	Conducted		Radiated	
	Low-Frequency	High-Frequency	Low-Frequency	High-Frequency				Low-Frequency	High-Frequency	Low-Frequency	High-Frequency
Safety-Related	A	A	E	A	A	A	O	E	A	E	A
Important to Power Production	R	R	E	R	R	R	O	E	A	E	A
Non-Safety-Related	O	O	O	O	O	O	O	E	A	E	A

A = Applicable. These tests are applicable and typically addressed through testing, or an exemption including a technical justification for why the test is not required should be documented.

E = Evaluate. These tests are applicable, but may be dispositioned through evaluation. Design features/conditions as specified for each test type should be satisfied. If testing is not performed, the design conditions/features that address this equipment emissions source should be documented.

R = Recommended. These tests should be performed, or an exemption including a technical justification for why the test is not needed should be documented.

O = Optional. These tests are optional. Noise sources local to the equipment and installation practices should be considered in determining susceptibility testing needs for non-safety-related equipment.

Table 5-2
Testing Standards

Susceptibility Tests		
	MIL-STD-461E	Commercial Standard
Low-Frequency Conducted	CS101	IEC EN 61000 Part 4 Section 13 and 16
High-Frequency Conducted	CS114	IEC EN 61000 Part 4 Section 6
Low-Frequency Radiated	RS101	IEC EN 61000 Part 4 Sections 8, 9 and 10
High-Frequency Radiated	RS103	IEC EN 61000 Part 4 Section 3
Surge	CS116	IEC EN 61000 Part 4 Section 5 and 12 or IEEE C62.41-1991
Electrically-Fast Transient	CS115	IEC EN 61000 Part 4 Section 4 or IEEE C62.41-1991
Electrostatic Discharge	N/A	IEC EN 61000 Part 4 Section 2
Emissions Tests		
	MIL-STD-461E	Commercial Standard
Low-Frequency Conducted	CE101	None
High-Frequency Conducted	CE102	IEC EN 61000-6-4 or FCC 47 CFR Part 15
Low-Frequency Radiated	RE101	None
High-Frequency Radiated	RE102	IEC EN 61000-6-4 or FCC 47 CFR Part 15

Testing Standards

This guideline document draws from three families of EMI testing standards:

- Department of Defense Interface Standard MIL-STD-461E, “Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment”
- IEC Standard European Norm (EN) 61000, Electromagnetic Compatibility (EMC) - Part 3 “Limits” and Part 4 “Testing and Measurement Techniques”
- FCC 47CFR Part 15, “Radio Frequency Devices”

Equipment formerly tested and qualified according to earlier revisions of the above standards is considered acceptable if each applicable test type was performed according to the required testing parameters.

This document endorses both military and commercial standards where they can be supported by a technical basis. The purpose, methodology, and critical testing parameters, including testing levels and frequency ranges, were reviewed in determining what commercial standards (if any) could be endorsed for satisfying the requirements of each test type. This review included the IEC EN 61000 series; Federal Communications Commission (FCC) 47CFR Parts 15 and 18; International Special Committee for Radio Interference (CISPR) 11, 14, 15, 16, and 22; American National Standard Institute (ANSI) 63.4 and 63.12, and IEEE 187 and 1140 commercial standards. The recommended military and commercial standards are listed in Table 5-2. Note that where commercial standards are endorsed, recommended testing levels for each test type have been specified in this section.

Commercial standards listed above but not endorsed in the list in Table 5-2 could not be supported due to differences in testing methodologies, amplitudes, or range of frequencies. A documented technical basis should be provided when certification to a commercial testing standard not listed in Table 5-2 is used to satisfy any of the testing recommendations of this report.

Functional Requirements and Acceptance Criteria

Equipment functional requirements and acceptance criteria should be well understood and documented, as they are critical in evaluating the acceptability of test results. This information should be incorporated into testing plans and procedures developed prior to laboratory testing and should be documented in a test report. One option for ensuring that functional requirements and acceptance criteria are properly incorporated into testing documentation is to develop an EMI testing specification, which can be attached to or referenced in purchase orders [25].

All critical, essential, and protected equipment functions should be monitored for acceptable operation and performance before, during, and shortly after testing. Critical performance and acceptance criteria should be documented in testing procedures and monitored during testing. The test is considered a success if the equipment does not exhibit any malfunction, degradation, or deviation in performance or accuracy beyond documented acceptance criteria. Any anomalies during testing or malfunction, degradation, or deviation in performance should be documented and evaluated for acceptability.

Considerations for EMI Testing of Commercial Grade Equipment

Most equipment not designed to withstand the scope and amplitude of the testing specified by this report will not exhibit 100% acceptable results or performance. This is also true for most commercial grade equipment. Modifications to equipment shielding, filtering, and grounding may be necessary to achieve acceptable testing results. Modifications to standard commercial designs required to achieve acceptable testing results should be documented and the installed configuration should be controlled. Equipment should be installed with the same shielding, grounding and filtering modifications that were used to pass the laboratory qualification tests.

Component Level Replacement and EMC Qualification

In situations where system components are being replaced, it may be impractical to test the entire component/system due to factors such as size and availability. One method for qualifying replacement components is as follows:

1. Review operating experience and equipment history to determine the EMC performance of the existing system and its components. If the existing system has no identified EMI issues, proceed to Step 2.
2. Develop a test plan according to EPRI TR-102400 [25] to perform emissions and susceptibility testing according to the testing standards for the existing component (see Table 5-2). This plan should focus on measurements that identify the susceptibility thresholds and emissions for each applicable test type.
3. Compare the emissions and susceptibility thresholds between the existing component and the new component. The new component can be qualified for the application if testing demonstrates that the emissions from the new component are less than or equal to those from the existing component, and the susceptibility thresholds for the new component are greater than or equal to those for the existing component. The results of this analysis and the data should be documented in a final qualification report [25].

Testing Limits, Frequencies, and Other Considerations

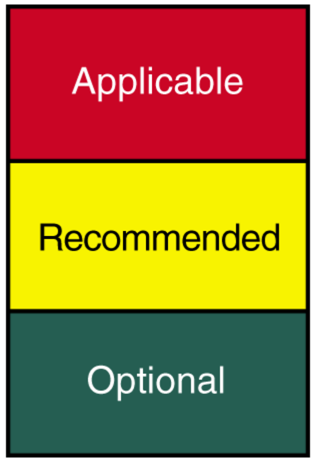
The following pages provide guidance for susceptibility testing and emissions monitoring for equipment. The icons that accompany the descriptions are color-coded in the following manner:

Red	=	Safety-related equipment
Yellow	=	Equipment important to power production
Green	=	Non-safety-related equipment

The text within each icon summarizes the recommended guidance, which can also be found in Table 5-1. For example, if the equipment is safety-related (red), then the test is **applicable** (i.e., it should be performed). If the equipment is important to power production (yellow), then the test is **recommended**. If the equipment is non-safety-related (green), then the test is **optional**, but may be prudent, depending on the specific circumstances.

Susceptibility Tests

Low-Frequency Conducted Susceptibility



Applicability

- Required for safety-related equipment
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives
Perform either the MIL-STD-461E test or the IEC tests.

- MIL-STD-461E, CS101
- IEC EN 61000-4-13 Class 2 or higher
- IEC EN 61000-4-16, Level 3 (see notes for applicability)

Purpose and Notes
This test verifies the ability of equipment to withstand signals coupled onto input power leads. It should be performed according to the CS101 or EN 61000-4-13 testing configuration. Figure 5-1 provides the recommended susceptibility limits in terms of dBμA (as opposed to voltage). To convert from the voltage limits specified in MIL-STD-461E to current limits, a transfer impedance of 0.5 ohms is used.

IEC 61000-4-16 applies only to certain installation conditions. This test should be considered for installations exposed to high common-mode disturbances originating from power lines and return leakage currents in the earthing/grounding system. See Appendix H for additional details.

Limits
See Figure 5-1

Frequency
MIL-STD-461E
For DC applications: 30 Hz to 150 kHz
For AC applications: 120 Hz (power frequency 2nd harmonic) to 150 kHz

IEC EN 61000-4-13
For AC applications: 16 Hz to 2.4 kHz

IEC EN 61000-4-16
For AC and DC applications: DC to 150 kHz

Regulatory Guide 1.180 Rev. 1 Differences
Regulatory Guide 1.180 Rev. 1 requires IEC EN 61000-4-16. See Notes above and Appendices H & I for details.

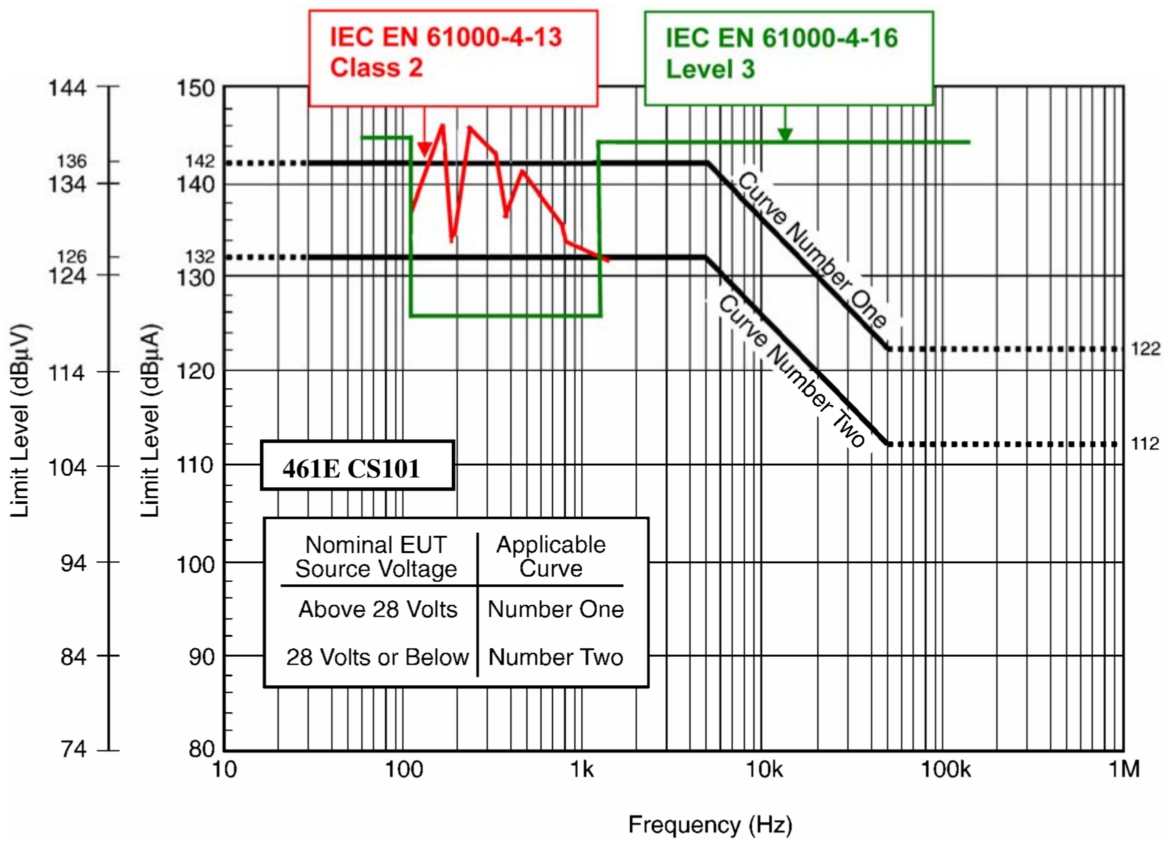
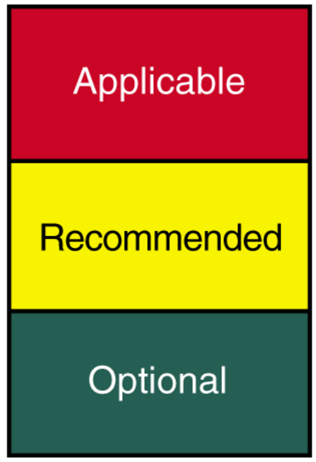


Figure 5-1
Low-Frequency Conducted Susceptibility Testing Limit

High-Frequency Conducted Susceptibility



Applicability

- Required for safety-related equipment
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives
Perform either the MIL-STD-461E test or the IEC test.

- MIL-STD-461E, CS114 Curve 3
- IEC EN 61000-4-6 Level 3

Purpose
This test verifies the ability of equipment to withstand radio-frequency signals coupled onto power and signal cables. It should be performed according to the CS114 or IEC EN 61000-4-6 test setup and data reported in dBμA. Equipment tested in accordance with MIL-STD-461E RS103 may be exempted from this test between 30 and 200 MHz.

Limits
See Figure 5-2

Frequency
MIL-STD-461E
10 kHz–200 MHz

IEC EN 61000-4-6
150 kHz –80 MHz

Notes

The test limit level for high frequency conducted susceptibility is based on the MIL-STD-461E CS114 Curve Number 3: use of the test requirements curve for Army Ground Installations would also be satisfactory, because it bounds the recommended test limits (see Figure 5-2).

Regulatory Guide 1.180 Rev. 1 Differences

Regulatory Guide 1.180 specifies a different, customized CS114 limit and different limits for power & signal cables for both the CS114 and IEC EN 61000-4-6 tests. See Appendices H & I for details.

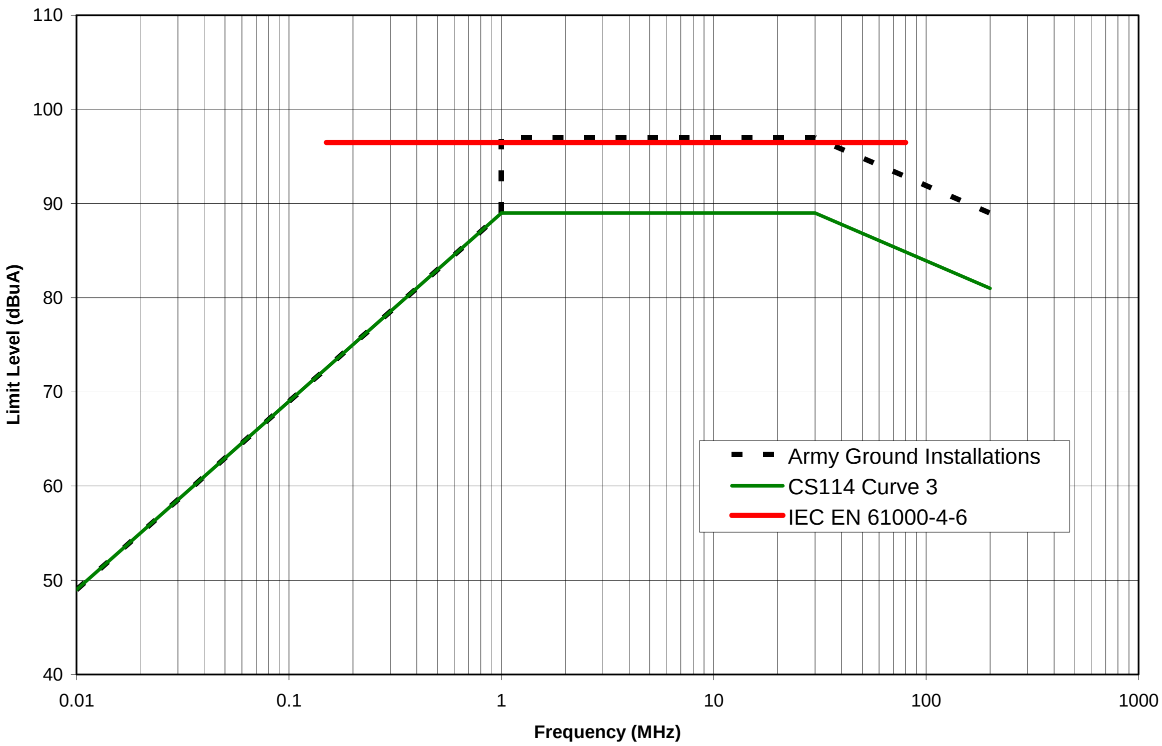
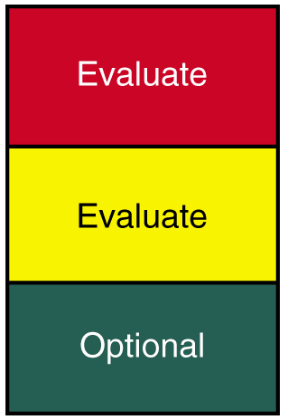


Figure 5-2
High-Frequency Conducted Susceptibility Testing Limit

Low-Frequency Radiated Magnetic Field Susceptibility



Applicability

- Evaluate for safety-related equipment as defined below
- Evaluate for equipment important to power production as defined below
- Optional for non-safety-related equipment as defined below

Testing Standards and Qualifications Alternatives
Perform either the MIL-STD-461E test or the IEC tests.

- MIL-STD-461E, RS101 Army applications
- IEC EN 61000-4-8 Class 4
- IEC EN 61000-4-9 Class 4
- IEC EN 61000-4-10 Class 4 (See Notes for applicability)

Purpose and Notes
This test verifies the ability of equipment to withstand radiated magnetic fields. It should be required for equipment installed in close proximity (< 1 m) to sources of large magnetic fields (> 300 A/m) or for installations that do not satisfy the limiting practices outlined in Section 4.

IEC EN 61000-4-10 is applicable only to equipment to be installed in certain environments. This test should be considered for installations near damped oscillatory magnetic field sources such as high voltage bus bar switching. For equipment to be installed in locations without such fields, the test need not be performed.

Limits
See Figure 5-3

Frequency
MIL-STD-461E
30 Hz–100 kHz

IEC EN 61000-4-8
60 Hz

IEC EN 61000-4-9
60 kHz –50 kHz

IEC EN 61000-4-10
100 kHz –1 MHz

Regulatory Guide 1.180 Differences
Regulatory Guide 1.180 Rev. 1 requires IEC EN 61000-4-10. See Notes above and Appendices H & I for details.

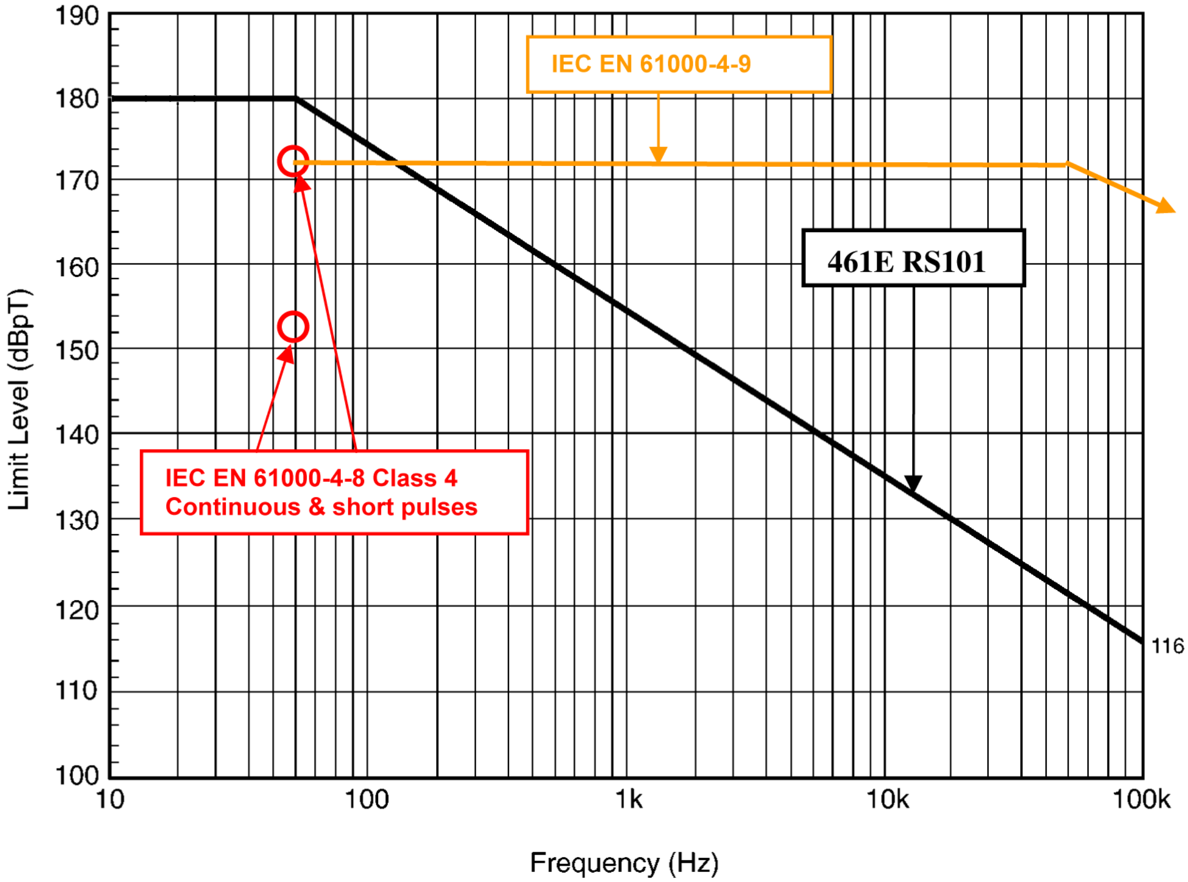
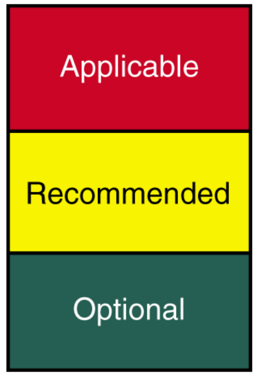


Figure 5-3
Low-Frequency Radiated Susceptibility Testing Limit

High-Frequency Radiated Electric Field Susceptibility



Applicability

- Required for safety-related equipment
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives
Perform either the MIL-STD-461E test or the IEC test.

- MIL-STD-461E, RS103 Navy Ships limit
- IEC EN 61000-4-3 Level 3

Purpose and Notes
This test verifies the ability of equipment to withstand radiated electric fields.

Equipment tested in accordance with IEC EN 61000-4-6 may be exempted from this test between 30 and 80 MHz.

The upper frequency limit of this test should be established by determining the highest known intentional frequency on site. This test should be performed to the highest known frequency or 1 GHz whichever is greater. Testing above 1 GHz is necessary to address the use of wireless devices and other devices operating at frequencies above 1 GHz.

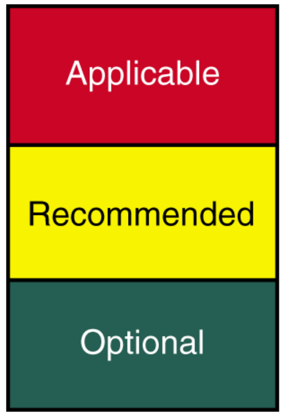
Limit
10 V/m for all test frequencies

Frequency
MIL-STD-461E
10 kHz–10 GHz or 30 MHz–10 GHz (if also performing CS114)

IEC EN 61000-4-3
26 MHz-1GHz

Regulatory Guide 1.180 Differences
None.

Surge



Applicability

- Required for safety-related equipment
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives
Perform either (a) both of the IEC tests or (b) the IEEE C62.41 test.

- IEC EN 61000-4-5 Level 3 for most plant systems for the considerations discussed below; Level 4 for systems connected to external lines
- IEC EN 61000-4-12 Level 3 for most plant systems for the considerations discussed below; Level 4 for systems connected to inductive loads
- IEEE Std. C62.41-1991, Category B - Low or Medium Exposure

Purpose
This test verifies the ability of equipment to withstand high-energy overvoltage conditions on power and interconnection lines due to switching and lightning transients.

Limits (See Notes)
Voltage = ± 2 kV_{p-p} for secondary or derived power distribution systems
Voltage = ± 4 kV_{p-p} for primary power connected to external lines
Voltage = ± 2 kV_{p-p} for shields and ground leads connected to remote (> 30 m) grounds

IEC EN 61000-4-5 Waveform
Pulse Shape
Impulse of 1.2 µs (± 20%) rise time, 50 µs pulse width, open circuit, double exponential
Impulse of 8 µs (± 20%) rise time, 20 µs pulse width, short circuit, double exponential

Repetition
Allow 30–120 seconds between surge tests

IEC EN 61000-4-12 Waveform
Pulse Shape
Oscillating wave with 75 ns (± 20%) rise time

Oscillation Frequencies
100 kHz & 1 MHz

Repetition
400 Hz repetition rate

Burst Duration
> 2 seconds

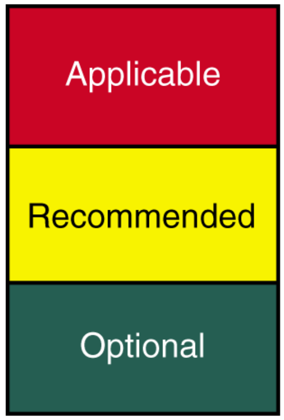
Notes
The MIL-STD-461E CS116 damped sinusoidal wave test represents coupled and not unidirectional energy. The slower rise time and longer duration result in a less challenging test than the combination wave test (IEC EN 61000-4-5). Thus, CS116 is not recommended.

Regulatory Guide 1.180 Differences

- Regulatory Guide 1.180 Rev. 1 endorses CS116 (but only for signal cables).
- Regulatory Guide 1.180 Rev. 1 specifies different levels for signal cables for CS116, IEC EN 61000-4-5 and IEC EN 61000-4-12.

See Notes above and Appendices H & I for details.

Electrically-Fast Transient/Burst



Applicability

- Required for safety-related equipment
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives
Perform either the MIL-STD-461E test or the IEC test or the IEEE C62.41 test.

- MIL-STD-461, CS115
- IEC EN 61000-4-4 Level 3 (see Notes)
- IEEE Std. C62.41-1991, Category B - Low Exposure

Purpose
The purpose of this test is to verify the ability of equipment to withstand repetitive fast transients (bursts) on supply, signal, and control cables due to switching transients created by inductive loads and relay contact bounce.

Limits (See Notes)
Voltage = ± 2 kV_{p-p} for power supply ports (with coupling/decoupling network)
Voltage = ± 1 kV_{p-p} for I/O, data, and control ports (with capacitive clamp)

Pulse Shape
Impulse of 5 ns (± 30%) rise time and 50 ns (± 30%) pulse width, double exponential

Repetition
Repetition rate = 5 kHz
Burst duration = 15 ms
Burst period = 300 ms

Notes

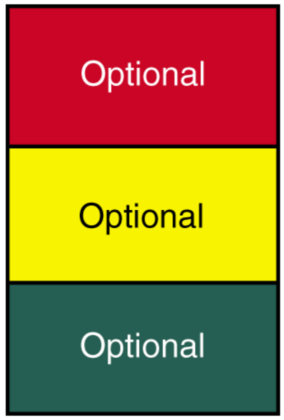
Control ports that control unsuppressed inductive loads should be tested to ± 2 kV_{p-p}. The coupling/decoupling network should be used for testing power or control ports that connect to unsuppressed inductive loads (such as relays and solenoids). I/O, data, and control cables routed with power supply or control cables with unsuppressed inductive loads should also be tested to ± 2 kV_{p-p}. The capacitive coupling clamp may be used for testing I/O, data, and control cables routed with power supply or control cables with unsuppressed inductive loads.

Regulatory Guide 1.180 Differences

- Regulatory Guide 1.180 Rev. 1 specifies CS115 only for signal cables and to a lower level than in MIL-STD-461E (2 A rather than 5 A).
- Regulatory Guide 1.180 Rev. 1 specifies levels of 2-4 kV for power and 1-2 kV for signal leads.

See Notes above and Appendices H & I for details.

Electrostatic Discharge



Applicability

- Optional for safety-related equipment
- Optional for equipment important to power production
- Optional for non-safety-related equipment

Testing Standard

- IEC EN 61000-4-2 Level 4 (see Notes)

Purpose

This test verifies the ability of equipment to withstand electrostatic discharge, which may occur from personnel coming into contact at human-machine interface points of equipment during normal operation.

Pulse Amplitude
± 15 kV air discharge
± 8 kV contact discharge

Pulse Wave Shape
Specified as current output from a 150 pF storage capacitor through a 330-ohm discharge resistance into a specific load defined in each referenced standard.

Pulse Rise Time
≤ 1 ns

Pulse Decay Time
Approximately 30 ns at 50% amplitude

Repetition

Apply a minimum of 10 simulations for each polarity at each test point while the system is operating.

Notes

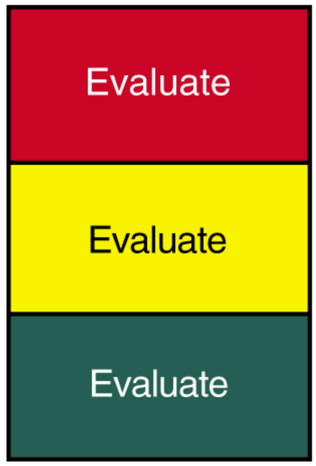
Because electrostatic discharge (ESD) is not considered a common-mode failure mechanism for safety-related systems, this is specified as an optional test. Test points should be selected on the basis of accessibility during normal operation. Components such as panel displays, keyboards, and controls may be touched during operation and should therefore be tested extensively. All human-machine interface points electrically isolated from ground should be tested. Side or rear panels not exposed during normal operation need not be tested directly. Cables entering the rear or sides should be tested at the entry point. The highest probability of interference will be at points where wire bundles or loops are close to the point of discharge. ESD tests should be performed when the relative humidity in the test facility is 30–60%.

Regulatory Guide 1.180 Differences

ESD is not discussed in Regulatory Guide 1.180 Rev. 1. See Notes above and Appendices H & I for details.

Emissions Tests

Low-Frequency Conducted Emissions



Applicability (See Notes)

- Evaluate for safety-related equipment
- Evaluate for equipment important to power production
- Evaluate for non-safety-related equipment

Testing Standard

- MIL-STD-461E, CE101-4, Navy ASW and Army aircraft limit

Purpose
The purpose of this test is to limit harmonics emissions on power cables to the levels shown in Figure 5-4 to ensure that new equipment does not adversely affect the quality of the power source to which it will be connected.

Notes
This test should be performed unless there are criteria for controlling the power quality of the equipment input power source.

Equipment may be exempt from this test if the following two conditions are met:

1. The power quality requirements of the equipment are consistent with the existing power supply and design practices include power quality controls.
2. The new equipment will not impose additional harmonic distortion on the power distribution system exceeding 5% total harmonic distortion (THD) or other power quality criteria established with a valid technical basis [2].

Limits
See Figure 5-4

Limit Relaxation
For CE101 testing, the limit may be relaxed as documented in Figure 5-4.

Frequency
MIL-STD-461E
For DC applications: 30 Hz–10 kHz
For AC applications: 120 Hz–10 kHz

Regulatory Guide 1.180 Differences
Regulatory Guide 1.180 Rev. 1 specifies CE101 Submarine limits for AC and a customized level of 130 dBμA for DC. See Notes above and Appendices H & I for details.

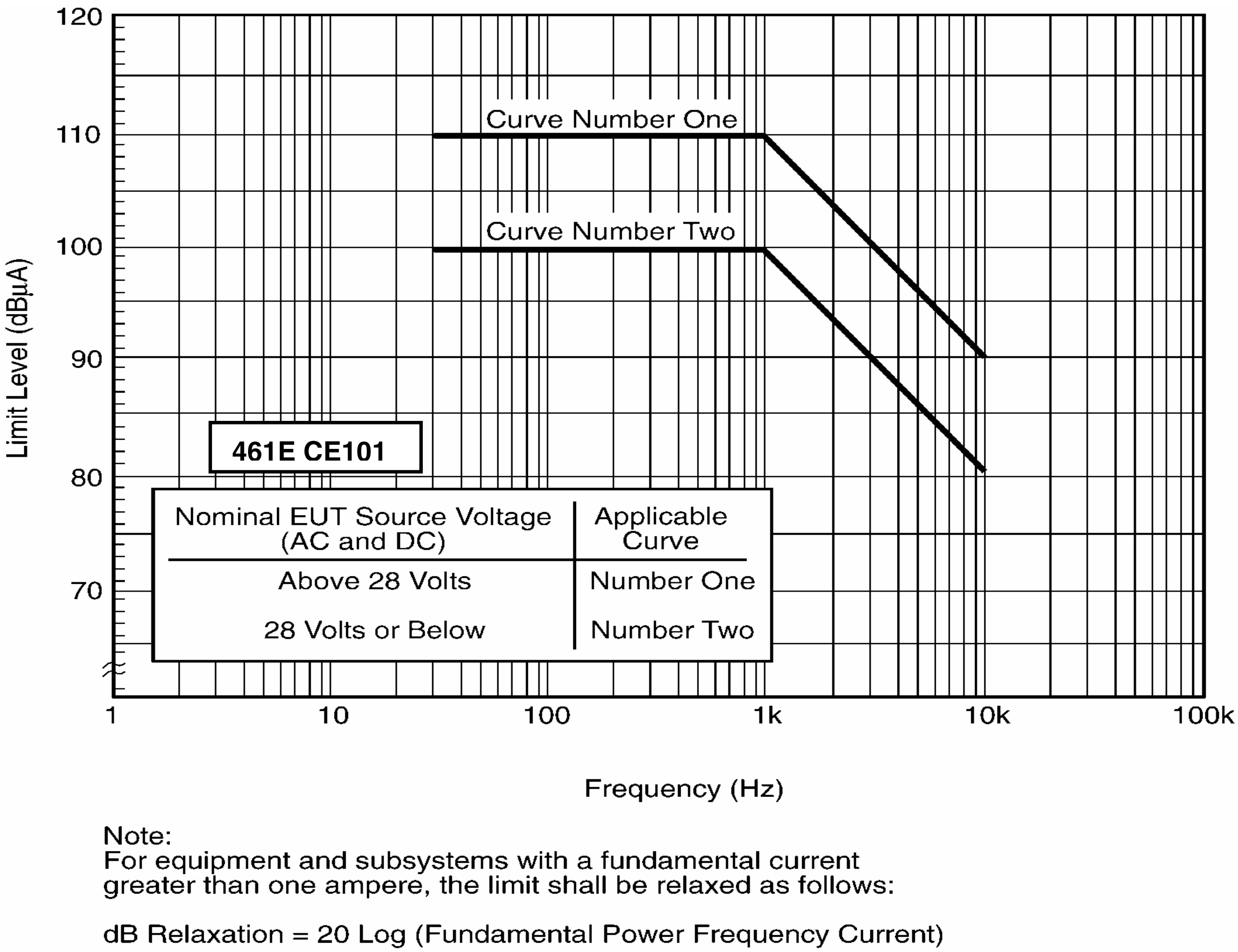
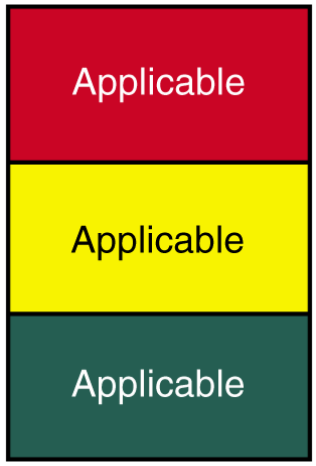


Figure 5-4
Low-Frequency Conducted Emissions Testing Limit

High-Frequency Conducted Emissions



Applicability

- Required for safety-related equipment
- Required for equipment important to power production
- Required for non-safety-related equipment

Testing Standards and Qualifications Alternatives
Perform either the MIL-STD-461E test, the IEC test or the FCC test.

- MIL-STD-461E, CE102
- IEC EN 61000-6-4 to the Class A or B limits for Group 1 per CISPR 11 measurement methods
- FCC 47 CFR Part 15, Class A or B limits

Purpose
This test limits equipment emissions on power cables, including returns and neutrals, to the levels defined in Figure 5-5. This ensures that new equipment emissions do not adversely affect existing plant equipment.

Notes
Figure 5-5 provides the recommended emissions limits in terms of dBμA as opposed to voltage. To convert from the voltage limits specified in MIL-STD-461E to current, a transfer impedance of 50 ohms is used. This impedance value is recognized as the nominal characteristic impedance of the interconnecting cables.

Limits
See Figure 5-5

Limit Relaxation
For CE102 the limit may be relaxed, depending on voltage level, as documented in Figure 5-5.

Frequency
MIL-STD-461E
10 kHz–10 MHz

IEC EN 61000-6-4
150 kHz–30 MHz

FCC 47 CFR Part 15
150 kHz–30 MHz

Regulatory Guide 1.180 Differences
Regulatory Guide 1.180 Rev. 1 specifies CE102 to a customized limit that is less restrictive than the MIL-STD-461E limit. See Notes above and Appendices H & I for details.

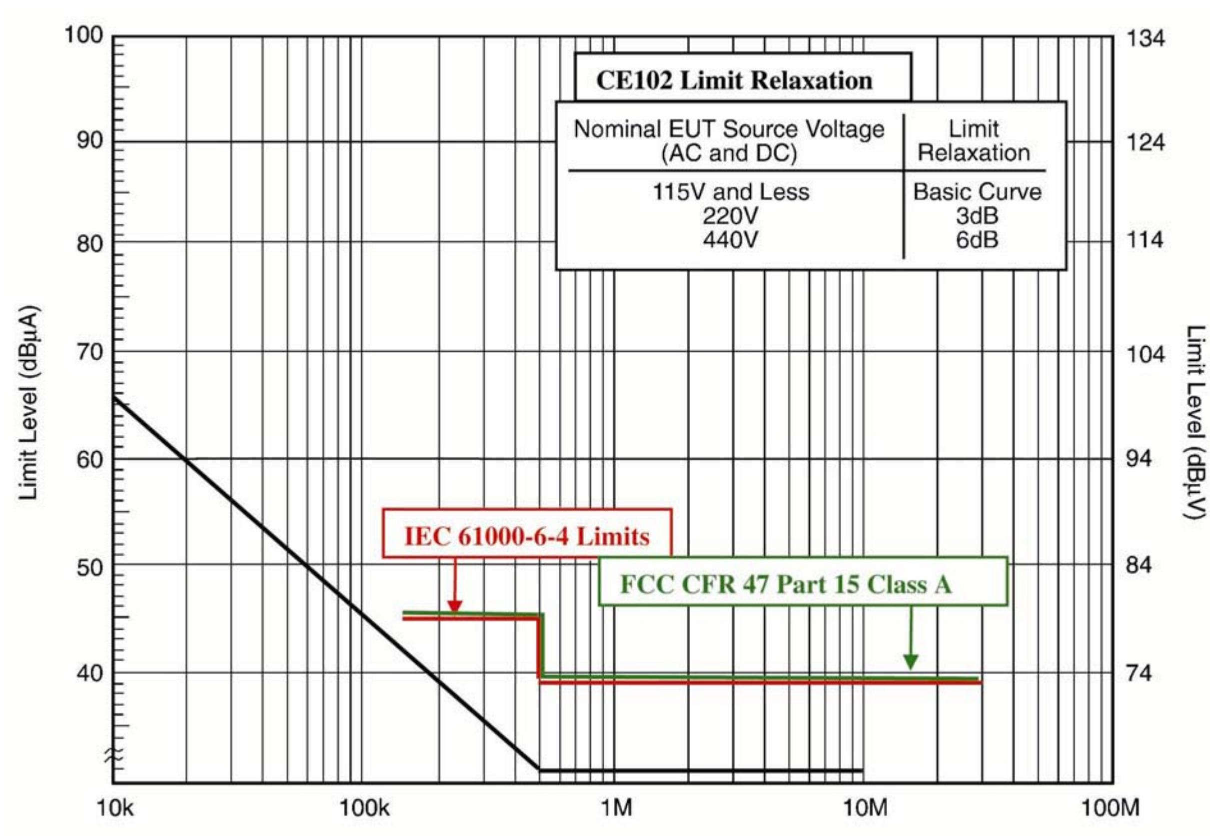
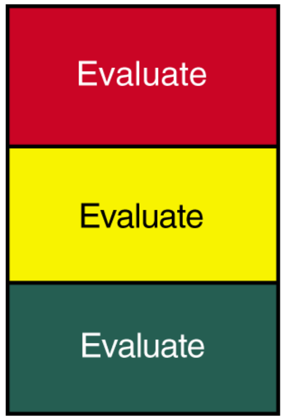


Figure 5-5
High-Frequency Conducted Emissions Testing Limit

Low-Frequency Radiated Magnetic Field Emissions



Applicability (See Notes)

- Evaluate for safety-related equipment
- Evaluate for equipment important to power production
- Evaluate for non-safety-related equipment

Testing Standard

- MIL-STD-461E, RE101 to the customized limit of Figure 5-6

The endorsement of a commercial standard to satisfy this testing requirement was not possible due to differences in the testing methodologies and frequency ranges.

Purpose
This test limits magnetic field equipment emissions to the levels defined in Figure 5-6 to ensure that new equipment emissions do not adversely affect existing plant equipment.

Notes
This test should be performed for new equipment (if it is a source of large magnetic fields [> 300 A/m]) installed in close proximity (< 1 meter) to equipment sensitive to magnetic fields (CRTs or magnetically operated sensors). This test should also be performed if the equipment and cable separation requirements of the EMI Limiting Practices are not satisfied. All measurements should be performed at 7 cm, as specified by RE101.

Limits
See Figure 5-6

Frequency
MIL-STD-461E
30 Hz–100 kHz

Regulatory Guide 1.180 Differences

Regulatory Guide 1.180 Rev. 1 specifies RE101 to a customized limit that is slightly different from the limit in Figure 5-6. See Notes above and Appendices H & I for details.

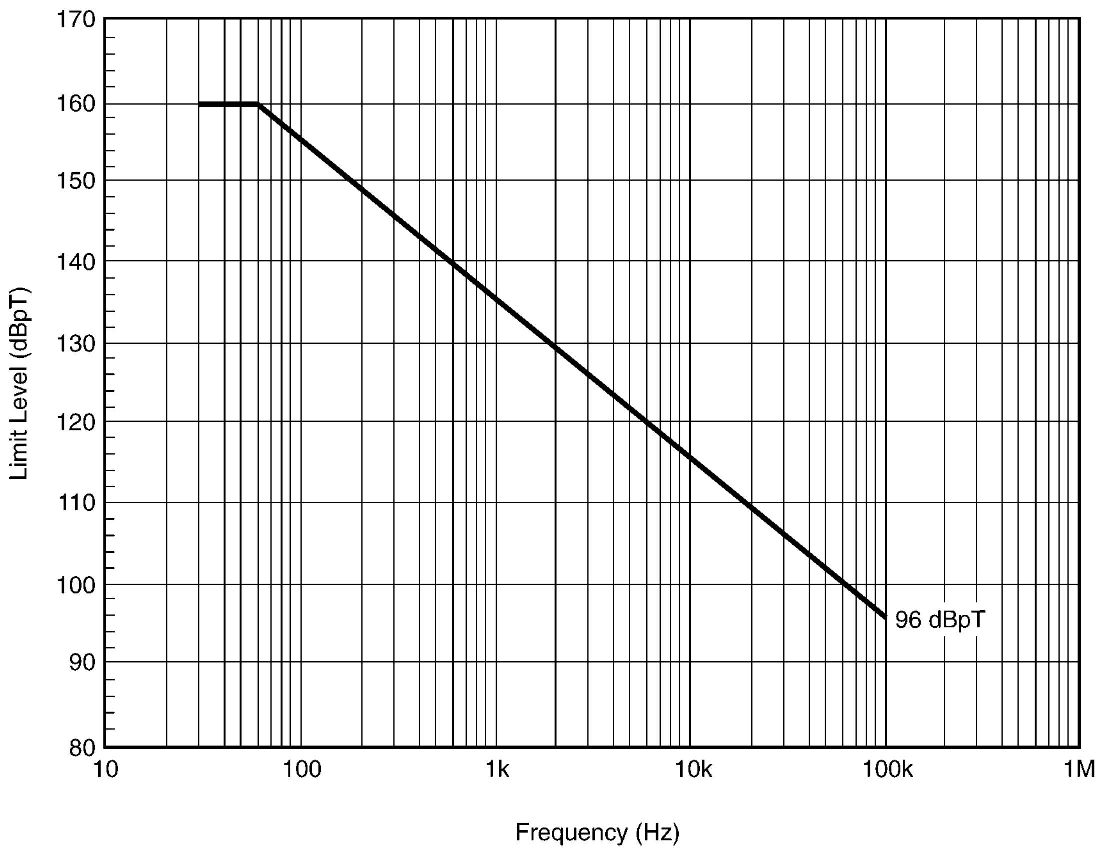
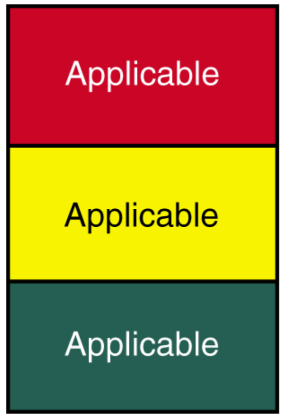


Figure 5-6
Low-Frequency Radiated Emissions Testing Limit

High-Frequency Radiated Electric Field Emissions



Applicability

- Required for safety-related equipment
- Required for equipment important to power production
- Required for non-safety-related equipment

Testing Standards and Qualifications Alternatives
Perform either the MIL-STD-461E test, the IEC test, or the FCC test.

- MIL-STD-461E, RE102-4 Limit for Navy Fixed & Air Force Ground Applications
- IEC EN 61000-6-4 to the Class A or B Limits for Group 1 per CISPR 11 measurement methods
- FCC 47 CFR Part 15 Class A or B Limits

Purpose
This test limits radiated electric field equipment emissions to the levels defined in Figure 5-7 to ensure that new equipment emissions do not adversely affect existing plant equipment.

Notes
This test should be performed up to 1 GHz or 5 times the highest internal generated frequency within the EUT, whichever is greater. Measurement beyond 10 GHz is not required.

Frequency
MIL-STD-461E
2 MHz–18 GHz

IEC EN 61000-6-4
30 MHz–1 GHz

FCC 47 CFR Part 15
30 MHz–1 GHz

Limits
See Figure 5-7

Regulatory Guide 1.180 Differences

- Regulatory Guide 1.180 Rev. 1 specifies RE102 to a slightly less restrictive customized limit.
- Regulatory Guide 1.180 Rev. 1 does not endorse FCC 47 CFR Part 15 to Class B limits, only Class A limits.

See Notes above and Appendices H & I for details.

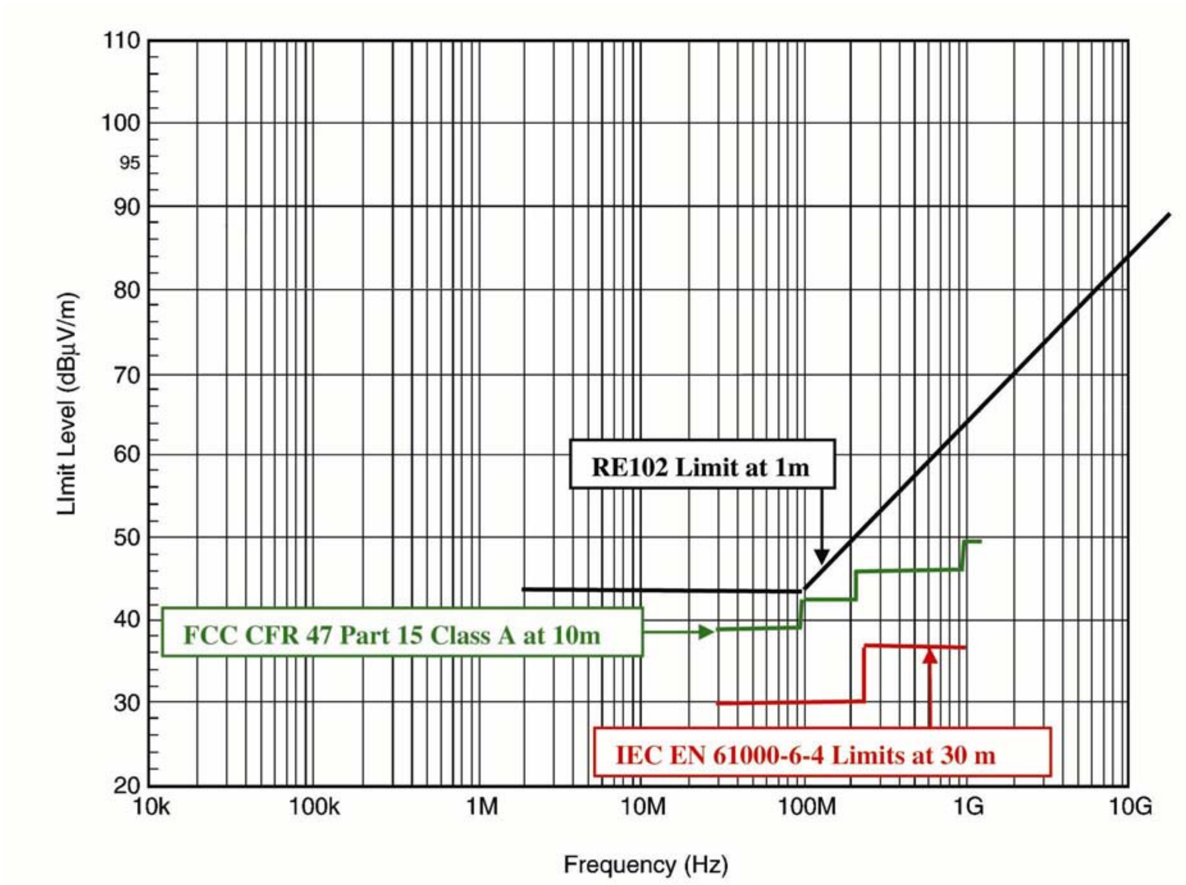


Figure 5-7
High-Frequency Radiated Emissions Testing Limit

6
MARGIN ANALYSIS OF RECOMMENDED TESTING LIMITS

The following information is reviewed in this section:

- Equipment susceptibility testing levels – to ensure that they bound (remain higher than) the highest composite plant emissions levels for all tested frequencies.
- The margin between equipment susceptibility testing levels and highest composite plant emissions – to ensure that adequate margin exists to address uncertainties and other analysis variables.
- Equipment emissions testing levels – to ensure that they remain sufficiently below the highest composite plant emissions levels. Equipment emissions levels must be maintained below existing plant emissions limits to ensure that they do not increase plant emissions levels in areas of concern.

Low-Frequency Conducted Emissions

All measured plant emissions are bounded by the equipment susceptibility testing limit.

The margin between the equipment susceptibility testing limit and highest composite plant emissions level is 14 dBμA (5 times greater) below 120 Hz and more than 30 dBμA (more than 32 times greater) beyond 1 kHz (see Figure 6-1). The smallest difference (14 dBμA) provides adequate margin and reasonable assurance of EMC. The differential-mode levels measured during these tests were generally higher than the common-mode levels. The common-mode emissions data are more indicative of actual EMI levels capable of affecting digital system operation, depending on the method of data transmission used in the digital system. Since the measurement of plant emissions includes transient emissions along with continuous-wave emissions, the margin between the plant emissions and the recommended equipment susceptibility limit is expected to be even larger between continuous-wave common-mode plant emissions and the equipment susceptibility testing limit.

The equipment emissions testing levels are sufficiently below the highest composite plant emissions levels from 120 Hz to 1 kHz. Above 1 kHz, the test levels are below the highest composite plant emissions by a small margin; however, this small difference is acceptable, because there are large amounts of margin between the equipment susceptibility testing limit and the highest composite plant emissions.

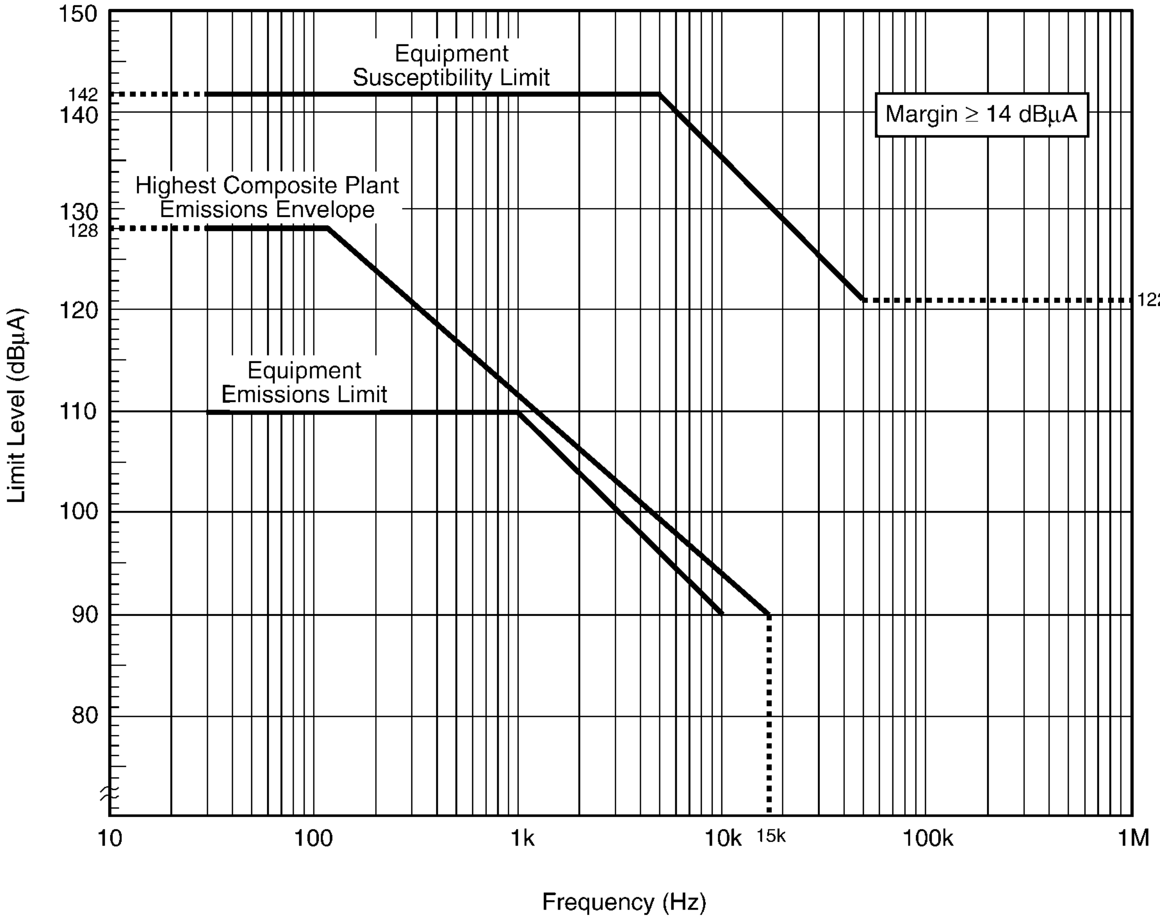


Figure 6-1
Low-Frequency Conducted Testing Limits and Margin Analysis

High-Frequency Conducted Emissions

The highest composite plant emissions envelope shown in Figure 2-3 does not form the basis for recommending equipment susceptibility testing limit for the reasons discussed in Appendices H and J. Figure 6-2 compares the recommended high-frequency conducted susceptibility limit to the recommended high-frequency conducted emissions limit. At low frequencies the allowable emissions level exceeds the susceptibility limits per MIL-STD-461E. Since the transmission paths of the energy for the emissions of the two tests are different (electrical conductors physically connected to the equipment for CE03 and CE102 versus coupling of electromagnetic fields from air to conductors for CS114), the tests should not be directly compared. The details are discussed in Section 5 and Appendices H and J of this report.

A margin analysis comparing the IEC testing limits to the highest composite plant emissions envelope over the range of testing frequencies for IEC EN 61000-4-6 revealed a minimum margin of approximately 8 dBµA at 150 kHz. At frequencies above 1 MHz, where the CS114 and 61000-4-6 testing limits are equal, the margin increases to approximately 18 dBµA or more.

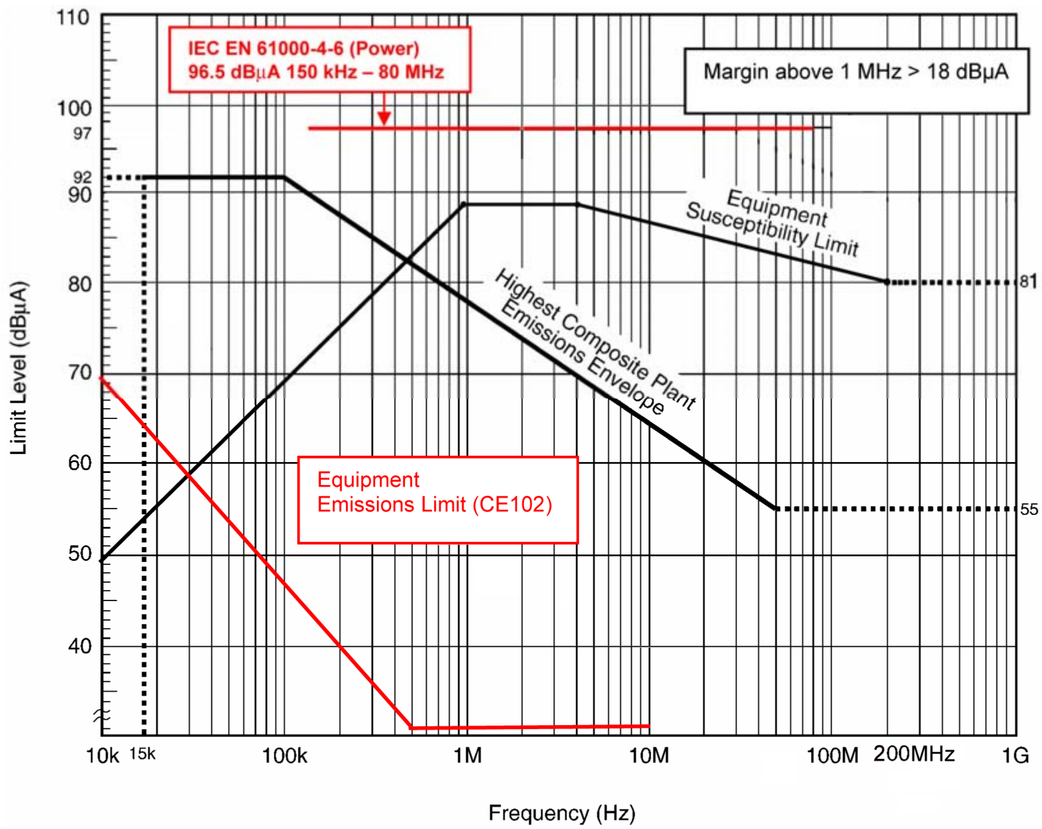


Figure 6-2
High-Frequency Conducted Testing Limits and Margin Analysis

Low-Frequency Radiated Magnetic Field Emissions

All measured plant emissions are bounded by the equipment susceptibility testing limit.

The margin between the equipment susceptibility level and the highest composite plant emissions level is 18 dBpT (7.9 times greater) between 30 and 60 Hz (see Figure 6-3). The margin is 20 dBpT (10 times greater) at frequencies above 60 Hz. This difference provides adequate margin and reasonable assurance of EMC. Because AC magnetic fields in the 30 Hz–50 kHz range exhibit rapid fall-off in field strength at short distances from the equipment that generates the EMI, measured values are expected to be much lower at distances just greater than 1 m from the source. As noted earlier, the highest magnetic fields displayed among the seven plants were recorded at the rear of a diesel control panel (162 dBpT) while the diesel generator was operating. This record is still 18 dBpT (7.9 times greater) below the recommended susceptibility test level. Again, a ferrous metal enclosure (such as the control panel cabinet) would reduce the level at least an additional 20 dBpT.

Although the equipment emissions testing levels exceed the highest composite plant emissions levels above 100 Hz, this condition is acceptable due to the rapid fall-off in field strength at short distances from the source. The 20-dBpT difference between the equipment susceptibility limit and equipment emissions limit provides adequate margin and reasonable assurance of EMC.

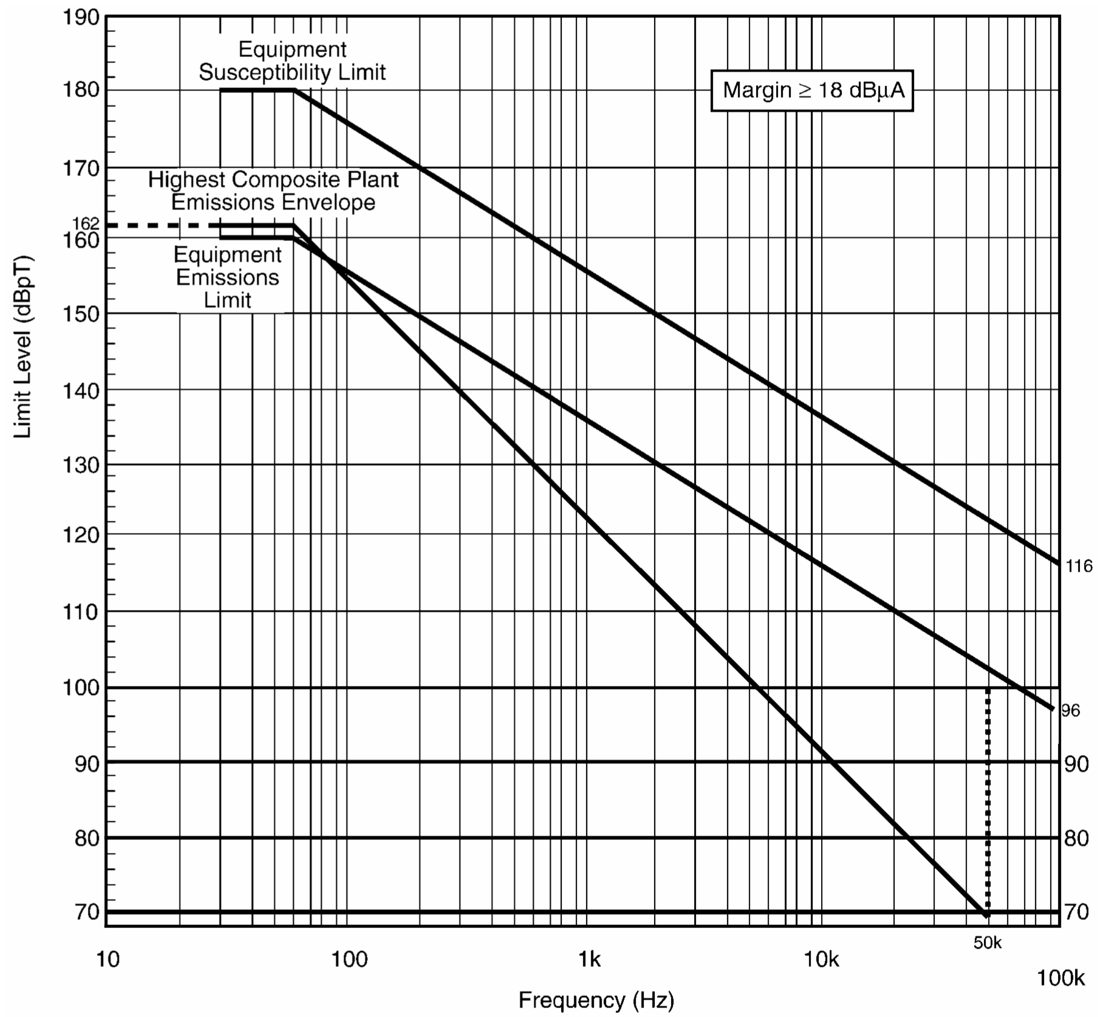


Figure 6-3
Low-Frequency Radiated Testing Limits and Margin Analysis

High-Frequency Radiated Electric Field Emissions

All measured plant emissions are bounded by the equipment susceptibility testing limit.

The margin between the equipment susceptibility level and the highest composite plant emissions level is 43 dBµV/m (141 times greater) between 100 and 200 kHz, excluding emissions from portable transceivers (see Figure 6-4). The margin is even greater at frequencies above 200 kHz. This difference provides adequate margin and reasonable assurance of EMC. Most plants place administrative controls on the use of portable transceivers near critical equipment to ensure that equipment susceptibility levels are not exceeded. See Section 4, “Practices to Ensure EMC,” for guidance on the use of exclusion zones to control use of portable transceivers. Technological trends indicate that plants are leaning toward higher frequency devices operating at lower power levels. This should further minimize the impact of these devices on digital equipment.

The equipment emissions testing levels are sufficiently below the highest composite plant emissions levels up to 100 MHz. Above 100 MHz, the equipment emissions limits increase to accommodate the use of new high-speed technology. Although the equipment emissions testing levels exceed the highest composite plant emissions levels above 700 MHz, this condition is acceptable because there are large amounts of margin (> 60 dBµV/m) between the equipment susceptibility testing limit and highest composite plant emissions level beyond 700 MHz.

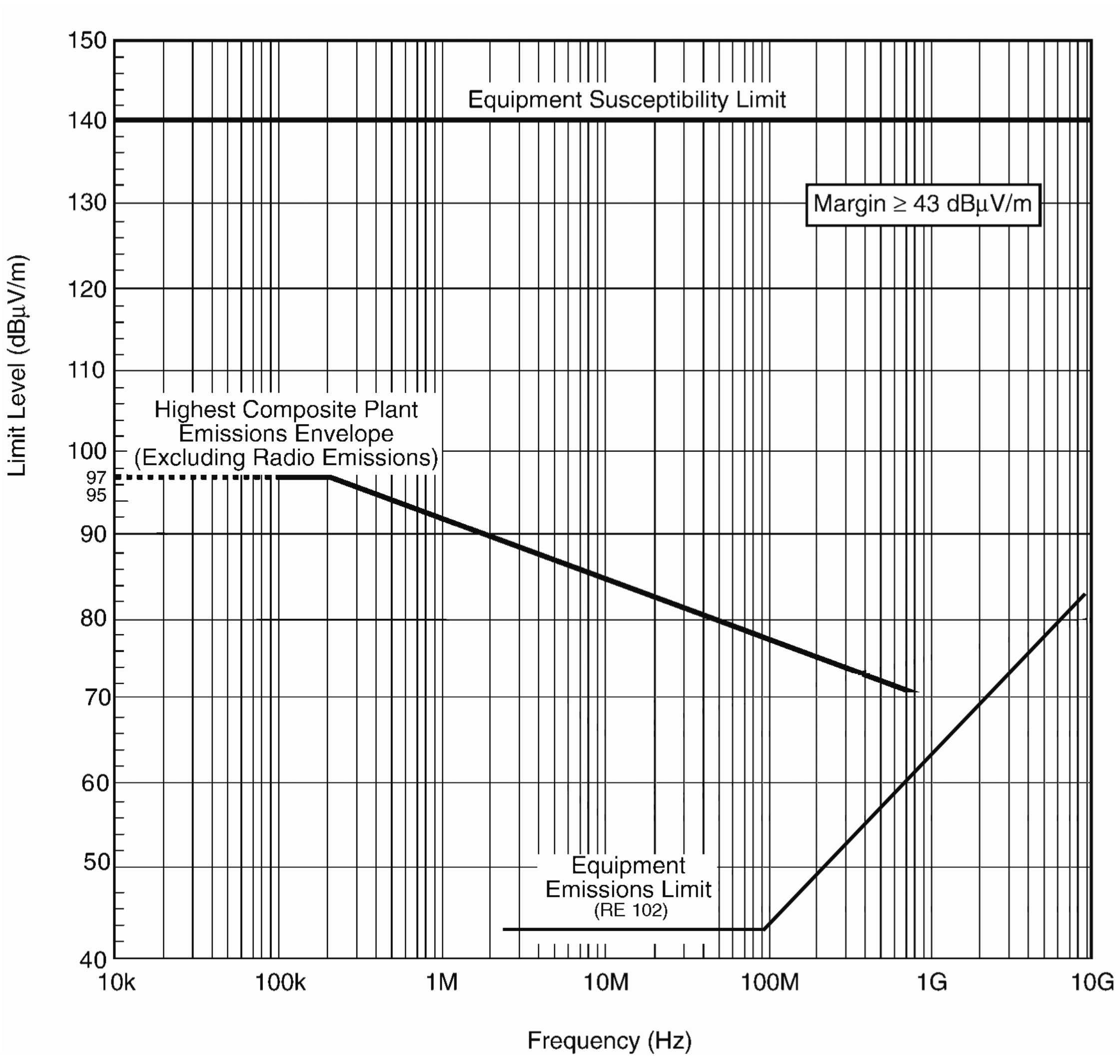


Figure 6-4
High-Frequency Radiated Testing Limits and Margin Analysis

Transient Emissions

All measured plant emissions are bounded by the equipment susceptibility testing limit.

The margin between the equipment susceptibility level and the highest composite plant emissions level is 22 dBµA (12.6 times greater) across all frequencies (see Figure 6-5).

Efforts were made during generic emissions testing to identify and cycle sources of interference during transient testing. Otherwise, measurements were collected over a short sampling period, typically 30 minutes and no more than 60 minutes. Despite these efforts, it cannot be guaranteed that the measured transient emissions represent the absolute plant maximum level. A 22-dBµA margin is therefore necessary to provide adequate margin and reasonable assurance of EMC.

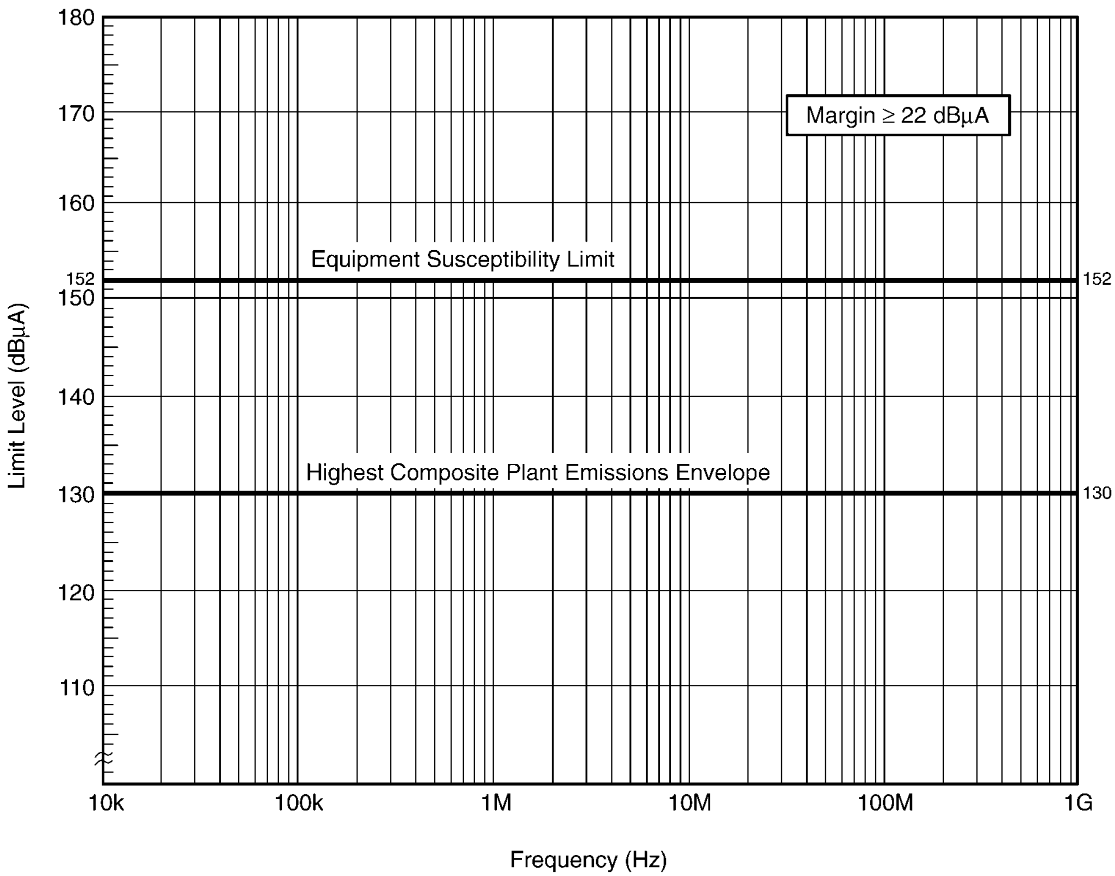


Figure 6-5
Transient Testing Limit Analysis

Generic Measurements Conclusions

The conclusions from the analysis and review of the prescribed testing limits and margins are as follows:

- The recommended susceptibility testing levels bound the highest measured plant emissions levels for all tested frequencies.
- The margin between equipment susceptibility testing levels and highest composite plant emissions is adequate to address uncertainties and other analysis variables and provides reasonable assurance of EMC.
- Recommended equipment emissions levels (limits) are sufficiently below the highest composite plant emissions levels that the emissions added by installation of new equipment do not result in an increase of overall plant emissions levels.

7 SUMMARY AND CONCLUSIONS

Operating experience has shown that most nuclear power industry EMI/RFI problems are primarily due to transient interference and inadequate control of portable communications devices. Transient interference is well understood and documented in various industry standards [29, 30]. Industry EMC standards do not require site emissions testing (mapping), but instead define equipment susceptibility testing levels based on expected plant emissions levels. Steady-state emissions recorded over a short period of time are unlikely to capture transient events. The most likely EMI/RFI emitters that could affect digital equipment operation are portable transceivers. It is reasonable to conclude that steady-state mapping is not useful for identifying these threats to digital systems.

Based on an understanding of interfering sources in nuclear power plants, generic emissions measurements were performed to characterize both steady-state and transient interference. Procedures were developed to measure the highest observed emissions environment for several plant systems. Plant emissions data have been obtained from seven plants and were used to justify EMC for digital modifications. The EMI Working Group has reviewed equipment susceptibility and emissions testing levels and compared them to the highest measured composite plant emissions levels. The following conclusions were derived from the analysis of the recommended testing levels and highest composite plant emissions data:

- The recommended susceptibility testing levels bound the highest composite plant emissions levels.
- The margin between equipment susceptibility testing levels and highest composite plant emissions is adequate to address uncertainties and other analysis variables and provides reasonable assurance of EMC.
- Recommended equipment emissions levels (limits) are sufficiently below the highest composite plant emissions levels to ensure that the emissions added by installation of new equipment do not result in an increase of overall plant emissions levels.

The EMI Working Group has also recommended EMI limiting plant practices, a set of design conditions that should be satisfied to help ensure that the highest observed plant emissions levels are bounded and the recommended equipment susceptibility testing levels are not exceeded. If the practices are satisfied, an EMI/RFI site survey will generally not be necessary. The recommended emissions and susceptibility levels have been conservatively established to ensure the future EMC of digital equipment with the industrial environment of a nuclear power plant. Guidelines were developed for proper grounding, equipment and cable separation, control of emissions from high-frequency EMI/RFI emitters and portable transceivers, and restriction of EMI sources in the vicinity of EMI/RFI sensitive equipment.

8
DEFINITIONS

Burst–A sequence of a limited number of distinct pulses or an oscillation of limited duration.

Continuous wave (CW)–Electromagnetic waves, the successive oscillations of which are identical under steady-state conditions.

Conducted emission–Desired or undesired electromagnetic energy that propagates along a conductor. Conducted emissions are referred to as conducted interference if they are undesired.

Degradation–An undesired departure in the performance of equipment from its expected performance.

EUT–Equipment under test.

Electric Field–Electric force that acts on a unit electric charge independent of the velocity of the charge.

Electric Field Strength–The magnitude of the electric field vector generally defined in volts per meter.

Electrically-Fast Transient (EFT)–Very short time duration (typically nanoseconds) of positive or negative excursions of voltage or current from steady-state condition on a nonperiodic basis.

Electromagnetic Compatibility (EMC)–The ability of equipment to function satisfactorily in its electromagnetic environment without introducing unacceptable electromagnetic emissions to other equipment in that environment.

Electromagnetic Environment–The electromagnetic fields, waves, or disturbances present in a transmission medium.

Electromagnetic Field–Time-varying field associated with the electric or magnetic forces as described by Maxwell equations.

Electromagnetic Interference (EMI)–A measure of electromagnetic radiation from equipment.

Electromagnetic Wave–A wave characterized by variations of electric and magnetic fields. Electromagnetic waves are known as radio waves, infrared waves, and light waves, depending on the frequency.

EMI/RFI Sensitive Cables/Conductors–Typically power and signal cables and conductors connected to low voltage I&C EMI/RFI sensitive equipment.

EMI/RFI Sensitive Equipment–Equipment characterized by its susceptibility to electromagnetic emissions. For the purposes of this report, it typically refers to digital, safety-related equipment; however, other types of equipment (safety or non-safety) can be classified as EMI/RFI sensitive.

Electrostatic Discharge (ESD)–The sudden transfer of electric charge between bodies at differing electrostatic potentials.

Immunity–The ability of equipment to perform without unacceptable degradation in the presence of electromagnetic emissions and disturbances.

Interference–Electrical noise that causes a disturbance or undesired response in equipment.

Magnetic Field–A state of a region such that a moving charged body in the region is subject to force in proportion to its charge and to its velocity.

Magnetic Field Strength–The magnitude of the magnetic field vector generally defined in amps per meter or picoTeslas.

New Equipment–Equipment installed after the issue date of this report.

Power Generation EMI/RFI Emitters–High voltage (typically 120 VAC and 125 VDC or higher) equipment including switchgear, motors, generators, transformers, inverters, power supplies, battery chargers, HVAC, lighting/dimmer panels, and other power generation equipment common to traditional power plant designs. Power supplies and transformers integral to the system are not included.

Surge–A short-duration, high-amperage electric current or high-amplitude voltage.

Susceptibility–The level at which an interfering electromagnetic emissions source interferes with the acceptable operation or performance of equipment.

9
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A

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B
EMI SOURCES IN THE POWER PLANT

Conducted Continuous-Wave Signals

Sources

Conducted continuous wave signals, observed as voltage or currents on conductors/cables, will range from 60 Hz power signals up to microwave communication frequencies.

At the lower frequencies, 10 kHz[1] and below, they will typically be due to lighting and power distribution system, including switching mode, DC power supplies. Major causes of EMI on the power distribution system are from the SCR based voltage controls.

At the higher frequencies, above 10 kHz, the continuous wave signals will be due to the pickup of radiated signals, possibly at the extremities of interconnecting cables to the digital safety system.

Coupling Mechanisms

The coupling mechanisms for the lower frequencies will be shared, common grounds or capacitive and inductive coupling between conductors/cables. At the lower frequencies the interconnecting conductors/cables may be analyzed as lumped circuit elements. The capacitive coupling and inductive coupling will tend to increase with increasing frequency. The shared, common signal returns (grounds) problem is significant at power frequencies and tends to decrease with increasing frequency.

Maximum Expected Level

The conducted continuous wave signals may be expressed in terms of voltage or current and the relationship of the voltage to current determines the impedance of the circuit. In that the impedance of the conductor/cable of a digital system will be unknown[2], a single expression of either volts or amperes will be misleading, tending to exaggerate voltage or current levels.

---

[1] This transition point between low-frequency conducted signals, which are analyzed by circuit analysis, and high-frequency signals, which respond much like radiated signals, will vary from 9 to 50 kHz in different standards. Any of these transition points may be used as long as they are used consistently.

[2] In the case of a radiating signal, the impedance of air/free space is well known. In the case of a conductor, the impedance may be the lumped impedance at lower frequencies, or characteristic impedance at higher frequencies.

For continuous wave signals, currents in the range of microamperes to 20 milliamperes[3] may be observed while voltages up to 1 volt root-mean-square (rms) are predicted for high-frequency pickup on conductors/cables. A 1 volt rms signal may be interpreted as 20 milliamperes on a 50 ohm characteristic impedance line (typical).

Radiated Continuous-Wave Signals

Sources

Continuous wave radiated signals are generated by some type of radiating antenna element, either intentional or inadvertent, which in turn is driven by a signal generator. Typical intentional radiating sources within the plant include: portable transceivers, perimeter security systems, cellular telephones, and microwave relays. Typical unintentional radiating sources include: arc welders, public address systems, switching mode power supplies, digital data transfer lines, motor/generator brush assemblies, arcing across poor connections in a power bus or ground system, switching devices such as silicon-controlled rectifiers (SCRs) and surge arrestors, and signal generators in measurement and control systems.

Coupling Mechanisms

Radiated signals are coupled by antennae, either intentional as in the case of a portable transceiver or cellular phone, or unintentional through a length or loop of cable or wire connecting to a digital system. The actual transfer of energy will be through the selective coupling of the electric field (dipole antenna) or the magnetic field (loop antenna). A radiated EMI wave or signal may be coupled to a pair of conductors or between a conductor and ground. It then becomes a guided wave, also discussed as a conducted continuous wave earlier in this appendix.

Maximum Expected Level

The EMI from a radiating source is generally measured as the strength of the electric field in terms of volts per meter, which falls off linearly as a function of distance from the source[4]. The electric field strength is proportional to the square root of the transmitter power.

[3] Typical currents measured on power conductors in a plant were less than 20 milliamperes above 1 kHz, selected to avoid the influence of the power frequency being carried by the conductors for normal operation.

[4] At a distance of 0.5 meter from a 5-watt spherical radiating source, the field strength in air would be 24.5 volts per meter, and at a distance of 1 meter, the field strength would be 12.24 volts per meter. Walkie-Talkies use antennae that have different gains and antenna patterns for direction transmission. Laboratory tests by a nuclear plant on 800-MHz, 3-watt Walkie-Talkies indicated an electric field strength of 10 volts per meter at a distance of 1 meter. This would be considered an ideal, highest level case.

The maximum expected field strength is expected to be caused by portable transceivers. A susceptibility test level of 10 volts per meter will provide a factor of 2.0 margin in excess of the expected level (that is, 5 V/m) due to controlled portable transceiver operation.

Surges

Sources

Surges are considered to be relatively high-energy, unidirectional pulses caused by lightning, load switching, and line faults. The classic surge waveform is described as a pulse with 1.2 microsecond rise time and 50 microsecond decay time, which is input to a high impedance circuit. Surges are generally encountered on the AC or DC power leads, on power grounds, and on conductors/cables that have no enveloping metallic shield from lightning or on conductors that connect between separate ground mats. Exposed power mains will be the main source of lightning caused surges. Lightning does not have to strike the power line or ground system directly to create a surge. The sudden return to earth of an induced charge, caused by elimination of the inducing charge, can cause significant surges in these systems. NRC Information Notice 2003-10 [48] describes the effects of a surge due to lightning on the alarm circuits of a criticality monitoring system.

Coupling Mechanisms

Surges are considered to be a directly coupled effect on power leads and grounds.

Maximum Expected Level

Expected surges on lines connecting to a digital safety system should be reduced significantly due to the location of the digital safety system and the source of power. If the power for the digital safety system is separately derived from the AC distribution system for the plant, the surges are expected to be significantly less than ± 2,000 volts (2kV).

Electrically-Fast Transients or Impulses

Sources

Electrically-fast transients or impulses are the low-energy equivalent of the surge. They are caused by nearby switching on short power distribution lines, where the actual energy stored in either the capacitance or inductance of the line and load is much less than a long power distribution line. In addition to being lower energy, the rise times of the pulses are much faster. A typical single pulse will have a rise time less than 5 nanoseconds and a pulse width of less than 50 nanoseconds. The amplitudes may be much higher than a surge, but these are quickly damped out due to the losses in the lines. Arcing during the switching will generally cause a burst of these pulses rather than just a single impulse. Unsuppressed relays or coils are the greatest cause of electrically fast transients, and transients can be generated even on 5 volt logic lines where the inductive load is the self-inductance of the line. These transients may have a DC reference on the line in which they are generated, and the ends of the line will cause reflections that will look like ringing. These transients will readily couple to other lines where the DC bias will be eliminated and the line resonances will result in a damped ringing effect. NRC Information Notices 93-29 [46] and 93-75 [47] describe problems caused by equipment that was susceptible to transients due to not being shielded or due to insufficient design.

Coupling Mechanisms

Coupling of a fast transient or burst of transients will most generally be caused by electric field coupling (relative capacitance) if the fast transient is defined as a voltage spike or by magnetic field coupling (relative loop area) if the fast transient is defined as a current spike. Shared, common ground (signal return) paths may also be a factor in that this will increase the relative loop area for coupling.

Maximum Expected Level

The expected level of the fast transient is expected to be significantly less than ± 2,000 volts (2kV) at the digital system input.

Electrostatic Discharges

Note: ESD is not considered a common mode failure mechanism for safety-related digital systems. It is recognized as a failure mechanism for digital components and is included in these recommendations as a prudent test to be performed in laboratory conditions on individual components.

Sources

ESD is the sudden transfer of charge between two bodies at differing electrostatic potential. The electrostatic potential may be created by an induced charge on a conductor or by bound charge on an insulator (normally created by triboelectric effects). The bound charge may be caused by casual rubbing between clothing, where better insulating materials retain the bound charge and more conductive materials leaking charge. The induced charge is caused by bringing a bound charge close to a conductor. The sudden transfer of charge may be a result of a spark between two bodies. In the case of the induced charge, the spark may be between the inducing bound charge and a third body. Some discussions also differentiate between a human discharge and a non-human discharge, called a furniture discharge, to the equipment. The actual EMI phenomenon remains the same.

Coupling Mechanisms

The ESD may be directly to the EUT or to nearby equipment or structures; the nearby discharges are more commonly called indirect discharges. The discharge voltage may be as high as 15 kV. The sudden transfer of charge may result in peak currents of over 10 A, but of very short time duration (less than 50 nanoseconds). An ESD event will produce electric field variations and magnetic field variations. The electric field variations will not penetrate conductive surfaces while the magnetic fields will penetrate all but ferrous materials. The magnetic field variations will readily cause EMI to be induced in conductor loops inside the equipment or cables near the discharge point.

The initiation of an ESD is most likely to be caused by the man-machine interface for nonmoving equipment such as digital control systems. Most likely points of contact will be keyboards, video terminals, or connectors. This makes the ESD event very localized and does not represent a common mode failure for a safety system.

An estimate can be made to determine how far apart components must be in order to conclude that they would not likely respond to the same ESD event. This can be accomplished by examining the test distances for the indirect ESD discharge. IEC 61000-4-2 (Figures 5 and 6) places the distance for test at 0.1 meter. A 1-meter separation without any intervening shields can be considered a safe separation distance since the far-field[5] radiated electric field emissions will have fallen off by a factor of ten and any near field levels will have fallen off by a factor of 100 or 1,000. An intervening conductive shield will reduce this critical distance even further.

Maximum Expected Level

The maximum expected level of an ESD is highly dependent on factors that affect the breakdown of air by the electrostatic potential and by the dissipation of charge through air ionization processes. The breakdown in air will be directly proportional to atmospheric pressure and inversely proportional to absolute temperature, and is also affected by humidity. The breakdown of air at sea level will be about 40% higher than the breakdown at 3,000 meters elevation. Electrostatic charge will dissipate much more rapidly in a humid environment than a dry environment and a decrease in relative humidity from 50 to 10% can be expected to double the ESD level. A conservative level for expected ESD can be taken from the maximum levels given in IEC 61000-4-2, Tables 1a and 1b: 8 kV for direct contact discharge ESD and 15 kV for air discharge ESD. The polarity of the ESD may be either positive or negative.

---

[5] For a 1 nanosecond rise time ESD, the high-frequency content can be defined as $1/(Tr\pi)$ or 318 MHz. The far-field will be defined as wavelength divided by 2π, or approximately 5 cm in air.

C

SAMPLE EMISSIONS DATA COLLECTED AT NUCLEAR POWER PLANTS

This Appendix contains samples of the raw emissions measurements collected to develop the composite emissions envelopes presented in Section 2. They are provided to show what emissions measurements can be expected to look like if taken at a plant. The limits shown in these graphs are not representative of the test limits recommended in this guideline, as most of the test procedures used have been superceded.

The measurements on page C-2 are of conducted emissions from 15kHz to 50 MHz, taken per the procedures of test CE-03.

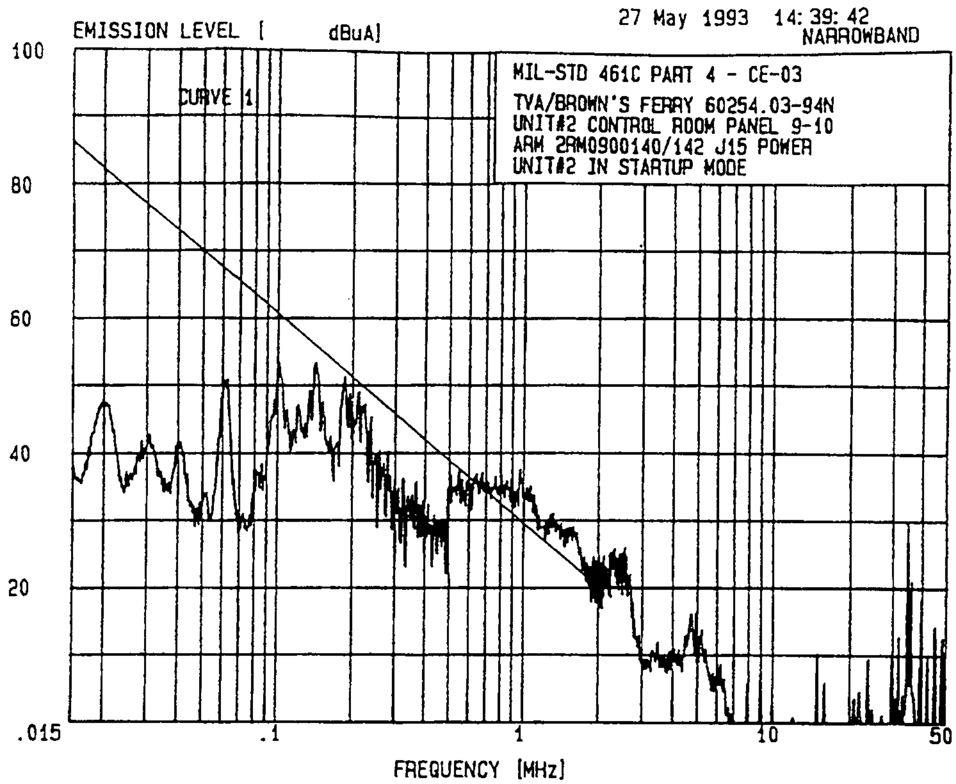
The measurements on page C-3 are of conducted emissions from 30Hz to 15kHz, taken per the procedures of test CE-01.

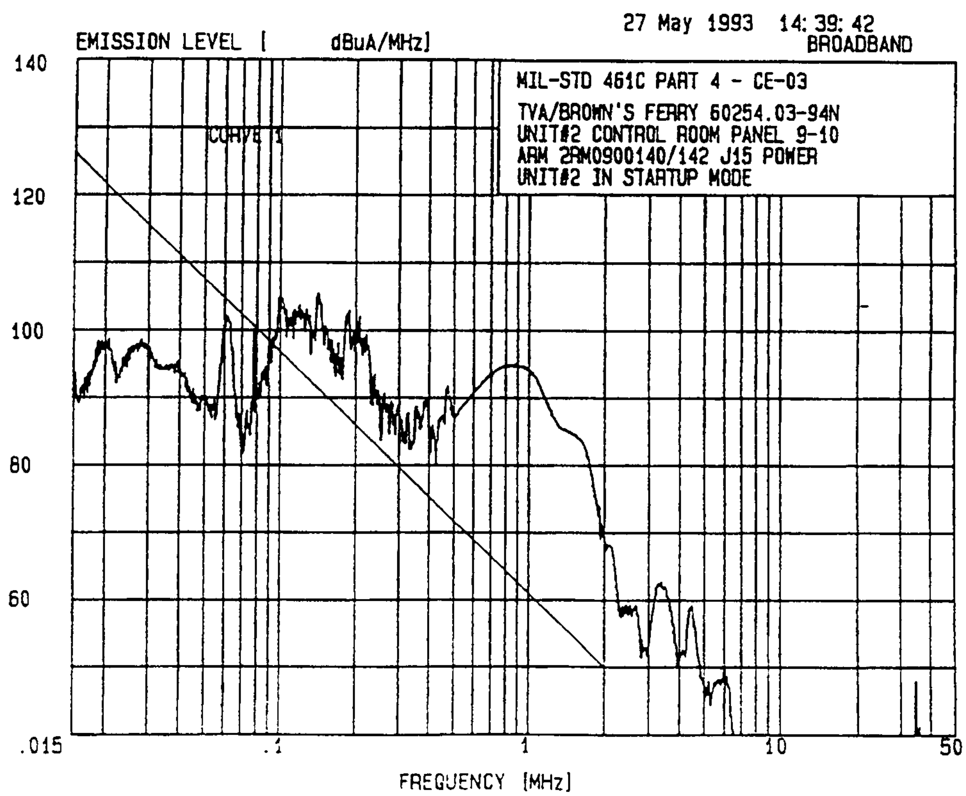
The measurements on page C-4 are of radiated emissions from 30Hz to 50kHz taken per the procedures of test RE-01.

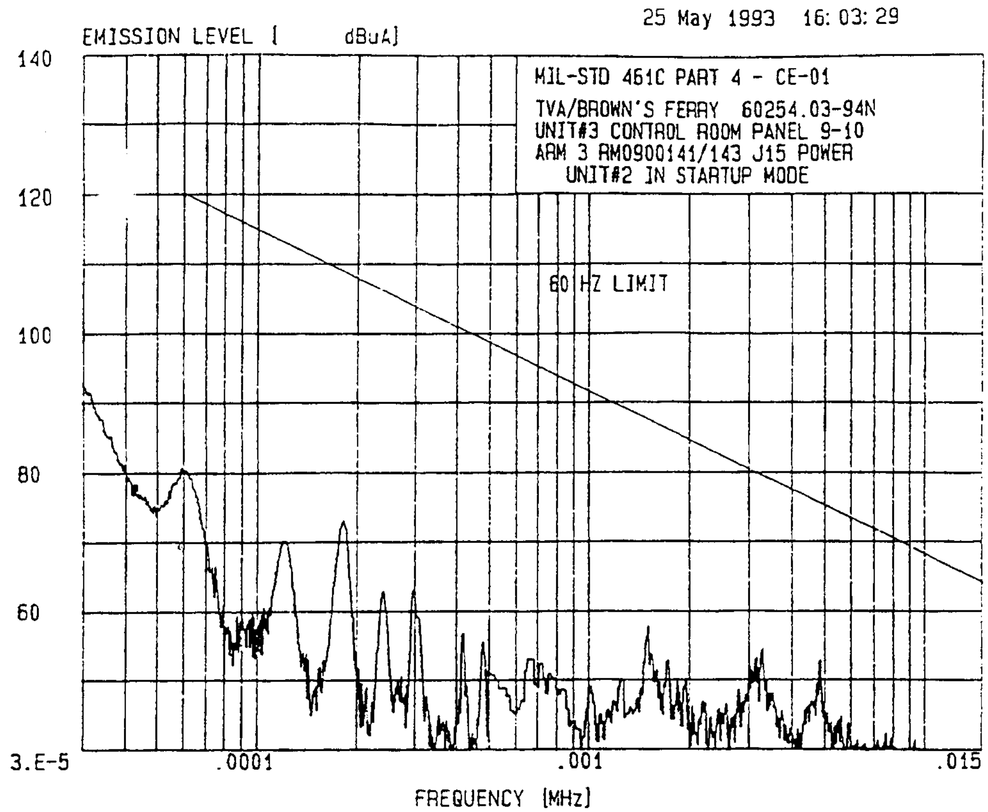
The measurements on page C-5 are of radiated emissions from 14kHz to 1GHz taken per the procedures of test RE-02.

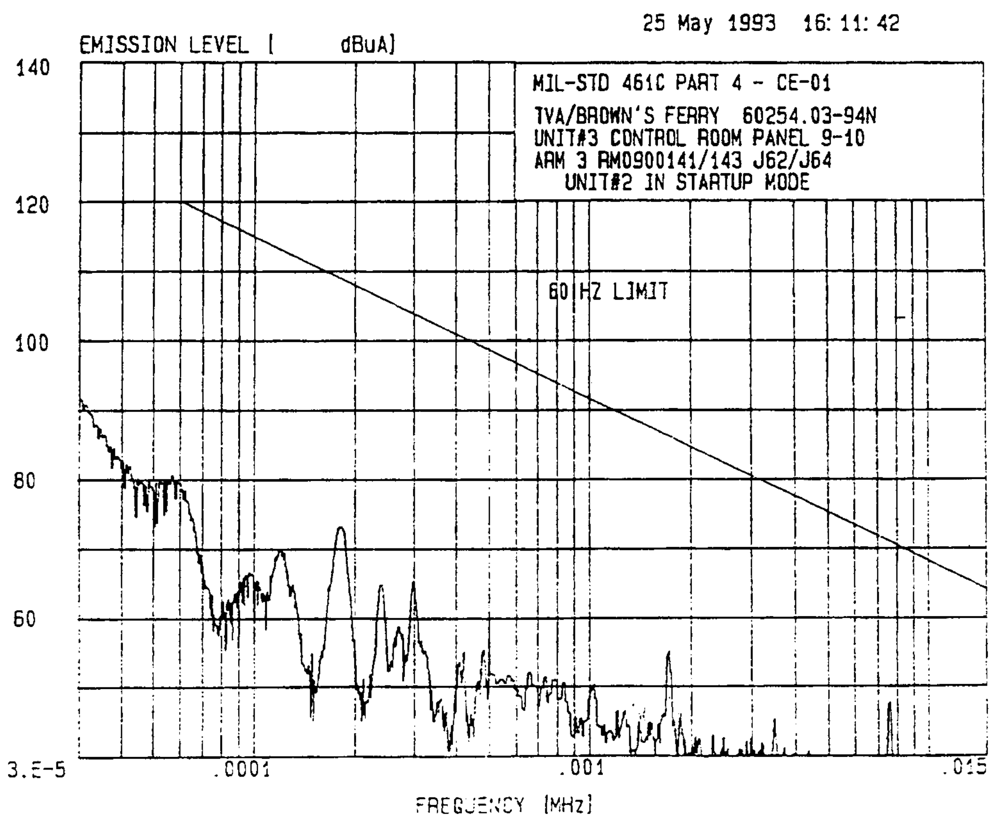
The measurements on page C-6 are of emissions during a transient, collected per the procedures of test CE-07.

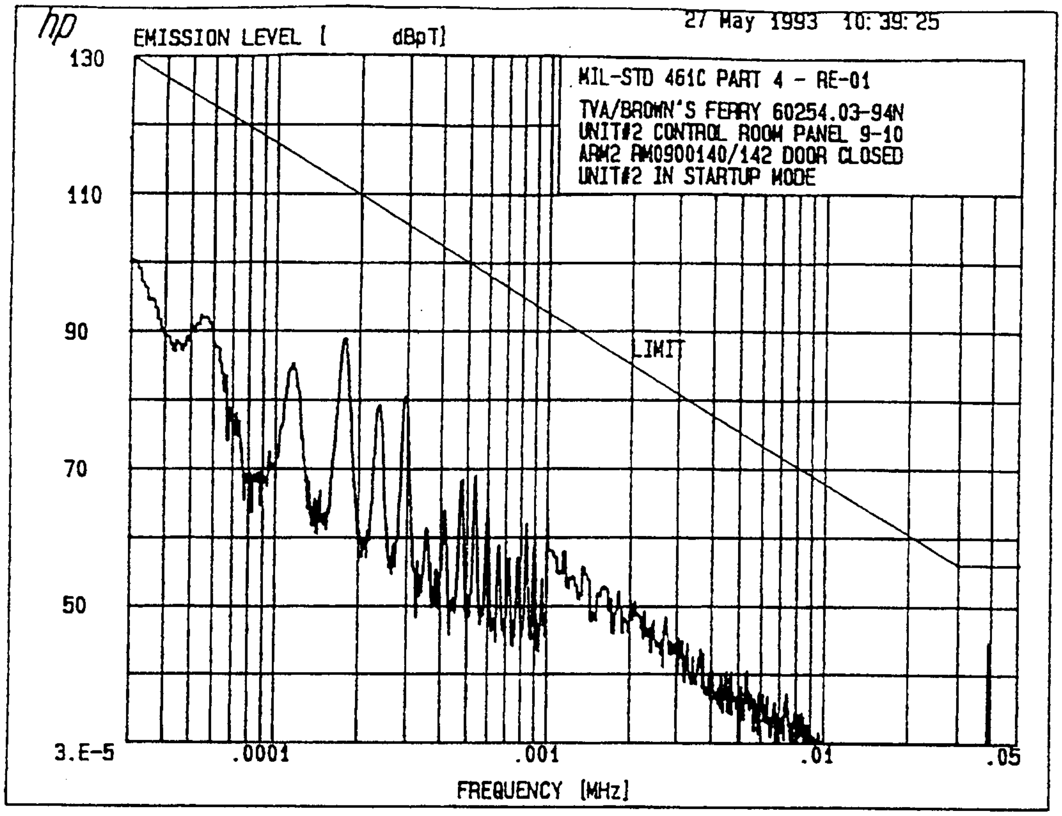
The measurements on page C-7 are of radiated emissions from 1GHz to 10GHz, taken per the procedures of test RE102.


EMISSION LEVEL [dBuA]
27 May 1993 14: 39: 42
NARROWBAND
MIL-STD 461C PART 4 - CE-03
TVA/BROWN'S FERRY 60254.03-94N
UNIT#2 CONTROL ROOM PANEL 9-10
ARM 2RM0900140/142 J15 POWER
UNIT#2 IN STARTUP MODE
CURVE 1
100
80
60
40
20
.015
.1
1
10
50
FREQUENCY [MHz]


EMISSION LEVEL [dBuA/MHz]
27 May 1993 14: 39: 42
BROADBAND
MIL-STD 461C PART 4 - CE-03
TVA/BROWN'S FERRY 60254.03-94N
UNIT#2 CONTROL ROOM PANEL 9-10
ARM 2RM0900140/142 J15 POWER
UNIT#2 IN STARTUP MODE
CURVE 1
140
120
100
80
60
.015
.1
1
10
50
FREQUENCY [MHz]


25 May 1993 16: 03: 29
EMISSION LEVEL [dBuA]
140
120
100
80
60
3.E-5
MIL-STD 461C PART 4 - CE-01
TVA/BROWN'S FERRY 60254.03-94N
UNIT#3 CONTROL ROOM PANEL 9-10
ARM 3 RM0900141/143 J15 POWER
UNIT#2 IN STARTUP MODE
60 HZ LIMIT
.0001
.001
.015
FREQUENCY [MHz]


25 May 1993 16: 11: 42
EMISSION LEVEL [dBuA]
140
120
100
80
60
3.E-5
MIL-STD 461C PART 4 - CE-01
TVA/BROWN'S FERRY 60254.03-94N
UNIT#3 CONTROL ROOM PANEL 9-10
ARM 3 RM0900141/143 J62/J64
UNIT#2 IN STARTUP MODE
60 HZ LIMIT
.0001
.001
.015
FREQUENCY [MHz]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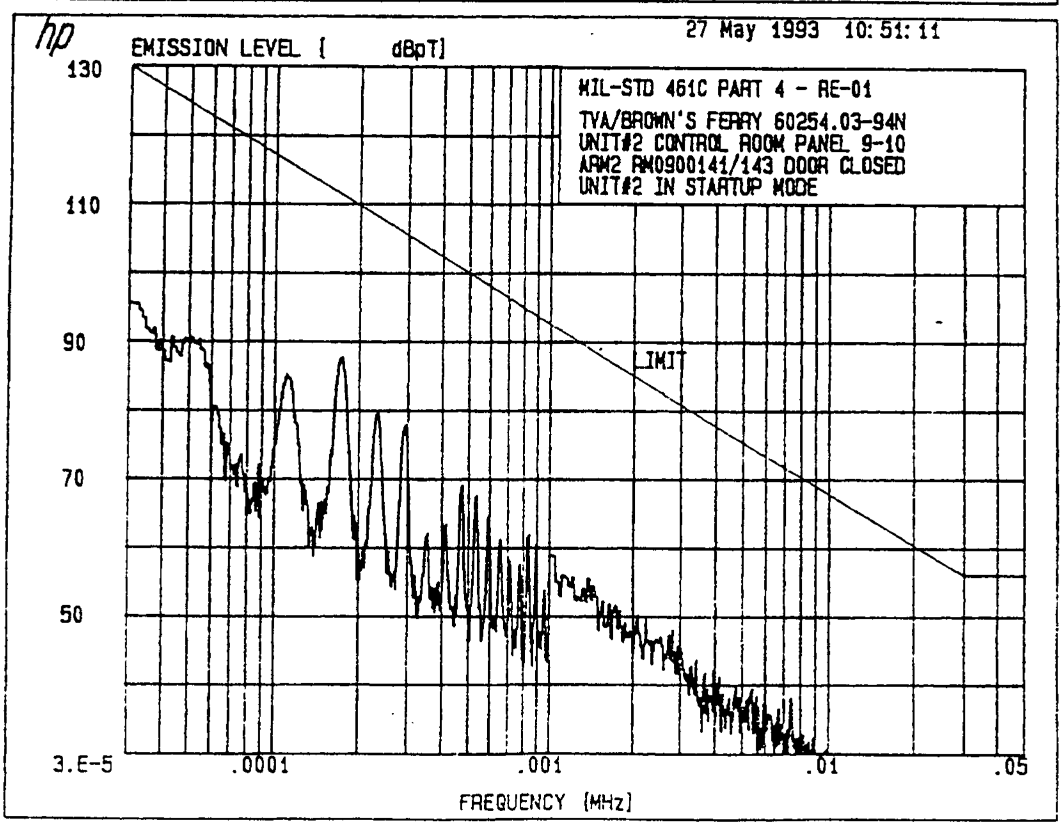
MIL-STD 461C PART 4 - RE-01
TVA/BROWN'S FERRY 60254.03-94N
UNIT#2 CONTROL ROOM PANEL 9-10
ARM2 RM0900140/142 DOOR CLOSED
UNIT#2 IN STARTUP MODE
LIMIT
130
110
90
70
50
3.E-5
.0001
.001
.01
.05
FREQUENCY [MHz]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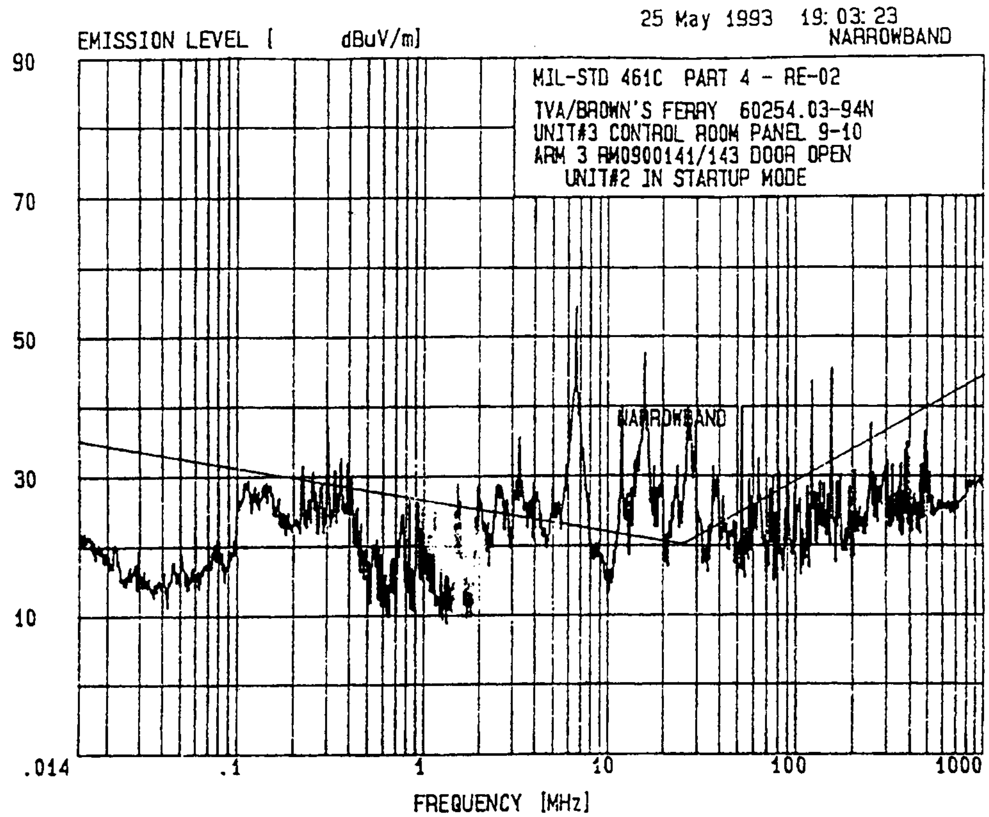
ARM2 RM0900141/143 DOOR CLOSED
UNIT#2 IN STARTUP MODE
LIMIT
130
110
90
70
50
3.E-5
.0001
.001
.01
.05
FREQUENCY [MHz]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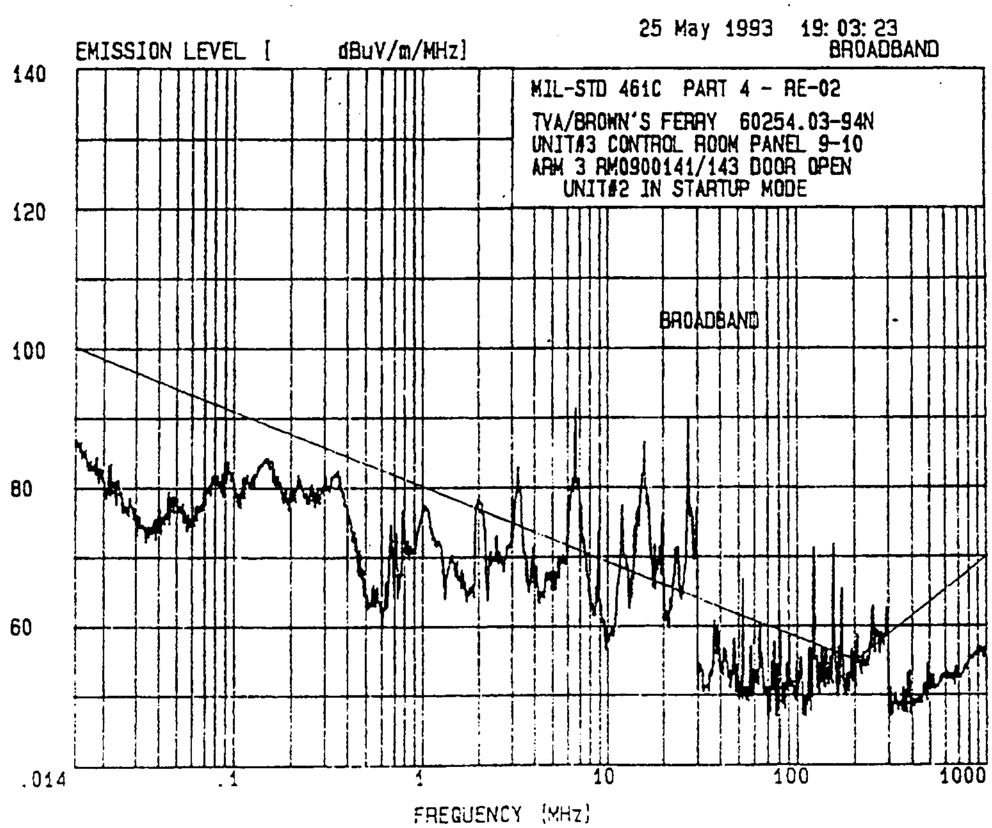
NARROWBAND
EMISSION LEVEL [dBuV/m]
MIL-STD 461C PART 4 - RE-02
TVA/BROWN'S FERRY 60254.03-94N
UNIT#3 CONTROL ROOM PANEL 9-10
ARM 3 RM0900141/143 DOOR OPEN
UNIT#2 IN STARTUP MODE
NARROWBAND
90
70
50
30
10
.014
.1
1
10
100
1000
FREQUENCY [MHz]


25 May 1993 19: 03: 23
BROADBAND
EMISSION LEVEL [dBuV/m/MHz]
MIL-STD 461C PART 4 - RE-02
TVA/BROWN'S FERRY 60254.03-94N
UNIT#3 CONTROL ROOM PANEL 9-10
ARM 3 RM0900141/143 DOOR OPEN
UNIT#2 IN STARTUP MODE
BROADBAND
140
120
100
80
60
.014
.1
1
10
100
1000
FREQUENCY [MHz]

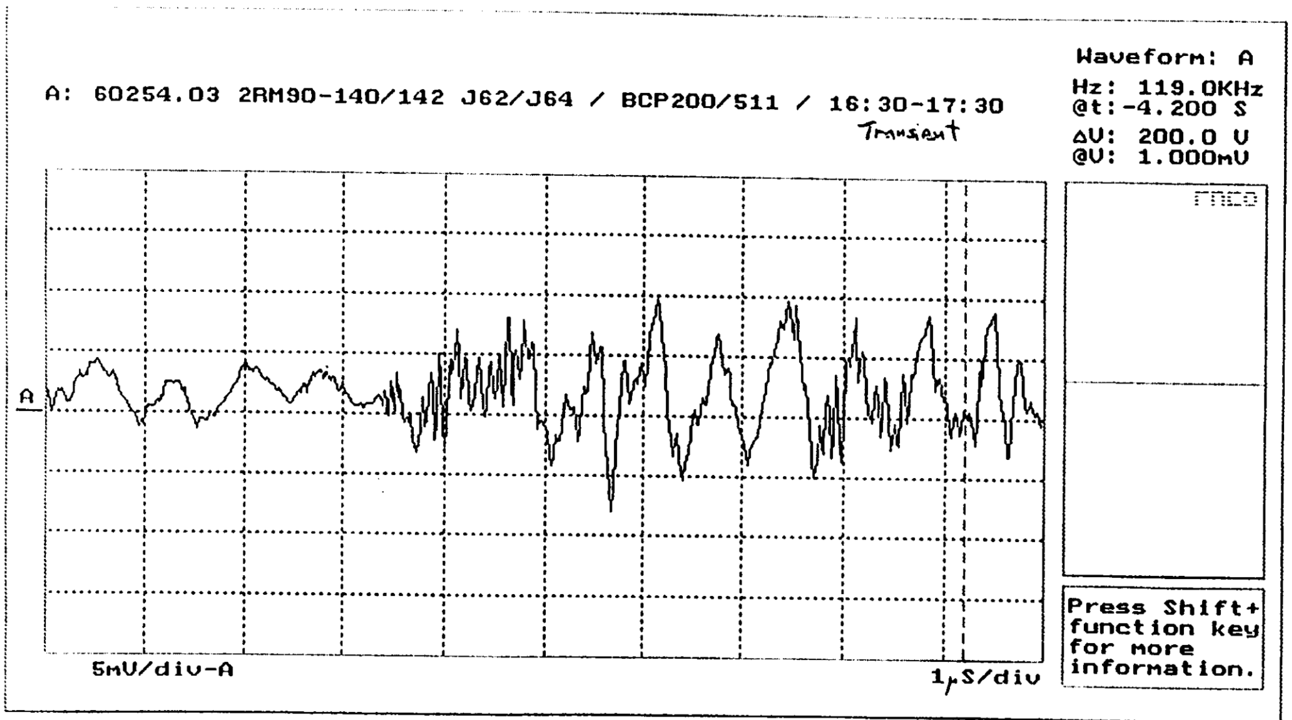
NTS

National
Technical
Systems

Acton Division
533 Main Street
Acton, MA 01720

DATA SHEET

Job Number 60254.03-94N   Date 5/27/93   Page 1 of 1



Customer TVA / Brown's Ferry

Test Sample Unit #2 Control Room

Test CE07

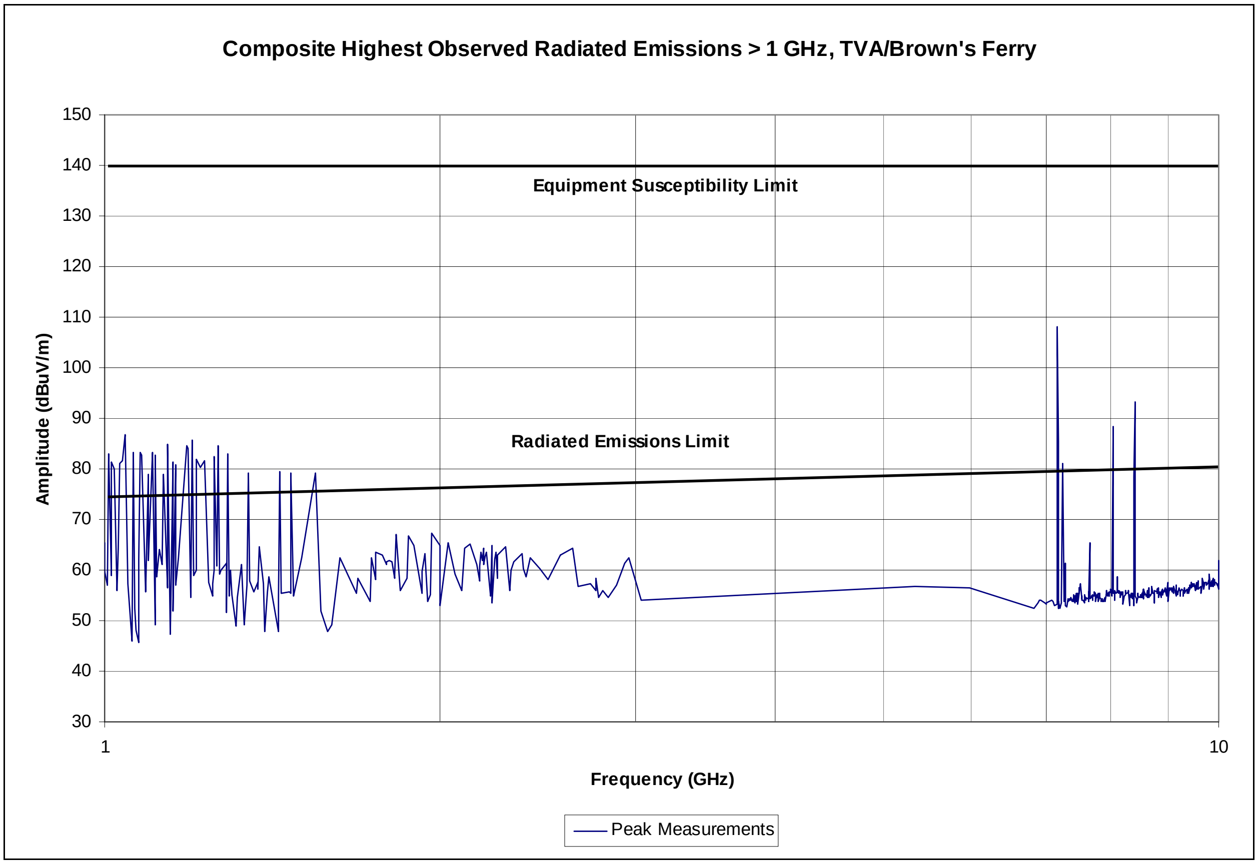
Test Technician N/A

Test Engineer G Bun

Specification NTS TP# 60254.02-94N-1 Rev 1

Model/Serial Number 2RM90-140/142 J62/J64 Signal Bundles

Mode of Operation Startup


Composite Highest Observed Radiated Emissions > 1 GHz, TVA/Brown's Ferry
150
140
130
120
110
100
90
80
70
60
50
40
30
Amplitude (dBuV/m)
Equipment Susceptibility Limit
Radiated Emissions Limit
1
10
Frequency (GHz)
Peak Measurements

D
NRC SAFETY EVALUATION REPORT

This appendix contains the safety evaluation report (SER) documenting the NRC's review of Revision 1 of TR-102323.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

April 17, 1996

Mr. Carl Yoder, Chairman
EPRI/Utility EMI Working Group
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, CA 94304

SUBJECT: REVIEW OF EPRI UTILITY WORKING GROUP TOPICAL REPORT TR-102323, "GUIDELINES FOR ELECTROMAGNETIC INTERFERENCE TESTING IN POWER PLANTS"

Dear Mr. Yoder:

By letter dated, December 19, 1994, EPRI submitted topical report TR-102323, "Guidelines for Electromagnetic Interference Testing in Power Plants." The staff has reviewed the topical report and prepared the enclosed safety evaluation report.

The staff has determined that TR-102323 contains an acceptable method of qualifying digital instrumentaion and control (I&C) equipment when a suitable demonstration is provided that the electromagnetic environment at the plant is similar to that identified in TR-102323. Licensees may utilize the TR-102323 approach when installing digital I&C modifications.

If you have any questions regarding this safety evaluation report, please contact Eric Lee at 415-3201.

Sincerely,

Bruce A. Boger, Director
Division of Reactor Controls
and Human Factors
Office of Nuclear Reactor Regulation

Enclosure: As stated

cc: Revis James, EPRI
Tony Pietrangelo, NEI
Ramesh Shanker, EPRI

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

ELECTRIC POWER RESEARCH INSTITUTE TOPICAL REPORT, TR-102323,

"GUIDELINES FOR ELECTROMAGNETIC INTERFERENCE TESTING IN POWER PLANTS"

1.0 SUMMARY

By letter dated December 19, 1994, the Electric Power Research Institute (EPRI) submitted topical report TR-102323, "Guidelines for Electromagnetic Interference Testing in Power Plants," for staff review. The topical report was developed by the EPRI Utility Working Group (the Working Group) to recommend alternatives for performing site-specific electromagnetic interference (EMI) surveys for qualifying digital plant safety instrumentation and control (I&C) equipment in a plant's electromagnetic (EM) environment. The recommendations contained in TR-102323 include: (1) a set of electromagnetic interference and radio frequency interference (EMI/RFI) susceptibility testing levels, (2) EMI eliminating practices, and (3) equipment EMI/RFI emission testing levels. The above recommendations are based on EMI/RFI emission data collected during 1993 and 1994 at seven nuclear power plants, and data collected prior to 1993 from other nuclear power plant sites.

ENCLOSURE

Based on the analysis presented, the staff concludes that the TR-102323 recommendations and guidelines provide an adequate method for qualifying digital I&C equipment for a plant's EM environment without the need for plant specific EMI surveys if the plant specific EM environment is confirmed to be similar to that identified in TR-102323.

2.0 BACKGROUND

Utilities are currently replacing analog I&C equipment with computer-based digital I&C equipment as the analog equipment becomes obsolete. Digital equipment, which operates at lower voltages than analog equipment, is more vulnerable to EMI/RFI random noise that has the potential to cause failures of redundant safety-related equipment.

The Working Group was formed to address the NRC staff's concerns regarding the effects of EMI/RFI on digital equipment operation. The Working Group consisted of EPRI personnel and personnel from interested utilities, and became active after a September 1992 EPRI Workshop on "Electromagnetic Interference Control in Modern Digital Instrumentation & Control System Upgrades." The mission of the Working Group was to:

1. Measure and evaluate nuclear plant EMI/RFI emission types and levels;

2. Develop procedures for the nuclear power industry to use to minimize the effects of EMI on plant I&C equipment; and

3. Recommend an appropriate set of EMI/RFI equipment emission levels and susceptibility test levels to qualify safety-related equipment for use in nuclear plant installations.

The work performed by the Working Group was the first systematic and extensive effort on EMI/RFI levels in nuclear power plants. For this effort, the Working Group developed generic test procedures for conducting five types of measurements based on military and industry standards and collected emission data at applicable locations in seven nuclear power plants. The plant emission data collected are reported in TR-102323 as a set of highest measured observations (Figures 5-2, 3, 4, 5, and 6).

TR-102323 was initially issued in draft form in April 1994. On July 14, 1994, representatives of the Working Group met with the NRC staff at NRC headquarters in Rockville, Maryland, to discuss issues raised by the staff from its review of the draft report. The issues discussed at that meeting included measured data confidence, safety margin, and highest measured emission levels. By letter dated August 8, 1994, the Working Group addressed the issues raised by the staff in the July 14, 1994 meeting, and in September 1994, EPRI published TR-102323 in final form and submitted it to the staff by letter dated December 19, 1994. On May 9 and 10, 1995, the Working Group and the staff met again at the EPRI Non-Destructive Evaluation Center in Charlotte, North Carolina, to discuss issues of concern to the staff. As a result of this meeting, by letter dated July 17, 1995, the Working Group proposed a revision to TR-102323 and provided additional information to address the staff concerns discussed at the May meeting. In the July 17, 1995 letter, the Working Group stated that TR-102323 would be a living document and would include new information with updated recommendations, as necessary based on industry experience. By letter dated October 19, 1995, the Working Group submitted Revision 1 to TR-102323, which incorporated modifications proposed in the Working Group's July 17, 1995, letter to the NRC and addressed additional issues discussed subsequent to that letter.

3.0 REVIEW CRITERIA

General guidance on environmental qualification of safety-related equipment is provided in 10 CFR Part 50, Appendix A, Criterion 4, "Environmental and Dynamic Effects Design Bases," and in Standard Review Plan Section 7.1, Appendix B, "Guidance For Evaluation of Conformance to IEEE Std 279." Although the NRC has not issued guidelines for reviewing the equipment qualification for a plant's EMI/RFI environment, the staff has used the guidance in the following standards in previous reviews of digital systems.

(1) MIL-Std-461C, "Electro-magnetic Emission and Susceptibility Requirements for the Control of Electro-magnetic Interference,"

(2) MIL-Std-462, "Electro-magnetic Interference Characteristics Measurement,"

(3) MIL-Std-461D, "Electro-magnetic Emission and Susceptibility Requirements for the Control of Electro-magnetic Interference,"

(4) MIL-Std-462D, "Electro-magnetic Interference Characteristics Measurement," and

(5) NUREG/CR-5941 "Technical Basis for Evaluating Electromagnetic and Radio-Frequency."

Additionally, NUREG/CR-5941 contains a comparison of the guidelines addressing EMI/RFI and surge in the following standards: MIL-Std-461C and 462, MIL-Std-461D and 462D, and IEC 801, "Electromagnetic Compatibility for Industrial Process Measurement and Control Equipment."

4.0 EVALUATION

4.1 MEASURED ENVIRONMENT DATA AND SUSCEPTIBILITY LIMITS

The Working Group performed site tests at seven plants in accordance with MIL-Std 461C test method CE07 and MIL-Std-462 test methods CE01, CE03, RE01, and RE02. The highest observed EMI/RFI emissions data collected in the various rooms of the seven plants were used to bound the recommended susceptibility test levels.

The rooms that the Working Group recommended for collecting plant EMI/RFI emission data included the control room, cable spreading room, turbine deck, switchgear rooms, battery rooms, diesel generator rooms, and remote shutdown panel room. These areas were considered typical locations for digital equipment installations.

A review of TR-102323, however, indicated that only at three of the seven plants were EMI/RFI emission data collected from a majority of the recommended areas. At the other four plants, EMI/RFI emission data were collected at the specific point of installation where digital equipment replaced analog equipment. The staff expressed concern to the Working Group that EMI emission data from limited areas of the seven power plants were insufficient to adequately envelope nuclear power plants in the United States.

The Working Group evaluated the staff concern and reported that the collected data are representative of the industry as a whole because the configurations of the plants where the data were collected included three out of four nuclear steam supply system vendors and five out of six different architect engineer balance-of-plant designs. Furthermore, the Working Group explained that only radiated electric field emission would be expected to show any significant variation from one plant space to another. Other effects of EMI/RFI are local (magnetic fields) or are due to wiring practices (conducted emissions and transients). Therefore, the fact that a large portion of the collected data is from the control room and adjacent spaces is not considered a significant issue for any of the EMI threats, except perhaps the radiated emissions threat. In addition, the collected data showed that, apart from handheld transmitters, a very large margin exists between the TR-102323 proposed susceptibility test level and the measured highest EM emission level.

The staff agreed with the Working Group's assessment that the majority of the EMI effects are local or are due to wiring practices, but disagreed with the Working Group's other assessment that the collected data are representative of the industry as a whole because, (1) the large variations in the data collected at the plants show that the location of rotating and electrical equipment affects the EMI/RFI environment and (2) the collected conducted emission data from the plants show significant variations from one plant space to another. For these reasons, the staff indicated that in order for EMI emission levels to be bounded for any location within the plant, additional data was needed from other locations and/or sufficiently high susceptibility levels recommended so that the margin will cover (a) instrumentation inaccuracies, (b) uncertainties in site surveys, (c) site variations, (d) lack of plant-specific data, and (e) variations in operating conditions.

To resolve the staff's concerns, the Working Group stated that the recommended equipment susceptibility test levels were based on a comparison of the test recommendations in MIL-Std-461 and 462, IEC 801-1 through 6, and applicable ANSI/IEEE EM testing standards to the EM emission levels identified in the data collected at Turkey Point, Zion, and other plants. Where necessary, susceptibility levels were revised to increase the margin in the recommended levels. In addition, the Working Group compared the highest observed EMI levels and the recommended susceptibility levels and identified the following values to show that the recommended susceptibility levels are sufficiently high to resolve the staff's concerns:

(1) 10 dB conducted emission noise

(2) 42 dB radiated emissions threat, and

(3) 25 dB surge/transient emissions threat

In order to provide additional technical bases for its conclusion that the collected data bounded the plants' EMI environments, the Working Group also provided a discussion of the safety margin (Section 4.1.1 below), its recommended EMI eliminating practices (Section 4.1.2 below), and its statistical analysis (Section 4.1.3 below). The staff's evaluation of the Working Group's discussion is described below.

4.1.1 Safety Margin

The Working Group determined that plant emission levels should not exceed a 6 dB safety margin below the susceptibility limit. This safety margin is derived from the following three error factors: (1) potential measurement errors (3.7 dB), (2) potential adjustment of measured levels to account for the impact of any EMI environmental conditions not directly addressed by a plant's generic test data collection (3 dB), and (3) potential growth in the plant's EMI environment with time (3 dB).

The staff agreed with the Working Group that the safety margin should be large enough to cover the above three error factors. However, the staff determined that based on the above three error factors, the safety margin should be 8 dB instead of 6 dB.

In its letter of July 17, 1995, the Working Group agreed with the staff's recalculated margin value of 8 dB but again stated that it believed that a 6 dB margin is sufficiently conservative because it represents a factor of two margin above the collected data. The staff further argued, however, that the safety margin needs to account for inaccuracies, uncertainties, and variations in instruments, plant locations and conditions during the data collection. The Working Group agreed with the staff and incorporated the 8 dB safety margin in the Revision 1 to TR-102323.

Based on the above review, the staff concludes that the 8 dB safety margin is acceptable to cover the Working Group's estimated measuring errors.

4.1.2 EMI Eliminating Practices

The EMI eliminating practices are a set of design conditions which, when followed, provide increased assurance that the highest observed plant emissions levels are bounded and the recommended equipment susceptibility test levels are adequate. These practices serve to limit the generation and coupling of EMI that would otherwise potentially invalidate the susceptibility testing levels established in TR-102323. Further recommendations to limit the effects of EMI are described in the EPRI EMI Handbook, which is referenced in TR-102323.

The staff agrees with the technical explanation of the EMI eliminating practices and the use of IEEE Std. 1050 "IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations," as described in Chapter 6 of TR-102323. In addition, the staff agrees that implementing EMI eliminating practices will reduce the EMI/RFI effects in the plant environment. However, the staff does not fully agree with Option 1 of Equipment Emission Testing Versus Design Requirements in Chapter 6. The first part of Option 1 recommends that digital replacement equipment be tested in accordance with the MIL-Std-462D CE 102 and RE 102 tests. The second part of Option 1 states that commercially testing digital replacement equipment in accordance with the Federal Communication Commission's (FCC) standards contained in 47 CFR Part 15 dealing with Class A equipment satisfies the first part of the Option 1 recommendation. The staff agrees with the first part of Option 1 but finds that the second part of Option 1 cannot replace the first part of Option 1 because the FCC tests do not cover the entire frequency ranges covered by the MIL-Std-462D CE 102 and RE 102 tests. Therefore, when the second part of Option 1 is used, the staff finds that a justification needs to be provided for not performing a low frequency test.

The Working Group agreed with the staff and Revision 1 to TR-102323 includes a modification to the second part of Option 1 to recommend two additional tests that will cover those frequency ranges not covered by the FCC tests. The staff finds the proposed revision to TR-102323 to be acceptable.

4.1.3 Statistical Analysis

The Working Group performed statistical analyses using EM emission data collected from seven plants. The first analysis showed a 90% confidence that 90% of all data would fall below the allowable plant susceptibility levels based on the following assumptions: (1) the seven plants where data were collected were selected randomly, (2) all measuring points (rooms) were the same, (3) all room configurations were identical, and (4) all plant conditions were the same.

In a letter dated April 3, 1995, the Working Group explained that another statistical analysis included in Appendix D of TR-102323 was performed based on the maximum observed measurement at any given frequency (the worst measurement out of a total of 70-140 measurements) in order to present conservatism in the results. This statistical analysis would increase the earlier statistical confidence because it considered, (1) the mean value and standard deviation of the highest observed measurements at each frequency, and (2) the actual number of data samples. Therefore, the Working Group concluded that this statistical analysis shows with 95% confidence that more than 95% of the EMI emissions in any nuclear power plant will be within the recommended susceptibility levels.

The staff disagrees with the conclusion that the above statistical analysis shows that with 95% confidence more than 95% of the data will be within the recommended susceptibility levels for any nuclear plant except for the seven plants measured. However, the staff believes that the analysis provides some confidence in the collected data. In addition, the staff recognizes that the Working Group's recommended EMI eliminating practices and the recommended margin between tested susceptibility levels and the plant's EMI environment provide the necessary confidence that the established susceptability levels are sufficiently bounding.

Based on the above discussion on safety margins, EMI eliminating practices, and statistical analysis, the staff agrees that there is adequate confidence that the recommended susceptibility levels envelope the EM emission data and provide an appropriate bound for other nuclear plants with similar EMI environments.

4.2 RECOMMENDED SUSCEPTIBILITY TEST

In Chapter 4 and Appendix B of TR-102323, the Working Group provides susceptibility test levels, defines test frequency ranges, and identifies applicable test methods as described in MIL-Std-461C, MIL-Std-462, MIL-Std-462D, and IEC 801 series for those frequency ranges. Based on the staff's evaluation (see Section 4.1), the staff accepts the recommended susceptibility tests described in TR-102323 for plant configurations similar to any one of the seven plants from which EM emission data was collected. The staff also accepts the susceptibility test frequency ranges provided in Appendix B. However, the Appendix B frequency ranges extend beyond the frequency ranges covered by some of the applicable test methods described in MIL-Std-461C, MIL-

Std-462, MIL-Std-462D, and IEC 801 series, which staff is presently using for its reviews. Therefore, the staff determined that licensees referencing TR-102323 would need to provide justification if the Appendix B frequency range exceeds the frequency range of the particular susceptibility test used for qualification testings.

In response to the staff's concern, in Chapter 4 and Appendix B to Revision 1 to TR-102323 the Working Group recommends that, if the Appendix B limits exceed the limits of the particular susceptibility test (described in one of the above identified standards) used, the licensee should provide justification that the qualification results from the performed test are valid over the entire range of the TR-102323 recommended frequencies. The staff finds this acceptable.

The staff also found that Notes 1 and 2 of TR-102323 Appendix B permit the interchanging of the radiated susceptibility test (synonymous with MIL-Std-461D, RS103) over a range of 10 kHz-1 GHz with the conducted susceptibility test (synonymous with MIL-Std-461D, CS114) over a range of 50 kHz-400 MHz. The frequency ranges of these tests, however, are not the same, and the staff determined that these tests are therefore, not interchangeable. The Working Group agreed with the staff, and in its July, 17, 1995, letter stated that it would revise TR-102323 to delete this interchanging of tests. Revision 1 to TR-102323 includes a deletion of the two notes that allowed the interchanging of the MIL-Std-461D, RS103 and CS114 tests. The staff finds this acceptable.

The staff also disagreed with the Working Group not recommending a low frequency range (30 Hz to 50 kHz) radiated susceptibility test for equipment qualification because low frequency magnetic field in the equipment location can attenuate rapidly within a short distance. The staff believes that such a test would provide increased assurance that equipment is not susceptible to radiated magnetic fields in the frequency range of 30 Hz to 50 kHz. In response, the Working Group agreed to revise TR-102323 to recommend a low frequency radiated susceptibility test limit consistent with Figure 5-4 of TR-102323. Licensees could, however, justify a less restrictive test limit under certain circumstances such as the presence of an equipment shield of ferrous metal or installing the new equipment at a substantial distance from potential sources. The staff finds this acceptable.

4.3 RECOMMENDED EMISSION TEST

The Working Group established allowable equipment emission levels, on the basis of measured plant emissions and susceptibility test limits, by assuring that:

1. Equipment emission levels are at least 20 dB below the corresponding susceptibility test levels.

2. Emissions from newly installed equipment do not significantly increase the overall plant emissions levels, and overall allowable equipment emission levels are significantly less than the allowable plant emissions levels.

The staff agreed with the TR-102323 guidelines for recommended emission tests, but disagreed with the Working Group's conclusion that the low frequency magnetic emissions test (which corresponds to MIL-Std-461D, RE101) and the low frequency conducted emissions test (which corresponds to MIL-Std-461D, CE101) are not necessary. MIL-Std-461D, RE101, provides guidance for testing to assure that fields generated by new equipment that is placed in an existing installation with other equipment which may be sensitive to magnetic induction at lower frequencies will not adversely affect the existing equipment. Therefore, the staff concluded that justification should be provided by a licensee when this test is not performed. In Revision 1 to TR-102323 submitted on October 19, 1995, however, the Working Group recommended that the RE101 test be conducted by a licensee only if the new equipment to be installed does not meet the design criteria discussed under EMI limiting practices (Chapter 6 of TR-102323) and if the new equipment is installed near magnetic field-sensitive equipment. The staff finds the Working Group's recommendation test to be an acceptable alternative to the RE101 test since the limiting practices and separation provide appropriate protection against low frequency magnetic emissions.

MIL-Std-461D, CE101 provides guidance for testing to assure that equipment placed in an existing installation does not affect the existing power supply. Alternatively, this test can be omitted if it can be demonstrated that the power quality requirements of the new equipment are consistent with the existing power supply. In its letter dated July 17, 1995, the Working Group stated that, although licensees do not generally have site-specific power quality requirements, preliminary results based upon 19 months of data indicate that the total harmonic distortion of a power distribution system is approximately 2% of the fundamental voltage. The staff, however, stated that the amount of distortion measured on an installation power line does not indicate how well the existing power system can tolerate the distortion which may be imposed by newly added equipment. Therefore, the CE101 test, an equivalent test, or specifying power quality requirements is necessary to ensure that new equipment will not adversely affect the existing system's power supply. The Working Group agreed with the staff and in Revision 1 to TR-102323, it recommended the CE101 test only for those plants that do not have power quality requirements criteria with a valid technical basis. The staff finds the Working Group's recommendations on the CE101 test to be acceptable for ensuring power supply integrity.

5.0 CONCLUSION:

Based on the above evaluation, the staff concludes that the EMI susceptibility test levels, EMI emission test levels and EMI eliminating practices recommended in TR-102323 provide an acceptable method for assessing the qualification of digital equipment to the nuclear plant EM environment without the need for plant specific EMI surveys if the plant specific EM environment is confirmed to be similar to that identified in TR-102323. The staff, therefore, concludes that the guidelines of TR-102323 may be used by licensees for EM environmental qualification of digital modifications.

E
SAMPLE TESTING PROCEDURE GUIDANCE

This appendix contains an outline that describes information that would likely appear in EMI test procedure documentation. The document shown is Defense Department Data Item Description (DID), "Electromagnetic Interference Test Procedures (EMITP)," DI-EMCS-80201B. It is provided here as an instructive example.

DATA ITEM DESCRIPTION

Title: Electromagnetic Interference Test Procedures (EMITP)

Number: DI-EMCS-80201B
Approval Date: 19990820
AMSC Number: F7355
Limitation:
DTIC Applicable:
GIDEP Applicable:
Office of Primary responsibility: F-11
Applicable Forms:

Use/relationships: The EMITP describes the measurement procedures that will be used to demonstrate that an equipment or subsystem complies with its contractual electromagnetic interference (EMI) requirements based on MIL-STD-461, including how the general test procedures in the standard will be applied to the specific equipment or subsystem.

This Data Item Description (DID) contains the format and content preparation instructions for the EMITP required by 5.1 of MIL-STD-461.

This DID is related to DI-emcs-80199B, Electromagnetic Interference Control Procedures (EMICP), and DI-EMCS-80200B, Electromagnetic Interference Test Report (EMITR).

This DID supersedes DI-EMCS-80201A.

Requirements:

1. Format. Contractor format is acceptable.
2. Content. The EMITP shall contain the following:

2.1 Introduction. The introduction of the EMITP shall include the following

a. A table describing all the tests to be performed, the applicable section within the EMITP, and the corresponding test procedure from MIL-STD-461.

b. Description of the Equipment Under Test (EUT), including its function, characteristics, intended installation, and power usage.

c. Approved exceptions or deviations from contractual test requirements, if any.

2.2 Applicable documents. Applicable documents shall be listed as follows:

a. Military (such as standards and specifications).

b. Company (such as in-house documents used for calibration or quality assurance).

c. Other Government or industry standards, specifications, and documents.

2.3 Test site. A Description of the test site shall be provided covering the following:

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a. Test facility and shielded enclosure or anechoic chamber, including size, characteristics, and placement of radio frequency (RF) absorbers.

b. Ground plane (size and type) and methods of grounding or bonding the EUT to the ground plane to simulate actual equipment installation.

c. Implementation of test precautions required by 4.3.7 of MIL-STD-461.

2.4 Test instrumentation. Test instrumentation to be used shall be described as follows:

a. Equipment nomenclature.

b. Characteristics of coupling transformers and band-reject filters.

c. Antenna factors of specified antennas, transfer impedances of current probes, and impedance of Line Impedance Stabilization networks (LISN).

d. Description of the operations being directed by computer programs/software for computer-controlled receivers, the verification techniques used to demonstrate proper performance of the software, and the specific versions of the software to be used.

e. Bandwidth (resolution and video) and scanning speeds of measurement receivers.

2.5 EUT setup. A description of the EUT test setup for each test shall cover the following:

a. Physical layout of the cable and EUT.

b. Cable types, characteristics, and construction details (see 4.3.8.6 of MIL-STD-461)

c. Position of the line impedance stabilization networks on the ground plane.

d. Use of bond straps and loads.

e. Test simulation and monitoring equipment.

2.6 EUT operation. A description of the EUT operation shall the following:

a. Modes of operation for each test, including operating frequencies (where applicable), and rationale for selection.

b. Control setting on the EUT.

c. Control setting on any test stimulation and monitoring equipment and characteristics of input signals.

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d. Operating frequencies (such as oscillator and clock frequencies) which may be expected to approach limits.

e. Performance checks initiated to designate the equipment as meeting minimal working standard requirements.

f. Enumeration of circuits, output, or displays to be monitored during susceptibility testing, as well as the criteria for determining degradation of performance.

2.7 Measurements. The following shall be described for each test.

a. Block diagram depicting test setup, including all pertinent dimensions.

b. Step-by-step procedures.

c. Test equipment used in performance of the test and the methods of grounding, bonding, or achieving electrical isolation of the measurement instrumentation.

d. Selection of measurement frequencies.

e. Information to be recorded during the test, including frequency and units of recorded information. Sample data sheets, test logs and graphs, including test limits, may be shown

f. Modulation characteristics and scan rates of the susceptibility test signals, if applicable.

3.0 End of DI-EMCS-80201B.

F

SAMPLE QUALIFICATION REPORT GUIDANCE

This appendix contains an outline that describes information that would likely appear in EMI test report documentation. The document shown is Defense Department Data Item Description (DID), "Electromagnetic Interference Test Report (EMITR)," DI-EMCS-80200B. It is provided here as guidance to aid a reviewer of an EMC qualification report. In addition to the components described in DI-EMCS-80200A, the following issues should also be reviewed and considered in assessing the qualification of any system or component:

- Test Plan or Procedure
- Contract or Purchase Order Number
- Name & location of facility that conducted tests
- Test Report properly signed and reviewed
- Date(s) of testing
- Description and disposition of EUT
- EMI Test Standards used
- Intended function (acceptance criteria) stated in advance
- Cables used
- Power input levels (voltage and current)
- List of tests performed with Pass or Fail
- Any deviations from the Test Plan
- Any anomalies or unusual events
- Identification of items that are not parts of EUT
- List of all test equipment, calibration date, accuracy and next calibration date (verify that all equipment was in calibration)
- Photographs of testing
- Test setup schematics of all EUT configurations
- Transfer impedances of all current probes
- Antenna factors for all antennas
- Impedance values of all LISNs or coupling capacitors
- Details on any suppression devices used

- Sample calculations where necessary
- Frequency ranges tested
- Cable loss factors
- Measurement uncertainty (new requirement of ISO Guide 17025)
- All data plots and RS field levels
- Ambient radiated emissions
- Statement on SE or shielded enclosure
- Spectrum analyzer scan speeds
- Spectrum analyzer bandwidths
- Antenna polarizations
- Resolution of any anomalies
- Accreditation of facility
- Quality Assurance Review
- Statement of Compliance with EPRI TR102323, Mil-Std 461 or Reg. Guide 1.180

DATA ITEM DESCRIPTION

Title: Electromagnetic Interference Test Report (EMITR)

Number: DI-EMCS-80200B
AMSC Number: F7354
DTIC Applicable:
Office of Primary Responsibility: F-11
Applicable Forms:

Approval Date: 19990820
Limitation:
GIDEP Applicable:

Use/Relationships: The EMITR provides the data and information necessary to evaluate compliance of an equipment or subsystem with its electromagnetic interference (EMI) control requirements based on MIL-STD-461, including the discussion of recommended corrective actions, if needed.

This Data Item Description (DID) contains the format and content preparation instructions for the EMITR required by 5.1 of MIL-STD-461.

This DID is related to DI-EMCS-80199B, Electromagnetic Interference Control Procedures (EMICP), and DI-EMCS-80201B, Electromagnetic Interference Test Procedures (EMITP).

This DID supersedes DI-EMCS-80200A.

Requirements:

1. Format. Contractor format is acceptable.
2. Content. The EMITR shall contain the following:

2.1. Administrative data. The EMITR shall contain an administrative section covering the following:

a. Contract number.

b. Authentication and certification of performance of the tests by a qualified representative of the procuring activity.

c. Disposition of the Equipment Under Test (EUT).

d. Description of the EUT, including its function, characteristics, intended installation, actual cable types (characteristics and construction details - see 4.3.8.6 of MIL-STD-461), and electrical current usage on each power input line.

e. List of tests performed with pass/fail indications.

f. Any approved deviations from contractual test procedures or limits previously authorized.

g. Identification of Non-Developmental Items (NDI) and Government Furnished Equipment (GFE) that may be part of the EUT.

h. Traceability of test equipment calibration.

i. A reference to the approved EMI test procedure (EMITP).

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2.2. Detailed results. A separate appendix shall be prepared for each test. If deviations from an approved test procedure occurred during the test program, an additional appendix shall be provided with the "as run" procedures showing all red-lines and procuring activity concurrence. A separate appendix shall be provided for log sheets. Each test appendix shall contain the following factual data:

a. Test equipment nomenclature, serial numbers, version of software used (if any), and calibration due date.

b. Photographs or diagrams of the actual test set up and EUT, with identification.

c. Transfer impedance of current probes.

d. Antenna factors.

e. Impedance values of Line Impedance Stabilization Networks (LISN).

f. Identification of any suppression devices used to meet the contractual requirements, including schematics, performance data, and drawings.

g. Sample calculations, such as conversions of measured levels for comparison against the applicable limit.

h. The ambient radiated and conducted electromagnetic emission profile of the test facility, when necessary.

i. Data, and data presentation, as specified in the "data presentation" sections of the individual test procedures of MIL-STD-461.

j. Scan speeds.

k. Measurement receiver bandwidths.

l. Antenna polarization.

m. Power line voltages, frequencies, and power factor.

n. Low-noise amplifiers (LNA) compression points.

o. Any thresholds of susceptibility that were determined.

2.3. Conclusions and recommendations. Conclusions and recommendations shall be provided, including results of the tests in brief narrative form, a discussion of any remedial actions already initiated, and proposed corrective measures required (if necessary) to assure compliance of the equipment or subsystem with the contractual EMI requirements.

3. End of DI-EMCS-80200B.

G

TECHNICAL BASES FOR CHANGES FROM REV. 1 TO REV. 2 OF TR-102323

This appendix outlines the technical bases for changes made from Revision 1 to Revision 2 of TR-102348. The changes primarily affected the testing guidelines (Section 5 of this report.) Note that some of these changes have been superceded in the current revision (Revision 3); these are addressed in Appendix H. The information in this appendix is provided to allow tracing the evolution of the current guidelines from those evaluated by the NRC in Revision 1 per the SER in Appendix E.

Low Frequency Conducted Susceptibility Changes

Change #1: High frequency roll-off beyond 5 kHz

- Basis #1: These changes are consistent with MIL-STD-461E and RG 1.180.

Change #2: Introduced a new level for EUT operating at 28 VDC or below.

- Basis #2: These changes are consistent with MIL-STD-461E and RG 1.180.

Change #3: Low frequency starting point of 2nd harmonic of power frequency.

- Basis #3: These changes are consistent with MIL-STD-461E and RG 1.180.

Change #4: We now accept testing in accordance with IEC 61000-4-13 to Class 3 limits.

- Basis #4: The CS101 and 61000-4-13 testing methodologies are similar, however the most significant difference is that 4-13 terminates at 2.4 kHz. This issue has been addressed by documenting that this test is not acceptable if EUT will be exposed to switching power supplies, static frequency converters, induction motors, welding machines or similar equipment.

High Frequency Conducted Susceptibility Changes

Change #1: Added new limit for signal cables

- Basis #1: Previous limit was established based on plant emissions measured on power cables, therefore a new limit was introduced to allow relaxation for signal cables based on 461E CS114 Curve #2 which is supported by comparison with collected plant emissions data beyond 1 MHz. Note that it may be more appropriate to specify the limits recommended for Army Ground Facilities (Curve #3 from 10 kHz to 2 MHz and Curve #4 from 2MHz to 200 MHz) until additional data is collected for signal cables.

Change #2: Limit reduced for power cables from 103 dBμA to 97 dBμA.

- Basis #2: The limit was reduced to allow for relaxation and a new margin of 6 dBμA. The new limit of 97 dBμA was selected because it aligns with 461E limit Curve #4.

Change #3: High frequency roll-off beyond 20 MHz.

- Basis #3: The previous limit was flat across all tested frequencies. The high frequency roll-off brings this test into better alignment with 461E CS114 and Reg. Guide 1.180.

Change #4: Testing terminates at 200 MHz as opposed to 400 MHz.

- Basis #4: There is no need to perform this test above 200 MHz since high frequency radiated testing starts at 2MHz. This change also brings this test into better alignment with 461E CS114 and Reg. Guide 1.180.

Low Frequency Radiated Susceptibility Changes

Change #1: Endorsement of IEC 61000-4-8

- Basis #1: Although there are major differences in the scope and methodology of the MIL-STD 461E RS101 test and the IEC 61000-4-8, 9 & 10 tests, these tests collectively meet the intent of demonstrating immunity of equipment to radiated magnetic fields.

High Frequency Radiated Susceptibility Changes

Change #1: Allowance to start test at 30 MHz provided tests CS114 or 61000-4-6 is also performed.

- Basis #1: This change brings this test recommendation into better alignment with 461E RS103 and Reg. Guide 1.180.

Change #2: Extended tested frequency range from 1 GHz to 10 GHz.

- Basis #2: Extending the tested frequency range was necessary to address the increased demand and use of equipment operating at frequencies above 1 GHz.

Surge

Change #1: Changed Limits:
Reduced secondary or derived power distribution system voltage test limit from 3 kV to 2 kV.
Increased primary power connected to external lines voltage test limit from 3 kV to 4 kV.
Reduced shields & ground leads connected to remote (> 30m) grounds voltage test limit from 3 kV to 2 kV.

- Basis #1: This change brings this test recommendation into better alignment with IEC 61000-4-5 and is supported by the existing compatibility margins documented in TR-102323. The changes noted above are changes to both TR-102323 Rev. 1 and RG 1.180 which both currently specify 3 kV limits.

Electrically-Fast Transients/Bursts

Change #1: Changed Scope:
Differentiated testing for power ports vs. I/O, data & control ports. Specified the use of the coupling/decoupling network for testing power ports. Allowed the use of the coupling clamp for testing I/O, data and control ports.

- Basis #1: This change brings this test recommendation into better alignment with IEC 61000-4-4.

Change #2: Changed Limits:
Reduced testing level for power ports voltage from 3 kV to 2 kV. Reduced testing level for I/O, data and control ports from 3 kV to 1 kV. Specified that Control ports that control unsuppressed inductive loads should be tested to +/- 2 kV_{p-p}. Specified that Input/Output (I/O), data and control cables routed with power supply or control cables with unsuppressed inductive loads should also be tested to +/- 2 kV_{p-p}.

- Basis #2: This change brings this test recommendation into better alignment with IEC 61000-4-4 and is supported by the existing compatibility margins documented in TR-102323. The changes noted above are changes to both TR-102323 Rev. 1 and RG 1.180 which both currently specify 3 kV limits for all connection ports.

Electrostatic Discharge

No changes.

Low Frequency Conducted Emissions Changes

Change #1: Introduced a new level for EUT operating at 28 VDC or below.

- Basis #1:These changes are consistent with MIL-STD-461E for Navy & Army aircraft, however RG 1.180 specifies limits that most closely match a submarine platform.

Change #2: Low frequency starting point of 2nd harmonic of power frequency.

- Basis #2: These changes are consistent with MIL-STD-461E and RG 1.180.

Change #3: We now allow a db relaxation limit defined as db Relaxation = 20 log (Fundamental Power Frequency Current).

- Basis #3: These changes are consistent with RG 1.180, however MIL-STD-461E does not specify a limit dB relaxation for CE101-4 (Navy & Army aircraft).

Change #4: Reduced TR-102323 Rev. 1 limit (more restrictive) from 122 dBµA at 30Hz to 110 dBµA at 60 Hz for source voltages above 28 V and down to 100 dBµA for source voltages less than or equal to 28 V.

- Basis #4: Since the primary concern of this test is to control fundamental power frequency harmonics, reduction of the limit up to 1kHz is appropriate.

High Frequency Conducted Emissions Changes

Change #1: Changed part of limit curve from 78 dBμA at 50 kHz & 60 dBμA at 100 kHz to 90 dBμA at 10 kHz & 60 dBμA at 100 kHz. This change effectively reduced the TR-102323 Rev. 1 limit (more restrictive) from 50 kHz to 100 kHz.

- Basis #1: This change was necessary to support starting this test at 10 kHz. The new section of the limit curve remains at or below the highest composite plant emissions level.

Change #2: Change tested frequency range from 50 kHz - 400 MHz to 10 kHz - 10 MHz.

- Basis #2: This change was made to align this test with the recommended frequency ranges of MIL-STD-461E & RG 1.180.

Change #3: We now allow a db relaxation limit for equipment operating voltages above 115 VAC.

- Basis #3: This change was made to better align this test with the recommendations of MIL-STD-461E & RG 1.180.

Low Frequency Radiated Emissions Changes

Change #1: Specified measurements be performed at 7 cm.

- Basis #1: This change was made to better align this test with the recommendations of MIL-STD-461E.

High Frequency Radiated Emissions Changes

Change #1: Changed limit curve to allow the maximum allowable equipment emissions from either TR-102323 Rev. 1 or RG 1.180 from 10 kHz to 1 GHz.

- Basis #1: This change was made to provide testing relief where it was supported by either TR-102323 Rev. 1 or RG 1.180 while still maintaining equipment emissions levels low enough to prevent significant increases in plant emissions levels.

Change #2: Extended tested frequency range from 1 GHz to 10 GHz or 10 times the highest intentionally generated frequency within the equipment under test, whichever is greater.

- Basis #2: Extending the tested frequency range was necessary to address the increased demand and use of equipment operating at frequencies above 1 GHz.

Change #3: Endorsed testing in accordance with commercial standards FCC 47CFR Part 15 Class A or B and EN 55022 [31] Class A or B.

- Basis #3: Although there are differences in the methodology and range of tested frequencies, this test controls equipment emissions to prevent an increase in plant emissions that would potentially invalidate the susceptibility limit. The group has concluded that endorsement of these commercial standards is acceptable in this case due to the large (43 dBμV/m) margin between the emissions and susceptibility limits.

H

TECHNICAL BASES FOR TR-102323 REV. 3 UPDATES AND VARIANCES WITH RG 1.180 REV. 1

This appendix outlines the technical bases for changes made from Revision 2 to Revision 3 (the current revision) of TR-102323. The changes primarily affected the testing guidelines (Section 5 of this report). The information in this appendix allows tracing the evolution of the current guidelines from those evaluated by the NRC in Revision 1 per the SER in Appendix E.

This appendix also provides technical background for the differences between Revision 3 of TR-102323 and Regulatory Guide 1.180. This should be useful when it is necessary to develop justification for applying the TR-102323 Revision 3 recommendations rather than those of the Regulatory Guide. Appendix I summarizes the differences among the various revisions of TR-102323 and Regulatory Guide 1.180 in tabular formats.

Applicability

Change #1: Changed conducted high frequency emissions testing from “evaluate” to “applicable.”

Basis #1: This change is necessary to ensure continuity, coverage and adequate control of high frequency equipment emissions and bring these recommendations into alignment with RG 1.180 Rev. 1.

Low Frequency Conducted Susceptibility Changes

Change #1: Reduced IEC 61000-4-13 testing limit from Level 3 to Level 2.

Basis #1: Class 2 (Level 2) limits provide adequate compatibility margins and are consistent with the recommendations of RG 1.180 Rev. 1.

Change #2: Added endorsement of IEC 61000-4-16 testing scope, but identified it as optional.

Basis #2: IEC 61000-4-16 is a conducted, common-mode test that has no equivalent in the MIL-STD-461 testing scope. Low frequency (< 150 kHz) common-mode disturbances have not been identified as a concern in nuclear power plant emissions testing. The purpose of this test is to demonstrate electrical and electronic equipment immunity to conducted, common mode disturbances such as those originating from power line currents and return leakage currents in the earthing/grounding system. This test is not relevant for equipment ports connected to short cables & having a length less than 20 m or less. Resistive (or common impedance) coupling can directly affect signal lines, as in the case of earthed signal source, or can inject current into the shield of a signal cable. This type of coupling can appear the most relevant and sometimes may be considered inclusive of the effects of capacitive and inductive coupling.

This test will identify equipment that is susceptible to power line fundamental and harmonic noise and is specifically designed to identify equipment that is sensitive to common impedance coupling, including equipment with unbalanced sensor inputs and improperly terminated shield conductors. In a power plant the fundamental harmonic is not easily isolated from equipment and cabling due to the abundance of 60-cycle energy. Devices that are susceptible to this type of interference are generally identified immediately. (Example: A sound system with a fundamental power harmonic hum.) Because this test offers little value in addition to or in lieu of IEC 61000-4-13, it is considered optional and not generally required.

High Frequency Conducted Susceptibility Changes

Change #1: Deleted separate test level for signal leads so that the guidelines now recommend use of the same level for power and signal leads.

Basis #1: Because this is a test for susceptibility to an RF energy-induced phenomenon, the test levels should be the same for both power and signal cables, as both are equally exposed to this source. This is the practice in IEC EN 61000-4-6, MIL-STD-461E, and RTCA DO-160 for high-frequency conducted susceptibility testing; however, NRC RG 1.180 Revision 1 recommends testing signal leads to a level 6 dBµA (or 10 dBµV) below the level for power leads.

Change #2: The EMI Working Group has determined that MIL-STD-461E CS114 Curve #3 should be the recommended test level for high frequency conducted susceptibility. Since use of curve #3 alone is not a standard test level in MIL-STD-461E, the Revision 3 guidelines state that testing to the standard test levels for an Army Ground installation per MIL-STD-461E, which bounds curve #3, is also acceptable. The recommended test level for testing conducted per IEC EN 61000-4-6 is Level 3.

Basis #2: MIL-STD-461E curve #3 is recommended because the 89 dBµA plateau of this curve conservatively bounds the conducted emissions current produced by a 10 V/m radiated electric field, which is 83.5 dBµA. A 10 V/m electric field is the limit for high-frequency radiated susceptibility testing under MIL-STD-461E RS103 or IEC EN 61000-4-3. The 5.5 dBµA margin to conducted emissions produced by that high level of radiated emissions is considered to be more than adequate to assure EMC with respect to high frequency conducted susceptibility.

IEC test EN 61000-4-6 Level 3 is designed to have a test level sufficient to ensure EMC in an industrial environment similar to a nuclear power plant. The IEC EN 61000-4-6 test level is 140 dBµV, which converts to 96.5 dBµA using the 150 Ohm characteristic impedance used in this test. This emission current conservatively bounds the emission current produced by a 10 V/m radiated electric field, 83.5 dBµA. See Figures H-1 and H-2 for graphs of the MIL-STD-461E and IEC EN 61000-4-6 high frequency conducted susceptibility test levels.

The EPRI EMI Working Group has abandoned use of conducted emissions data measured per conducted emissions test CE03 as a basis for CS114 test levels. The reasons for not using the emissions data measured per CE03 are described in detail in the EPRI Technical Update "Review of High Frequency Conducted Susceptibility Limits, Assessment of CS114 Test Limits in TR-102323," Report Number 1007998.

In summary, EPRI Report Number 1007998 documents several technical factors, including inappropriate methods for collecting and applying conducted emissions measurements. These factors indicate that CE03 and CE102 measurements do not properly characterize the continuous-wave, steady-state conducted emissions level caused by radiated emissions. The EMI Working Group concluded that conducted emissions data should not be used to establish test limits for CS114 because of the fundamental differences between the conducted emissions measurement method and the purpose of applying test signals for CS114. The following discussion provides in-depth background on the development of high-frequency conducted susceptibility testing methods and the technical justification for use of the levels recommended in this guideline.

Reason for the CS114 Testing Method

MIL-STD-461 and -462 were originally promulgated in the late 1960s to control Electromagnetic Interference (EMI) emissions and susceptibility in U.S. military equipment. MIL-STD-461 provided test levels and MIL-STD-462 provided test methods. The radiated susceptibility tests were broken into a low frequency (30 Hz – 100 kHz) magnetic test (RS01) and a higher frequency (10 kHz – 40 GHz) electric field test (RS03). As the standard matured to MIL-STD-461C in the mid 1980s, it was well known that performing the RS03 test in the frequency range of approximately 10 kHz – 1 MHz was problematic. This was due to the long wavelengths of the field (30 km at 10 kHz and 300 m at 1 MHz) and the relatively small rooms where the testing was required to be performed. Other issues were the electrically small size of the antennas used to produce the field and the use of 1-meter cable lengths if the exact cable lengths were unknown, which was the typical situation. This led to very poor coupling of the electric field to the equipment under test or its cables, and difficulty in producing the required current in the equipment under test.

The Royal Air Force in England was struggling with coupling lower frequency RF energy to long cable harnesses in their aircraft whose length could not be replicated in the small EMC laboratory testing chambers. This led the British EMC engineers to develop a "Bulk-Current Injection (BCI)" test method. The idea behind this method is to directly inject energy into the cable harness to simulate low frequency electromagnetic energy coupling onto longer cable harnesses. This method proved to be helpful in identifying equipment susceptibility and was quickly adopted by RTCA DO-160, which is endorsed by the FAA for EMC of avionics on commercial aircraft.

MIL-STD-461D Test Method CS114

MIL-STD-461C had associated with it 6 Notices (changes) to MIL-STD-462, with each branch of the military requiring different testing methods. The U.S. Navy (custodian of MIL-STD-

461/462) decided in early 1990s to perform a complete re-write of the standards to incorporate new test techniques, test equipment, and to eliminate all the Notices to MIL-STD-462. The Navy convened a MIL-STD-461D committee with representatives from all the services along with industry representation. As part of this major revision, a subcommittee was formed to incorporate the BCI test method developed in Britain.

In order to establish test levels, the sub-committee performed current measurements on copper tubes (these were used rather than cables because they have very low inductance, thus are the worst case for RF coupling) supported 5 cm above a ground plane and terminated with 100 ohms. This setup was then exposed to continuous wave (CW) radiated fields at 1, 50, 100, and 200 V/m over the frequency range 10 kHz – 400 MHz. The induced currents were then plotted and used to establish test limits for the new test method in MIL-STD-461/462D using BCI, which is test CS114.

The MIL-STD data correlated well with the British data and the DO-160 data. The MIL-STD data showed poor coupling at 10 kHz, with induced current increasing with frequency up to 1 MHz. The coupled current remains constant until 30 MHz, where inductance in the setup begins to decrease the coupled current. Additional Navy studies showed that lower frequency noise on electronic equipment power leads was almost exclusively from harmonics of the power frequency, switching mode supply harmonics, and transients. Since CS101 (the committee renumbered the test from CS01 to CS101, RE01 to RE101 etc.) would cover the lower frequency noise, CS114 would cover the higher frequencies and CS116 would cover the transients, the committee decided to drop the CS02 test requirement.

CS114 Revisions in TR-102323

As has been stated, the original issue of TR-102323 attempted to incorporate the test methods of MIL-STD-461C/462, MIL-STD-461D/462D, and the IEC requirements. The EPRI EMI Working Group that wrote TR-102323 Revision 0 and Revision 1 reviewed plant test data which contained transient data that could not be separated from the continuous wave data. As a result, the CS114 level was set based on some peak transient data, which leads to an overly conservative test level at the lower frequencies in the test. These frequencies are where the majority of the energy lies for typical power line transients, and these transients raised the measured conducted emissions. This situation has resulted in many vendors designing robust power line filters and the over-use of ferrites to pass the CS114 test. Electronic equipment is being designed to operate in an unrealistic environment for nuclear power plants.

The second revision of TR-102323 partially corrected this situation by looking at the data collected in 1994 and more recently collected by Oak Ridge National Laboratory which clearly showed a lower amplitude on signal leads than power leads for frequencies less than ~1 MHz. Revision 2 allowed for a different CS114 limit on power and signal leads.

This third revision of TR-102323 has corrected the situation by using a limit from MIL-STD-461E (which incorporates minor revisions from MIL-STD-461D and combines MIL-STD-462D with -461D). The limit curve reflects the resonance characteristics of the radiated emissions coupling onto a conductor. The recommended level was obtained by examining the DO-160 limit curves, which specify the corresponding continuous wave radiated field levels. The DO-160 limit curves follow the transfer function discussed in Section 50.12 of MIL-STD-461E (Reference 6, pages A-73 and A-74). This section of MIL-STD-461E describes the radiated electric fields used to induce current in the laboratory testing that developed the limit curves for CS114. The electric field used for curve #5 (the highest test level) was 200 V/m (166 dBμV), which is very strong and much higher than would be expected in a nuclear power plant.

As a point of comparison, this guide, IEC EN 61000-4-3 and RG 1.180 Rev. 1 all recommend a radiated high frequency electric field susceptibility test level of 10 V/m. For low frequency electric field susceptibility, the recommended test levels in this guide and in RG 1.180 range from 59 to 72 dBμV (for test RE102). MIL-STD-461E states that an electric field of 1 V/m induces 1.5 mA of current in the test set-up used to establish the CS114 test levels. Using this result, an electric field of 10 V/m would induce current of 15 mA, or 83.5 dBμA at the resonance frequency of a conductor of representative length and impedance. At 10 kHz, from the curves in DO-160, the current would be 49.5 dBμA. Since radiated emissions limits for equipment are less than 10 V/m. testing for high frequency conducted susceptibility at levels of induced current based on a 10 V/m radiated electric field is conservative. The CS114 limit level curve in MIL-STD-461E that bounds 49.5 dBμA at 10 kHz and 83.5 dBμA at 1 MHz is curve #3, which has a level of 49 dBμA at 10 kHz and 89 dBμA from 1 to 30 MHz.

Testing of Surge and EFT Emissions During Conducted Measurements

In 2004, testing was performed at Tennessee Valley Authority (TVA) EMC labs to determine whether the conducted emissions measurements used as the basis for conducted susceptibility test levels may have captured and included transient events, thus resulting in inappropriately high levels. The test used a 50-ohm load terminating a 10 m cable. The load was subjected to surge or EFT waveforms applied line to neutral (differential mode). Conducted emissions measurements were made using a FCC F-52 current probe and an Agilent E7404A Spectrum Analyzer. The testing found that if a surge or EFT event occurs in the time window of the spectrum analyzer collecting emissions measurements, significant energy is recorded. During testing the surge energy was found to fall off (decrease) in the ~50MHz region, but EFT energy was recorded into the high MHz region. Should this test be duplicated using a common-mode emissions source, similar results would be expected. The conclusion of the testing was that a spectrum analyzer will record transient energy during measurement of conducted emissions and that energy recorded in this manner cannot be distinguished from continuous wave energy (see Appendix J for test results). The testing provides further support for the conclusions of the EMI Working Group that conducted emissions measurements capture transient emissions that are not meant to be tested for by conducted susceptibility test CS114.

Conclusion

TR-102323 Revision 3 has corrected an issue with over-testing of high frequency conducted susceptibility limits at lower frequencies that existed in earlier revisions. The over-test was the result of a misapplication of in-plant conducted emissions data that included transient emissions and other signals that are not intended to be represented by the emissions in CS114. With the latest revision, TR-102323 is now aligned with MIL-STD-461E, RTCA DO-160D, and IEC EN 61000-4-6. The CS114 recommended level of curve #3 will test equipment to a realistic conducted emissions environment from radiated electric field noise coupled onto the signal or power leads. Transients that occur on the power leads will be addressed by test method CS116 or IEC EN 61000-4-5.

Comparison with Regulatory Guide 1.180 Revision 1

Power Cables – The MIL-STD-461E CS114 limit levels per curve #3 or for Army Ground Installations are recommended for power cables by this report (see Figure H-1). The Army Ground Installations limit consists of CS114 curve #3 from 10 kHz to 1 MHz and curve #4 from 1 MHz to 200 MHz.

Regulatory Guide 1.180 Rev. 1 recommends a CS114 test level of 97 dBμA for frequencies from 200 kHz to 30 MHz, but has a higher level of 100 dBμA below 200 kHz (see Figure H-1). Thus, below 1 MHz, the Regulatory Guide 1.180 Rev. 1 test levels are up to 51 dBμA higher than the test levels recommended here. The Regulatory Guide 1.180 Rev. 1 test level is based on the composite CE03 envelope measured by EPRI and on some conducted emissions data reported in NUREG/CR-6436 and analyzed in NUREG/CR-6431. The level in RG 1.180 is selected so as to maintain an 8 dBμA margin to the highest composite conducted emissions envelope in TR-102323 Revision 1. The margin is to account for transients and analysis uncertainty. As discussed, high-frequency conducted emissions measurements are not considered applicable to high-frequency conducted susceptibility testing per CS114. Since the limit levels for CS114 in MIL-STD-461E were developed using radiated emissions, the limit curve for high-frequency conducted susceptibility testing should follow a limit level curve from MIL-STD-461E with roll-off at frequencies below 1 MHz and above 30 MHz rather than having a flat level.

Signal Cables – MIL-STD-461E CS114 limit levels per curve #3 or for Army Ground Installations are recommended for signal cables by this report, which is the same as for power cables. RG 1.180 Rev. 1 recommends a test level of 91 dBμA for signal cables for frequencies from 10 kHz to 30 MHz. Thus, below 1 MHz, the RG 1.180 Rev. 1 test levels are up to 48 dBμA higher than the test levels recommended here. From 1 MHz to 30 MHz, the level recommended in RG 1.180 Rev. 1 is only 2 dBμA higher than the level recommended in this guide.

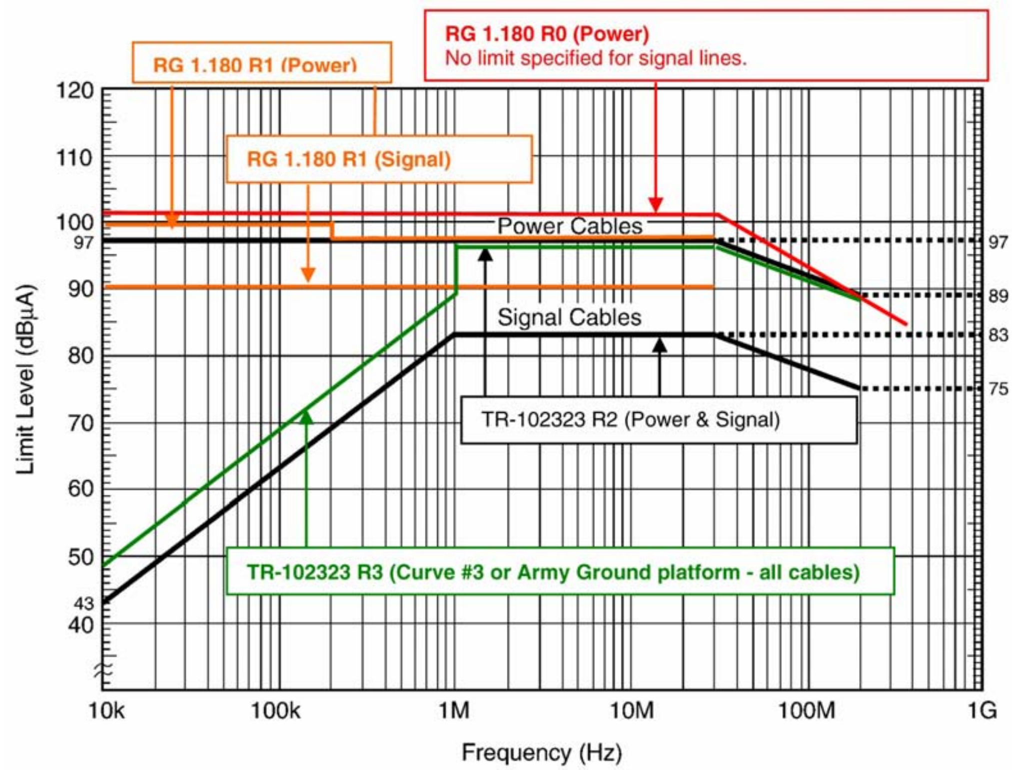

Figure H-1
Mil-Std-461E High Frequency Conducted Susceptibility Testing Limits

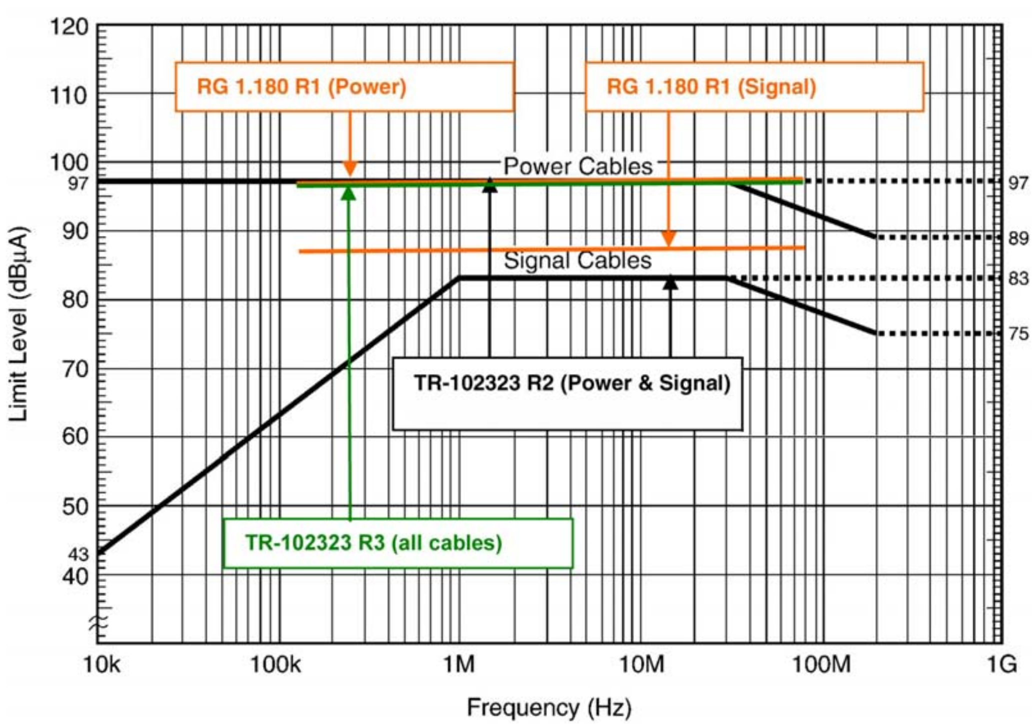

Figure H-2
IEC 61000-4-6 High Frequency Conducted Susceptibility Testing Limits

Low Frequency Radiated Susceptibility Changes

Change #1: Added endorsement of IEC 61000-4-9 & 10.

Basis #1: Although there are differences in the scope and methodology of the MIL-STD 461E RS101 test and the IEC 61000-4-8, 9 & 10 tests, these tests collectively meet the intent of demonstrating immunity of equipment to radiated magnetic fields. Note that IEC EN 61000-4-10 was included as a test that applies only for equipment to be installed in certain EMI environments, and would not typically be required. IEC EN 61000-4-10 should only be necessary where there are concerns for damped oscillatory magnetic field sources such as high voltage bus bar switching.

High Frequency Radiated Susceptibility Changes

Change #1: Specified MIL-STD-461E Navy Ships limits for RE102 testing.

Basis #1: This platform was selected because it provides a constant limit of 10 V/m across all testing frequencies.

Change #2: Add note that equipment tested in accordance with IEC 61000-4-6 may be exempted from this test between 30 and 80 MHz.

Basis #2: This note acknowledges the overlap between IEC 61000-4-6 and 61000-4-3 between 30-80 MHz.

Change #3: Add note stating, "The upper frequency limit of this test should be established by determining the highest known intentional frequency on site. This test should be performed to the highest known frequency or 1 GHz whichever is greater. Testing above 1 GHz is necessary to address the use of wireless devices and other devices operating at frequencies above 1 GHz.

Basis #3: This note was necessary to address the emissions from the introduction of wireless devices at frequencies greater than 1 GHz into nuclear power plant environments.

Surge

Change #1: IEC 61000-4-12 Level 3 for most plant systems and Level 4 for systems connected to inductive loads.

Basis #1: This change addresses the potential concern about the lack of a damped oscillatory wave in the surge testing scope and also better aligns the recommendations for this test with those of RG 1.180 Rev. 1.

Change #2: Added endorsement of IEEE Std. C62.41-1991, Category B - Low or Medium Exposure surge testing.

Basis #2: This change adds another acceptable testing standard and is consistent with the recommendations of RG 1.180 Rev. 1.

Electrically-Fast Transients/Bursts

Change #1: Added endorsement for MIL-STD-461 CS115 test.

Basis #1: This change acknowledges that CS115 waveform is acceptable and is consistent with the recommendations of RG 1.180 Rev. 1.

Change #2: Added endorsement of IEEE Std. C62.41-1991, Category B - Low or Medium Exposure surge testing.

Basis #2: This change adds another acceptable testing standard and is consistent with the recommendations of RG 1.180 Rev. 1.

Electrostatic Discharge

No changes.

Low Frequency Conducted Emissions Changes

Change #1: Deleted recommendation to perform IEC EN 61000-3-2 as an option for low frequency conducted emissions measurements.

Basis #1: The IEC 61000-3-2 scope states, "This part of IEC 61000 is applicable to electrical and electronic equipment having an input current up to and including 16 A per phase, and intended to be connected to public low-voltage distribution systems." The scope also states that "For systems with nominal voltages less than 220V (line-to-neutral), the limits have not yet been considered." Annex C of the standard discusses its application to several types of electrical and electronic equipment typically found in a residence. Because this standard does not directly address industrial plant equipment and because limits for systems below 220 V are not defined, the endorsement in Revision 2 of the IEC 61000-3-2 test to Class D limits has been deleted.

High Frequency Conducted Emissions Changes

Change #1: Changed applicability from "Evaluate" to "Applicable."

Basis #1: This change was necessary to ensure continuity and coverage of high-frequency emissions testing and recognizes that efforts to install power line filtering and other emissions control techniques may not achieve the desired results. Testing is appropriate to ensure desired design goals are achieved.

Change #2: Added IEC 61000-6-4 test to CISPR 11 measurement methods.

Basis #2: This change was made to align this test with the recommendations of RG 1.180 Rev. 1 and recognizes that the IEC 61000-6-4 and CISPR 11 methods adequately control equipment emissions. See Figure 5-5.

Change #3: Added FCC 47 CFR Part 15, Class A limits.

Basis #3: This change was made to align this test with the recommendations of RG 1.180 Rev. 1 and recognizes that the IEC 61000-6-4 and CISPR 11 methods adequately control equipment emissions. See Figure 5-5.

Low Frequency Radiated Emissions Changes

No changes.

High Frequency Radiated Emissions Changes

Change #1: Changed RE102 limit to RE102-4 limit for Navy Fixed and Air Force Ground applications.

Basis #1: This change was made to select the 461E platform that met minimum requirements to maintain compatibility margins. The Navy Mobile and Army ground limits are more restrictive and acceptable as well.

Change #2: Clarified endorsement of IEC 61000-6-4 to CISPR 11 measurement methods.

Basis #2: This change was made to align this test with the recommendations of RG 1.180 Rev. 1 and recognizes that the IEC 61000-6-4 and CISPR 11 methods adequately control equipment emissions. See Figure 5-6.

I

COMPARISON OF TR-102323 REV. 3 TO RG 1.180 REV. 1

This appendix summarizes the differences among the various revisions of TR-102323 and Regulatory Guide 1.180 Revision 1. The information is presented here in tabular format. Detailed discussion of the specific test recommendations is contained in Appendix H. Note that the applicability designations in the table use different definitions in the TR and the RG.

Tables I-1 and I-2 summarize applicability of EMC testing recommended by TR-102323 Rev. 3 and RG 1.180 Rev. 1. Table I-3 compares the testing recommendations of TR-102323 Rev. 3 and RG 1.180 Rev. 1. Table I-4 summarizes the changes from Revision 2 to Revision 3 of TR-102323, the changes from Revision 0 to Revision 1 of RG 1.180, and compares recommended test levels for emissions and susceptibility tests.

Table I-1
EPRI TR-102323 Rev. 3 Test Applicability

	Susceptibility Tests							Emissions Tests			
	Conducted		Radiated		Surge	EFT	ESD	Conducted		Radiated	
	Low-Frequency	High-Frequency	Low-Frequency	High-Frequency				Low-Frequency	High-Frequency	Low-Frequency	High-Frequency
Safety-Related	A	A	E	A	A	A	O	E	A	E	A
Important to Power Production	R	R	E	R	R	R	O	E	A	E	A
Non-Safety-Related	O	O	O	O	O	O	O	E	A	E	A

A = **Applicable.** These tests are applicable, and this characteristic of equipment performance is typically addressed through testing or an exemption including a technical justification for why the test is not required should be documented.

E = **Evaluate.** These tests are applicable, but are sometimes dispositioned through evaluation. Design features/conditions as specified for each test type should be satisfied. If testing is not performed, the design conditions/features that address this equipment emissions source shall be documented.

R = **Recommended.** These tests should be performed, or an exemption including a technical justification for why the test is not needed should be documented.

O = **Optional.** These tests are optional. Noise sources local to the equipment and installation practices should be considered in determining susceptibility testing needs for non-safety-related equipment.

Notes:

1. This table is the same as Table 5-1.

Table I-2
NRC Regulatory Guide 1.180 Rev. 1 Test Applicability

	Susceptibility Tests							Emissions Tests			
	Conducted		Radiated		Surge	EFT	ESD	Conducted		Radiated	
	Low-Frequency	High-Frequency	Low-Frequency	High-Frequency				Low-Frequency	High-Frequency	Low-Frequency	High-Frequency
Safety-Related	A	A	X	A	A	A	N/A	X	A	X	A
Non-Safety-Related Equipment That Can Affect Safety-Related Equipment (Note 1)	A	A	X	A	A	A	N/A	X	A	X	A

A = **Applicable.** The NRC considers these tests to be applicable and typically expects that they be performed or that an exemption including a technical justification for why the test is not required will be documented.

X = **Exemption is possible.** RG 1.180 allows for an exemption of this test when the following issues are addressed (see Note 3):
Low-Frequency Conducted Emissions – power quality controls and emissions does not exceed 5% THD
Low-Frequency Radiated Emissions – proximity to equipment sensitive to magnetic fields
Low-Frequency Radiated Susceptibility – proximity to magnetic field sources
This category is similar to Evaluate in Table I-1 above.

Notes:

1. RG 1.180 does not have a category for equipment important to power production, and recommends the same testing for safety-related and non-safety related equipment that can affect safety-related equipment. Non safety-related equipment that does not affect safety-related equipment is not in the scope of RG 1.180.
2. RG 1.180 does not allow mixing of tests from different standards for sets of tests. For emissions testing, the MIL-STD-461E, IEC or FCC testing scope should be completed in its entirety. For susceptibility testing the 461E or IEC testing scope should be completed in its entirety.
3. The exemption criteria in RG 1.180 are the same as those discussed in section 5 of this report, for those tests where RG 1.180 allows exemptions.

Table I-3
TR-102323 and RG 1.180 Differences in Test Applicability

	Susceptibility Tests							Emissions Tests			
	Conducted		Radiated		Surge	EFT	ESD	Conducted		Radiated	
	Low-Frequency	High-Frequency	Low-Frequency	High-Frequency				Low-Frequency	High-Frequency	Low-Frequency	High-Frequency
Safety-Related	A	A	E (TR) X (NRC)	A	A	A	O	E (TR) X (NRC)	A	E (TR) X (NRC)	A
Important to Power Production (see Note 1)	R	R	E	R	R	R	O	E	A	E	A
Non-Safety-Related	O (TR) A (NRC)	O (TR) A (NRC)	O (TR) X (NRC)	O (TR) X (NRC)	O (TR) A (NRC)	O (TR)A (NRC)	O	E (TR) X (NRC)	A	E (TR) X (NRC)	A

A = **Applicable.** Both TR-102323 Rev. 3 and the NRC consider these tests to be applicable.

E = **Evaluate.** This category is used only in TR-102323, and covers tests for which the NRC guidance allows exemptions as listed in this table.

X = **Exemption.** RG 1.180 allows for an exemption of this test when certain issues are addressed. See Table I-2 for details.

R = **Recommended.** These tests should be performed, or an exemption including a technical justification for why the test is not needed should be documented. This category is not used by RG 1.180, and is used for equipment applications not specifically addressed by RG 1.180 (equipment important to power production).

O = **Optional.** These tests are optional. Noise sources local to the equipment and installation practices should be considered in determining susceptibility testing needs for non-safety-related equipment. This category is not used by RG 1.180, and it is applied in this guideline only to non safety-related equipment or for the special case of ESD testing.

Notes:

1. RG 1.180 does not have a category for equipment important to power production, and recommends the same testing for safety-related and non-safety related equipment that can affect safety-related equipment. It does not address other non safety-related equipment.

Table I-4
Changes in Test Levels in TR-102323 and Reg. Guide 1.180

This table shows the tests and test levels recommended by TR-102323 Revision 2, TR-102323 Revision 3, NRC RG 1.180 Revision 0 and RG 1.180 Revision 1 for easy reference and comparison. Where there is a difference between the current EPRI and NRC EMC guidelines, those test levels are entered in red.

EMC Standard Test	TR-102323 Rev. 2	TR-102323 Rev. 3	RG 1.180 Rev. 0	RG 1.180 Rev. 1
Susceptibility Tests				
Low-Frequency Conducted				
MIL-STD-461	Rev. E CS101 (Omission from 50 kHz – 150 kHz)	Rev. E CS101	Rev. C CS01 Rev. D CS101	Rev. E CS101
IEC EN 61000-4-13	Level 3	Class 2 or higher	N/A	Class 2
IEC EN 61000-4-16	N/A	*Level 3* Only in isolated applications	N/A	*Level 3 (Power)* *Level 2 or 3 (Signal)*
High-Frequency Conducted				
MIL-STD-461	Rev. E CS114 Custom Curve #4 (Power Cables) Curve #2 (Signal Cables) See Figure H-1	*CS114 Curve #3 See Figure H-1*	Rev. C CS02 Custom Curve Rev. D CS114 Custom Curve See Figure H-1	*Rev. E CS114 Custom Curve #4 (Power Cables) 91 dBμA (Signal Cables) See Figure H-1*
IEC EN 61000-4-6	Figure 5-2 Custom Curve (Power Cables) Custom Curve (Signal Cables)	*Level 3 (140 dBμV) for all cables See Figure H-2*	N/A	*Level 3 (140 dBμV) for Power Level 2 or 3 (130 or 140 dBμV) for Signal cables See Figure H-2*
Low-Frequency Radiated				
MIL-STD-461	Rev. E RS101 (Limit curve has an error from DC to 30 Hz)	Rev. E RS101	Rev. C RS01 Rev. D RS101	Rev. E RS101
IEC EN 61000-4-8	Level 5	Class 4	N/A	Class 4
IEC EN 61000-4-9	N/A	Class 4	N/A	Class 4

Table I-4
Changes in Test Levels in TR-102323 and Reg. Guide 1.180 (Continued)

EMC Standard Test	TR-102323 Rev. 2	TR-102323 Rev. 3	RG 1.180 Rev. 0	RG 1.180 Rev. 1
Low-Frequency Radiated				
IEC EN 61000-4-10	N/A	Class 4 Only in isolated applications	N/A	Class 4
High-Frequency Radiated				
MIL-STD-461	Rev. E RS103 (10 V/m)	Rev. E RS103 (10 V/m)	Rev. C RS03 (10 V/m) Rev. D RS103 (10 V/m)	Rev. E RS103 (10 V/m)
IEC EN 61000-4-3	Level 3 (10 V/m)	Level 3 (10 V/m)	N/A	Level 3 (10 V/m)
Surge				
MIL-STD-461 (Damped Oscillatory Wave)	N/A Due to concerns regarding CS116 testing scope (damped oscillatory wave only) and 10 A limit	*N/A* *Due to concerns regarding CS116 testing scope (damped oscillatory wave only)*	N/A	*Rev. E* *CS116* *(damped oscillatory wave) to custom level of 5A for signal leads*
IEC EN 61000-4-5 (Combination Wave)	Level 3 - 2 kV (most systems) Level 4 - 4 kV (externally connected systems)	*Level 3 - 2 kV (most internal systems)* *Level 4 - 4 kV (externally connected systems)* *Standard specifies applicability and levels for interconnection lines*	N/A	*Level 3, 4 or X (custom) at 2, 4 or 6 kV (Power)* *Level 2 or 3 at 1 or 2 kV (Signal)*
IEC EN 61000-4-12 (Ring & Damped Oscillatory Wave)	N/A	*Level 3 –2 kV (most systems)* *Level 4 – 4 kV (systems connected to inductive loads)* *Standard specifies applicability and levels for interconnection lines*	N/A	*Level 3 or 4 levels of 2 or 4 kV (Power)* *Level 2 or 3 Level of 1or 2 kV (Signal)*

Table I-4
Changes in Test Levels in TR-102323 and Reg. Guide 1.180 (Continued)

EMC Standard Test	TR-102323 Rev. 2	TR-102323 Rev. 3	RG 1.180 Rev. 0	RG 1.180 Rev. 1
Surge				
IEEE Std C62.41-1991	N/A Due to lack of use by most equipment vendors.	*Ring wave to Category B – Low or Medium Exposure levels of 2 or 4 kV Combination wave to Category B – Low or Medium Exposure levels of 2 or 4 kV*	Ring & Combination waves to 3 kV	*Ring wave to Category B – Low or Medium Exposure levels or Category C Exterior level of 2, 4 or 6 kV Combination wave to Category B – Low or Medium Exposure levels or Category C Exterior level of 2 or 4 kV*
Electrically-Fast Transient				
MIL-STD-461	N/A Due to concerns regarding CS115 limit of 5A	*Rev. E CS115*	N/A	*Rev. E CS115 to custom level of 2A for signal leads*
IEC EN 61000-4-4	Level 3 (2 kV – Power) (1 kV – Signal)	*Level 3 (2 kV – Power) (1 kV – Signal)*	N/A	*Level 3 or 4 at 2 or 4 kV (Power) Level 2 or 3 At 1or 2 kV (Signal)*
IEEE Std C62.41-1991	N/A	*EFT waveform to Category B – Low or Medium Exposure levels of 2 kV (Power) and 1 kV (Signal)*	EFT waveform to 3 kV	*EFT waveform to Category B – Low or Medium Exposure levels of 4 kV (Power) and 2 kV (Signal)*
Electrostatic Discharge				
IEC EN 61000-4-2	Level 4 (8 kV/15 kV)	Level 4 (8 kV/15 kV)	N/A	N/A
Emissions Tests				
Low-Frequency Conducted				
MIL-STD-461	Rev. E CE101	*Rev. E CE101 Navy & Army aircraft limit*	Rev. C CE01 Rev. D CE101	*Rev. E CE101 Submarine limits for AC; customized level of 130 dBμA for DC*

Table I-4
Changes in Test Levels in TR-102323 and Reg. Guide 1.180 (Continued)

EMC Standard Test	TR-102323 Rev. 2	TR-102323 Rev. 3	RG 1.180 Rev. 0	RG 1.180 Rev. 1
Emissions Tests				
Low-Frequency Conducted				
IEC EN 61000-3-2	Custom limit curve based on 461 defined limit	*No longer recommended*	N/A	*N/A*
High-Frequency Conducted				
MIL-STD-461	Rev. E CE102 to customized limit	*Rev. E CE102 with no customization*	Rev. C CE03 Rev. D CE102	*Rev. E CE102 with customized limit curve*
IEC EN 61000-6-4	N/A	Class A limits to CISPR 11 method for Group 1	N/A	Class A limits to CISPR 11 method for Group 1
FCC 47 Part 15	N/A	Class A limits	N/A	Class A limits
Low-Frequency Radiated				
MIL-STD-461	Rev. E RE101 to customized limit	Rev. E RE101 to custom limit	Rev. C RE01 Rev. D RE101	Rev. E RE101 to customized limit
High-Frequency Radiated				
MIL-STD-461	Rev. E RE102 to customized limit	*Rev. E RE102 to Navy Fixes and Air Force Ground applications limit*	Rev. C RE02 Rev. D RE102	*Rev. E RE102 to customized limit*
IEC EN 61000-6-4	Class A limits to CISPR 22 method	*Class A or B limits to CISPR 11 method for Group 1*	N/A	*Class A limits to CISPR 11 method for Group 1*
FCC 47 Part 15	Class A or B limits	*Class A or B limits*	N/A	*Class A limits*

J
TVA LABS SURGE AND EFT TESTING

Additional surge and EFT testing was performed at Tennessee Valley Authority (TVA) labs to identify if previously collected and reported CE03 plant emissions testing may have captured and included transient events. The tests used a 50-ohm load terminated on the end of a 10 m cable. The load was subjected to a surge/EFT applied line-to-neutral (differential). Surge and EFT voltages ranged from 200V to 2000V. Measurements were made using a FCC F-52 current probe and an Agilent E7404A Spectrum Analyzer. The test results are shown in the following graphs. Figure J-1 shows the cumulative results of the tests all the test conditions. Figures J-2 through J-9 show the tests individually. Note that the resistor in the test setup failed during the final test run (surge testing at 2000V) in Figure J-9.

The testing determined that if the surge or EFT event occurs in the time window of the spectrum analyzer, significant energy is recorded. During testing the surge energy was found to fall off (decrease) in the ~50MHz region, but EFT energy was recorded into the high MHz region. Should this test be duplicated using a common-mode emissions source, similar results would be expected. The conclusions from the testing are that a spectrum analyzer will record transient energy during a normal sweep, and that energy recorded in this manner cannot be distinguished from continuous wave energy. Thus, since the conducted emissions measurements collected in 1993-1994 (see section 2) did not distinguish between continuous and transient emissions, the measurements include both transient and continuous emissions, and the net effect is to make the measured emissions higher. This results in the bounding emissions envelope (see Figure 2-3) being artificially high compared to what would be expected if a technique that measured only continuous emissions were used. This testing supports one conclusion of the EPRI review of the basis for CS114 test levels, which is that the measured emissions were higher than the continuous conducted emissions present. For a complete summary of the technical justification for changing the basis for CS114 test levels, see Appendix H.

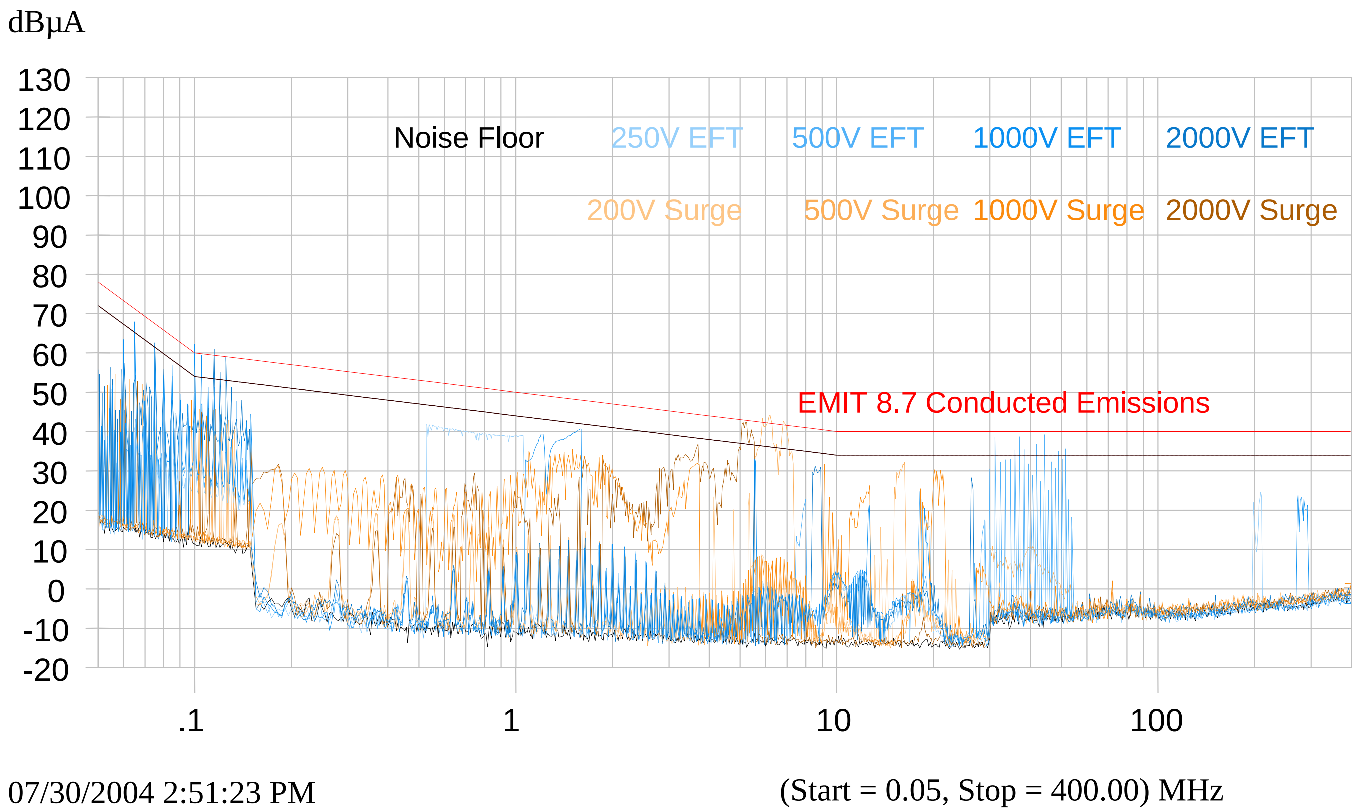

Figure J-1
Composite Results of Surge/EFT Testing into 50 Ohm Load

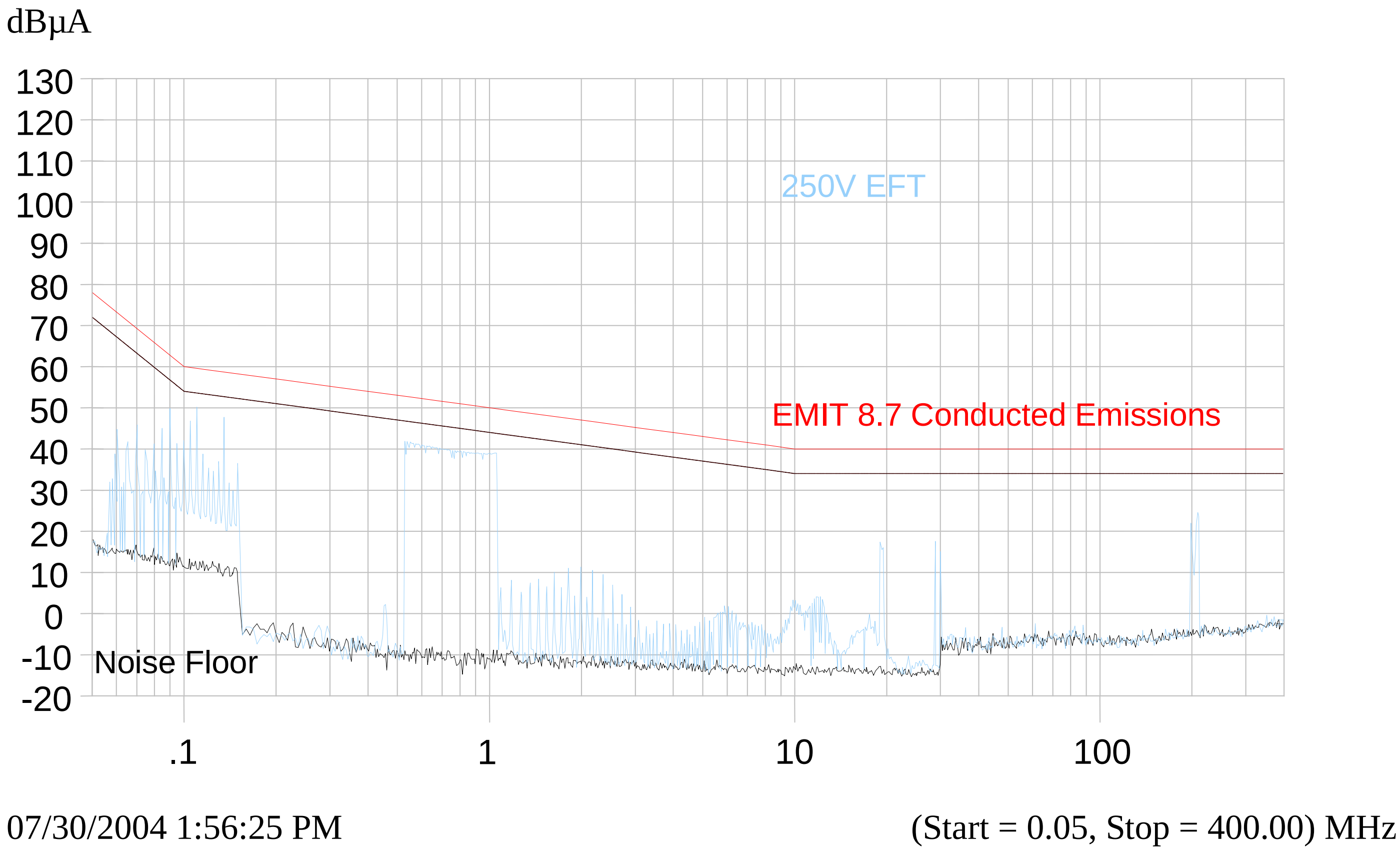

Figure J-2
Results of EFT Testing at 250 V into 50 Ohm Load

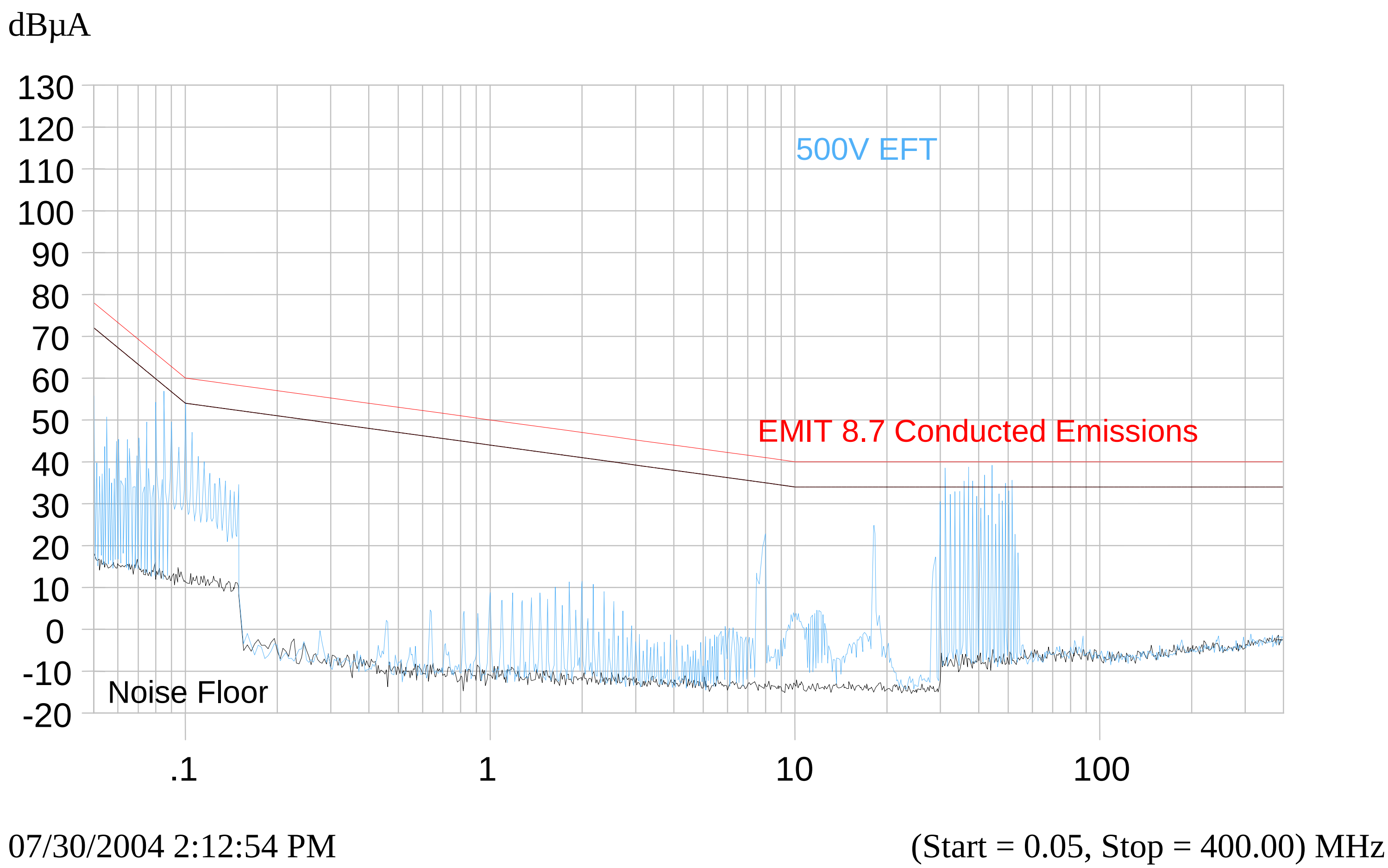

Figure J-3
Results of EFT Testing at 500 V into 50 Ohm Load

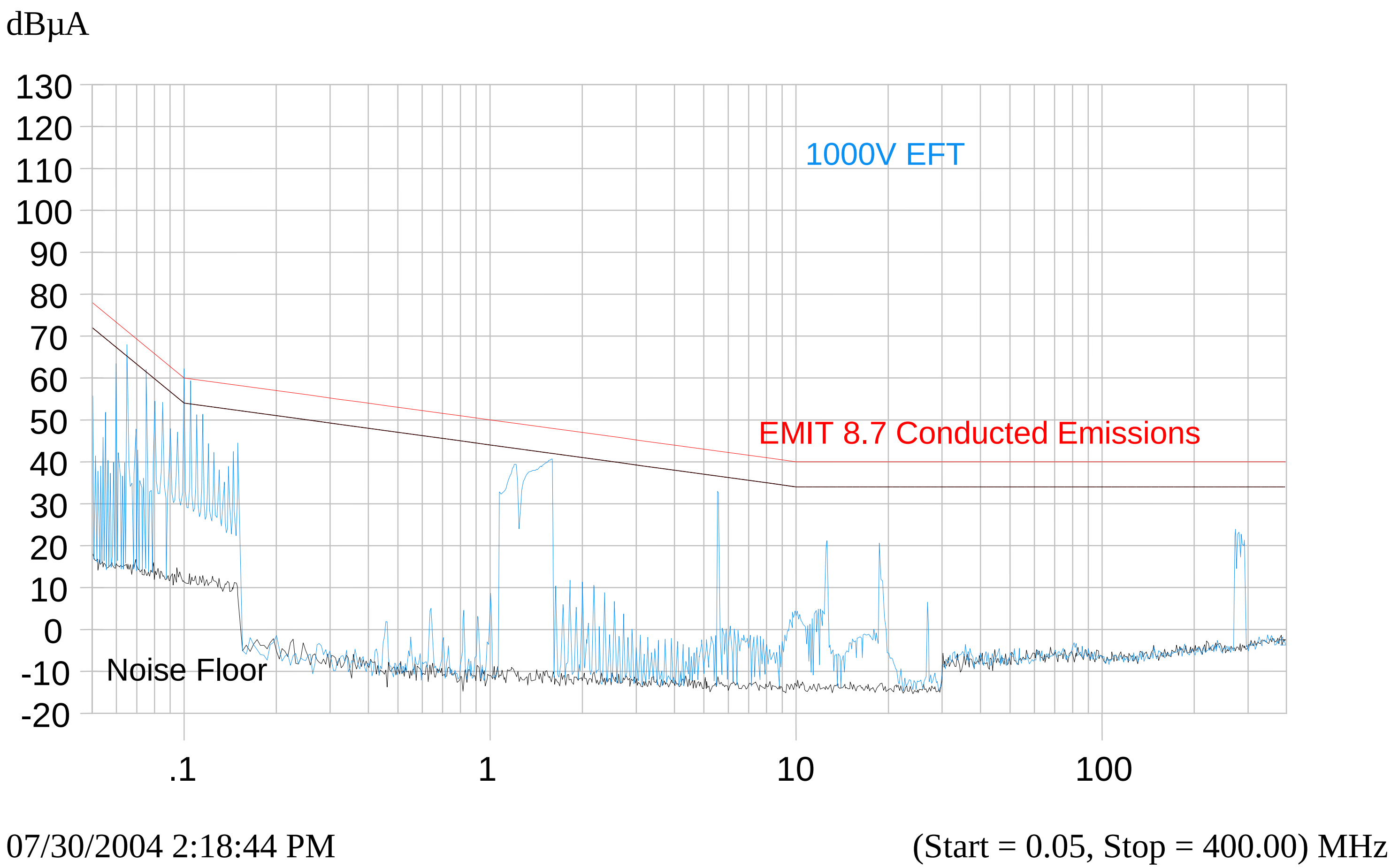

Figure J-4
Results of EFT Testing at 1000 V into 50 Ohm Load

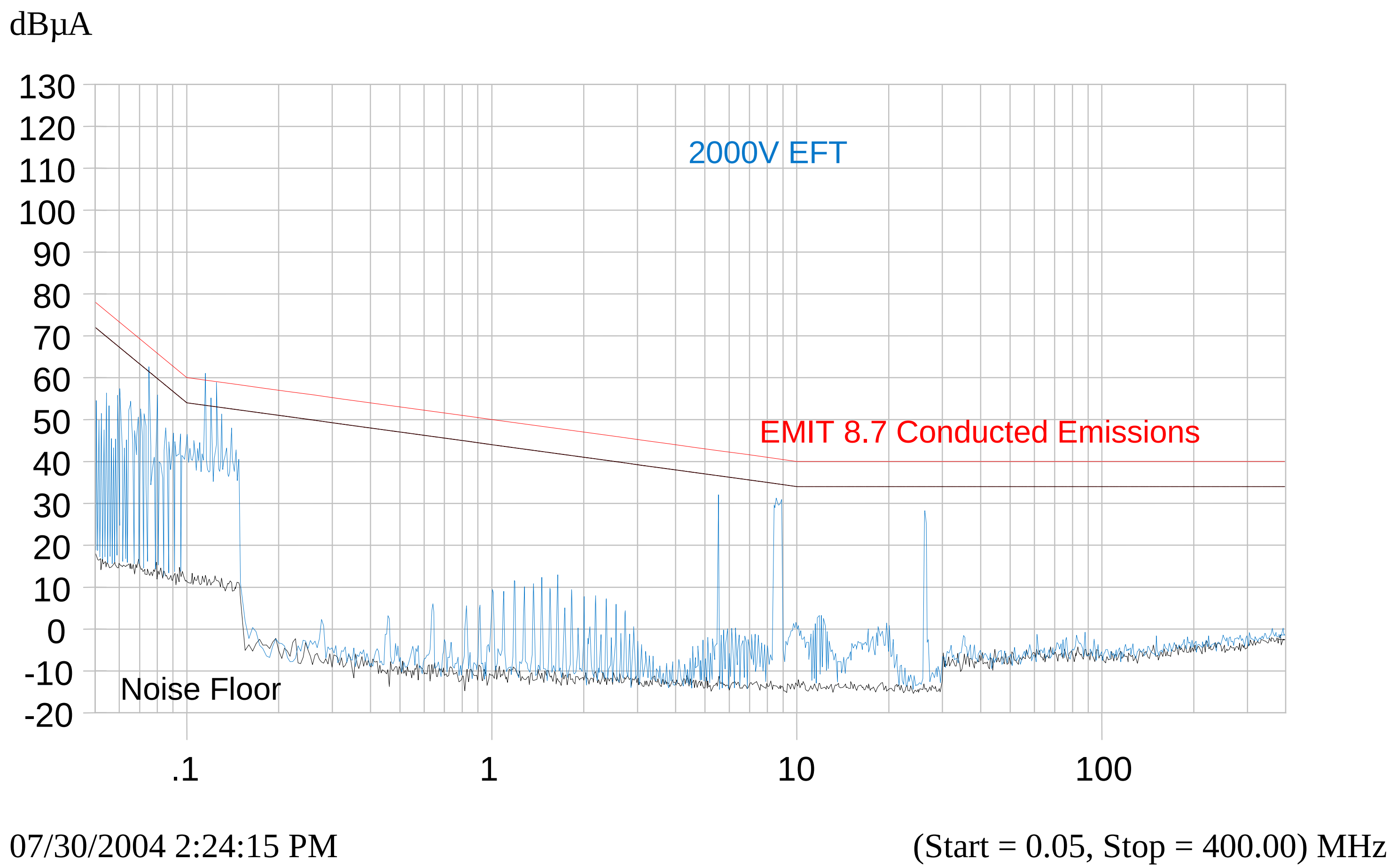

Figure J-5
Results of EFT Testing at 2000 V into 50 Ohm Load

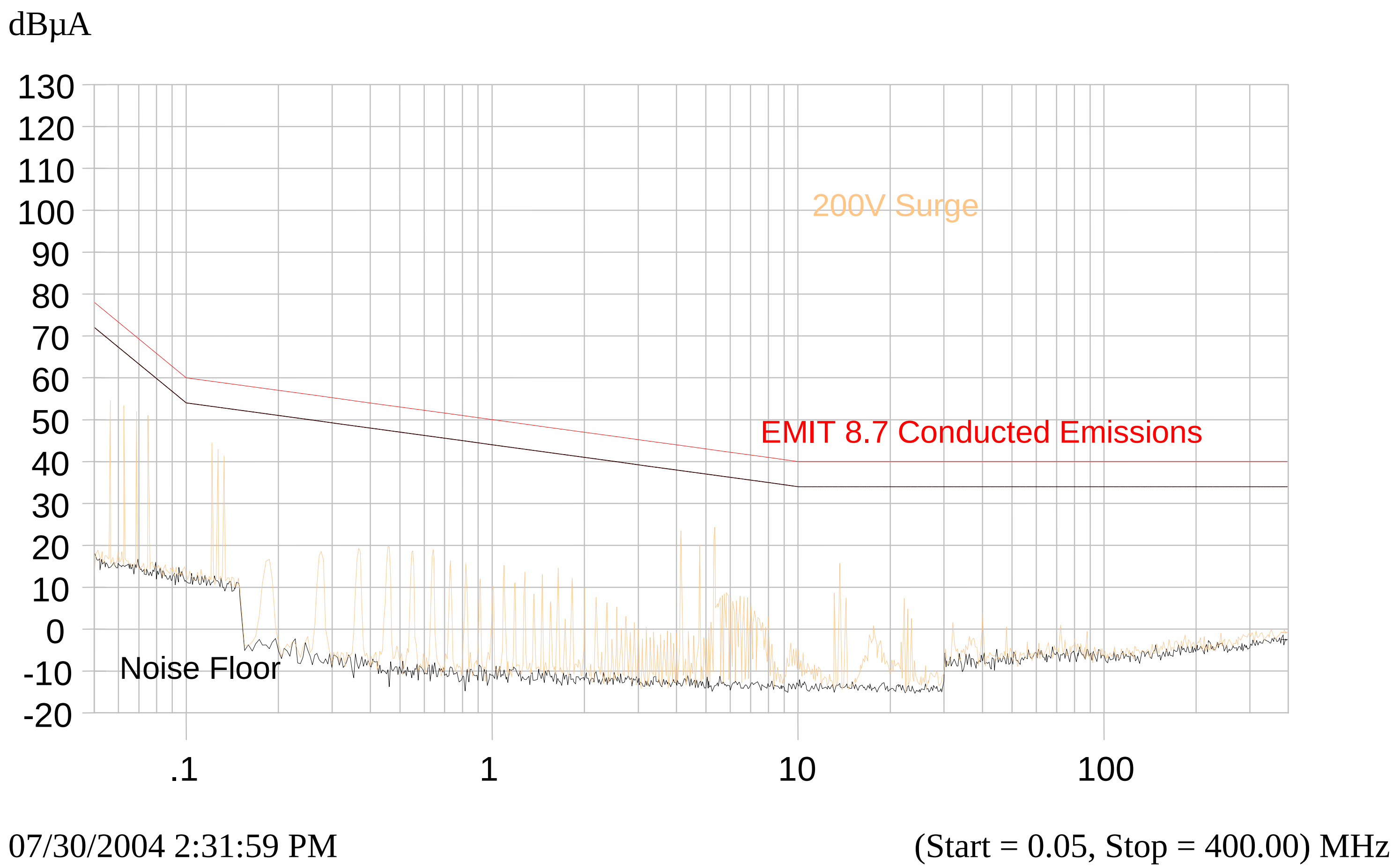

Figure J-6
Results of Surge Testing at 200 V into 50 Ohm Load

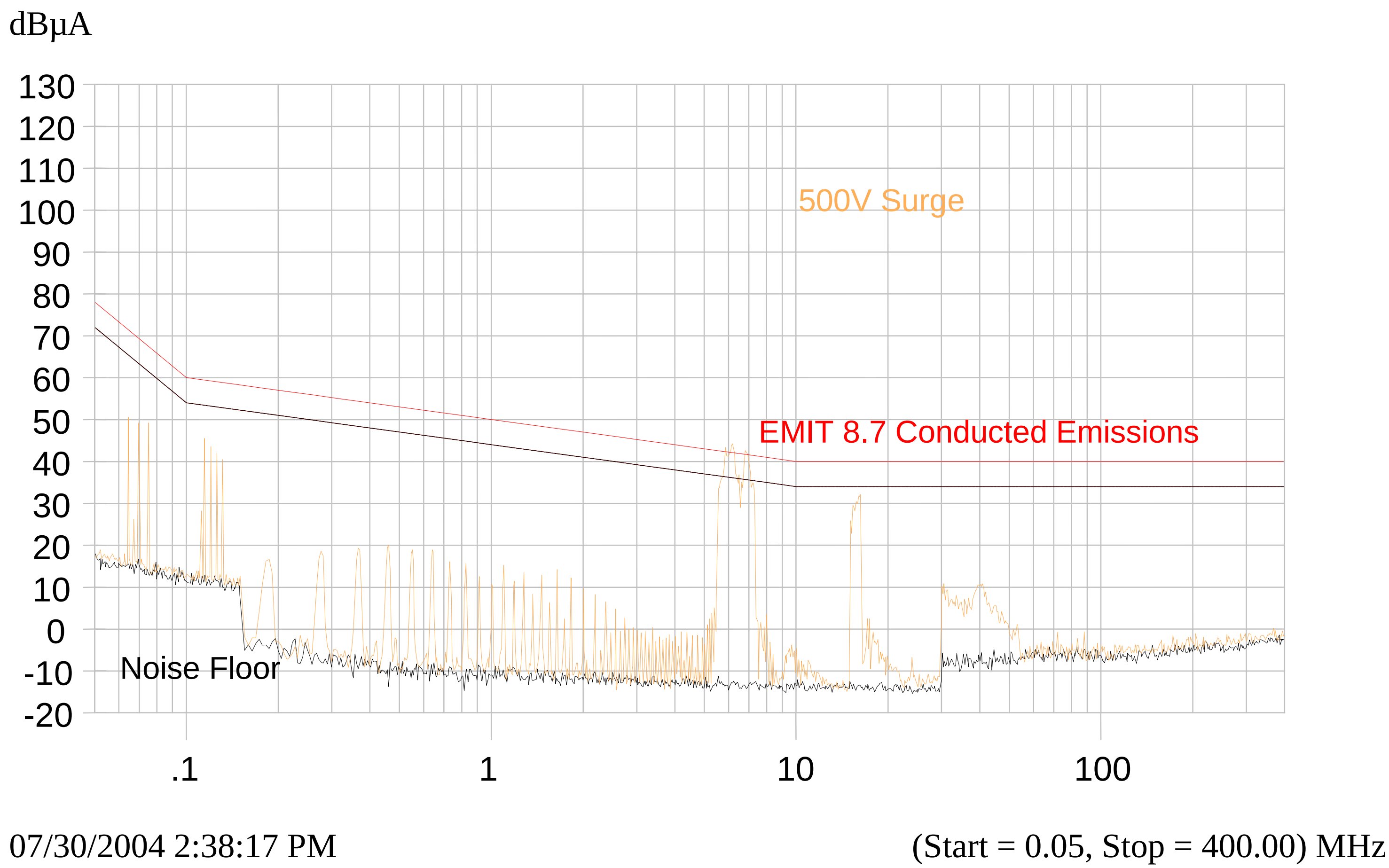

Figure J-7
Results of Surge Testing at 500 V into 50 Ohm Load

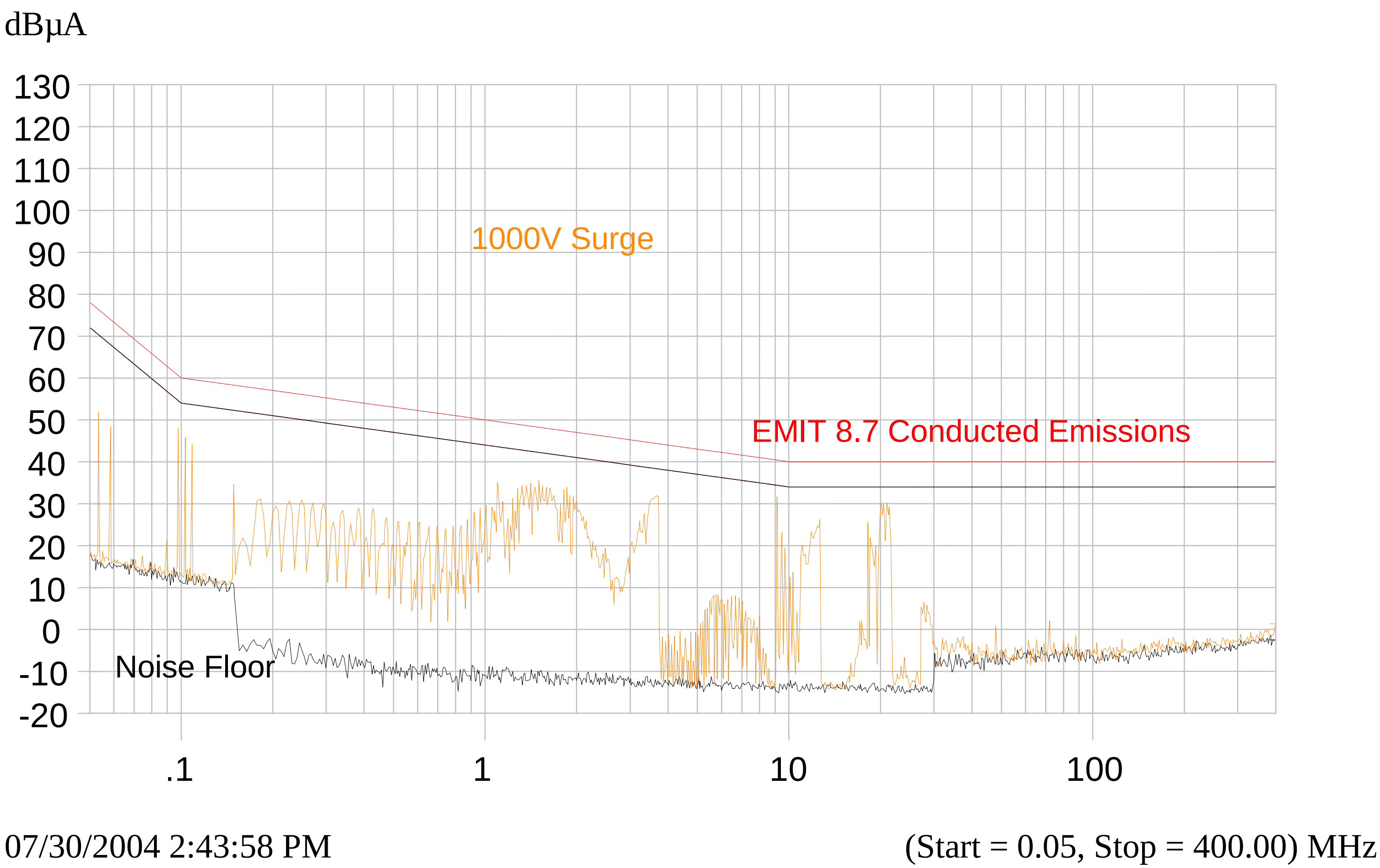

Figure J-8
Results of Surge Testing at 1000 V into 50 Ohm Load

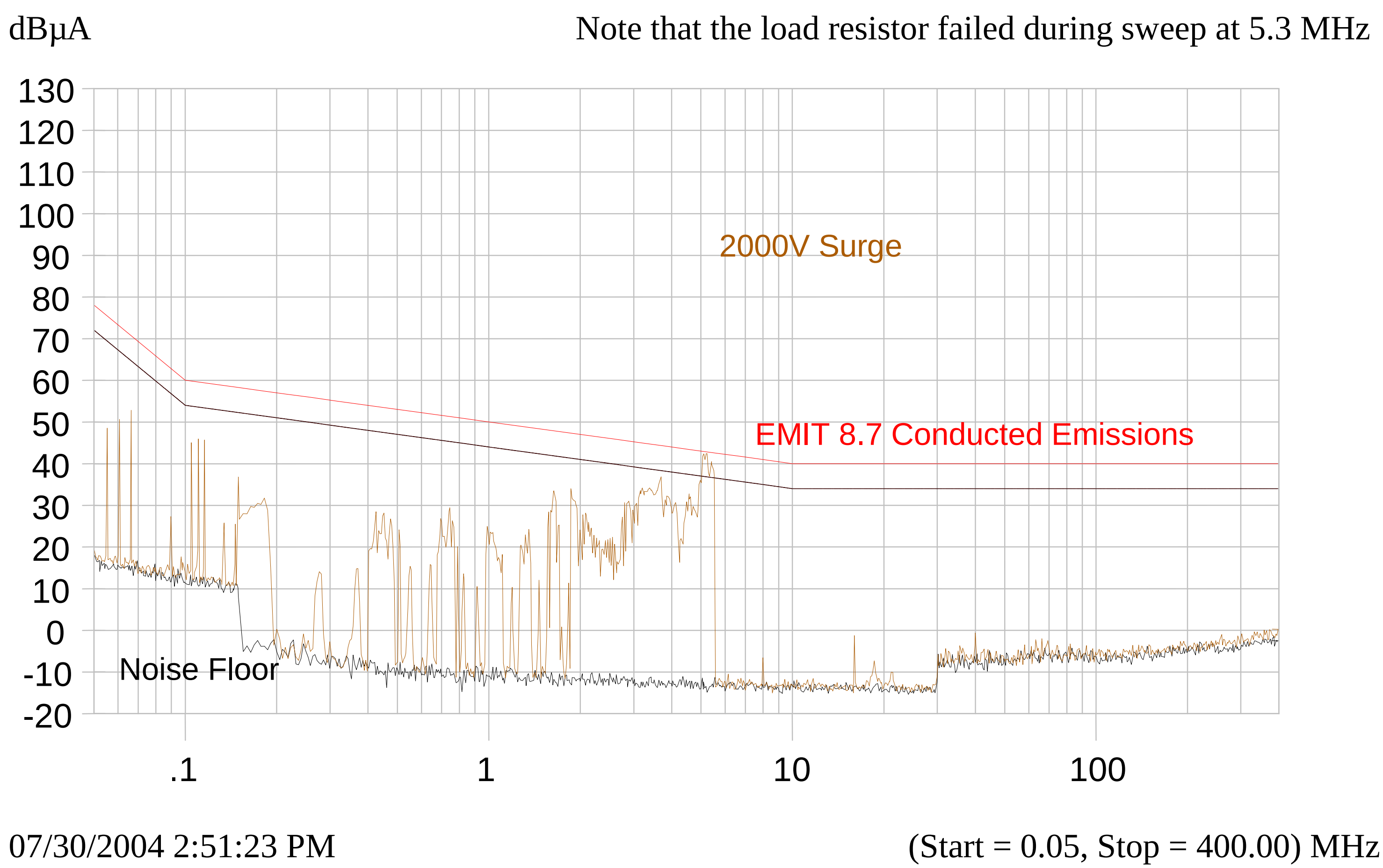

Figure J-9
Results of Surge Testing at 2000 V into 50 Ohm Load

Program:
Nuclear Power

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