Context Model Library – EMI Susceptibility via Cables

Abstract: *This report presents a set of modeling methods and general context models for predicting susceptibility of electronic equipment to MIL-STD-461F environments with respect to reception of interference via the cable/connector assemblies. The primary focus of the resulting methods and models is to support the DARPA Component, Context, and Manufacturing Model Library (C2M2L) effort to reduce the design and development cycle time of military ground vehicles. The report contains three parts – System Electromagnetic Environment Flowdown to Equipment and Cable/Connector Assemblies, Modeling Method for Cable/Connector Assemblies, and Detailed Example.*

1. INTRODUCTION

Electronic subsystems and equipment in military ground vehicles are subject to Electromagnetic Interference (EMI) from sources internal and external to the vehicle via pick-up and subsequent conduction through the cables and wires attached to the equipment. The general external electromagnetic environment presented to a military system (aircraft, ship, ground vehicle) is defined in MIL-STD-464C, "*Electromagnetic Environment Effects Requirements for Systems*." In the end, the system level electromagnetic environment presents itself at the equipment connector pins as a voltage or current with an equivalent source impedance to result in potential upset of the electrical interface and/or damage to electronic components, unless adequate protection is part of the equipment and/or cable-connector assembly design. The interference voltage or current may be a transient (typically described in the time domain), or it may be a somewhat steady-state condition at a particular frequency.

The typical electromagnetic interference environments that are presented to cable-connector assemblies for equipment in military vehicles are defined in standards such as MIL-STD-461F, "*Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*." MIL-STD-464C section 5.7 specifically calls out the interference control requirements of MIL-STD-461 for individual subsystems and equipment.

The requirements in MIL-STD-461F represent the electromagnetic environment expected at subsystems and equipment, and the associated cables, with adjustments made for standard laboratory test setups for compliance verification. MIL-STD-461F contains various "limits" for each type of electromagnetic environment based on the type of platform (system) and the location of the subsystem or equipment and its associated cabling within the system. MIL-STD-461F also contains the compliance verification test methods for each electromagnetic environment. A key requirement is to verify compliance with cables that are representative of the intended installation. Section 2 of this report thus addresses the external electromagnetic environments and presents the cable environment models in detail.

Typically, the design and analysis for EMI compliance of equipment and subsystems falls into two areas – the equipment items themselves and the cable/connector assemblies.

Design of the equipment for EMI compliance centers around designing circuits, both electrically and mechanically (e.g. printed circuit board layout) for low emissions and a high level of immunity, and designing chassis shielding to provide electromagnetic attenuation at least as great as the difference between circuit's emission levels and immunity and the required emissions limit and the external electromagnetic environment to which the equipment must be immune to. The equipment design may also utilize filtering, typically low pass networks, at the shield boundary to attenuate interference picked up by external wires and cable, as well attenuate internally generated noise to reduce its radiation via external wires and cables. Modeling and analysis allows filter performance prediction to be made before hardware is built. Performance with respect to the attenuation of the interference needs to be considered along with the filter's effect on the desired signal it going through it.

The second area of design and analysis for EMI control and compliance centers around the cable/connector assembly design. Cable/connector assembly design and analysis for EMC considers conductor size, characteristic impedance, electrical terminations, shielding, shield characteristics, shield termination methods, shield ground references and coupling between conductors within a cable bundle, and the resulting voltages and currents coupled in from the external environment. It is the cable/connector assembly modeling that is the focus of this effort. Modeling and simulation can be used early in the system design to analyze trade-offs between cable and connector weight (shielding), filtering, signaling schemes and electrical interface design.

This report documents a set of generic context environment models and modeling methods to allow prediction of the interference coupled to equipment connector pins and interface circuits resulting from exposure of the vehicle's cables to radiated and conducted (induced) interference.

Stimuli to the model include the CS114, CS115, CS116, RS103 and RS105 environments as applied per MIL-STD-461F.

Section 2 of this report shows how the system level environments translates to the applicable MIL-STD-461F environment. These applicable environments, and hence the stimuli to the simulation models, are described as CS114, CS115, CS116, RS103 and RS105. A model of each of the five environments is provided.

Inputs to the cable model will include cable and connector cross-section details, transfer impedance of the cable and connector shielding, and interface circuit design details.

Outputs from the simulations using these models would include the time domain and/or frequency domain interference presented at the connector pins in terms of voltages and currents. The resulting interference levels can then be compared to the levels of the desired signals and component damage threshold levels to determine if interface failure (upset) and/or component damage is expected. Of course if unacceptable upset and/or damage is predicted, changes to the design of the cable and/or the protection at the interface circuits can be made to improve the probability of electromagnetic compatibility and first time design success. Section 3 of this report presents the modeling and simulation methodology.

As transfer impedance of a cable shield characteristic that is often not available from the shield vendor, methods are presented to allow the determination the transfer impedance of cable shields and connectors.

It should be noted that simulation of electromagnetic effects is a complex computational intensive effort. Computer based modeling tools continue to evolve with ever increasing capability. This project identified a simulation tool that is believed to be the best mix between tool capability, user base, and ease of use with respect to model development and analysis against the MIL-STD-461F susceptibility environments as seen at equipment interface cables typically used in a military vehicle. Section 4 of this report presents a detailed analysis example for a multi-branch cable that may be found in a vehicle.

1.1 SCOPE

This report documents the findings with respect to the scope in Rockwell Collins Environmental Effects Engineering C2M2L Statement of Work (Appendix A). Specifically, the following is presented.

- The system level electromagnetic environment and flowdown to subsystems, equipment and cables
- Interference environment models as present at the cables
- Cable/connector assembly modeling approach
- Definition of required model inputs
- Methods of obtaining model inputs
- Simulation of the electromagnetic environments
- Model and simulation workflow
- Examples
- Cable Shield Transfer Impedance Determination

1.2 REFERENCE DOCUMENTS

The following documents are referenced in this report and may be referred to for addition information and background.

MIL-STD-464C – *Department of Defense Interface Standard: Electromagnetic Effects Requirements for Systems,* 1 December 2010.

MIL-STD-461F – *Department of Defense Interface Standard: Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*, 10 Dec 2007.

MIL-HDBK-235-1C – *Department of Defense Handbook: Military Operational Electromagnetic Environment Profiles, General Guidance*, 1 Oct 2010

MIL-HDBK-235-8 (Classified) – *Department of Defense Handbook: External Electromagnetic Environment Levels from High-Power Microwave Systems (U).*

IEC 61000-2-13 - *Electromagnetic Compatibility – Part 2-13: Environment – High-Power Electromagnetic (HPEM Environments – Radiated and Conducted*, First edition, March 2005.

IEC 61000-4-35 - *Electromagnetic Compatibility – Part 4-35: Testing and Measurement Techniques – HPEM Simulator Compendium*, Edition 1.0, July 2009.

MIL-STD-2169 (Classified) – *High Altitude Electromagnetic Pulse Environment (U).*

1.3 Units of Measure

Unless specifically noted otherwise, the units of measure for quantities presented herein are assumed to be as listed in table 1.3-1.

Table 1.3-1. Units of Measure

Quantity	Unit	Symbol
Area	Sq meter	m^2
Capacitance	Farad	F
Charge	Coulomb	C
Conductivity	Siemens per meter	S/m
Current	Ampere	A
Electric Field Strength (E-field Strength)	Volt per meter	V/m
Impedance	Ohm	Ω
Inductance	Henry	H
Length	meter	m
Magnetic Field Strength (H-field strength)	Ampere per meter	A/m
Permeability	Henry per meter	H/m
Permittivity	Farad per meter	F/m
Power	Watt	W
Resistance	Ohm	Ω
Voltage	Volt	V

1.4 List of Acronyms

The following acronyms are used herein.

BCI	Bulk Cable Injection
CST	Computer Simulation Technology AG
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EM	Electromagnetic
EME	Electromagnetic Environment
EMP	Electromagnetic Pulse
ESD	Electrostatic Discharge
RF	Radio Frequency
HEMP	High-altitude Electromagnetic Pulse
NEMP	Nuclear (generated) Electromagnetic Pulse
HPM	High-Power Microwave
ICD	Interface Control Document
LISN	Line Impedance Stabilization Network
rms	Root Mean Square
LRU	Line Replaceable Unit
I/O	Input / Output

1.5 Definitions

Definitions of key terms used within this report are presented below. They are applicable per EMI requirements stated in MIL-STD-464C and MIL-STD-461F. However, they, in particular those associated with shielding, may be slightly different with respect to the EMI requirement and environments stated in DO-160G and other environment/requirement documents related to civil aviation platforms.

Cable - A set of one or more conductors following a common route designed to provide a particular interface, such as power input, Ethernet, analog video output, digital video input. The conductors in a cable are assumed to be electromagnetically coupled to each other, although coupling may be weak between conductors separated by shields.

Cable Bundle - A complete section of a cable harness containing all the conductors that interface to a particular connector. A cable bundle will contain one or more cables. Technically, a cable bundle may consist of only one wire or lead. The conductors in a cable bundle, and the conductors within the cables they contain (if applicable) are assumed to be electromagnetically coupled to each other, although coupling may be weak between conductors separated by shields. A cable bundle runs between two connectors, between one connector and a branch node, or, between to branch nodes. From the standpoint of applying the MIL-STD-461F CS114, CS115 and CS116 threats, a cable bundle includes all the conductors associated with a particular equipment connector.

Cable Harness – A set of cable bundles used for interconnection of equipment items and to the boundary of its electromagnetic volume of interest (if applicable) within a simulation problem space. Electromagnetic coupling between conductors in different cable bundles that make up a cable harness may be present, although it is often insignificant and thus analytically ignored when compared to other couplings of concern. For the analysis described herein, electromagnetic coupling between cable bundles that make up a cable harness will be ignored.

Equipment item – A electric item designed and typically procured as a stand-alone item that is directly attached to the vehicle or equipment mounting structure (e.g. communications equipment rack) designed principally for mechanical interfacing equipment to a vehicle (e.g. equipment rack). Equipment items connect to other equipment items within a system or subsystem via cable assemblies. An item, from an EMI control standpoint, that is applicable to the EMI requirements contained in MIL-STD-461F with minimal tailoring.

Electronic Module – A function specific subassembly that is part of a higher level equipment item. Modules typically interface with other modules through backplanes and are often shielded from some of the electromagnetic environments present at the equipment and subsystem levels. With the exception of areas where a module interfaces to other equipment via platform cables, this effort does not address modules.

Gross over-shielded Bundle – A shield cable bundle containing a relatively high quality bundle shield, with the shield being electrically bonded to a conductive backshell on the bundle's connectors such that, for all practical purposes, the interference present on the shielded conductors from the external environment applied in the vicinity of the over-shield will be due to environment induced current flow on the over-shield rather than from direct coupling to the external environment.

Gross overbraid shield – A shield on a gross over-shielded bundle that uses a MIL QQB575R or equivalent braid bundle shield.

Ground plane - A reference plane for the electromagnetic environment and for physical objects used in an electromagnetic model or simulation. The ground plane, per common convention in EMI/EMC problems, is located at z = 0 in the 3-dimensional Cartesian coordinate problem space. The ground plane is a conductor, but it does not have to be a perfect conductor.

Grounded node – A node containing a conductor that connects to the ground plane at the physical planar (x-y plane if z = 0 plane is the ground plane) location of the node.

Node – A point in three dimensional space that can be used as a terminus for a segment and/or a set of conductors.

Platform – A physical structure that hosts system electronic equipment. Examples include aircraft, ground vehicles, fixed facility buildings and soldiers (for a soldier-mounted system)

Shield - A conductor used for one or more of the following purposes:

(a) A conductor not specifically designed as a signal return, but rather for the attenuation of electromagnetic energy that is being imposed upon a wire, a group of wires, a cable, a cable bundle and/or a cable harness by geometrically surrounding the conductors being shielded. The imposed interference may be from the external environment or from other conductors. A shield over a wire pair that interfaces a remote temperature sensor (thermo-resistor) located in an area of intense electromagnetic radiation to a data acquisition receiver/processor is an example of this type of shield.

(b) A conductor not specifically designed as a signal return, but rather for the reduction of coupling from a particular wire, a group of wires, a cable, a cable bundle and/or a cable harness to the environment by geometrically surrounding the conductors being shielded. The shield of a shielded twisted pair cable used use for a transformer coupled Ethernet interface is an example of this type of shield – the shield is used to reduce emissions from the cable.

(c) A signal or power return conductor having a cross-section that surrounds the signal or power conductor(s) designed with the intention of reducing signal radiation, reducing the coupling of external interference and/or providing a particular characteristic transmission line impedance. The shield on a coax cable used for cable TV is an example of this type of shield, as well as the shield on a transition minimized differential signaling pair used in a Digital Video Interface (DVI) interface (the shield is the signal return).

Route – A physical path, consisting of one or more segments, for a cable and/or cable bundle.

Segment – A physical path between two nodes.

Shielded Cable – A cable (per definition above) containing one or more shields (as defined above).

Shielded Cable Bundle – A cable bundle (as defined above) containing a shield, or multiple layers of shields, that run the length of the bundle and geometrically surrounds the conductors in the bundle.

System - A composite of equipment, subsystems, skilled personnel, and techniques capable of performing or supporting a defined operational role (MIL-STD-464C definition). With respect to hardware, "system" refers to top level platform (ship, aircraft, fixed station, ground vehicle).

Subsystem – One or more integrated equipment items interfaced within a system or platform to perform a top level function.

2. THE ELECTROMAGNETIC ENVIRONMENTS

The baseline system level electromagnetic environment for military ground vehicles is specified in MIL-STD-464C. This standard contains a "main body" which states a baseline set of requirements and electromagnetic environments that systems are exposed to. It also contains an appendix which provides rationale, guidance, and lessons learned for each requirement to enable the procuring activity to tailor the baseline requirements for a particular situation. Further guidance on specific tailoring of the environment is provided in MIL-HDBK-235-1C. In general, the system level environments presented in MIL-STD-461C are "worst case". Often, after consideration of mission, platform locations and the critically of equipment, subsystem or system survival and operational needs with trade-offs centered around weight, cost and procurement schedule, the procuring agency may present only a subset of the requirements as being applicable. As an example, with respect to the nearby lightning threat (the baseline threat is specified with a 10 meter distance), MIL-STD-464C states: "Many ground systems can accept some risk that the system operates only after a moderate lightning strike at a reasonable distance. For example, a requirement for equipment in a tactical shelter to survive a 90th percentile lightning strike at 50 m may represent a reasonable risk criteria for that shelter. This type of requirement would result in a high level of general lightning protection at a reduced design and test cost.

2.1 Semantics

Per MIL-STD-464C, the term "system" refers to a composite of equipment, subsystems, skilled personnel, and techniques capable of performing or supporting a defined operational role. With respect to hardware, "system" refers to top level platform (ship, aircraft, fixed station, ground vehicle). This is how "system" will be used in this endeavor.

MIL-STD-461C defines a "subsystem" as a collection of devices or equipments designed and integrated to function as a single entity. A military vehicle may contain several subsystems, examples including a power distribution subsystem, a satellite radio navigation subsystem, a high frequency communication radio subsystem, an engine control system and a fire control subsystem. The subsystem not only includes equipment, but cables as well. Platform or facility cables and their associated connectors are often referred to as a subsystem by themselves –"cable/connector assemblies" with be used to describe this type of asset.

Subsystems contain integrated equipment items interfaced within a system or platform with specific cabling. An "equipment item" typically refers to a Line Replaceable Unit (LRU) that receives operating power, signal I/O and control functions via platform or facility wiring and is designed perform a specific function or task, and which can typically be procured as a stand-alone item.

Equipment may contain "modules", which may be line or field replaceable entities. When considering electromagnetic environments, "modules" are notably different than "equipment items" in that they often do not mechanically interface directly with the system platform or facility equipment racks, but rather interface to a host equipment item which may provide it conditioned power, filtered signal I/O, and/or electromagnetic shielding. Because of this, modules typically cannot easily be tested by themselves in an electromagnetic environment derived from the system level electromagnetic environment. Hence the lowest level EMI compliance verification, and requirements for procurement, typically occur at the equipment item level. It is very important to delineate these levels of distinction as this will drive how the system level environment is modeled to various parts of the system, especially when procurement of equipment, cables and modules is considered.

2.2 Ground Vehicle System Electromagnetic Environments

The baseline electromagnetic environment seen by ground vehicle systems is presented in MIL-STD-464C. The environments include those in which the source is from within the system as well as those that are sourced from outside the system. Each is described below, noting the absolute threat levels may be tailored by the procuring activity based on system location, mission profile and other previously mentioned trade-offs.

2.2.1 Radiated Radio Frequency (RF) Electromagnetic Environment (RF EME)

Radio and radar transmitters can present very high levels of energy and electromagnetic field strength to a system and the equipment and subsystems it contains. This type of environment is referred to as the external Radio Frequency (RF) Electromagnetic Environment (EME). RF EME is described in terms of field strength as a function of frequency. Table 4 in MIL-STD-464C presents the RF EME applicable to ground systems. This table represents typical worst-case fields strengths that may be present in the area in which a ground system is operating. The sources of these electromagnetic fields is radiation from transmitter antennas of known radios used for communication, navigation and surveillance.

If a ground vehicle were to be operated on a ship deck, the baseline levels in table 1 of MIL-STD-461C may apply as well.

Typically, the vehicle / platform structure provides some (6 to 20 dB) attention of this environment with respect to subsystems and equipment contained within.

2.2.2 Electromagnetic Pulse (EMP)

MIL-STD-464C states: "*The system shall meet its operational performance requirements after being subjected to the EMP environment. This environment is classified and is currently defined in MIL-STD-2169. This requirement is applicable only if invoked by the procuring activity. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.*" Note that MIL-STD-2169 is a classified document. Often, if the EMP environment is applicable, subsystem and equipment specifications will contain detailed requirements with respect to required recovery time and output and actions during the recovery period. As an example, a mission display may be required to recover within 40 seconds after the EMP event and must never provide misleading or non-current data. The terms High-altitude Electromagnetic Pulse (HEMP) and Nuclear Electromagnetic Pulse (NEMP) are often synonymous with the term "EMP."

2.2.3 Lightning Effects

MIL-STD-464C presents aspects of the lightning environment that are relevant for designing protection against the direct effects lightning. "Direct effects" refers to the situation were the lightning channel attaches to the system. Also provided are aspects of the lightning environment associated with a direct strike that are relevant for protecting the platform from indirect effects. Based on the electrical characteristics of the platform or facility, the direct effects environment will induce currents into wires, cables and cable bundles inside the platform or facility as well as produce voltages at equipment connector pins. Thus indirect effects particulars can vary considerably between platforms and facilities and between locations within a platform or facility.

Indirect effects particulars for civil aircraft subsystems and equipment are typically determined by detailed testing, often on scale models or representative production sections of aircraft containing proposed cable assemblies. For subsystems and equipment on ships, ground platforms, ground facilities, and often military aircraft, generic “catch-all” equipment and subsystem standards, such as ANSI C62.14, IEC 61000-4 and -5 and CS115 and CS116 from MIL-STD-461F, are used to define the indirect effects environment as present at cable assemblies and/or connector pins.

2.2.4 High Power Microwave (HPM)

MIL-STD-464C notes the existence of hostile radio frequency environments produced by microwave sources (weapon) capable of emitting high power or high energy densities. The weapon may produce, and direct at the system (e.g. ground vehicle), microwaves in the form of a single pulse, repetitive pulses, pulses with complex modulation, or continuous wave (CW) characteristics.

MIL-STD-464C (section 5.4) states the following about HPM: “*The system shall meet its operational performance requirements after being subjected to the narrowband and wideband HPM environments. Applicable field levels and HPM pulse characteristics for a particular system shall be determined by the procuring activity based on operational scenarios, tactics, and mission profiles using authenticated threat and source data such as the Capstone Threat Assessment Report. This requirement is applicable only if specifically invoked by the procuring activity. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.*”

The details of the HPM sources are generally classified. MIL-HDBK-235-8 (Classified) provides information on HPM threats. Appendix A.5.4 in MIL-STD-464C provides methods to compute resulting threat levels from a given HPM threat at a particular distance from the threat’s victim.

IEC 61000-2-13 defines a set of typical radiated and conducted High Power Electromagnetic (HPEM) environment waveforms that may be encountered from an intentional generator targeting a civilian facility. IEC 61000-4-35 provides information about existent system-level HPEM simulators and their applicability as test facilities and validation tools for HPEM immunity testing. The terms Ulta Wideband (UWB) and High-Power Electromagnetic (HPEM) used in IEC 61000-2-13 are generally synonymous with the term HPM as used in military standards.

2.2.5 Electrostatic Discharge

MIL-STD-464C defines an Electrostatic Discharge (ESD) environment for electrical and electronic subsystems as an 8 kV contact discharge or a 15 kV air discharge. In both cases the discharge capacitance is 150 pF and the discharge resistance is 330 ohm, with the circuit inductance not to exceed 5 microhenry. This environment, as a worst case, is thus assumed to be present at equipment and cable assemblies. Although requirements for compliance testing to these exact requirements is typically not present in subsystem and equipment procurement documents, the intent is absorbed in other subsystem and equipment level EMI control compliance requirements.

2.2.6 Internally Generated Electromagnetic Energy

MIL-STD-464C requires that the electromagnetic environment generated by equipment and subsystem is required to be controlled per MIL-STD-461. MIL-STD-461 places limits on conducted and radiated emissions from equipment and systems. These limits are generally designed to protect system radio receivers from interference that may enter via the radio's antenna located within the system. Interference present at equipment and associated cables from energy unintentionally radiated and conducted from other nearby equipment is typically orders of magnitude less what is seen from the environments described in 2.3.1 through 2.3.5 above.

2.3 Electromagnetic Environment for Ground Vehicle Subsystems and Equipment

Figure 2.3-1 is a diagram illustrating how the system level electromagnetic threat environments described in section 2.2 above flow down to subsystems, equipment and associated cables.

From a procurement standpoint, the vehicle or platform is specified to exhibit electromagnetic compatibility (EMC) per a system level standard, such as MIL-STD-464C. With respect to immunity from the threats described in 2.2 above, compliance is verified typically by limited testing at the system level. Application of the complete threat environments as described in MIL-STD-464C is impractical. However, it is practically possible to set limits and demonstrate electromagnetic control compliance at the equipment and subsystem level. Hence MIL-STD-464C states: "*Individual subsystems and equipment shall meet interference control requirements (such as the conducted emissions, radiated emissions, conducted susceptibility, and radiated susceptibility requirements of MIL-STD-461) so that the overall system complies with all applicable requirements of this standard. Compliance shall be verified by tests that are consistent with the individual requirement (such as testing in accordance with MIL-STD-461).* " Thus equipment and subsystems, with their associated cables, are procured with the requirement to comply, with verification by test and/or analysis, to an equipment/subsystem EMI control standard, such as MIL-STD-461F.

MIL-STD-461F essentially condenses the many complex and extensive collection of external and internally generated electromagnetic threats present at the system or platform level and consolidates them into a practical set of generic requirements that can be economically tested and analyzed at the subsystem and equipment levels. The limits in MIL-STD-461F do consider a small amount of shielding and threat attenuation that may be provided by the host platform. For instance, the generic RF E-field radiated susceptibility requirement (RS103) for army ground equipment and associated cabling is 50 V/m from 30 MHz to 18 GHz, using 1 kHz, 50% duty cycle pulse modulation. This is notably different than the external EME stated for ground systems shown in MIL-STD-464. This is illustrated in figure 2.3-2. As seen in figure 2.3-2 the MIL-STD-464C EME threat for ground vehicles contains many different frequency ranges, each containing a different type of modulation, and with high peak field strength levels. Note that the 50 V/m MIL-STD-461F requirement also considers the internal threats, such as RF produced by on-board radio antennas, to equipment. It is also important to note that testing systems, and large subsystems and equipment to the MIL-STD-464C levels is costly, as generally any swept frequency radiated E-field environment with peaks and/or averages greater than 600 V/ and 200 V/m, respectively, is considered very expensive to produce for testing items larger than a breadbox.

The following sections describe influencing factors, tailoring considerations, and the interference model for each of the five MIL-STD-461F electromagnetic environments that may be applicable to susceptibility via cables in ground vehicles.

SCOPE OF THIS EFFORT

(SOW in Appendix A)

Ground Vehicle External Electromagnetic Environment → Attenuation & waveform altering by the Vehicle → Consolidated Subsystem & Equipment Requirements per MIL-STD-461F → Cables Connected to Equipment subject to MIL-STD-461F immunity requirements

Ground Vehicle External Electromagnetic Environment

Described in MIL-STD-464C w/tailoring per procurement specification

- RF EME
- EMP
- Lightning
- HPM
- ESD
- Internal EMI

Actual levels depend on type of system and intended mission environment … several curves and tables presented in MIL-STD-464C.

MIL-STD-464C RF EME levels are “worst case”. Need to be in the beam of the higher frequency sources to obtain full exposure level.

Attenuation & waveform altering by the Vehicle

Large amounts of shielding (> 20 dB) is not typical due to vehicle operation with open doors and hatches and other large openings.

Vehicle structure elements and material typically reduce many threat levels, as seen by subsystems and equipment, by 6 to 20 dB.

Vehicle structure also alters the time and frequency domain characteristics of the external environment as seen by equipment and cables.

Per the vehicle’s mission, exposure to full threat levels may be very unlikely.

Due the broad frequency content and relatively high frequencies contained in the energy of the EM environments, along with the relatively large electromagnetic volume occupied by the vehicle, brute force modeling/simulation of the external environments to cables and equipment at the platform level is not practical with today’s modeling and simulation technology.

Consolidated Subsystem & Equipment Requirements per MIL-STD-461F

- Conducted Susceptibility – RF (CS114)
- Conducted Susceptibility – Impulse Excitation (CS115)
- Conducted Susceptibility – Damped Sinusoidal Transients (CS116)
- Radiated Susceptibility – RF Electric Field (RS103)
- Radiated Susceptibility – Transient Electromagnetic Field (RS105)

Most of the requirements have several limits …. The applicable limit depends on location of subsystem, equipment and cables.

Standardized test setups to allow testing (and simulation & analysis) of subsystems and equipment in a laboratory environment.

Limits consider test setup specifics in the translation from the system environment to the testable subsystem and equipment environments/ requirements.

Limits are based on history and demonstrated performance on existing platforms.

Limits may be tailored … if direct exposure to particular threat is expected and immunity is a “must always have”, MIL-STD-461F requirements may be tailored upward to the full threat level.

Cables Connected to Equipment subject to MIL-STD-461F immunity requirements

MIL-STD-461F requires compliance with installation representative cables and grounding/bonding.

Cables placed 5 cm above a ground plane bench.

Limits placed on the length of representative cable to allow a standard and repeatable method of compliance verification.

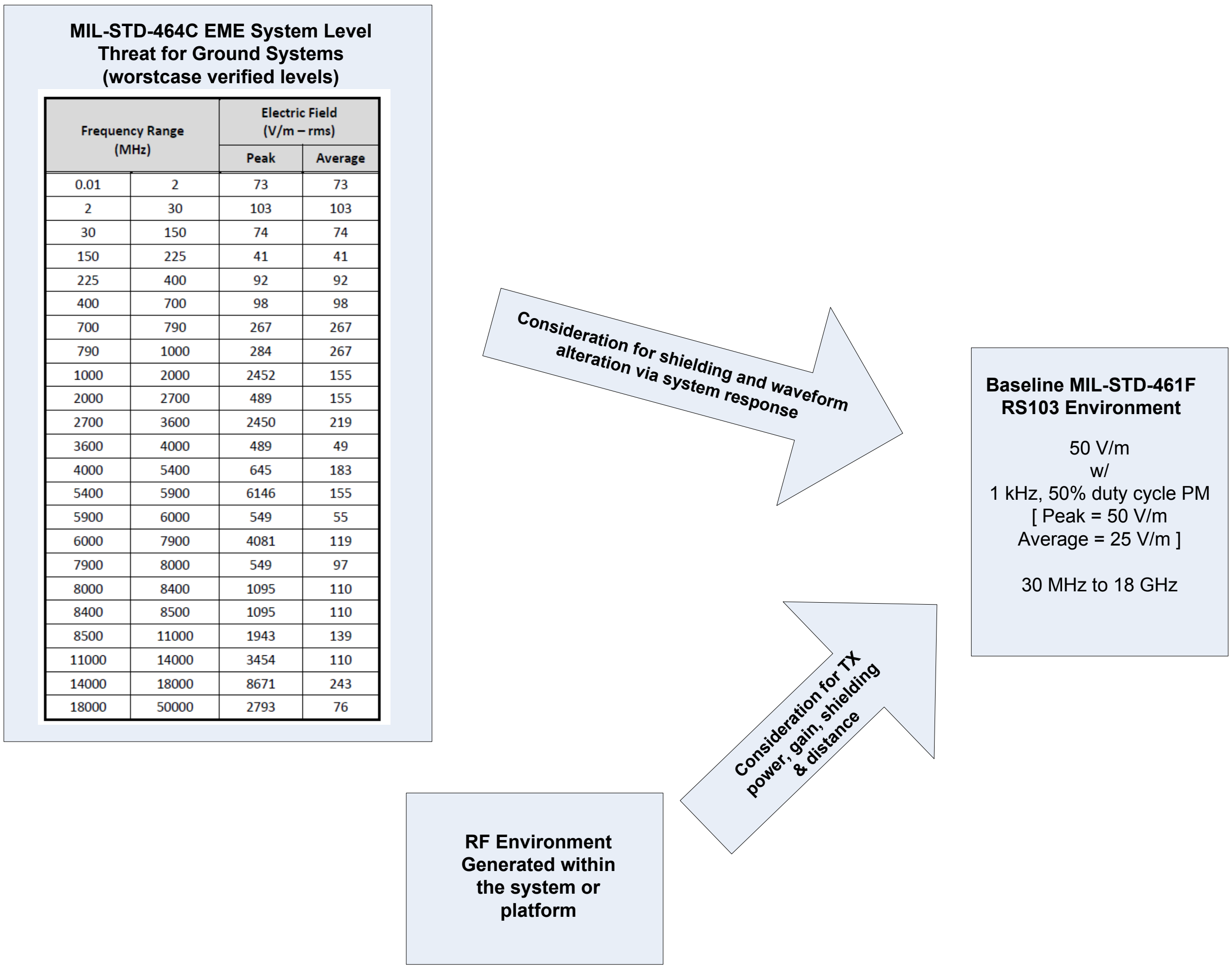
Signal lines must be loaded per Interface Control Document (ICD).

Power lines connect to standard network.

Susceptibility occurs when interference coupled into victim circuits via cables and wires appears at intolerable or damaging levels.

State-of-the-art electromagnetic modeling technology and simulation tools allow prediction of circuit interference levels from MIL-STD-461F environments.

Figure 2.3-1. Flow-down of System Level Electromagnetic Threats to Equipment, Subsystems and Cables



Frequency Range (MHz)		Electric Field (V/m – rms) Peak	Average
0.01	2	73	73
2	30	103	103
30	150	74	74
150	225	41	41
225	400	92	92
400	700	98	98
700	790	267	267
790	1000	284	267
1000	2000	2452	155
2000	2700	489	155
2700	3600	2450	219
3600	4000	489	49
4000	5400	645	183
5400	5900	6146	155
5900	6000	549	55
6000	7900	4081	119
7900	8000	549	97
8000	8400	1095	110
8400	8500	1095	110
8500	11000	1943	139
11000	14000	3454	110
14000	18000	8671	243
18000	50000	2793	76

Figure 2.3-2. Origin of Baseline MIL-STD-461F RS103 Requirement Applicable to Ground System Equipment

2.3.1 Conducted Susceptibility - RF – CS114 Environment Model

The CS114 environment involves injection of RF over the frequency range of 10 kHz to 200 MHz on to all cables bundles[1], as well as the power cable without the return and ground conductors, in turn, using a current transformer injection probe. Injection occurs 10 cm from the equipment connector. The system level RF EME environment, and the internal system / platform transmitters and electrical equipment, produce the CS114 threat described in MIL-STD-461F at cables connecting to equipment and subsystems. The CS114 requirement is stated in terms of induced cable current from a source with a specified impedance and a limited power output capability. Figure 2.3.1-1 shows baseline CS114 limits. Figure 2.3.1-2 shows limit applicability as a function of platform type. From figure 2.3.1-2, we see that for Army ground platforms, curve 3 and curve 4 are applicable for the 10 kHz to 2 MHz and the 2 MHz to 200 MHz frequency ranges, respectively.

[1] Includes power cables/bundles containing all applicable return and ground conductors.

The levels noted in figure 2.3.1-1 are to be applied to cable bundles that are representative of the intended installation, as documented in the Interface Control Document (ICD), vehicle wiring diagrams, and/or the equipment installation manual. "Representative" equates to identical cable and wire cross-section, identical or electromagnetically equivalent connector assemblies, identical wire and cable shield properties (if shielding is applicable), and identical shield and wiring termination, routing, and grounding at the connectors.

The equipment subject to the CS114 environment must be electrically bonded to the copper bench in a manner that represents how it is bonded (or not bonded) to the host platform. Key quantities to consider in equipment bonding include DC resistance, contact locations, bonding conductor material and geometry (if applicable), and the amount of surface area at bond between conductive surfaces.

The MIL-STD-461F CS114 requirements are also normalized to a condition where the cables under test are placed 5 cm above a conductive ground plane bench. Length may be limited to 10 meters if the installation cable is longer than 10 meters. If the length is unknown, a compliant default length of 3 meters is typically used, as this allows compliance to other baseline conditions stated in elsewhere in MIL-STD-461F.

The cables must also be terminated with loads to simulate the electrical properties (impedance, grounding, balance, and so forth) present in the actual installation.

Power leads are to be between 2 and 2.5 meters long and terminated into a line impedance stabilization network (LISN). Figure 2.3.1-3 shows a schematic of the LISN. The purpose of the LISN is to provide a standardized platform-representative power system impedance to the equipment or subsystem being tested or analyzed.

As noted in MIL-STD-461F, the limits are derived from measurements made on platforms that were basically electrically conductive, but not designed to have intentionally shielded volumes. Also, as noted in MIL-STD-461F, the platform can be illuminated with a low level version of the EME threats while monitoring induced levels on cables, scaling the measured levels by the same factor used for the EME threat to determine the expected levels to tailor the baseline requirements.

MIL-STD-461F presents specific requirements for the application of the CS114 environment to cables and leads – proper attention to these details will assure correct translation of the system environment to the cable/connector assemblies. Figure 2.3.1-4 describes the CS114 environment in terms of an electrical model with equations that can be used to simulate the environment as applied to cable bundles, and to power cables with power returns and grounds excluded.

Note that figure 2.3.1-4 contains three schematics. The first is for the establishment of the reference maximum interference power from the environment source that could be coupled to the cable bundle of interest. The second two schematics represent the interference as applied to the cable bundle or cable of interest. If the cable bundle has a gross over-shield (often implemented with a MIL QQB575R braid shield and thus referred to as a "gross overbraid shield"), then injection of the interference would be viewed as direct coupling to the over-shield conductor only. Characteristics of the over-shield will determine coupling from it to the conductors it covers.

The third schematic in figure 2.3.1-4 applies to cable bundles and cables that do not contain a gross over-shield. In this case, each conductor, or the shields on the shielded cables, would be subjected to the direct injection of the environment. The total bundle injected current would divide amongst the outer conductors based on their terminating impedances and other electrical characteristics.

Per the equations in figure 2.3.1-4, the environment model essentially applies current to a cable bundle or power cable less the returns and grounded conductors, through an injection probe driven by a source initially set to produce the current indicated in figure 2.3.1-1 into a 100 Ohm loop, with that source level being reduced, if required, to the point where the resulting cable bundle current is limited to twice the figure 2.3.1-1 current. It should be noted that the aforementioned levels are peak detected, but stated as the rms value of a continuous sinewave having that peak level. The CS114 RF is 1 kHz pulse modulated with a 50% duty cycle. The injection probe model shown in figure 2.3.1-4 produces an insertion loss that is compliant to the MIL-STD-461F requirements.

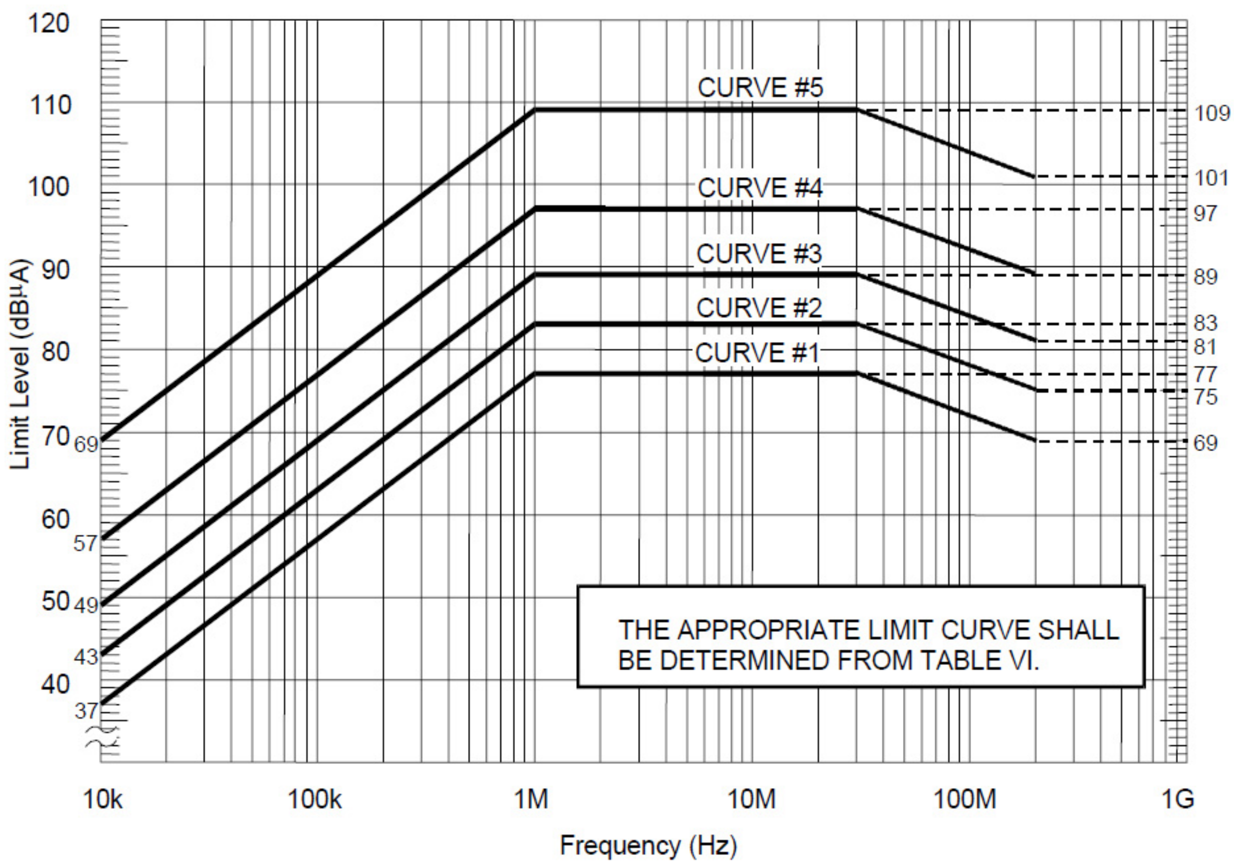


Figure 2.3.1-1. CS114 Current Limits

		LIMIT CURVE NUMBERS SHOWN IN FIGURE CS-114-1 AND LIMITS							
PLATFORM / FREQUENCY RANGE		AIRCRAFT (EXTERNAL OR SAFETY CRITICAL)	AIRCRAFT INTERNAL	ALL SHIPS (ABOVE DECKS) AND SUBMARINES (EXTERNAL)*	SHIPS (METALLIC) (BELOW DECKS)	SHIPS (NON METALLIC) (BELOW DECK)**	SUBMARINE (INTERNAL)	GROUND	SPACE
4 kHz to 1MHz	N	-	-	77 dBμA	77 dBμA	77 dBμA	77 dBμA	-	-
10 kHz to 2 MHz	A	5	5	2	2	2	1	3	3
	N	5	3	2	2	2	1	2	3
	AF	5	3	-	-	-	-	2	3
2 MHz to 30 MHz	A	5	5	5	2	4	1	4	3
	N	5	5	5	2	4	1	2	3
	AF	5	3	-	-	-	-	2	3
30 MHz to 200 MHZ	A	5	5	5	2	2	2	4	3
	N	5	5	5	2	2	2	2	3
	AF	5	3	-	-	-	-	2	3

KEY: A = Army
N = Navy
AF = Air Force

* For equipment located external to the pressure hull of a submarine but within the superstructure, use SHIPS (METALLIC) (BELOW DECKS)

** For equipment located in the hanger deck of Aircraft Carriers

Figure 2.3.1-2. CS114 Limit Curve Applicability

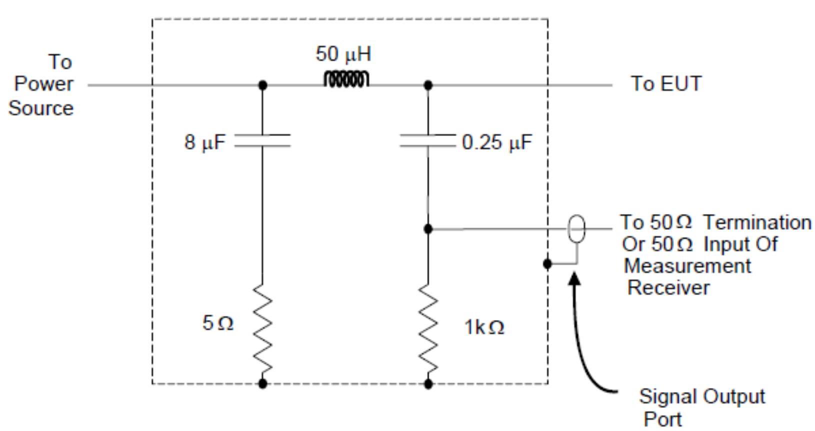


Figure 2.3.1-3. MIL-STD-461F Power Line Impedance Stabilization Network (LISN)

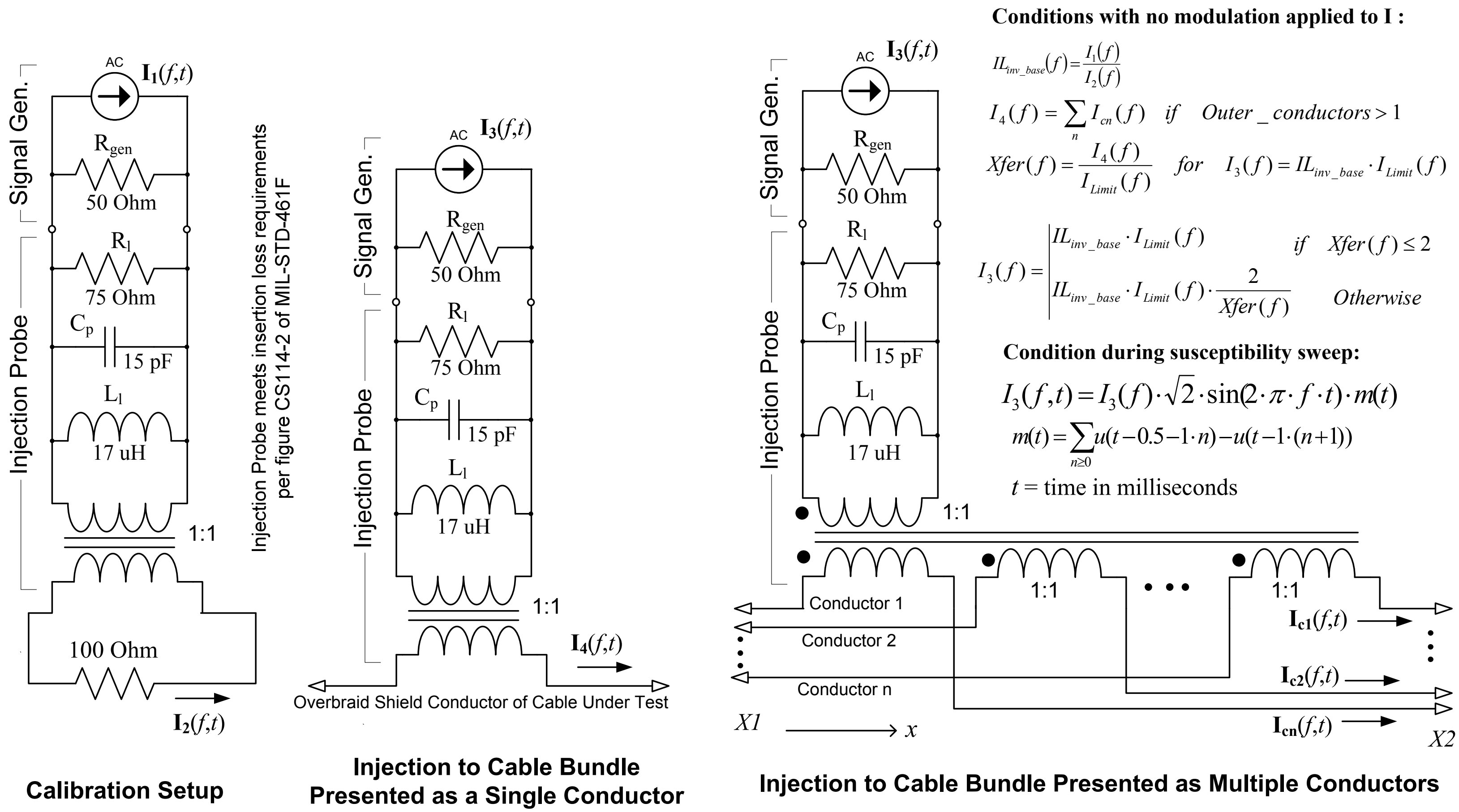


Figure 2.3.1-4. CS114 Environment Model

2.3.2 Conducted Susceptibility – Bulk Cable Injection, Impulse Excitation – CS115 Environment Model

The CS115 environment involves injection of fast transition time pulses on to cable bundles[2] as well power cables with power returns and grounds excluded. The CS115 environment presents transients at the platform's cables that may be expected to result from the external lighting, certain HPM environments and EMP environments, as well as transients from platform switching operations and equipment/subsystem ESD. The CS115 excitation is a trapezoid pulse at the generator output; the actual waveform on the cable bundle or cable will be dependent on natural resonance conditions associated with cable and characteristics of the interfacing circuits.

Since this requirement is transient in nature, it may be acceptable from a system performance standpoint if desired signals are overcome with the transient, as response smoothing, signal processing and/or data error correction may make the incident transparent to the user. This must be considered before drawing conclusions from a simulation of the application of the CS115 environment to cable bundles, and power cables with returns and grounds excluded.

CS115 is applied to cable bundles and power cables with returns and grounds excluded using an injection probe (current transformer). Figure 2.3.2-1 shows the CS115 current waveform that would be present in a 100 Ohm calibration loop if the injection probe had a flat frequency response. Realistically, the current pulse in the 100 Ohm calibration loop would appear as shown in figure 2.3.2-2 (from MIL-STD-461F). The calibration pulse is considered compliant if the peak current is equal to 5 Amperes and the rise and fall times are no greater than 2 nanoseconds, as shown in figure 2.3.2-2.

After the transient generator is adjusted to produce a compliant pulse into a 100 Ohm loop, the injection probe is moved to each cable bundle, and then to each power cable with returns and grounds excluded, in turn, to allow application of the reference transient. The cable bundles must be representative of the intended installation. "Representative" equates to identical cable and wire cross-section, identical or electromagnetically equivalent connector assemblies, identical wire and cable shield properties (if shielding is applicable), and identical shield and wiring termination, routing, and grounding at the connectors.

The equipment subject to the CS115 environment must be electrically bonded to the copper bench in a manner that represents how it is bonded (or not bonded) to the host platform. Key quantities to consider in equipment bonding include DC resistance, contact locations, bonding conductor material and geometry (if applicable), and the amount of surface area at bond between conductive surfaces.

The MIL-STD-461F CS115 requirements are also normalized to a condition where the cables under test are placed 5 cm above a conductive ground plane bench. Length may be limited to 10 meters if the installation cable is longer than 10 meters. If the length is unknown, a compliant default length of 3 meters is typically used, as this allows compliance to other baseline conditions stated in MIL-STD-461F.

The cables must also be terminated with loads to simulate the electrical properties (impedance, grounding, balance, and so forth) present in the actual installation.

Power leads are to be between 2 and 2.5 meters long and terminated into a line impedance stabilization network (LISN). Figure 2.3.1-3 shows a schematic of the LISN. The purpose of the LISN is to provide a platform representative power system impedance to the equipment or subsystem being tested or analyzed.

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[2] Includes power cables/bundles containing all applicable return and ground conductors.

The CS115 pulses are to be applied at a 30 Hz rate for one minute to ensure that a sufficient number of pulses are applied to provide confidence that the equipment will not be upset.

MIL-STD-461F presents specific requirements for the application of the CS115 environment to cables bundles and power cables without returns and grounds – proper attention to these details will assure correct translation of the system environment to the cable/connector assemblies.

Figure 2.3.2-3 describes the CS115 environment in terms of an electrical model with equations that can be used to simulate the environment as applied to cable bundles, and to power cables with power returns and grounds excluded.

Note that figure 2.3.2-3 contains three schematics. The first is for verification that the CS115 source can produce the required transient into a 100 Ohm loop. The second two schematics represent the interference as applied to the cable bundle of interest. If the cable bundle has a gross over-shield (often implemented with a MIL QQB575R braid shield and thus referred to as a "gross overbraid shield"), then injection of the interference would be viewed as direct coupling to the over-shield conductor only. Characteristics of the over-shield will determine coupling from it to the conductors it covers.

The third schematic in figure 2.3.2-3 applies to cable bundles that do not contain a gross over-shield. In this case, each conductor, or the shields on the shielded cables, would be subjected to the direct injection of the environment. The total bundle injected current would divide amongst the outer conductors based on their terminating impedances and other electrical characteristics.

Per the equations in figure 2.3.2-3, the environment model essentially applies current to a cable bundle or power cable less the return and ground conductors, through an injection probe driven by a source initially set to produce the current pulse shown in figure 2.3.2-2 into a 100 Ohm loop. The injection probe model shown in figure 2.3.2-3 is compliant to the MIL-STD-461F requirements as it produces a transient current into a 100 Ohm loop with the specified transition time, pulse width and peak amplitude. The circuit model of the probe represents the Solar EMC 9142-1N injection probe.

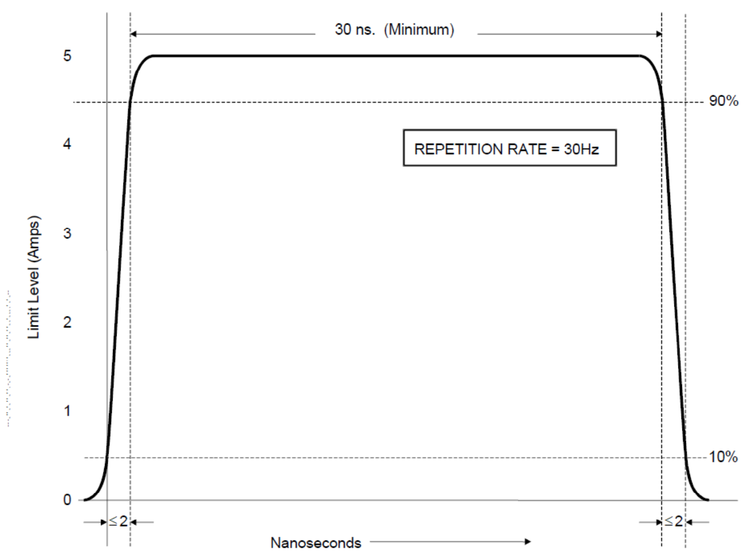


Figure 2.3.2-1. CS115 Pulse Waveform

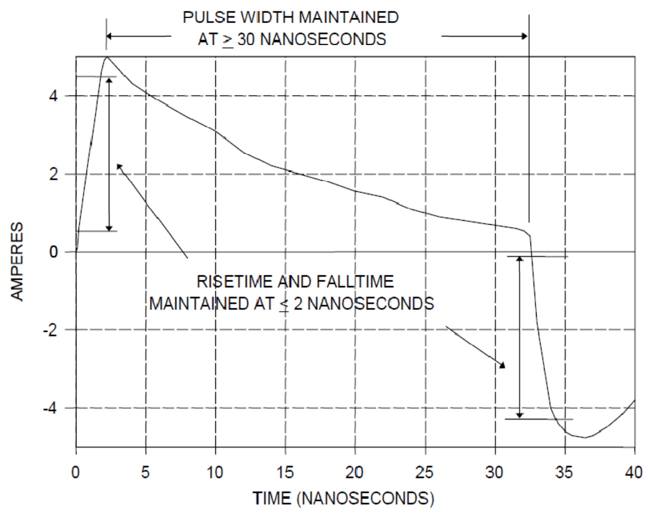


Figure 2.3.2-2. Compliant Injected CS115 Pulse Waveform in to 100 Ohm Loop

DRAFT IN PROGRESS

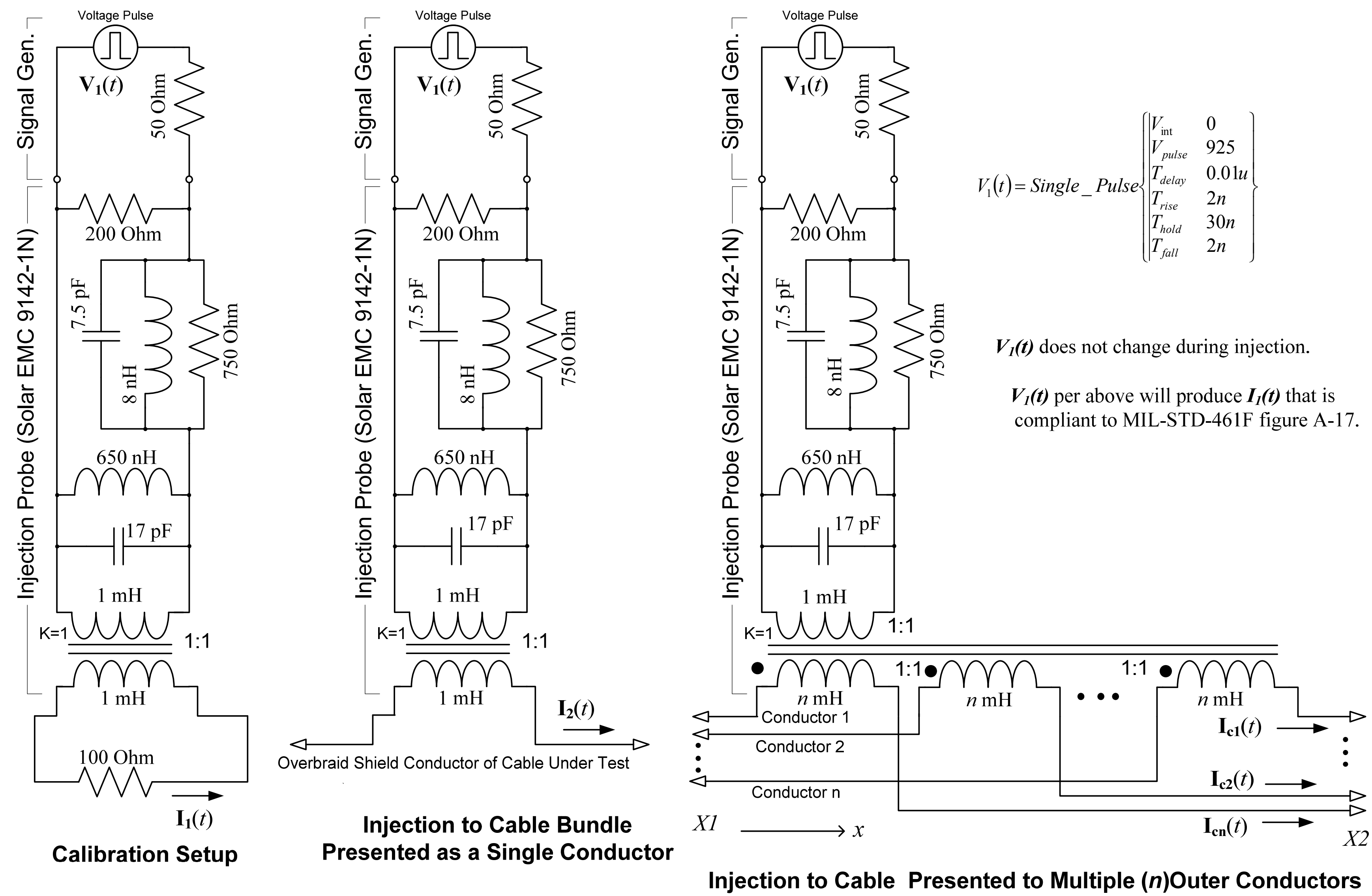


Figure 2.3.2-3. CS115 Environment Model

2.3.3 Conducted Susceptibility – Damped Sinusoidal Transients – CS116 Environment Model

The CS116 environment involves injection of damped sinusoidal transients over the frequency range of 10 kHz to 100 MHz on to all cables bundles[3], the power cables by themselves, as well as individual high side power leads, in turn, using a current transformer injection probe. The CS116 environment simulates electrical current and voltage waveforms occurring in platforms from excitation of natural resonances. (In contrast, CS115 excites natural resonances.) Damped sinusoidal waveforms are a common occurrence on platforms from both external stimuli such as lightning and EMP, and from platform electrical switching phenomena. Waveforms appearing on cables can be due to the cable itself resonating or due to voltage and current drives resulting from other resonances on the platform. Wide frequency coverage (10 kHz to 100 MHz) is included in the base environment to account for a wide range of possible conditions.

Since this requirement is transient in nature, it may be acceptable from a system performance standpoint if desired signals are overcome with the transient, as response smoothing, signal processing and/or data error correction may make the incident transparent to the user. This must be considered before drawing conclusions from a simulation of the application of the CS116 environment to cable bundles, power cables and individual high side power leads.

Figure 2.3.3-1 shows the required damp sinusoid current waveform as present when injected into a 100 Ohm loop. Figure 2.3.3-2 presents the limit values for I_p. Typically, evaluation by test is performed at 10 kHz, 100 kHz, 1 MHz, 3 MHz, 10 MHz, 30 MHz and 100 MHz.

The damped sinusoid waveforms are to be applied to cable bundles that are representative of the intended installation. "Representative" equates to identical cable and wire cross-section, identical or electromagnetically equivalent connector assemblies, identical wire and cable shield properties (if shielding is applicable), and identical shield and wiring termination, routing, and grounding at the connectors.

The equipment subject to the CS116 environment must be electrically bonded to the copper bench in a manner that represents how it is bonded (or not bonded) to the host platform. Key quantities to consider in equipment bonding include DC resistance, contact locations, bonding conductor material and geometry (if applicable), and the amount of surface area at bond between conductive surfaces.

The MIL-STD-461F CS116 requirements are also normalized to a condition where the cables under test are placed 5 cm above a conductive ground plane bench. Length may be limited to 10 meters if the installation cable is longer than 10 meters. If the length is unknown, a compliant default length of 3 meters is typically used, as this allows compliance to other baseline conditions stated in MIL-STD-461F.

The cables must also be terminated with loads to simulate the electrical properties (impedance, grounding, balance, and so forth) present in the actual installation.

Power leads are to be between 2 and 2.5 meters long and terminated into a line impedance stabilization network (LISN). Figure 2.3.1-3 shows a schematic of the LISN. The purpose of the LISN is to provide a platform representative power system impedance to the equipment or subsystem being tested or analyzed.

As noted in MIL-STD-461F, the limits are set at levels that cover most induced levels found in platforms during system-level testing to external transient environments.

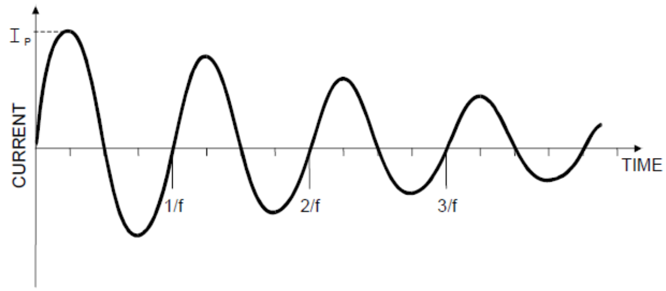
[3] Power cables to be include in the bundle if present with other cables using the same connector.

MIL-STD-461F presents specific requirements for the application of the CS116 environment to cable bundles, power cables and high side power leads – proper attention to these details will assure correct translation of the system environment to the cable/connector assemblies. Figure 2.3.3-3 describes the CS116 environment in terms of an electrical model with equations that can be used to simulate the environment as applied to cable bundles, power cables and high side power leads.

Note that figure 2.3.3-3 contains three schematics. The first is for the establishment of the source characteristics that will produce the required damped sinusoid current pulse into the base 100 Ohm calibration loop. The second two schematics represent the interference as applied to the cable bundle of interest. If the cable bundle has a gross over-shield (often implemented with a MIL QQB575R braid shield and thus referred to as a "gross overbraid shield"), then injection of the interference would be viewed as direct coupling to the over-shield conductor only. Characteristics of the over-shield will determine coupling from it to the conductors it covers. The second schematic in figure 2.3.3-3 is also applicable to individual high side power leads.

The third schematic in figure 2.3.3-3 is applicable to a multiple conductor cable bundle that does not contain a gross over-shield. In this case, each conductor, or the shields on the shielded cables that make up the outer conductors of the cable bundle, would be subjected to the direct injection of the environment. The total bundle injected current would divide amongst the outer conductors based on their terminating impedances and other electrical characteristics.

Per the equations in figure 2.3.3-3, the environment model essentially applies current to a cable bundle, a power cable, or an individual lead, through an injection probe, driven by a source initially set to produce the current waveform described in figures 2.3.3-1 and 2.3.3-2 into a 100 Ohm loop. That source level is reduced, if required, to the point where the resulting peak cable bundle, cable or lead current is limited to the value shown figure 2.3.3-2. The injection probe model shown in figure 2.3.3-3 produces an insertion loss that is compliant to the MIL-STD-461F requirements and is representative of what would be expected to be used in an EMI test lab. The circuit model of the probe represents the ETS Lindgren models 95236-1 and 95242-1 injection probes.



NOTES: 1. Normalized waveform: $e^{(\pi f t)/Q} \sin(2\pi ft)$

Where:
f = Frequency (Hz)
t = Time (sec)
Q = Damping factor, 15±5

2. Damping factor (Q) shall be determined as follows:

$$Q = \frac{\pi(N - 1)}{\ln(I_P/I_N)}$$

Where:
Q = Damping factor
N = Cycle number (i.e. N = 2, 3, 4, 5,...)
I_P = Peak current at 1st cycle
I_N = Peak current at cycle closest to 50% decay
ln = Natural log

3. I_P as specified in Figure CS116-2

Figure 2.3.3-1. CS116 Waveform

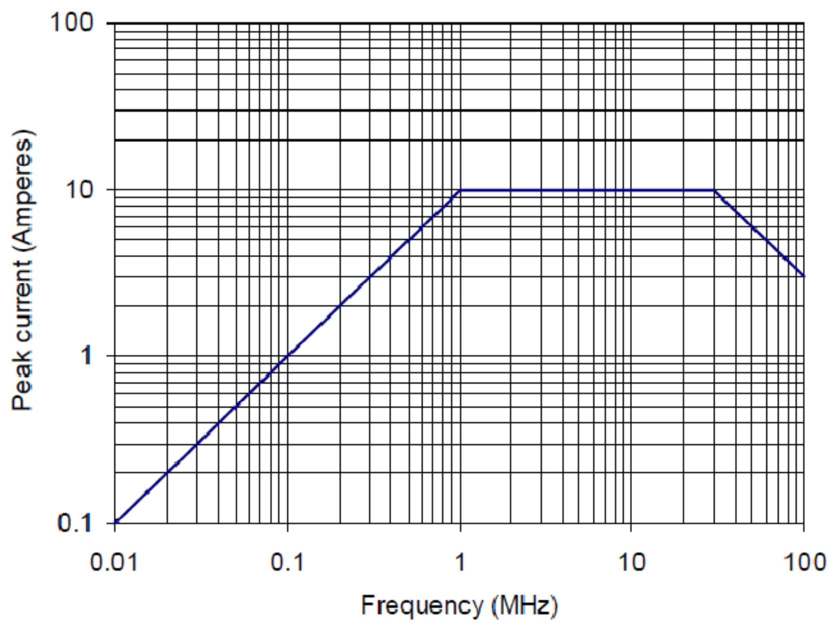
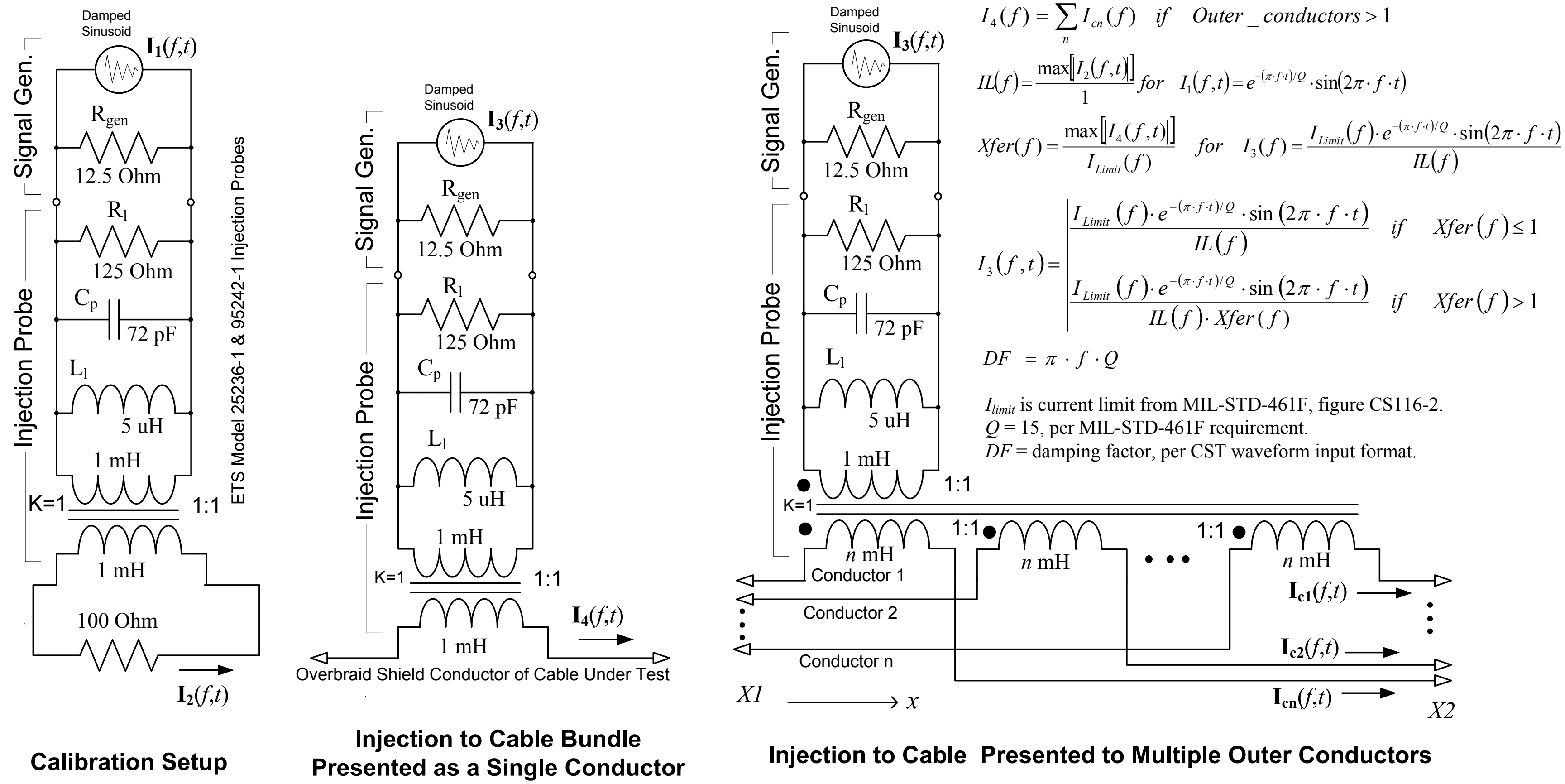


Figure 2.3.3-2. CS116 Ip Limit



$$I_4(f) = \sum_n I_{cn}(f) \quad if \quad Outer\_conductors > 1$$

$$IL(f) = \frac{\max\left[I_2(f,t)\right]}{1} \; for \quad I_1(f,t) = e^{-(\pi \cdot f \cdot t)/Q} \cdot \sin(2\pi \cdot f \cdot t)$$

$$Xfer(f) = \frac{\max\left[I_4(f,t)\right]}{I_{Limit}(f)} \quad for \quad I_3(f) = \frac{I_{Limit}(f) \cdot e^{-(\pi \cdot f \cdot t)/Q} \cdot \sin(2\pi \cdot f \cdot t)}{IL(f)}$$

$$I_3(f,t) = \begin{cases} \dfrac{I_{Limit}(f) \cdot e^{-(\pi \cdot f \cdot t)/Q} \cdot \sin(2\pi \cdot f \cdot t)}{IL(f)} & if \quad Xfer(f) \le 1 \\ \dfrac{I_{Limit}(f) \cdot e^{-(\pi \cdot f \cdot t)/Q} \cdot \sin(2\pi \cdot f \cdot t)}{IL(f) \cdot Xfer(f)} & if \quad Xfer(f) > 1 \end{cases}$$

$$DF = \pi \cdot f \cdot Q$$

I_{limit} is current limit from MIL-STD-461F, figure CS116-2.
Q = 15, per MIL-STD-461F requirement.
DF = damping factor, per CST waveform input format.

Figure 2.3.3-3. CS116 Environment Model

2.3.4 Radiated Susceptibility- Electric Field - RS103 Environment Model

After consideration of the EME threat and how the fields are attenuated and altered by a typical ground vehicle structure between the threat and the equipment and subsystem, as well as measurements of field strengths present at subsystems and equipment due to radiation from on-board radio transmitter antennas, MIL-STD-461F specifies a baseline E-field environment of 50 V/m from 30 MHz to 18 GHz at equipment and subsystems. This environment is specified under a particular test setup for application of the 50 V/m field.

Although the system level EME environment specified in MIL-STD-464C extends down to 2 MHz, and many ground vehicle do contain on-board HF radio transmitters (2 to 30 MHz), there is no radiated E-field requirement for the 2 to 30 MHz frequency range in MIL-STD-461F. This is because equipment and subsystems, if susceptible to this environment in the 2 to 30 MHz frequency range, would be most like be susceptible via the field inducing current into the interconnect cables, not via pickup at a circuit card. The CS114 environment, conducted RF susceptibility, considers the MIL-STD-464C EME and on-board transmitter threats in the 2 to 30 MHz frequency range.

As noted in MIL-STD-461F, the base E-field threat levels present at subsystems and equipment may be tailored by the procuring activity based on particular situations. MIL-HDBK-235 is cited for guidance. However, from a practical stand-point, if the base MIL-STD-461F 50 V/m environment is tailored upward, it is simply increased to the full MIL-STD-464C EME system level threat (see figure 2.3-2), which, as far as average levels are concerned, equates to an increase of about 14 dB, worst case. The MIL-STD-461F RS103 50 V/m environment is pulse modulated with 50% duty cycle and a 1 kHz pulse rate. The MIL-STD-464C radiated environment for ground systems above 1 GHz is also pulse modulated, but with a duty cycle notable shorter than 50%.

For evaluation against the RS103 environment, the cable bundles must be representative of the intended installation. “Representative” equates to identical cable and wire cross-section, identical or electromagnetically equivalent connector assemblies, identical wire and cable shield properties (if shielding is applicable), and identical shield and wiring termination, routing, and grounding at the connectors.

The equipment subject to the RS103 environment must be electrically bonded to the copper bench in a manner that represents how it is bonded (or not bonded) to the host platform. Key quantities to consider in equipment bonding include DC resistance, contact locations, bonding conductor material and geometry (if applicable), and the amount of surface area at bond between conductive surfaces.

The MIL-STD-461F RS103 environment requirements are also normalized to a condition where the cables under test are placed 5 cm above a conductive ground plane bench. Length may be limited to 10 meters if the installation cable is longer than 10 meters. If the length is unknown, a compliant default length of 3 meters is typically used, as this allows compliance to other baseline conditions stated in MIL-STD-461F.

The cables must also be terminated with loads to simulate the electrical properties (impedance, grounding, balance, and so forth) present in the actual installation.

Power leads are to be between 2 and 2.5 meters long and terminated into a line impedance stabilization network (LISN). Figure 2.3.1-3 shows a schematic of the LISN. The purpose of the LISN is to provide a platform representative power system impedance to the equipment or subsystem being tested or analyzed.

In general, the RS103 environment baseline for exposure of cable bundles is to have at least 2 meters of cable bundle, starting the equipment connector, exposed to the field with the direction of propagation normal to the run of the cable bundle. Thus simulation models should be set up to provide at least 2 meters of cable bundle running perpendicular to the direction of propagation. Looping the cable back and forth such that additional lengths run parallel to the direction of field propagation should be avoided. For each direction of propagation (there may be many if a complex cable harness is being analyzed) the field must be applied with both horizontal and vertical polarization, assuming the plane of the cable run and ground plane bench are horizontal. From a simulation standpoint, this may be done by running the simulation twice for each direction of propagation – once with horizontal polarization and once with vertical polarization, or combining polarizations for the each propagation direction by using an E-field vector 45 degrees from horizontal, setting the E-field magnitude at sqrt(2) x required base level. However, this is often argued as a worst case test or analysis since, in practice, the system cables will only see one polarization being dominate at the baseline level – the component in the other polarization being much less. However, the maximum amount of pessimism would be limited to 20*log* (*sqrt*(2)) = 3 dB.

2.3.5 Radiated Susceptibility - Transient Electromagnetic Field - RS105 Environment Model

MIL-STD-464C states: "*The system shall meet its operational performance requirements after being subjected to the EMP environment. This environment is classified and is currently defined in MIL-STD-2169. This requirement (environment) is applicable only if invoked by the procuring activity. Compliance shall be verified by system, subsystem, and equipment level tests, analysis, or a combination thereof.*" Note that MIL-STD-2169 is a classified document. Often, if the EMP environment is applicable, subsystem and equipment specifications will contain detailed requirements with respect to required recovery time and actions and outputs during the recovery period. As an example, a mission display may be required to recover within 40 seconds after the EMP event and must never provide misleading or non-current data. The terms High-altitude Electromagnetic Pulse (HEMP) and Nuclear Electromagnetic Pulse (NEMP) are often synonymous with the term "EMP."

The RS105 requirement in MIL-STD-461F is an attempt to provide a representative unclassified compilation of various EMP environments that may be seen by subsystems and equipment in unshielded systems and platforms.

The RS105 requirement is technically applicable only to equipment enclosures, as the result of EMP on to cable bundles and power leads is covered under the generic CS116 environment. However, there may be instances where the installation cables are relatively short ($\leq$ 10 meters) and it may be more practical, in lieu of applying CS116, to subject the cable harness to the RS105 environment along with the equipment enclosure. Examples include soldier mounted systems and small vehicles. In these cases test or modeling with respect to the RS105 environment may be more appropriate. Hence a model of the RS105 environment for cables is included herein.

The RS105 environment is a radiated planewave with the characteristics shown in figure 2.3.5-1. Figure 2.3.5-2 is a photograph a RS105 test of a small subsystem. Clearly, this setup will expose cables to the RS105 environment.

With respect to short cables, the RS105 environment is typically modeled with the cables 5 cm above a ground plane bench, as with the other MIL-STD-461F setups, with the plane wave propagation in the direction of the cable run and the E-field set normal to the ground plane. For complex cable harnesses, the model may include application of the field with multiple directions of propagation (each applied as a separate case), always with the E-field normal to the ground plane.

Often when the RS105 environment is to be applied to equipment or subsystem cables, the cable and equipment layout on the ground plane used for RS103 is directly used for application of the RS105 environment – a parallel plate transmission line plate is placed above the ground plane over the equipment and cables.

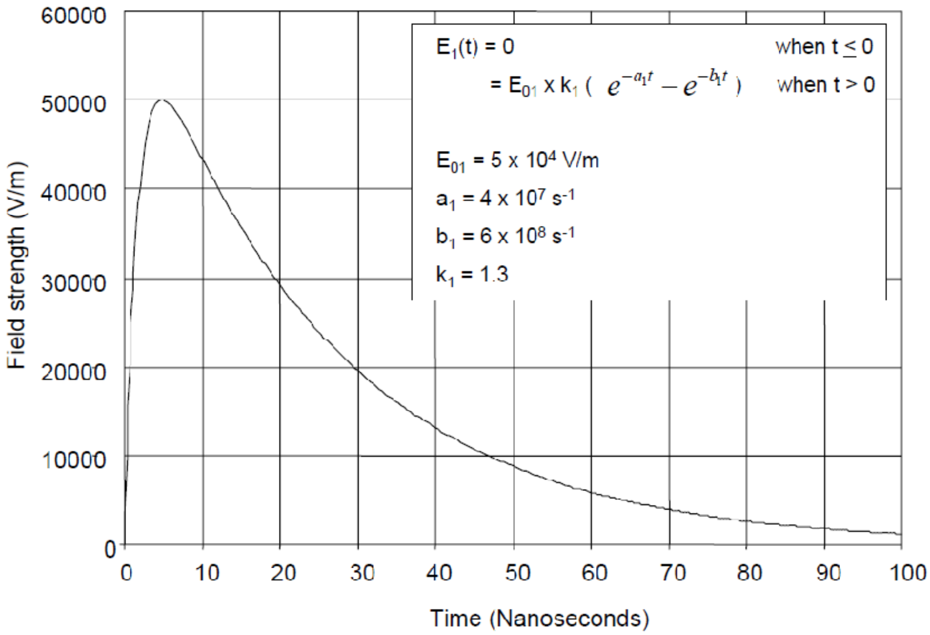


Figure 2.3.5-1. RS105 Waveform

From www.montena.com

Figure 2.3.5-2. RS105 Setup Example for a Subsystem

3.0 MODEL USE & SIMULATION METHODOLOGY

4.0 CABLE SIMULATION MODEL EXAMPLE

5.0 TRANSFER IMPEDANCE OF SHIELDS