POWERING PROGRESS THROUGH
SCIENCE AND TECHNOLOGY

EPRI

January 22, 2001

Document Control Desk
United States Nuclear Regulatory Commission
Rockville, MD 20852
Attn: Leonard Olshan NRC/NRR 301-415-1419

Subject: EPRI Report PID 1000603, *Guidelines for EMI Testing in Power Plants: Revision 2 to TR-102323*

Gentlemen:

This letter and enclosure are a follow up to the meeting held January 16, 2001 between the EPRI Electromagnetic Interference (EMI) Working Group and the NRC staff to review subject report to seek the Commission's endorsement of the approach described. The enclosure is a copy of the report and we seek approval of the guidelines detailed in the topical report, per discussions at the meeting. In addition, we request that the fees for review be waived per the waiver criteria in Part 170, as explained below; following a discussion of the background behind the development of the revised guidelines.

BACKGROUND

EPRI prepared a set of guidelines for EMI testing in power plants and submitted it to the NRC in 1994. The NRC published an SER in response in 1996[1] which endorsed the approach but required the margins between equipment susceptibility limits and the highest plant emissions be increased, from 6 dB to 8 dB. EPRI published Rev 1 to the guidelines in 1997[2].

EPRI reassembled the EMI Working Group in 2000 after being directed by the EPRI I&C Advisory Subcommittee to develop a revision to the existing EPRI EMI Guidelines, based on plant operating experience and guidance in Reg Guide 1.180 issued by the NRC in January 2000[3].

The Working Group, which consists of representatives of nuclear utilities, equipment vendors, and system integrators, met several times last year. It was especially useful to the Working Group to have NRC staff present at all the meetings in 2000 during

---

[1] Letter from Bruce Bolger, Director Division of Reactor Controls and Human Factors, Office of NRR, to MR. Carl Yoder, EPRI EMI Working Group Chairman, April 17, 1996

[2] EPRI Technical Report TR-102323-R1, "Guidelines for EMI Testing in Power Plants—Rev 1", January 1997.

[3] U.S. Nuclear Regulatory Commission. "Guidelines for Evaluating Electromagnetic and Radio Frequency Interference in Safety-Related Instrumentation and Control Systems". Reg. Guide 1.180, 2000.

add Leonard Olshan, 40 rids

T010

development of the subject guidelines and to benefit from the many valuable technical insights provided. The main purpose for the revision was to re-establish equipment emission and susceptibility test limits in order to reduce excessive conservatism. In addition the guidelines consider broader monitoring for emission and ensuring equipment susceptibility for frequency ranges above 1 GHz due to wider use of newer telecommunication devices.

FEES

EPRI requests that the NRC review fees be waived per the waiver criteria in 10CFR170.21, footnote 4, which states that "fees will not be assessed for requests/reports submitted to the NRC: ... (3) as a means of exchanging information between industry organizations and the NRC for the purpose of supporting generic regulatory improvements or efforts".

The subject topical report is a revision to generic guidance for digital equipment modifications followed by all nuclear plants since 1996 . EPRI has conducted several training courses to assure that their members are able to meet the guidance effectively and efficiently.

The revised guidelines are expected to clarify:

- Equipment emissions testing limits and susceptibility limits
- Applicability for non-safety related equipment
- Use of commercial standards

Since these guidelines are used to clarify and implement regulatory guidance in 2001, the improvements in this guideline constitute an improvement in how industry will follow that regulatory guidance. Thus the waiver criteria above are met.

In closing, we believe that our interactions with the NRC staff during the development of the topical report have been constructive and beneficial. If you have any questions about this report, please contact me at 704-547-6127 or e-mail at **rshankar@epri.com.**

Sincerely,

RShankar

Ramesh Shankar
Manager, Instrumentation and Control

c: J Shank, PSE&G
M Syed, TXU
R Brehm, TVA
N Eisenmann, Entergy
W Messer, Duke Energy
S Lee, Southern Company
J Lance, EPRI
J Lang, EPRI
G Vine, EPRI

EPRI

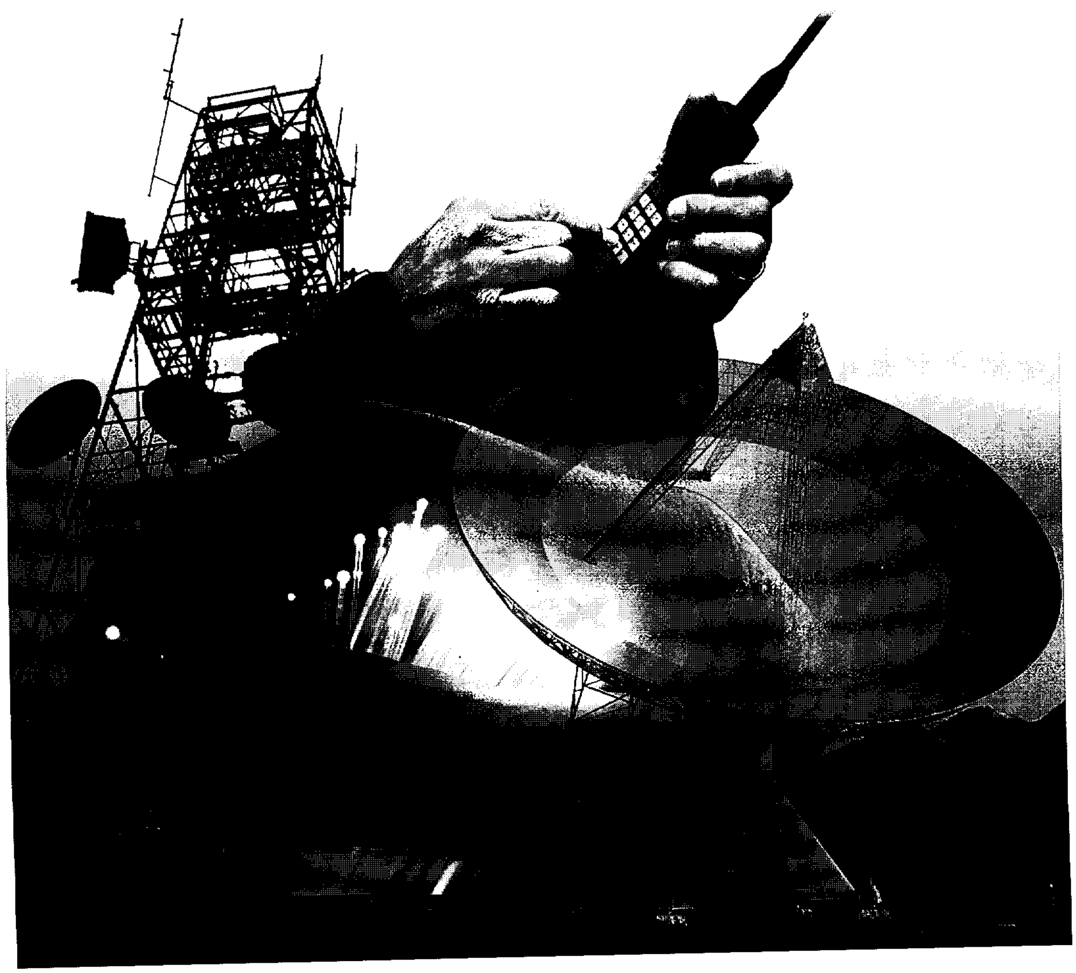
Guidelines for Electromagnetic Interference Testing of Power Plant Equipment

Revision 2 to TR-102323

LICENSED MATERIAL

WARNING:
Please read the License Agreement on the back cover before removing the Wrapping Material.

Technical Report



Instrumentation & Control

I&C

Guidelines for Electromagnetic Interference Testing of Power Plant Equipment

Revision 2 to TR-102323

1000603

Final Report, November 2000

EPRI Project Manager
R. Shankar

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

EPRI

ORDERING INFORMATION

Requests for copies of this report should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, CA 94523, (800) 313-3774.

CITATIONS

This report was prepared by principal investigators:
J. Shank
M. Syed
N. Eisenmann
R. Brehm
W. Messer
S. Lee
J. Hazeltine
J. Press
R. Carritte
C. Vitalbo
F. O'Connor

This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Guidelines for Electromagnetic Interference Testing of Power Plant Equipment: Revision 2 to TR-102323, EPRI, Palo Alto, CA: November 2000. 1000603.

REPORT SUMMARY

This revision to the original guide, which received U.S. NRC approval in a Safety Evaluation Report (SER) in April 1996, reduces excessive conservatism in plant equipment emission and susceptibility testing limits. It identifies emissions sources in nuclear power plants, recommends susceptibility and emissions standards, and details design and layout practices for minimizing susceptibility to electromagnetic interference (EMI).

Background

Nuclear power plants are replacing obsolete analog instrumentation and control (I&C) systems with more efficient and economical digital systems. The NRC is concerned about the effects of EMI and radio-frequency interference (RFI) on the safe and reliable operation of digital systems. EPRI published a guide in 1997 to develop practical alternatives to ensure electromagnetic compatibility of safety-related digital equipment in nuclear plants. It established bounding emission limits based on plant measurements and used these bounds to establish susceptibility test limits that provided adequate margin of safety. To ensure adherence to bounding limits, the guide recommended controlling emissions of systems/equipment in close proximity. The EPRI guidance has been a *de facto* standard followed by domestic and nuclear plants to justify digital upgrades of safety-related equipment.

Objective

- To provide a basis for revised EMI limits and obtain NRC approval

Approach

The EPRI project team reviewed emissions measurements collected at nuclear power plants and emissions data collected by the NRC in the 1980s from two plants in operating and shutdown modes. Additional data were obtained in 1993 and 1994 from seven plants representing different geographical conditions, plant configurations, and nuclear steam supply system vendor designs. The data—obtained according to newly defined procedures—allowed investigators to comprehensively assess the ambient environment for both steady-state and transient EMI. Based on observed levels of EMI in nuclear power plants, the team developed guidelines for equipment susceptibility tests and testing levels as well as control of equipment emissions. Substantial technical dialogue with the NRC ensured its concurrence with the developed approach.

This guide revises the limits to reduce excessive conservatism, based on plant operating experience since the first version of the guide was released and broader frequency ranges to accommodate newer telecommunication devices.

Results

This guide defines recommended generic EMI susceptibility and emissions test levels to be used in establishing equipment electromagnetic compatibility 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.

EPRI Perspective

The initial version of the guide was submitted to the NRC in September 1994 for issuance of an SER. The NRC published an SER in April 1996. Revision 1 of the guide was published in January 1997 to modify margins between equipment susceptibility test limits and the highest plant emissions (8 dB vs. 6 dB in the original guide), per the SER.

Revision 2 was developed to re-establish equipment emission and susceptibility test limits in order to reduce excessive conservatism, based on plant operating experience and guidance in Regulatory Guide 1.180, issued by the NRC in January 2000. In addition, the guide considers broader monitoring for emissions and ensuring equipment susceptibility for frequency ranges above 1 GHz due to the wider use of newer telecommunication devices. This guide contains the following revisions:

- Modified and clarified equipment susceptibility testing limits
- Modified and clarified equipment emissions testing limits
- Clarified applicability for non-safety-related equipment
- Clarified use and endorsement of commercial standards

Keywords

Electromagnetic interference
Monitoring
Instrumentation
Control
Digital systems

ABSTRACT

This study was prompted by utilities desiring a more complete understanding of the electromagnetic interference (EMI) problem and to provide technically sound alternatives to demonstrate that EMI will not affect the operation of sensitive electronic equipment. Emissions data acquired previously from two nuclear plants along with 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 included in 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 minimum EMI limiting practices and guidance on equipment emission levels.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Background

Nuclear power plants are considering replacing obsolete analog instrumentation and control (I&C) systems with digital systems. The U.S. Nuclear Regulatory Commission (NRC) had expressed concern about the effects of electromagnetic emissions (called electromagnetic interference [EMI] or radio-frequency interference [RFI]) on the safe and reliable operation of digital systems. Several utilities were required to develop a quantitative description of the plant electromagnetic emissions at the location of the digital equipment installation to demonstrate that emission levels were below equipment EMI/RFI susceptibility levels. The requirement to perform an EMI site survey for an analog-to-digital replacement is an added operations and maintenance (O&M) cost burden.

In 1995, EPRI published TR-102323, *Guidelines for Electromagnetic Interference Testing in Power Plants.* The NRC issued a Safety Evaluation Report (SER) in 1996, endorsing the guidelines (see Appendix D). EPRI published a later revision to align it with margins allowed by the SER [1]. The 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 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]. The strategy followed was similar to the EPRI guidelines but differed in limits for the various tests.

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 those deemed important for power production.

Section 5, "Equipment Susceptibility and Emissions Testing Guidance," defines equipment susceptibility and emissions testing requirements for safety-related and non-safety-related equipment important to power production. The minimum EMI limiting practices detailed in Section 6 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 are other acceptable ways to address any particular electromagnetic interference concern or threat. Deviation from this report is acceptable if an adequate technical justification and basis are documented in the equipment qualification information.

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 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 electromagnetic compatibility for nuclear power plant equipment. The bases of the recommendations are international and domestic EMI MIL-STDs and analysis of EMI measurement 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 6).

Report Organization

The report is organized into nine sections and a list of references. Section 2 describes electromagnetic emissions data and MIL-STDs used to describe equipment emission limits. Data acquired by the NRC from two nuclear plants in the 1980s were analyzed to assess levels of interference. Section 3 contains analysis of the data and descriptions of the types and expected levels of interference expected in nuclear power plants. Section 4 provides recommended generic emissions testing guidance and the results of testing at seven different plants. Section 5 defines the scope and applicability for equipment susceptibility and emissions testing. Section 6 defines minimum EMI limiting practices utilities must comply with to ensure that plant emissions levels are bounded and the recommended susceptibility levels are not exceeded. Section 7 summarizes the limits on equipment emissions, plant emissions, and equipment susceptibility. Section 8 contains an overall summary and conclusions.

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 data obtained at nuclear plants are provided in Appendix C. Appendix D contains a copy of the NRC SER. Appendices E and F contain a sample testing procedure and qualification report under Defense document EMITR (DI-EMCS-8021A and DI-EMCS-80200A).

The Technical Basis for the changes in susceptibility and emission requirements from Rev. 1 to Rev. 2 (the current report) is documented in Appendix G.

2
EMISSIONS DATA DESCRIPTION

Introduction

The EMI/RFI emissions data reported in this document were collected from a number of plants, using procedures based on standards developed by the MIL-STD for measuring emissions from equipment. The need to define the EMI/RFI emissions environment of equipment to be installed in a plant required an adaptation of the procedures defined in the MIL-STD for determining plant EMI/RFI emissions, rather than measuring and controlling the 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 relevant standard is MIL-STD 461/462 [4].

The measurements selected for the plant emissions mapping consisted of the measurement of current on the interconnecting cables and conductors using a current probe and the measurement of radiated fields and waves 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 7) 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.

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.

Past licensees 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 2-1 illustrates the recommended equipment emissions levels for CE03 (MIL-STD-461C) and CE102 (MIL-STD-461D). Both of these test procedures deal with measuring the conducted current emissions on the power and interconnecting cables from the equipment over the frequency range of about 10 kHz to 50 MHz. However, 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 2-1 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 higher in amplitude.

Figure 2-1 also illustrates a typical conducted equipment susceptibility limit. In order to achieve EMC between equipment, susceptibility levels must be higher than emissions levels. Figure 2-2 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.

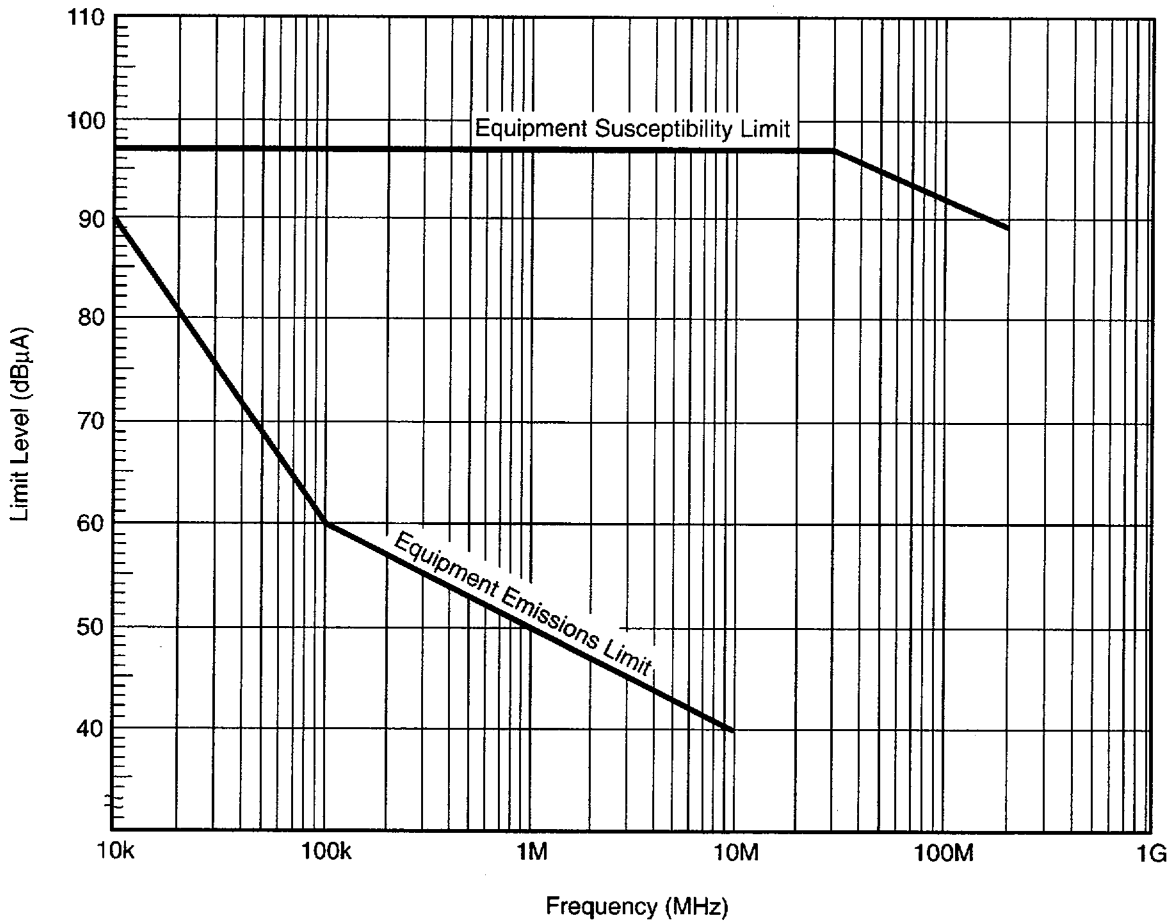


Figure 2-1
High-Frequency Conducted Testing Limits

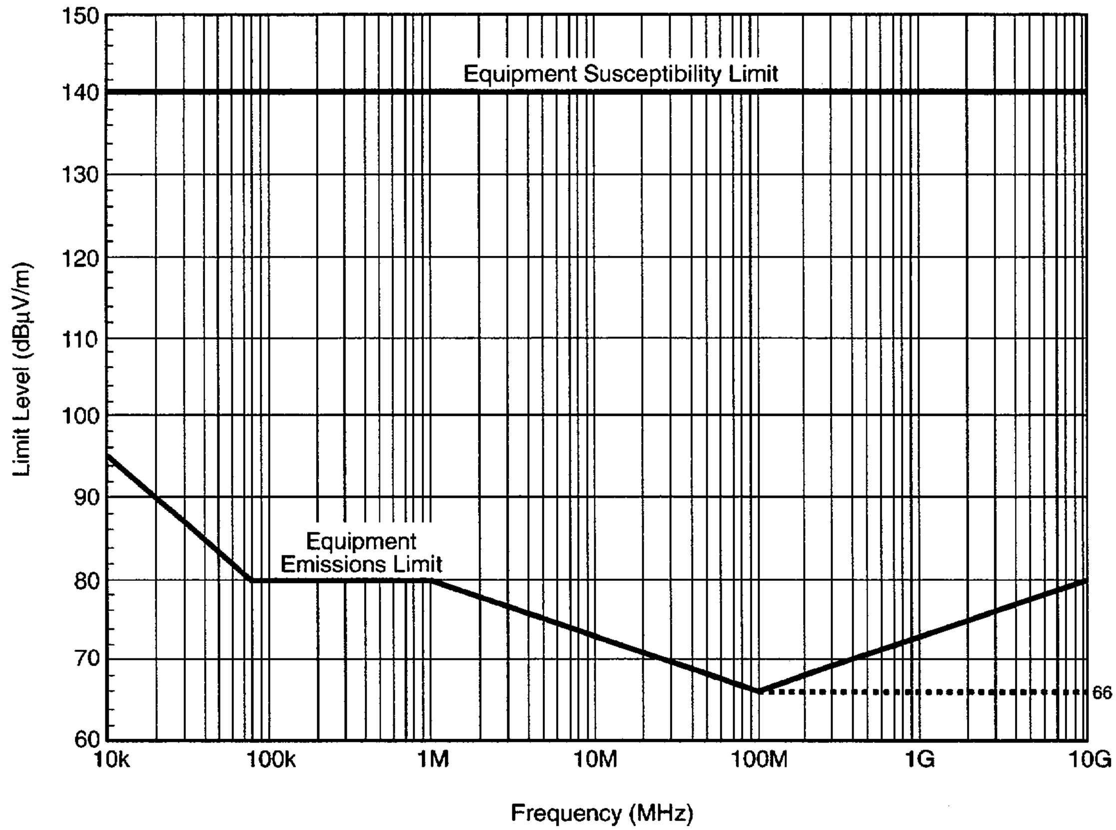


Figure 2-2
High-Frequency Radiated Testing Limits

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.

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.

Plant Emissions Data 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 Zion or Turkey Point data. However, it was worthwhile to review the approach and the findings and to examine the large amount of EMI data in the report. Measurements were concentrated on 60-Hz systems, and measurement equipment 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 made 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.

Procedure for Obtaining Early Emissions Data

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 was required to apply 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 with measurement probes located at precise distances and to minimize all 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 requirements.

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.

NRC Research and Applicable Guidance

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]. 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.

NUREG/CR-6436 documents radiated electric and magnetic field data and some conducted EMI data [11]. 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]. The operating envelopes and testing limits endorsed in NUREG/CR-6431 [10] and Regulatory Guide 1.180 [2] are generally consistent with those recommended in this report. The data reported in NUREG/CR-6436 [11] are generally consistent with the data collected for and reported here and also support the use of the equipment susceptibility and emissions testing limits and other criteria and recommendations documented in this report.

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 in 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].

3
EVALUATION OF PLANT EMISSIONS DATA

Introduction

This section contains an evaluation of plant emissions data obtained at Commonwealth Edison Co.'s Zion plant and Florida Power & Light Co.'s Turkey Point plant. The analysis was performed prior to development of equipment susceptibility testing guidance by the 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 (see Section 4).

Conducted Emissions

Considerable data were taken on AC and DC power leads at Zion and Turkey Point in accordance with CE01 and CE03 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 adequately explained.

No attempt was made to differentiate between emissions coming from the load connected to the power leads or 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 shown 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 that 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 that the equipment has not been tested with at least a 6-dB margin for conservatism. MIL-STD-461C radiated susceptibility test RS02 imposes a narrow-band signal measured according to procedure with a narrow-band conventional voltmeter instrument.

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 radiation 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 6.

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].

4 GUIDELINES FOR GENERIC PLANT EMISSIONS MEASUREMENTS

The 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 were not conducted in differential modes, nor were data collected individually from the power and signal leads. The group developed a set of measurement specifications, which are described in this section.

Data have been 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

Generic Measurements Procedures

The generic emissions measurement procedures 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.

Recommended Emissions Measurements

The group recommended that the following measurements be made to describe the ambient environment:

- 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 15 kHz and 50 MHz in common and differential modes.
- 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.

---

[1] Indicates features or measurements specified by the EPRI/Utility EMI Working Group but not previously requested by the NRC.

Collecting Emissions Data at EMI/RFI Sensitive Equipment

The group has 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.

Section 3 of this report notes the importance of distance in defining the amplitude of potential EMI sources. For conducted emissions, higher frequencies (low kHz range and above) attenuate rapidly. Section 3 notes that 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. Section 3 notes that 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 6, “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 4-1 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.

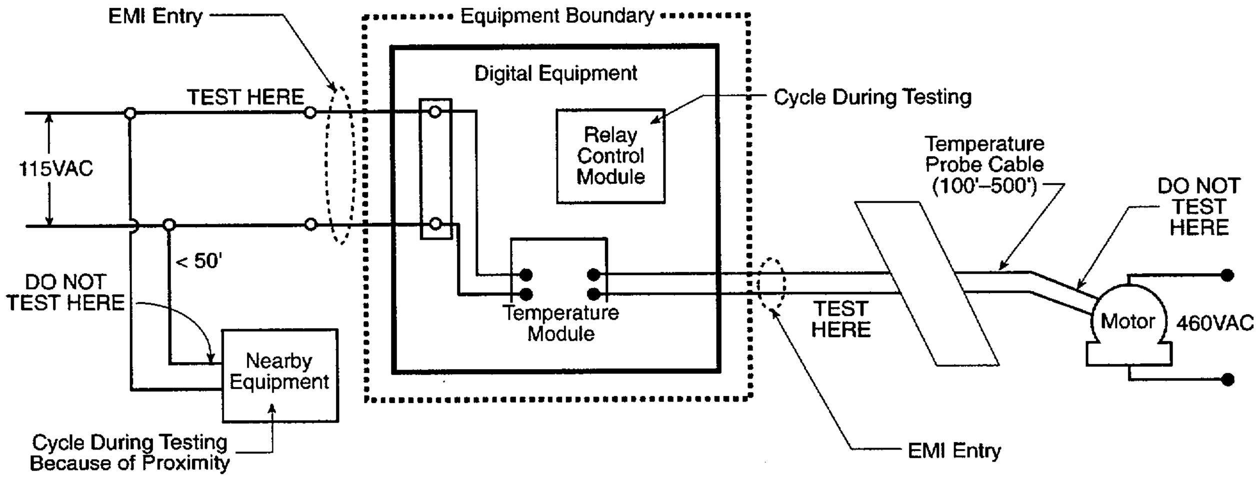


Figure 4-1
Schematic Illustration of EMI Sources From Surrounding Equipment and Measurement Locations

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 an EMI Survey

Several plants have been planning and implementing modifications to install digital equipment in safety-related systems. The current NRC practice of evaluating equipment EMC is to compare the vendors' 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 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 were 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 was required to demonstrate 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 4-2 through 4-6 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 not indicative of the actual emissions measured at any given location.

Also illustrated in Figures 4-2 through 4-6 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. This plot is used in Section 7 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 4-2 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.

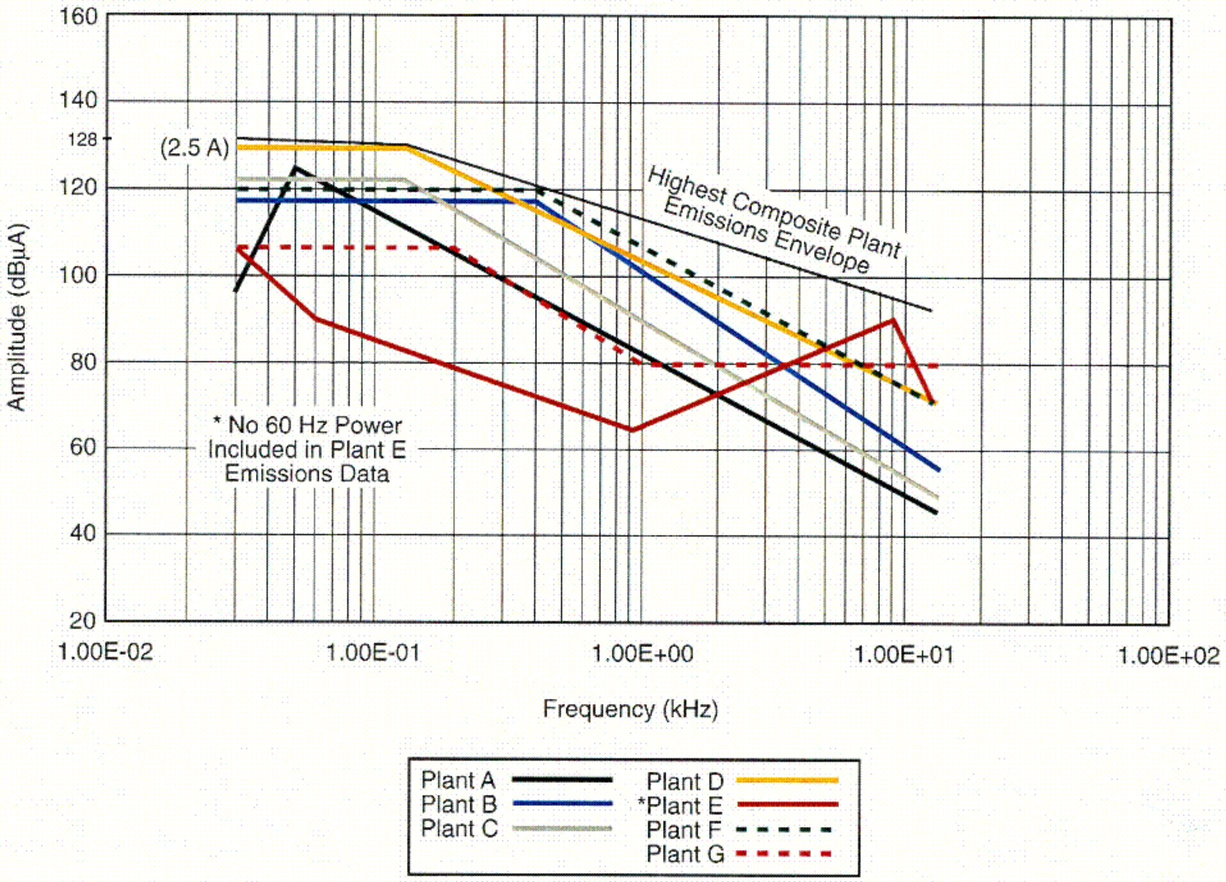


Figure 4-2
Composite Highest Observed Plant Conducted Emissions (CE01) Envelope at Seven Nuclear Power Plants

C-1

High-Frequency Conducted Emissions

Figure 4-3 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 and represent continuous-wave, steady-state high-frequency conducted plant emissions. Again, emissions were measured on power and signal lines in both common- and differential-mode.

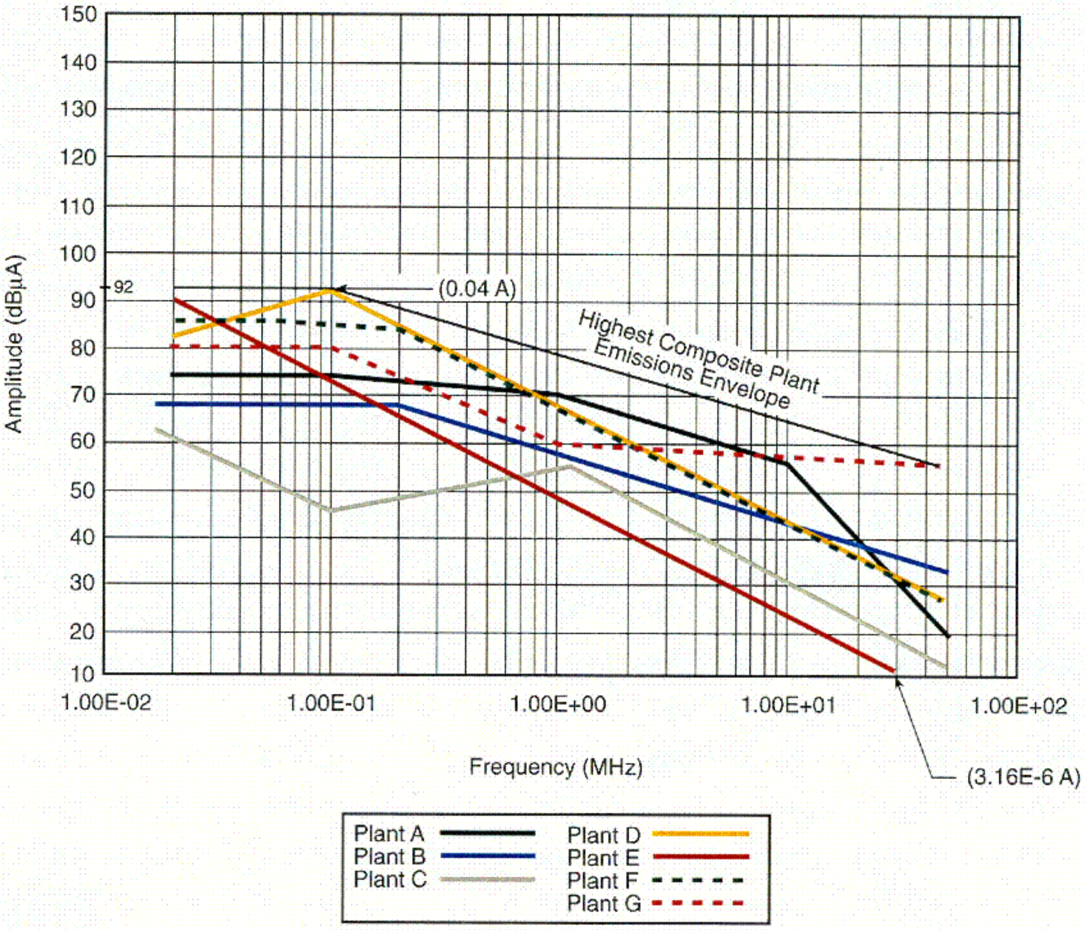


Figure 4-3
Composite Highest Observed Plant Conducted Emissions (CE03) Envelope at Seven Nuclear Power Plants

Radiated Magnetic Field Emissions

Figure 4-4 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.

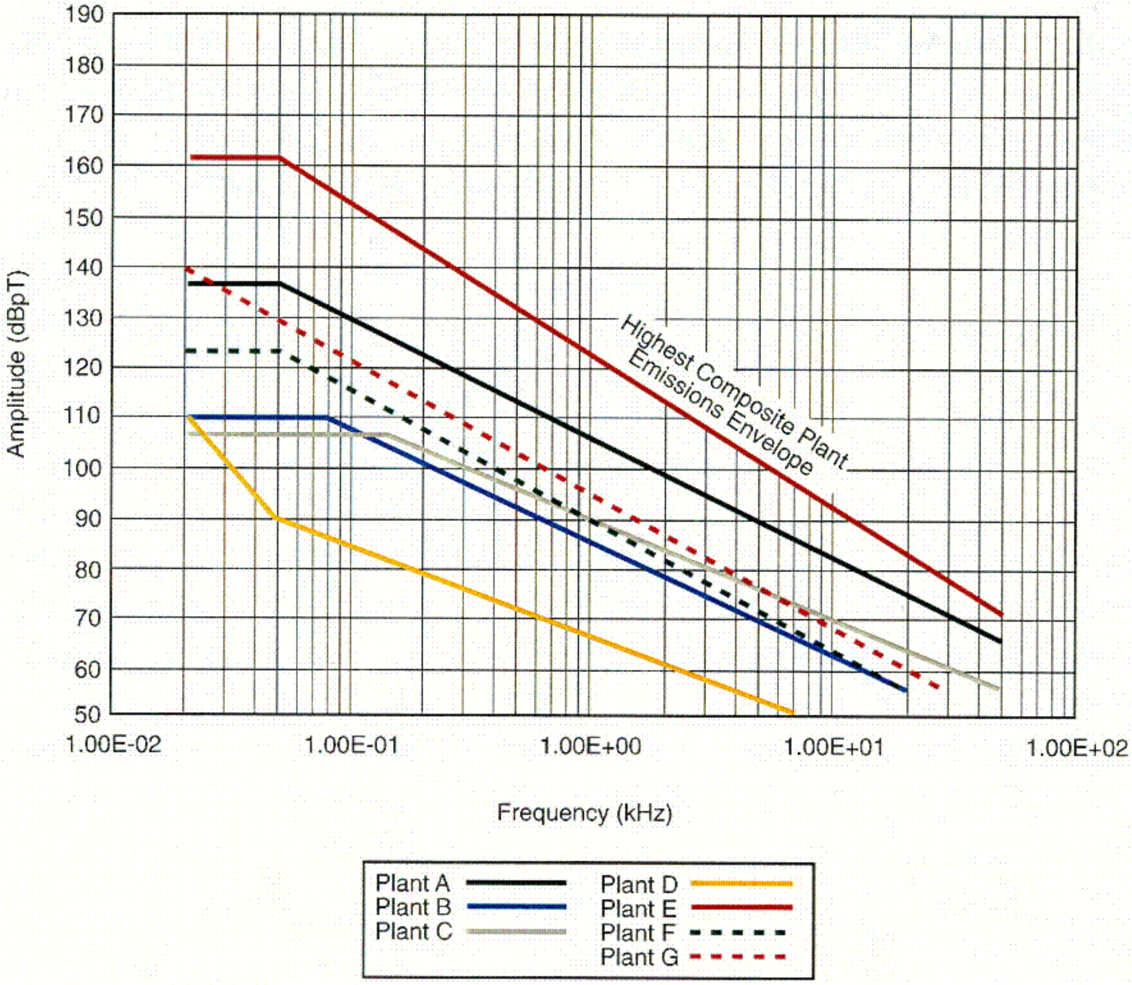


Figure 4-4
Composite Highest Observed Plant Radiated Emissions (RE01) Envelope at Seven Nuclear Power Plants

Radiated Electric Field Emissions

Figure 4-5 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 6, "Minimum EMI Limiting Practices," 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.

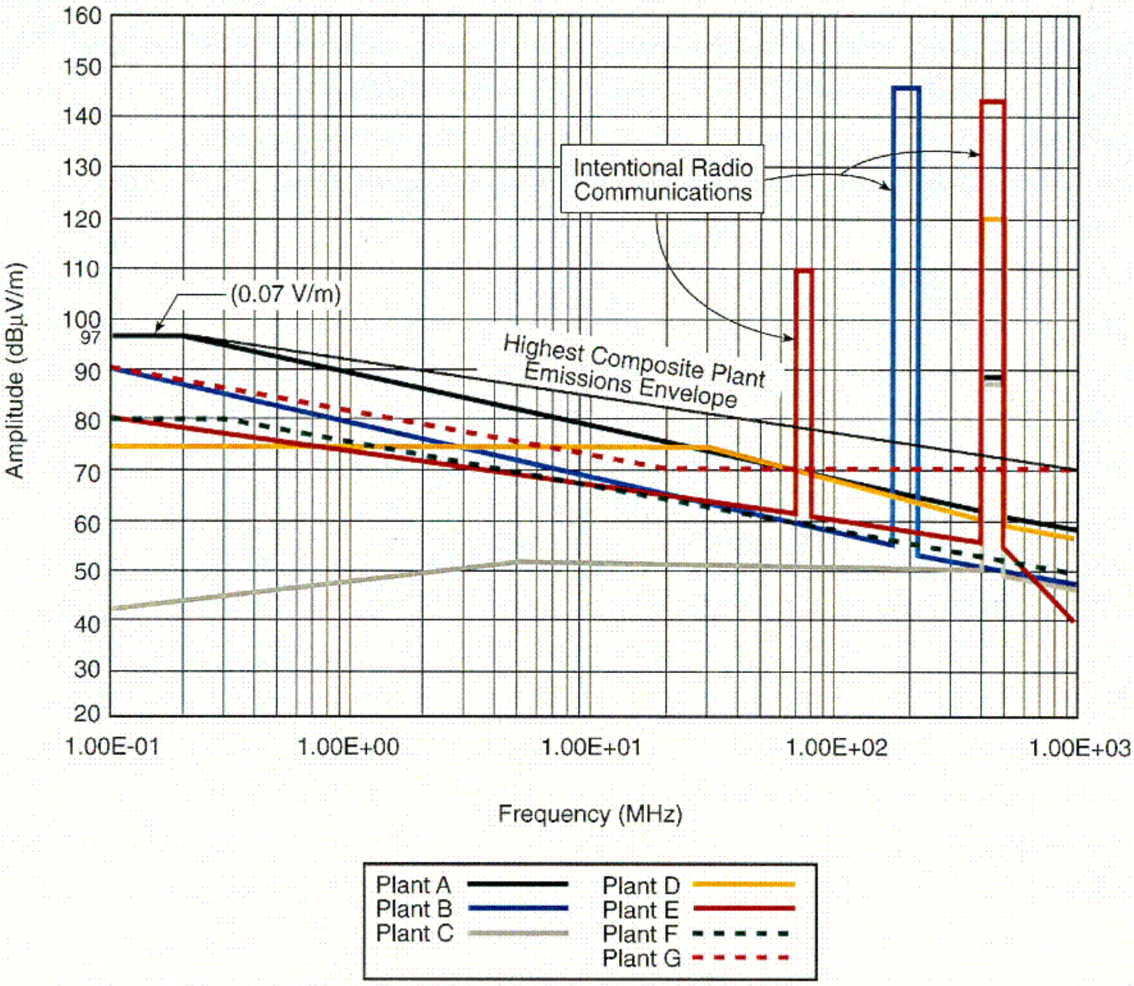


Figure 4-5
Composite Highest Observed Plant Radiated Emissions (RE02) Envelope at Seven Nuclear Power Plants

Conducted Transient Emissions

Figure 4-6 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 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.

C-4

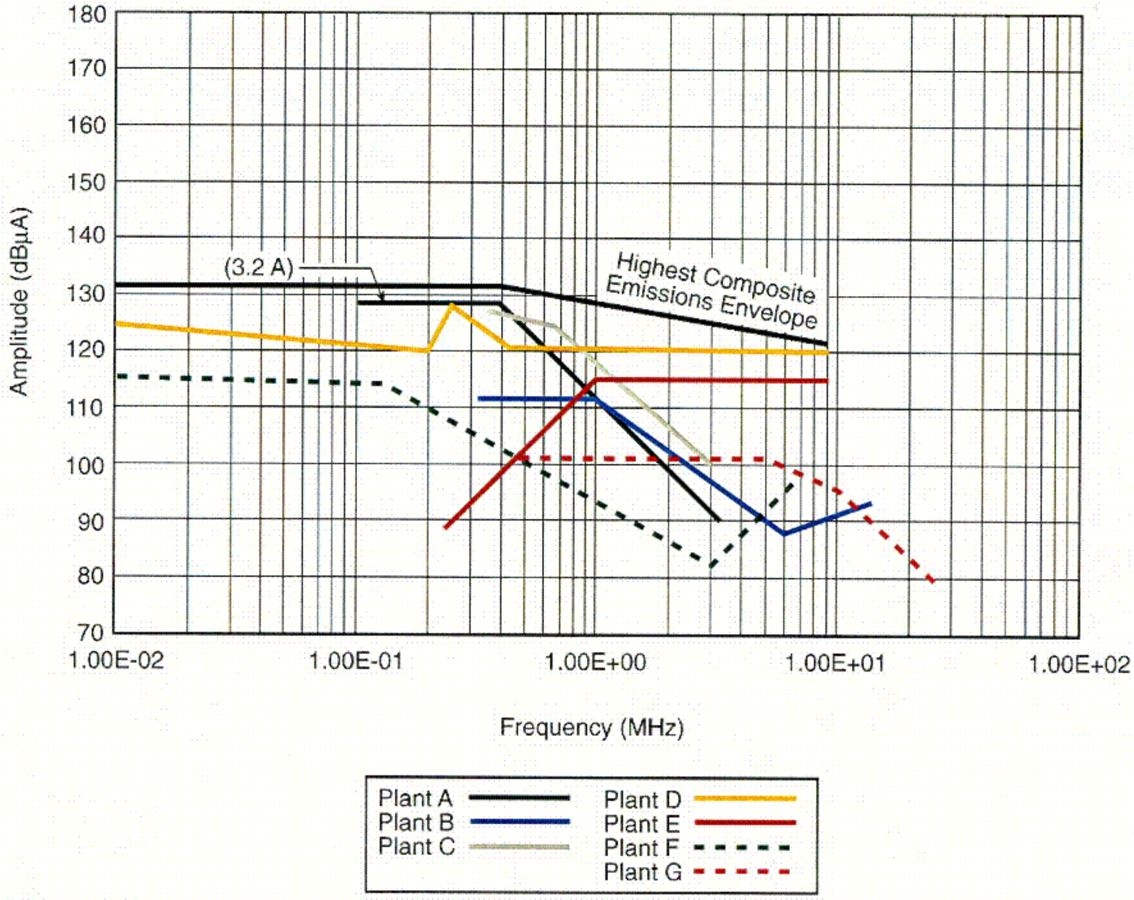


Figure 4-6
Composite Highest Observed Transient Plant Emissions (CE07) Envelope at Seven Nuclear Power Plants

C-5

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 reasonably ensure that the new equipment will not interfere with the function or 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 shall be addressed for all analog and digital electronic equipment with DC operating voltages (for example, 3-, 5-, 12-, and 15- VDC supply systems) or clock frequencies greater than 9 kHz. The scope of testing is defined in Table 5-1. Acceptable testing standards are documented 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	E	E	A
Important to Power Production	R	R	E	R	R	R	O	E	E	E	A
Non-Safety-Related	O	O	O	O	O	O	O	E	E	E	A

A = Applicable. These tests shall be performed, or an exemption including a technical justification for why the test is not required shall be documented.

E = Evaluate. These tests shall be performed, or design features/conditions as specified for each test type shall 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.

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"

Equipment formerly tested and qualified according to earlier revisions of the above standards is 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 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 (ANS) 63.4 and 63.12, and IEEE 187 and 1140 commercial standards. The military and commercial standards found to be acceptable are listed in Table 5-2. Note that where commercial standards were endorsed, required 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 requirements of this report.

Table 5-2
Testing Standards

Susceptibility Tests		
	MIL-STD-461E	Commercial Standard
Low-Frequency Conducted	CS101	IEC EN 61000 Part 4 Section 13
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
Electrically-Fast Transient	CS115	IEC EN 61000 Part 4 Section 4
Electrostatic Discharge	N/A	IEC EN 61000 Part 4 Section 2
Emissions Tests		
	MIL-STD-461E	Commercial Standard
Low-Frequency Conducted	CE101	IEC EN 61000 Part 3 Section 2
High-Frequency Conducted	CE102	None
Low-Frequency Radiated	RE101	None
High-Frequency Radiated	RE102	FCC 47 CFR Part 15 or EN 55022

Functional Requirements and Acceptance Criteria

Equipment functional requirements and acceptance criteria should be well understood and documented. This information should be incorporated into testing plans and procedures developed prior to laboratory testing and must be understood to evaluate the acceptability of equipment responses and results 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 specification tolerances. Any anomalies during testing or malfunction, degradation, or deviation in performance shall 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 acceptable results or performance if tested. 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 must be documented and the installed configuration controlled. Equipment designs that cannot be installed with the shielding, grounding, or filtering modifications required to successfully pass laboratory testing can not be qualified.

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:

- 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, it is acceptable to proceed with this approach.
- 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.

- Develop a test plan according to EPRI TR-102400 [25] to perform emissions and susceptibility testing according to the testing standards for the replacement component (see Table 5-2).
- 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 icon located next to each description is 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 (required)**. 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**.

Susceptibility Tests

Low-Frequency Conducted Susceptibility

Applicable
Recommended
Optional

Applicability
- Required for safety-related equipment (unless an exemption is obtained)
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives
- MIL-STD-461E, CS101.
- IEC 61000-4-13 Level 3 if EUT will not be exposed to switching power supplies, static frequency converters, induction motors, welding machines, or similar equipment. If the EUT is electrically connected to these types of loads, this testing certification is not acceptable.
- Perform testing according to CS101 or 61000-4-13 to the parameters defined below.

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 test setup and data reported in units of dBμA. Figure 5-1 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 limits, a transfer impedance of 0.5 ohms is used.

Limits
See Figure 5-1

Frequency
For DC applications: 30 Hz to 50 kHz
For AC applications: 120 Hz (power frequency second harmonic) to 50 kHz

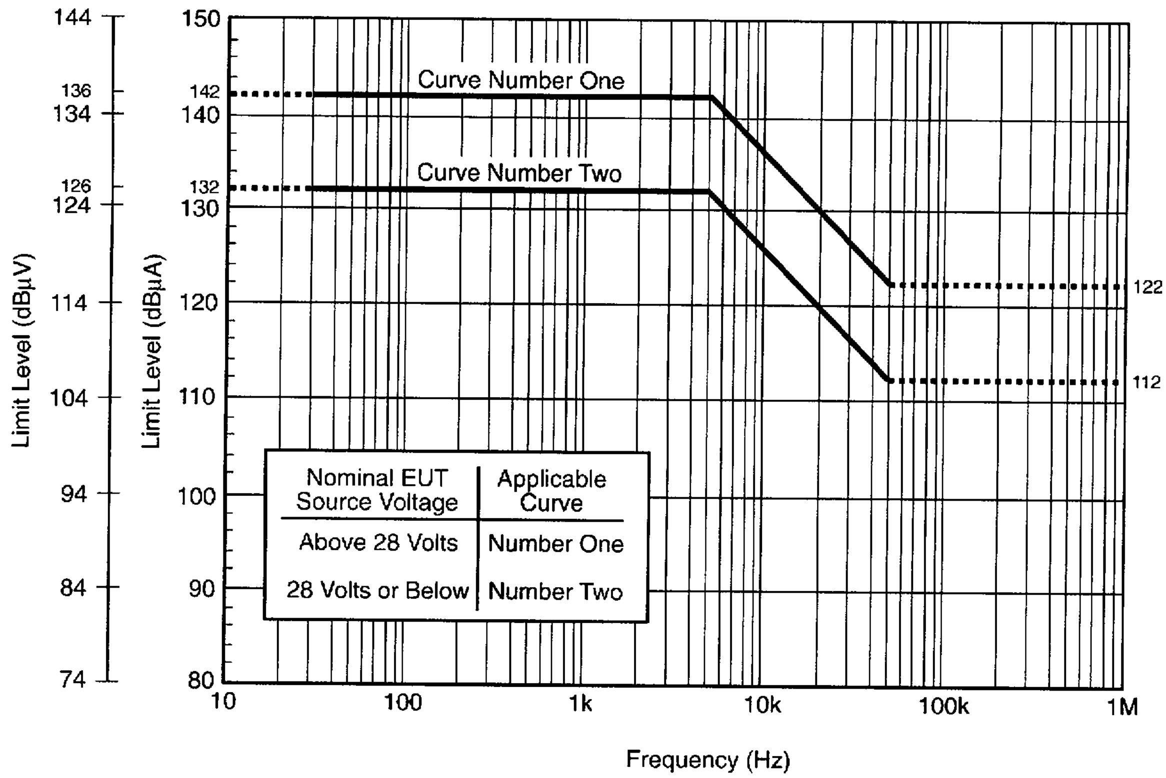


Figure 5-1
Low-Frequency Conducted Susceptibility Testing Limit

High-Frequency Conducted Susceptibility

Applicable

Recommended

Optional

Applicability

- Required for safety-related equipment (unless an exemption is obtained)
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives

Perform testing according to CS114 or 61000-4-6 to the parameters defined below

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 61000-4-6 test setup and data reported in dBμA. Equipment tested according to MIL-STD-461E RS103 may be exempted from this test between 30 and 200 MHz.

Limits

See Figure 5-2

Frequency

10 kHz–200 MHz

Notes

The limits defined in MIL-STD-461E, CS114 are not acceptable due to significant differences in the susceptibility limits required by this document between 10 kHz and 2 MHz and those allowed by CS114.

The limits defined in IEC 61000-4-6 are not acceptable for meeting the requirements of this test due to significant differences in the limits required by this document between 10 kHz and 2 MHz and those specified for IEC 61000-4-6 Levels 1, 2, and 3.

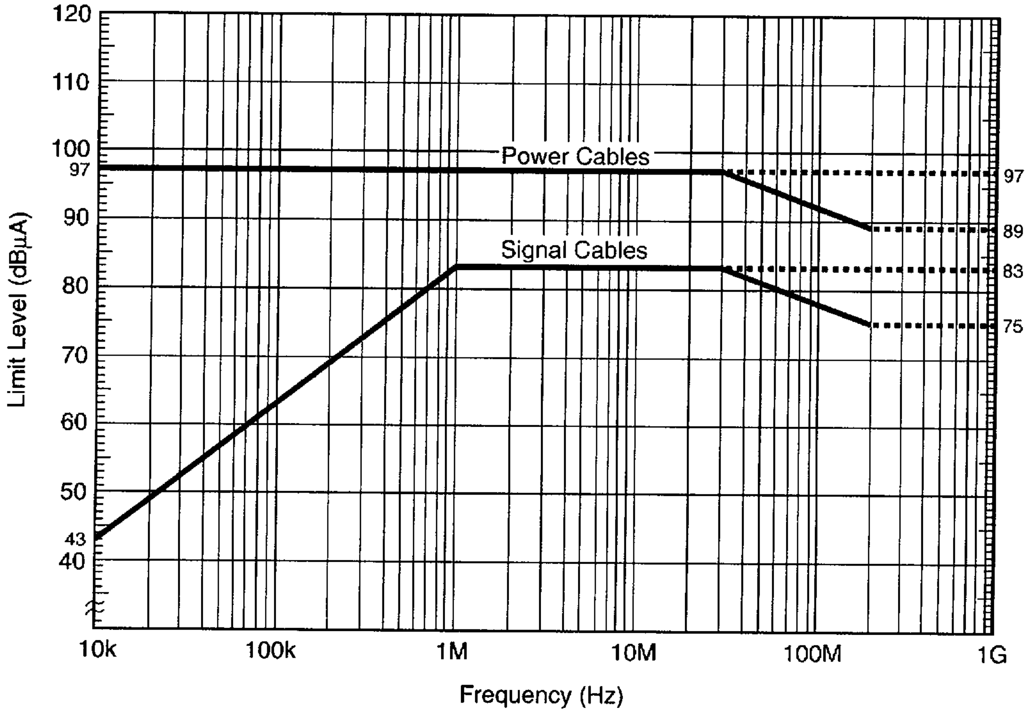


Figure 5-2
High-Frequency Conducted Susceptibility Testing Limit

Low-Frequency Radiated Susceptibility

Evaluate	
Evaluate	
Optional	

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

- MIL-STD-461E, RS101
- IEC 61000-4-8 Level 5

Purpose and Notes

This test verifies the ability of equipment to withstand radiated magnetic fields. It is required for equipment installed in close proximity (< 1 m) to sources of large magnetic fields (> 600 A/m) or for installations that do not satisfy the limiting practices outlined in Section 6.

Limits

See Figure 5-3

Frequency

30 Hz–100 kHz

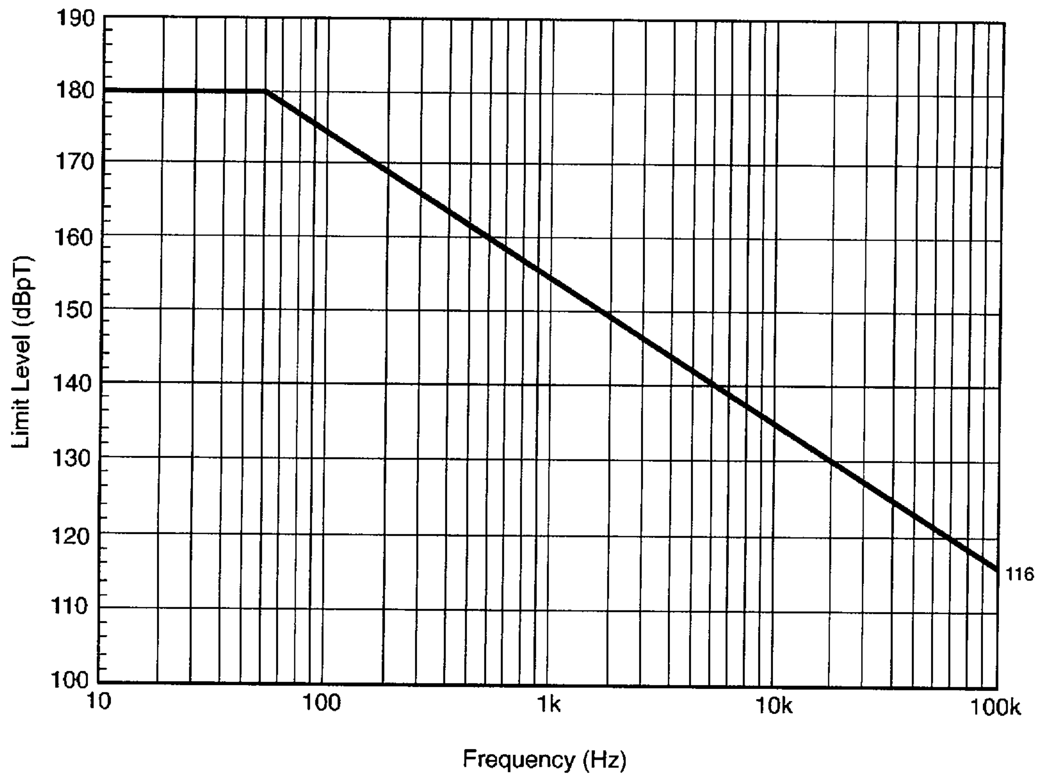


Figure 5-3
Low-Frequency Radiated Susceptibility Testing Limit

High-Frequency Radiated Susceptibility

Applicable
Recommended
Optional

Applicability

- Required for safety-related equipment (unless an exemption is obtained)
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives

- MIL-STD-461E, RS103 (Note: RS103 testing certification is acceptable only if the equipment also has CS114 Curve #4 testing certification)
- IEC 61000-4-3 Level 3 to 10 GHz. This is acceptable only if the testing to 61000-4-6 has been performed.
- Perform testing according to RS 103 or 61000-4-3 to the parameters defined below.

Purpose

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

Limit

10 V/m for all test frequencies

Frequency

10 kHz–10 GHz or 30 MHz–10 GHz (if also performing CS114 or 61000-4-6)

Surge

Applicable

Recommended

Optional

Applicability

- Required for safety-related equipment (unless an exemption is obtained)
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives

- IEC 61000-4-5 Level 3 for most plant systems for the considerations discussed below; Level 4 for systems connected to external lines
- Perform testing according to 61000-4-5 to the parameters defined below

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

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

Notes

- Apply to power lines and outer conductors/shield of all cables that connect to external structures or facilities unless cables are run in continuous conduit. Apply between power conductors and between conductors and ground. This test is not required for input/output (I/O), data, and control cables less than 30 m in length. Connection to cables/line will be made according to the selected standard with a nominal source impedance of 10 ohms. Equipment tested for surges should include surge protection devices. After the test, the surge protection device may be replaced or confirmed to be in good working condition before being returned to service.
- The ring wave test (CS116) represents coupled and not unidirectional energy. The slower rise time and shorter duration result in a less challenging test than the combination wave test (61000-4-5). The 100 kHz ring of the CS116 test represents the resonance of a long line. Typical resonant frequencies in power plants are in the low MHz region. The combination wave (61000-4-5) better simulates the nuclear plant environment.
- MIL-STD-461E, CS116 testing certification is not acceptable because the maximum testing limit of 10A (140 dBµA) does not provide adequate compatibility margin.

Electrically-Fast Transient/Burst

Applicable

Recommended

Optional

Applicability

- Required for safety-related equipment (unless an exemption is obtained)
- Recommended for equipment important to power production
- Optional for non-safety-related equipment

Testing Standards and Qualifications Alternatives

- IEC 61000-4-4 Level 3 (see Notes)
- Perform testing according to 61000-4-4 to the parameters defined below.

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 shall be tested to ± 2 kV_{p-p}. The coupling/decoupling network shall 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 shall 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.
- Test signal should be injected according to the selected standard. Connections will be made according to the selected standard with a nominal source impedance of 50 ohms.
- MIL-STD-461E, testing certification is not acceptable because the maximum testing limit of 5A (134 dBμA) does not provide adequate compatibility margin.

Electrostatic Discharge

Optional	
Optional	
Optional	

Applicability

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

Testing Standards and Qualifications Alternatives

- IEC 61000-4-2 Level 4 (see Notes)
- Perform testing according to 61000-4-2 to the parameters defined below

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 is 30–60%.

Low-Frequency Conducted Emissions

Evaluate
Evaluate
Evaluate

Applicability (See Notes)

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

Testing Standards and Qualifications Alternatives

- MIL-STD-461E, CE101
- IEC 61000-3-2
- Perform testing according to CE101 or 61000-3-2 to the parameters defined below

Purpose

The purpose of this test is to limit equipment 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 is required unless there are criteria for controlling the power quality of the equipment input power source. New equipment procured should function reliably within established power quality criteria. The power quality requirements of the equipment will be consistent with the existing power source. 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]. This test should be performed in accordance with the CE101 test setup and data reported in units of dBμA.

Limits

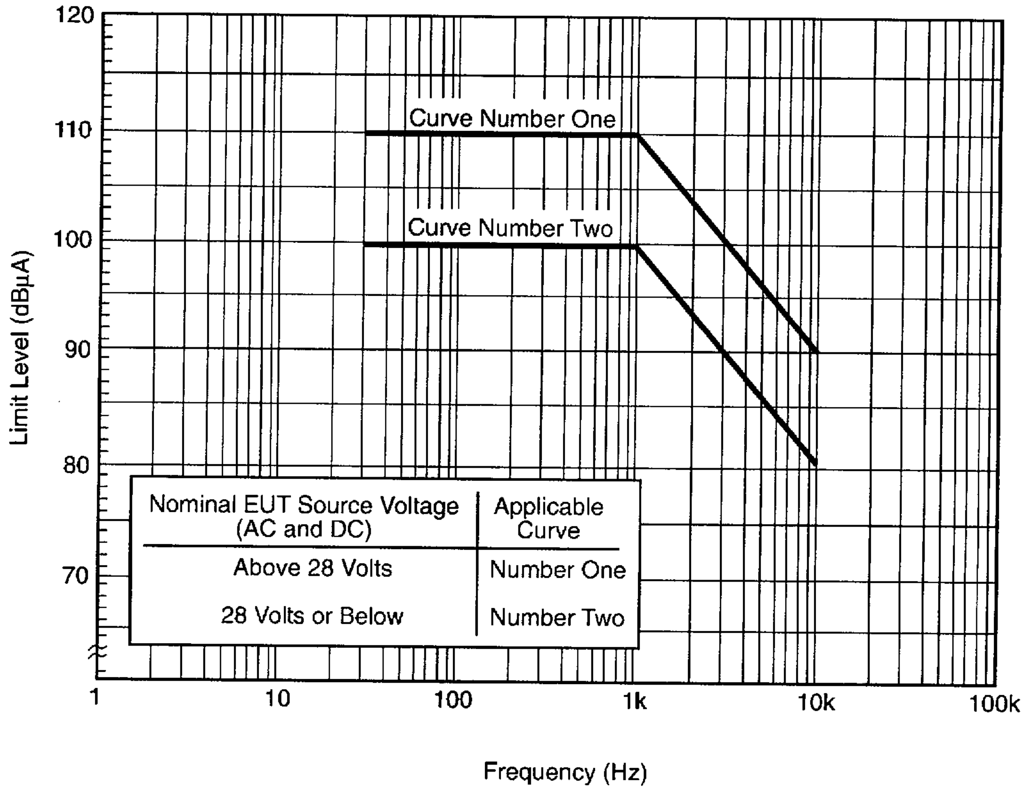
See Figure 5-4

Limit Relaxation

The limit may be relaxed as documented in Figure 5-4

Frequency

For DC applications: 30 Hz–10 kHz
For AC applications: 120 Hz–10 kHz



Note:
For equipment and subsystems with a fundamental current greater than one ampere, the limit shall be relaxed as follows:

dB Relaxation = 20 Log (Fundamental Power Frequency Current)

Figure 5-4
Low-Frequency Conducted Emissions Testing Limit

High-Frequency Conducted Emissions

Evaluate
Evaluate
Evaluate

Applicability

- Evaluate for safety-related equipment if design criteria are satisfied
- Evaluate for equipment important to power production if design criteria are satisfied
- Evaluate for non-safety-related equipment if design criteria are satisfied

Testing Standards and Qualifications Alternatives

- MIL-STD-461E, CE102
- Perform testing according to CE102 to the parameters defined below

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

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.

Design Criteria and Notes

This test is required unless the final installed design includes power line filters or other emission suppression techniques on the AC power inputs [25]. This test should be performed in accordance with the CE101 test setup and data reported in units of dBμA. The CE102 test differs from the CE101 test in that CE102 measures the voltage out of a line impedance stabilization network (LISN) while CE101 measures current on the cables. 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

The limit may be relaxed as documented in Figure 5-5

Frequency

10 kHz–10 MHz

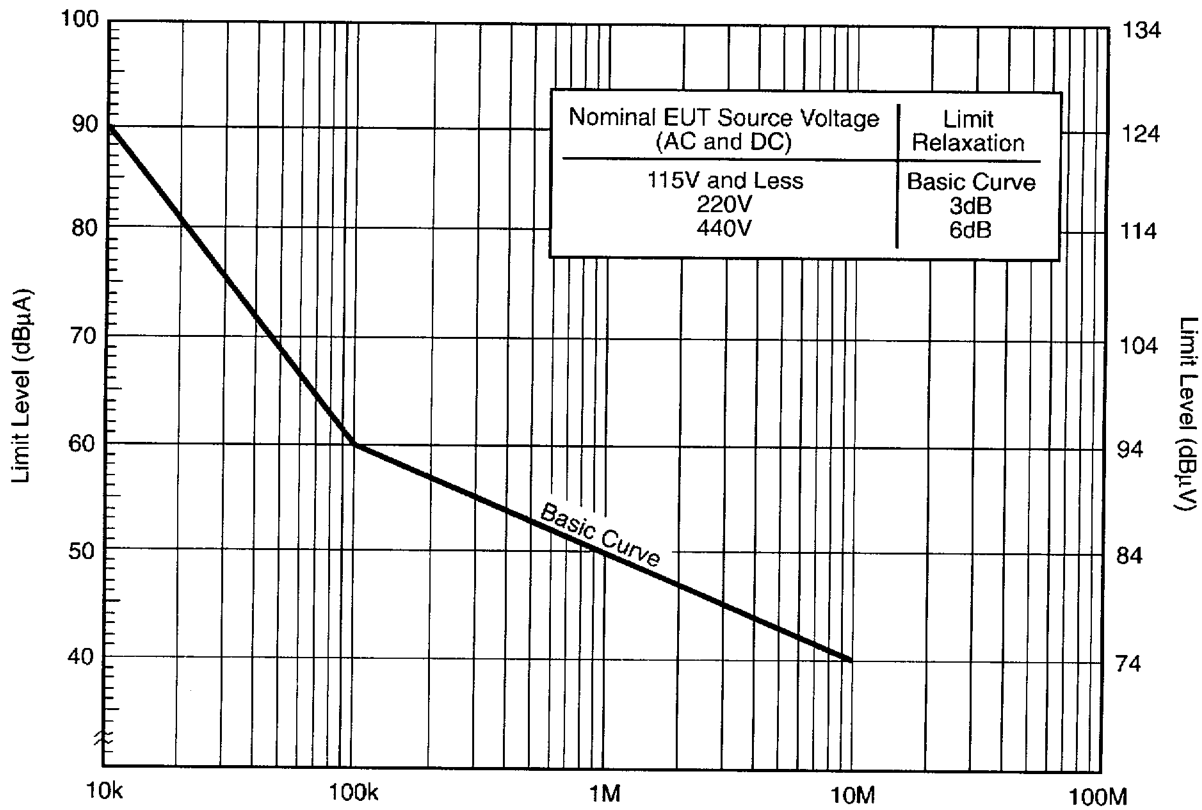


Figure 5-5
High-Frequency Conducted Emissions Testing Limit

Low-Frequency Radiated Emissions

Evaluate

Evaluate

Evaluate

Applicability (See Notes)

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

Testing Standards and Qualifications Alternatives

- MIL-STD-461E, RE101
- Perform testing according to RE101 to the parameters defined below

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 is required for new equipment (which is a source of large magnetic fields [> 600 A/m]) installed in close proximity (< 1 meter) to equipment sensitive to magnetic fields (CRTs or magnetically operated sensors). This test is also required 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

30 Hz–100 kHz

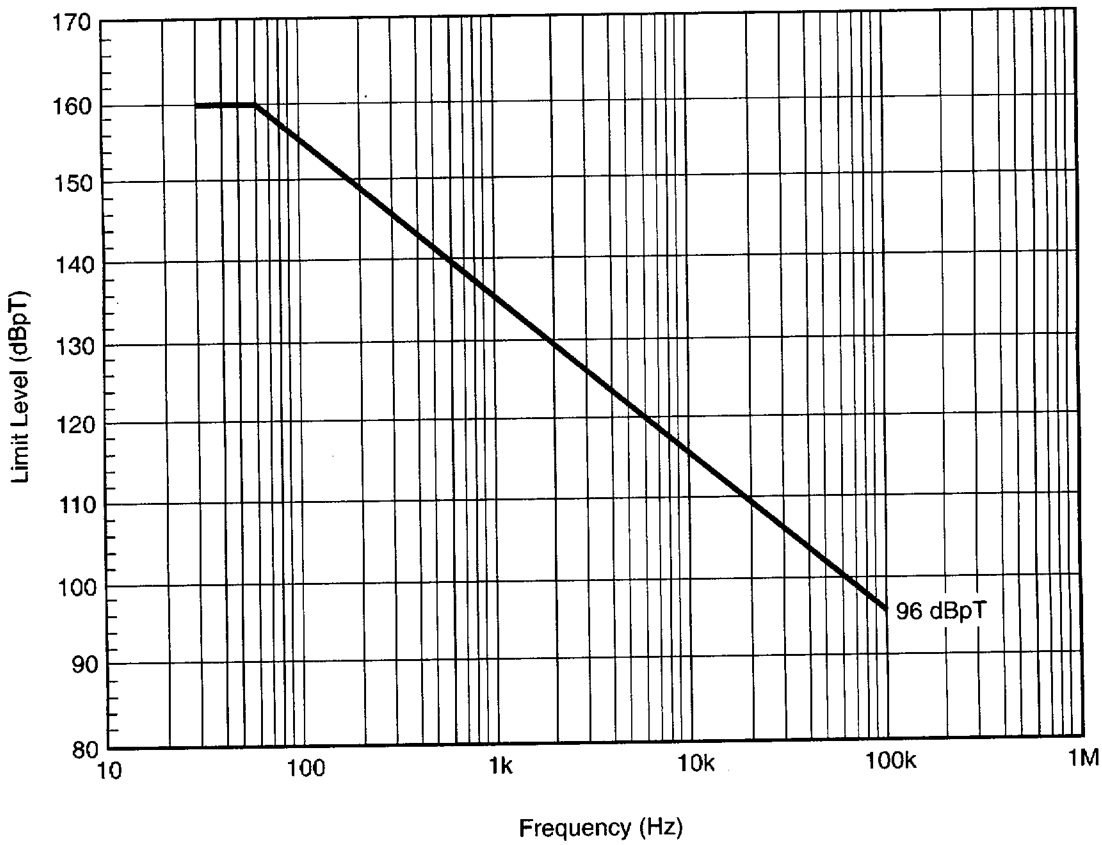


Figure 5-6
Low-Frequency Radiated Emissions Testing Limit

High-Frequency Radiated Emissions

Applicability

• Required for safety-related equipment (unless an exemption is obtained)	Applicable
• Required for equipment important to power production (unless an exemption is obtained)	Applicable
• Required for non-safety-related equipment (unless an exemption is obtained)	Applicable

Testing Standards and Qualifications Alternatives

- MIL-STD-461E, RE102
- FCC 47 CFR Part 15 Class A or B
- EN 55022 Class A or B is acceptable if the highest clock frequency is less than 200 MHz
- Perform testing according to RE102 to the parameters defined below (see Notes)

Purpose

This test limits 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

10 kHz–10 GHz

Limits

See Figure 5-7

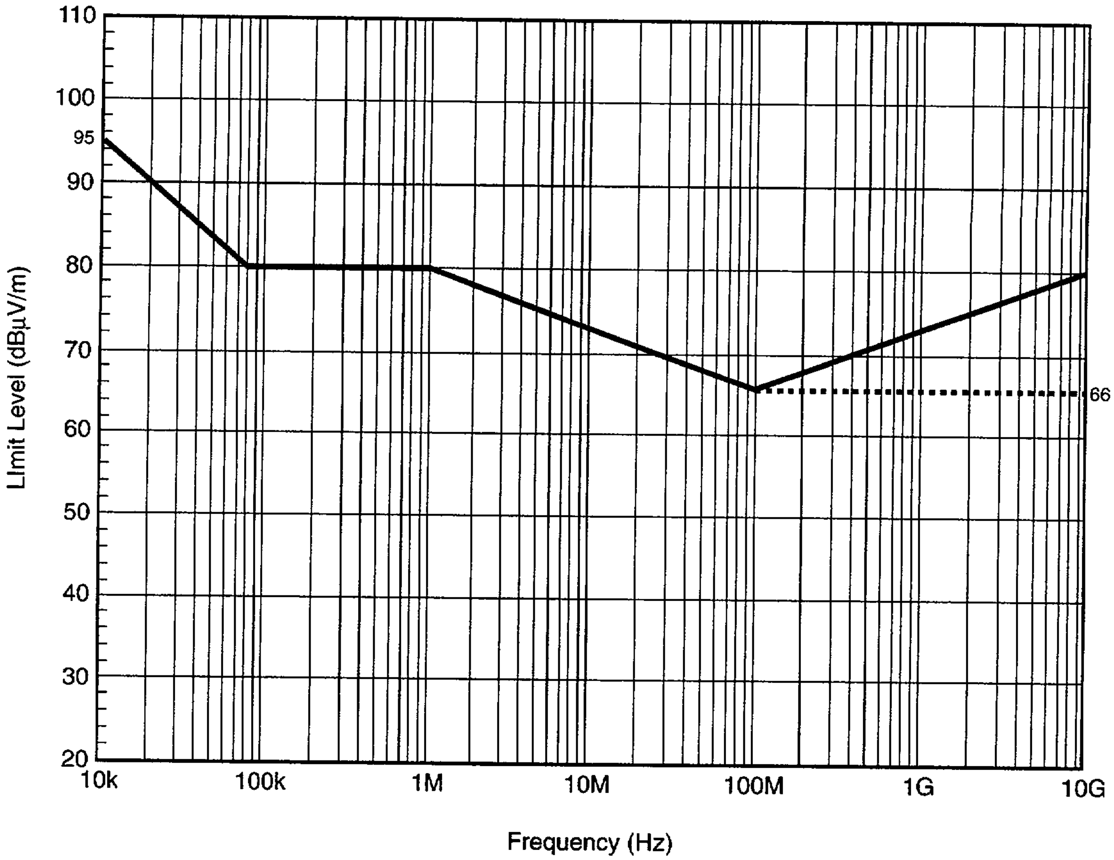


Figure 5-7
High-Frequency Radiated Emissions Testing Limit

6 MINIMUM EMI LIMITING PRACTICES

This section defines EMI limiting practices recommended by the group 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 is not necessary. If any of these practices detailed below is not satisfied, additional engineering evaluation is required 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.

Requirements

Requirements will be designated by the use of the verb "shall." Requirements must be followed to ensure that recommended equipment susceptibility limits are not exceeded.

Recommendations

Recommendations will be designated by the use of the verb "should." Recommendations should be implemented where possible; however, they are not required. Implementation of recommended limiting practices provides additional means of controlling equipment emissions.

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 must 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:

$$V_d = (30P)^{0.5}/d \qquad \text{(eq. 6.1)}$$

where

P is the effective radiated power of the transceiver in watts

d is the distance in meters from the transceiver

V_d is the field strength in volts per meter

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 6.1.
2. Determine the minimum transceiver exclusion distance corresponding to the calculated transceiver field strength at 1 m (see Figure 6-1).

The minimum exclusion distance is 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 their use in rooms where EMI/RFI sensitive equipment is located. The group recognizes the need to use these devices and has developed this guidance to support their use where transceivers and EMI/RFI sensitive equipment must operate in a shared environment.

The transceiver's field strength can be measured using the procedure found in TIA/EIA 603 [26]. These measurements shall be performed at three frequencies covering the top, bottom, and middle of each band that the transceiver operates. The equipment must be used in a mode that generates the maximum power level for these tests.

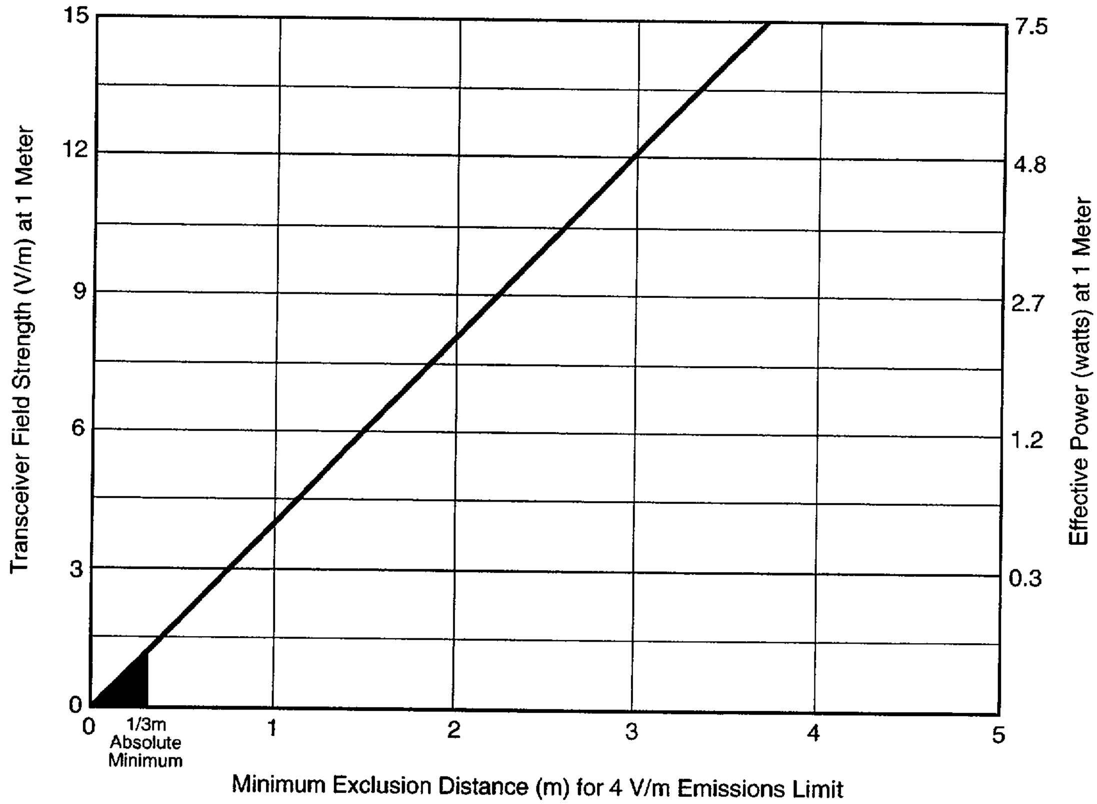


Figure 6-1
Recommended Minimum Exclusion Distance (in Meters) as a Function of Transceiver Field Strength (V/m) at 1 Meter

Arc Welding

Arc welding should be prohibited in rooms containing inservice EMI/RFI sensitive safety equipment. Arc welding that is necessary in areas with potentially EMI/RFI sensitive equipment in service shall be controlled using shielded enclosures around the welding equipment and power line filters on power cables.

Grounding

The shields of EMI/RFI sensitive cables and conductors longer than 2 m shall 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) must be 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 6-1. Figure 6-2 illustrates equipment and cable separation requirements.

Table 6-1
Equipment and Cable Separation Requirements 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 6-1 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 6-1 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.

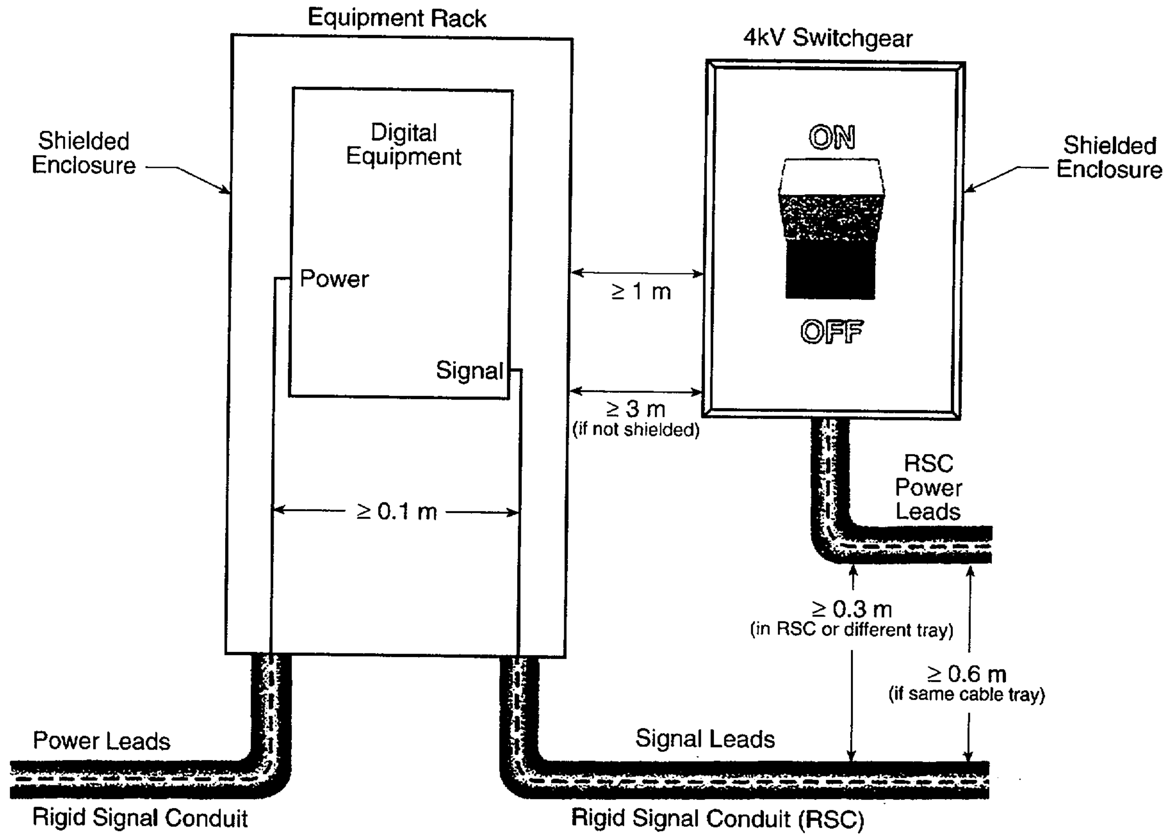


Figure 6-2
Illustration of Equipment and Cable Separation Requirements for Power Generation EMI/RFI Emitters

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 minimized 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 shall 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 shall also be floated for the installed system or equipment.
- Equipment tested in the laboratory with power line filters and radio-frequency chokes shall 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 shall be used during laboratory testing.
- Equipment grounding designs for the installed system or component shall be the same during laboratory testing.
- External cables and termination hardware used during laboratory testing shall be the same as those in the installed configuration.
- Internal distribution of power and signal cabling during the test shall 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.

7 TESTING LIMITS AND MARGIN ANALYSIS

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) at 120 Hz and more than 30 dBμA (more than 32 times greater) beyond 1 kHz (see Figure 7-1). The smallest difference (14 dBμA) provides adequate margin and reasonable assurance of EMC. Note that the highest measured levels were measured in differential mode. The differential-mode levels are generally higher than common-mode levels. The common-mode emissions data are more indicative of actual EMI levels capable of affecting digital system operation. The margin 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 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 level above 1 kHz.

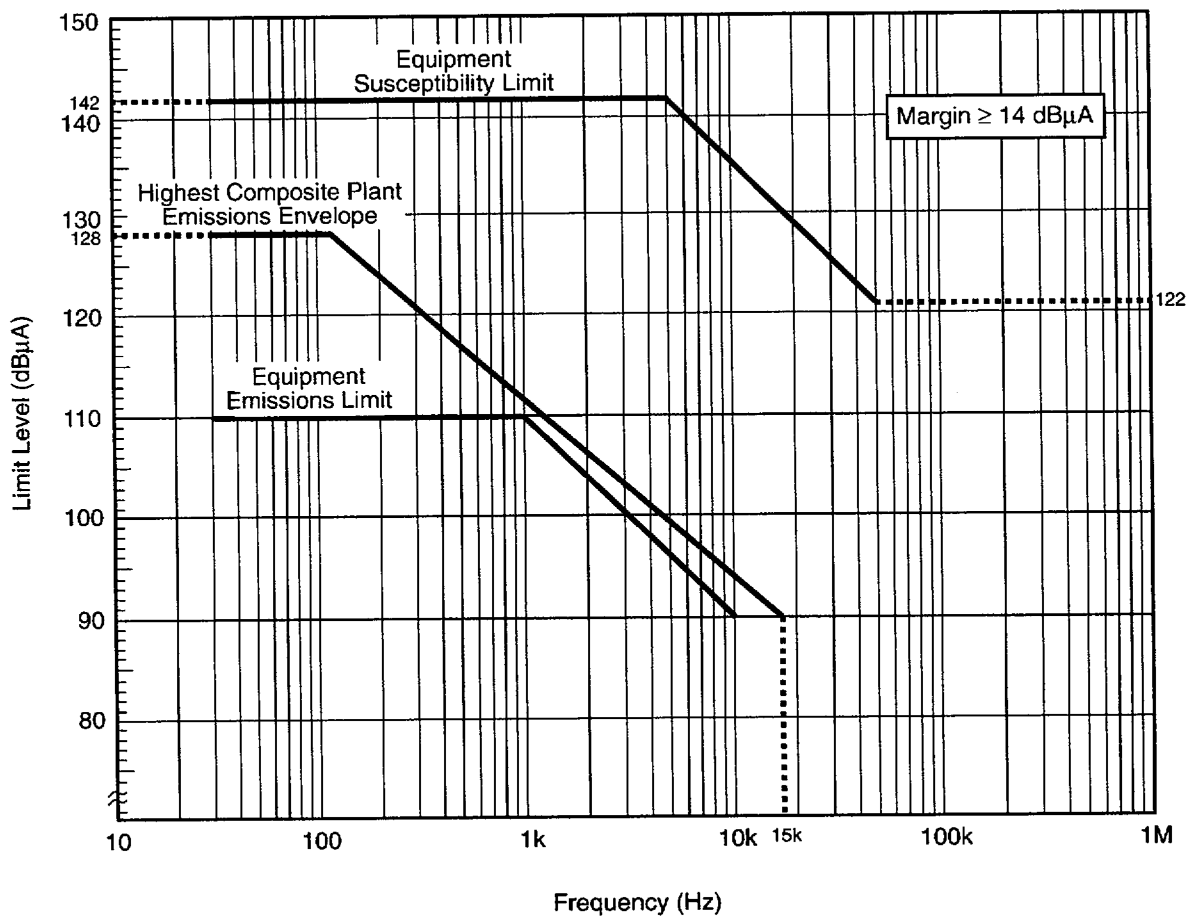


Figure 7-1
Low-Frequency Conducted Testing Limits and Margin Analysis

High-Frequency Conducted 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 5 dBμA (1.8 times greater) between 15 kHz and 100 kHz (see Figure 7-2). The margin is 19 dBμA (8.9 times greater) at frequencies above 1 MHz. Although the margin between the equipment susceptibility level and highest composite plant emissions level is only 5 dBμA (as opposed to the recommended minimum of 8 dBμA), this difference provides adequate margin and reasonable assurance of EMC. This compatibility is a result of the 38-dBμA margin between the highest composite plant emission and the equipment susceptibility limit at this frequency. The elevated plant emissions levels were due to differential-mode signals measured on power cables. The differential-mode levels are generally higher than common-mode levels. The common-mode emissions data are more indicative of actual EMI levels capable of affecting digital system operation. The margin between the highest composite continuous-wave common-mode plant emissions and the equipment susceptibility level is expected to be much larger.

The equipment emissions testing levels are sufficiently below the highest composite plant emissions levels across all frequencies.

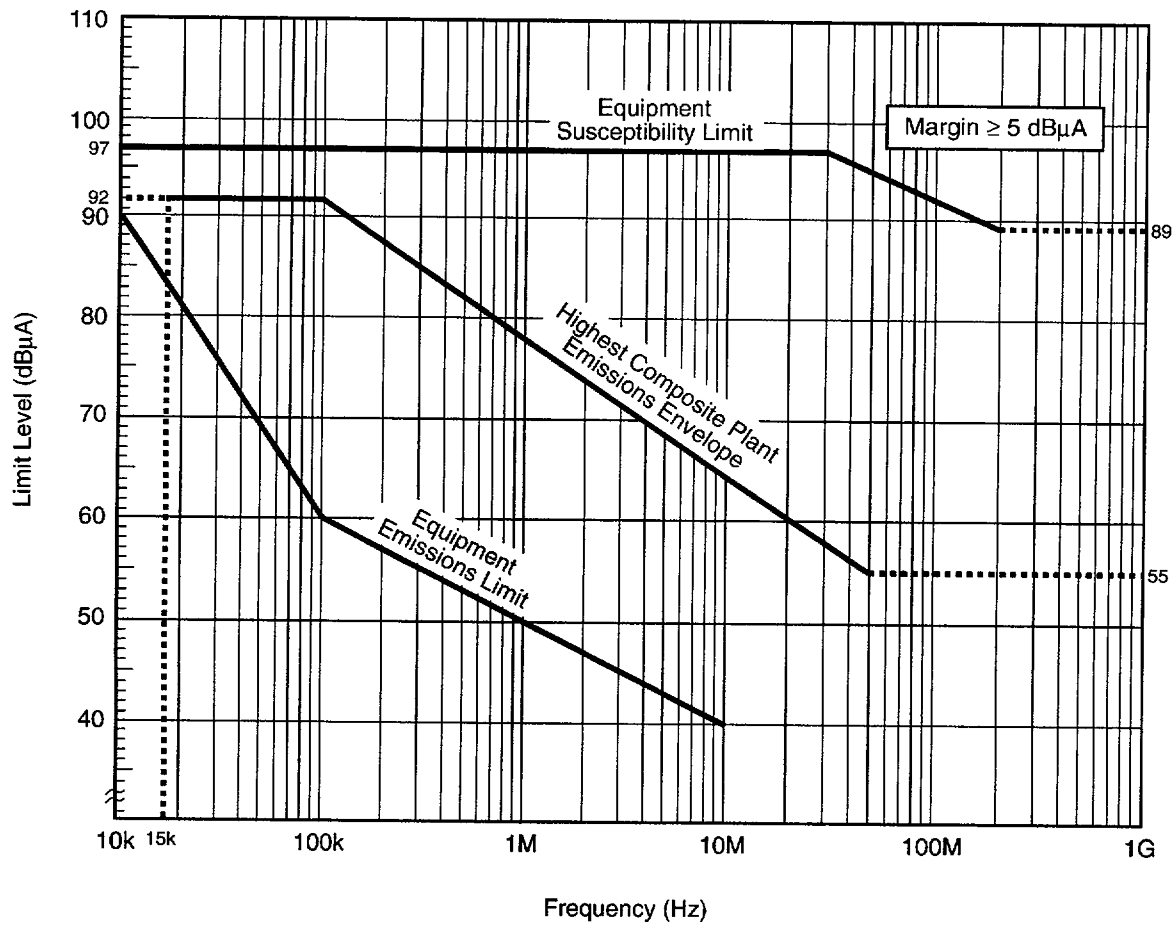


Figure 7-2
High-Frequency Conducted Testing Limits and Margin Analysis

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 7-3). 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.

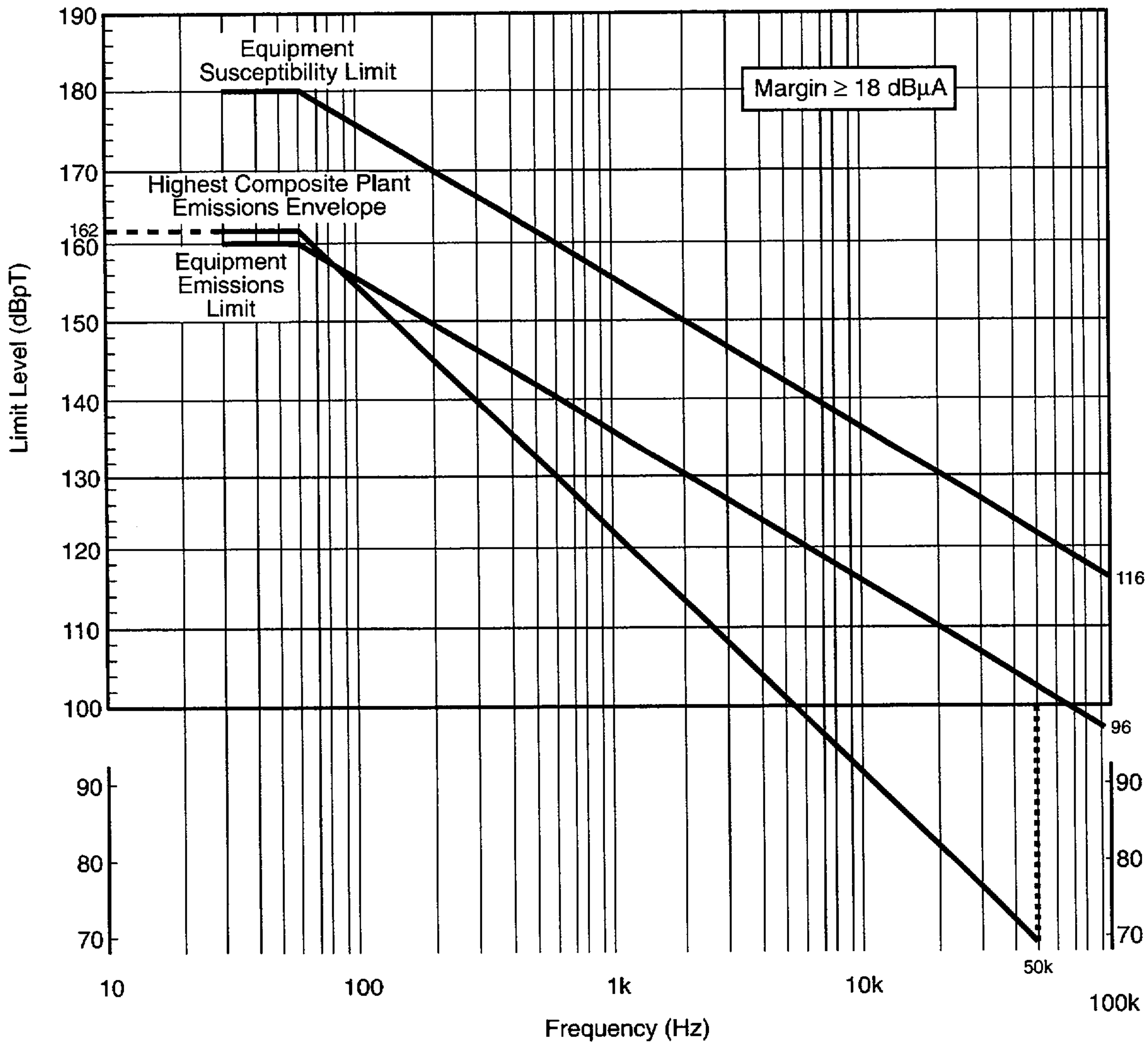


Figure 7-3
Low-Frequency Radiated Testing Limits and Margin Analysis

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 7-4). 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. Specific independent controls of portable communications emissions levels are required to ensure that equipment susceptibility levels are not exceeded. See Section 6, "Minimum EMI Limiting Practices," for guidance on the control 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.

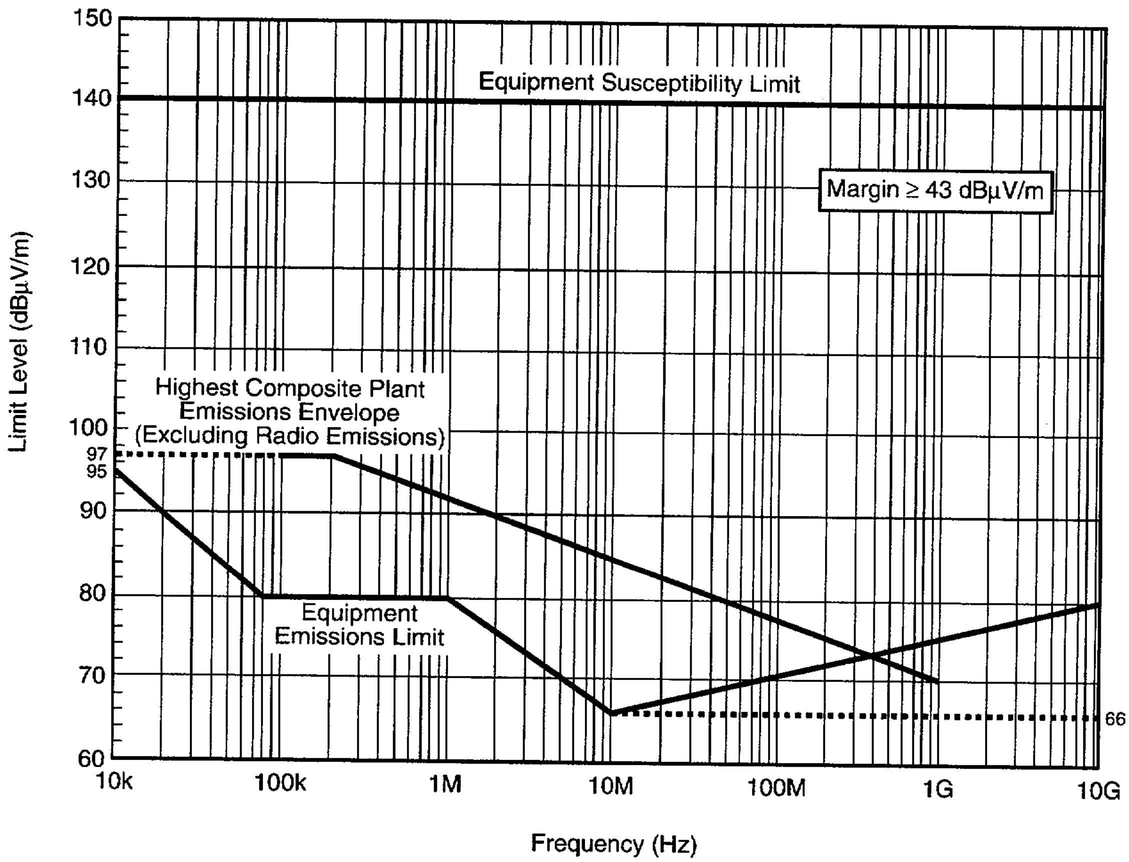


Figure 7-4
High-Frequency Radiated Testing Limits and Margin Analysis

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 7-5).

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.

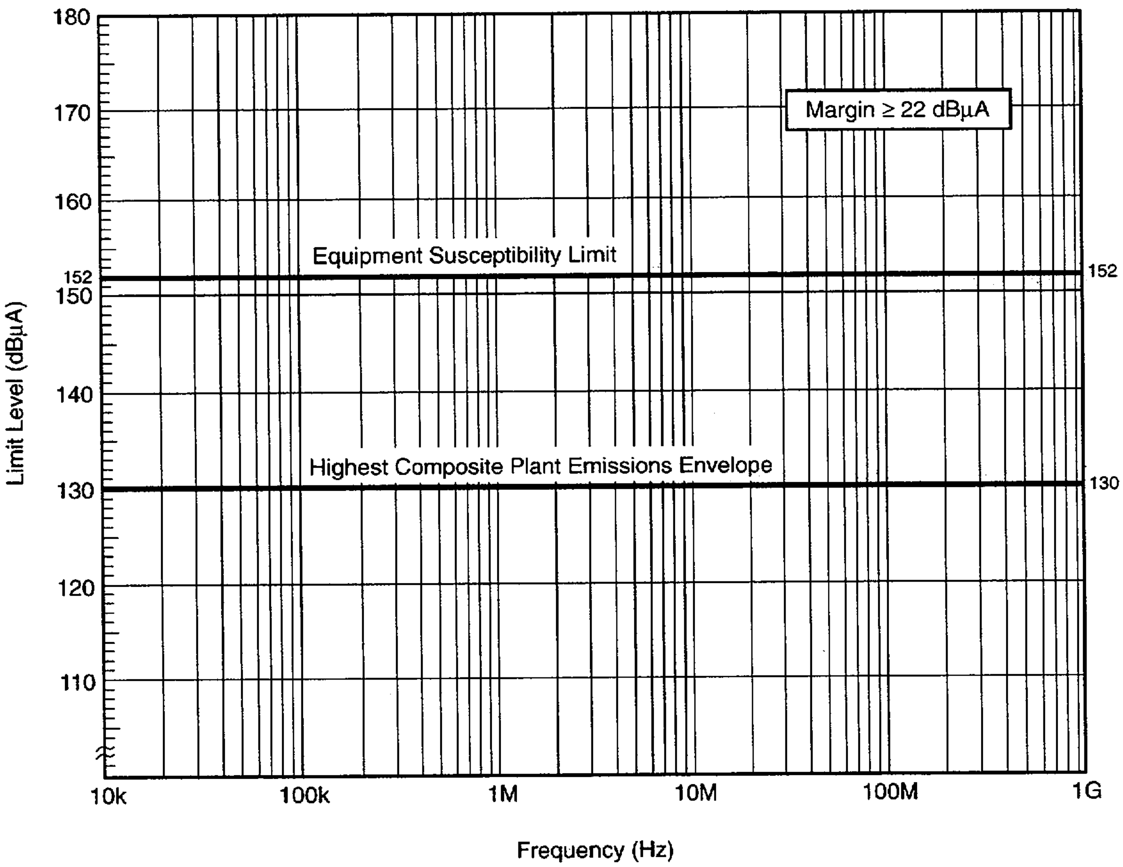


Figure 7-5
Transient Testing Limit Analysis

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 in addressing uncertainties and other analysis variables and provides reasonable assurance of EMC.

Because recommended equipment emissions levels remain sufficiently below the highest composite plant emissions levels and control equipment emissions, overall plant emissions levels are not increased in areas of concern.

8 SUMMARY AND CONCLUSIONS

Operating experience has identified 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 required to justify digital modifications and demonstrate equipment EMC with the ambient environment. The group has reviewed equipment susceptibility testing levels and compared them to 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 group's 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 in addressing uncertainties and other analysis variables and provides reasonable assurance of EMC.
- Because recommended equipment emissions levels remain sufficiently below the highest composite plant emissions levels and control equipment emissions, overall plant emissions levels are not increased in areas of concern.

The group has also recommended a set of minimum EMI limiting plant practices to ensure that equipment susceptibility levels are not exceeded. The EMI limiting practices are a set of design conditions that shall be satisfied to 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 is not 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 restricting EMI sources in the vicinity of EMI/RFI sensitive equipment. It was recommended that portable transmitters' radiated electric field strength be limited to 4 V/m at a distance of 1 m.

Finally, limits for controlling equipment emissions in the power plant were established on the basis of the measured plant emissions and the recommended susceptibility testing limits.

9 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.

10
REFERENCES

1. *Guidelines for Electromagnetic Interference Testing in Power Plants.* EPRI, Palo Alto, CA: 1997. TR-102323-R1.

2. U.S. Nuclear Regulatory Commission. *Guidelines for Evaluating Electromagnetic and Radio Frequency Interference in Safety-Related Instrumentation and Control Systems.* Reg. Guide 1.180, 2000.

3. *Electromagnetic Interference Control in Modern Digital Instrumentation & Control System Upgrades.* EPRI Workshop, Baltimore, MD (September 1992).

4. *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.* MIL-STD-461E, August 1999.

5. International Electrotechnical Commission (IEC) Standard 61000, Electromagnetic Compatibility (EMC) Part 3, "Limits" and Part 4, "Testing and Measurement Techniques":

   EN 61000-3-2, Rev. 1995, "Limits for Harmonic Currents Emissions" (equipment input current ≤ 16A per phase)

   EN 61000-4-2, Rev. 1999, "Electrostatic Discharge Immunity Test"

   EN 61000-4-3, Rev. 1998, "Radiated Radio-Frequency, Electromagnetic Field Immunity Test"

   EN 61000-4-4, Rev. 1995, "Electrically-Fast Transient/Burst Immunity Test"

   EN 61000-4-5, Rev. 1995, "Surge Immunity Test"

   EN 61000-4-6, Rev. 1996, "Immunity to Conducted Disturbances, Induced by Radio-Frequency Fields"

   EN 61000-4-8, Rev. 1993, "Basic Immunity Standard Power Frequency Magnetic Field Test"

   EN 61000-4-13 CDV, "Basic Immunity Standard for Harmonics and Inter-Harmonics"

6. U.S. Nuclear Regulatory Commission, *Investigation of Electromagnetic (EMI) Levels in Commercial Nuclear Power Plants.* NUREG/CR3270, UCID19703, August 1983.

7. *Recommended Practice for an Electromagnetic Site Survey*. IEEE Standard 473, 1997.

8. *Electromagnetic Susceptibility of Process Control Instrumentation*. Scientific Apparatus Makers Association (SAMA), Process Measurement Control, Inc. (PMC) Document 33.1, 1978. Note: This standard has been withdrawn with no superceding document.

9. *Electromagnetic (Radiated) Environment Considerations for Design and Procurement of Electrical and Electronic Equipment*. MIL-HDBK 235-1B.

10. U.S. Nuclear Regulatory Commission, *Recommended Electromagnetic Operating Envelopes for Safety-Related I&C Systems in Nuclear Power Plants*. NUREG/CR6431, January 2000.

11. U.S. Nuclear Regulatory Commission, *Survey of Ambient Electromagnetic and Radio-Frequency Interference in Nuclear Power Plants*. NUREG/CR6436, November 1996.

12. U.S. Nuclear Regulatory Commission, *Technical Basis for Evaluating Electromagnetic and Radio Frequency Interference in Safety-Related I&C Systems*. NUREG/CR5941, April 1994.

13. *Zion Safety Evaluation Report for the Westinghouse Eagle 21 Upgrade*, Office of Nuclear Reactor Regulation, June 9, 1992. Docket Nos. 50-295 and 50-304.

14. *Use of Portable Radio Transmitters in Nuclear Power Plants*. U.S. NRC Information Notice IN 83-83. 1983.

15. ANSI/IEEE C37.90.1, *IEEE Guide for Surge Withstand Capability (SWC) Tests* 1994. Supplement to Section 9 of ANSI/IEEE C37.90, IEEE Standard *Relays and Relay Systems Associated with Electric Power Apparatus*.

16. *Guide for Instrumentation and Control Equipment Grounding in Generating Stations*. IEEE 1050-1996.

17. *Guide for the Installation of Electric Equipment to Minimize Noise Inputs to Controllers from External Sources*. IEEE Standard 518, 1996.

18. *Evaluation of EMC of Connecticut Yankee Digital Feedwater Control System*. Prepared by CHAR Services, Report CSR026B. August 1993.

19. *EMI Mapping of Control Rooms and Refuel Floor, TVA's Browns Ferry Station, Units 1, 2, and 3*. Prepared by National Technical Systems, Report 60251-94N-1. June 1993.

20. *EMI Mapping of Control Rooms, CP&L's Brunswick Units 1 & 2*. Prepared by National Technical Systems, Report 60254.04-94N-1. June 1993.

21. *EMI Mapping of Control Rooms and Refuel Floor, Centerior Energy's Perry Plant*. Prepared by National Technical Systems, Report 60254.04-94N-1. November 1993.

22. *Analysis of Point of Installation and Generic Emissions EMI Data, Georgia Power Company's A. Vogtle Electric Generating Plant*. Prepared by National Technical Systems, Report 31319-94M. February 1994.

23. *Analysis of Point of Installation and Generic Emissions EMI Data, Philadelphia Electric Co.'s Peach Bottom Units 2 and 3.* Prepared by National Technical Systems, Report 31288-94M-1. February 1994.

24. *Electromagnetic Interference (EMI) Test Report on the On-Site Mapping of the Control Room Area at Palo Verde Nuclear Generating Station (PVNGS) Unit 3.* Prepared by Wyle Laboratories, Report 68900-01. June 1994.

25. *Handbook for Electromagnetic Compatibility of Digital Equipment in Electric Power Plants: Vol. I, Fundamentals of EMI Control, and Vol. II, Implementation Guide for EMI Control.* EPRI, Palo Alto, CA: June 1994 (Vol. 1) and October 1994 (Vol. 2). TR-102400.

26. *Land Mobile FM or PM Communications Equipment Measurement and Performance Standards,* ANSI/TIA/EIA Electronic Industries Association (EIA) 603, 1993.

27. *Recommended Practice for Powering and Grounding of Sensitive Electronic Equipment.* ANSI/IEEE Standard 1100, 1999 (also called *Emerald Book*).

28. *National Electrical Code Handbook,* NFPA #70HB93.

29. *ANSI/IEEE Recommended Practice on Surge Voltages in Low Voltage ac Power Circuits.* ANSI/IEEE C62.41-1995.

30. *Guide on Surge Testing for Equipment Connected to Low Voltage ac Power Circuits.* ANSI/IEEE C62.45-1998.

31. International Special Committee for Radio Interference (CISPR) 22. *Emission Requirements for Information Technology Equipment.* EN 55022, 1992.

A
EMI WORKING GROUP MEMBERS

Clifford L. Bailey
Arizona Public Service Co.

Rick Brehm
Tennessee Valley Authority

Robert Carritte
MPR Associates, Inc.

John Chiarella
Connecticut Yankee Atomic Power Co.

Ray DiSandro
PECO Energy Co.

Norman R. Eisenmann
Entergy Nuclear Generation Co.

Gale Hanson
Arizona Public Service Co.

Joseph Hazeltine
Wyle Laboratories, Inc.

Agustin Henriquez
Illinois Power Co.

Revis James
EPRI

Seyavash Karimian
Public Service Electric and Gas

Sang D. Lee
Southern Nuclear Operating Co.

Lori McGuire
Centerior Energy

Dick Meininger
CHAR Services

James E. Mellers
Pacific Gas & Electric Company

Wade Messer, II
Duke Energy Corp.

Marty Metcalf
National Technical Systems

Ky D. Nguyen
Arizona Public Service Co.

Finbarr O'Connor
IIT Research Institute

Frank C. Poley
Duke Power Company

James Press
National Technical Systems

Ifti Rana
Southern Nuclear Operating Co.

James W. Shank
Public Service Electric & Gas

Ramesh Shankar
EPRI Charlotte

Jim Spadafore
Niagara Mohawk Power Corp.

Moazam Syed
TXU Electric

Carl Vitalbo
Westinghouse Electric Co.

Gerald Wood
Entergy Operations, Inc.

Carl Yoder
Baltimore Gas & Electric Co.

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 mechanism for the lower frequencies will be due to shared, common grounds or due to 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.

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.

---

[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.

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.

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.

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.

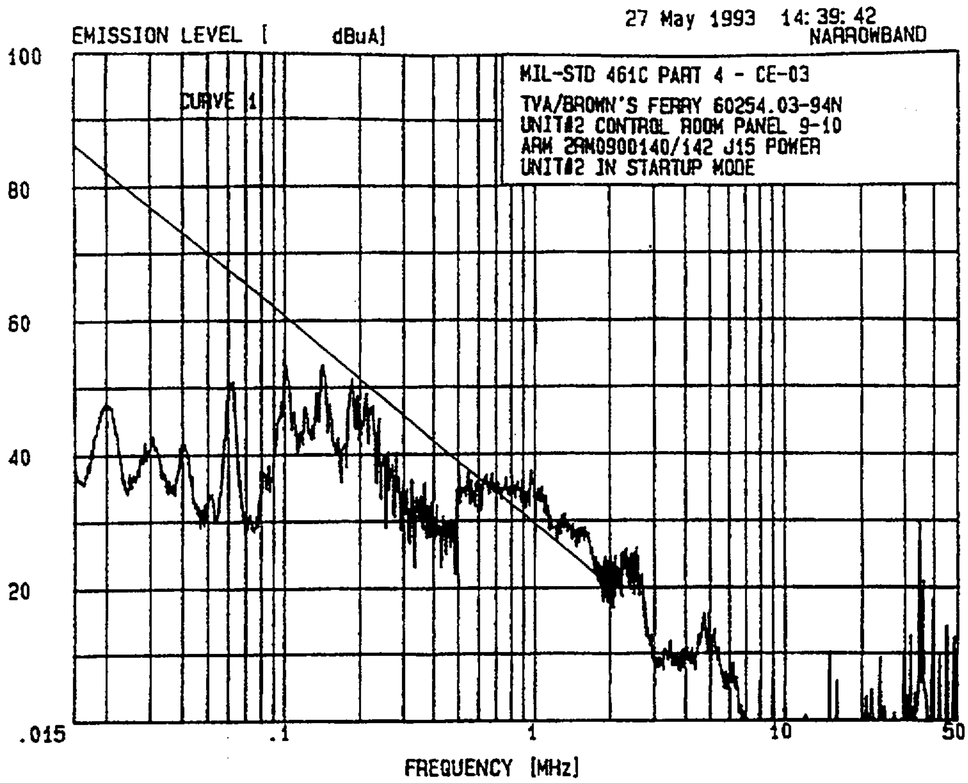
An estimate can be made to determine how far apart components must be in order to conclude that they would not likely respond to the same ESD event. This can be accomplished by examining the test distances for the indirect ESD discharge. IEC 61000-4-2 (Figures 5 and 6) places the distance for test at 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.

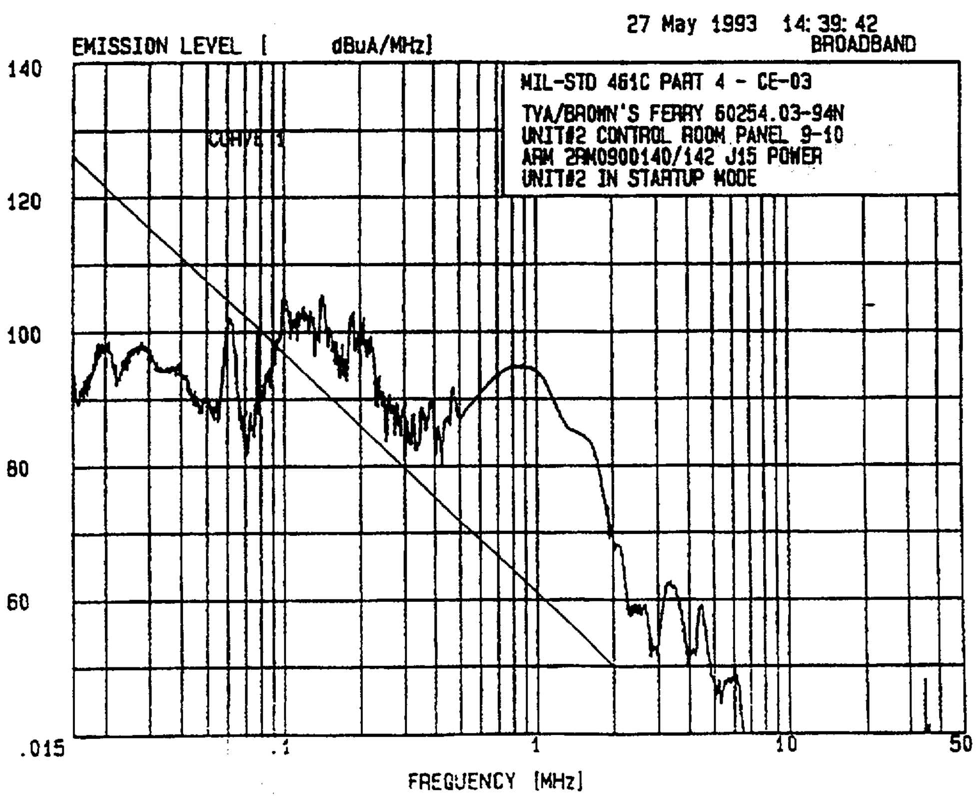
Maximum Expected Level

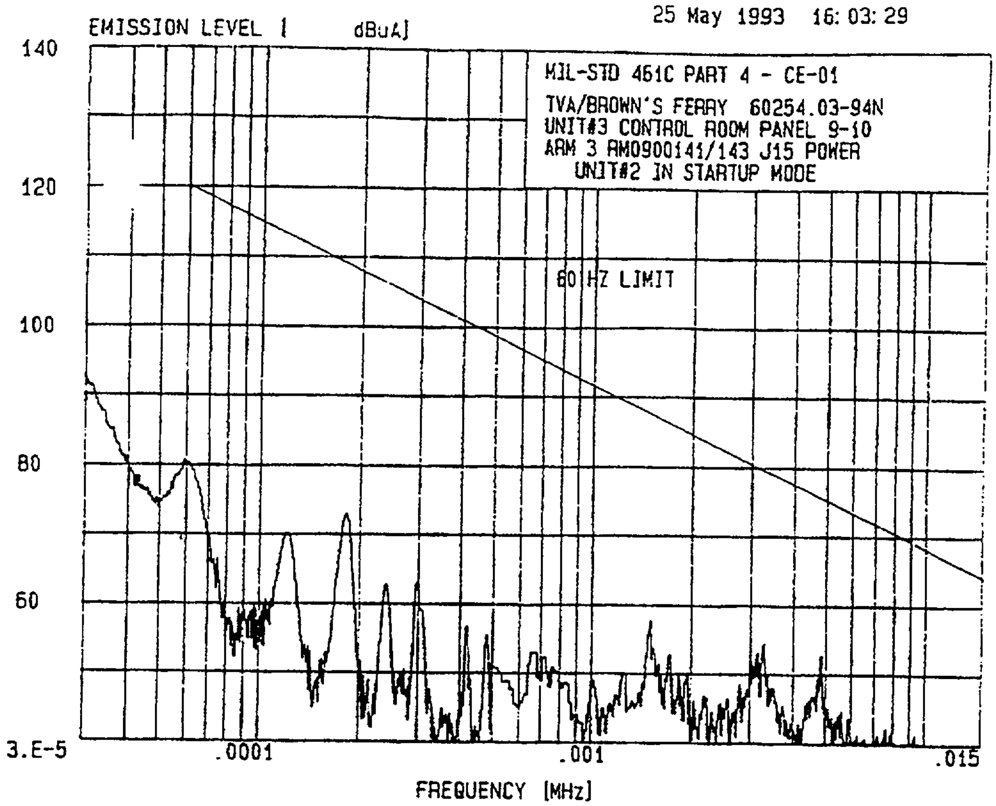
The maximum expected level of an ESD is highly dependent on factors that affect the breakdown of air by the electrostatic potential and by the dissipation of charge through air ionization processes. The breakdown in air will be directly proportional to atmospheric pressure and inversely proportional 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.

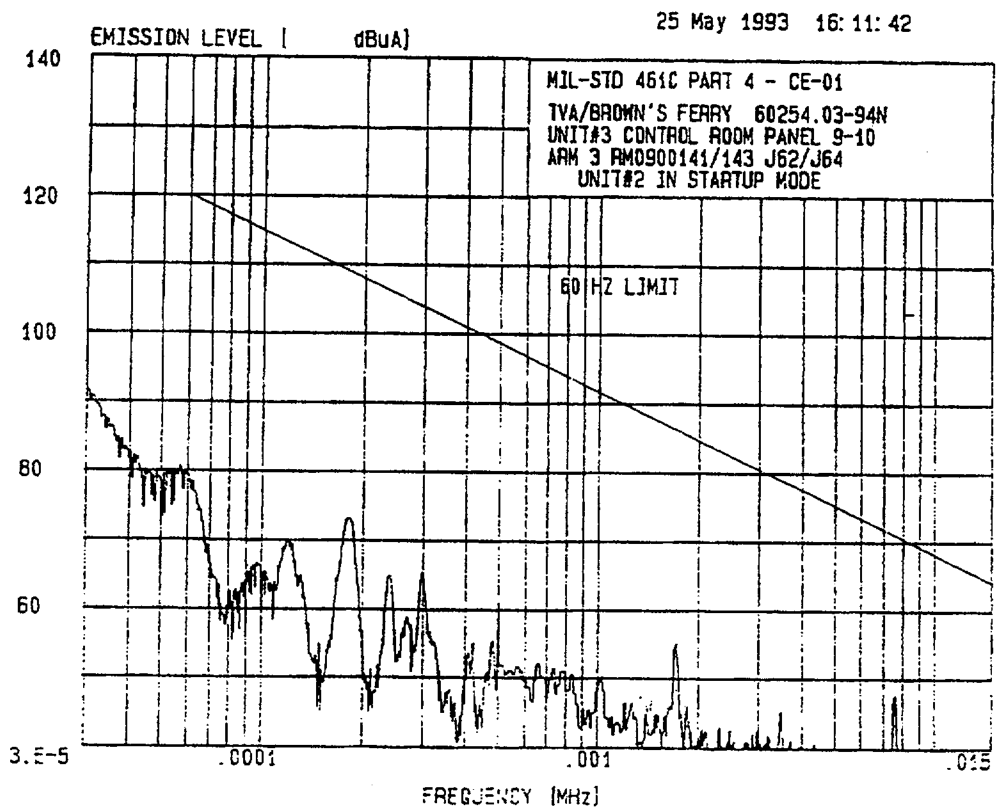
[5] For a 1 nanosecond rise time ESD, the high-frequency content can be defined as $1/(T_r \pi)$, or 318 MHz. The far-field will be defined as wavelength divided by 2π, or approximately 5 cm in air.

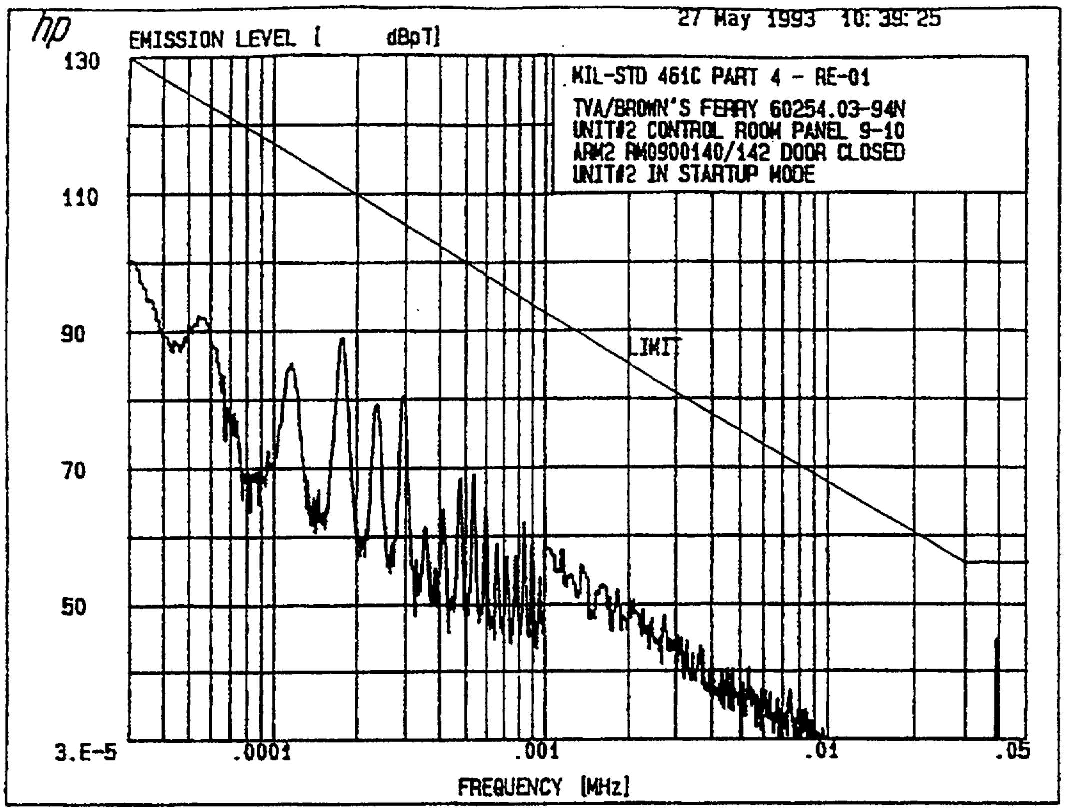
C
SAMPLE EMISSIONS DATA COLLECTED AT NUCLEAR POWER PLANTS

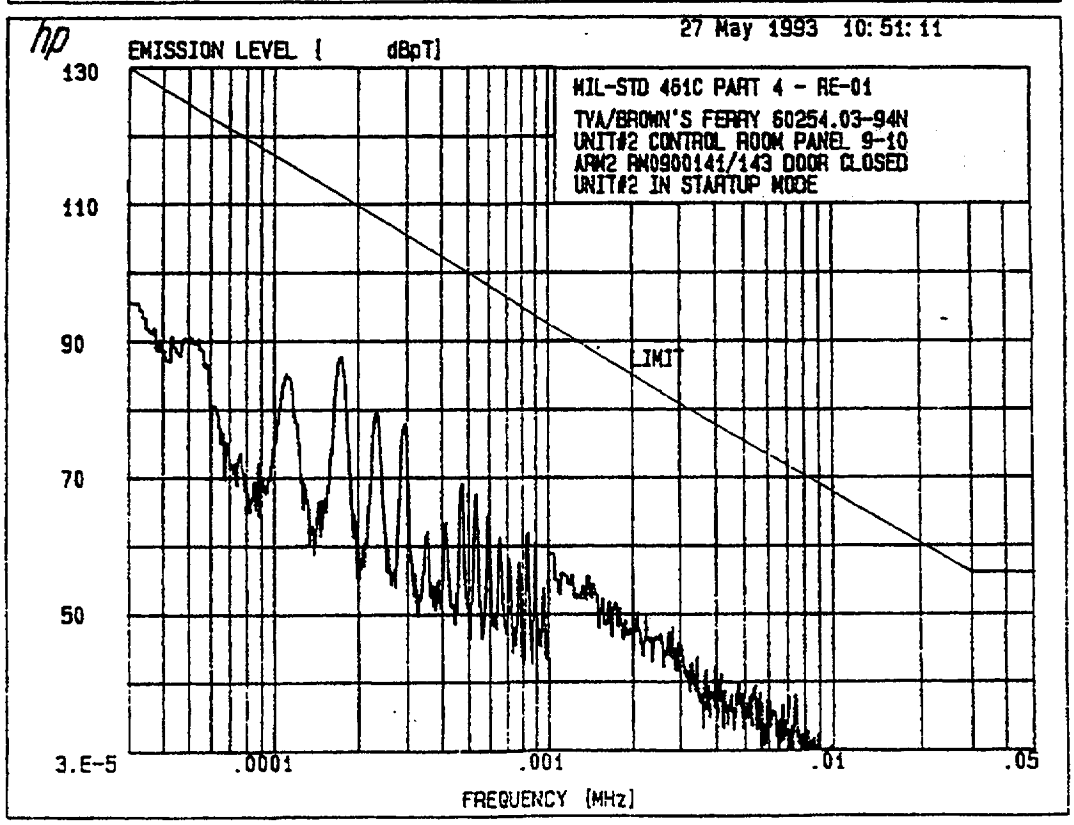

27 May 1993 14:39:42
NARROWBAND
EMISSION LEVEL [dBuA]
MIL-STD 461C PART 4 - CE-03
TVA/BROWN'S FERRY 60254.03-94N
UNIT#2 CONTROL ROOM PANEL 9-10
ARM 2RM0900140/142 J15 POWER
UNIT#2 IN STARTUP MODE
CURVE 1
100
80
60
40
20
.015
.1
1
10
50
FREQUENCY [MHz]

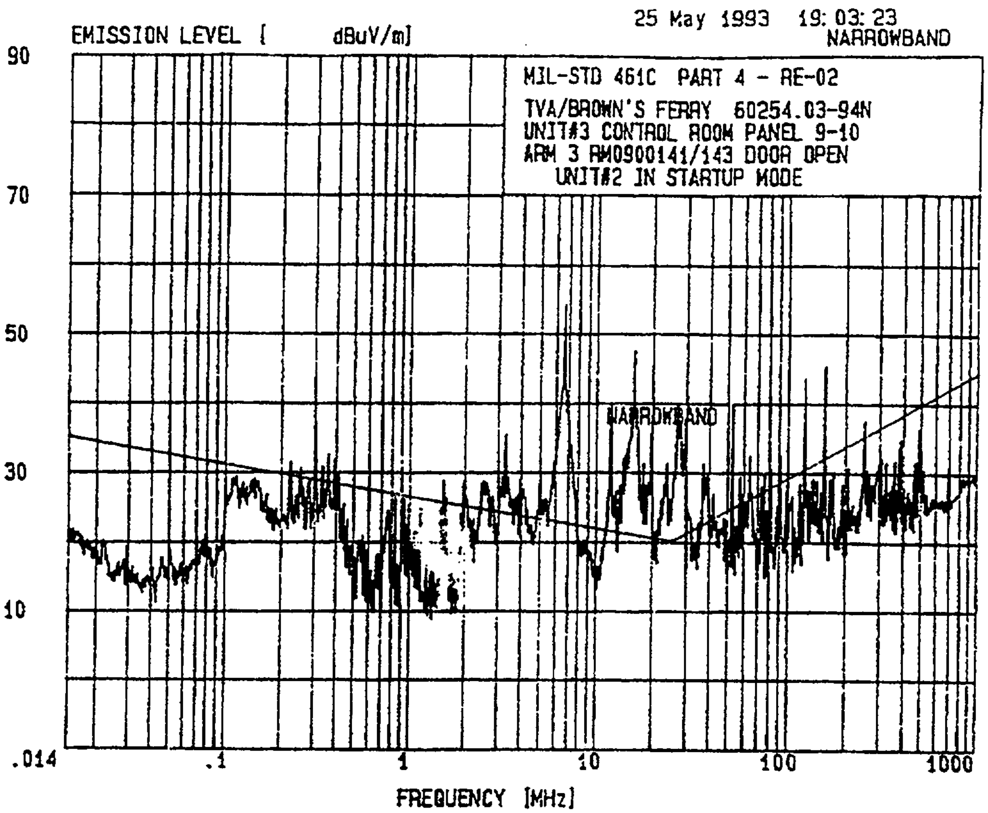

27 May 1993 14:39:42
BROADBAND
EMISSION LEVEL [dBuA/MHz]
MIL-STD 461C PART 4 - CE-03
TVA/BROWN'S FERRY 60254.03-94N
UNIT#2 CONTROL ROOM PANEL 9-10
ARM 2RM0900140/142 J15 POWER
UNIT#2 IN STARTUP MODE
CURVE 1
140
120
100
80
60
.015
.1
1
10
50
FREQUENCY [MHz]

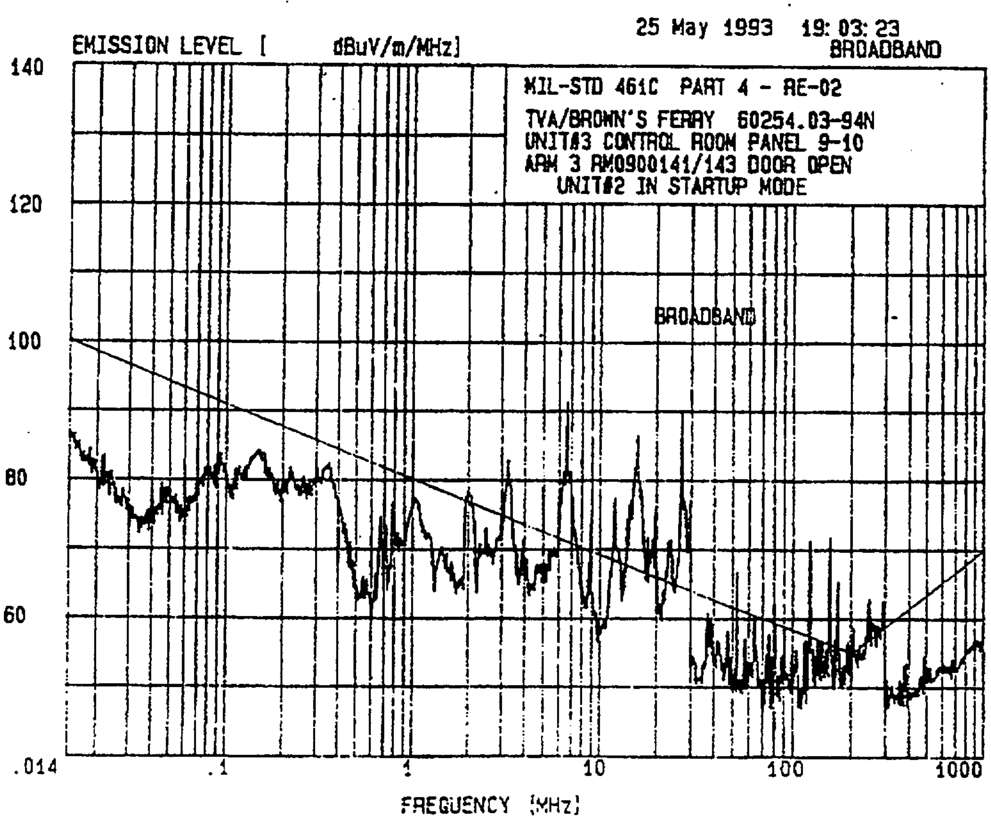

EMISSION LEVEL [dBuA]
25 May 1993 16:03:29
MIL-STD 461C PART 4 - CE-01
TVA/BROWN'S FERRY 60254.03-94N
UNIT#3 CONTROL ROOM PANEL 9-10
ARM 3 RM0900141/143 J15 POWER
UNIT#2 IN STARTUP MODE
60 HZ LIMIT
140
120
100
80
60
3.E-5
.0001
.001
.015
FREQUENCY [MHz]


EMISSION LEVEL [dBuA]
25 May 1993 16:11:42
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
140
120
100
80
60
3.E-5
.0001
.001
.015
FREQUENCY [MHz]


27 May 1993 10: 39: 25
EMISSION LEVEL [dBpT]
130
110
90
70
50
3.E-5
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
.0001
.001
.01
.05
FREQUENCY [MHz]


27 May 1993 10: 51: 11
EMISSION LEVEL [dBpT]
130
110
90
70
50
3.E-5
MIL-STD 461C PART 4 - RE-01
TVA/BROWN'S FERRY 60254.03-94N
UNIT#2 CONTROL ROOM PANEL 9-10
ARM2 RM0900141/143 DOOR CLOSED
UNIT#2 IN STARTUP MODE
LIMIT
.0001
.001
.01
.05
FREQUENCY [MHz]


25 May 1993 19: 03: 23
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

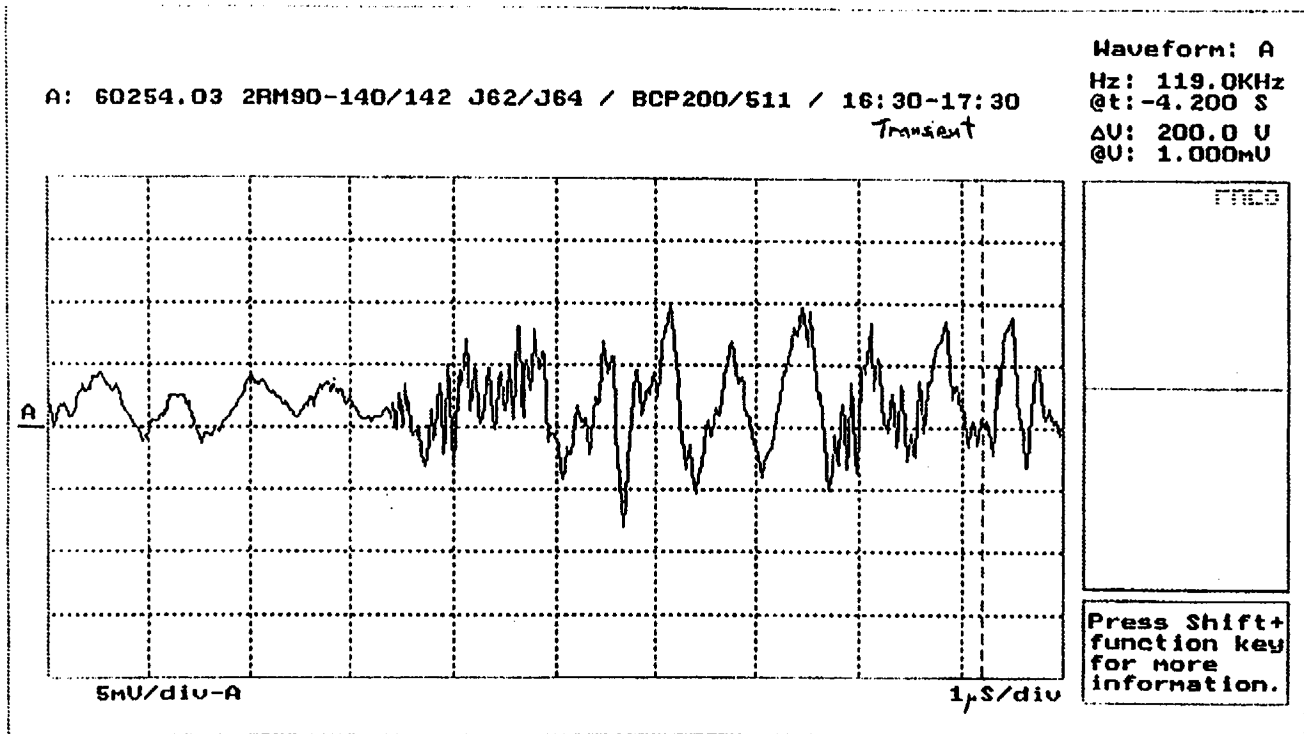
National
Technical
Systems

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. Burn

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

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

Mode of Operation Startup

D
NRC SAFETY EVALUATION REPORT

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

DI-EMCS-80201A

Block 10, Preparation Instructions (Continued)

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

a. Military (e.g., standards and specifications).
b. Company (any in-house documents for calibration or quality assurance).
c. Other Government or industry standards, specifications, or documents.

10.3.3 Test site. A description of the test site, covering the following:

a. Description of test facility and shielded enclosure or anechoic chamber, including size, characteristics, and placement of radio frequency (RF) absorbers.
b. Description of the ground plane (size and type) and methods of grounding or bonding the EUT to the ground plane in order to simulate actual equipment installation.
c. Description of how test precautions required by 4.7 of MIL-STD-462 shall be implemented.

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

a. Equipment nomenclature and calibration due date.
b. Bandwidth (resolution and video) and scanning speeds of measurement receivers.
c. The characteristics of coupling transformers and band-reject filters.
d. Antenna factors of specified antennas, transfer impedances of current probes, and impedance of Line Impedance Stabilization Networks (LISN).
e. Description of the operations being directed by software for computer-controlled receivers, and of the verification techniques used to demonstrate proper performance of the software; also, identify the specific version of the software to be used.

10.3.5 EUT setup. A description of the EUT test setup for each test shall cover the actual physical layout of the cables and EUT, cable types or characteristics and construction details (see 4.8.5 of MIL-STD-462), the position of the line impedance stabilization networks on the ground plane, and the location of bond straps, loads, and test sets.

10.3.6 EUT operation. A description of the EUT operation shall cover the following:

a. Modes of operation for each test and operating frequency.
b. Control settings on the EUT.
c. Control settings on any test sets employed or characteristics of input signals.
d. Test frequencies (e.g., oscillator and clock frequencies) which may be expected to approach requirements and limits.
e. Performance checks initiated to designate the equipment as meeting minimal working standard requirements.
f. Circuits, outputs, or displays to be monitored during susceptibility testing shall be enumerated, as well as the criteria for monitoring degradation of performance.

(Continued on Page 3)

Page 2 of 3 Pages

DI-EMCS-80201A

Block 10, Preparation Instructions (Continued)

10.3.7 Measurements. The measurements to be employed to demonstrate compliance with contractual requirements shall be described. The following shall be indicated 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 isolation for 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.

F
SAMPLE QUALIFICATION REPORT

MAY 0
2

DATA ITEM DESCRIPTION

Form Approved OMB No. 0704-0188

Public reporting for this collection of information is estimated to average 110 hours per response, including time for reviewing instructions, searching existing data sources gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the office of Management and Budget, Paperwork Reduction Project(0704-0188), Washington, DC 20503.

1. TITLE	2. IDENTIFICATION NUMBER
ELECTROMAGNETIC INTERFERENCE CONTROL PROCEDURES (EMICP)	DI-EMCS-80199A

3. DESCRIPTION / PURPOSE

3.1 This EMICP provides data to evaluate the contractor's design procedures and techniques used to meet equipment or subsystem contracted electromagnetic interference (EMI) control requirements based on MIL-STD-461.

4. APPROVAL DATE (YYMMDD)	5. OFFICE OF PRIMARY RESPONSIBILITY	6a. DTIC APPLICABLE	6b. GIDEP APPLICABL
930111	EC		

7. APPLICATION / INTERRELATIONSHIP

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

7.2 This DID is applicable when an electronic, electrical, or electromechanical equipment or subsystem is required to meet contractual EMI requirements based on MIL-STD-461.

7.3 This DID supersedes DI-EMCS-80199.

8 APPROVAL LIMITATION	9a. APPLICABLE FORMS	9b. AMSC NUMBER
		N6853

10. PREPARATION INSTRUCTIONS

10.1 Reference documents. The applicable issue of the documents cited herein, including their approval dates and dates of any applicable amendments, notices, and revisions, shall be as specified in the contract.

10.2 Format. The EMICP format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions.

10.3 Content. The EMICP shall contain the following:

10.3.1 Management. The EMICP shall define the specific organizational responsibilities, lines of authority and control, and the implementation planning, including milestones and schedules. In addition, the detailed EMI requirements to be imposed on subcontractors and a definition of responsibility for associated contractor equipment, Government Furnished Equipment, and subcontractor vendor items shall be indicated. A description of the equipment or subsystem, its characteristics, where known, and intended installation or platform shall also be indicated. Plans and procedures for

(Continued on Page 2)

11. DISTRIBUTION STATEMENT

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

DD Form 1664, APR 89 *Previous editions are obsolete.* Page 1 of 2 Pag
135/123

MAY 8 1993
2

DATA ITEM DESCRIPTION

Form Approved OMB No. 0704-0188

Public reporting for this collection of information is estimated to average 110 hours per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the office of Management and Budget, Paperwork Reduction Project(0704-0188), Washington, DC 20503.

1. TITLE

ELECTROMAGNETIC INTERFERENCE TEST REPORT (EMITR)

2. IDENTIFICATION NUMBER

DI-EMCS-80200A

3. DESCRIPTION / PURPOSE

3.1 This EMITR provides the data and information necessary to evaluate an equipment or subsystem compliance with its contractual Electromagnetic Interference (EMI) Control requirements based on MIL-STD-461, including the discussion of recommended corrective actions, if needed.

4. APPROVAL DATE (YYMMDD)	5. OFFICE OF PRIMARY RESPONSIBILITY	6a. DTIC APPLICABLE	6b. GIDEP APPLICABLE
930111	EC		

7. APPLICATION / INTERRELATIONSHIP

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

7.2 This DID is applicable when an electronic, electrical, or electromechanical equipment and subsystem is required to comply with contractual EMI requirements based on MIL-STD-461.

7.3 This DID supersedes DI-EMCS-80200.

8. APPROVAL LIMITATION	9a. APPLICABLE FORMS	9b. AMSC NUMBER
		N6854

10. PREPARATION INSTRUCTIONS

10.1 Reference documents. The applicable issue of the documents cited herein, including their approval dates and dates of any applicable amendments, notices, and revisions, shall be as specified in the contract.

10.2 Format. The EMITR format shall be contractor selected. Unless effective presentation would be degraded, the initially used format arrangement shall be used for all subsequent submissions.

10.3 Content. The EMITR shall contain the following:

10.3.1 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).

(Continued on Page 2)

11. DISTRIBUTION STATEMENT

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.

DD Form 1664, APR 89 — Previous editions are obsolete. — Page 1 of 2 Pages
135/123

DI-EMCS-80200A

Block 10, Preparation Instructions (Continued)

d. Description of the EUT, including function and intended use or installation, actual cable types or characteristics and construction details (see 4.8.5 of MIL-STD-462), and electrical current (Root Mean Square for Alternating Current) level on each power input line.
e. List of tests performed with pass/fail indications.
f. Any approved deviation from contractual test procedures, test limits, or test frequencies previously authorized.
g. Identification of Non-Developmental Items (NDI) and Government Furnished Equipment (GFE) that may be part of the EUT.

10.3.2 Appendices. A separate appendix shall be prepared for each test. Each appendix shall cover the applicable test procedure or reference to the approved EMI Test Procedures (EMITP), data sheets, graphs, illustrations, and photographs. If deviations from an approved test procedure occurred during the test program, an additional appendix shall be provided with the "as run" procedures with all red-lines and procuring activity concurrences. The log sheets shall be contained in a separate appendix which shall be shown last. Each appendix shall contain the following factual data:

a. Nomenclature of interference measuring equipment.
b. Serial numbers of interference measuring equipment and version of software used.
c. Due date of calibration of interference measuring equipment, procedures used and the traceability.
d. Photographs or diagrams of the actual test set up and EUT, with identification.
e. Transfer impedance of current probes.
f. Antenna factors and Low-Noise Amplifiers' (LNA's) compression points.
g. Impedance values of Line Impedance Stabilization Networks (LISN).
h. If suppression devices are employed to meet the contractual requirements, they shall be identified, using schematic, performance data, and drawings.
i. Sample calculations, such as conversions of measured levels for comparison against the applicable limit.
j. The ambient radiated and conducted electromagnetic emission profile of the test facility, when necessary.
k. Data, and data presentation, as specified in paragraph 5 of the individual test methods of MIL-STD-462.
l. Scan speeds.
m. Measurement bandwidths.
n. Antenna polarization.
o. Power line voltages, frequencies, and power factor.

10.3.3 Recommendations and conclusions. Recommendations and conclusions shall be described, including results of the tests in brief narrative form, a discussion of remedial actions initiated, and proposed corrective measures recommended to assure compliance of the equipment or subsystem with the contractual EMI requirements.

Page 2 of 2 Pages

G
TECHNICAL BASIS DOCUMENT

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 Reg. Guide 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 Reg. Guide 1.180.

Change #3: Low-frequency starting point of second harmonic of power frequency

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

Change #4: We now accept testing in accordance with EN 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 MIL-STD-461E CS114 Curve #2, which is supported by comparison with collected plant emissions data beyond 1 MHz. Note: 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 2 MHz to 200 MHz) until additional data are 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 MIL-STD-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 MIL-STD-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 because high-frequency radiated testing starts at 2 MHz. This change also brings this test into better alignment with MIL-STD-461E CS114 and Reg. Guide 1.180.

Low-Frequency Radiated Susceptibility Changes

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

- Basis #1: Although there are major differences in the scope and methodology of the MIL-STD 461E RS101 test and the EN 61000-4-8 test, this test meets 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 if test CS114 or 61000-4-6 is also performed

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

Change #2: Extended the 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 to 2 kV. Increased primary power connected to external lines voltage test limit from 3 to 4 kV. Reduced shields and ground leads connected to remote (> 30 m) grounds voltage test limit from 3 to 2 kV.

- Basis #1: This change brings this test recommendation into better alignment with EN 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 Reg. Guide 1.180; both currently specify 3 kV limits.

Electrically-Fast Transients/Bursts

Change #1: Changed Scope—differentiated testing for power ports vs. input/output (I/O), data, and 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 EN 61000-4-4.

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

- Basis #2: This change brings this test recommendation into better alignment with EN 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 Reg. Guide 1.180; 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 and Army aircraft; however, Reg. Guide 1.180 specifies limits that most closely match a submarine platform.

Change #2: Low-frequency starting point of second harmonic of power frequency

- Basis #2: These changes are consistent with MIL-STD-461E and Reg. Guide 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 Reg. Guide 1.180; however, MIL-STD-461E does not specify a limit dB relaxation for CE101-4 (Navy and Army aircraft).

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

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

High-Frequency Conducted Emissions Changes

Change #1: Changed part of limit curve from 78 dBμA at 50 kHz and 60 dBμA at 100 kHz to 90 dBμA at 10 kHz and 60 dBμA at 100 kHz. This change effectively reduced the TR-102323 Rev. 1 limit (more restrictive) from 50 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 and Reg. Guide 1.180.

Change #3: We now allow a dB relaxation limit for equipment operating voltages greater than 115 VAC

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

Low-Frequency Radiated Emissions Changes

Change #1: Specified measurements shall 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 Reg. Guide 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 Reg. Guide 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 to 10 GHz or 5 times the highest internally generated frequency within the EUT, 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.

Target:
Nuclear Power

About EPRI

EPRI creates science and technology solutions for the global energy and energy services industry. U.S. electric utilities established the Electric Power Research Institute in 1973 as a nonprofit research consortium for the benefit of utility members, their customers, and society. Now known simply as EPRI, the company provides a wide range of innovative products and services to more than 1000 energy-related organizations in 40 countries. EPRI's multidisciplinary team of scientists and engineers draws on a worldwide network of technical and business expertise to help solve today's toughest energy and environmental problems.

EPRI. Electrify the World

Printed on recycled paper in the United States of America

1000603

EPRI • 3412 Hillview Avenue, Palo Alto, California 94304 • PO Box 10412, Palo Alto, California 94303 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com