JOTP-062
4 Aug 2015

# DEPARTMENT OF DEFENSE

# JOINT ORDNANCE TEST PROCEDURE (JOTP)

## Personnel-borne ElectroStatic Discharge (PESD) and Helicopter-borne ElectroStatic Discharge (HESD) Requirements for Ordnance

**Joint Munitions Safety Test (JMST) Working Group**

Joint Ordnance Test Procedure (JOTP)-062
Personnel-borne ElectroStatic Discharge (PESD) and Helicopter-borne ElectroStatic Discharge (HESD) Requirements for Ordnance

| **DOCUMENT COMPLETION DATE:** | **TITLE AND SUBTITLE:** |
|---|---|
| 4 August 2015 | Joint Ordnance Test Procedure (JOTP)-062<br>Personnel-borne ElectroStatic Discharge (PESD) and Helicopter-borne ElectroStatic Discharge (HESD) Requirements for Ordnance |

| **PREPARING ACTIVITY:** | **SPONSORING ACTIVITY:** |
|---|---|
| Joseph Sferrella<br>Naval Ordnance Safety and Security Activity (NOSSA)<br>Weapons Assessment (N8)<br>3817 Strauss Avenue, Suite 108<br>Indian Head, MD 20640-5151 | Range Infrastructure Division (CSTE-TM)<br>US Army Test and Evaluation Command<br>2202 Aberdeen Boulevard<br>Aberdeen Proving Ground, MD 21005-5001 |

**DISTRIBUTION STATEMENT:**

Distribution Statement A. Approved for public release; distribution is unlimited.

**ABSTRACT:**

The PESD procedure applies to all ordnance in all commodity categories. The HESD procedure applies to ordnance items and their operational HESD exposure as identified in the HESD procedure and consists of the bare man carry test, the external carry (installed on aircraft) test, the hot tube loaded (install/uninstall on operating ungrounded aircraft) test, and the Vertical Replenishment (packaged configuration) test.

**COORDINATION DRAFT REVIEWED BY:**
This document was coordinated with the following Standardization Offices: AR, AS, EA, MC, MI, MR, OS, TE, AF-2, AF-70, and AF-99. In addition, the document was also coordinated with the Joint Weapon Safety Working Group.

**ASSIST COORDINATION DATE:** 7 May 2015

**IMPLEMENTATION PLAN:**
This JOTP shall serve as the US Joint Services Hazards of ElectroStatic Discharge (ESD) Safety Test Procedures with regards to conventional munitions until which time the content of this document is included in the next revision of Military Standard (MIL-STD) 331, MIL-STD-464, Department of Defense Manual (DoDM) 3222 (Electromagnetic Compatibility and Electronic Warfare), and Standardization Agreement (STANAG 4370)/Allied Environmental Conditions and Test Publication (AECTP) 500 (Electromagnetic Environmental Effects Test and Verification) Category 508 (Ordnance/Munitions Verification Testing), and AECTP 250 (Electrical and Electromagnetic Environmental Conditions), Leaflet 253 (Electrostatic Charging, Discharge, and Precipitation Static) . Upon approval of the next revisions of MIL-STD-331, MILSTD-464, DoDM 3222, and STANAG 4370/AECTP 250/500, thorough review of this document shall be conducted with the intent to supersede.

**APPROVING AUTHORITY:**

JOSE GONZALEZ      11/3/15
Date

Deputy Director, Land Warfare & Munitions
Office of the Under Secretary of Defense for
Acquisition, Technology and Logistics

# Table of Contents

## Executive Summary

## Section 1 PESD

## Figures



## Tables

**RECORD OF CHANGES**

| Change Date | Date Entered | Effective Date | By Whom Entered |
|---|---|---|---|
| | | | |

# Executive Summary

Military Standard 464 (MIL-STD-464) provides the top level requirements for ordnance safety when ordnance items or systems are exposed to personnel and helicopter borne electrostatic Discharge (PESD and HESD). However, the requirements are general and do not provide specific instruction necessary to evaluate ordnance items for compliance to these general requirements. Military Standard 331 (MIL-STD-331) provides some additional requirements and guidance for the electrostatic discharge (ESD) tests, but this additional guidance is not specific and has enabled different interpretations by the Services. Therefore, the current implementation of the existing requirements is not consistent across the Services which can lead to re-testing items to meet the specific Service's interpretation.

This Joint Ordnance Test Procedure (JOTP) PESD and HESD document evaluated the existing ESD test approach used by each of the Services, and the general requirements in MIL-STD-464 to determine a common Joint Service ESD test approach. This JOTP provides all procedures, requirements, and data necessary to produce consistent and repeatable results independent of the test facility, test site, or Service conducting the testing.

The PESD procedure applies to all ordnance in all commodity categories. The HESD procedure applies to ordnance items and their operational HESD exposure as identified in the HESD procedure and consists of the bare man carry test, the external carry (installed on aircraft) test, the hot tube loaded (install/uninstall on operating ungrounded aircraft) test, and the Vertical Replenishment (packaged configuration) test.

Joint Service validation testing was performed to: (1) harmonize the differences in the existing ESD test procedures used by each of the Services; (2) reduce redundant testing; and (3) meet the ordnance safety requirements in MIL-STD-464. The results of that testing are contained in Appendix B and have been incorporated into this document.

This Page Left Blank Intentionally

# JOINT ORDNANCE TEST PROCEDURE (JOTP) FOR PERSONNEL-BORNE ELECTRO-STATIC DISCHARGE (PESD)

## Section 1: PESD

### 1. INTRODUCTION.

Section 1 of this document has been developed to address Personnel borne Electrostatic discharge (PESD) safety and operability testing. It is the PESD test procedure for all ordnance/ munition types for the purpose of Joint service assessment and testing of conventional (non-nuclear) munitions. This procedure specifies PESD requirements for all ordnance items including bare energetic materials that are cataloged and/or fielded with local or national stock numbers.

### 2. SCOPE.

2.1. Purpose.

The purpose of PESD testing is to determine if exposure of ordnance items, ordnance electrical interfaces, and related systems, including but not limited to firing circuits and control electronics (weapon release, intent to launch, etc.) to the PESD test requirements defined in Paragraph 4 due to personnel handling results in a safety and/or operability hazard such as ordnance initiation, Electro-explosive Device (EED)/Electrically Initiated Device (EID) initiation, firing circuit initiation, performance degradation, electrical interface malfunction, or dudding in accordance with the requirements of MIL-STD-464 and MIL-STD-331. PESD exposure shall be assessed or tested for bare energetic materials, bare devices, and bare All Up Rounds (AURs) in the worst case operational mode during any of the stockpile to safe separation sequence (S4) phases (i.e. transportation/storage, assembly/disassembly, staged, loading/unloading, platform loaded, and immediate post launch) .

Note: EED /EID are considered the same for the purposes of this document and the terms are used interchangeably.

2.2. Application.

Data obtained through use of this document shall be included in the ordnance item/munition safety data package. The PESD test requirements are applicable to all ordnance items (with and without EIDs), ordnance subsystems, ordnance related equipment, launchers, remote control devices, EIDs and firing/monitoring circuits, including those installed external to aircraft and vehicles.

PESD test requirements may be applicable at either or both the equipment /system/AUR level and the device level depending on the configuration, assembly and use of the item in the field. The PESD requirements shall be applied to selected test points on the test item, without regard to procedural controls for the test item (such as a requirement to wear a static dissipative wrist strap and ground before handling the item), which could possibly be contacted by personnel during the different configurations/modes of operation including: transportation/storage, assembly/disassembly, staged, loading/unloading, platform loaded, and immediate post launch. Unauthorized non-standard configurations do not need to be addressed such as disassembly of an AUR that is not authorized in the field. Specific PESD test requirements are identified in Paragraph 4.

Note: For the purposes of this document, the test item may be either a single self-contained ordnance device (hereafter referred to as device or EID) with a single percussion initiation system or single EID; or the test item may be an ordnance system/AUR (hereafter referred to as system or AUR) with multiple ordnance and/or related items assembled in one unit.

2.3. Limitations.

This document is only applicable to conventional (non-nuclear) munitions to aid in the item, device, system, or AUR safety and operability assessment. This document is not intended to be used to aid the assessment of effectiveness, reliability or performance of an ordnance item/munition.

## 3. REFERENCE PESD GUIDANCE.

NOTE: Text in paragraph 3 in italics is material extracted from MIL-STD-464 and MIL-STD-331, respectively; non-italicized text is JOTP procedure wording.

**MIL-STD-464C states:**
*5.8.3: Ordnance subsystems shall not be inadvertently initiated or dudded by a 25 kilovolt ESD caused by personnel handling. Compliance shall be verified by test (such as MIL-STD-331 or AECTP-500, Category 508 Leaflet 2), discharging a 500 picofarad capacitor through a 500 ohm resistor with a circuit inductance not to exceed 5 microhenry to the ordnance subsystem (such as electrical interfaces, enclosures, and handling points).*

**MIL-STD-331C states:**
***F1.4.2.1 Personnel-borne ESD test.*** *The energy delivered to each of the calibration test loads given in Table F1-1 shall be between 0.18% and 0.22% (when using a 500 ohm series resistance) or between 0.018% and 0.022% (when using a 5000 ohm series resistance) of the energy stored on capacitor C. F1.7.3.2.1 provides a description of the threat to fuzes or their subsystems caused by an electrostatic discharge from a human body. F1.7.4 provides a description of the required instrumentation and a procedure for measuring the energy delivered by the test apparatus used to simulate the threat. Calibration test waveforms should fall within the bounds specified in Figures F1-2 through F1-5, as applicable.*

The Safe and Operable requirements are defined in MIL-STD-331C:

***4.6.2.1*** *a.* ***Safe for use.*** *The fuze shall maintain its safety features in a condition which will not create a hazard for personnel or cause any subsequent action which will compromise the safety conditions required during handling, transportation, storage and use. Fuze use includes installation and firing or release of the weapon where damage or irregularity does not prevent assembly of the fuze to the weapon or loading.*

For the purposes of PESD testing, the safe for use requirement applies to all ordnance items and materials, not just fuzes.

***4.6.2.2 Operable.(Reliable)*** *When the fuze is provided its required inputs, it shall perform to completion of its function and sequence producing all required outputs within the operating period or at the specified time. Determination of operability may require firing the fuze using a procedure adapted to the type of fuze being tested and its associated munition.*

3.1 Implementation of Guidance.

All items containing any energetic material or that control items containing energetic material shall remain safe and operable during and after exposure to the PESD test requirement, and meet its performance requirements during and after exposure to the PESD test requirement, with parameters specified by MIL-STD-464C, Paragraph 5.8.3 and MIL-STD-331C paragraph F1.4.2.1.

PESD shall be tested and/or assessed for all ordnance devices and AUR items in the Bare/man-carry configuration i.e. out of the packaged configuration with all protection devices removed such as shorting clips, etc.

## 4. PESD REQUIREMENTS.

4.1. Discharge Points.

PESD testing shall be performed to any point on the device/AUR that may be contacted by personnel or become charged during transportation/storage, assembly/disassembly, staged, loading/unloading, platform loaded, and immediate post launch and in the worst case operational mode (powered-on, unpowered, armed, etc.) in each configuration including each pin on ordnance electrical interfaces, non-metal components, and related items, including but not limited to firing circuits and control electronics (weapon release, intent to launch, etc.). The assessment from Paragraph 5 of this document should be used to determine the discharge points.

4.2. Bare Devices.

Bare Electrically initiated devices, electrically initiated devices in an AUR that have either one or both pins accessible on an external connector, and percussion initiated devices that are not in a faraday cage (as defined in this document) shall be tested according to the PESD requirements in Table 1 and the electrical schematic of Figure 1. These devices shall be tested live in the pin to pin mode, the pin to case mode, and the shorted pin to case mode with no dudding or initiation, and must be subjected to no-fire and all-fire testing after the PESD test to verify conformance with safety specifications of the device.

### 4.3. AUR Devices.

Electrically initiated devices in an AUR that are not connected to the exterior electrical connector, and operability testing of the AUR electronics shall be tested to the requirements of Table 2 and the electrical schematic of Figure 1.

### 4.4. Performance Requirements.

During and after exposure to the PESD test requirements, the device/AUR, including associated launchers, remote control devices, and associated internal electronics shall meet the performance requirements detailed in their specifications with no safety or operability/performance failures or malfunctions and without resetting or re-powering the device or AUR. Momentary upsets that auto-correct (without operator action) and have no effect on the operation of the item, such that it produces all required outputs at the specified time are allowed.

## 5. PESD PRE TEST ASSESSMENT.

Use of previous analyses and/or test data from previous variants of the same AUR may be evaluated and incorporated into the test planning and pre-test assessment in order to enhance and/or reduce the scope of the new testing, and to provide justification for the new test item configurations and test approach. A pre-test assessment is performed to include the following for test planning:

a) Determine PESD energy points of entry (points possibly contacted by personnel during assembly, handling, etc. or possible entry points from near or direct strike discharges) through an analysis of the complete drawing package that specifically identifies all the materials of construction for the device or AUR. Energy entry points include switches, displays, battery terminals, output terminals, electrical interfaces, device joints and discontinuities, and non-conductive surfaces, etc.

b) Determine the PESD external and internal current paths through an analysis of the electrical interface and mechanical interface drawings for the device or AUR. This may not be possible with non-metallic materials or with internal coupling paths.

c) Determine the most/least susceptible test item configurations and possible modes of operation based on personnel handling without regard to procedural controls during any of the S4 phases (bare, assembly/disassembly, loading/unloading, powered on, armed, etc.).

d) Determine test item data required to be monitored or tested during or after PESD testing to evaluate the safety and operability/performance effects on the test item. This includes bridgewire resistance, communication links, programming modes, firing circuits, safe/arm indicators, etc. that are part of the device or AUR.

e) Determine test item PESD protection features and their predicted performance and whether they are repairable or replaceable.

f) Determine procedures and equipment required to verify the post PESD test performance for each device, circuit, AUR, and non-faraday cage component.

## 6. PREVIOUS TEST DATA AND/OR ANALYSIS REQUIREMENTS.

The following are exceptions to conducting the PESD test on a new or modified ordnance device or AUR, or a subcomponent of the AUR. These exceptions only cover the energetic items, and any circuitry that is part of the AUR that was previously tested or analyzed that has not been changed as specified below. Any changes to the circuitry or energetic items must be addressed in the testing for the new/modified ordnance device or AUR, or a subcomponent of the new/modified AUR.

### 6.1. Faraday Cage Design.

Devices: Any device, AUR, or subcomponent of an AUR, that is completely surrounded by metal with no openings and has no external electrical connectors/leads or conductive mix primer/initiator is by design a faraday shield and is safe for bare PESD exposure, provided all of the following are met:

a) All components of the device are constructed of metal material of minimum 0.016 inch thickness and with low bonding resistance (less than 1 ohm) across any non- welded components.

b) Official signed drawings documenting the component materials of all components surrounding the energetic material are required to provide ESD faraday cage designation. Performance specifications are not acceptable if the component materials are not specified for the device, AUR, or subcomponent of an AUR.

6.1.2 If the device or AUR does not meet all the requirements above, then testing shall be required:

The device or AUR with live EEDs and/or energetic material must be tested to the requirements of Table 1 with 22 sets of positive and negative direct contact discharges to the thinnest and/or non-metallic section(s) of the container/device without initiation/dudding.

6.2. Other Qualifications.

If the device, AUR, or a subcomponent of an AUR was tested bare and officially qualified in accordance with MIL-DTL-23659F (General Design Specification for Electric Initiators), additional PESD testing is not required. A copy of the Qualification test report that identifies the item certified and drawings for the device that identify that same item as a component of the AUR must be provided to validate the previous qualification applies to the new item. If there is additional circuitry in front of the MIL-DTL-23659 item in the AUR device, an inert test item may be used for the PESD testing to validate the operability of the circuitry.

If the device, AUR, or a subcomponent of an AUR was tested live in accordance with the requirements of Allied Environmental Conditions and Test Procedures (AECTP) 508 Leaflet 2 and the official test report provides the test data required in this document to evaluate both safety and operability of the item, additional testing may not be required.

6.3. Previous Test Data.

Previous test results and/or analysis on a previous variant of a new item may be used in the certification of a new item to reduce the scope of testing of the new item if the previous testing completely documented the safety and operability requirements for PESD as detailed in this document and if the following apply:

6.3.1 The new item/AUR is a variant of a previously fielded device, AUR, or subcomponent of an AUR. The new variant shall be analyzed and tested for:

a. Changes to energetic components,

b. Changes to system construction materials, and

c. Changes to electrical connectors/firing circuits as a minimum.

Only the new energetic items, sections with different materials of construction, or new electrical interfaces/firing circuits shall be tested in accordance with the requirements of this document.

6.3.2 The new item contains energetic devices that were PESD tested through previous live testing in accordance with the requirements of this document, and no changes to the materials of construction for the item or AUR have been made. These energetic devices do not need to be tested for the new item for safety concerns, but for any new or modified firing circuits or other circuitry that are in the new AUR or new subcomponent of the AUR of these previously PESD tested items, those circuits shall be tested for operability/performance along with any other energetic devices that do not have live test results.

## 7. TEST EQUIPMENT AND INSTRUMENTATION.

### 7.1. Voltage, Capacitance, Discharge Inductance, and Resistance.

The voltage, capacitance, resistance, and discharge circuit inductance, including the inductance of the capacitor and wiring to the probes shall be in accordance with the values in Tables 1 and 2. Inductance shall be measured at a nominal 1 kHz frequency.

**Table 1: PESD Requirements for Bare Devices**

| Voltage | Capacitance (farad) | Discharge Inductance (Henry (H)) | Series Resistance (ohms (Ω)) |
|---|---|---|---|
| ± 25,000 ± 500 volts | 500 ± 5% pF | 5 μH max | 5000 ± 5% Ω |
| ± 25,000 ± 500 volts | 500 ± 5% pF | 5 μH max | 500 ± 5% Ω |

Note: Use both a 500 ohm and 5000 ohm resistance to maintain consistency with MIL-DTL-23659 and MIL-STD-331 requirements. No additional resistance or inductance shall be added to the circuit except for incidental inductance in the capacitor, resistor, and wiring. A minimum of 22 devices shall be tested with 4 discharges as defined in Table 1 in each configuration (pin to pin, pin to case, and shorted pin to case).

**Table 2: PESD Requirements for AUR Devices and Operability**

| Voltage | Capacitance (farad) | Discharge Inductance (Henry (H)) | Series Resistance (ohms (Ω)) |
|---|---|---|---|
| ± 25,000 ± 500 volts | 500 ± 5% pF | 5 μH max | 500 ± 5% Ω |

Note: Requirements are different in the AUR configuration because the pins for the EIDs are not accessible and this test configuration is worst case. No additional inductance shall be added to the circuit except for incidental inductance in the capacitor, resistor, and wiring.

### 7.2. Discharge Methods.

There are two acceptable methods for discharge that can be employed for PESD testing including direct contact discharge and approaching probe discharge:

a) Direct Contact Discharge: This method uses a discharge electrode from the test generator that is placed in direct contact with the selected test point and the discharge is triggered (manually or remotely) with a discharge switch in the test generator. This is the test method that must be used for bare device testing and for pins on an electrical connector to maintain compatibility with MIL-DTL-23659F requirements.

b) Approaching Probe Discharge: This method positions the discharge electrode from the test generator approximately 1 foot from the selected test point, and the discharge electrode is moved at a minimum speed of 1 foot per second to the test point to initiate a discharge. If there is a possibility that the discharge could arc to another surface instead of the selected test point (such as a different pin on a connector), a salient shall be attached to the test point to direct the discharge to the selected discharge point without the possibility of arcing to an unintended discharge point.

In order to meet the PESD requirements of this document, regardless of the discharge method used, the energy monitored at the calibration test load using the selected discharge method for testing must be within the limits identified in Paragraph 8 of this document.

Figure 1 defines the circuit schematic to be used for bare/AUR PESD testing.

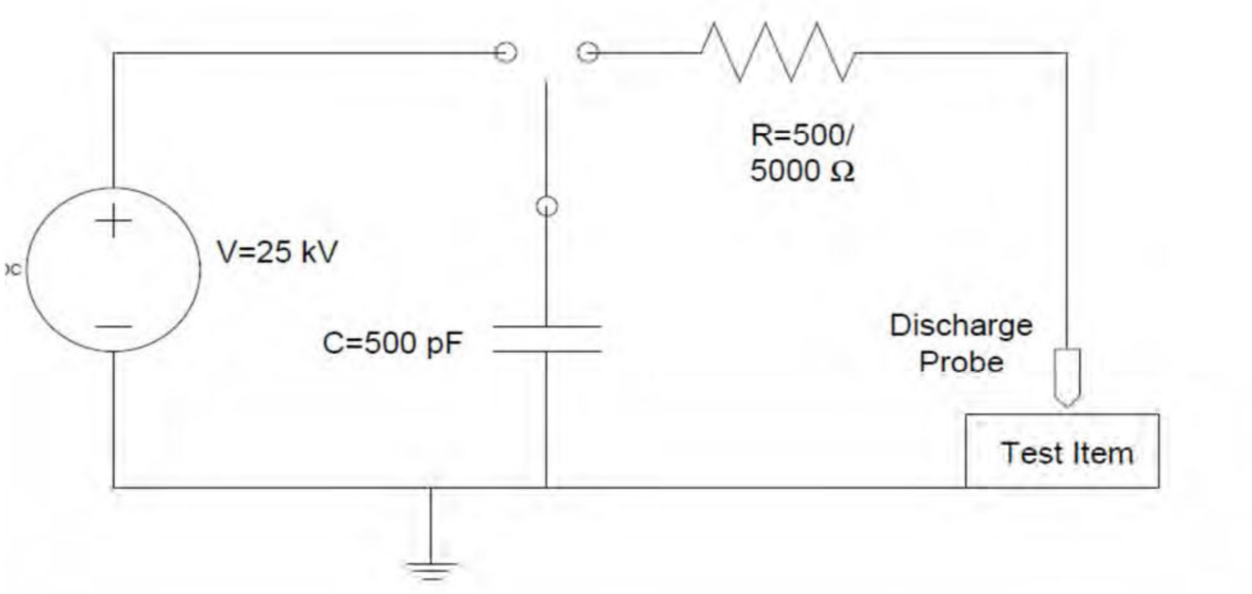



**Figure 1: PESD Electrical Schematic**

7.3. Instrumentation.

The test measurement equipment shall have:

a) A minimum bandwidth of DC to 200 MHz

b) A minimum rise time of 2 nanoseconds

Unless otherwise stated, test equipment accuracy/tolerances shall meet the following minimum requirements:

1) Distance: ± 5 %
2) Frequency: ±2 %
3) Amplitude, ± 2 %
4) Time (waveforms): ± 2 %
5) Resistors: ± 5 %
6) Capacitors: ± 5 %
7) Current: ± 2 %
8) Voltage: ± 2 %

## 8. CALIBRATION REQUIREMENTS.

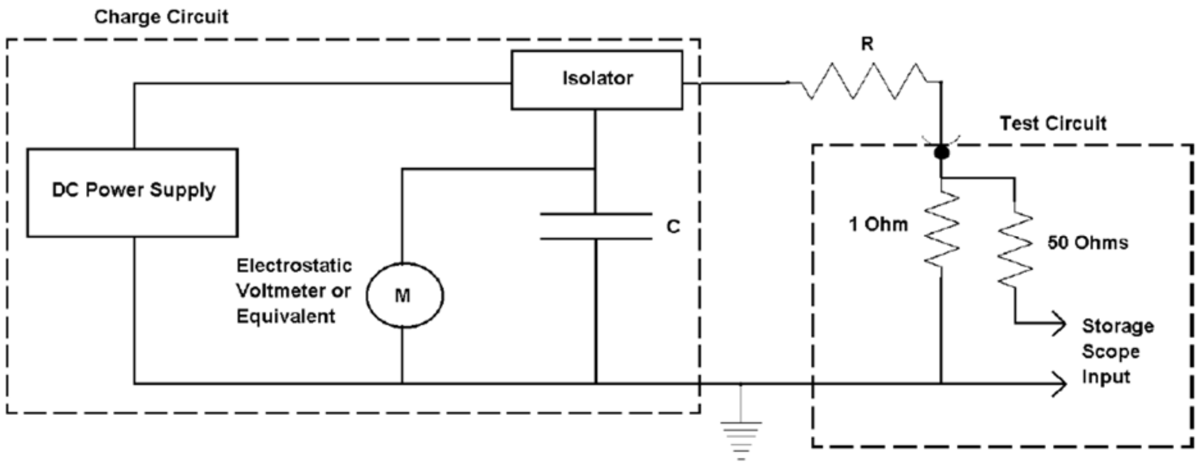
The energy measured during calibration shall be as defined in Figure 3 when using a 500 ohm series resistance or Figure 4 when using a 5000 ohm series resistance of the energy stored on capacitor C. The upper and lower limits for the waveforms are based on the maximum and minimum energy output of the circuit in Figure 1 using the component tolerances in Table 1. Calibration test waveforms should fall within the bounds specified in Figure 3 for 500 ohm series resistance and Figure 4 for 5000 ohm series resistance. Both voltage and current based waveforms are provided. The voltage calibration test load shall be a 1 ohm coaxial resistor to ensure proper frequency response as shown in Figure 2a. For additional information on these limits, see Appendix 1 and 2.

A shorted discharge to the ground plane from the test electrode using a current transformer on the output as shown in Figure 2b may be used to generate a current waveform with the upper and lower limits as shown in Figures 3 and 4. The calculations for the current based waveforms can be found in Appendix A for the 500 ohm circuit and in Appendix B for the 5000 ohm circuit.

The energy delivered to the test item from the test equipment shall be verified and recorded on a daily basis prior to testing and at the conclusion of testing for the day at a minimum in accordance with the calibration limits of Figures 3 and 4. If a salient is used on the test item, it shall be considered part of the discharge circuit and used during calibration.

Any commercial ESD test equipment shall be analyzed for compliance with the calibration waveforms and circuit schematic for suitability to the requirements of this document. Equipment claiming MIL-STD-331 or MIL-STD-464 compliance does not imply the equipment meets the performance requirements of this document.

All test and measurement equipment must be in current calibration for the test data to be valid. Any attenuation used in the measurement circuit must be calibrated and clearly identified on the data plots to verify the results.




**Note: Scope input impedance must be set to 50 ohms**

**Figure 2a: MIL-STD-331 Voltage Calibration Circuit**

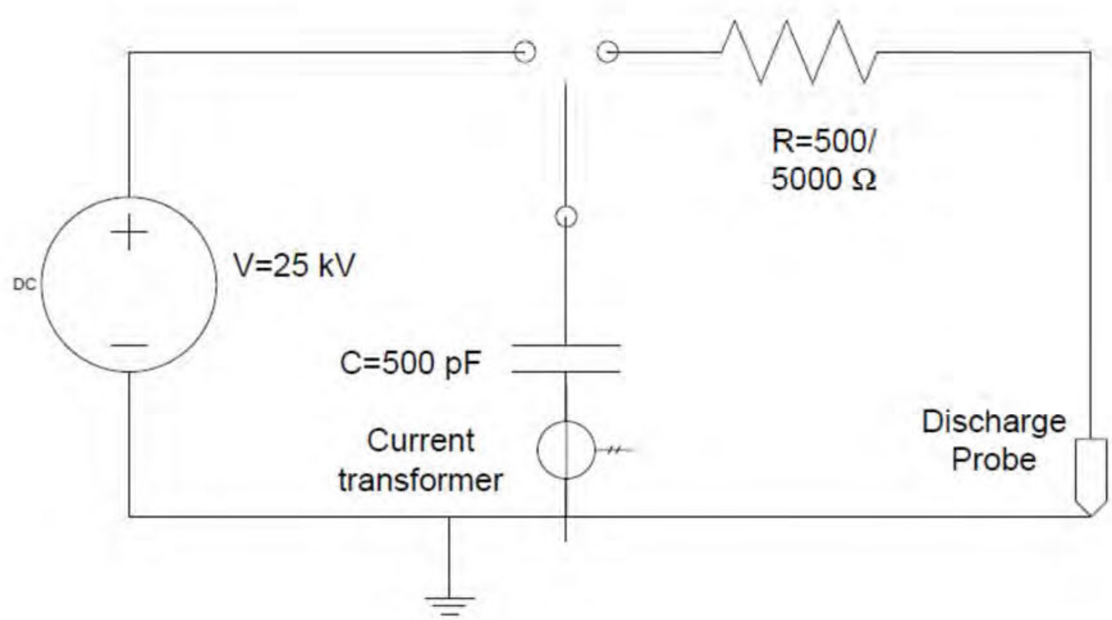



**Figure 2b: PESD Shorted Discharge Current Calibration**

**Figure 2: PESD Calibration Circuit**

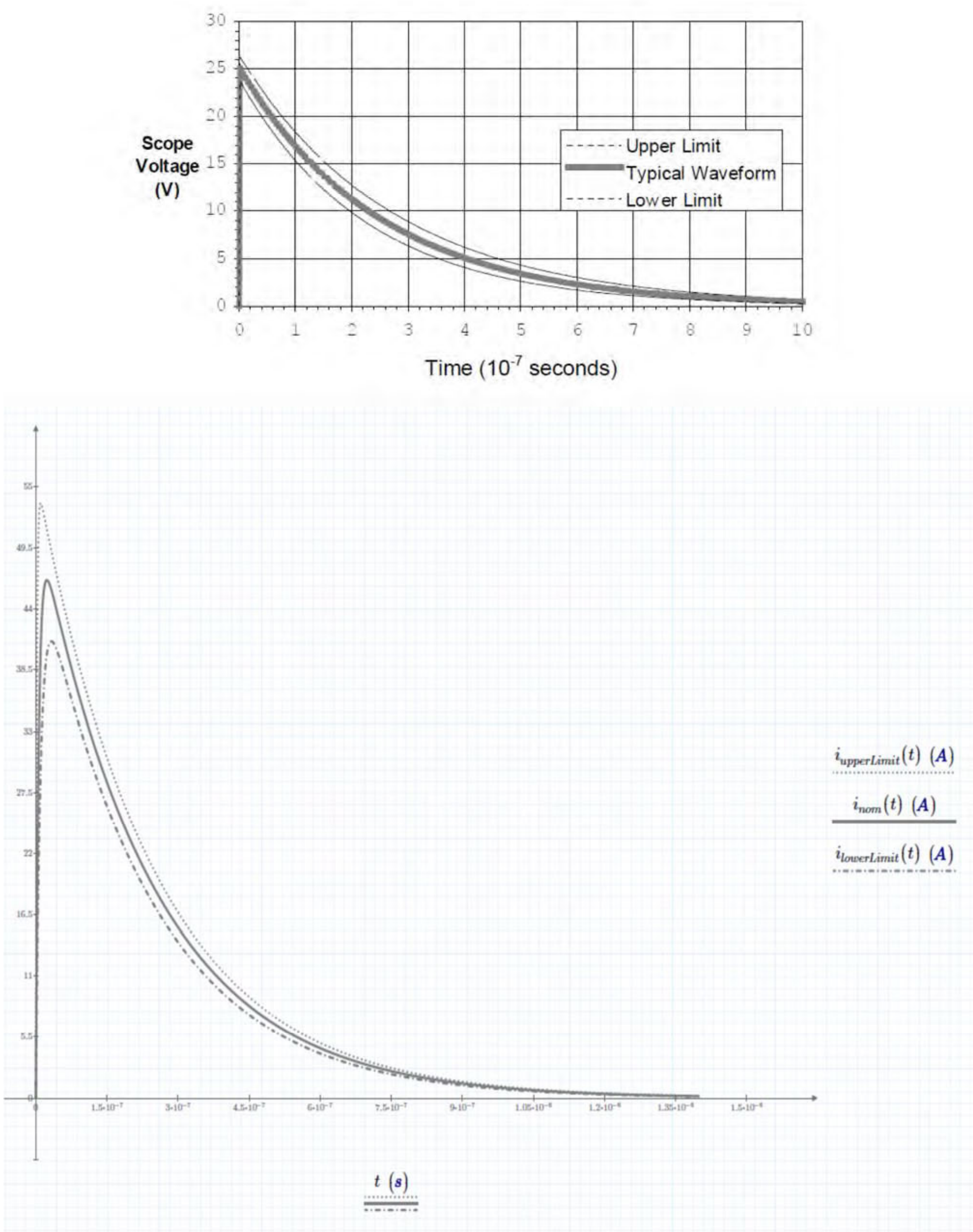



**Figure 3: 500 ohm PESD Voltage/Current Waveforms with Limits**

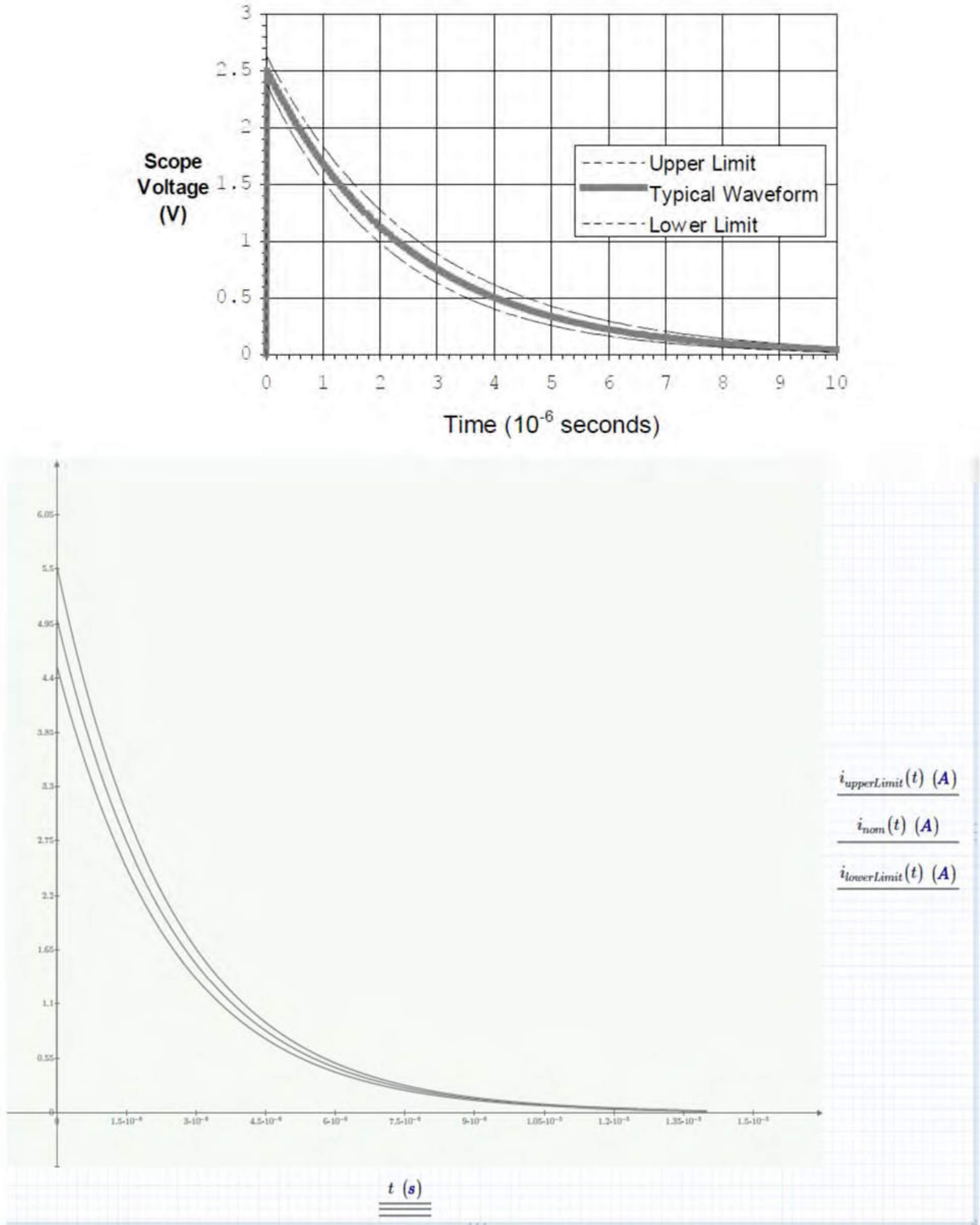



**Figure 4: 5000 ohm PESD Voltage/Current Waveforms with Limits**

## 9. TEST SAMPLE QUANTITIES.

Minimum sample size for AUR PESD testing shall be 22 items for all ordnance commodity categories. No inert testing is allowed unless the AUR or the subcomponent of the AUR has been verified as a faraday cage as defined in this document or has previously been tested live in accordance with Paragraph 4 of this document. Irrespective of the sample size used for the testing, the equivalent number of discharges delivered to 22 samples must be delivered to the sample size used for testing.

Minimum sample size is 22 items for bare devices or devices that are not identified in Table 3 Ordnance Commodity Categories such as: electrically initiated devices, electrically initiated devices in an AUR that have either one or both pins accessible on an external connector, bare energetic material, and percussion initiated devices that are not in a faraday cage as defined in this document. No inert testing is allowed unless the item has been verified as a faraday cage in accordance with the requirements of this document or has previously been tested live in accordance with Paragraph 4 of this document.

**Table 3: PESD Ordnance Commodity Categories**

| **Commodity:** |
|---|
| Large Caliber Ammunition |
| Medium Caliber Ammunition |
| Small Caliber Ammunition |
| Non-Lethal Ammunition |
| Man Emplaced Ammunition |
| Air Launched Missile/Rocket |
| Surface Launched Missile/Rocket |
| Man Carried Missile/Rocket |
| Pyrotechnics |
| Fuze and Ignition Systems |
| Underwater |

### 9.1 Incremental Voltage Testing.

A minimum of four devices of the 22 samples required for PESD testing in the tested configuration (bare or AUR) must receive incremental voltage testing using the component requirements of Table 2 (one positive and one negative discharge through a 500 ohm resistor) and voltages of 5 kV, 10 kV, 15 kV, 20 kV, and 25 kV to document the safety and operability of the item to all possible PESD exposures. Two of the devices shall be tested using positive voltages with one device tested starting at 5 kV and increasing the voltage up to 25 kV in 5 kV steps, and the other device starting at 25 kV and decreasing the voltage in 5 kV steps down to 5 kV. The other two devices shall be tested using negative voltages in a similar fashion (One device starting at negative 5 kV and decreasing the voltage to negative 25 kV in 5 kV steps, and the other device starting at negative 25 kV and increasing the voltage in 5 kV steps up to negative 5 kV). Irrespective of the sample size used for the testing, the equivalent number of discharges delivered to four samples must be delivered to the sample size used for testing. The four devices required for this testing shall be from the 22 total samples required for testing.

## 10. TEST ITEM CONFIGURATION.

If the device or AUR contains electrically initiated devices and/or electrically initiated devices connected to an external connector of the AUR that have not been tested to the requirements of this document or if MIL-DTL-23659 data is not available, then testing of the live EID(s) is required. Test live EIDs (not installed) for the pin to pin, pin to case, and shorted pin to case. Test device or AUR with live EEDs installed to each external electrical contact and non-metallic entry point. 22 samples minimum are required using direct contact discharge only.

a) Electrically initiated devices:

1) Contained in a non-faraday cage AUR and not connected to an exterior electrical connector, or
2) Which have not previously been tested in the same AUR configuration, or
3) With different circuitry leading to the EID than a previously tested version,

must be tested with live EIDs in the AUR configuration.

4) Operability/performance testing of the AUR electronics between the external connector and a MIL-DTL-23659/bare PESD tested (to the requirements of this document) EID internal to the AUR may be performed using an inert/instrumented EID.

b) Percussion Initiated Devices.

1) Percussion initiated devices not in a documented faraday cage or other non-electric devices must be tested live.

2) Test configuration shall be live (not installed) if the item will be used in a standalone configuration, or in the AUR if the item will only be in the AUR configuration.

### 10.1. Configuration Changes.

Any change to a previously PESD tested and/or certified device or AUR, including changes to component materials, energetic materials, EIDs, packaging, electrical interfaces, communication interfaces, or remote devices shall be subjected to PESD testing to verify the new configuration meets the PESD requirements of this document and assigned a new nomenclature/cataloging number.

### 10.2. Instrumented Testing.

Instrumented testing shall not be performed on electrically initiated devices that have not been tested live either at the device level or in the AUR configuration as defined in Paragraph 4 until a Joint Service agreement on instrumentation methods and procedures are developed. Additional investigation is needed to develop a Joint Service instrumented testing methodology that will provide the safety and operability data for an EID that will include the specific instrumentation, data acquisition, and safety and operability margins for pin to pin, pin to case, and AUR PESD testing. Instrumented testing is allowed for items where the electrical/firing interface has changed, but no changes were made to the EED.

## 11. PESD TEST PROCEDURE REQUIREMENTS.

### 11.1. Bare EED/Initiator Discharges.

Discharges to pairs of pins or leads in all combinations and between the shorted pins or leads (all pins or leads shorted to each other external to the device) and the case of the initiator using the direct contact discharge method only. The pin to case and shorted pins to case discharge connection shall be maintained for 60 seconds. Salients must be used to direct the discharge to the pins or leads in the electrical connector. EEDs must be subjected to no-fire and all fire testing after the PESD test to verify conformance with safety and performance specifications of the device.

### 11.2. Bare and AUR Device Discharges.

Discharges to all electrical interfaces using the direct contact discharge method including: each pin on an external connector that connects directly or indirectly to an EED, firing circuit, control interface, or any other ordnance related function such as antennas or inductive antennas for fuzes are required. All plastic and non-metallic components of a device or AUR that contain ordnance, circuitry that controls the ordnance, or provides a path to the internal components of the device shall receive discharges. Any other possible entry points including joints between sections and covers over cabling shall also be tested. Salients must be used to direct the discharge to test points where arcing could occur to adjacent surfaces such as electrical pins on a connector. EEDs must be subjected to no-fire and all fire testing after the PESD test to verify conformance with safety and performance specifications of the device.

### 11.3. Component Testing.

Items with a remote control shall be tested as individual components (transmitter and receiver), and as a system with both components operating to determine if a discharge to one of the system components can cause a safety or operability consequence in the other component.

### 11.4. Test Sequences.

An equivalent of 22 test sequences shall be conducted when testing to the personnel-borne ESD threat in order to demonstrate 90% operability with 90% confidence. A test sequence is defined as a series of discharges to the device or AUR in accordance with the requirements of Table 1 (4 total discharges per test point) or Table 2 (2 total discharges per test point) as applicable at the test points identified in the pre-test assessment (Paragraph 5 of this document). Subsequent sequences may be conducted by using different items/munitions or on the same item/munition with a different set of EIDs and electronic/electrical subsystems. If the subsequent testing uses the same device or AUR with the same EEDs, functional verification and bridgewire resistance testing should be performed after each series of discharges as defined above, unless documented in the test plan.

11.5. Arming.

Operational conditions may require that an armed item be handled; therefore PESD testing shall include testing in the armed condition for any device that could possibly be handled in the armed condition without regard to operational procedures.

11.6. Bridgewire Resistance Measurements.

Prior to and after the PESD test, bridgewire resistance measurements must be made for all live EIDs in the device or AUR with a bridgewire measurement device for the specific devices being measured.

11.7. Verification of Circuit Functionality.

All electronic circuits/firing circuits and components shall be verified to function normally prior to and after PESD testing.

11.8. Temperature and Humidity.

The test shall be conducted on devices at an ambient temperature of +23°C±10°C (+73°F±18°F). Relative humidity of the test chamber shall be no greater than 50 percent. The device shall be preconditioned at +23°C±3°C (+73°F± 5°F), relative humidity no greater than 50 percent for no less than 24 hours prior to testing. If the size of the AUR precludes indoor controlled testing, test shall be performed at the lowest humidity possible, but as a minimum, there shall be no moisture on the test item (non-condensing humidity level).

## 12. POST PESD TEST REQUIREMENTS.

12.1. No-Fire Safety Requirement.

All EIDs subjected to live PESD testing shall be subjected to bridgewire resistance measurement and no fire performance testing in accordance with MIL-DTL-23659 after PESD testing to verify the item still meets its no fire (safety) requirement. Following the no-fire testing, these items shall be subjected to all-fire testing in accordance with the all fire specification for the item to verify the item has not dudded.

12.2. Inspection.

All EIDs and percussion initiated devices not in a documented faraday cage or other non-electric devices subjected to live PESD testing shall be inspected for initiation and function tested after PESD exposure to verify proper operation.

12.3. Operability.

A complete checkout/functional test of the device or AUR to include all electrical interfaces shall be completed after each set of discharges to verify the item is functional and was not damaged or affected by the PESD test discharges.

Items with a remote control shall be verified to function normally after each set of discharges. Both transmit and receive functions shall be tested and verified operational.

Any functional or operational anomaly that prevents the device or AUR from completing its function when commanded after the selected number of PESD discharges shall be considered an operability failure.

12.4. Data Collection.

Record the following for each discharge:

a) Stimulus waveform parameter data / plots.

b) Test configuration / test mode.

c) Test discharge point.

d) Post-discharge functional check pass/fail results.

e) Visual damage inspection results.

f) Test item responses (e.g. components affected, wire/cable currents, EID currents, upsets, recovery times, etc.).

g) EID bridgewire resistance and determination of degradation, if required.

h. Date, time, location, temperature, and humidity for each discharge.

## 13. PESD TEST ASSESSMENT AND ANALYSIS REPORT.

13.1. Data Sharing.

In order to facilitate data sharing across the Services and to ensure test data consistency and consistent operational guidance, an ESD test report shall be developed as part of every ESD test. All ESD test reports shall be provided to the Defense Information Systems Agency/Joint Spectrum Center (JSC) for incorporation into the JSC Ordnance Electromagnetic Environmental Effects Risk Assessment Database (JOERAD). All ESD test reports shall also be provided to the Navy Electromagnetic Environmental Effects (E3) knowledge system for incorporation into the E3 database at www.e3teamonline.com.

13.2. Test Report.

Test reports shall contain the following information and documentation as a minimum:

13.2.1 Drawing Package: A complete drawing package for the device or AUR identifying all materials of construction and all electrical interfaces.

13.2.2 PESD Test Record consisting of the following:

1) Date(s) of test

2) Test location/facility

3) Test personnel names

4) Test and conditioning records documenting compliance with the following:

5) All test equipment/instrumentation used to measure the waveforms, type/model/serial number, equipment/instrumentation calibration data, and including the calibration waveforms as specified in Paragraph 8.

6) Configuration of test item, Mark (MK), Mod, nomenclature/Department of Defense Identification Code (DODIC), model, drawing, part number, revision, as applicable. The description should include any deletions or variations of the test item from the final configuration of the live ordnance item. The configuration shall also include a complete description of the test item for PESD testing including if it is powered on, armed, electrical interface pins designated for each test, etc.

7) Test item record: Each test article shall be identified and described by a test item record. The record shall include pre-test performance, performance during the test, and post-test performance information and documents as described below:

13.2.3 Pre-test Performance. The operation/function of the device or AUR shall be verified and documented in accordance with Paragraph 11.7 prior to PESD testing to provide a reference for the operability assessment. This includes any functional tests required to verify proper operation of the device or AUR, including operation of remote controlled devices. A record shall be made of all data to determine compliance with required performance and, when applicable, to provide a reference level or criteria for checking desired performance of the test item during or at the conclusion of the test. If several tests are to be performed in sequence and the cumulative effect of use conditions is desired, then the measurement of performance level prior to each individual test may be deleted and only the pre-sequence measurement performed. The pre-test performance check may be made after installation of the item under test if installation conditions necessitate it. Pre PESD test bridgewire resistance measurements are part of the pre-test performance data as specified in Paragraph 11.6.

13.2.4 Performance During Test. When operation of the test item is required during the test, a record shall be kept of the data for comparison with pre-test or post-test performance as required. The conditions during the performance check shall be those specified in the individual test.

13.2.5 Post-test Performance. The operation of the test item shall be verified and documented at the conclusion of the test as specified in Paragraphs 4.4 and 12.3, and compared with pre-test performance or during-test performance, whichever is required for determining the operability of the item from the PESD testing. This functional test shall include the operation and status of any remote controlled device(s). Also, post PESD test bridgewire resistance measurements, no fire test results, and all fire test results are part of the post-test performance documentation that must be included.

13.2.6 Photograph of each test configuration and test point with any salients used to direct PESD discharges to the specific test points

13.2.7 All test results, data, and ESD calibration waveforms including reduced voltage test results.

13.2.8 Analysis of test results and data:

Test data shall be compared and evaluated against the criteria set forth in MIL-STD-464, MIL-STD-331, the test item specification, and test item test plan to determine if the item met the required criteria. Deficiencies shall be identified, and documented.

The PESD post test data shall be compared to the applicable criteria set forth in the TEST ITEM specification, and TEST ITEM test plan and the pre-test baseline measurements to determine the extent to which the test criteria are met and the effects of the PESD test requirements on the TEST ITEM.

13.3. Conclusion on the ESD Sensitivity of the Item and Criteria for Assigning the PESD Code.

13.3.1 Device Condition After Personnel-borne ESD (bare) Tests. At the completion of these tests, the ordnance shall be safe for transportation, storage, handling and use, as well as operable during and after any possible S4 PESD exposure. Safety and operability failures are evaluated separately. No safety failures are allowed for fleet issued items.

13.3.2 Safe for Use. In accordance with Paragraph 3.1, no ordnance item may be dudded or fire. Ordnance use includes installation, firing or release of the ordnance. This requirement includes passing the reduced voltage tests also.

13.3.3 Operable. In accordance with Paragraph 3.1, when the ordnance is provided its required inputs, it shall perform to completion of its function and sequence producing all required outputs within the operating period or at the specified time after all PESD exposure. This requirement includes passing the reduced voltage tests also.

13.3.4 If the test item is not both safe and operable as described above for any PESD exposure, it is sensitive to PESD exposure.

13.3.5 Assignment of Joint Service PESD Code: At the conclusion of all testing and after analysis of all results, the ordnance shall be assigned a PESD Code as delineated below.

**PS**: Safe and operable. This indicates that the ordnance is both safe and operable for PESD exposure. It has passed live PESD testing to all EIDs and/or energetic material with no dudding or initiation, and has passed PESD testing to all electrical interfaces that control or interface to the item with no effect on performance or functioning as described in 13.3.2 and 13.3.3 above.

**PO**: Safe but not operable. This indicates that the ordnance is safe but not operable, or was not tested/evaluated for operability. It has passed live PESD testing to all EIDs and/or energetic material with no dudding or initiation. However, it failed or was not tested for one or more operable requirements and may not perform or function as designed. The operability failures do not affect the safety (no duding or initiation) of the item.

**PH**: Not safe or operable. This indicates that the ordnance is neither safe nor operable, or was not tested/evaluated for safety and operability. It failed live PESD testing or was not tested/evaluated to one or more EIDs and/or energetic material with either dudding or initiation or both. In addition, it failed or was not tested/evaluated for one or more operable requirements and may not perform or function as designed. This code shall only be assigned for items not for Service use in the field such as bare energetic components being shipped from a manufacturer to an assembly facility.

13.4. Safety Data Package.

The results of all PESD testing and analysis conducted relevant to assessing the ordnance item/munitions safety for service shall be compiled into a safety data package for review. The package must include the previously-approved test plan, including the rationale for any variance from the joint requirements. In addition, any deviation from that approved plan shall be presented along with an analysis showing why the results should be accepted. The package must also provide any safety and operability deductions derived from those results.

# JOINT ORDNANCE TEST PROCEDURE (JOTP) FOR HELICOPTER-BORNE ELECTRO-STATIC DISCHARGE (HESD)

## Section 2: HESD Testing

### 14. INTRODUCTION.

Section 2 of this document has been developed to address HESD ordnance safety and operability testing. It is the HESD test procedure for all ordnance/munition types for the purpose of Joint service assessment and testing of conventional (non-nuclear) munitions. This procedure specifies HESD requirements for all ordnance items including bare energetic materials that are cataloged and/or fielded with local or national stock numbers.

### 15. SCOPE.

15.1. Purpose.

The purpose of HESD testing is to determine if exposure of ordnance items, ordnance electrical interfaces, and related systems, including but not limited to firing circuits and control electronics (weapon release, intent to launch, etc.) to the HESD test requirements defined in Paragraph 17 due to operating helicopter and/or aircraft exposure results in a safety and/or operability hazard such as ordnance initiation, Electro-explosive Device (EED) /Electrically Initiated Device (EID) initiation, firing circuit initiation, performance degradation, electrical interface malfunction, or dudding in accordance with the requirements of MIL-STD-464 and MIL-STD-331. Helicopter ESD exposure shall be assessed or tested for man carry (bare, outside the shipping container), Vertical replenishment (VERTREP), external carry, and hot tube loading/ unloading during any of the stockpile to safe separation sequence (S4) phases (e.g. transportation/storage, assembly/disassembly, staged, loading/unloading, platform loaded, and immediate post launch).

Note: EED/EID are considered the same in this document and the terms are used interchangeably.

Note: HESD refers to one or more of the following: VERTREP (Ordnance Information System (OIS) packaged/shipping/storage) configuration, bare/man carry (out of shipping container and carried in to or out of operating aircraft) configuration, external-carry/captive-carry (mechanically and electrically attached to aircraft and exposed to in flight charging) configuration, and hot tube loaded (mechanically and electrically loaded or unloaded to an operating ungrounded aircraft) configuration HESD requirements.

15.2. Application.

Data obtained through use of this document shall be included in the ordnance item/munition safety data package. The HESD test requirements are applicable to all ordnance items (with and without EIDs), ordnance subsystems, ordnance related equipment, launchers, remote control devices, EIDs and firing/monitoring circuits, including those installed external to aircraft and vehicles, those carried outside the shipping container internal to the aircraft, and for hot tube loading operations.

HESD test requirements may be applicable at either or both the equipment/system/ All Up Round (AUR) level and the device level depending on the configuration, assembly, and use of the item in the field. The HESD requirements shall be applied to selected test points on the test item, without regard to procedural controls for the test item (such as a requirement to wear a static dissipative wrist strap and ground before handling the item), which could possibly make contact with a charged aircraft or become charged during the different configurations/modes of operation including: transportation/VERTREP, man-carry transporting (internal, outside the shipping container), external carry, and hot tube loading/ unloading. Unauthorized non-standard configurations do not need to be addressed such as disassembly of an AUR that is not authorized in the field. Specific HESD test requirements are identified by ordnance commodity in Paragraph 17.

Note: For the purposes of this document, the test item may be either a single self- contained ordnance device (hereafter referred to as device or EID) with a single percussion initiation system or single EID; or the test item may be an ordnance system/AUR (hereafter referred to as system or AUR) with multiple ordnance and/or related items assembled in one unit.

15.3. Limitations.

This document is only applicable to conventional (non-nuclear) munitions to aid in the item, device, system, or AUR safety and operability assessment. This document is not intended to be used to aid the assessment of effectiveness, reliability or performance of an ordnance item/AUR.

## 16. REFERENCE HESD AND P-STATIC GUIDANCE.

NOTE: Text in paragraph 3 in italics is material extracted from MIL-STD-464 and MIL-STD-331, respectively; non-italicized text is JOTP procedure wording.

**MIL-STD-464 states:**

***MIL-STD-464C, 5.8.1 Vertical lift and in-flight refueling.***

*The system shall meet its operational performance requirements when subjected to a 300 kilovolt discharge. This requirement is applicable to vertical lift aircraft, in-flight refueling of any aircraft, any systems operated or transported externally by vertical lift aircraft, and any man portable items that are carried internal to the aircraft. Compliance shall be verified by test (such as MIL-STD-331 or AECTP-500, Category 508 Leaflet 2 for ordnance), analysis, inspections, or a combination thereof. The item configuration may be packaged or* *bare, depending on the stockpile to safe separation sequence, but the specific configuration must be noted in the test report. The test configuration shall include electrostatic discharge (ESD) in the vertical lift mode and in-flight refueling mode from a simulated aircraft capacitance of 1000 picofarads, through a maximum of one (1) ohm resistance with a circuit inductance not to exceed 20 microhenry*.

**MIL-STD-331C states:**

***F1.4.2.2 Helicopter-borne ESD test.*** *The energy delivered to the calibration test load given in Table F1-I shall be between 80% and 100% of the energy stored on capacitor C.*

The Safe and Operable (reliable) requirements are defined in MIL-STD-331C:

***4.6.2.1*** *a.* ***Safe for use.*** *The fuze shall maintain its safety features in a condition which will not create a hazard for personnel or cause any subsequent action which will compromise the safety conditions required during handling, transportation, storage and use. Fuze use includes installation and firing or release of the weapon where damage or irregularity does not prevent assembly of the fuze to the weapon or loading.*

Note: For the purposes of Joint HESD testing, the safe for use requirement applies to all ordnance items and materials, not just fuzes.

***4.6.2.2 Operable.(Reliable)*** *When the fuze is provided its required inputs, it shall perform to completion of its function and sequence producing all required outputs within the operating period or at the specified time. Determination of operability may require firing the fuze using a procedure adapted to the type of fuze being tested and its associated munition.*

### 16.1. Implementation of Guidance

All items containing any energetic material or that control energetic items containing energetic material shall remain safe and operable during and after exposure to the HESD test requirements, and meet its performance requirements during and after exposure to the HESD test requirements, with parameters specified by MIL-STD-464C, Paragraph 5.8.1 and 5.8.2, and MIL-STD-331C paragraph F1.4.2.2.

### 16.2. HESD Guidance.

HESD shall be tested and/or assessed for all ordnance devices and AUR items in the following exposures:

a) VERTREP for packaged items in the documented packaged configuration. This requirement applies to all items.

b) Bare/man-carry for items carried out of the packaged configuration into or out of operating aircraft.

c) External carry for items already mechanically and electrically attached to the exterior of aircraft and exposed to in-flight charging.

d) Hot tube loaded for items that are mechanically and electrically installed and connected on ungrounded operating aircraft.

## 17. HESD REQUIREMENTS:

### 17.1. HESD Test Requirements.

HESD testing shall be to any point on the item/AUR that may be contacted or become charged during VERTREP, hot tube loading/unloading, external carry, and/or man-carry/internal transport, and in the appropriate worst case operational mode (powered on, unpowered, armed, etc.) in each configuration including ordnance electrical interfaces (including but not limited to firing circuits, control electronics, weapon release, intent to launch, etc.). The assessment from Paragraph 18 of this document should be used to determine the discharge points.

### 17.2. VERTREP Requirements.

All devices that contain energetic material, electrically initiated devices, and/or percussion initiated devices that are not in a faraday cage package (as defined according to this document) shall be tested in the packaged VERTREP configuration according to the HESD requirements in Table 4. If the device/item contains only energetic material (percussion devices, no EED) that is not in a faraday cage as defined in this document, then the VERTREP testing must include the live energetic material. All items must be evaluated using live EEDs or energetic material according to the electrical schematic of Figure 6. This requirement shall apply to all items from every commodity category from Table 5.

### 17.3. Bare/Man Carry Requirements.

Any device that could possibly be carried bare (outside the shipping container) on an aircraft that contains energetic material, electrically initiated devices, and/or percussion initiated devices that are not in a faraday cage (as defined in this document) shall be tested according to the HESD requirements in Table 4. All items must be evaluated using live EED's or energetic material if not a faraday cage in the man carry (bare configuration) according to the electrical schematic of Figure 5. This requirement shall apply to all items in the following commodity categories from Table 5: Small Caliber Ammunition; Non-Lethal Ammunition; Man Emplaced Ammunition; Man Carried Missile/Rocket; Pyrotechnics; Fuze and Ignition Systems; and any air launched rockets/missiles that could be carried bare on/in a helicopter or other aircraft, and other items from the remaining commodity categories that could be carried bare on an aircraft.

17.4. External Carry.

Any device that could possibly be carried externally (outside the shipping container) on an aircraft that contains energetic material, electrically initiated devices, and/or percussion initiated devices that are not in a faraday cage (as defined in this document) shall be tested according to the HESD requirements in Table 4. All items must be evaluated using live EEDs or energetic material if not a faraday cage in the external carry configuration according to the electrical schematic of Figure 5. This requirement shall apply to all items in the following commodity categories from Table 5: Air Launched Missile/Rocket and any other items that could be carried external on an aircraft.

17.5. Hot Tube Loaded.

Any device that could possibly be hot tube loaded/unloaded into/out of a launcher or onto an operating aircraft that contains energetic material, electrically initiated devices, and/or percussion initiated devices that are not in a faraday cage (as defined in this document) shall be tested according to the HESD requirements in Table 4. All items must be evaluated using live EEDs or energetic material if not in a faraday cage in the hot tube loaded configuration according to the electrical schematic of Figure 5. This requirement shall apply to all items in the following commodity categories from Table 5: Air Launched Missile/Rocket and any other items that could be hot loaded on an aircraft.

17.6. Performance Requirements.

During and after exposure to the HESD test requirements, the energetic item or AUR, including associated launchers, remote control devices, and associated electronics shall meet the performance requirements detailed in their specifications with no safety or operability/performance failures or malfunctions and without resetting or re-powering the device or AUR. Momentary upsets that auto-correct (without operator action) and have no effect on the operation of the item, such that it produces all required outputs at the specified time are allowed.

## 18. PRE HESD TEST ASSESSMENT.

Use of previous analyses and/or test data from previous variants of the same AUR may be evaluated and incorporated into the test planning and pre-test assessment in order to enhance and/or reduce the scope of the new testing, and to provide justification for the new test item configurations and test approach. A pre-test assessment is performed to include the following for test planning:

a) Determine HESD energy points of entry (points possibly contacted with a charged aircraft or entry points from near or direct strike discharges) through an analysis of the complete drawing package that specifically identifies all the materials of construction for the device or AUR, and the shipping/packaging configuration. Energy entry points include switches, displays, battery terminals, output terminals, electrical interfaces, containers/container joints or discontinuities, and non-conductive surfaces, etc.

b) Determine the HESD external and internal current paths through an analysis of the container, electrical and mechanical interface drawings for the device or AUR. This may not be possible with non-metallic materials or with internal coupling paths.

c) Determine the most/least susceptible test item configurations and possible modes of operation based on aircraft exposure without regard to procedural controls during transportation/VERTREP, man-carry transporting (internal), external carry, and hot tube loading/ unloading.

d) Determine test item data required to be monitored or tested during or after HESD testing to evaluate the safety and operability/performance effects on the test item. This includes bridgewire resistance, communication links, programming modes, firing circuits, safe/arm indicators, etc. that are part of the device or AUR.

e) Determine test item HESD protection features and their predicted performance and whether they are repairable or replaceable.

f) Determine procedures and equipment required to verify the post HESD test performance for each device, circuit, AUR, and non-faraday cage component.

## 19. PREVIOUS TEST DATA AND/OR ANALYSIS REQUIREMENTS.

The following are exceptions to conducting the HESD test on a new or modified ordnance device or AUR, or a subcomponent of the AUR. These exceptions only cover the energetic items, and any circuitry that is part of the AUR that was previously tested or analyzed that has not been changed as specified below. Any changes to the circuitry or energetic items must be addressed in the testing for the new/modified ordnance device or AUR, or a subcomponent of the new/modified AUR.

### 19.1. Faraday Cage Design.

19.1.1 Devices: Any device, AUR, or subcomponent of an AUR, that is completely surrounded by metal with no openings and has no external electrical connectors/leads or conductive mix primer/initiator is by design a faraday shield and is safe for bare HESD exposure, provided all of the following are met:

a) All components of the device are constructed of metal material of minimum 0.016 inch and with low bonding resistance (less than 1 ohm) across any non- welded components.

b) Official signed drawings documenting the component materials of all components surrounding the energetic material are required to provide ESD faraday cage designation. Performance specifications are not acceptable if the component materials are not specified for the device, AUR, or subcomponent of an AUR.

19.1.2 Shipping Containers: Any shipping/packaging container that is completely made of metal and has no external electrical connectors/leads or openings (such as vents, etc.) is by design a faraday cage/shield and provides protection to any device contained inside from HESD exposure, provided all of the following are met:

a) All components of the shipping/packaging container are constructed of metal material of minimum 0.016 inch thickness and with low bonding resistance (less than 1 ohm) across any non- welded components.

b) Official signed drawings documenting the component materials of all components of the shipping/packaging container are required to provide faraday shield ESD designation. Performance specifications are not acceptable if the component materials are not specified for all components of the shipping/packaging container.

19.1.3 If the device or shipping container/packaging does not meet all the requirements above, then testing shall be required:

The container/packaging containing the device or AUR with live EEDs and/or energetic material must be tested to the requirements of Table 4 with 10 sets of positive and negative direct contact discharges to the thinnest and/or non-metallic section(s) of the container/device without melt/burn through, or initiation/dudding.

19.2. Previous Test Data.

Previous test results and/or analysis on a previous variant of a new item may be used in the certification of a new item to reduce the scope of testing of the new item if the previous testing completely documented the safety and operability requirements for HESD as detailed in this document and if the following apply:

19.2.1 The new item/AUR is a variant of a previously fielded device, AUR, subcomponent of an AUR, or shipping container. The new variant and/or shipping container shall be analyzed and tested for:

a) Changes to energetic components,

b) Changes to system construction materials, and

c) Changes to electrical connectors/electrical interfaces as a minimum.

Only the new energetic items, sections with different materials of construction, or new electrical interfaces/firing circuits shall be tested in accordance with the requirements of this document.

19.2.2 The new item contains energetic devices that were HESD tested through previous live testing in accordance with the requirements of this document, and no changes to the materials of construction for the item or AUR. These energetic devices do not need to be tested for the new item for safety concerns, but for any new or modified firing circuits or other circuitry in the new AUR or new subcomponent of the AUR of these previously HESD tested items, those circuits shall be tested for operability along with any other energetic devices that do not have live test results.

## 20. TEST EQUIPMENT AND INSTRUMENTATION.

### 20.1. Voltage, Capacitance, Discharge Inductance, and Resistance.

The voltage, capacitance, resistance, and discharge circuit inductance, including the inductance of the capacitor and wiring to the probes shall be in accordance with the values in Table 4. Inductance shall be measured at a nominal 1 kHz frequency.

**Table 4: HESD Requirements**

| Voltage | Capacitance (farad) | Discharge Inductance (Henry (H)) | Series Resistance (ohms (Ω)) |
|---|---|---|---|
| ± 300,000 ± 500 V | 1000 pF ± 5% | ≤1 Ω | < 20 µH |

NOTE: No additional resistance or inductance shall be added to the circuit. Only the capacitor, switches, wiring, and discharge electrode/cable are allowed in the circuit.

### 20.2. Discharge Methods.

There are two acceptable methods for discharge that can be employed for HESD testing including direct contact discharge and approaching probe discharge.

a) Direct Contact Discharge: This method uses a discharge electrode from the test generator that is placed in direct contact with the selected test point and the discharge is triggered (manually or remotely) with a discharge switch in the test generator. This is the discharge method that must be used for man-carry/bare and hot tube loading HESD testing using the electrical schematic of Figure 5.

b) Approaching Probe Discharge: This method positions the discharge electrode from the test generator approximately 4 feet from the selected test point, and the discharge electrode is moved at a minimum speed of 2 feet per second to the test point to initiate a discharge. If there is a possibility that the discharge could arc to another surface instead of the selected test point (such as a different pin on a connector), a salient shall be attached to the test point to direct the discharge to the selected discharge point without the possibility of arcing to an unintended discharge point. This is the discharge method that must be used for VERTREP and external carry HESD testing using the electrical schematic of Figure 6.

In order to meet the HESD requirements of this document, regardless of the discharge method used, the energy measured during the calibration discharge using the selected discharge method for testing must be within the limits shown in Figure 7.

20.3. Circuit Schematics.

a) Figure 5 defines the circuit schematic to be used for bare/man-carry and hot tube loaded HESD testing

b) Figure 6 defines the circuit schematic to be used for VERTREP and External carry HESD testing.

20.4. Instrumentation.

The test measurement equipment shall have:

a) Minimum bandwidth of DC to 200 MHz
b) Minimum rise time of 2 nanoseconds

Unless otherwise stated, test equipment accuracy/tolerances shall meet the following minimum requirements:

a) Distance: ± 5 %
b) Frequency: ±2 %
c) Amplitude, ± 2 %
d) Time (waveforms): ± 2 %
e) Resistance: ± 1 %
f) Capacitors: ± 5 %
g) Current: ± 2 %
h) Voltage: ± 2 %

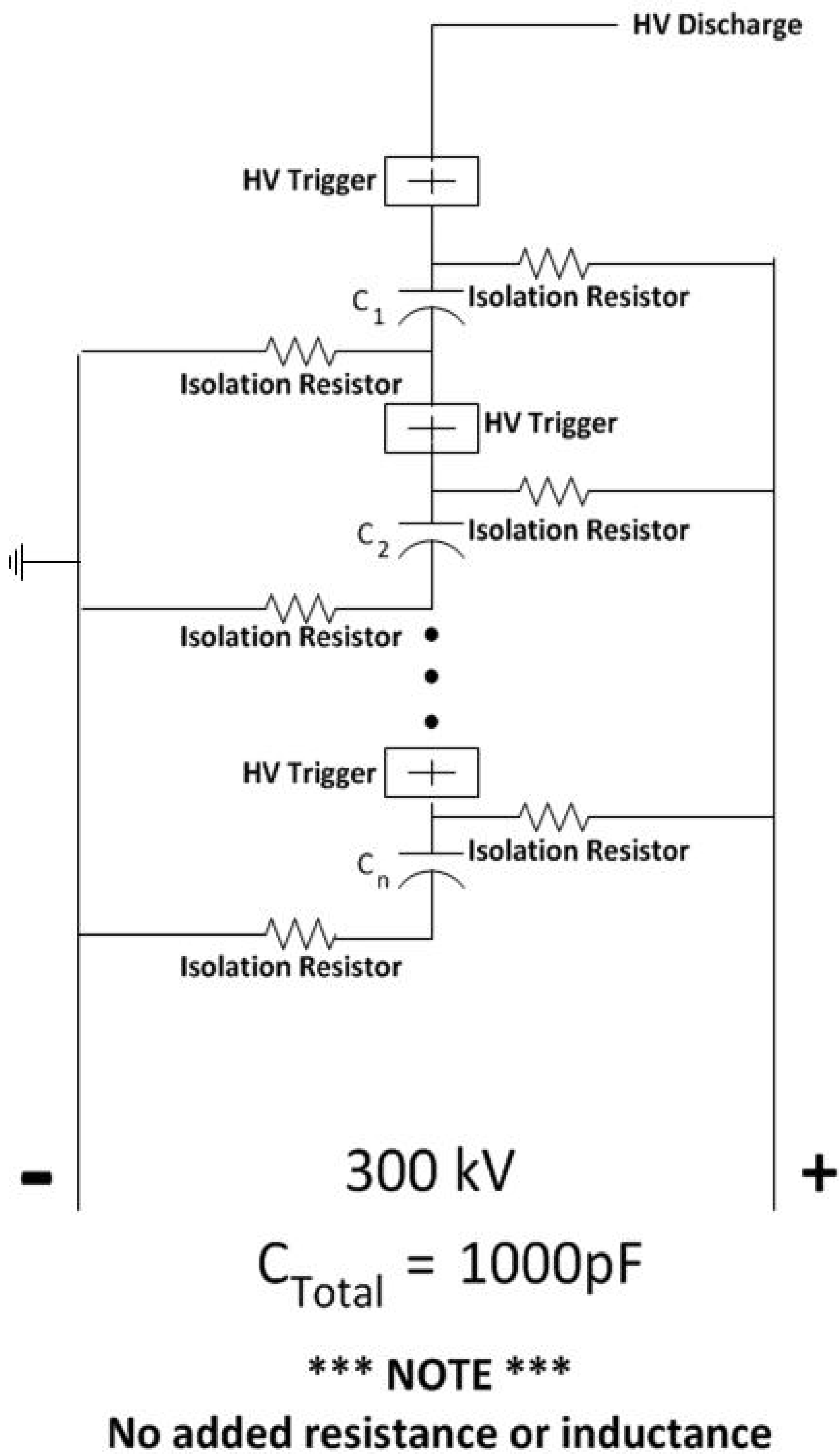



**Figure 5: Bare/Man-carry/Hot Tube Loaded Electrical Schematic**

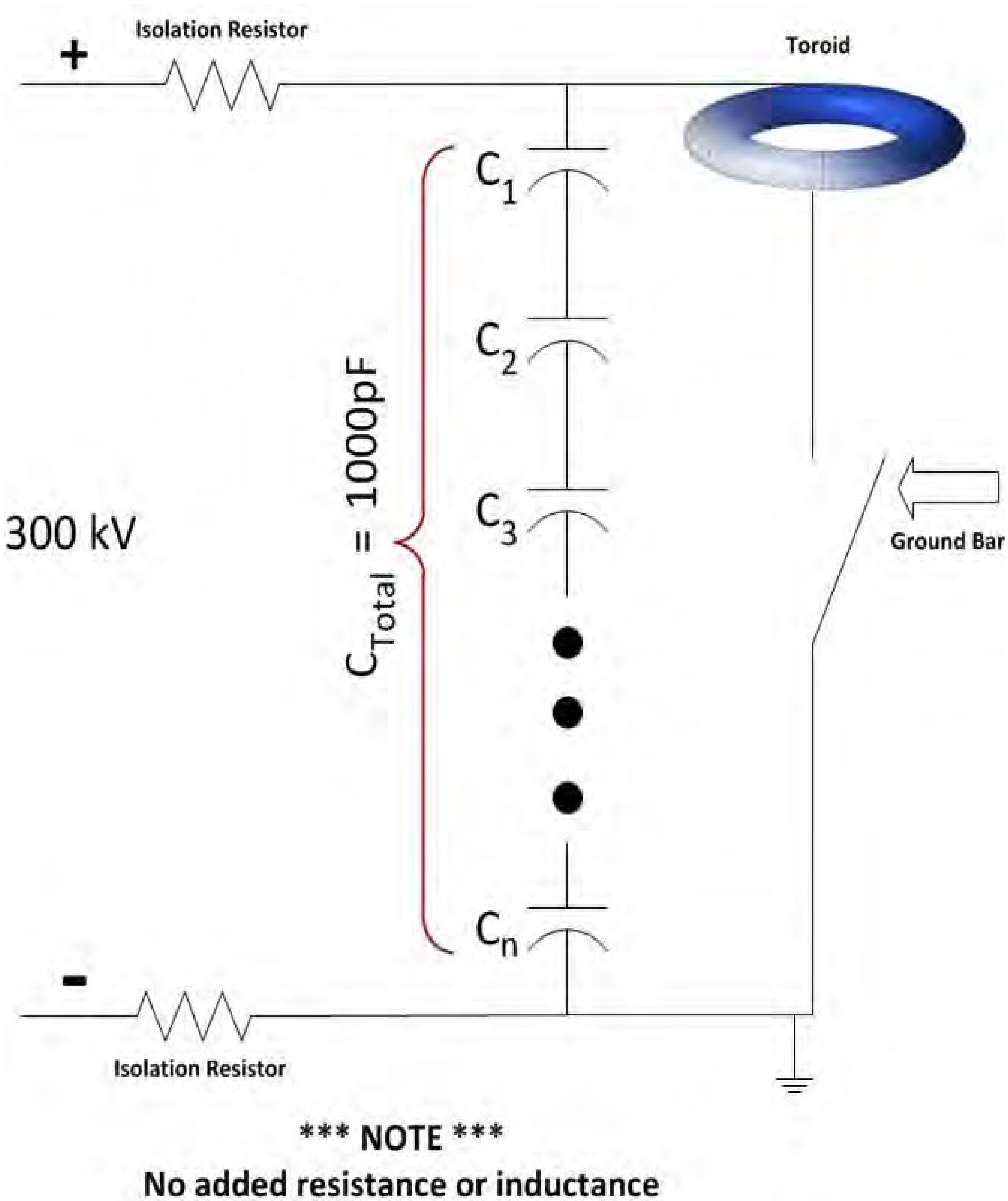



**Figure 6: VERTREP/External Carry Electrical Schematic**

## 21. CALIBRATION REQUIREMENTS.

The energy measured during calibration shall be as defined in Figure 7. The upper (iUL) and lower (iLL) limits for the waveforms are based on the maximum and minimum energy output of the circuit in Figures 5 and 6 using the component tolerances in Table 4. Calibration test waveforms shall fall within the upper and lower limits specified in Figure 7. For additional information on these limits, see Appendix A3.

The calibration test shall be a shorted discharge to the ground plane from the test electrode using a current transformer to measure the current for the man carry/hot tube loaded configuration, and a shorted discharge to the toroid from the test ground electrode for the VERTREP/external carry configuration.

The energy delivered to the test item from the test equipment shall be verified and recorded on a daily basis prior to testing and at the conclusion of testing for the day at a minimum in accordance with the calibration limits of Figure 7. If a salient is used on the test item, it shall be considered part of the discharge circuit and used during calibration.

Any commercial ESD test equipment shall be analyzed for compliance with the calibration waveforms and circuit schematic for suitability to the requirements of this document. Equipment claiming MIL-STD-331 compliance does not imply the equipment meets the performance requirements of this document.

All test and measurement equipment must be in current calibration for the test data to be valid. Any attenuation used in the measurement circuit must be calibrated and clearly identified on the data plots to verify the results.

## 22. TEST SAMPLE QUANTITIES.

Minimum sample size for AUR HESD testing shall be 10 items for all ordnance commodity categories. No inert testing is allowed unless the device/AUR or the subcomponent of the AUR has been verified as a faraday cage or has previously been tested live in accordance with Paragraph 17 of this document. Irrespective of the sample size used for the testing, the equivalent number of discharges delivered to 10 samples must be delivered to the sample size used for testing.

Minimum sample size is 10 items for bare devices or devices that are not identified in Table 5 ordnance commodity categories such as: electrically initiated devices, electrically initiated devices in an AUR that have either one or both pins accessible on an external connector, bare energetic material, and percussion initiated devices that are not in a faraday cage as defined in this document. No inert testing is allowed unless the item has been verified as a faraday cage in accordance with the requirements of this document or has previously been tested live in accordance with Paragraph 17 of this document.

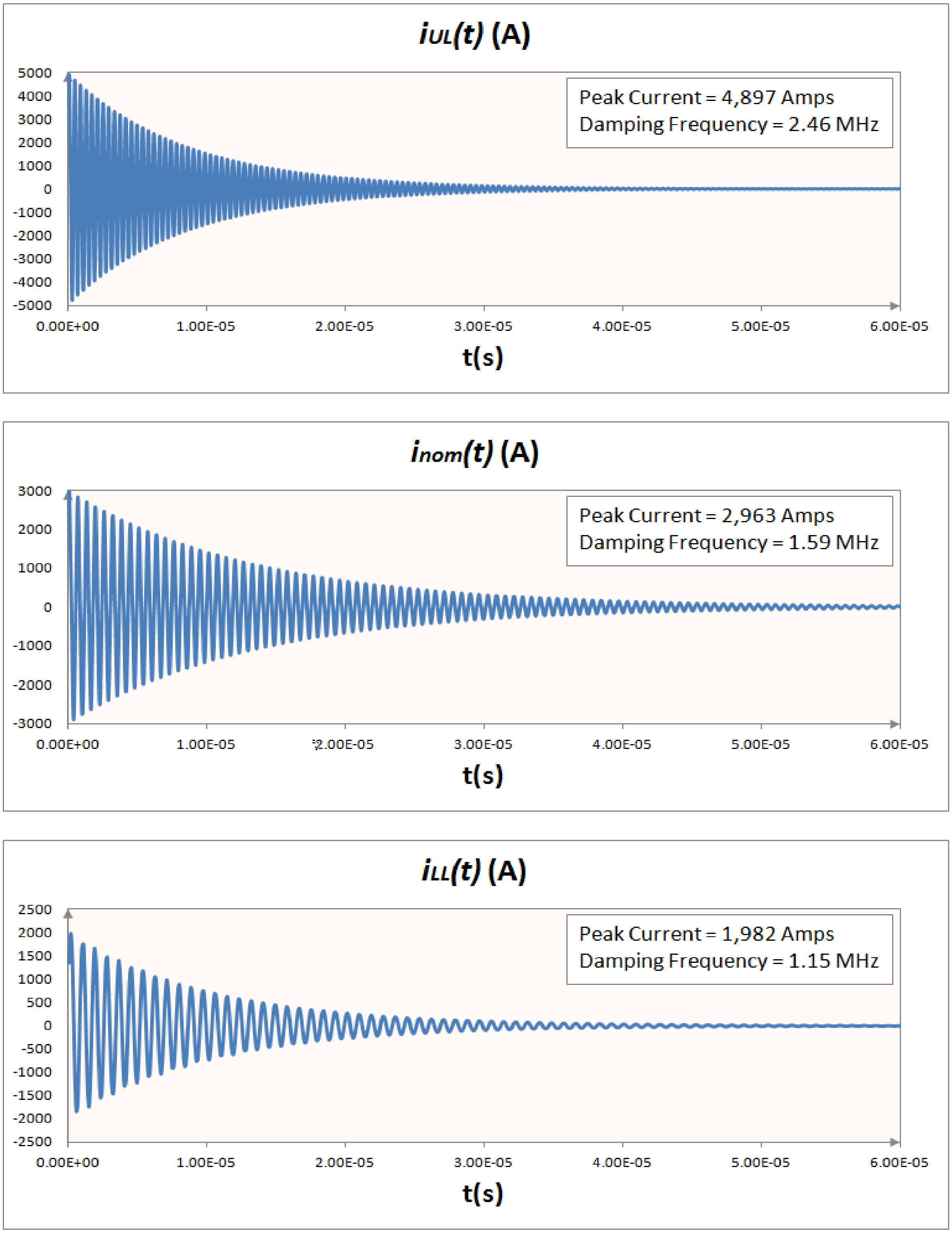



**Figure 7: HESD Current Waveforms with Upper, Nominal, and Lower Limits**

**Table 5: HESD Ordnance Commodity Categories**

| **Commodity:** |
|---|
| Large Caliber Ammunition |
| Medium Caliber Ammunition |
| Small Caliber Ammunition |
| Non-Lethal Ammunition |
| Man Emplaced Ammunition |
| Air Launched Missile/Rocket |
| Surface Launched Missile/Rocket |
| Man Carried Missile/Rocket |
| Pyrotechnics |
| Fuze and Ignition Systems |
| Underwater |

22.1. Incremental Voltage Testing.

A minimum of four devices of the 10 samples required for HESD testing in the tested configuration (bare/man-carry, hot tube loaded, external carry, or VERTREP) must receive incremental voltage testing using the component requirements of Table 4 and voltages of 50 kV, 100 kV, 150 kV, 200 kV, 250 kV, and 300 kV using the appropriate electrical test equipment schematic from Figure 5 for bare/man carry/hot tube loaded configuration or Figure 6 for VERTREP/external carry configuration to document the safety and operability of the item to all possible HESD exposures. One of the devices shall be tested using positive voltages starting at 50 kV and increasing the voltage up to 300 kV in 50 kV steps, and the other device shall be tested starting at 300 kV and decreasing the voltage in 50 kV steps down to 50 kV. The other two devices shall be tested using negative voltages in a similar incremental voltage fashion (One device starting at negative 50 kV and decreasing the voltage to negative 300 kV in 50 kV steps, and the other device starting at negative 300 kV and increasing the voltage in 50 kV steps up to negative 50 kV). Irrespective of the sample size used for the incremental voltage testing, the equivalent number of discharges delivered to 4 samples must be delivered to the sample size used for this testing. The four devices required for this testing shall be from the 10 total samples required for testing.

## 23. TEST ITEM CONFIGURATION.

If the device or AUR contains electrically initiated devices and/or electrically initiated devices connected to an external connector of the AUR that have not been tested to the requirements of this document, then testing with live EID(s) is required. Test bare device/AUR with live EIDs in the man-carry or hot tube loaded configuration using direct contact discharge only; test packaged device or AUR with live EIDs in the VERTREP or external carry configuration using approaching probe discharge only unless the EIDs are internal to the AUR and meet the faraday cage protection requirements as defined in this document.

23.1. Electrically Initiated Devices.

Electrically initiated devices contained in a non faraday cage AUR and not connected to an exterior electrical connector:

1) Which have not previously been tested in the same AUR configuration, or

2) With different circuitry leading to the EID than a previously tested version,

must be tested with live devices in the AUR configuration.

Note: Operability testing of the AUR electronics leading to a previously tested EID internal to the AUR may be performed using an inert/instrumented EID.

23.2. Percussion Initiated Devices.

Percussion initiated devices not in a documented faraday cage or other non-electric devices must be tested live. Test configuration shall be bare for man carry/hot tube loaded evaluation, in the shipping configuration for VERTREP evaluation, and in the installed configuration with cabling attached for the external carry evaluation.

23.3. Configuration Changes.

Any change to a previously HESD tested and/or certified device or AUR, including changes to component materials, energetic materials, EIDs, packaging/shipping container, electrical interfaces, communication interfaces, or remote devices shall be subjected to HESD testing to verify the new configuration meets the requirements of this document and assigned a new nomenclature/cataloging number.

23.4. Instrumented Testing.

Instrumented testing shall not be performed on electrically initiated devices that have not been tested live either at the device level or in the AUR configuration as defined in Paragraph 17 until Joint Service agreement on instrumentation methods and procedures are developed. Additional investigation is needed to develop a Joint Service instrumented testing methodology that will provide the safety and operability data for an EID that will include the specific instrumentation, data acquisition, and safety and operability margins for HESD testing. Instrumented testing is allowed for items where the electrical/firing interface has changed, but no changes were made to the EED.

## 24. HESD TEST PROCEDURE REQUIREMENTS.

24.1. Man carry/Bare Discharges.

For man carry and hot tube loading exposure, direct contact discharges to all electrical interfaces including: each pin on an external connector that connects directly or indirectly to an EED, firing circuit, control interface, or any other ordnance related function such as antennas or inductive antennas are required. All plastic and non-metallic components of a device or AUR that contain ordnance, circuitry that controls the ordnance, or provides a path to the internal components of an AUR shall receive direct contact discharges. Any other possible entry points including joints between sections and covers over cabling shall also be tested. Salients must be used to direct the discharge to test points where arcing could occur to adjacent surfaces such as electrical pins on a connector. If the item is bare energetic material, the material must be in a container of similar size as the test sample and isolated from the ground plane to preclude arcing around the energetic material, and have small openings for the salients to replicate the reaction when the material is in an enclosed device. EEDs must be subjected to no-fire and all fire testing after the test to verify conformance with safety and operability specifications of the device.

24.2. VERTREP Discharges.

For VERTREP exposure, approaching probe discharges shall be to any point on the non-faraday cage shipping container near any electrical interface, firing circuit, EED, antenna, plastic component, or ordnance material that may provide a path for the discharge energy to the ordnance item or AUR. Salients must be used to direct the discharge to test points where arcing could occur to adjacent surfaces. EED's must be subjected to no-fire and all fire testing in accordance with the requirements in MIL-DTL-23659 after the VERTREP test to verify conformance with safety and operability specifications of the device.

24.3. External Carry Discharges.

For external carry exposure, items shall be tested with all electrical cables attached and approaching probe discharges shall be to any point on the installed external carry configuration item near any electrical interface, firing circuit, EED, antenna, plastic component, metal joint, or ordnance material that may provide a path for the discharge energy to the ordnance item or AUR. Salients must be used to direct the discharge to test points where arcing could occur to adjacent surfaces. EEDs must be subjected to no-fire and all fire testing after the test to verify conformance with safety and operability specifications of the device.

24.4. Hot Tube Loaded Discharges.

For hot tube loaded exposure, items shall be tested with direct contact HESD discharges to all external electrical pins, antennas, and non-metallic points of entry that may provide a path for the discharge energy to the ordnance item or AUR. Salients must be used to direct the discharge to test points where arcing could occur to adjacent surfaces. EEDs must be subjected to no-fire and all fire testing after the test to verify conformance with safety and operability specifications of the device.

24.5. Component Testing.

Items with a remote control shall be tested as individual components (transmitter and receiver), and as a system with both components operating to determine if a discharge to one of the system components can cause a safety or operability consequence in the other component.

24.6. Test Sequences.

An equivalent of 10 test sequences shall be conducted when testing to the helicopter-borne ESD threat. A test sequence is defined as a series of discharges to the device or AUR in accordance with the requirements of Table 4 (2 minimum discharges per test point) at the test points identified in the pre-test assessment (paragraph 18 of this document). Subsequent sequences may be conducted by using a different device/AUR or on the same device/AUR with a different set of EIDs and electronic/electrical subsystems. If the subsequent testing uses the same device or AUR with the same EEDs, functional verification and bridgewire resistance testing should be performed after each series of discharges as defined above, unless documented in the test plan.

24.7. Arming.

Operational conditions may require that an bare/man carry armed item be handled or carried when in or around operating rotary winged aircraft; therefore HESD testing shall include testing in the armed condition for any device that could possibly be exposed to operating helicopters or aircraft in the bare/man carry configuration in the armed condition without regard to operational procedures.

24.8. Bridgewire Resistance Measurements.

Prior to and after the HESD test, bridgewire resistance measurements must be made for all live EIDs in the device or AUR with a bridgewire measurement device for the specific devices being measured.

24.9. Verification of Circuit Functionality.

All electronic circuits/firing circuits and components shall be verified to function normally prior to and after HESD testing.

24.10. Temperature and Humidity.

The test shall be conducted on devices at an ambient temperature of +23°C±10°C (+73°F±18°F). Relative humidity of the test chamber shall be no greater than 50 percent. The device shall be preconditioned at +23°C±3°C (+73°F± 5°F), relative humidity no greater than 50 percent for no less than 24 hours prior to testing. If the size of the AUR precludes indoor controlled testing, test shall be performed at the lowest humidity possible, but as a minimum, there shall be no moisture on the test item (non-condensing humidity level).

## 25. POST HESD TEST REQUIREMENTS.

### 25.1. No-Fire Safety Requirement.

All EIDs subjected to HESD testing shall be subjected to bridgewire resistance measurement and no fire performance testing in accordance with MIL-DTL-23659 after HESD testing to verify the item still meets its no fire (safety) requirement. Following the no fire testing, these items shall be subjected to all fire testing in accordance with the all fire specification for the item to verify the item has not dudded.

### 25.2. Inspection.

All EIDs and percussion initiated devices not in a documented faraday cage or other non-electric devices shall be inspected for initiation and function tested after HESD exposure to verify proper operation.

### 25.3. Operability.

A complete checkout/functional test of the device or AUR to include all electrical interfaces shall be completed after each set of discharges to verify the item is functional and was not damaged or affected by the HESD test discharges.

Items with a remote control shall be verified to function normally after each set of discharges. Both transmit and receive functions shall be tested and verified operational.

Any functional or operational anomaly that prevents the device or AUR from completing its function when commanded after the selected number of HESD discharges shall be considered an operability failure.

### 25.4. Data Collection.

Record the following for each discharge:

a) Stimulus waveform parameter data / plots.

b) Test configuration / test mode.

c) Test discharge point.

d) Post-discharge functional check pass/fail results.

e) Visual damage inspection results.

f) Test item responses (e.g. components affected, wire/cable currents, EID currents, upsets, recovery times, etc.).

g) EID bridgewire resistance and determination of degradation, if required.

h) Date, time, location.

## 26. HESD TEST ASSESSMENT AND ANALYSIS REPORTS.

### 26.1. Data Sharing.

In order to facilitate data sharing across the Services and to ensure test data consistency and consistent operational guidance, an ESD test report shall be developed as part of every ESD test. All ESD test reports shall be provided electronically in pdf format to the Defense Information Systems Agency/ the Defense Information Systems Agency/Joint Spectrum Center (JSC) for incorporation into the JSC Ordnance Electromagnetic Environmental Effects Risk Assessment Database (JOERAD). All ESD test reports shall also be provided to the Navy E3 knowledge system for incorporation into the E3 database at www.e3teamonline.com.

### 26.2. Test Report.

Test reports shall contain the following information and documentation as a minimum:

26.2.1. Drawing Package: A complete drawing package for the device or AUR identifying all materials of construction and all electrical interfaces.

26.2.2. HESD Test Record consisting of the following:

1) Date(s) of test

2) Test location/facility

3) Test personnel names

4) Test and conditioning records documenting compliance with the following:

5) All test equipment/instrumentation used to measure the waveforms, type/model/serial number, equipment/instrumentation calibration data, and including the calibration waveforms as specified in Paragraph 21.

6) Configuration of test item, Mark (MK), Mod, nomenclature /Department of Defense Identification Code (DODIC), model, drawing, part number, revision, as applicable. The description should include any deletions or variations of the test item from the final configuration of the live ordnance item. The configuration shall also include a complete description of the test item for HESD testing including if it is powered on, armed, electrical interface pins designated for each test, etc.

7) Test item record: Each test article shall be identified and described by a test item record. The record shall include pre-test performance, performance during the test, and post-test performance information and documents as described below.

26.2.3 Pre-test Performance.

The operation/function of the device or AUR shall be verified and documented in accordance with Paragraph 24.10 prior to HESD testing to provide a reference for the operability assessment. This includes any functional tests required to verify proper operation of the device or AUR, including operation of remote controlled devices. A record shall be made of all data to determine compliance with required performance and, when applicable, to provide a reference level or criteria for checking desired performance of the test item during or at the conclusion of the test. If several tests are to be performed in sequence and the cumulative effect of use conditions is desired, then the measurement of performance level prior to each individual test may be deleted and only the pre-sequence measurement performed. The pre-test performance check may be made after installation of the item under test if installation conditions necessitate it. Pre HESD test bridgewire resistance measurements are part of the pre-test performance data as specified in Paragraph 24.9.

26.2.4 Performance During Test.

When operation of the test item is required during the test, a record shall be kept of the data for comparison with pre-test or post-test performance as required. The conditions during the performance check shall be those specified in the individual test.

26.2.5 Post-test Performance. The operation of the test item shall be verified and documented at the conclusion of the test as specified in Paragraphs 17.7 and 25.3, and compared with pre-test performance or during-test performance, whichever is required for determining the operability of the item from the HESD testing. This functional test shall include the operation and status of any remote controlled device(s). Also, post HESD test bridgewire resistance measurements, no fire test results, and all fire test results are part of the post-test performance documentation that must be included.

26.2.6. Photographs of each test configuration and test point with any salients used to direct HESD discharges to the specific test points.

26.2.7 All test results, data, and ESD calibration waveforms including reduced voltage test results.

26.2.8. Analysis of Test Results and Data. Test data shall be compared and evaluated against the criteria set forth in MIL-STD-464, MIL-STD-331, the test item specification, and test item test plan to determine if the item met the required criteria. Deficiencies shall be identified, and documented.

The HESD post test data shall be compared to the applicable criteria set forth in the TEST ITEM specification, and TEST ITEM test plan and the pre-test baseline measurements to determine the extent to which the test criteria are met and the effects of the HESD test requirements on the TEST ITEM.

26.3. Conclusion on the ESD Sensitivity of the Item and Criteria for Assigning the HESD Code.

26.3.1 Device Condition After Helicopter-borne ESD Tests. At the completion of these tests, the ordnance shall be safe for transportation, storage, handling and use, as well as operable during and after any possible S4 HESD exposure. Safety and operability failures are evaluated separately. No safety failures allowed for bare/man carry/hot tube loaded items or for packaged items.

26.3.2 Safe for Use. In accordance with Paragraph 16.1, no ordnance item may be dudded or fire. Ordnance use includes installation, firing or release of the ordnance. This requirement includes passing the reduced voltage tests also.

26.3.3 Operable. In accordance with Paragraph 16.1, when the ordnance is provided its required inputs, it shall perform to completion of its function and sequence producing all required outputs within the operating period or at the specified time after any possible HESD exposure. This requirement includes passing the reduced voltage tests also.

26.3.4 If the test item is not both safe and operable as described above for any possible HESD exposure (man carry/hot tube loaded, VERTREP, and P-static), it is sensitive to one or more HESD exposures.

26.3.5 Assignment of Joint Service HESD Code: At the conclusion of all testing and after analysis of all results, the ordnance shall be assigned a HESD Code as delineated below:

**HS**: Safe and operable for bare/man carry/hot tube loading HESD exposure. This indicates that the ordnance is both safe and operable for HESD exposures including man carry/hot tube loading and VERTREP. It has passed live HESD testing to all EID's and/or energetic material with no dudding or initiation, and has passed HESD testing to all electrical interfaces that control or interface to the item with no effect on performance or functioning as described in 26.3.2 and 26.3.3 above. The HS code indicates the item is safe and operable for VERTREP and external carry exposure also.

**HV:** Safe and operable for VERTREP HESD exposure. This indicates that the ordnance is both safe and operable after VERTREP HESD exposure only. It has passed live HESD testing in the shipping configuration with no dudding or initiation with no effect on performance or functioning as described in 26.3.2 and 26.3.3 above. All items must be tested or analyzed to at least the VERTREP requirements.

**HE**: Safe and operable for external carry HESD exposure. This indicates that the ordnance is both safe and operable for external carry and VERTREP HESD exposures only. It has passed live HESD testing in the external carry configuration with no dudding or initiation, and with no effect on performance or functioning as described in 26.3.2 and 26.3.3 above. The ordnance has also been evaluated or tested for VERTREP exposure in the shipping configuration also. The HE code indicates the item is safe and operable for VERTREP and external carry exposure.

26.4. Safety Data Package.

The results of all HESD testing and analysis conducted relevant to assessing the ordnance item/munitions safety for service shall be compiled into a safety data package for review. The package must include the previously-approved test plan, including the rationale for any variance from the joint requirements. In addition, any deviation from that approved plan shall be presented along with an analysis showing why the results should be accepted. The package must also provide any safety and operability deductions derived from those results.

**Appendix A**

# PESD AND HESD CALIBRATION CALCULATIONS

# Appendix A

## Calculations for Personnel Bourne ESD (PESD) with nominal values of 25kV, 500 Ohms, and 500 pF

(Only positive traces are shown negative traces are identical except inverted)

Time span and initial condition values:

$$t := (0, .001 \cdot \mu s .. 1.4 \cdot \mu s)$$

$$i_{initial} := 0\ A$$

Nominal values for voltage, resistance, inductance, and capacitance:

$$R_{nom} := 500\ \Omega \qquad C_{nom} := 500\ pF \qquad L_{nom} := 3\ \mu H \qquad V_{nom} := 25000\ V$$

Calculations for alpha and omega based on nominal values listed above:

$$\alpha_{nom} := \frac{R_{nom}}{2 \cdot L_{nom}} \qquad \omega_{nom} := \frac{1}{\sqrt{L_{nom} \cdot C_{nom}}}$$

$$\alpha_{nom} = (8.333 \cdot 10^7)\ \frac{1}{s} \qquad \omega_{nom} = (2.582 \cdot 10^7)\ \frac{1}{s}$$

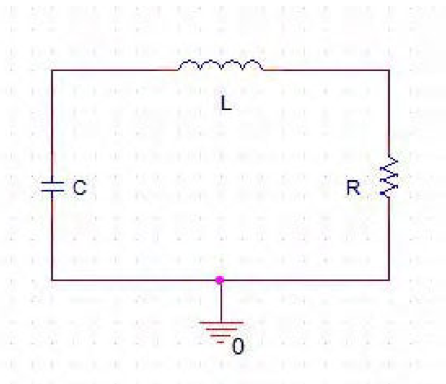



Figure 1 Series RLC Circuit

Calculations for S1 and S2 based on nominal values of alpha and omega

$$s_{1nom} := -\alpha_{nom} + \sqrt{\alpha_{nom}{}^2 - \omega_{nom}{}^2} \qquad s_{2nom} := -\alpha_{nom} - \sqrt{\alpha_{nom}{}^2 - \omega_{nom}{}^2}$$

$$s_{1nom} = -4.101 \cdot 10^6\ \frac{1}{s} \qquad s_{2nom} = -1.626 \cdot 10^8\ \frac{1}{s}$$

Calculations for A1 and A2 based on nominal values:

$$A_{2nom} := \frac{\left(\frac{-1}{L_{nom}} \cdot (R_{nom} \cdot i_{initial} + V_{nom})\right) - (i_{initial} \cdot s_{2nom})}{(s_{2nom} - s_{1nom})}$$

$$A_{2nom} = 52.588\ A$$

$$A_{1nom} := i_{initial} - A_{2nom}$$

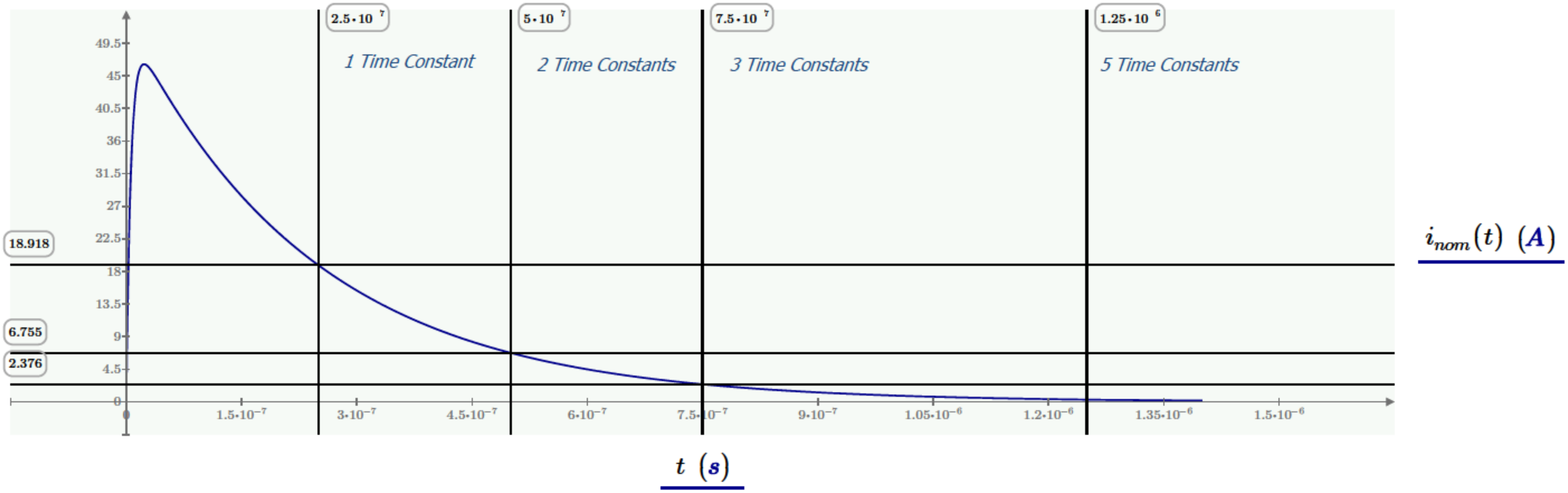
$$A_{1nom} = -52.588\ A$$

Double exponential equation for current & voltage waveforms based on nominal value calculations:

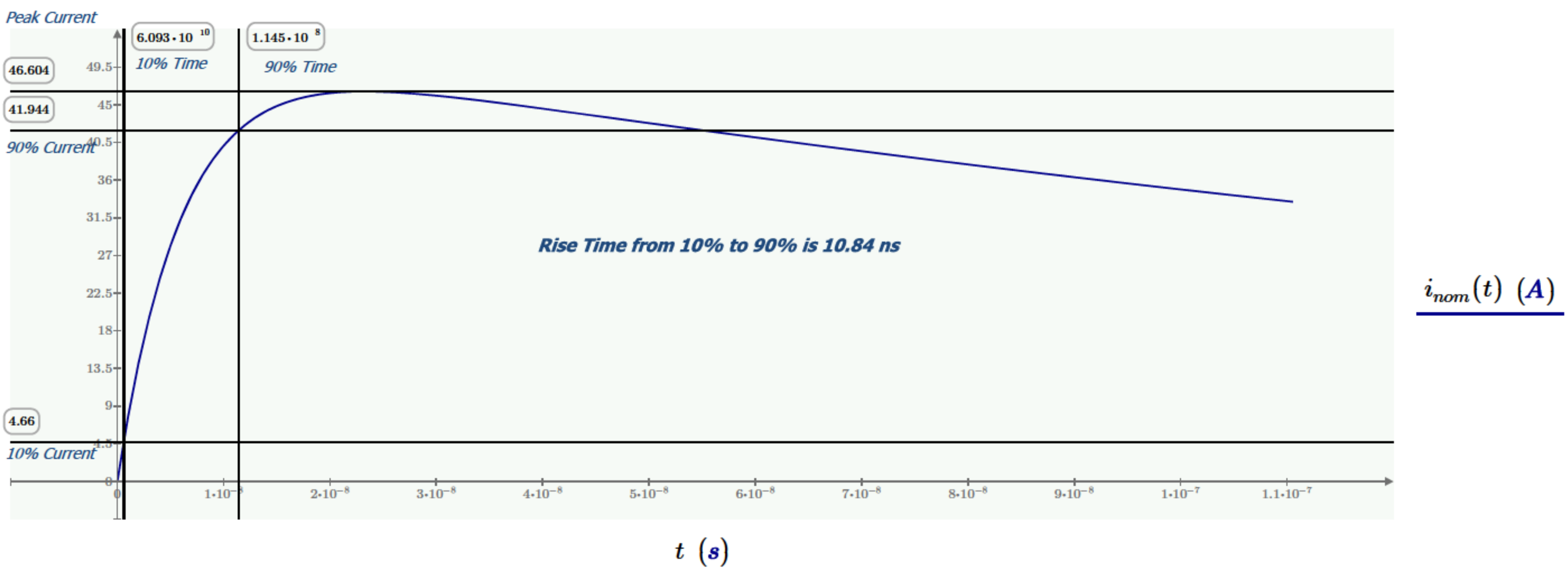
$$i_{nom}(t) := -\left(A_{1nom} \cdot e^{s_{1nom} \cdot t} + A_{2nom} \cdot e^{s_{2nom} \cdot t}\right) \qquad V_{Rnom}(t) := i_{nom}(t) \cdot R_{nom}$$

# Appendix A

## Double exponential graph of current waveform using nominal values




## Zoomed in View of Rise Time



Appendix A

Upper Limit values for voltage (maximum), resistance (minimum), inductance (minimum), and capacitance (maximum):

$R_{min} := R_{nom} - (R_{nom} \cdot 0.05)$ $C_{max} := C_{nom} + (C_{nom} \cdot 0.05)$ $L_{min} := 1\ \mu H$ $V_{max} := 25500\ V$

$R_{min} = 475\ \Omega$ $C_{max} = 525\ pF$

Calculations for alpha and omega based on Upper Limit values listed above:

$$\alpha_{upperLimit} := \frac{R_{min}}{2 \cdot L_{min}} \qquad \omega_{upperLimit} := \frac{1}{\sqrt{L_{min} \cdot C_{max}}}$$

$$\alpha_{upperLimit} = (2.375 \cdot 10^8)\ \frac{1}{s} \qquad \omega_{upperLimit} = (4.364 \cdot 10^7)\ \frac{1}{s}$$

Calculations for S1 and S2 based on Upper Limit values of alpha and omega listed above:

$$s_{1upperLimit} := -\alpha_{upperLimit} + \sqrt{\alpha_{upperLimit}^{\ 2} - \omega_{upperLimit}^{\ 2}} \qquad s_{2upperLimit} := -\alpha_{upperLimit} - \sqrt{\alpha_{upperLimit}^{\ 2} - \omega_{upperLimit}^{\ 2}}$$

$$s_{1upperLimit} = -4.044 \cdot 10^6\ \frac{1}{s} \qquad s_{2upperLimit} = -4.71 \cdot 10^8\ \frac{1}{s}$$

Calculations for A1 and A2 based on Upper Limit values listed above:

$$A_{2upperLimit} := \frac{\left(\frac{-1}{L_{min}} \cdot (R_{min} \cdot i_{initial} + V_{max})\right) - (i_{initial} \cdot s_{2upperLimit})}{(s_{2upperLimit} - s_{1upperLimit})}$$

$$A_{2upperLimit} = 54.614\ A$$

$$A_{1upperLimit} := i_{initial} - A_{2upperLimit}$$

$$A_{1upperLimit} = -54.614\ A$$

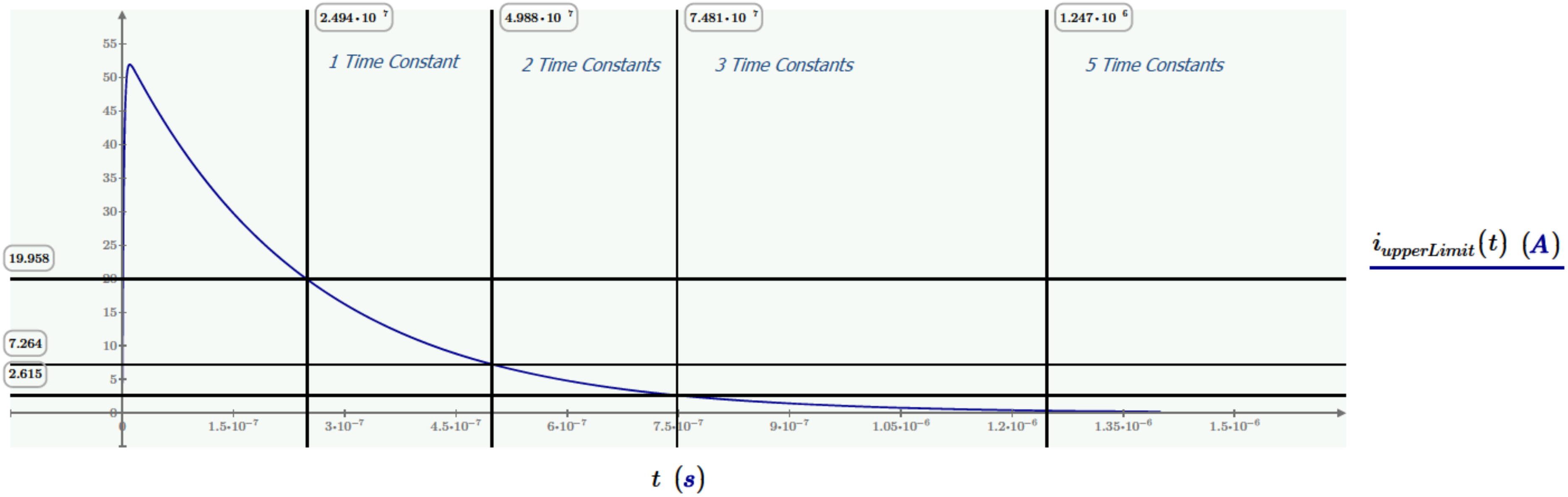
Double exponential equation for current & voltage waveforms based on Upper Limit value calculations:

$$i_{upperLimit}(t) := -\left(A_{1upperLimit} \cdot e^{s_{1upperLimit} \cdot t} + A_{2upperLimit} \cdot e^{s_{2upperLimit} \cdot t}\right)$$

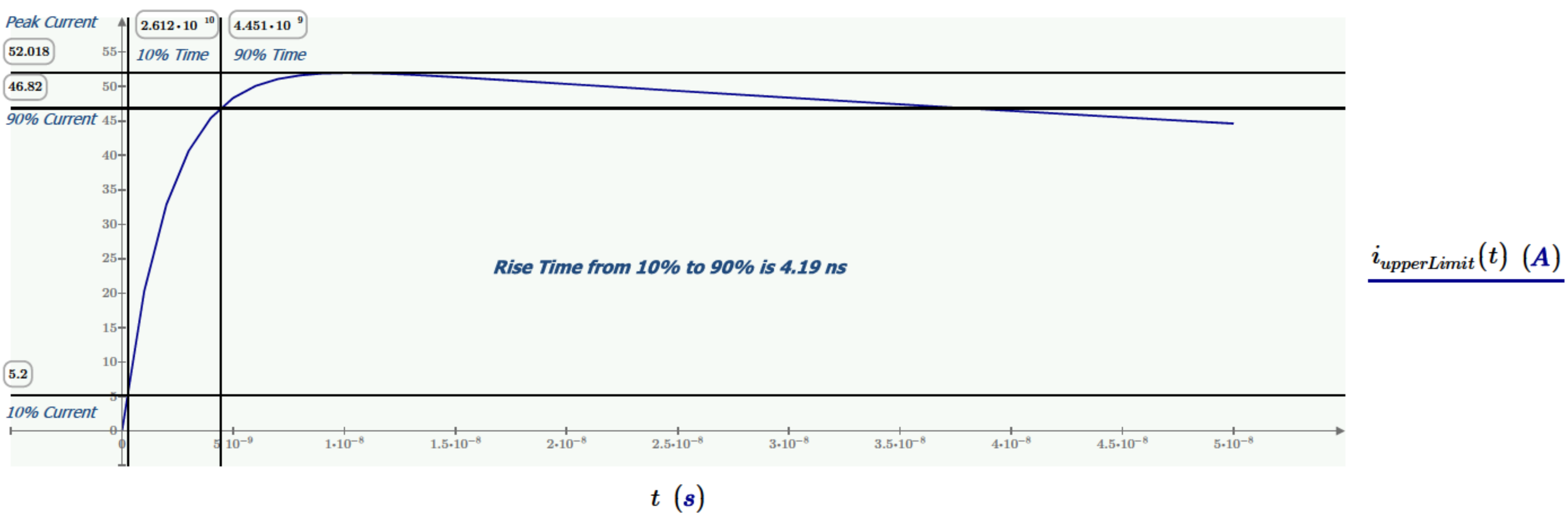
$$V_{RupperLimit}(t) := i_{upperLimit}(t) \cdot R_{min}$$

## Appendix A

### Double Exponential Waveform Graph Based on Upper Limit Values




### Zoomed in View of Rise Time



Lower Limit values for voltage (minimum), resistance (maximum), inductance (maximum), and capacitance (minimum):

$$R_{max} := R_{nom} + (R_{nom} \cdot 0.05) \qquad C_{min} := C_{nom} - (C_{nom} \cdot 0.05) \qquad L_{max} := 5\ \mu H \qquad V_{min} := 24500\ V$$

$$R_{max} = 525\ \Omega \qquad C_{min} = 475\ pF$$

Calculations for alpha ans omega based on Lower Limit values listed above:

$$\alpha_{lowerLimit} := \frac{R_{max}}{2 \cdot L_{max}} \qquad \omega_{lowerLimit} := \frac{1}{\sqrt{L_{max} \cdot C_{min}}}$$

$$\alpha_{lowerLimit} = (5.25 \cdot 10^{7})\ \frac{1}{s} \qquad \omega_{lowerLimit} = (2.052 \cdot 10^{7})\ \frac{1}{s}$$

Calculations for S1 and S2 based on the Lower Limit values of alpha and omega listed above:

$$s_{1lowerLimit} := -\alpha_{lowerLimit} + \sqrt{\alpha_{lowerLimit}^{2} - \omega_{lowerLimit}^{2}} \qquad s_{2lowerLimit} := -\alpha_{lowerLimit} - \sqrt{\alpha_{lowerLimit}^{2} - \omega_{lowerLimit}^{2}}$$

$$s_{1lowerLimit} = -4.176 \cdot 10^{6}\ \frac{1}{s} \qquad s_{2lowerLimit} = -1.008 \cdot 10^{8}\ \frac{1}{s}$$

Calculations for A1 and A2 based on Lower Limit values listed above:

$$A_{2lowerLimit} := \frac{\left(\frac{-1}{L_{max}} \cdot (R_{max} \cdot i_{initial} + V_{min})\right) - (i_{initial} \cdot s_{2lowerLimit})}{(s_{2lowerLimit} - s_{1lowerLimit})}$$

$$A_{2lowerLimit} = 50.7\ A$$

$$A_{1lowerLimit} := i_{initial} - A_{2lowerLimit}$$

$$A_{1lowerLimit} = -50.7\ A$$

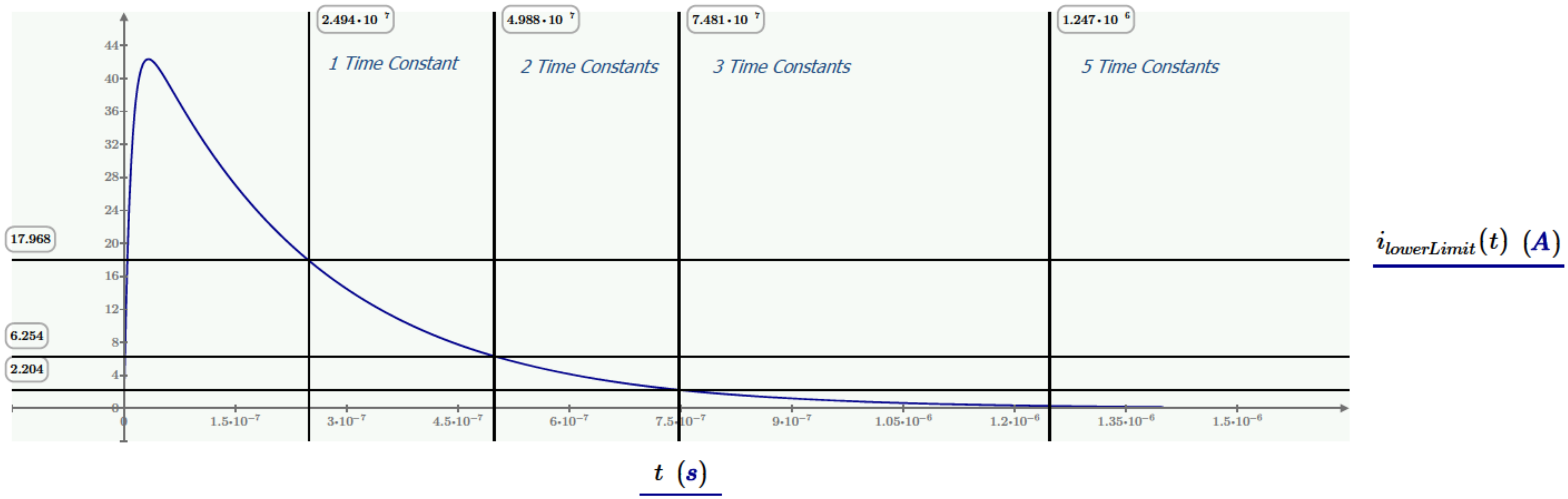
Double exponential equation for current & voltage waveforms based on Lower Limit value calculations:

$$i_{lowerLimit}(t) := -\left(A_{1lowerLimit} \cdot e^{s_{1lowerLimit} \cdot t} + A_{2lowerLimit} \cdot e^{s_{2lowerLimit} \cdot t}\right)$$

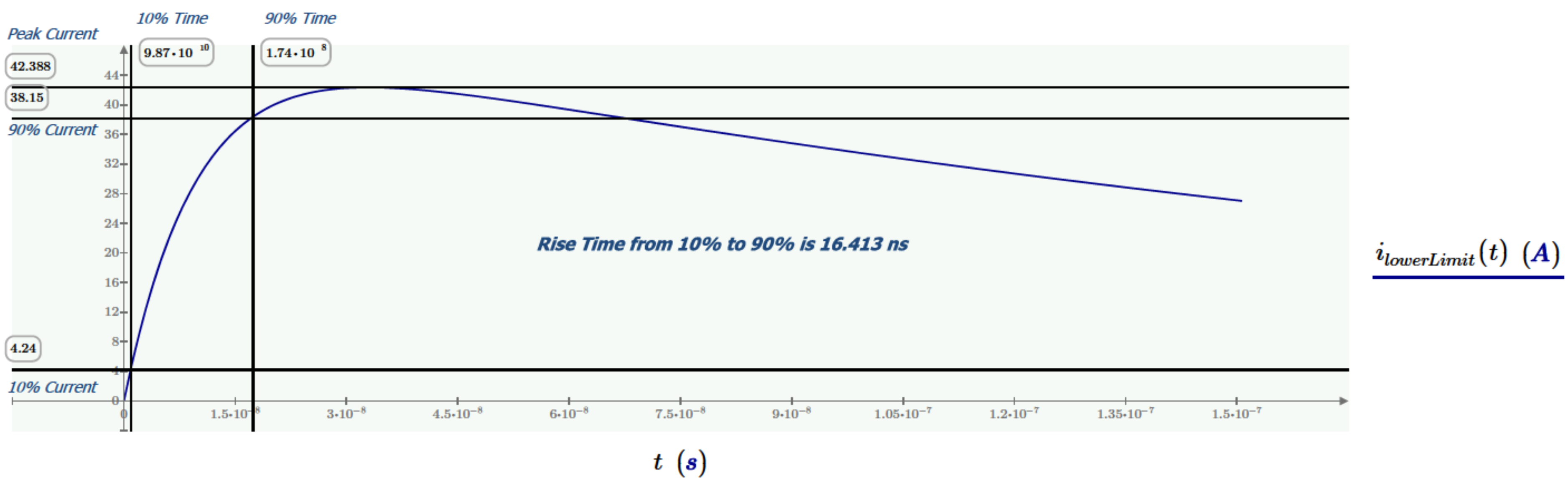
$$V_{RlowerLimit}(t) := i_{lowerLimit}(t) \cdot R_{max}$$

Appendix A

Double Exponential Current Waveform Graph Based on Lower Limit Values

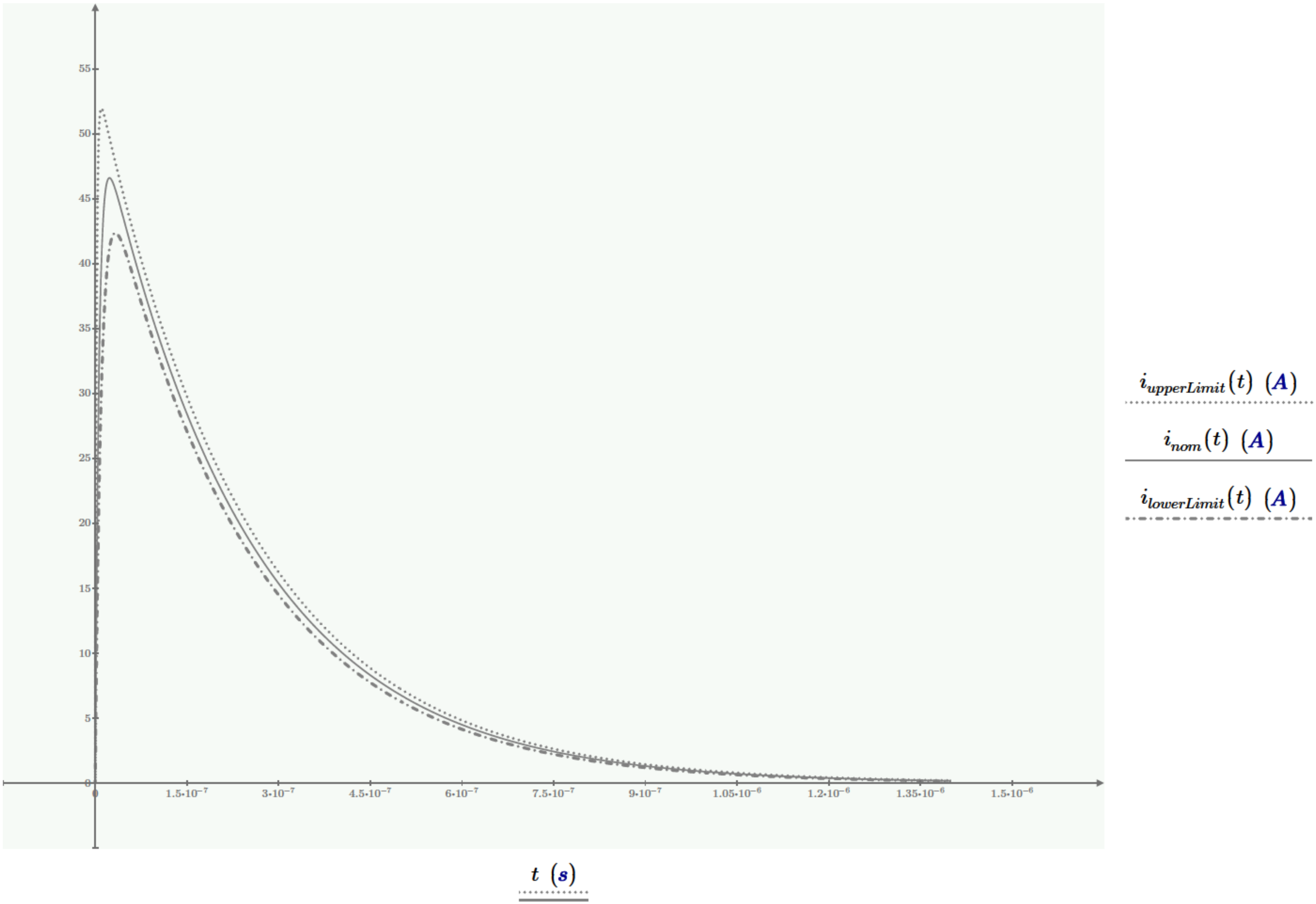



Zoomed in View of Rise Time



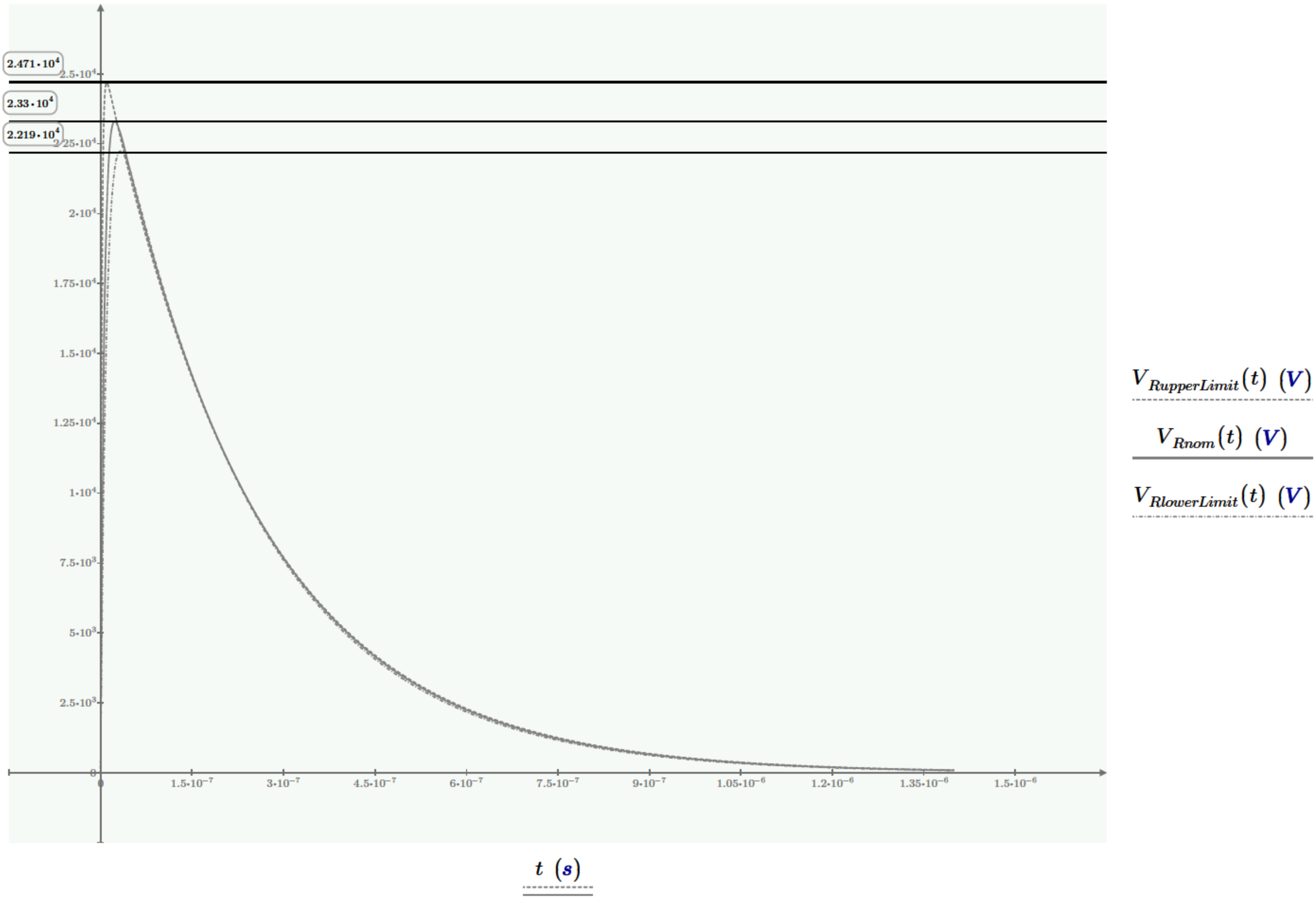
# Appendix A

## Current Waveform Graphs with Upper, Nominal, & Lower Values



# Appendix A

## Voltage Waveform Graphs with Upper, Lower, & Nominal Values



# Appendix A

Calculations for Personnel Bourne ESD (PESD) with nominal values of 25kV, 5000 Ohms, and 500 pF

(Only positive traces are shown negative traces are identical except inverted)

Time span and initial condition values:

$$t := (0, .0003 \cdot \mu s .. 13 \cdot \mu s)$$

$$i_{initial} := 0\ A$$

Nominal values for voltage, resistance, inductance, and capacitance:

$$R_{nom} := 5000\ \Omega \qquad C_{nom} := 500\ pF \qquad L_{nom} := 3\ \mu H \qquad V_{nom} := 25000\ V$$

Calculations for alpha and omega based on nominal values listed above:

$$\alpha_{nom} := \frac{R_{nom}}{2 \cdot L_{nom}} \qquad \omega_{nom} := \frac{1}{\sqrt{L_{nom} \cdot C_{nom}}}$$

$$\alpha_{nom} = \left(8.333 \cdot 10^{8}\right) \frac{1}{s} \qquad \omega_{nom} = \left(2.582 \cdot 10^{7}\right) \frac{1}{s}$$

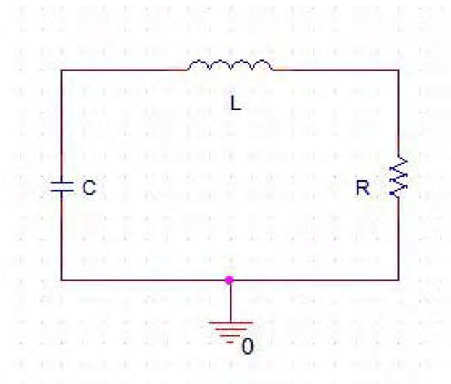



Figure 1 Series RLC Circuit

Calculations for S1 and S2 based on nominal values of alpha and omega

$$s_{1nom} := -\alpha_{nom} + \sqrt{{\alpha_{nom}}^{2} - {\omega_{nom}}^{2}} \qquad s_{2nom} := -\alpha_{nom} - \sqrt{{\alpha_{nom}}^{2} - {\omega_{nom}}^{2}}$$

$$s_{1nom} = -4.001 \cdot 10^{5}\ \frac{1}{s} \qquad s_{2nom} = -1.666 \cdot 10^{9}\ \frac{1}{s}$$

Calculations for A1 and A2 based on nominal values:

$$A_{2nom} := \frac{\left(\frac{-1}{L_{nom}} \cdot \left(R_{nom} \cdot i_{initial} + V_{nom}\right)\right) - \left(i_{initial} \cdot s_{2nom}\right)}{\left(s_{2nom} - s_{1nom}\right)}$$

$$A_{2nom} = 5.002\ A$$

$$A_{1nom} := i_{initial} - A_{2nom}$$

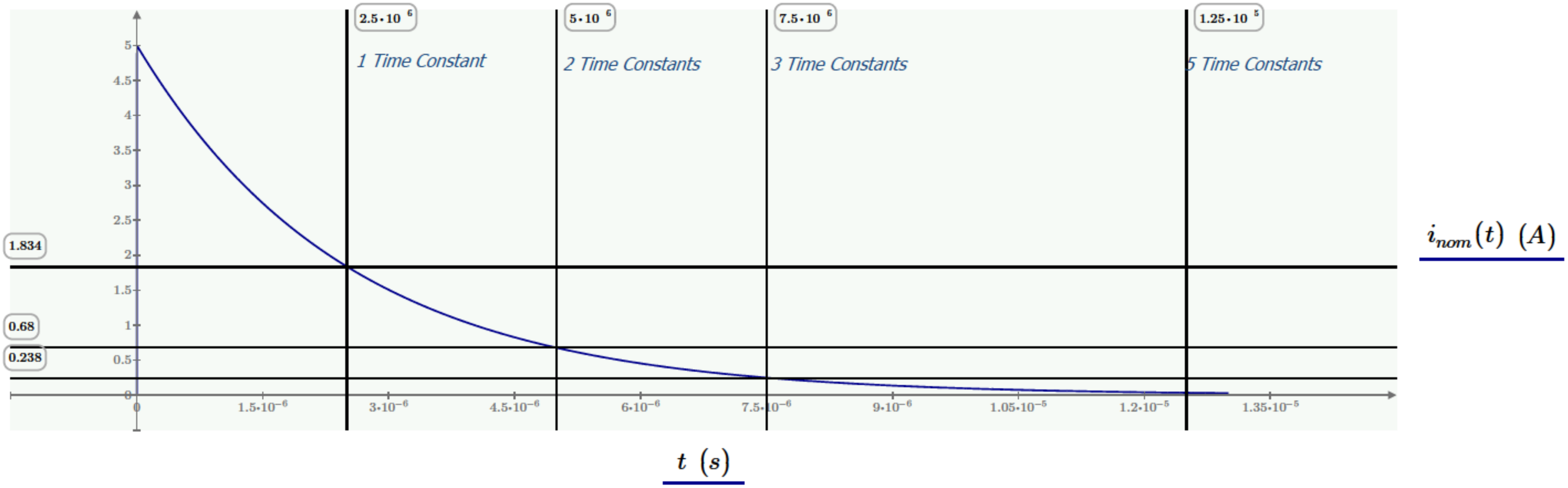
$$A_{1nom} = -5.002\ A$$

Double exponential equation for current & voltage waveforms based on nominal value calculations:

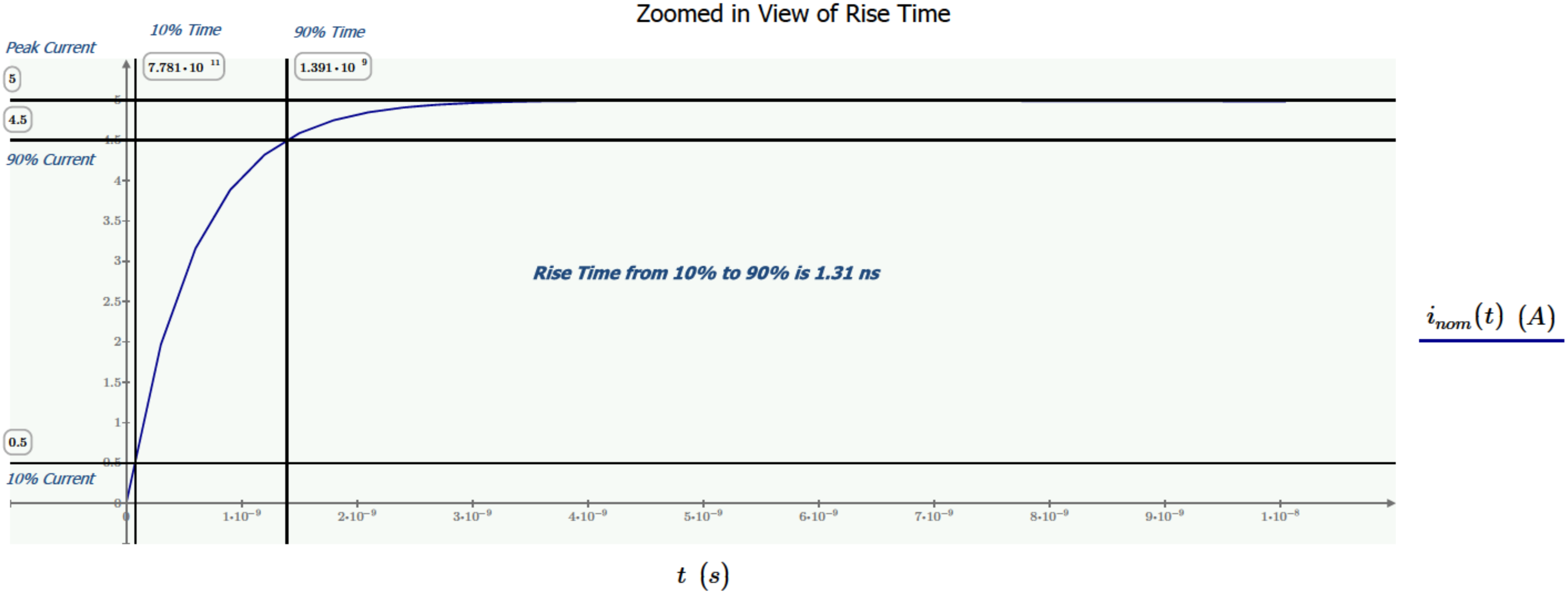
$$i_{nom}(t) := -\left(A_{1nom} \cdot e^{s_{1nom} \cdot t} + A_{2nom} \cdot e^{s_{2nom} \cdot t}\right) \qquad V_{Rnom}(t) := i_{nom}(t) \cdot R_{nom}$$

## Appendix A

Double exponential graph of current waveform using nominal values




Zoomed in View of Rise Time



Upper Limit values for voltage (maximum), resistance (minimum), inductance (minimum), and capacitance (maximum):

$$R_{min} := R_{nom} - \left(R_{nom} \cdot 0.05\right) \qquad C_{max} := C_{nom} + \left(C_{nom} \cdot 0.05\right) \qquad L_{min} := 1\ \mu H \qquad V_{max} := 25500\ V$$

$$R_{min} = \left(4.75 \cdot 10^{3}\right)\ \Omega \qquad C_{max} = 525\ pF$$

Calculations for alpha and omega based on Upper Limit values listed above:

$$\alpha_{upperLimit} := \frac{R_{min}}{2 \cdot L_{min}} \qquad \omega_{upperLimit} := \frac{1}{\sqrt{L_{min} \cdot C_{max}}}$$

$$\alpha_{upperLimit} = \left(2.375 \cdot 10^{9}\right) \frac{1}{s} \qquad \omega_{upperLimit} = \left(4.364 \cdot 10^{7}\right) \frac{1}{s}$$

Calculations for S1 and S2 based on Upper Limit values of alpha and omega listed above:

$$s_{1upperLimit} := -\alpha_{upperLimit} + \sqrt{{\alpha_{upperLimit}}^{2} - {\omega_{upperLimit}}^{2}} \qquad s_{2upperLimit} := -\alpha_{upperLimit} - \sqrt{{\alpha_{upperLimit}}^{2} - {\omega_{upperLimit}}^{2}}$$

$$s_{1upperLimit} = -4.01 \cdot 10^{5}\ \frac{1}{s} \qquad s_{2upperLimit} = -4.75 \cdot 10^{9}\ \frac{1}{s}$$

Calculations for A1 and A2 based on Upper Limit values listed above:

$$A_{2upperLimit} := \frac{\left(\frac{-1}{L_{min}} \cdot \left(R_{min} \cdot i_{initial} + V_{max}\right)\right) - \left(i_{initial} \cdot s_{2upperLimit}\right)}{\left(s_{2upperLimit} - s_{1upperLimit}\right)}$$

$$A_{2upperLimit} = 5.369\ A$$

$$A_{1upperLimit} := i_{initial} - A_{2upperLimit}$$

$$A_{1upperLimit} = -5.369\ A$$

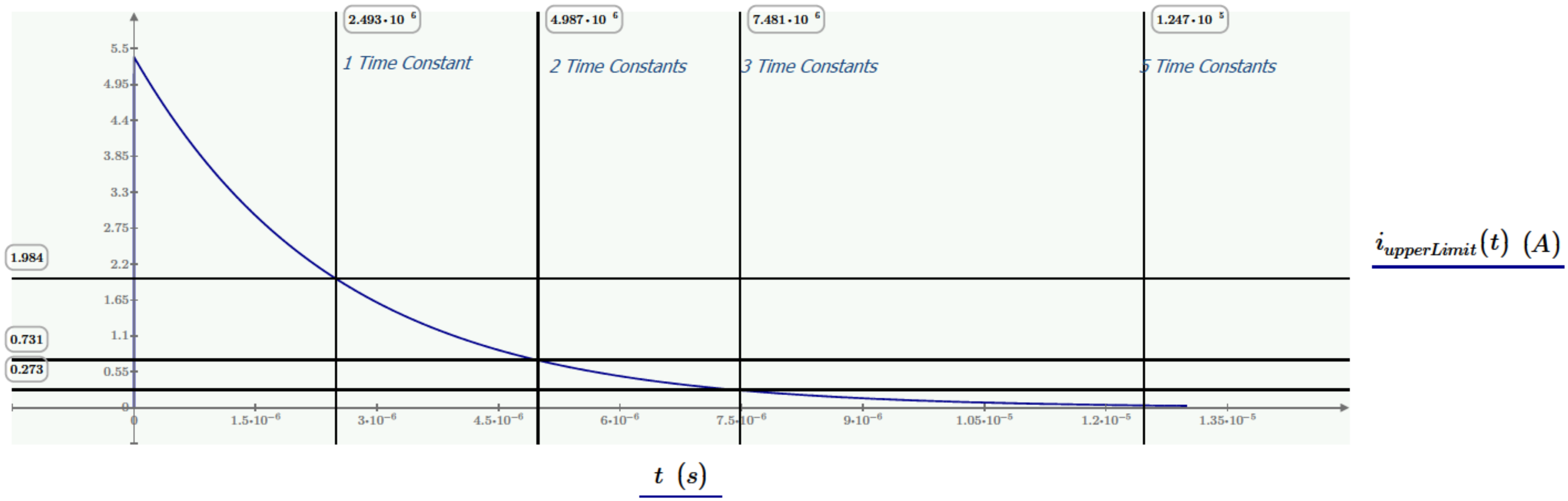
Double exponential equation for current & voltage waveforms based on Upper Limit value calculations:

$$i_{upperLimit}(t) := -\left(A_{1upperLimit} \cdot e^{s_{1upperLimit} \cdot t} + A_{2upperLimit} \cdot e^{s_{2upperLimit} \cdot t}\right)$$

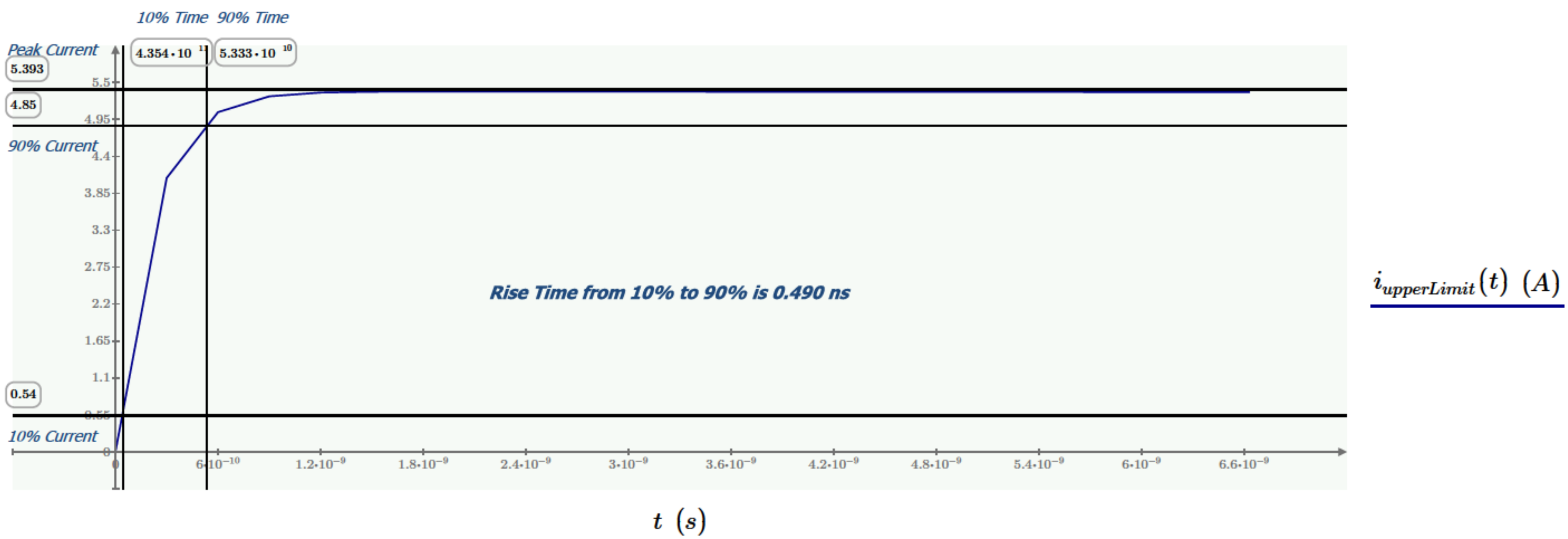
$$V_{RupperLimit}(t) := i_{upperLimit}(t) \cdot R_{min}$$

Appendix A

Double Exponential Waveform Graph Based on Upper Limit Values




Zoomed in View of Rise Time



Lower Limit values for voltage (minimum), resistance (maximum), inductance (maximum), and capacitance (minimum):

$$R_{max} := R_{nom} + \left(R_{nom} \cdot 0.05\right) \qquad C_{min} := C_{nom} - \left(C_{nom} \cdot 0.05\right) \qquad L_{max} := 5\ \mu H \qquad V_{min} := 24500\ V$$

$$R_{max} = \left(5.25 \cdot 10^{3}\right)\ \Omega \qquad C_{min} = 475\ pF$$

Calculations for alpha ans omega based on Lower Limit values listed above:

$$\alpha_{lowerLimit} := \frac{R_{max}}{2 \cdot L_{max}} \qquad \omega_{lowerLimit} := \frac{1}{\sqrt{L_{max} \cdot C_{min}}}$$

$$\alpha_{lowerLimit} = \left(5.25 \cdot 10^{8}\right)\ \frac{1}{s} \qquad \omega_{lowerLimit} = \left(2.052 \cdot 10^{7}\right)\ \frac{1}{s}$$

Calculations for S1 and S2 based on the Lower Limit values of alpha and omega listed above:

$$s_{1lowerLimit} := -\alpha_{lowerLimit} + \sqrt{\alpha_{lowerLimit}^{\ 2} - \omega_{lowerLimit}^{\ 2}} \qquad s_{2lowerLimit} := -\alpha_{lowerLimit} - \sqrt{\alpha_{lowerLimit}^{\ 2} - \omega_{lowerLimit}^{\ 2}}$$

$$s_{1lowerLimit} = -4.012 \cdot 10^{5}\ \frac{1}{s} \qquad s_{2lowerLimit} = -1.05 \cdot 10^{9}\ \frac{1}{s}$$

Calculations for A1 and A2 based on Lower Limit values listed above:

$$A_{2lowerLimit} := \frac{\left(\frac{-1}{L_{max}} \cdot \left(R_{max} \cdot i_{initial} + V_{min}\right)\right) - \left(i_{initial} \cdot s_{2lowerLimit}\right)}{\left(s_{2lowerLimit} - s_{1lowerLimit}\right)}$$

$$A_{2lowerLimit} = 4.67\ A$$

$$A_{1lowerLimit} := i_{initial} - A_{2lowerLimit}$$

$$A_{1lowerLimit} = -4.67\ A$$

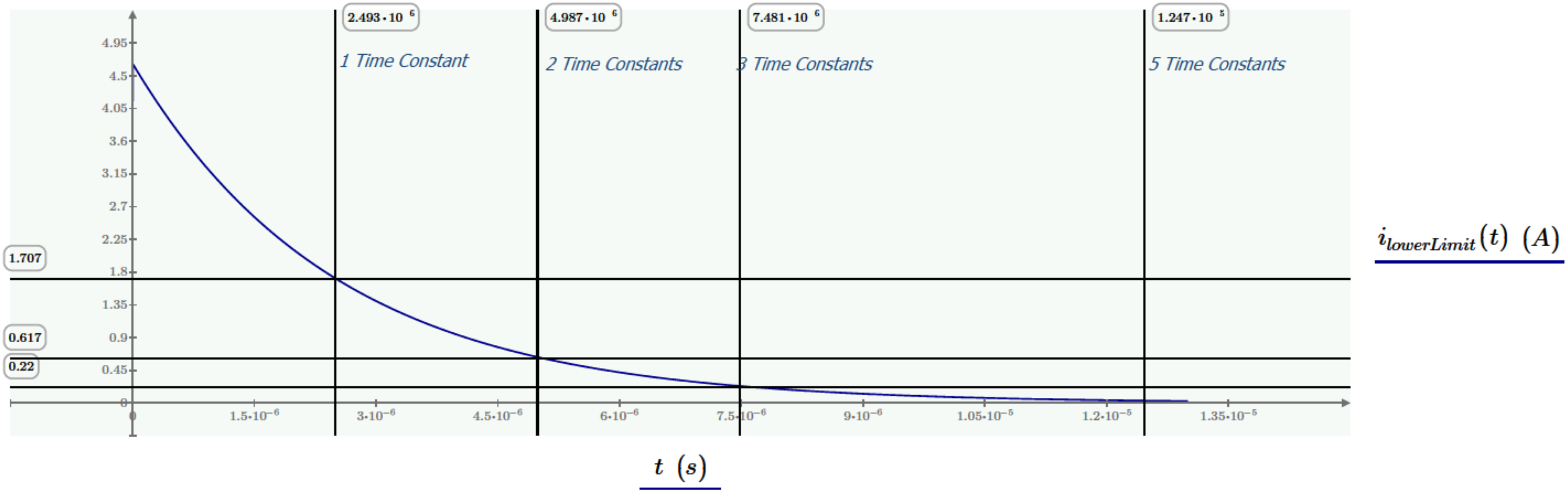
Double exponential equation for current & voltage waveforms based on Lower Limit value calculations:

$$i_{lowerLimit}(t) := -\left(A_{1lowerLimit} \cdot e^{s_{1lowerLimit} \cdot t} + A_{2lowerLimit} \cdot e^{s_{2lowerLimit} \cdot t}\right)$$

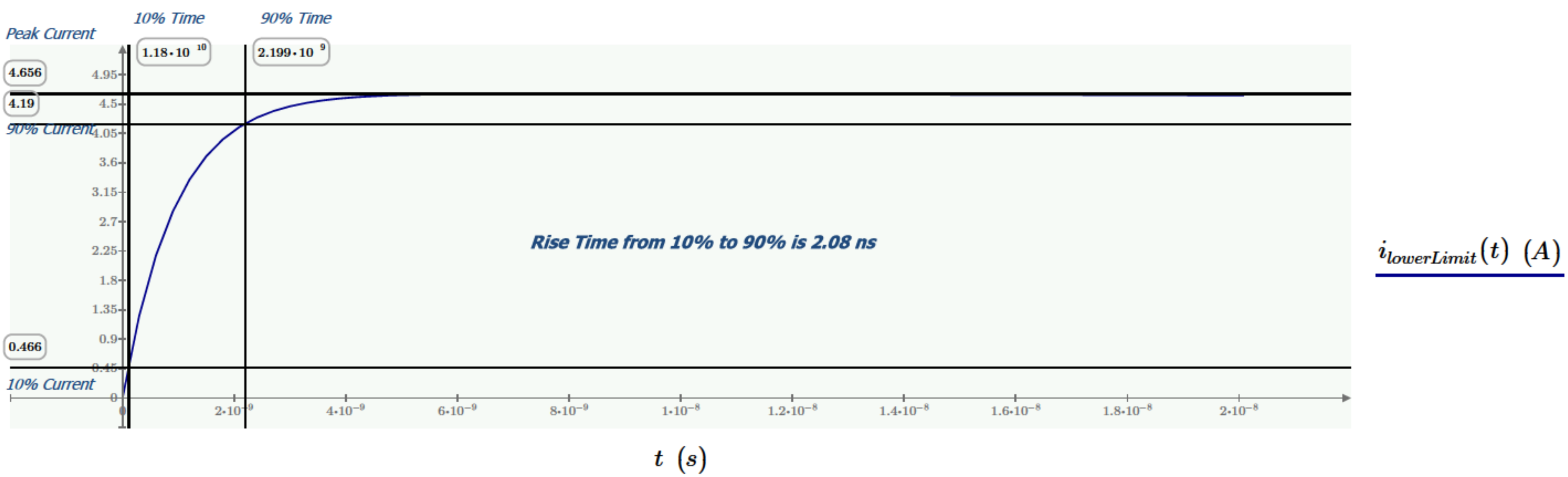
$$V_{RlowerLimit}(t) := i_{lowerLimit}(t) \cdot R_{max}$$

# Appendix A

## Double Exponential Current Waveform Graph Based on Lower Limit Values

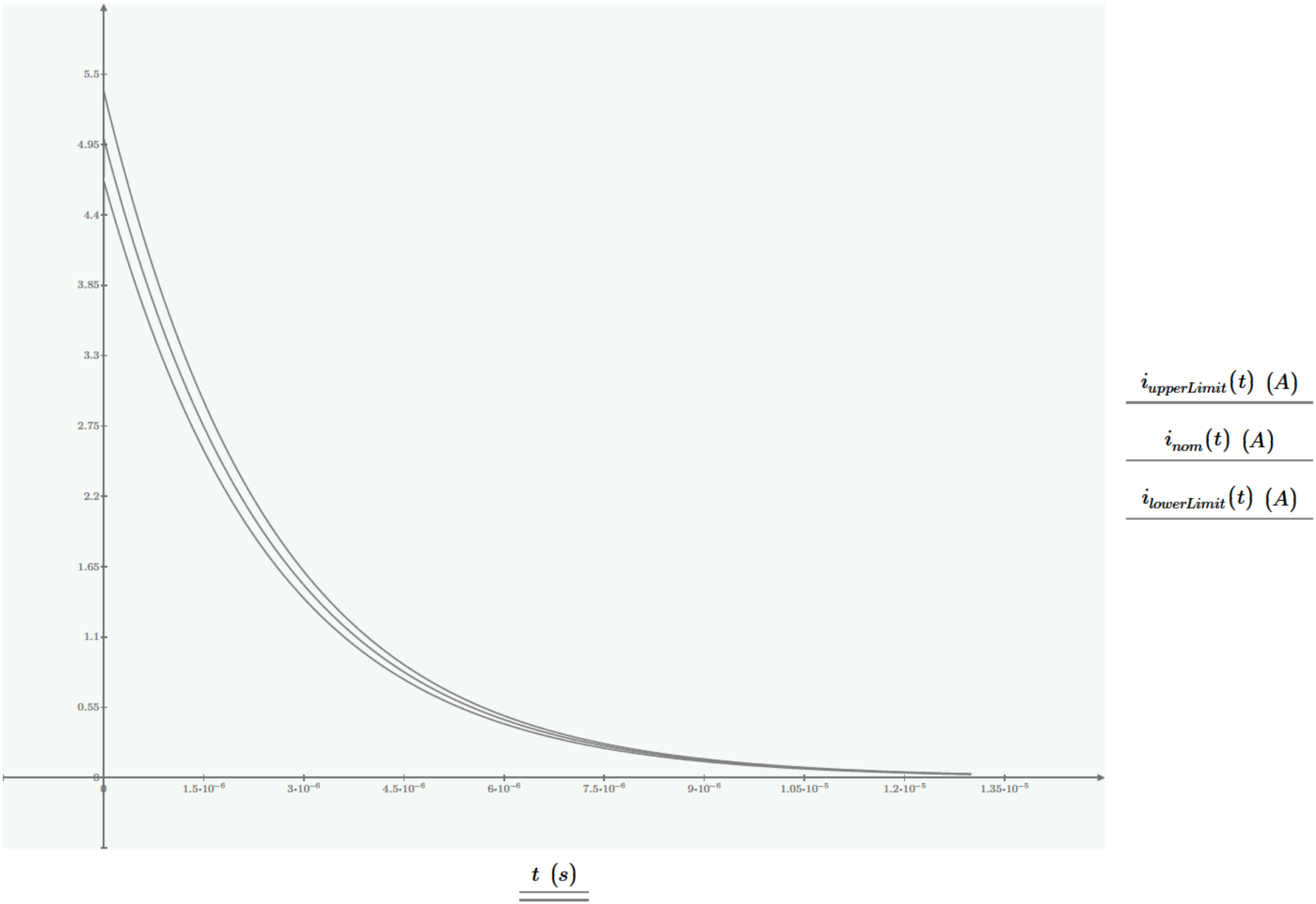



## Zoomed in View of Rise Time



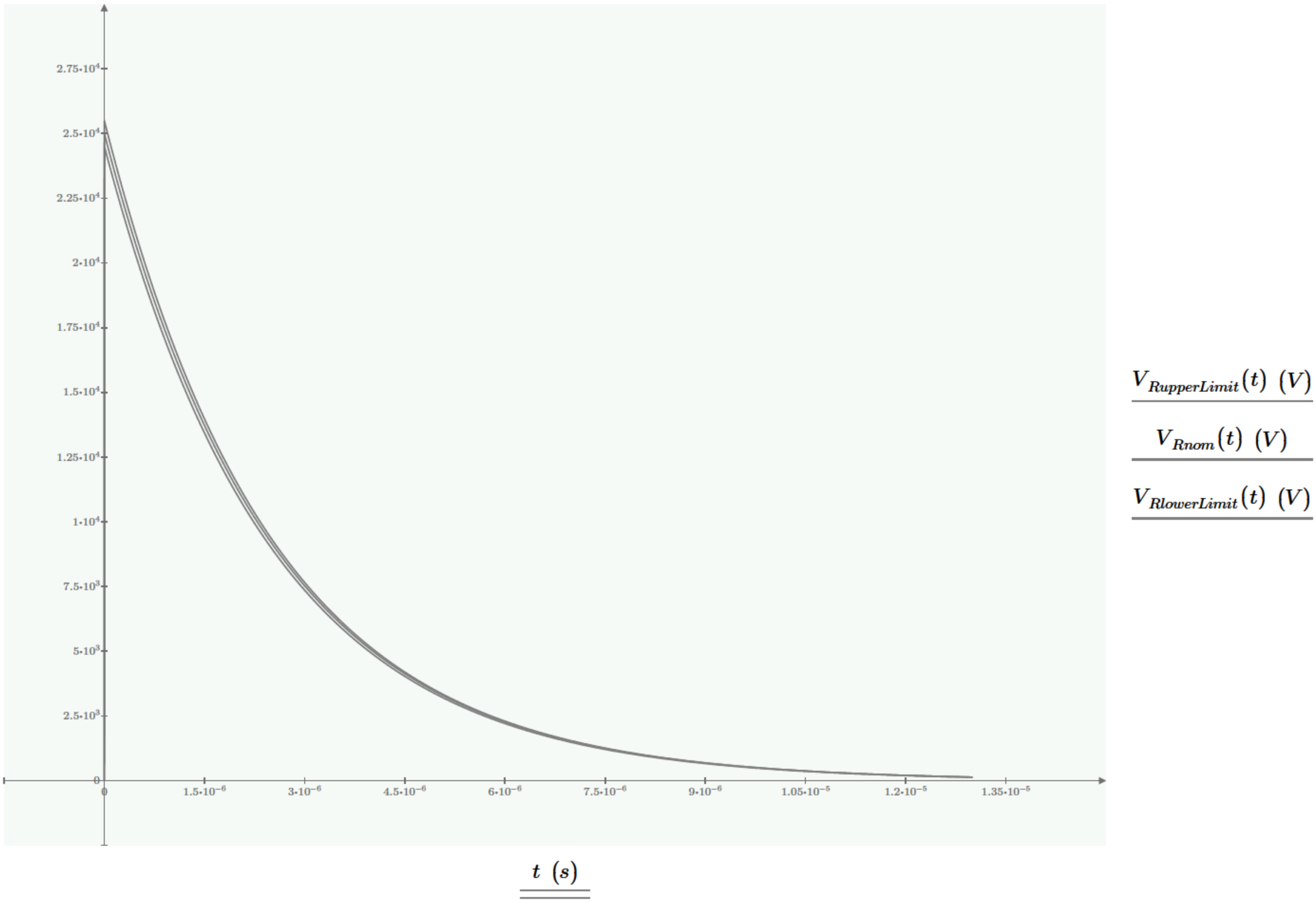
# Appendix A

## Current Waveform Graphs with Upper, Nominal, & Lower Values



Appendix A

Voltage Waveform Graphs with Upper, Lower, & Nominal Values



Appendix A

Calculations for Helicopter Bourne ESD (HESD) with nominal values of 300kV, 1.5 Ohms, 10 uH, and 1000 pF
(All traces shown are positive negative traces are identical except inverted)

Time span and initial condition values:

$$t := (0, .01 \cdot \mu s .. 60 \cdot \mu s)$$

$$i_{initial} := 0\ A$$

Nominal values for voltage, resistance, inductance, and capacitance:

$$R_{nom} := 1.5\ \Omega \qquad C_{nom} := 1\ nF \qquad L_{nom} := 10\ \mu H \qquad V_{nom} := 300000\ V$$

Calculations for alpha and omega based on nominal values listed above:

$$\alpha_{nom} := \frac{R_{nom}}{2 \cdot L_{nom}} \qquad \omega_{onom} := \frac{1}{\sqrt{L_{nom} \cdot C_{nom}}}$$

$$\alpha_{nom} = (7.5 \cdot 10^4)\ \frac{1}{s} \qquad \omega_{onom} = (1 \cdot 10^7)\ \frac{1}{s}$$

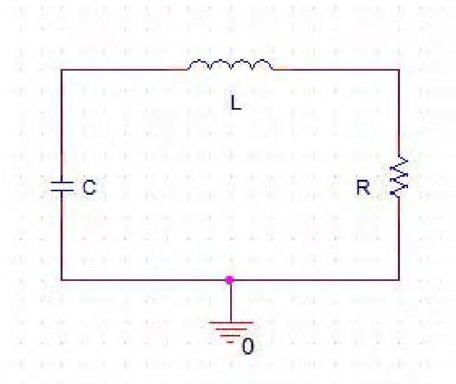



Figure 1 Series RLC Circuit

Calculations for damping frequency based on nominal values of alpha and omega

$$\omega_{dnom} := \sqrt{\frac{1}{L_{nom} \cdot C_{nom}} - \left(\frac{R_{nom}}{2 \cdot L_{nom}}\right)^2}$$

$$\omega_{dnom} = (10 \cdot 10^6)\ \frac{1}{s}$$

Calculations for A1 and A2 based on nominal values:

$$A_{1nom} := V_{nom} \qquad A_{1nom} = (3 \cdot 10^5)\ V$$

$$A_{2nom} := \frac{\alpha_{nom} \cdot A_{1nom}}{\omega_{dnom}} \qquad A_{2nom} = (2.25 \cdot 10^3)\ V$$

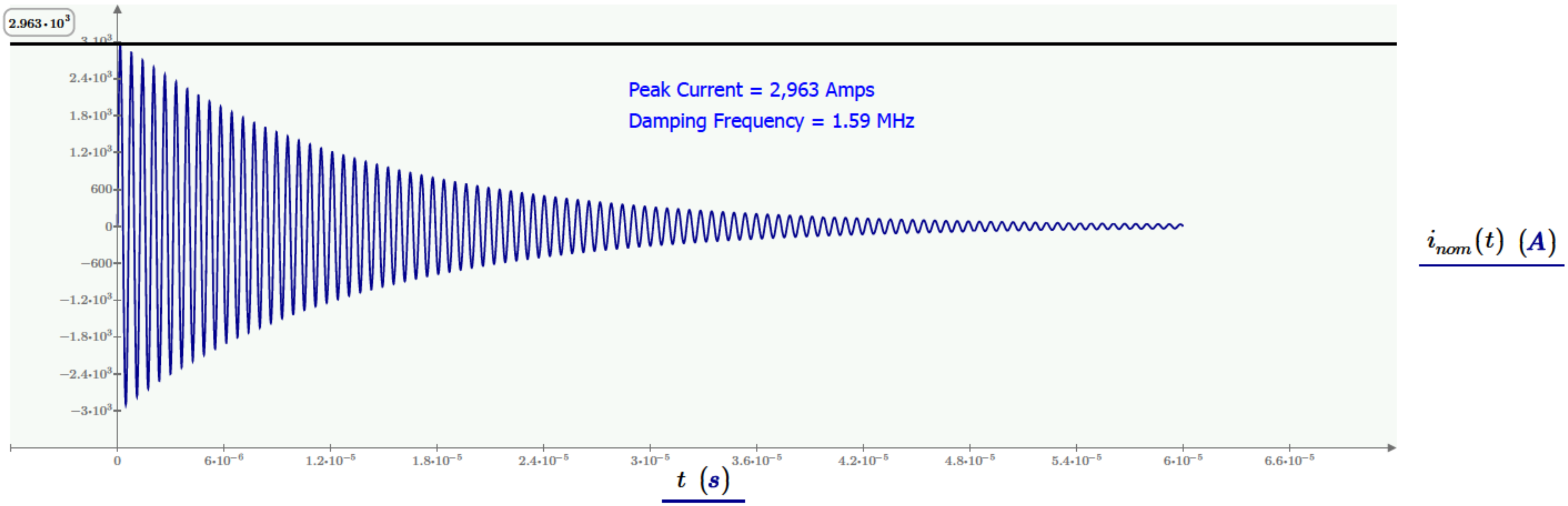
Double exponential equation for current & voltage waveforms based on nominal value calculations:

$$i_{nom}(t) := \left((-C_{nom}) \cdot \left(e^{-\alpha_{nom} \cdot t}\right)\right) \cdot \left(\left(\left(A_{2nom} \cdot \omega_{dnom} - A_{1nom} \cdot \alpha_{nom}\right) \cdot \cos\left(\omega_{dnom} \cdot t\right)\right) + \left(\left(-A_{2nom} \cdot \alpha_{nom} - A_{1nom} \cdot \omega_{dnom}\right) \cdot \sin\left(\omega_{dnom} \cdot t\right)\right)\right)$$

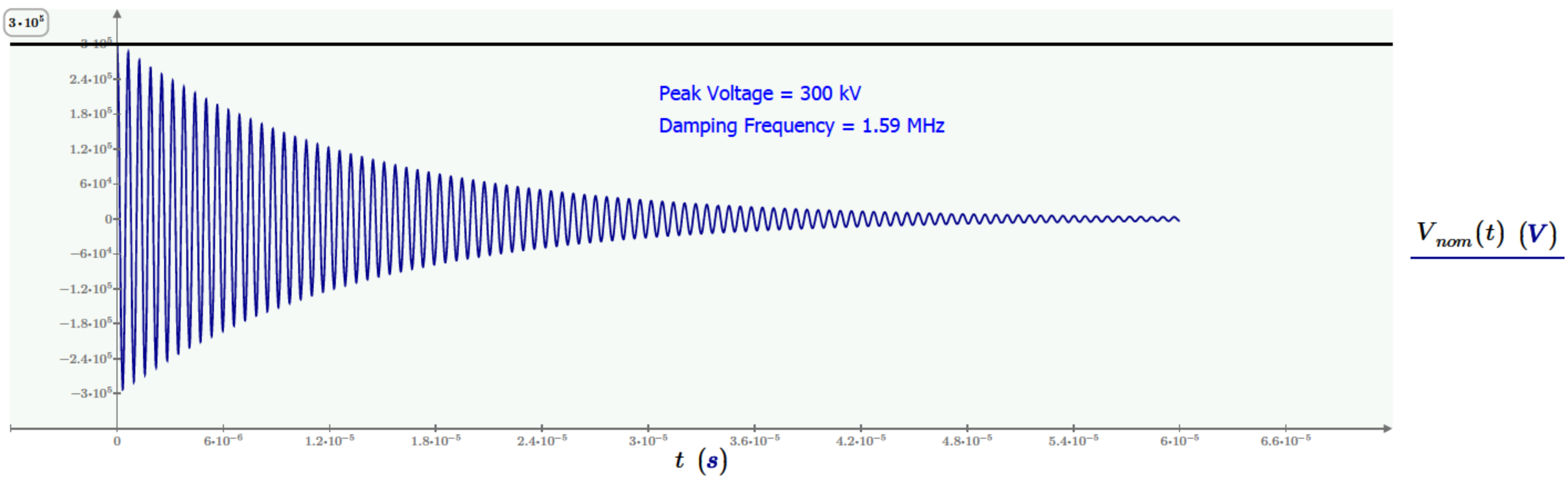
$$V_{nom}(t) := e^{-\alpha_{nom} \cdot t} \cdot \left(A_{1nom} \cdot \cos\left(\omega_{dnom} \cdot t\right) + A_{2nom} \cdot \sin\left(\omega_{dnom} \cdot t\right)\right)$$

# Appendix A

Double exponential graph of current waveform using nominal values




Double exponential graph of voltage waveform using nominal values



Upper Limit values for voltage (maximum), resistance (minimum), inductance (minimum), and capacitance (maximum):

$R_{min} := 0.95 \cdot \Omega$ $\quad C_{max} := 1050 \cdot pF$ $\quad L_{min} := 4\ \mu H$ $\quad V_{max} := 306000\ V$

Calculations for alpha and omega based on Upper Limit values listed above:

$$\alpha_{UL} := \frac{R_{min}}{2 \cdot L_{min}} \qquad \omega_{oUL} := \frac{1}{\sqrt{L_{min} \cdot C_{max}}}$$

$$\alpha_{UL} = \left(1.188 \cdot 10^{5}\right) \frac{1}{s} \qquad \omega_{oUL} = \left(1.543 \cdot 10^{7}\right) \frac{1}{s}$$

Calculations for damping frequency based on Upper Limit values of alpha and omega listed above:

$$\omega_{dUL} := \sqrt{\frac{1}{L_{min} \cdot C_{max}} - \left(\frac{R_{min}}{2 \cdot L_{min}}\right)^{2}}$$

$$\omega_{dUL} = \left(1.543 \cdot 10^{7}\right) \frac{1}{s}$$

Calculations for A1 and A2 based on Upper Limit values listed above:

$$A_{1UL} := V_{max} \qquad A_{1UL} = \left(3.06 \cdot 10^{5}\right) V$$

$$A_{2UL} := \frac{\alpha_{UL} \cdot A_{1UL}}{\omega_{dUL}} \qquad A_{2UL} = \left(2.355 \cdot 10^{3}\right) V$$

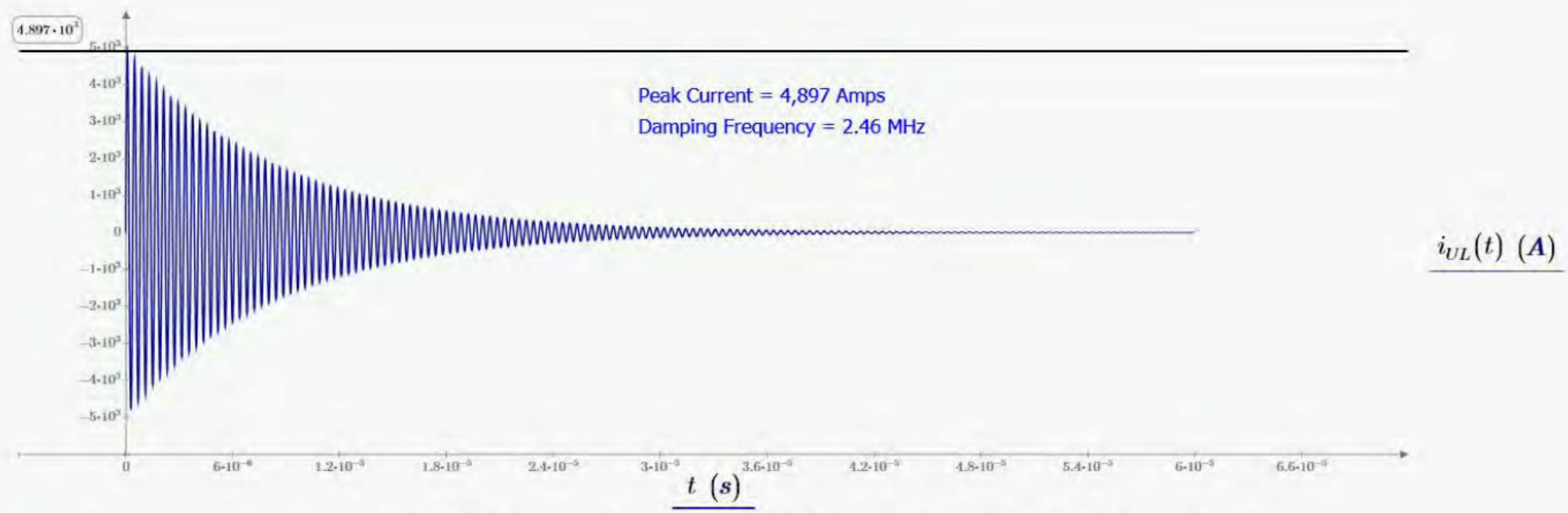
Double exponential equation for current & voltage waveforms based on Upper Limit value calculations:

$$i_{UL}(t) := \left(\left(-C_{max}\right) \cdot \left(e^{-\alpha_{UL} \cdot t}\right)\right) \cdot \left(\left(\left(A_{2UL} \cdot \omega_{dUL} - A_{1UL} \cdot \alpha_{UL}\right) \cdot \cos\left(\omega_{dUL} \cdot t\right)\right) + \left(\left(-A_{2UL} \cdot \alpha_{UL} - A_{1UL} \cdot \omega_{dUL}\right) \cdot \sin\left(\omega_{dUL} \cdot t\right)\right)\right)$$

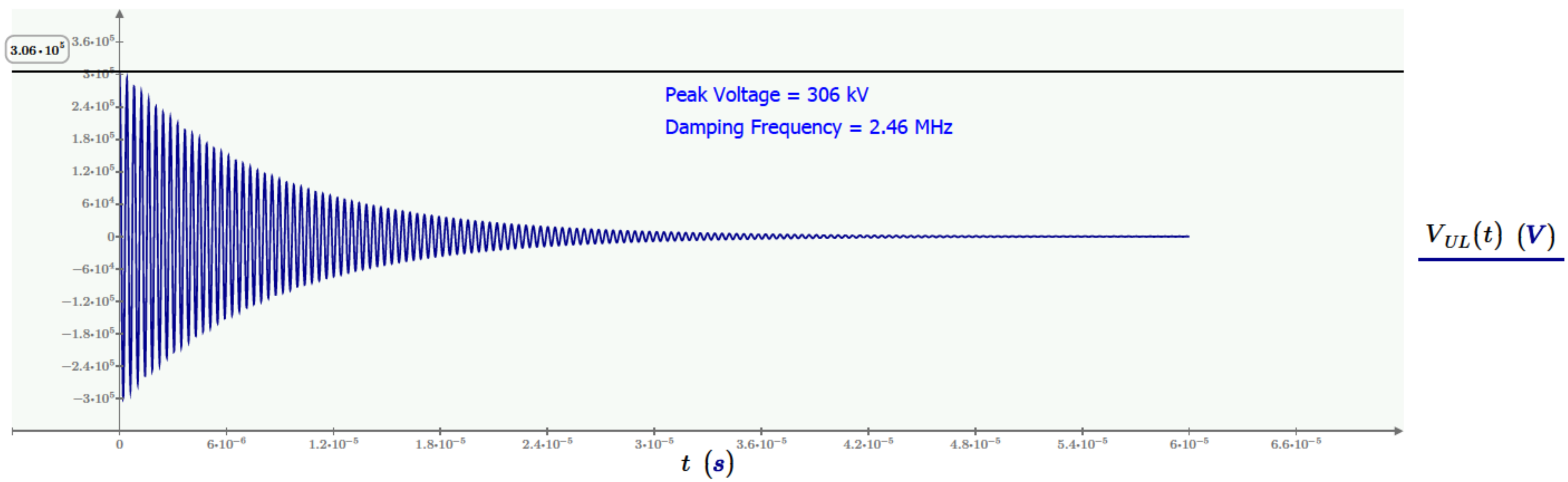
$$V_{UL}(t) := e^{-\alpha_{UL} \cdot t} \cdot \left(A_{1UL} \cdot \cos\left(\omega_{dUL} \cdot t\right) + A_{2UL} \cdot \sin\left(\omega_{dUL} \cdot t\right)\right)$$

Appendix A

Double exponential graph of current waveform using Upper Limit values




Double exponential graph of voltage waveform using Upper Limit values



Lower Limit values for voltage (minimum), resistance (maximum), inductance (maximum), and capacitance (minimum):

$R_{max} := 4\ \Omega$ $\quad C_{min} := 950\ pF$ $\quad L_{max} := 20\ \mu H$ $\quad V_{min} := 294000\ V$

Calculations for alpha and omega based on Lower Limit values listed above:

$$\alpha_{LL} := \frac{R_{max}}{2 \cdot L_{max}} \qquad \omega_{oLL} := \frac{1}{\sqrt{L_{max} \cdot C_{min}}}$$

$$\alpha_{LL} = \left(1 \cdot 10^{5}\right) \frac{1}{s} \qquad \omega_{oLL} = \left(7.255 \cdot 10^{6}\right) \frac{1}{s}$$

Calculations for damping frequency based on Lower Limit values of alpha and omega listed above:

$$\omega_{dLL} := \sqrt{\frac{1}{L_{max} \cdot C_{min}} - \left(\frac{R_{max}}{2 \cdot L_{max}}\right)^{2}}$$

$$\omega_{dLL} = \left(7.254 \cdot 10^{6}\right) \frac{1}{s}$$

Calculations for A1 and A2 based on Lower Limit values listed above:

$$A_{1LL} := V_{min} \qquad A_{1LL} = \left(2.94 \cdot 10^{5}\right) V$$

$$A_{2LL} := \frac{\alpha_{LL} \cdot A_{1LL}}{\omega_{dLL}} \qquad A_{2LL} = \left(4.053 \cdot 10^{3}\right) V$$

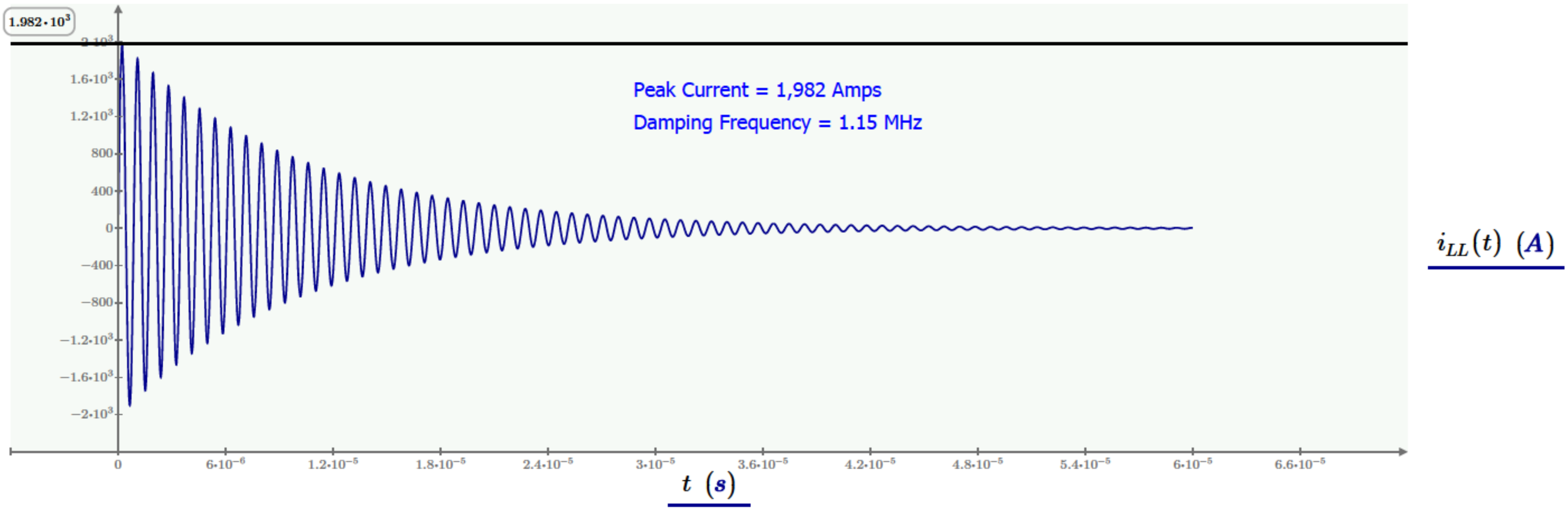
Double exponential equation for current & voltage waveforms based on Lower Limit value calculations:

$$i_{LL}(t) := \left(\left(-C_{min}\right) \cdot \left(e^{-\alpha_{LL} \cdot t}\right)\right) \cdot \left(\left(\left(A_{2LL} \cdot \omega_{dLL} - A_{1LL} \cdot \alpha_{LL}\right) \cdot \cos\left(\omega_{dLL} \cdot t\right)\right) + \left(\left(-A_{2LL} \cdot \alpha_{LL} - A_{1LL} \cdot \omega_{dLL}\right) \cdot \sin\left(\omega_{dLL} \cdot t\right)\right)\right)$$

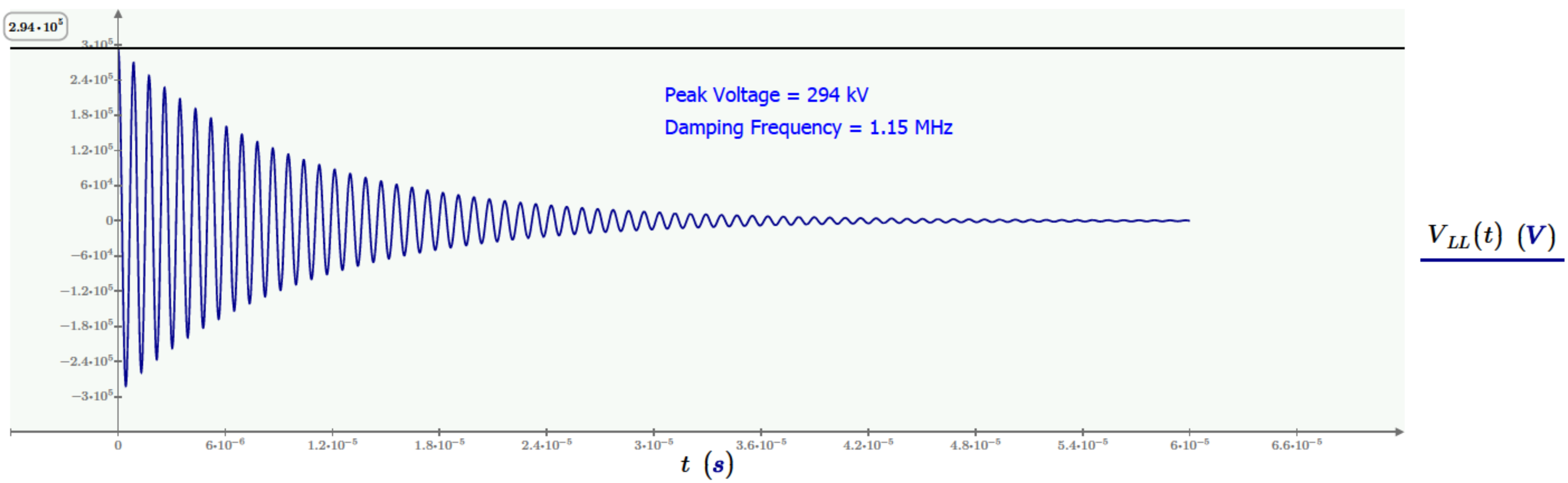
$$V_{LL}(t) := e^{-\alpha_{LL} \cdot t} \cdot \left(A_{1LL} \cdot \cos\left(\omega_{dLL} \cdot t\right) + A_{2LL} \cdot \sin\left(\omega_{dLL} \cdot t\right)\right)$$

Appendix A

Double exponential graph of current waveform using Lower Limit values

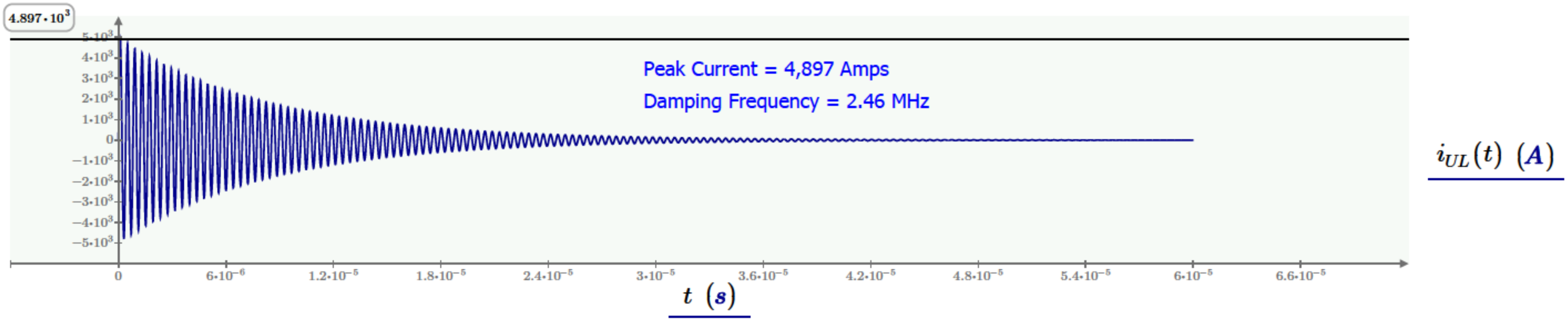


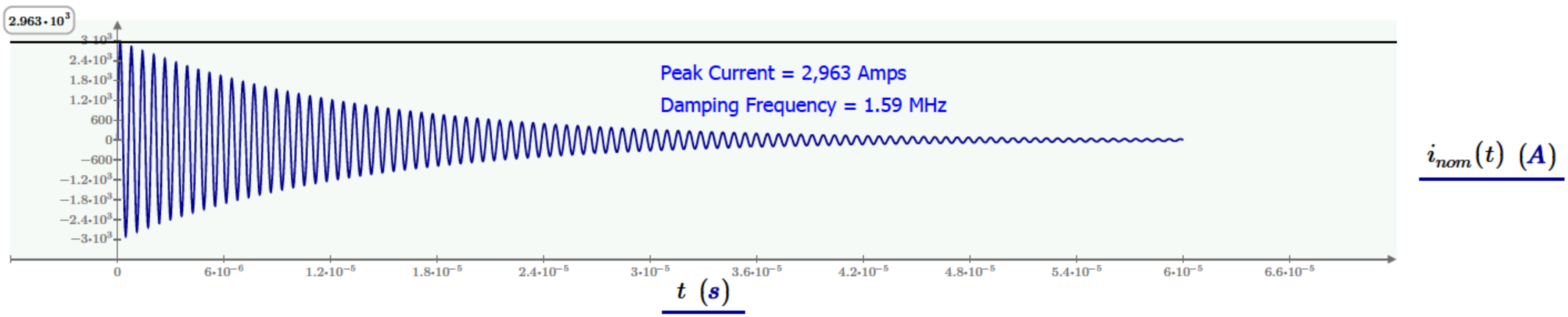

Double exponential graph of voltage waveform using Lower Limit values

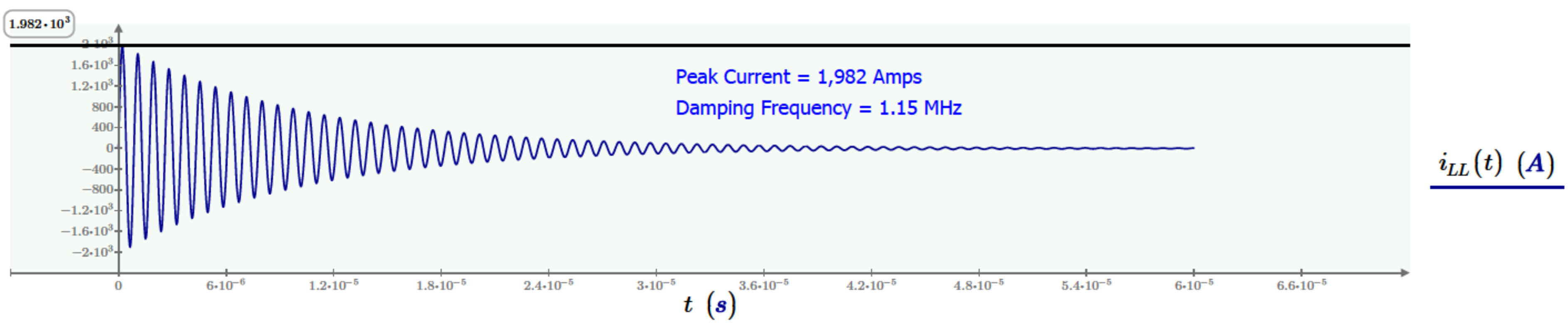


# Appendix A

## Current Waveform Graphs with Upper, Nominal, & Lower Values

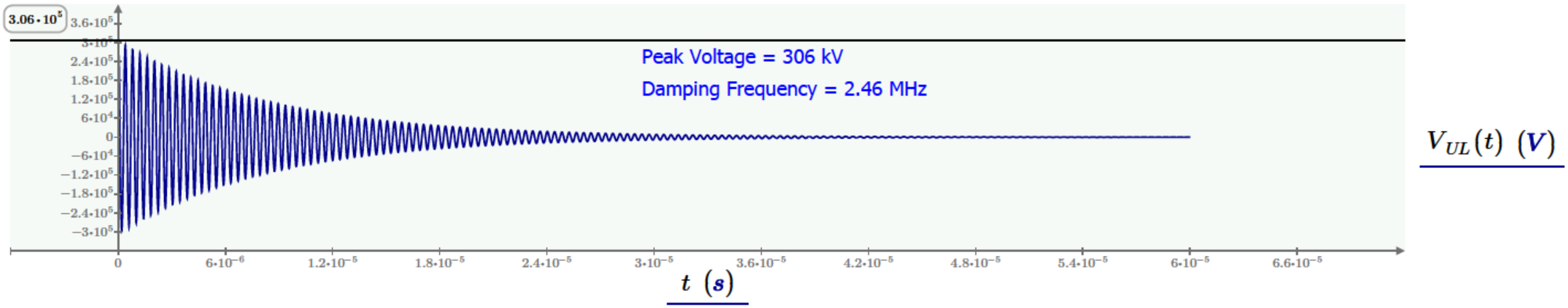


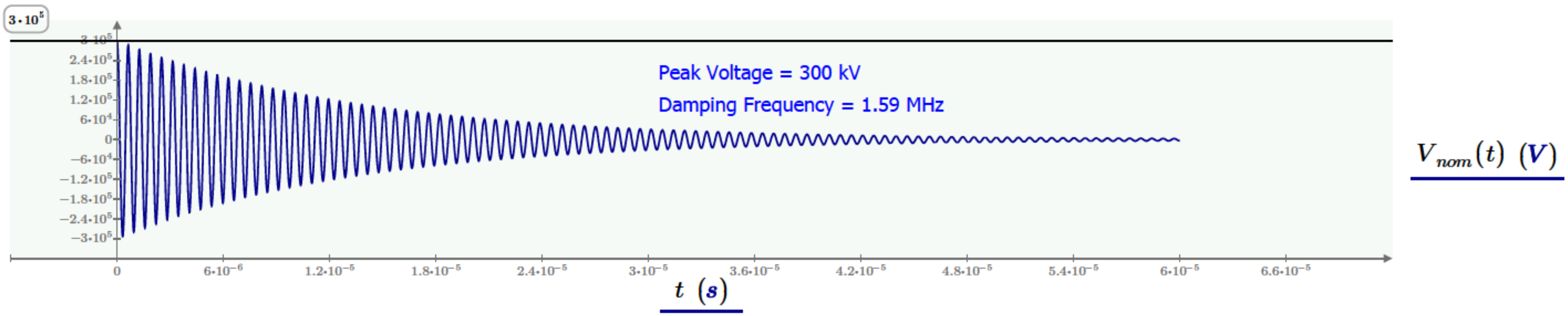



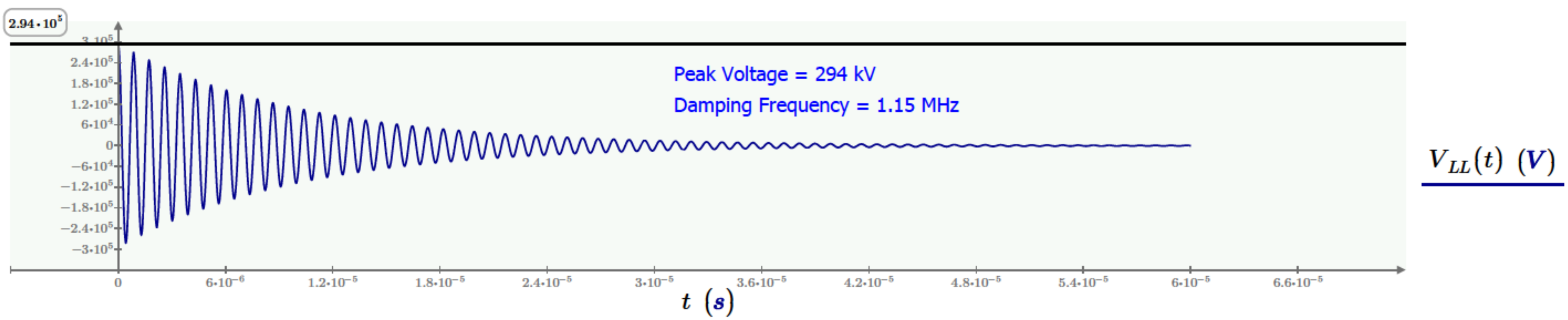



# Appendix A

## Voltage Waveform Graphs with Upper, Nominal, & Lower Values



# Appendix B

# JOTP TEST REPORTS

# Joint Ordnance Test Procedure

## Personnel and Helicopter ESD Validation Test Report

Final 3/8/13

# Executive Summary

MIL STD 464C provides the top level requirements for ordnance safety when ordnance items or systems are exposed to personnel and helicopter borne ElectroStatic Discharge (ESD). However, the requirements are general and do not provide specific instruction to evaluate ordnance items to these general requirements. MIL STD 331 provides some additional requirements and guidance for the ESD tests, but this additional guidance is not clear and complete enough to eliminate different interpretations by the Services. Therefore, the current implementation of the existing requirements is not consistent across the Services and leads to re-testing items to meet the specific Service's interpretation.

The JOTP validation testing evaluated the existing ESD test approach used by each of the Services, and the general requirements in MIL STD 464C to determine a common Joint Service ESD test approach that provides all data necessary for each Service to accept the results from the Joint Service test and produce consistent and repeatable results.

As a result of the validation testing, the following changes will be integrated into the JOTP Personnel ESD (PESD) and Helicopter ESD (HESD) documents to provide additional specific guidance for performing the testing, documenting the testing, and classification of the results:

1. Calculated current-based calibration waveforms with upper and lower limits will be added to the PESD document, along with specific calibration requirements: during testing, to be included in test reports, and for all test related equipment.

2. Calculated current-based calibration waveforms with upper and lower limits will be added to the HESD document, along with specific calibration requirements: during testing, to be included in test reports, and for all test related equipment.

3. Specific test equipment configuration requirements and minimum sample size requirements will be added to the HESD document by ordnance commodity for containerized ordnance testing, bare ordnance testing, and p-static ordnance testing.

4. Minimum sample size requirements will be added to the PESD document by ordnance commodity.

5. Specific Personnel and Helicopter ESD codes will be assigned to all ordnance items to clearly indicate the ESD susceptibility of the item based on the ESD test results.

## Review and Concurrence

Redstone Test Center:

Sr. Electronics Engineer: Jeff Craven

CRAVEN.JEFFERY.D.1230665016

Digitally signed by CRAVEN.JEFFERY.D.1230665016
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=CRAVEN.JEFFERY.D.1230665016
Date: 2013.03.19 09:14:05 -05'00'

Redstone Test Center:

Engineer III, AI Signal Research, Inc.: Thomas E. Roy

Thomas E Roy

White Sands Test Center:

Electromagnetic Radiation Branch Chief: Stephanie Jesson

JESSON.STEPHANIE.S.1232198768

Digitally signed by JESSON.STEPHANIE.S.1232198768
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=JESSON.STEPHANIE.S.1232198768
Date: 2013.03.11 14:06:43 -06'00'

White Sands Test Center:

Facility Engineer: Dr. William Roberts

ROBERTS.WILLIAM.LEONARD.1297715808

Digitally signed by ROBERTS.WILLIAM.LEONARD.1297715808
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=ROBERTS.WILLIAM.LEONARD.1297715808
Date: 2013.03.11 14:29:05 -06'00'

Naval Surface Warfare Center, Indian Head:

Navy ESD Technical Agent: Spencer Johnson

JOHNSON.SPENCER.T.1364442544

Digitally signed by JOHNSON.SPENCER.T.1364442544
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USN, cn=JOHNSON.SPENCER.T.1364442544
Date: 2013.03.11 15:25:31 -04'00'

Naval Ordnance Safety and Security Activity:

Navy E3 Ordnance Safety: Joe Sferrella

SFERRELLA.JOSEPH.V.1229422975

Digitally signed by SFERRELLA.JOSEPH.V.1229422975
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USN, cn=SFERRELLA.JOSEPH.V.1229422975
Date: 2013.03.11 14:48:38 -04'00'

# Table of Contents

Appendix

JOTP ESD Validation Test Report

**1.0 Purpose:**

The purpose of the JOTP ESD Validation testing is:

1. To determine if the different test methods, equipment, and procedures used by the Services produced similar results for ordnance items exposed to the PESD and HESD test requirements in the JOTP PESD and HESD documents.

2. To develop calibration requirements and calibration waveforms for the PESD and HESD environments to validate each Service's test equipment and procedures, which are not defined in MIL STD 464C.

3. To determine which specific ESD tests must be performed on each type of ordnance item to eliminate repeated ESD testing by each Service to satisfy Service specific interpretations of the MIL STD 464C ESD requirements.

**2.0 Background:**

MIL STD 464C provides the top level requirements for ordnance safety when ordnance items or systems are exposed to personnel and helicopter borne ESD. However, the requirements are general and do not provide specific instruction to ensure the implementation of the general requirements by each of the Services produce consistent and repeatable results. Additionally, the general requirements in MIL STD 464C do not specify that each potential ESD exposure for any ordnance item must be evaluated by the Service performing the ESD testing to address all possible operational exposures. Currently, each Service only evaluates an ordnance item to its specific operational requirements, and the ESD "certification" process for each Service is different. MIL STD 331 provides some additional detailed guidance on performing ESD testing, but this standard only applies to fuzes, and does not specify the ESD test requirements with enough detail to produce consistent implementation by the Services.

**2.1** The MIL STD 464C requirements for Helicopter ESD are:

**"A.5.8.1 Vertical lift and in-flight refueling.**
*The system shall meet its operational performance requirements when subjected to a 300 kilovolt discharge. This requirement is applicable to vertical lift aircraft, in-flight refueling of any aircraft, any systems operated or transported externally by vertical lift aircraft, and any man portable items that are carried internal to the aircraft. Compliance shall be verified by test (such as MIL-STD-331 or AECTP-500, Category 508 Leaflet 2 for ordnance), analysis, inspections, or a combination thereof. The item configuration may be packaged or bare, depending on the stockpile to safe separation sequence, but the specific configuration must be noted in the test report. The test configuration shall include electrostatic discharge (ESD) in the vertical lift mode and in-flight refueling mode from a simulated aircraft capacitance of 1000 picofarads, through a maximum of one (1) ohm resistance with a circuit inductance not to exceed 20 microhenry.*
**Requirement Rationale (A.5.8.1):**

Any type of aircraft can develop a static charge on the fuselage from p-static charging effects addressed in 5.8.2 of this standard. Aircraft that have the capability for lifting cargo or performing in-flight refueling have special operational concerns. In the case of vertical lift, the accumulated charge can cause an arc between the hook and the cargo during pick-up or between the suspended cargo and the earth during delivery. In the case of in-flight refueling, the tanker aircraft can be at one voltage potential and the aircraft to be refueled will be at a different potential, possibly resulting in an arc during mating of the two aircraft. The maximum expected discharge level for either of these cases is 300 kV. The resulting electrical transients can affect both the aircraft and the suspended cargo.

**Requirement Guidance (A.5.8.1):**

For vertical lift capability, the requirement should be applied to both the lifting aircraft and the system being lifted. The concern is for the safe and satisfactory operation of the vertical lift system hardware and no degradation or permanent damage of other mission equipment. For in-flight refueling, the requirement should be applied to the equipment and subsystems that are functioning during refueling. Equipment located near the refueling hardware is of primary concern. Potential hazards due to the presence of ignitable fuel vapors also need to be addressed.

For sling loaded ordnance, this requirement is applicable in addition to 5.8.3 of this standard. Examples of systems operated externally by vertical lift aircraft are dipping SONAR and apparatus used for helicopter rescue. The discharge occurs for these systems when the item approaches or contacts the surface of the earth or water.

**Requirement Lessons Learned (A.5.8.1):**

To protect personnel on the ground from receiving electrical shocks, it is standard practice for rotorcraft to touch the ground with the hook before it is connected to the cargo. As the cargo is lifted, the whole system (aircraft and cargo) will become recharged. Again, when the cargo is lowered to the ground, it must touch the ground to be discharged before handling by personnel. The aircraft system and cargo often see several electrical discharges as the vertical lift process is executed.

During in-flight refueling, pilots have reported seeing arcing between the refueling probe and the fueling basket during mating. These discharges were several inches long. Based on these observations, the 300 kV number was derived. Aircraft that have experienced discharges from in-flight refueling have had upsets to the navigation system resulting in control problems.

**Verification Rationale (A.5.8.1):**

The path of the discharge is somewhat unpredictable. Inspections and analysis are needed to verify that assumptions on current flow path are reasonable and that protection is appropriately implemented. Testing is necessary to evaluate possible paths where the discharge event may occur. The 1000 picofarad capacitance used for testing represents a reasonable value for a large size aircraft.

**Verification Guidance (A.5.8.1):**

The testing for vertical lift equipment on the aircraft has involved injecting the cargo hook with discharges from a mini-Marx generator. Testing for the in-flight refueling has involved injecting the in-flight refueling probe on the aircraft with discharges from a mini-Marx generator. Both positive and negative discharge voltages have been used for both types of testing. Aircraft equipment are monitored for upset or failure.

Testing of the vertical-lift cargo has involved applying mini-Marx discharges to the shipping container or directly to the cargo system depending upon the configuration used in transport. The

container should have discharges applied to several locations around the container. After the discharge, the system is checked for proper operation.
MIL-STD-331 or NAVSEAINST 8020.19 provides guidance on issues with explosive devices and additional background."

**2.2** The MIL STD 464C requirements for Personnel ESD are:

**"A.5.8.3 Ordnance subsystems.**
*Ordnance subsystems shall not be inadvertently initiated or dudded by a 25 kilovolt ESD caused by personnel handling. Compliance shall be verified by test (such as MIL-STD-331 or AECTP-500, Category 508 Leaflet 2), discharging a 500 picofarad capacitor through a 500 ohm resistor with a circuit inductance not to exceed 5 microhenry to the ordnance subsystem (such as electrical interfaces, enclosures, and handling points.*

**Requirement Rationale (A.5.8.3):**
Explosive subsystems are used for many purposes including store ejection from aircraft, escape systems, rocket motors, and warhead initiation. Voltages and discharge energies associated with ESD can inadvertently ignite or fire these devices. The consequences can be hazardous.
**Requirement Guidance (A.5.8.3):**
This requirement is based on charge levels that could possibly be developed on personnel. All explosive subsystems should meet this requirement to guarantee safe personnel handling.
**Requirement Lessons Learned (A.5.8.3):**
Explosive subsystems have been initiated by ESD caused from human contact or other sources of ESD.
**Verification Rationale (A.5.8.3):**
Due to the safety critical nature of maintaining explosive safety, the high confidence provided by testing is necessary to ensure that requirements are met.
**Verification Guidance (A.5.8.3):**
During testing, circuit inductance should be limited to 5 microhenries.
The 500 picofarad capacitor and 500 ohm resistor, different from the model used in section 5.8.4 of this standard, was selected to simulate worst-case characteristics of a human body discharge due to the critical nature of ordnance. A significant number of components must be tested to provide a statistical basis for concluding that the requirement is met. For EIDs, the discharges must be applied in both pin-to-pin and pin-to-case modes for both polarities.
**Verification Lessons Learned (A.5.8.3):**
A ground launched missile being removed from a container exploded. It was hypothesized the accident could have been caused by an electrostatic discharge to the propellant (not to the EID)."

**2.3 Requirements Discussion:**

Section A.5.8.1 of MIL STD 464C clearly calls out several operational helicopter ESD exposures that could possibly be experienced by an ordnance item. However, the last part of the discussion only references the VERTREP and in flight refueling test modes, and indicates if other exposure modes are expected, then those should be tested also. The guidance also clearly states that any item that is carried attached to the airframe externally or carried outside the shipping container internally should be tested in the bare configuration. The only specific guidance is the component values and the voltage level for the HESD test. MIL STD 331 provides some additional guidance for HESD testing, but does not clearly identify calibration requirements, test equipment and procedure requirements, or apply to all ordnance items. Currently, each Service has interpreted the requirements differently resulting in ESD testing that does not address the operational requirements of the other Services, resulting in additional and/or duplicated testing by the other Services to get the necessary data for certification.

Section A.5.8.3 of MIL STD 464C provides specific guidance for the component values and the voltage level for the PESD test, and for the discharges to be applied in both the pin to pin and pin to case modes for EID's. However, there is no other specific guidance for other ordnance items except bare EED's or for calibration.

Both the PESD and HESD test requirements in MIL STD 464 specify that compliance shall be verified by test, but the existing references do not apply to all ordnance items, and do not provide specific guidance for testing to ensure consistent and repeatable results that are acceptable for all Services. Each Service also has different ESD test "certification" methods that are not consistent, and different interpretations of the results required for approving any ordnance item for field use.

**3.0 Validation Test Requirements:**

This section will identify the differences in the ESD test processes used by the Services, and the differences in the interpretations of the MIL STD 464C and MIL STD 331 requirements. The differences will be investigated during the validation testing to provide a common ESD test procedure, a common test requirement for all ordnance items, a common test result certification, and test calibration for use by all the Services.

For the purposes of this document, the following definitions will apply:

VERTREP testing and/or VERTREP mode will refer to containerized HESD testing; VERTREP test equipment will refer to the unique "charged item" HESD test equipment setup. This is the standard Army test equipment and test configuration. The terms VERTREP, Army, containerized/packaged, and charged item will be used interchangeably in this document to refer to HESD testing of packaged ordnance items. The VERTREP mode uses the approaching probe to a test point test method to initiate the discharge.

Marx testing and/or Marx mode will refer bare/man carry/hot tube loaded HESD testing; Marx test equipment will refer to the Marx generator HESD test equipment setup. This is the standard Navy test equipment and test configuration. The terms Marx, Navy, and bare/man carry/hot tube loaded will be used interchangeably in this document to refer to HESD testing of bare ordnance items. The Marx mode uses direct contact of the probe with the test point test method and a remote triggered switch to initiate a discharge.

**3.1**: Correlation of test effects from different HESD test equipment (Marx generator for bare item testing vs. VERTREP equipment for charged item testing) for all HESD operational exposures from MIL STD 464C.

Rationale: MIL STD 464C calls out 2 different HESD requirements to evaluate: (1) VERTREP and (2) bare item carry. The only additional guidance provided is the voltage level, capacitance, and maximum circuit resistance and inductance.

-The Navy currently uses a switch controlled Marx generator to perform direct contact testing for both VERT REP and bare item carry HESD testing, and records calibration discharges for all testing and provides these plots in reports. The rationale for this approach by the Navy was that the bare item testing was the most severe test, and the test equipment and procedures were designed to replicate a charged helicopter touching a bare ordnance item.

-The Army uses a different approach where the item is charged to 300 kV, then a ground rod is moved quickly to a test point until a discharge occurs through some air gap. The rationale for this approach by the Army was that all items would be exposed to the VERTREP environment, and test equipment and procedures were designed to replicate a ground staff touching a charged ordnance item in the packaged configuration.

-MIL STD 331 has a clear requirement for energy delivered to the test load (80% of the energy stored on the capacitor), but there is no requirement to measure this energy prior to testing. These test procedure differences have possibly caused different test results in the services.

JOTP requirements: The different test procedures currently used bring up a viable question as to previous test results where the Army testing produced failures in the packaged configuration that the Navy testing did not duplicate; and the Navy produced failures in the bare configuration that Army testing did not duplicate. These test result discrepancies need to be investigated. The causal factors that led to these test discrepancies need to be understood and corrected so there is a common test procedure that produces identical results in each ordnance configuration that each service will accept.

The question to be answered is: does charging the item and then discharging to a grounded point through an air gap produce different results on the item as opposed to triggering the charge on the capacitor to a grounded item. The hypotheses to be investigated during the validation testing are: that the electrical failure paths are different for the two approaches; and/or that the voltage/energy level is different within the two approaches that produce the different results. MIL STD 464C is clear with respect to the amount of the energy stored on the capacitor that must be transferred to the test item, but does not provide guidance on direct contact discharge or approaching probe discharge methods, or the preferred approach for VERTREP and bare item testing. See section 4.1 for results for the test equipment effects validation testing.

**3.2**: Instrumentation methods for verifying PESD and HESD test equipment.

Rationale: MIL STD 464C specifies the component values for 25 kV PESD and 300 kV HESD test, but does not provide guidance for verification or calibration the test equipment energy output. An instrumentation method is necessary for each test facility or Service to properly document and validate their testing and for the independent test facilities to verify and/or repeat the results of another facility. Additionally, an instrumentation method is necessary to evaluate any differences in the test methods and procedures used by the Services, and the effect of a particular test method on an inert ordnance item. Since instrumentation and data acquisition is often a source of incorrect data and dispute of results between different test facilities, evaluating the instrumentation used to record the calibration and energy output at each facility is necessary.

Currently:
Navy uses a Pearson Electronics 110A current transformer and a 5 GHz digital storage oscilloscope with external attenuators to record the current pulse from the Marx test equipment. There is no recording of the voltage output waveform. All three components are calibrated on a regular basis.

Army uses several different Pearson Electronics current transformers (310, 3025), the Nanofast instrumentation system with internal attenuators to convert the electrical signals to fiber optic signals and a 5 GHz digital storage oscilloscope to record the current pulse from the VERTREP test equipment. Only the oscilloscope and current transformers are calibrated.

JOTP Requirements: The Services need to evaluate and agree on an acceptable instrumentation method or methods that provide identical data to validate the test equipment (calibration), test methods, and discrepancies between test results. Go-No Go testing with a live ordnance item cannot provide the necessary answers for test equipment validation and calibration, nor can it provide answers for discrepancies between test results. To obtain the data needed for the JOTP ESD procedures for Joint Service use, an instrumentation test method is required to measure both the electrostatic field inside the container, and the current/energy on a bridgewire for bare items and items inside a container to fully evaluate any difference in the test methods on the test item. See section 4.2 for results for the instrumentation methods validation testing.

**3.3**: Develop a calibration method and requirements for HESD testing.

Rationale: MIL STD 464C specifies the voltage level, capacitance, and maximum circuit resistance and inductance for the HESD circuit. MIL STD 331 has a clear requirement for energy delivered to the test load, but there is no requirement to document this energy prior to testing as is required for PESD testing. Neither standard provides a reference HESD calibration waveform either as is provided in MIL STD 331 for PESD testing.

JOTP Requirements: MIL STD 464C has clear requirements on the amount of energy stored on the capacitor that must be delivered to the test item, but does not provide calibration curves or any guidance on how to document the test equipment/setup similar to what is provided for the PESD test setup and equipment. MIL STD 331 and some NATO documents discuss using a 100 ohm resistor for the calibration resistance, but do not document where that requirement originates or provide a waveform for reference. Additionally, using a resistance this high makes it much more difficult to use the resultant waveform to evaluate the HESD test equipment performance. It is clear that some of the energy during a discharge event is lost ionizing an air gap if it exists, and therefore at some distance from the test item the requirements of MIL STD 464C would not be met. Specifying a nominal calibration waveform with upper and lower limits that applies to both the VERTREP and Marx test equipment would eliminate any discrepancies in the HESD test results. The calibration method will also investigate during the validation testing acceptable methods to measure the waveforms, and any differences in the calibration procedures that may apply to the different discharge methods (direct contact and approaching probe), and make measurements using these calibration procedures to validate the energy delivered to the calibration setup for incorporation into test reports. See section 4.3 for results from the calibration methods and requirements validation testing.

**3.4**: Validate calibration setup for PESD testing.

Rationale: MIL STD 331 specifies the use of a 50:1 voltage divider for the calibration circuit and provides voltage waveforms for test equipment calibration. The Army and Navy do not use this divider because it cannot be used during testing since it would affect the energy delivered to the test item, but rather use a shorted discharge to the ground plane and monitor the current using a transformer. New calculated waveforms based on the circuit components required in MIL STD 464C are in the PESD procedure for this shorted discharge with upper and lower limits based on the component tolerances, but no documentation has been generated on any difference in the energy delivered to a test item using direct contact discharge or approaching probe discharge.

JOTP Requirements: The PESD procedure requires calibration curves at the beginning and end of each day as part of the test report documentation. Since some of the energy on the capacitor is lost to ionizing any air gap, there is a limit to the air gap distance or probe speed that would not meet the requirements of MIL STD 464C. Testing will be performed to validate that each test approach meets the upper and lower limits for the new current based waveforms, and document any limits in air gap distance or probe speed that fail to meet the requirements. Also, validate the new calibration waveforms with different commercially available and custom designed PESD test equipment. See section 4.4 for results from the PESD calibration setup validation testing.

**3.5**: Validate the safe and operable requirement for all HESD testing, and required test configurations.

Rationale: MIL STD 464C specifies that the system must meet its operational performance requirements after being subjected to a 300 kV ESD discharge, which implies the item must be safe and operable after exposure. There is no discussion that this requirement applies only to the VERTREP configuration. The Navy interprets this requirement as the item must be safe and operable after HESD exposure, whether in the VERTREP or bare configuration. However, MIL STD 331 only requires the item to be safe after bare HESD exposure. There is no MIL STD 331 requirement for operation after bare exposure to HESD. The Army seems to follow the MIL STD 331 requirement for HESD bare testing. These requirements from the MIL STD's seem to conflict, and a common interpretation of the requirements of MIL STD 464C must be investigated during the validation testing and implemented for Joint Service Testing.

JOTP Requirements: Currently, the Army has up to three helicopter ESD tests that could be performed depending on the type of ordnance item: (1) VERTREP mode, (2) bare (man carry/hot tube loaded) mode, and (3) High Voltage Corona (HVC) tests. VERTREP mode is in the shipping configuration; bare mode is outside the container in the appropriate worst case exposure configuration (powered, unpowered, armed, etc); and the High Voltage Corona (HVC) mode is HESD exposure in the external aircraft carry and/or in flight configuration. The Army HVC test is a charged item test in the operational configuration for ordnance, and will be investigated during the validation testing for meeting the MIL STD 464C requirements for p-static testing of ordnance. The Navy currently tests to the worst configuration (either VERTREP, bare/man carry, or HVC), and assesses each of the other configurations based on the results of the worst case test depending on the type of ordnance item. However, there is no consensus among the Services or guidance in MIL STD 464C on which tests apply to specific types of ordnance items, the configuration of the test item for each type of test, the test equipment setup for each type of test, or the pass/fail criteria for each type of exposure. These discrepancies will be investigated during the validation testing. See section 4.5 for results for the safe and operable requirement and ordnance item test configuration validation testing.

## 4.0 Validation Test Results:

The validation results below correlate to the appropriate subsection from section 3 validation test requirements. The test equipment models and manufacturers are noted for all equipment used for measuring the data for documentation purposes. Multiple models of the current transformers were used to validate the output between all the various models currently used by the Services.

**4.1 Requirement 1:** Correlation of test effects from different HESD test equipment (Marx generator for bare item testing vs. VERTREP equipment for charged item testing) for all HESD operational exposures from MIL STD 464C.

Validation Test Plan Requirements:
A. Measure the output from VERTREP/containerized/charged item HESD test equipment. Is it repeatable for waveform and trigger gap distance? Can a fixed trigger gap be designed into the system to specify in the JOTP HESD document?
B. Measure the output from Bare carry/hot tube load (Marx) HESD test equipment. Is it repeatable for waveform? Can the VERTREP test setup duplicate the Marx output waveform and energy so separate test equipment is not required to be specified in the JOTP HESD document?

Validation Test Requirement 1 Procedure:
A. The VERTREP equipment was set up with the toroid (output from capacitor bank) on top of a 4 foot tall PVC cage. The toroid was approximately 4 feet above the ground. The capacitor bank was charged to approximately 300 kV (6 capacitors in a series configuration). The ground probe was moved to the toroid rapidly to generate the discharge from the capacitor bank. Approximate probe speed is 4 feet per second. A Pearson Electronics current transformer (several different models used) was cabled to the Nanofast Instrumentation system for measuring the output current. See Figure 1 for a picture of the VERTREP test setup.
B. The Bare carry/hot tube load (Marx) test equipment was set up with output probe on top of a PVC cage. The probe was approximately 4 feet above the ground. The ground probe was placed next to the output probe. The capacitor bank was charged to approximately 100 kV (3 capacitors in a series configuration). The discharge switch was triggered remotely to initiate the discharge. A Pearson Electronics current transformer (several different models used) was cabled to the

Nanofast Instrumentation system for measuring the output current. See Figure 2 for a picture of the Marx test setup.

Validation Test Requirement 1 Results:
A. The VERTREP HESD test equipment setup does provide repeatable waveforms from the calibration test setup and the trigger gap distance is repeatable. The energy in the discharge was approximately 80% of the energy stored on the capacitor. See Figure 3 for a picture of the VERTREP test setup output waveform. Currently, the probe is moved manually to the test object to trigger the discharge, and specifying a trigger gap distance for a calibration setup would be possible. However, this approach would not work for non-conductive test objects as the trigger gap distance would need to be reduced in order to trigger a discharge. It is possible to specify a initial maximum gap from the ground probe to the toroid, and a minimum speed to move the ground probe to the toroid to trigger the discharge.

Figure 1: VERTREP test equipment setup

Figure 2: Marx test equipment setup

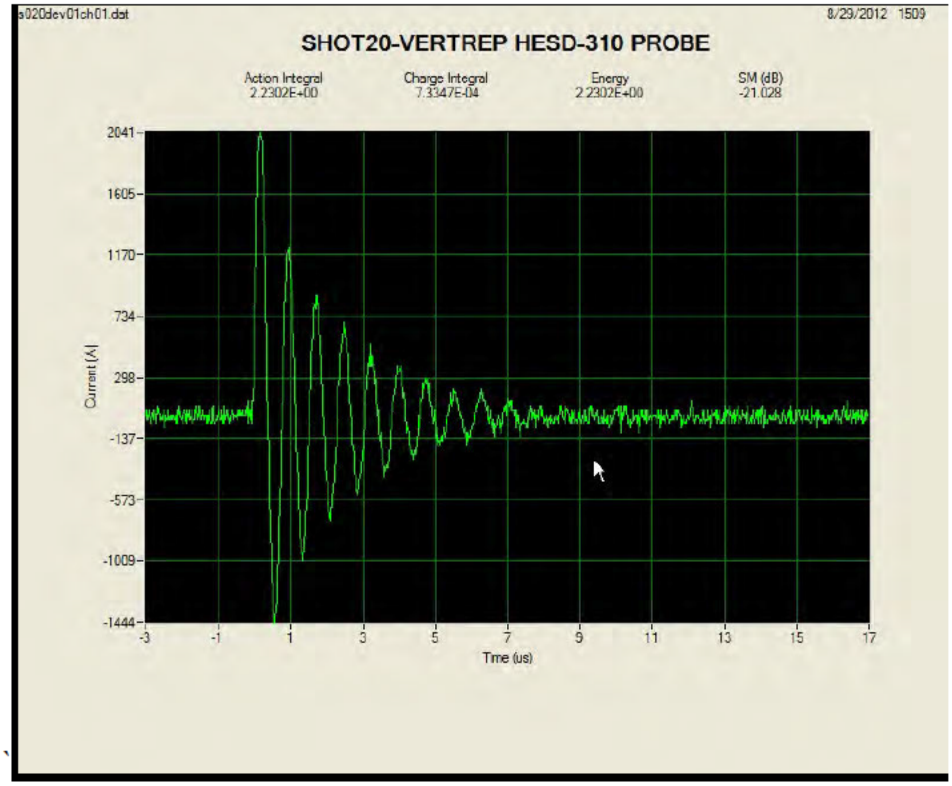



Figure 3: VERTREP calibration discharge

B. The Marx HESD test equipment setup provides repeatable waveforms from the calibration test setup and the trigger discharge is repeatable. The energy in the discharge was approximately 100% of the energy stored on the capacitor with a direct contact discharge. See Figure 4 for a picture of the Marx test setup output waveform from the Army test equipment and Figure 5 for a picture of the Marx test setup output from the Navy test equipment. Army and Navy trigger methods use a switch to trigger the discharge, and both setups allow for direct contact or approaching probe discharges which can direct the energy to a specific test point on the test item.

Validation Test Requirement 1 Results Discussion:

Testing with the Marx setup at Redstone and previous testing at NSWC Indian Head with the Navy Marx setup indicates that the maximum air gap distance is approximately 9 inches for an air gap discharge, compared to 18 inches air gap for the VERTREP test setup. Through testing, it was determined that the Marx setup with an air gap distance of 6 inches produced the same energy to the test item as an 18 inch air gap with the VERTREP test equipment.

**However, additional testing discussed later clearly shows that although the energy output of the test equipment could be made equal between the VERTREP and Marx systems, the different test setups had a considerable difference on the current induced on a bridgewire inside a non-metallic container. Conclusions that will be incorporated into the JOTP procedure from this testing will be discussed in section 5.**

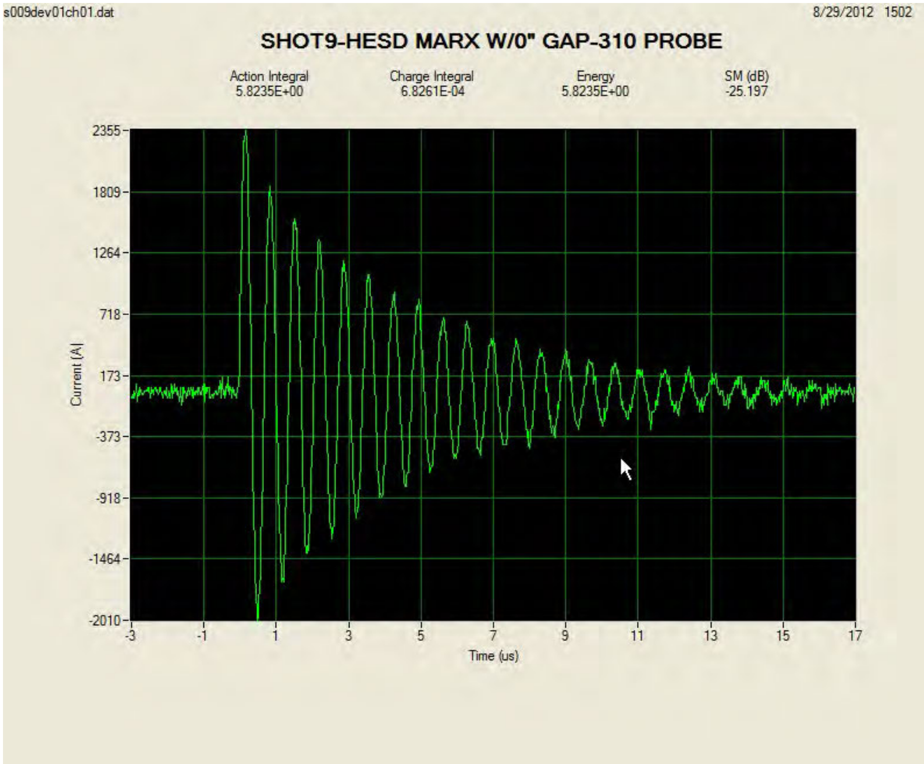



Figure 4: Marx calibration discharge from Army test equipment

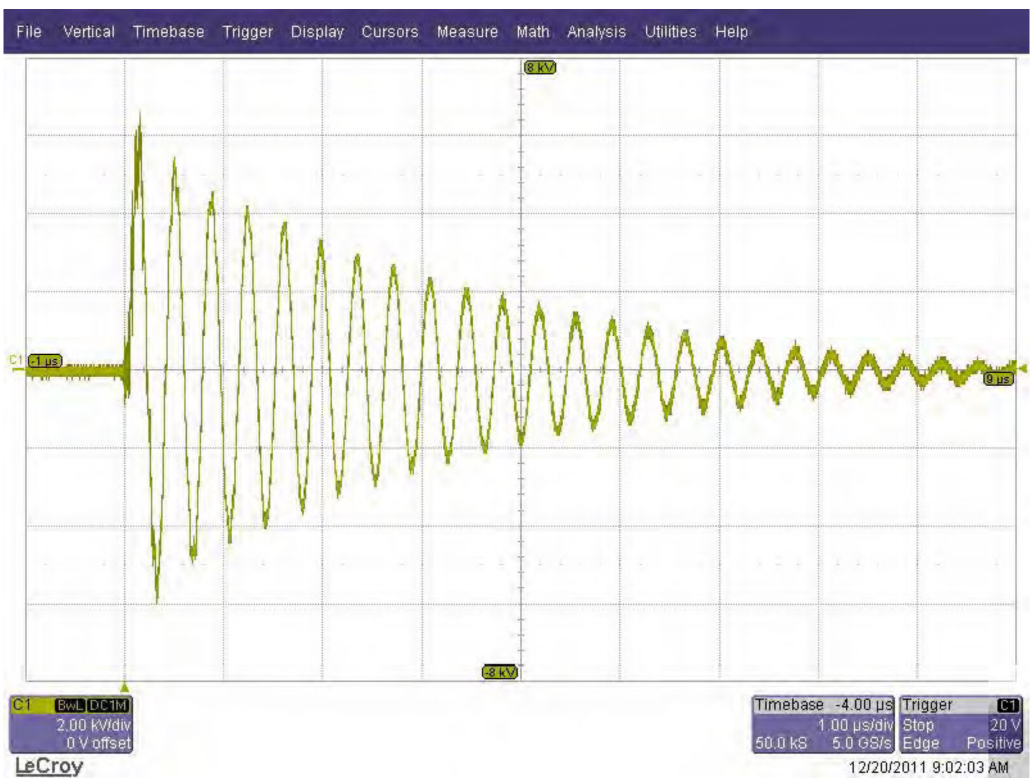



Figure 5: Marx calibration discharge from Navy test equipment

**4.2 Requirement 2:** Instrumentation methods for verifying PESD and HESD test equipment.

Validation test plan Requirements:
A. Measure the output from VERTREP HESD test equipment discharged to an inert bridgewire in a wooden box using Nanofast instrumentation system and Pearson current transformers (possibly several models). Are the captured waveforms from the 2 current transformers identical within measurement accuracy? Are the captured waveforms repeatable using the same test setup?
B. Measure the output from Bare carry/hot tube load (Marx) HESD test equipment discharged to an inert bridgewire in a wooden box using Nanofast instrumentation system and Pearson current transformers (possibly several models with different amplitude, frequency range, slew rate). Are the captured waveforms from the 2 sensors identical within measurement accuracy? Are the captured waveforms repeatable using the same test setup?

Validation Test Requirement 2 Procedure:
A. To investigate the effects that the VERTREP test equipment would have on a bridgewire inside a container, a 1 ohm loop of stainless steel wire was attached to a connector to simulate a bridgewire and placed inside a Pelican plastic (non-conductive) shipping container. Several different models of Pearson current transformers were used to measure the current induced on the bridgewire from the ESD discharges. The current transformer (several different models used to validate multiple models for repeatable results) was cabled to the Nanofast Instrumentation system for measuring the current on the inert bridgewire and the current output from the VERTREP test setup. Additionally, the inert bridgewire was replaced with an E field probe inside the container and the tests repeated. The sealed container was tested in the VERTREP test configuration. Both instrumentation setups were also tested inside a metal ammunition container (ammo can). See Figure 6 for a picture of the inert bridgewire setup inside the container and Figure 7 for a picture of the VERTREP test setup of the container.

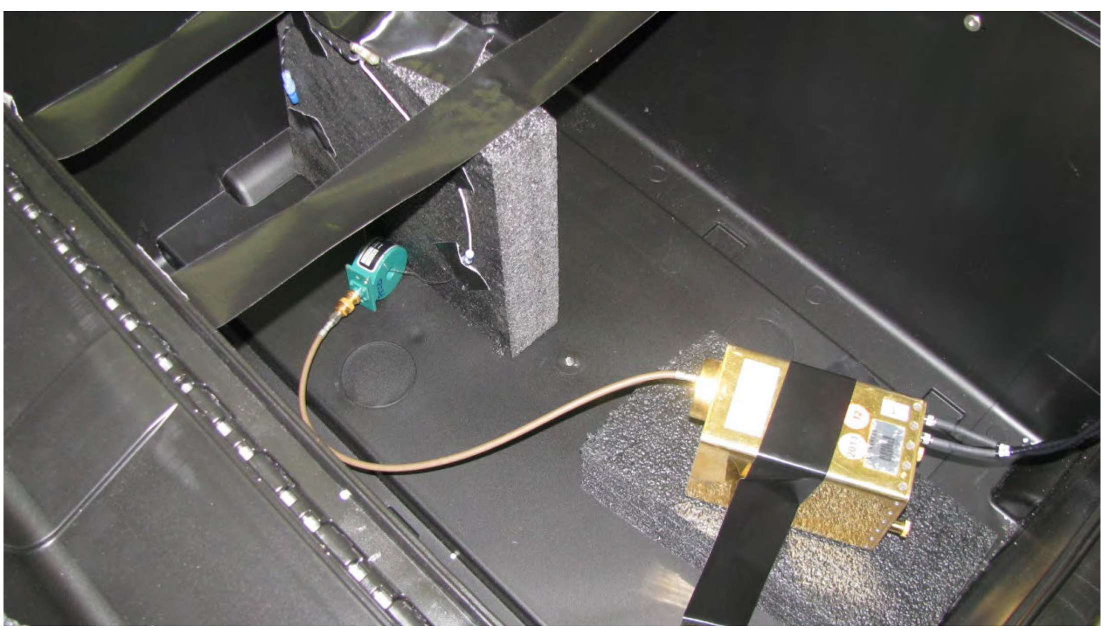


Figure 6: Inert bridgewire setup inside shipping container

Figure 7: Inert bridgewire inside shipping container VERTREP test setup

B. To investigate the effects that the Marx test equipment would have on a bridgewire inside a container, a 1 ohm loop of stainless steel wire was attached to a 2 pin connector to simulate a bridgewire in an initiator and placed inside a Pelican plastic (non-conductive) shipping container. Several different models of Pearson current transformers were used to measure the current induced on the bridgewire from the ESD discharges. The current transformer was cabled to the Nanofast Instrumentation system for measuring the current on the inert bridgewire and the current output from the Marx test setup. Additionally, the inert bridgewire inside the container was replaced with an E field probe and the tests repeated. The sealed container was tested in the Marx test configuration. Both instrumentation setups were also tested inside a metal ammo can. See Figure 8 for a picture of the Marx instrumentation test setup.

Figure 8: Inert bridgewire inside shipping container Marx test setup

Validation Test Requirement 2 Results:
A. The VERTREP test setup used two different methods: an electric field monitor and an inert 1 ohm bridgewire with several different models of Pearson current transformers (2877 and 4100) with both tested inside a metal ammo can and a Pelican non-conductive plastic case. Both current transformers produced identical results and were repeatable with the VERTREP test equipment in each container. However, the measured data clearly showed that the fields produced in the plastic container were much higher than the fields produced in the metal ammo container. See Figure 9 for a picture of the VERTREP instrumentation test setup output waveform from the E field probe in the plastic container, and Figure 10 for a picture of the VERTREP instrumentation test setup output waveform from the E field probe in the metal container.

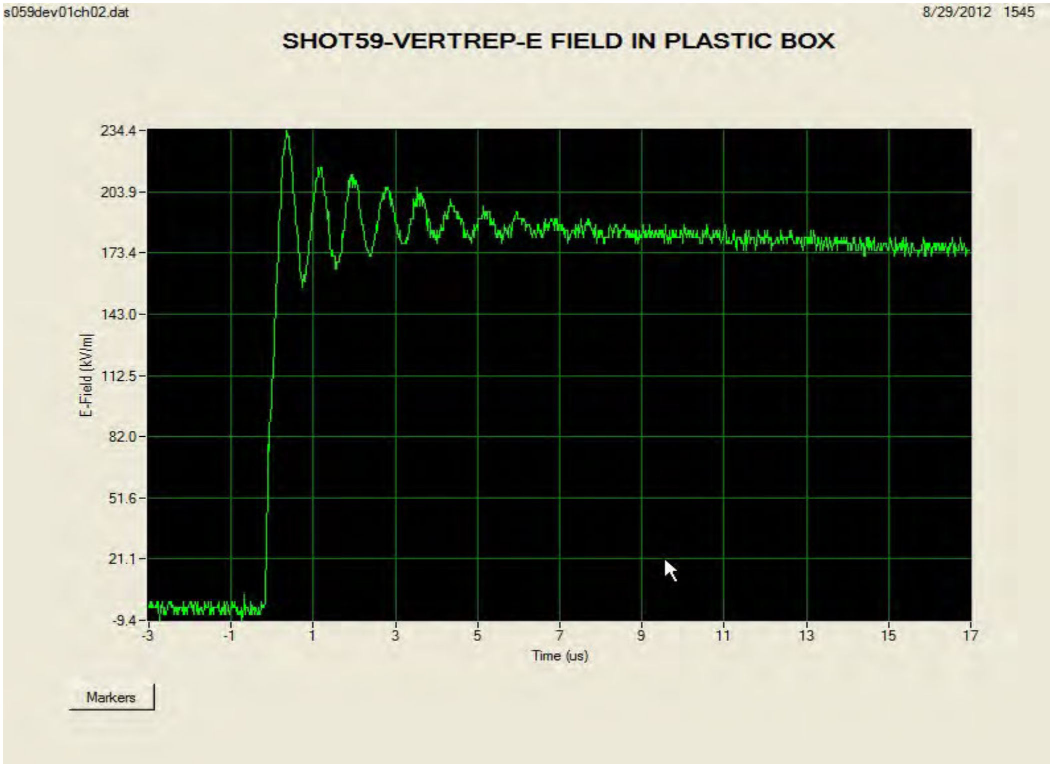



Figure 9: E field probe inside the plastic shipping container VERTREP test waveform


Figure 10: E field probe inside the metal shipping container VERTREP test waveform

B. The test setup used two different methods: an electric field monitor and an inert 1 ohm bridgewire with several different models of Pearson current transformers (2877 and 4100) with both tested inside a metal ammo can and a pelican non-conductive plastic case. Both current transformers produced identical results and were repeatable with the Marx test equipment in each container. However the test results clearly showed the electric field measurements and the current through the inert bridgewire were much lower with the Marx setup than with the VERTREP setup when in a non-conductive container. When using a metal container, the results were identical. See Figure 11 for a picture of the Marx instrumentation test setup output waveform from the E field probe in the plastic container, and Figure 12 for a picture of the Marx instrumentation test setup output waveform from the E field probe in the metal container.

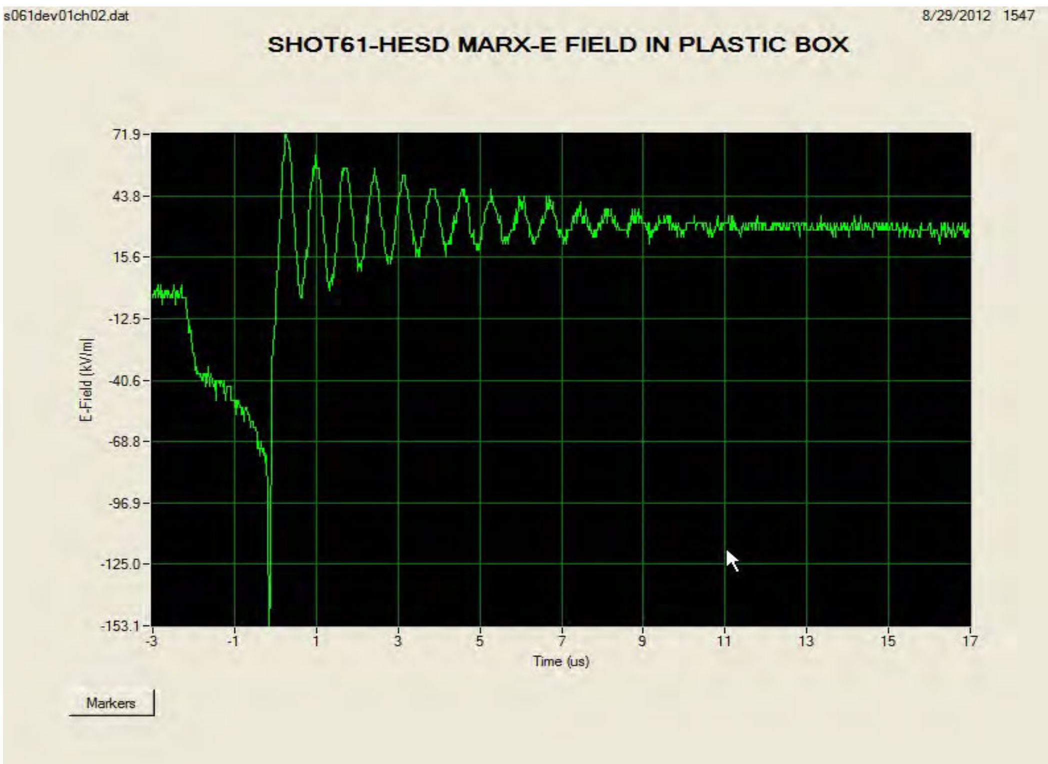



Figure 11: E field probe inside plastic shipping container Marx test waveform

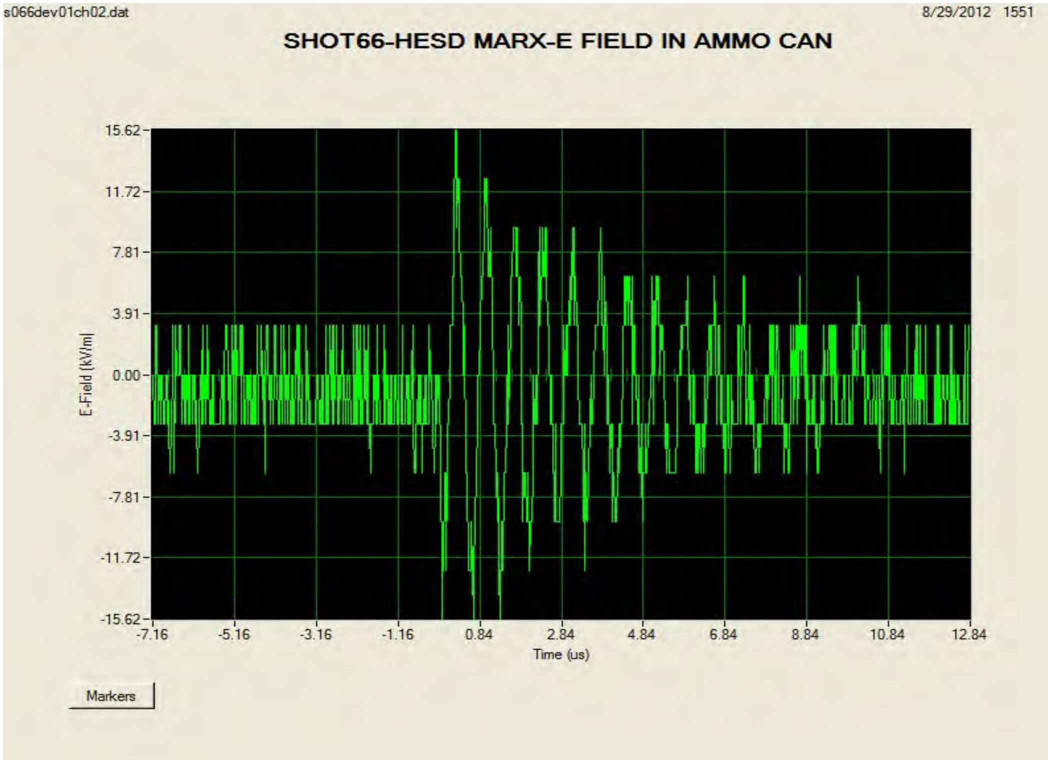



Figure 12: E field probe inside metal shipping container Marx test waveform

<u>Validation Test Requirement 2 Results Discussion:</u>
The test results (Figures 9 through 12) clearly show the electric field (E field) measurements and the current through the inert bridgewire were much lower with the Marx setup than with the VERTREP setup when in a non-conductive container. The values for the peak field measurements were approximately 72 kV/m for the Marx setup and 235 kV/m for the VERTREP setup. The E fields were identical for the VERTREP and Marx test setups in the metal ammo container (faraday cage). The VERTREP test method is more representative of simulating the charge that will accumulate on a container during vertical replenishment.

**The validation test results and EED/EID test failures noted during previous Army testing with this method that could not be duplicated with the Navy Marx setup support these results. The VERTREP test setup produces higher electric fields inside containers that are not a complete metal faraday cage.**

**4.3 Requirement 3:** Develop a calibration method and requirements for HESD testing.

<u>Validation test plan Requirements:</u>
A. Determine test equipment and setup requirements for VERTREP testing and for Man carry/hot tube loaded (Marx) configurations for JOTP HESD testing.
B. Develop repeatable calibration requirements for both VERTREP test equipment and for man carry/hot tube load (MARX) test equipment including specifying approaching probe speed and waveforms to be included in the JOTP HESD procedures.

Validation Test Requirement 3 Procedure:

A. Test equipment used several different models of Pearson current transformers (310 and 3025). The current transformer was cabled to the Nanofast Instrumentation system and digital oscilloscope for measuring the current output from the Marx and VERTREP test setup. VERTREP equipment was set up with the toroid (output from capacitor bank) on top of a 4 foot tall PVC cage. The toroid was approximately 4 feet above the ground. The capacitor bank was charged to approximately 300 kV (6 capacitors in a series configuration). The ground probe was moved to the toroid rapidly to generate the discharge from the capacitor bank. Approximate probe speed is 4 feet per second. The Marx test equipment was set up with output probe on top of a PVC cage. The probe was approximately 4 feet above the ground. The ground probe was placed next to the output probe. The capacitor bank was charged to approximately 300 kV (3 capacitors in a series configuration). The discharge switch was triggered remotely to initiate the discharge.

B. Calibration waveforms and requirements were developed based on the circuit component values and accuracy requirements currently in MIL STD 464C and MIL STD 331. Additionally, the calibration was done as a “shorted” discharge, since there was no traceability to using a 100 ohm resistor in the existing documents to the energy output of the helicopter test circuit.

Validation Test Requirement 3 Results:

A. The test setup for VERTREP testing used the capacitor bank and toroid isolated from the ground plane by a minimum of 4 feet charged to 300 kV. The capacitor bank and toroid were directly connected to the output of the power supply. The ground probe was moved manually towards the toroid until a discharge occurred. Approximate discharge distance was 18 inches. These waveforms were repeatable and consistent.

The test setup for Man carry/hot tube loading testing used the Marx generator and toroid isolated from the ground plane by a minimum of 4 feet charged to 300 kV. The ground probe was placed directly in contact with the toroid. An electric trigger was used to initiate the discharge from the Marx generator. These waveforms were repeatable and consistent.

B. VERTREP calibration requirements: The capacitor bank output is connected to a toroid with no disconnect switch in the output path. The toroid is isolated from ground by a minimum of 4 feet. The ground probe is moved manually or automatically at a minimum speed of 4 ft/sec to the toroid to initiate discharge of the capacitor back after fully charged. The current transformer is located on ground side of the VERTREP test equipment. The VERTREP circuit schematic is shown in Figure 13.

Marx (Man carry/Hot tube loading) calibration requirements: The capacitor bank output is connected to a toroid with a disconnect switch in the output path. The toroid is isolated from ground by a minimum of 4 feet. The ground probe is placed in contact with toroid, and the switch closed to initiate discharge of capacitor back after fully charged. The current transformer is placed on ground side of the Marx test equipment. The Marx circuit schematic is shown in Figure 14.

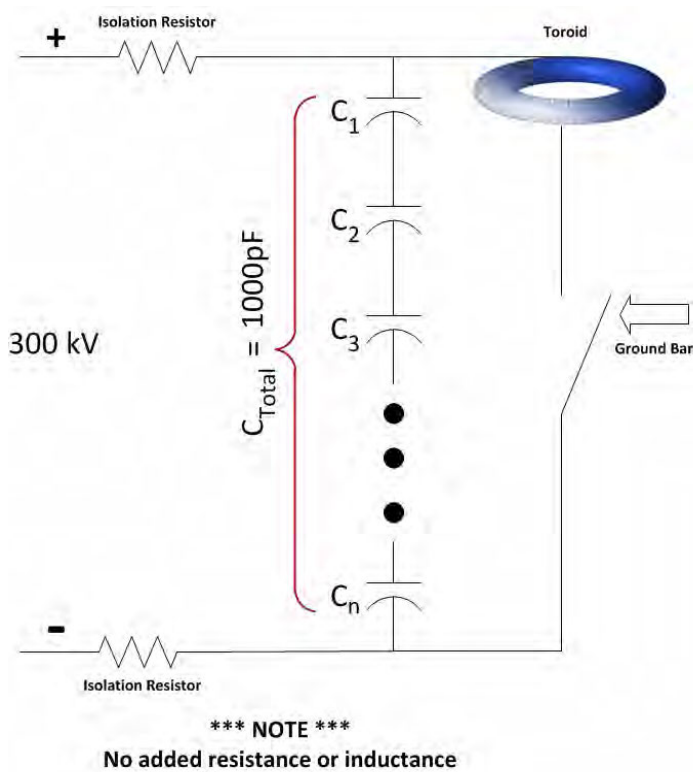



Figure 13: VERTREP Test Equipment Schematic

Validation Test Requirement 3 Results Discussion:
Although the waveforms for the VERTREP test setup and the Marx test setup were repeatable and consistent within each test setup, there was a difference of approximately 15% in the measured energy output between the two different test setups as can be seen in Figures 3 and 4.

**However, using the tolerances for the charge voltage and capacitance values specified in the HESD procedure, and allowing for the range of the resistance and inductance specified to produce a nominal, a maximum, and a minimum output, the output of the HESD circuit would be allowed to vary between a peak current of 3000 amps to 6000 amps as shown in the calculations and waveforms in Appendix A.  If the test equipment produces a current output waveform that falls within the upper and lower limits for amplitude and time of the calculated waveform in Appendix A, the test equipment, instrumentation, and test results are acceptable.**

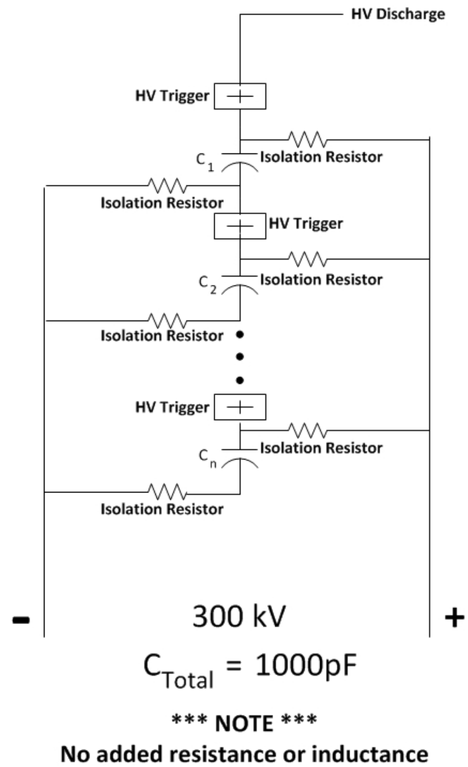



Figure 14: Marx Test Equipment Schematic

The only guidance in the existing documents for the HESD circuits is the component values. However, in order to calibrate the test equipment, some reference must be used. MIL STD 331 references using a 100 ohm resistor for calibration, but using this resistor masks the critical information about the circuit performance that is readily determined from a shorted discharge to the ground plane. Some facilities have interpreted the 1 ohm resistance and the 20 microHenry component values as a requirement to add these component values to the circuit as separate components, and others have interpreted the component values as the maximum values that should be measured from the assembled circuit. The different approaches would have a large impact on the energy output from the circuit. Every capacitor has an equivalent series resistance, and every connection in the circuit adds resistance in addition to the cabling resistance that will affect the circuit dynamically, and therefore the output of the circuit. Measuring the assembled circuit resistance and inductance is not easily done though, and would require specialized equipment to perform at each facility. Using this approach would require performing this measurement every day that testing is performed. Measuring the resistance of the cabling would not be a good indicator of the overall circuit resistance, and calculating the circuit inductance and/or resistance based on wire tables would be inaccurate also. Additionally, measuring the circuit resistance does not take into account the resistance of the air gap either from the ground probe to the toroid for the VERTREP setup or across the air gap switches used in the Marx setup that will have an effect on the output of the circuit during the actual discharge event. The Navy did some limited testing and found that the measured resistance and inductance of the circuit does not agree with an analysis of the output waveform that backed out the resistance and inductance values. The measured resistance and inductance were within the MIL STD 464C requirements, but when an analysis of the circuit output waveform was performed, these numbers were higher than the measured results.

An alternate calibration approach is to calculate the circuit output waveforms based on the known component values and tolerances. This would provide an easy method to verify the circuit prior to testing, and be similar in the approach used for the PESD circuit calibration requirements. However, based on the measured resistance compared to output waveform differences, the maximum resistance used in calculating the calibration waveforms was raised to levels that matched the analysis of the Army waveforms for the VERTREP test equipment. This test setup would normally show higher resistance due to the 18 inch arc gap during the discharge. As shown in Appendix A, the resistance range used for calculating the waveforms is 1 to 4 ohms, the inductance range is 3 to 20 microHenries, and the voltage range is 294,000 volts to 306,000 volts.

**All equipment and components used in the measurement of the calibration waveform and test data must be calibrated on a regular basis to provide traceability and repeatability of the test results. This includes the oscilloscope, the current transformer, the attenuators, and any other signal processing devices such as the Nanofast equipment.**

**4.4 Requirement 4:** Validate calibration setup for PESD testing.

Validation Test Plan Requirements:
A. Determine test equipment and setup requirements for JOTP PESD testing.
B. Develop repeatable calibration requirements for PESD test equipment including specifying probe speed and waveforms to be included in the JOTP PESD procedures.

Validation Test Requirement 4 Procedure:
A. The commercially available test equipment evaluated included the Noiseken ESS 2000 and EMC Partner ESD 3000 during the validation testing, and waveforms from the Navy built PESD equipment. Both of the commercial PESD testers use a handheld "gun" with the discharge probe, so a current transformer was installed over the ground salient, and the gun was positioned approximately 1 foot from the salient. The Navy PESD equipment is controlled remotely and the discharge probe is connected directly to the ground plane for calibration. Instrumentation utilized was the Pearson Electronics models 2877 and 4100 current transformers, and the Nanofast Instrumentation system with attenuators and 5GHz digital oscilloscope for the Army setup. The Navy uses the Pearson Electronics model 2877 current transformer, an external attenuator, and a 5 GHz digital oscilloscope.
B. For both the Noiseken ESS 2000 and EMC Partner ESD 3000 ESD machines, the discharge gun was moved at a speed of 1 foot per second to the salient to initiate the discharge. For the Navy equipment, the discharge triggered remotely.

Validation Test Requirement 4 Results:
A. PESD calibration can be either with the 50:1 divider in order to measure voltage as documented in MIL STD 331 or using a shorted discharge with a current transformer to capture the current waveform. Test data is only valid if the test equipment calibration waveforms are within the upper and lower limits of the reference calibration waveforms for each day of testing.

The current transformer specifications shall accurately measure the rise time, maximum peak amplitude, and frequency response of the PESD circuit calibration waveform.
B. All equipment used for measuring the PESD circuit output must accurately measure a minimum rise time of 2 nanoseconds and have a minimum bandwidth of 200 MHz and be currently calibrated. The calibration information must be supplied as part of the test report.
The waveforms are based on the component tolerances from MIL STD 464C to give the nominal, minimum (lower), and maximum (upper) current/voltage output from the required test circuit. See Figure 15 for the PESD instrumentation test setup output waveform from the Noiseken test equipment. See Figure 16 for the PESD instrumentation test setup output waveform from the ESD 3000 test equipment. See Figure 17 for the PESD instrumentation test setup output waveform from the Navy test equipment.

Validation Test Requirement 4 Results Discussion:
Current based waveforms have been developed based on the theoretical output of the PESD circuit using the nominal, maximum, and minimum circuit components and tolerances. The waveforms were not developed using modeling software, but mathematical software to eliminate errors common in modeling software. See Appendix B for the calculation of the 500 ohm circuit reference calibration output and Appendix C for the calculation of the 5000 ohm circuit reference calibration output. The calibration discharge method must be the same as the test discharge method (either direct contact or approaching probe), and the calibration waveforms for whichever discharge method is used must be within the calibration waveform upper and lower limits prior to the start of testing.

The circuit schematics and operating procedures for commercial ESD equipment should be reviewed prior to use in testing to evaluate the suitability of the design to the MIL STD 464C requirements for PESD testing. Any additional circuit components that add resistance or inductance may render the output waveforms out of compliance with the calibration waveforms. Stating the commercial or custom PESD circuit or device has a 500 pF capacitor and a 500 ohm resistor does not imply the output waveforms meet the calibration waveform requirements. Additionally, some of these devices have settings for either “air” discharge or “contact” discharge that may have an effect on the output waveform. The user should know and understand what changes are made to the circuitry when selecting between the different discharge methods, and verify that the different discharge settings meet the waveform requirements prior to performing the test.


Figure 15: PESD instrumentation test setup output waveform from the Noiseken equipment


Figure 16: PESD instrumentation test setup output waveform from the ESD 3000 equipment

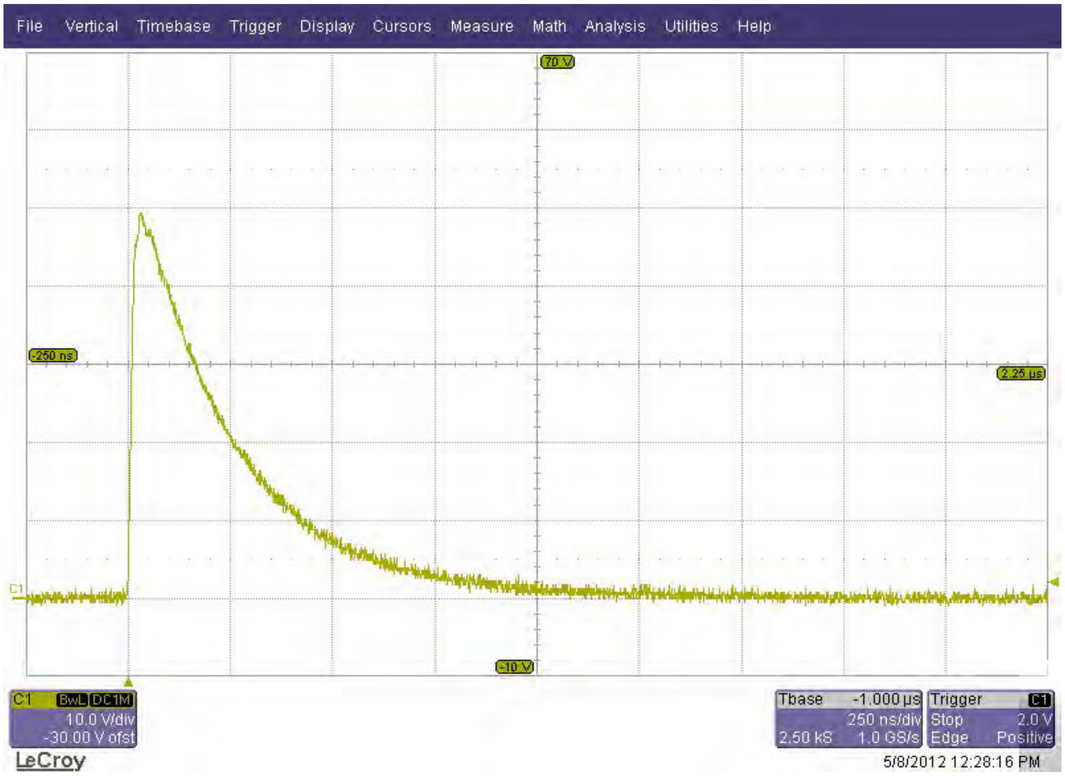



Figure 17: PESD instrumentation test setup output waveform from the Navy equipment

**4.5 Requirement 5:** Validate the safe and operable requirement for all HESD testing, and required test configurations.

<u>Validation Test Plan Requirements:</u>
A. Document current HESD test configurations and changes required for Joint Service ESD testing.
B. Determine HESD test result requirements for all test configurations. Is Safe and Operable required after HESD exposure for all configurations, or does Safe and Operable apply for VERTREP test and just Safe (not Operable) required for bare exposure?

<u>Validation Test Requirement 5 Procedure:</u>
A. Currently, there are 3 different HESD tests between the services: (1) the packaged VERTREP test of ordnance in the packaged configuration, (2) the man carry/bare item testing, and (3) a High Voltage Corona (HVC) test the Army applies to in flight items (externally carried aircraft items, mortars, etc.). The HVC test is similar to the VERTREP test where the item is installed as it is in flight and isolated from the ground plane and charged to 300 kV, and then a ground probe is applied to different points to initiate a discharge. The HVC test can apply to powered or unpowered ordnance. The three tests may not apply to all items, but the tests do meet all the test requirements specified in MIL STD 464C. However, there is currently no method to document what tests are required for each class of ordnance for Joint Service use. Currently, the following apply:
Army: VERTREP test applied to packaged ordnance from system requirements/Army E3 board

High Voltage Corona applied to externally carried aircraft ordnance and in flight ordnance from system requirements/Army E3 board.
Man carry/bare item testing rarely performed.

Navy: Packaged ordnance (VERTREP) always required but usually analyzed due to all metal container/faraday cage properties from NAVSEAINST 8020.19/NOSSA requirements. However, if testing is required in the packaged configuration due to a non-metallic container, this testing is currently done using the bare item (Marx) test equipment. Man carry/bare testing is performed if possible exposure (applied to shoulder launched, small arms, bare explosives, etc to all connectors and external points) from NAVSEAINST 8020.19/NOSSA requirements. Analysis is usually performed to equal the Army HVC test.

B. Safe and Operable required to pass each type of testing (VERTREP mode, Man carry/bare mode, and HVC mode (in flight). This is based on the requirement from MIL STD 464C: *The system shall meet its operational performance requirements when subjected to a 300 kilovolt discharge.*

Validation Test Requirement 5 Results:

All Services must perform VERTREP testing on all ordnance items and provide Safe and Operable results in the packaged configuration using the VERTREP test equipment, procedures, and calibration requirements. If the item is not Safe and Operable after testing, packaging changes must be made to meet the safe and operable requirement and retested to the new packaging configuration.

All Services must perform Man carry/hot tube loading testing on all ordnance items in the bare configuration using the Marx test equipment, procedures, and calibration requirements. If the item does not meet the safe and operable requirement after testing, the item must be listed as sensitive to this environment. Test discharge points in this configuration must be directed to the most sensitive locations on the test item including any external connectors using direct contact or salients. Test item configuration must also be documented clearly such as powered on, armed, etc. If the item could possibly be armed or contacted at a particular point in the bare configuration, it must be tested.

All Services must perform the High Voltage Corona test on any ordnance item that is carried externally on any aircraft or could experience in flight charging such as artillery and mortars. Test item configuration must also be documented clearly such as powered on, armed, etc. Test discharge points in this configuration must be directed to the most sensitive locations on the test item using direct contact or salients. If the item could possibly be armed or contacted at a particular point in the bare configuration, it must be tested.

Validation Test Requirement 5 Results Discussion:

MIL STD 464C clearly defines that any item that experiences VERTREP, is carried externally to the aircraft, or carried internal to the aircraft must be tested for helicopter ESD exposure. Each of the services implemented the testing in different ways, and usually did not perform all the required tests /analyses or address them adequately in the reports. There are no new tests being added, however, there is a change as to how the test equipment will be configured for each type of HESD test and call out minimum sample sizes. The HESD procedure will define which types of HESD test will be required for each type of item, so each service will have all the necessary data and does not need to perform testing that another service did not.

**5.0 Conclusions:**

**Requirement 1:** Correlation of test effects from different HESD test equipment (Marx generator for bare item testing vs. VERTREP equipment for charged item testing) for all HESD operational exposures from MIL STD 464C.

The VERTREP test setup that the Army currently uses is more representative of the charging that will occur to sling loaded ordnance during vertical replenishment and externally carried ordnance than the typical Marx generator setup. This VERTREP setup also induces much higher voltages inside a non-metallic container as evidenced by the test results discussed in section 4.2. The test results from the different test setups currently used by the Army and Navy provide support for previous testing where the Army had failures that the Navy could not duplicate.

The VERTREP HESD test setup is identical to the circuit defined in MIL STD 331 and meets the requirements in MIL STD 464C, with a minor change to the method used to charge the capacitor(s) and the test item. In the typical Marx generator test setup, the capacitor(s) is isolated from the test item as the capacitors are charged, then a switch is closed to deliver the energy from the capacitor(s) to the test item. In the VERTREP test setup, the test item is not isolated from the capacitor(s) and power supplies during the charging phase, so the test item reaches the same voltage as the charge voltage on the capacitors before the ground probe is brought up to the test item to discharge the circuit. This test setup change for Joint Service HESD testing allows the test item to be at the charge voltage for an extended period of time (about 30 seconds to 1 minute); similar to what would be experienced during a VERTREP operation, prior to being discharged by moving the ground probe to the test item in approximately 1 second. The VERTREP test circuit shall be designed as in Figure 13. All containerized HESD testing and all externally carried/mounted ordnance High Voltage Corona testing shall use the VERTREP test equipment setup.

The Marx HESD test setup that the Navy currently uses is more representative of a discharge that will occur to a bare item being transported internally to the aircraft and to hot tube loading ordnance. This setup does provide approximately 15% more energy to the test item than the VERTREP test setup based on the limited testing done, and it is easier to direct the discharge using a remotely controlled relay to a certain point using a salient with direct contact discharge. The Marx test circuit shall be designed as in Figure 14. All bare HESD testing shall use the Marx test equipment setup.

The VERTREP and Marx generator test equipment/test setup outputs do fall within the HESD calibration output upper and lower limits provided in this report.

**Requirement 2:** Instrumentation methods for verifying PESD and HESD test equipment.

Several different types of current transformers were evaluated, and the current transformer specifications accurately measure the rise time, maximum peak amplitude, and frequency response of the HESD circuit calibration output waveform. The current transformer should be placed on the ground lead from the HESD circuit. The reference calibration waveforms will be current based using a shorted discharge to the ground plane. This will provide the best indication to verify proper operation and calibration of all system components prior to testing each day.

**Requirement 3:** Develop a calibration method and requirements for HESD testing.

VERTREP calibration requirements: The capacitor bank output is connected to a toroid with no disconnect switch in the output path. The toroid is isolated from ground by a minimum of 4 feet. The ground probe is manually or automatically moved at a minimum speed of 4 ft/sec to the toroid to initiate discharge of the capacitor after fully charged. The current transformer is placed on the ground side of the VERTREP test equipment. The VERTREP circuit schematic shall be added to the HESD procedure.
Marx (Man carry/Hot tube loading) calibration requirements: The capacitor bank output salient is connected to the ground plane with a disconnect switch in the output path. A remote controlled switch is closed to initiate discharge of the capacitor bank after fully charged. The current transformer is placed on the ground side of the test equipment. The Marx circuit schematic will be added to the HESD procedure.

All components used to measure the VERTREP or Marx HESD circuit output shall be calibrated on a regular basis including the current transformer, any signal attenuators, any signal transformers (Nanofast equipment), and the data recording devices (oscilloscopes). Calibration must be performed at the beginning and the end of each day of testing. Calibration waveforms must fall within the upper and lower limits from the reference waveform in Appendix A that will be included in the HESD procedure prior to beginning any testing.

Calibration waveforms are based on the circuit component values and tolerances listed in the HESD document. No resistors or inductors may be added to the circuit.

**Requirement 4:** Validate calibration setup for PESD testing.

PESD calibration can be either with the 50:1 divider in order to measure voltage as defined in MIL STD 331 or using a shorted discharge with a current transformer to capture the current waveform. Test data is only valid if the test equipment calibration waveforms are within the upper and lower limits of the reference calibration waveforms for each day of testing. Current based waveforms have been developed based on the theoretical output of the PESD circuit using the nominal, maximum, and minimum circuit components and tolerances.

All equipment used for measuring the PESD circuit output must accurately measure a minimum rise time of 2 nanoseconds and have a minimum bandwidth of 200 MHz and be currently calibrated. The calibration information must be supplied as part of the test report. The calibration discharge method must be the same as the test discharge method (either direct contact or approaching probe), and the calibration waveforms for whichever discharge method is used must be within the calibration waveform upper and lower limits prior to the start of testing.

**Requirement 5:** Validate the Safe and Operable requirement for all HESD testing, and required test configurations.

All ordnance items must be tested or analyzed for the Helicopter ESD exposure environments listed in Table 1 by commodity. If the item is a perfect faraday cage, an analysis may be performed. If the item is not a faraday cage and previous test results on an identical item has not been performed, testing must be performed. If previous test data is available for a previous version of the item, an analysis may be performed using the previous results and the changes from the previous configuration.

VERTREP testing must be performed on all items and provide Safe and Operable results in the packaged configuration using the VERTREP test equipment, procedures, and calibration requirements. If the item is not Safe and Operable after testing, packaging changes must be made to meet the Safe and Operable requirement and the item must be retested in the new packaging configuration.

Man carry/hot tube loading testing must be performed on all items in the bare configuration using the Marx test equipment, procedures, and calibration requirements. If the item does not meet the Safe and Operable requirement after testing, the item must be listed as sensitive to this environment. Test discharge points in this configuration must be directed to the most sensitive locations on the test item including any external connectors and pins using direct contact or salients. Test item configuration must also be documented clearly such as powered on, armed, etc. If the item could possibly be armed or contacted at a particular point in the bare configuration, it must be tested.

The High Voltage Corona test must be performed on any item that is carried externally on any aircraft or could experience in flight charging such as artillery and mortars. If the item is not Safe and Operable after testing, changes must be made to meet the Safe and Operable requirement and the item must be retested in the new design configuration. Test item configuration must also be documented clearly such as powered on, armed, etc. Test discharge points in this configuration must be directed to the most sensitive locations on the test item using direct contact or salients. If the item could possibly be armed or contacted at a particular point in the bare configuration, it must be tested.

**Table 1: HESD minimum sample size and test configuration by commodity**

| Commodity | VERTREP | Bare | In Flight(HVC) | Minimum Sample Size |
|---|---|---|---|---|
| | VERTREP Test Equip | Marx Test Equip | VERTREP Test Equip | |
| Large Caliber Ammunition | Yes | Yes* Note 1 | Yes* Note 1 | 4 |
| Medium Caliber Ammunition | Yes | Yes* Note 1 | Yes* Note 1 | 5 |
| Small Caliber Ammunition | Yes | Yes* Note 1 | No | 10 |
| Non-Lethal Ammunition | Yes | Yes | No | 10 |
| Man Emplaced Ammunition | Yes | Yes | No | 10 |
| Air Launched Missile/Rocket | Yes | No | Yes | 1 |
| Surface Launched Missile/Rocket | Yes | No | Yes | 1 |
| Man Carried Missile/Rocket | Yes | Yes | Yes | 1 |
| Pyrotechnics | Yes | Yes | No | 10 |
| Fuze and Ignition Systems | Yes | Yes | No | 10 |
| Underwater | Yes | Yes* Note 2 | No | 1 |

Note: If the item is an all up round consisting of several sub-components, it will be tested to the commodity item test and sample size requirements in Table 1 that define the all up round. If the item is a sub-component of an all up round (such as a fuze for a large caliber ammunition item), it will be tested to the sub-component commodity item (fuze and ignition systems) test and sample size requirements in Table 1.

Note 1: If the item is all metal, or the fuze system was tested separately, an analysis may be performed. The ESD sensitivity for the all up round will be to the most sensitive component if the testing is at the component level.

Note 2: Ordnance items that could not be exposed to helicopter ESD in the unpackaged configuration, such as torpedoes, large ship deployed mines etc., do not need to be tested, but this reasoning must be noted in the report. Other items that could receive bare exposure to helicopter ESD must be tested or analyzed.

**6.0 Recommendations:**

1. Gather all existing and new MIL DTL 23659 qualification test reports into a central database for Joint Service use. This will provide necessary information that will reduce the amount of testing required for all Services.

2. Implement all changes from the conclusion section of this document into the PESD and HESD JOTP procedures.

# Appendix A

# HESD Calibration Calculations

Appendix B

Calculations for Helicopter Bourne ESD (HESD) with nominal values of 300kV, 1.5 Ohms, 10 uH, and 1000 pF
(All traces shown are positive negative traces are identical except inverted)

Time span and initial condition values:

$$t := (0, .01 \cdot \mu s .. 60 \cdot \mu s)$$

$$i_{initial} := 0\ A$$

Nominal values for voltage, resistance, inductance, and capacitance:

$$R_{nom} := 1.5\ \Omega \qquad C_{nom} := 1\ nF \qquad L_{nom} := 10\ \mu H \qquad V_{nom} := 300000\ V$$

Calculations for alpha and omega based on nominal values listed above:

$$\alpha_{nom} := \frac{R_{nom}}{2 \cdot L_{nom}} \qquad \omega_{onom} := \frac{1}{\sqrt{L_{nom} \cdot C_{nom}}}$$

$$\alpha_{nom} = (7.5 \cdot 10^4)\ \frac{1}{s} \qquad \omega_{onom} = (1 \cdot 10^7)\ \frac{1}{s}$$

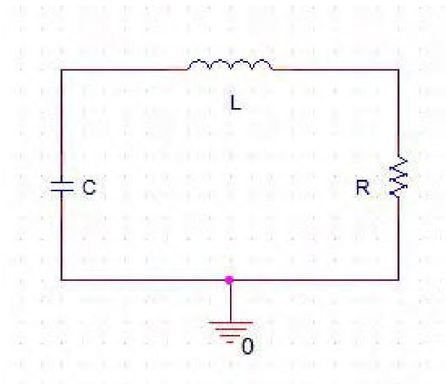



Figure 1 Series RLC Circuit

Calculations for damping frequency based on nominal values of alpha and omega

$$\omega_{dnom} := \sqrt{\frac{1}{L_{nom} \cdot C_{nom}} - \left(\frac{R_{nom}}{2 \cdot L_{nom}}\right)^2}$$

$$\omega_{dnom} = (10 \cdot 10^6)\ \frac{1}{s}$$

Calculations for A1 and A2 based on nominal values:

$$A_{1nom} := V_{nom} \qquad A_{1nom} = (3 \cdot 10^5)\ V$$

$$A_{2nom} := \frac{\alpha_{nom} \cdot A_{1nom}}{\omega_{dnom}} \qquad A_{2nom} = (2.25 \cdot 10^3)\ V$$

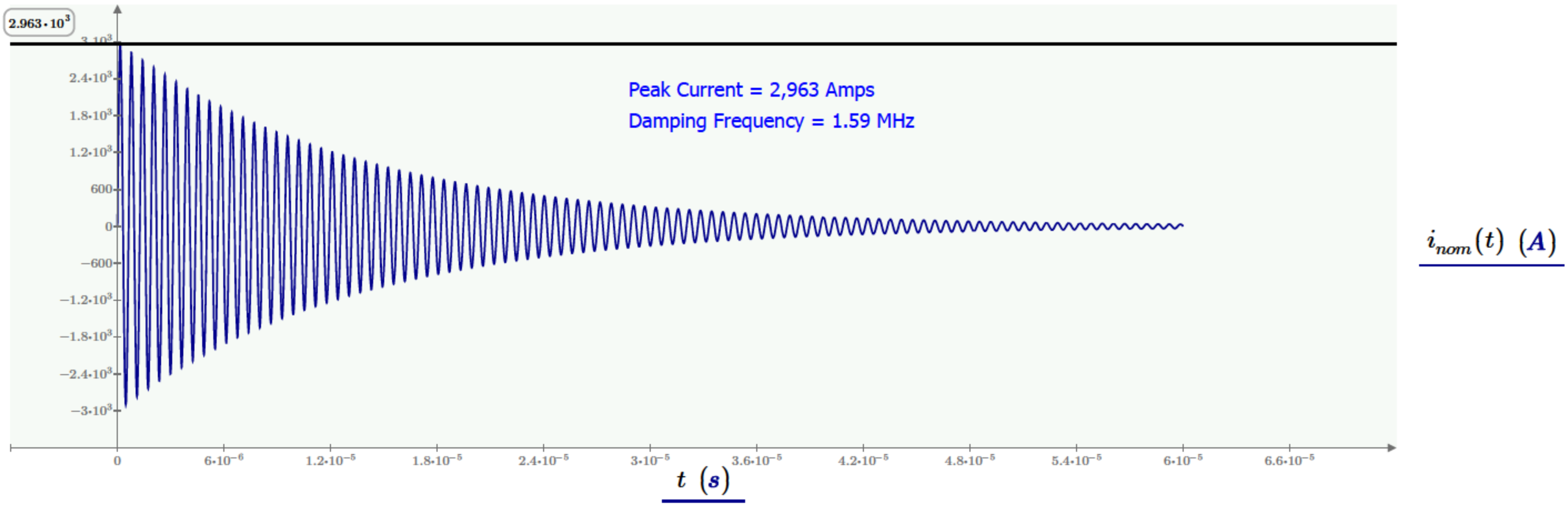
Double exponential equation for current & voltage waveforms based on nominal value calculations:

$$i_{nom}(t) := \left(\left(-C_{nom}\right) \cdot \left(e^{-\alpha_{nom} \cdot t}\right)\right) \cdot \left(\left(\left(A_{2nom} \cdot \omega_{dnom} - A_{1nom} \cdot \alpha_{nom}\right) \cdot \cos\left(\omega_{dnom} \cdot t\right)\right) + \left(\left(-A_{2nom} \cdot \alpha_{nom} - A_{1nom} \cdot \omega_{dnom}\right) \cdot \sin\left(\omega_{dnom} \cdot t\right)\right)\right)$$

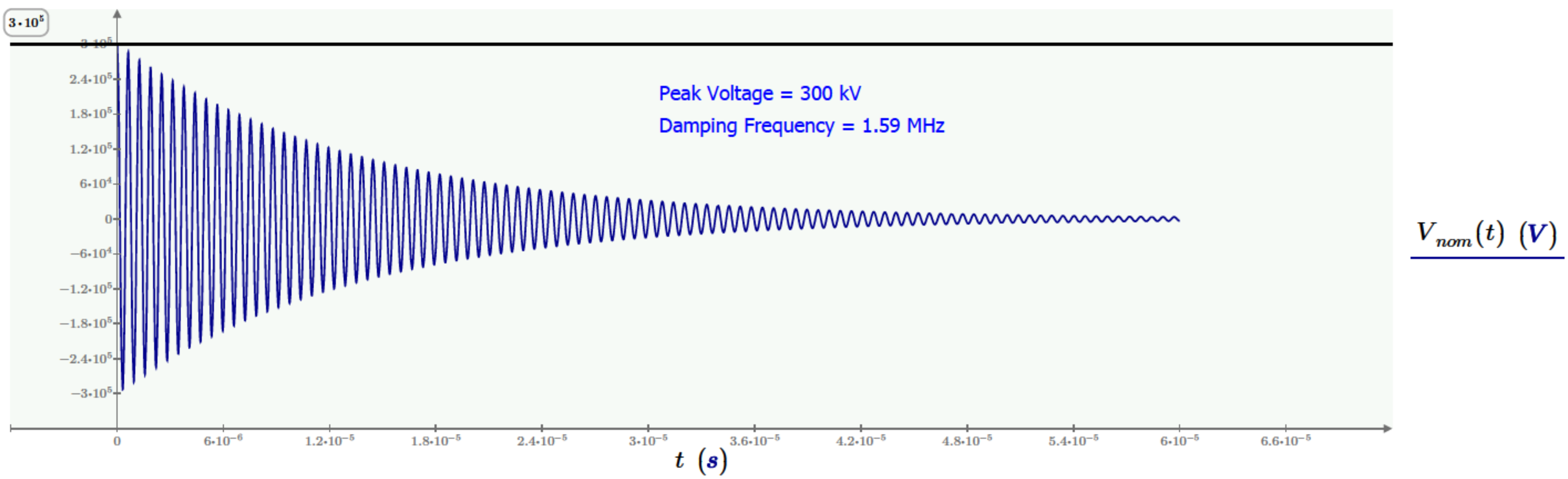
$$V_{nom}(t) := e^{-\alpha_{nom} \cdot t} \cdot \left(A_{1nom} \cdot \cos\left(\omega_{dnom} \cdot t\right) + A_{2nom} \cdot \sin\left(\omega_{dnom} \cdot t\right)\right)$$

Appendix B

Double exponential graph of current waveform using nominal values




Double exponential graph of voltage waveform using nominal values



Upper Limit values for voltage (maximum), resistance (minimum), inductance (minimum), and capacitance (maximum):

$R_{min} := 0.95 \cdot \Omega$ $\quad C_{max} := 1050 \cdot pF$ $\quad L_{min} := 4\ \mu H$ $\quad V_{max} := 306000\ V$

Calculations for alpha and omega based on Upper Limit values listed above:

$$\alpha_{UL} := \frac{R_{min}}{2 \cdot L_{min}} \qquad \omega_{oUL} := \frac{1}{\sqrt{L_{min} \cdot C_{max}}}$$

$$\alpha_{UL} = \left(1.188 \cdot 10^{5}\right) \frac{1}{s} \qquad \omega_{oUL} = \left(1.543 \cdot 10^{7}\right) \frac{1}{s}$$

Calculations for damping frequency based on Upper Limit values of alpha and omega listed above:

$$\omega_{dUL} := \sqrt{\frac{1}{L_{min} \cdot C_{max}} - \left(\frac{R_{min}}{2 \cdot L_{min}}\right)^{2}}$$

$$\omega_{dUL} = \left(1.543 \cdot 10^{7}\right) \frac{1}{s}$$

Calculations for A1 and A2 based on Upper Limit values listed above:

$$A_{1UL} := V_{max} \qquad A_{1UL} = \left(3.06 \cdot 10^{5}\right) V$$

$$A_{2UL} := \frac{\alpha_{UL} \cdot A_{1UL}}{\omega_{dUL}} \qquad A_{2UL} = \left(2.355 \cdot 10^{3}\right) V$$

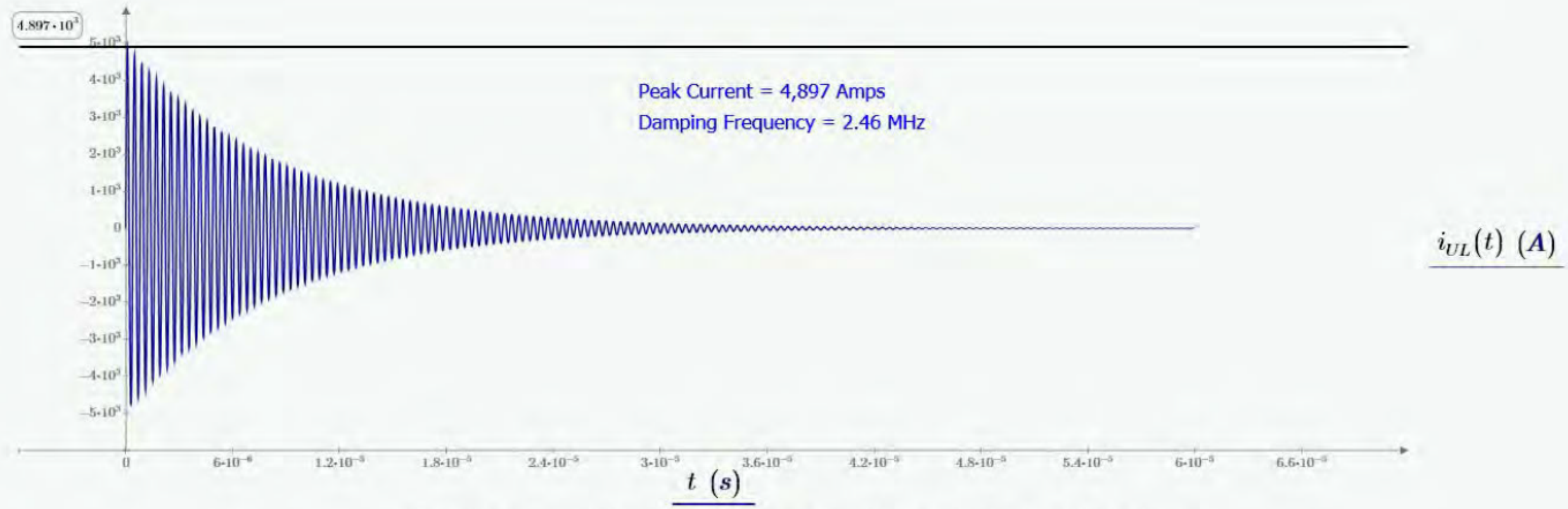
Double exponential equation for current & voltage waveforms based on Upper Limit value calculations:

$$i_{UL}(t) := \left(\left(-C_{max}\right) \cdot \left(e^{-\alpha_{UL} \cdot t}\right)\right) \cdot \left(\left(\left(A_{2UL} \cdot \omega_{dUL} - A_{1UL} \cdot \alpha_{UL}\right) \cdot \cos\left(\omega_{dUL} \cdot t\right)\right) + \left(\left(-A_{2UL} \cdot \alpha_{UL} - A_{1UL} \cdot \omega_{dUL}\right) \cdot \sin\left(\omega_{dUL} \cdot t\right)\right)\right)$$

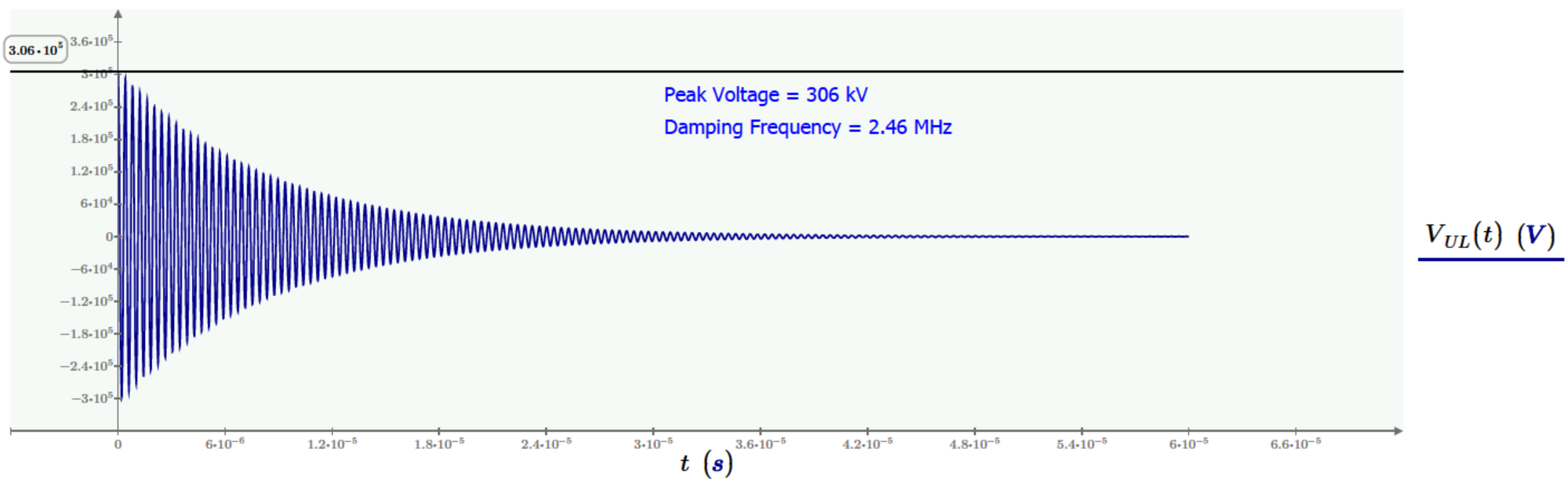
$$V_{UL}(t) := e^{-\alpha_{UL} \cdot t} \cdot \left(A_{1UL} \cdot \cos\left(\omega_{dUL} \cdot t\right) + A_{2UL} \cdot \sin\left(\omega_{dUL} \cdot t\right)\right)$$

Appendix B

Double exponential graph of current waveform using Upper Limit values




Double exponential graph of voltage waveform using Upper Limit values



Lower Limit values for voltage (minimum), resistance (maximum), inductance (maximum), and capacitance (minimum):

$R_{max} := 4\ \Omega$ $\quad C_{min} := 950\ pF$ $\quad L_{max} := 20\ \mu H$ $\quad V_{min} := 294000\ V$

Calculations for alpha and omega based on Lower Limit values listed above:

$$\alpha_{LL} := \frac{R_{max}}{2 \cdot L_{max}} \qquad \omega_{oLL} := \frac{1}{\sqrt{L_{max} \cdot C_{min}}}$$

$$\alpha_{LL} = \left(1 \cdot 10^{5}\right) \frac{1}{s} \qquad \omega_{oLL} = \left(7.255 \cdot 10^{6}\right) \frac{1}{s}$$

Calculations for damping frequency based on Lower Limit values of alpha and omega listed above:

$$\omega_{dLL} := \sqrt{\frac{1}{L_{max} \cdot C_{min}} - \left(\frac{R_{max}}{2 \cdot L_{max}}\right)^{2}}$$

$$\omega_{dLL} = \left(7.254 \cdot 10^{6}\right) \frac{1}{s}$$

Calculations for A1 and A2 based on Lower Limit values listed above:

$$A_{1LL} := V_{min} \qquad A_{1LL} = \left(2.94 \cdot 10^{5}\right) V$$

$$A_{2LL} := \frac{\alpha_{LL} \cdot A_{1LL}}{\omega_{dLL}} \qquad A_{2LL} = \left(4.053 \cdot 10^{3}\right) V$$

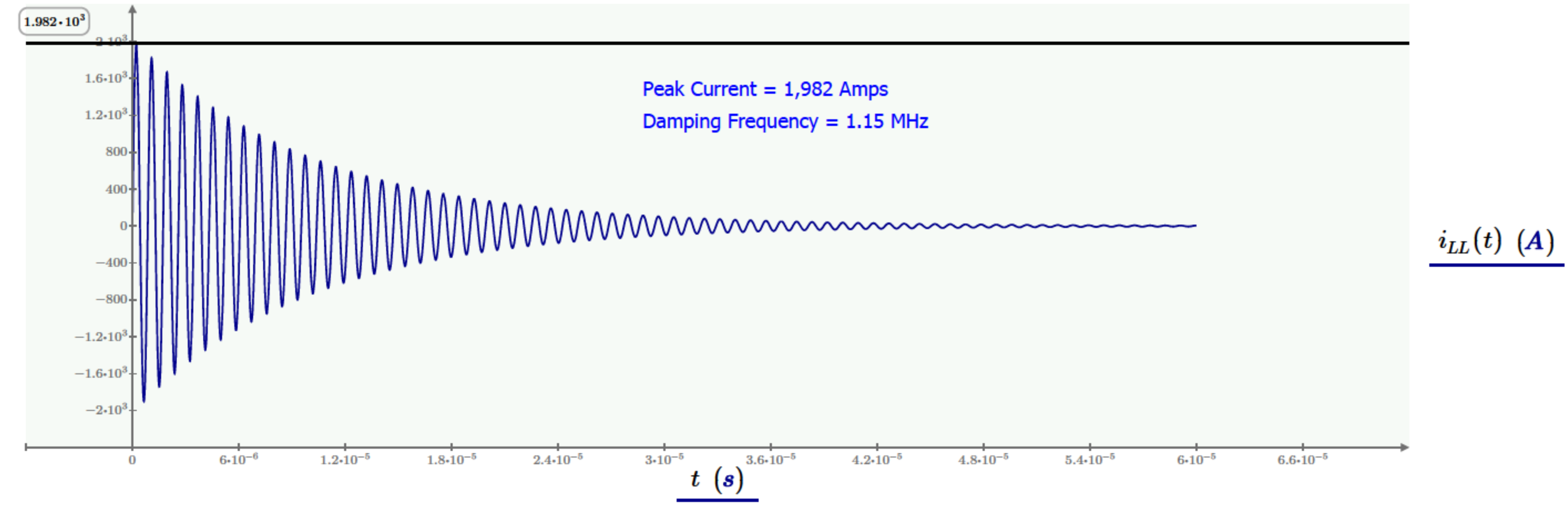
Double exponential equation for current & voltage waveforms based on Lower Limit value calculations:

$$i_{LL}(t) := \left(\left(-C_{min}\right) \cdot \left(e^{-\alpha_{LL} \cdot t}\right)\right) \cdot \left(\left(\left(A_{2LL} \cdot \omega_{dLL} - A_{1LL} \cdot \alpha_{LL}\right) \cdot \cos\left(\omega_{dLL} \cdot t\right)\right) + \left(\left(-A_{2LL} \cdot \alpha_{LL} - A_{1LL} \cdot \omega_{dLL}\right) \cdot \sin\left(\omega_{dLL} \cdot t\right)\right)\right)$$

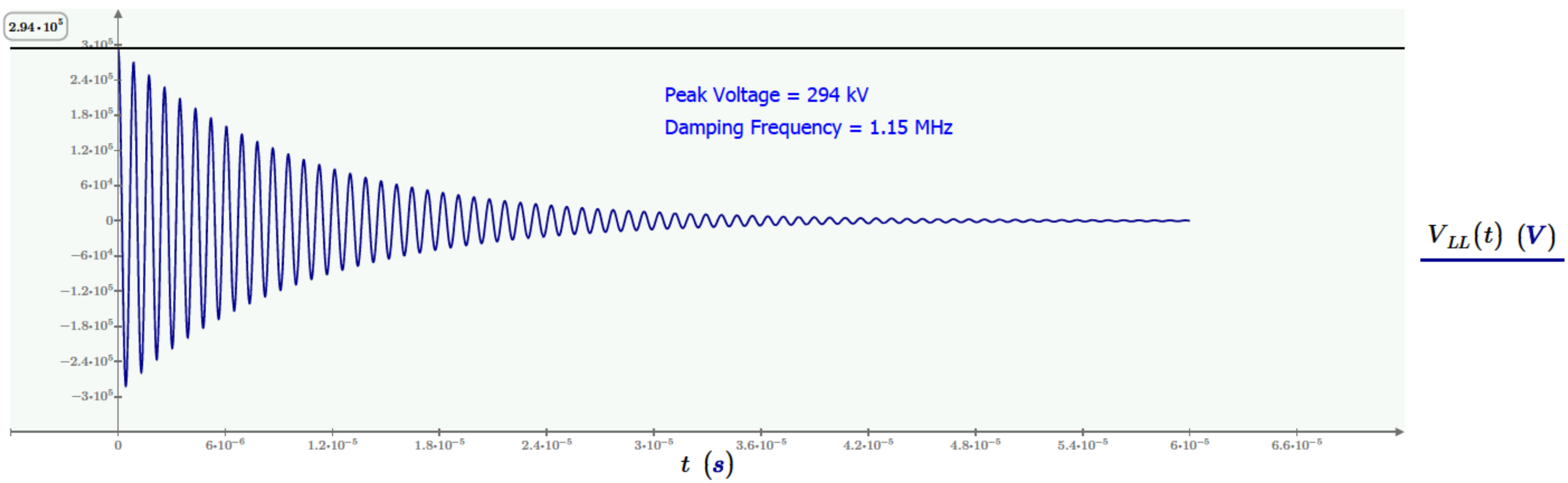
$$V_{LL}(t) := e^{-\alpha_{LL} \cdot t} \cdot \left(A_{1LL} \cdot \cos\left(\omega_{dLL} \cdot t\right) + A_{2LL} \cdot \sin\left(\omega_{dLL} \cdot t\right)\right)$$

Appendix B

Double exponential graph of current waveform using Lower Limit values

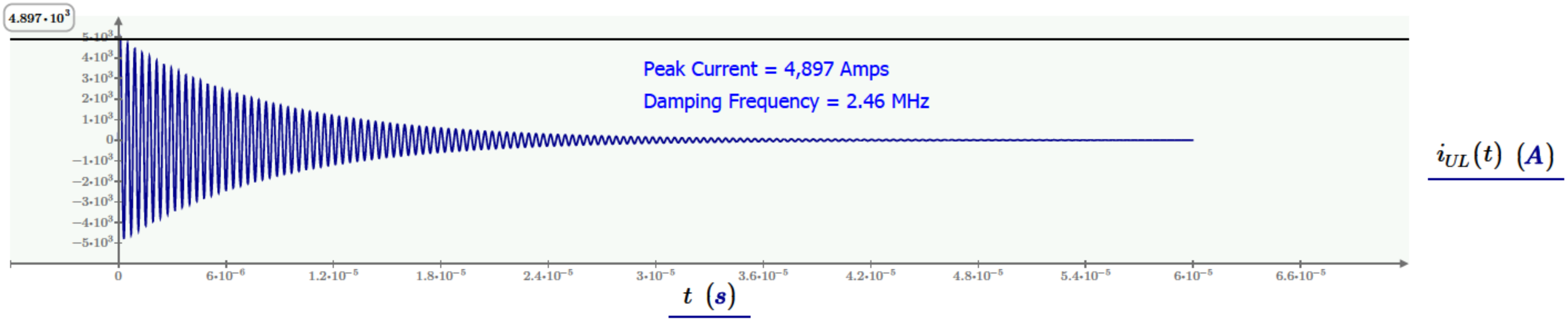


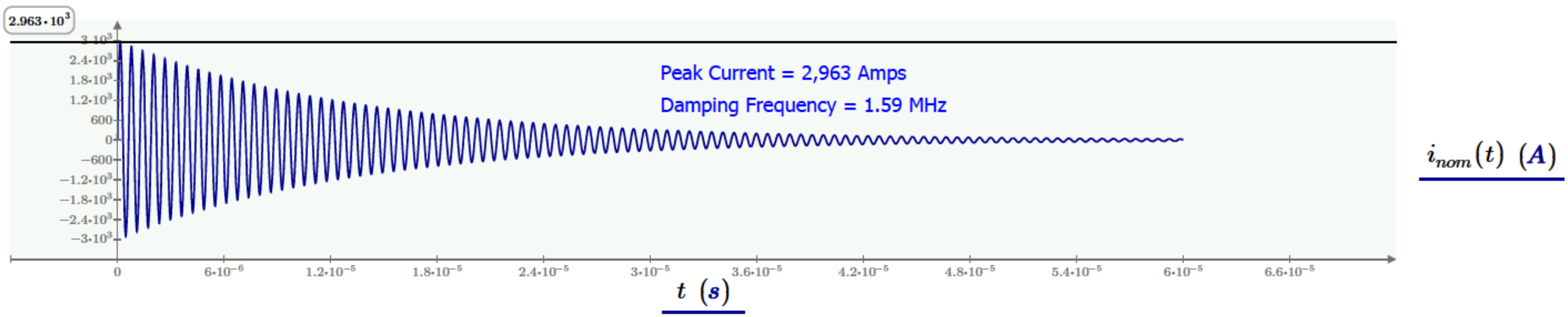

Double exponential graph of voltage waveform using Lower Limit values

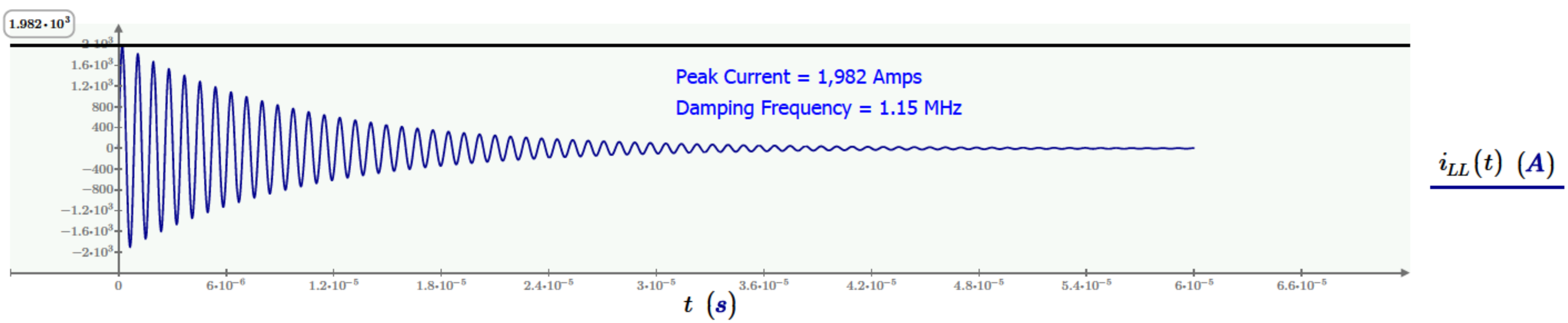


# Appendix B

## Current Waveform Graphs with Upper, Nominal, & Lower Values

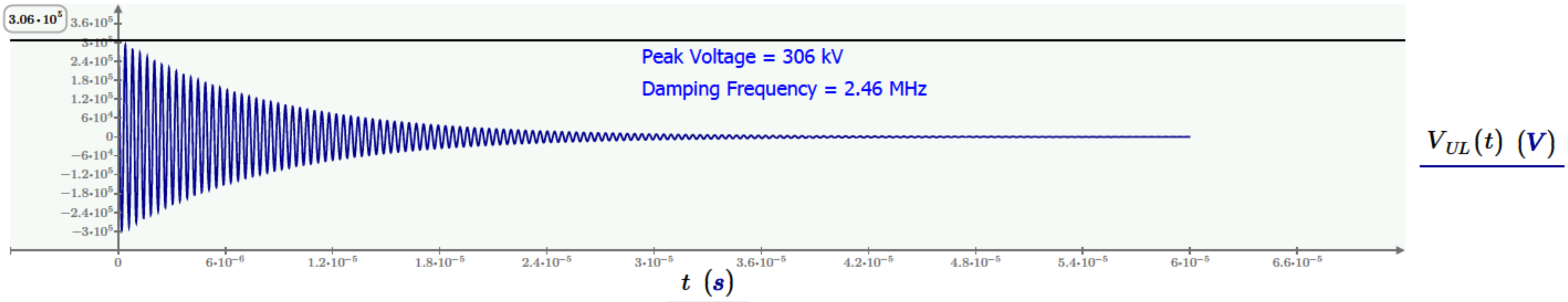


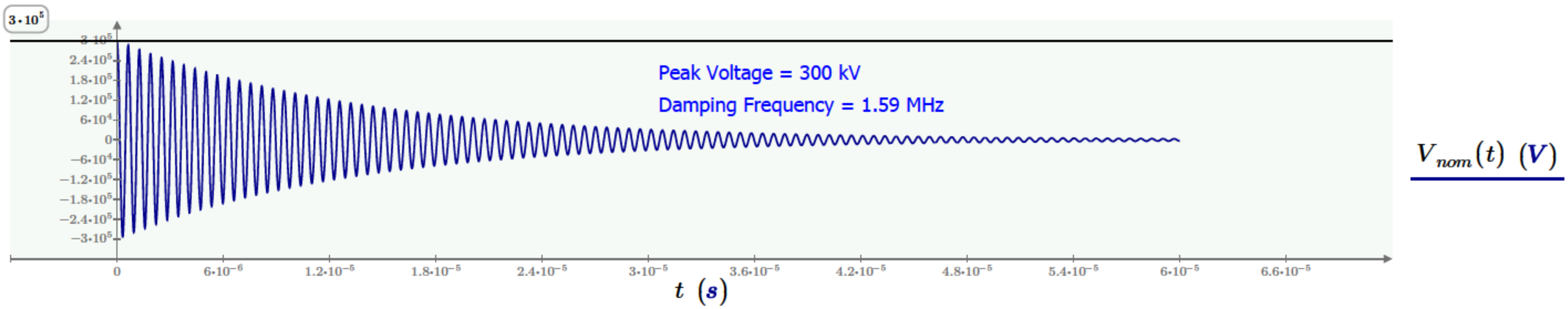



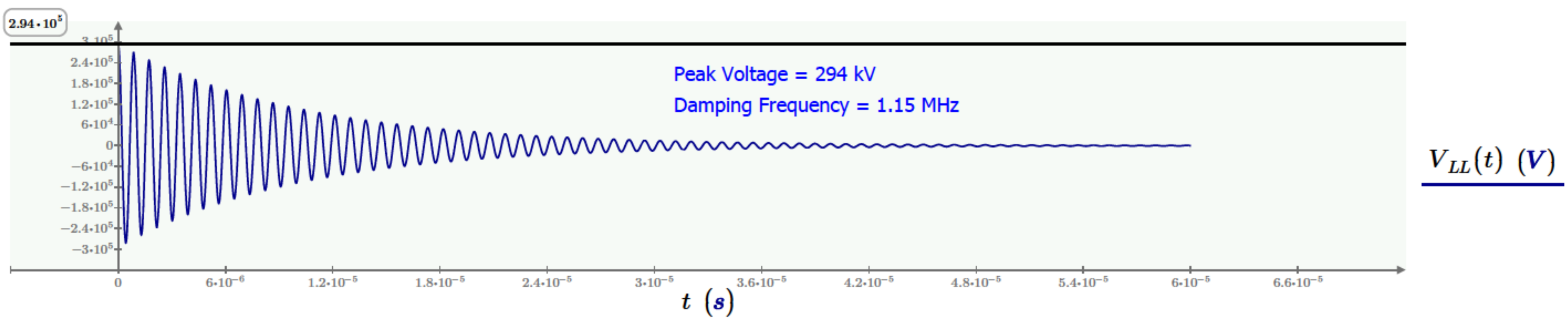



# Appendix B

## Voltage Waveform Graphs with Upper, Nominal, & Lower Values



# Appendix B

# PESD 500 Ohm Calibration Calculations

Appendix B

Calculations for Personnel Bourne ESD (PESD) with nominal values of 25kV, 500 Ohms, and 500 pF
(Only positive traces are shown negative traces are identical except inverted)

Time span and initial condition values:

$$t := (0, .001 \cdot \mu s .. 1.4 \cdot \mu s)$$

$$i_{initial} := 0 \; A$$

Nominal values for voltage, resistance, inductance, and capacitance:

$$R_{nom} := 500 \; \Omega \qquad C_{nom} := 500 \; pF \qquad L_{nom} := 3 \; \mu H \qquad V_{nom} := 25000 \; V$$

Calculations for alpha and omega based on nominal values listed above:

$$\alpha_{nom} := \frac{R_{nom}}{2 \cdot L_{nom}} \qquad \omega_{nom} := \frac{1}{\sqrt{L_{nom} \cdot C_{nom}}}$$

$$\alpha_{nom} = \left(8.333 \cdot 10^{7}\right) \frac{1}{s} \qquad \omega_{nom} = \left(2.582 \cdot 10^{7}\right) \frac{1}{s}$$

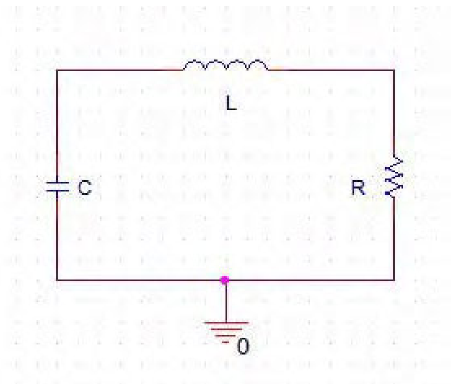



Figure 1 Series RLC Circuit

Calculations for S1 and S2 based on nominal values of alpha and omega

$$s_{1nom} := -\alpha_{nom} + \sqrt{\alpha_{nom}^{\;2} - \omega_{nom}^{\;2}} \qquad s_{2nom} := -\alpha_{nom} - \sqrt{\alpha_{nom}^{\;2} - \omega_{nom}^{\;2}}$$

$$s_{1nom} = -4.101 \cdot 10^{6} \frac{1}{s} \qquad s_{2nom} = -1.626 \cdot 10^{8} \frac{1}{s}$$

Calculations for A1 and A2 based on nominal values:

$$A_{2nom} := \frac{\left(\frac{-1}{L_{nom}} \cdot \left(R_{nom} \cdot i_{initial} + V_{nom}\right)\right) - \left(i_{initial} \cdot s_{2nom}\right)}{\left(s_{2nom} - s_{1nom}\right)}$$

$$A_{2nom} = 52.588 \; A$$

$$A_{1nom} := i_{initial} - A_{2nom}$$

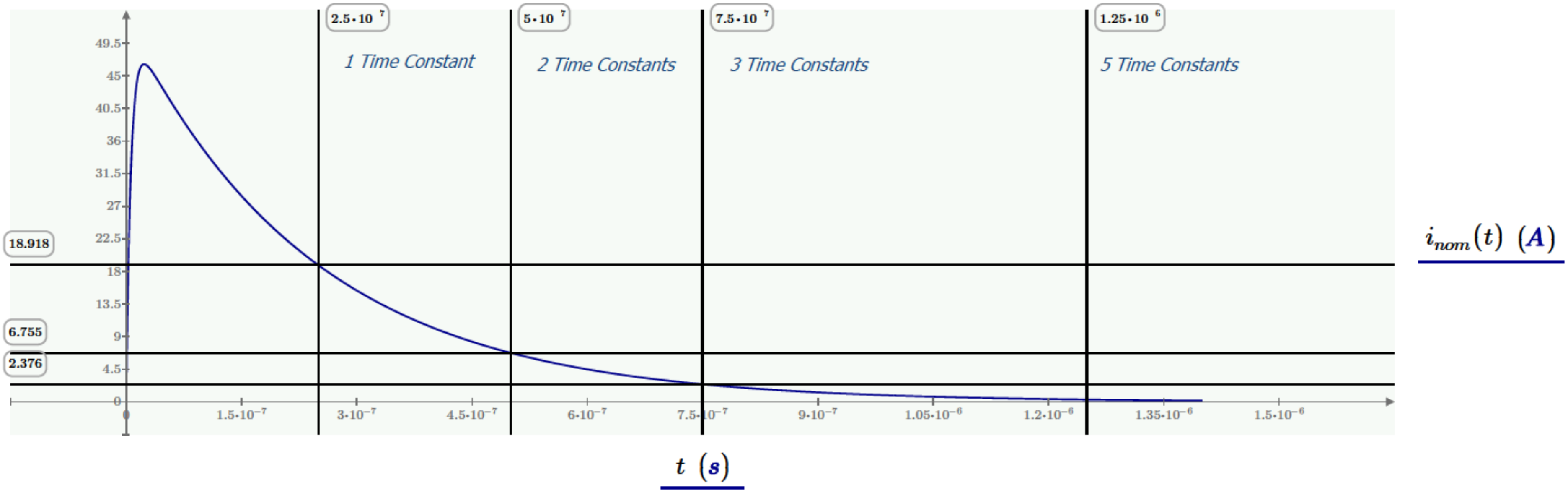
$$A_{1nom} = -52.588 \; A$$

Double exponential equation for current & voltage waveforms based on nominal value calculations:

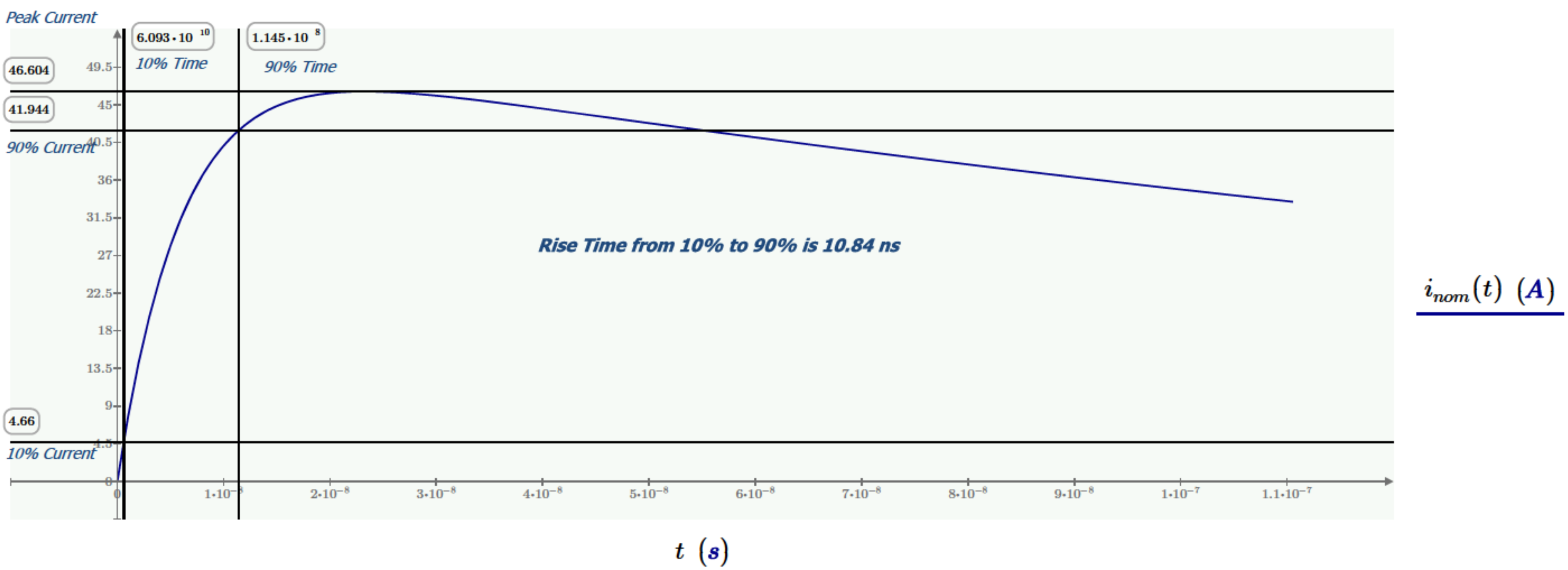
$$i_{nom}(t) := -\left(A_{1nom} \cdot e^{s_{1nom} \cdot t} + A_{2nom} \cdot e^{s_{2nom} \cdot t}\right) \qquad V_{Rnom}(t) := i_{nom}(t) \cdot R_{nom}$$

Appendix B

Double exponential graph of current waveform using nominal values




Zoomed in View of Rise Time



Upper Limit values for voltage (maximum), resistance (minimum), inductance (minimum), and capacitance (maximum):

$R_{min} := R_{nom} - (R_{nom} \cdot 0.05)$ $\quad C_{max} := C_{nom} + (C_{nom} \cdot 0.05)$ $\quad L_{min} := 1\ \mu H$ $\quad V_{max} := 25500\ V$

$R_{min} = 475\ \Omega$ $\quad C_{max} = 525\ pF$

Calculations for alpha and omega based on Upper Limit values listed above:

$$\alpha_{upperLimit} := \frac{R_{min}}{2 \cdot L_{min}} \qquad \omega_{upperLimit} := \frac{1}{\sqrt{L_{min} \cdot C_{max}}}$$

$$\alpha_{upperLimit} = (2.375 \cdot 10^{8})\ \frac{1}{s} \qquad \omega_{upperLimit} = (4.364 \cdot 10^{7})\ \frac{1}{s}$$

Calculations for S1 and S2 based on Upper Limit values of alpha and omega listed above:

$$s_{1upperLimit} := -\alpha_{upperLimit} + \sqrt{\alpha_{upperLimit}^{2} - \omega_{upperLimit}^{2}} \qquad s_{2upperLimit} := -\alpha_{upperLimit} - \sqrt{\alpha_{upperLimit}^{2} - \omega_{upperLimit}^{2}}$$

$$s_{1upperLimit} = -4.044 \cdot 10^{6}\ \frac{1}{s} \qquad s_{2upperLimit} = -4.71 \cdot 10^{8}\ \frac{1}{s}$$

Calculations for A1 and A2 based on Upper Limit values listed above:

$$A_{2upperLimit} := \frac{\left(\frac{-1}{L_{min}} \cdot (R_{min} \cdot i_{initial} + V_{max})\right) - (i_{initial} \cdot s_{2upperLimit})}{(s_{2upperLimit} - s_{1upperLimit})}$$

$$A_{2upperLimit} = 54.614\ A$$

$$A_{1upperLimit} := i_{initial} - A_{2upperLimit}$$

$$A_{1upperLimit} = -54.614\ A$$

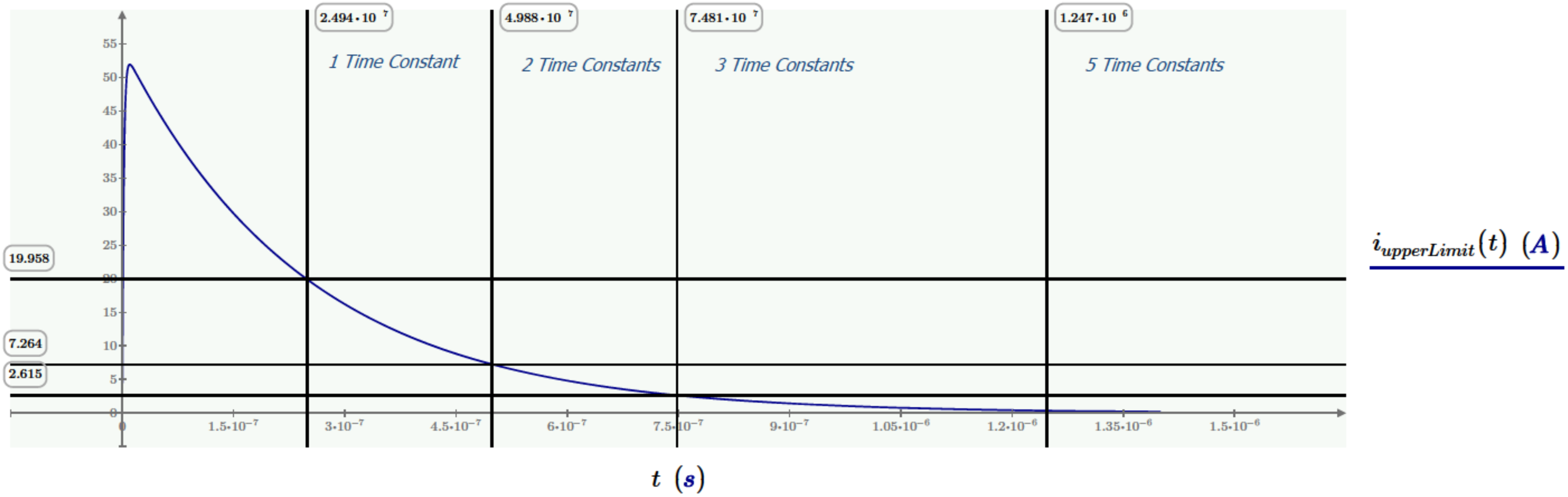
Double exponential equation for current & voltage waveforms based on Upper Limit value calculations:

$$i_{upperLimit}(t) := -\left(A_{1upperLimit} \cdot e^{s_{1upperLimit} \cdot t} + A_{2upperLimit} \cdot e^{s_{2upperLimit} \cdot t}\right)$$

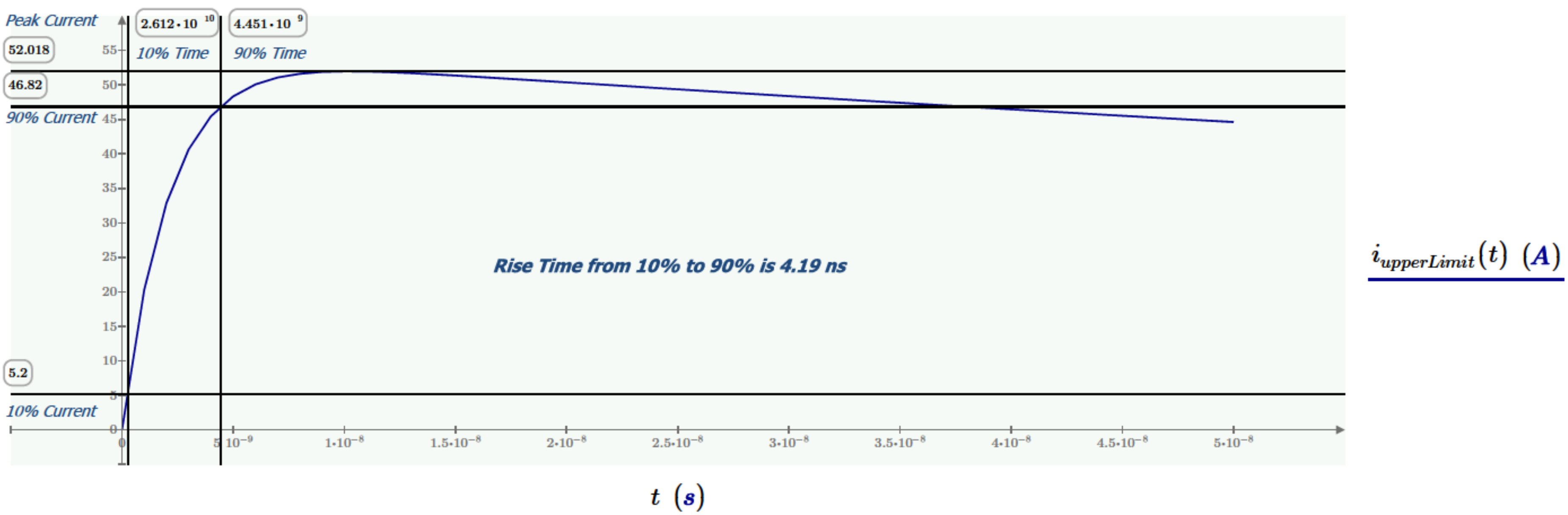
$$V_{RupperLimit}(t) := i_{upperLimit}(t) \cdot R_{min}$$

Appendix B

Double Exponential Waveform Graph Based on Upper Limit Values




Zoomed in View of Rise Time



Lower Limit values for voltage (minimum), resistance (maximum), inductance (maximum), and capacitance (minimum):

$R_{max} := R_{nom} + (R_{nom} \cdot 0.05)$ $C_{min} := C_{nom} - (C_{nom} \cdot 0.05)$ $L_{max} := 5\ \mu H$ $V_{min} := 24500\ V$

$R_{max} = 525\ \Omega$ $C_{min} = 475\ pF$

Calculations for alpha ans omega based on Lower Limit values listed above:

$$\alpha_{lowerLimit} := \frac{R_{max}}{2 \cdot L_{max}} \qquad \omega_{lowerLimit} := \frac{1}{\sqrt{L_{max} \cdot C_{min}}}$$

$$\alpha_{lowerLimit} = (5.25 \cdot 10^7)\ \frac{1}{s} \qquad \omega_{lowerLimit} = (2.052 \cdot 10^7)\ \frac{1}{s}$$

Calculations for S1 and S2 based on the Lower Limit values of alpha and omega listed above:

$$s_{1lowerLimit} := -\alpha_{lowerLimit} + \sqrt{\alpha_{lowerLimit}{}^2 - \omega_{lowerLimit}{}^2} \qquad s_{2lowerLimit} := -\alpha_{lowerLimit} - \sqrt{\alpha_{lowerLimit}{}^2 - \omega_{lowerLimit}{}^2}$$

$$s_{1lowerLimit} = -4.176 \cdot 10^6\ \frac{1}{s} \qquad s_{2lowerLimit} = -1.008 \cdot 10^8\ \frac{1}{s}$$

Calculations for A1 and A2 based on Lower Limit values listed above:

$$A_{2lowerLimit} := \frac{\left(\frac{-1}{L_{max}} \cdot (R_{max} \cdot i_{initial} + V_{min})\right) - (i_{initial} \cdot s_{2lowerLimit})}{(s_{2lowerLimit} - s_{1lowerLimit})}$$

$A_{2lowerLimit} = 50.7\ A$

$A_{1lowerLimit} := i_{initial} - A_{2lowerLimit}$

$A_{1lowerLimit} = -50.7\ A$

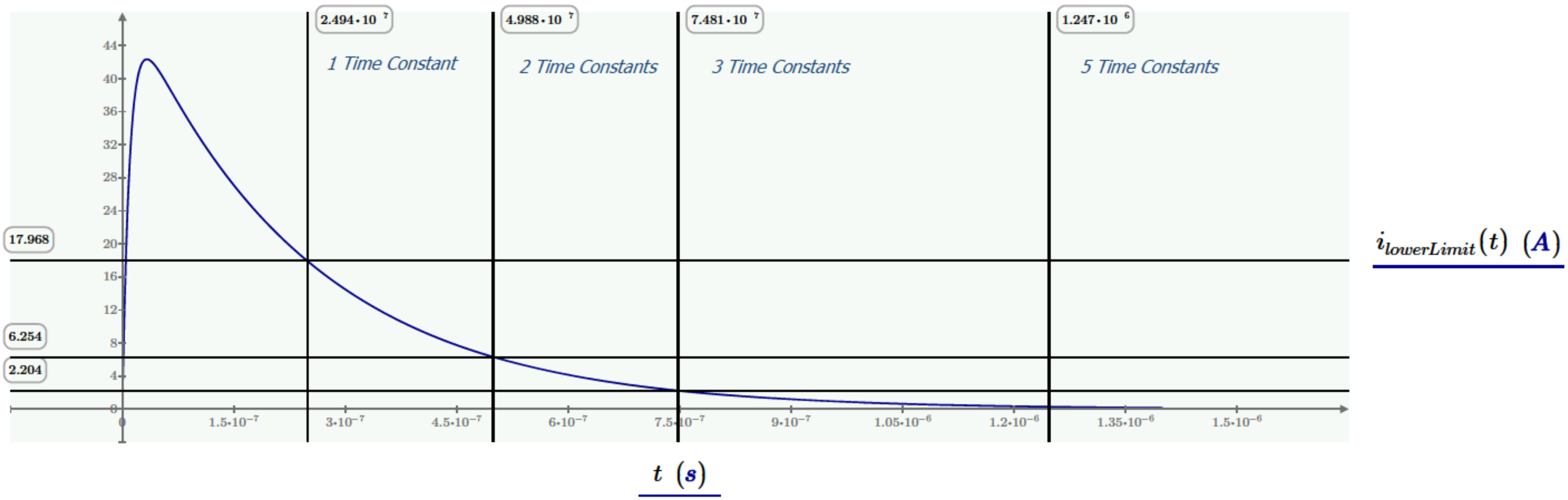
Double exponential equation for current & voltage waveforms based on Lower Limit value calculations:

$$i_{lowerLimit}(t) := -\left(A_{1lowerLimit} \cdot e^{s_{1lowerLimit} \cdot t} + A_{2lowerLimit} \cdot e^{s_{2lowerLimit} \cdot t}\right)$$

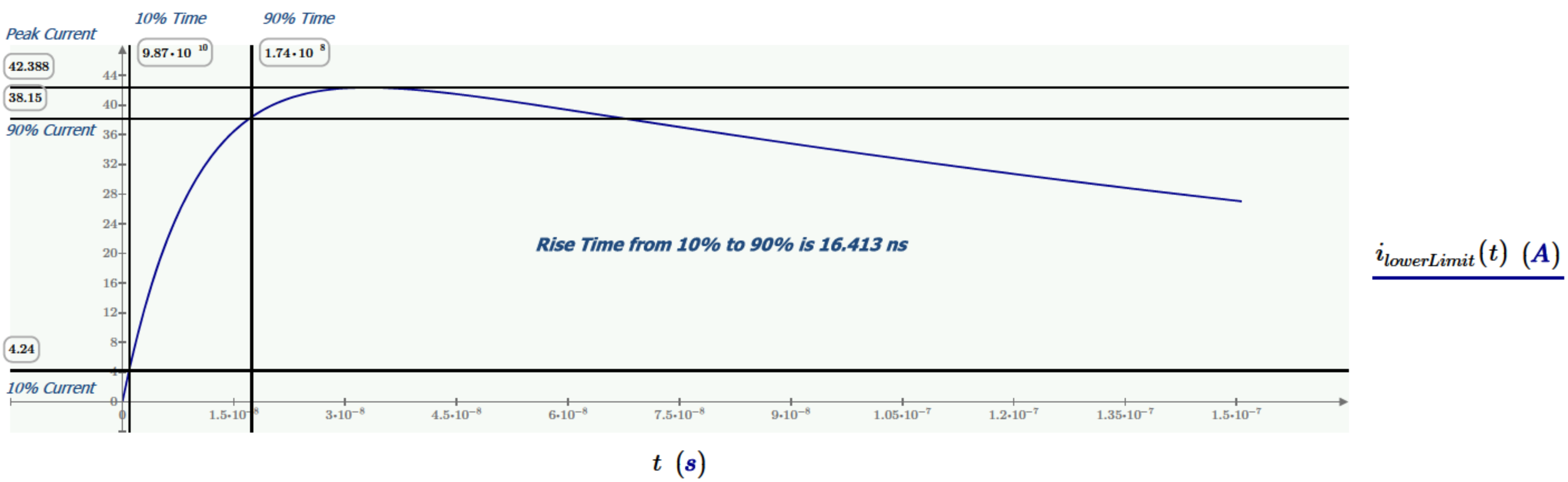
$$V_{RlowerLimit}(t) := i_{lowerLimit}(t) \cdot R_{max}$$

Appendix B

Double Exponential Current Waveform Graph Based on Lower Limit Values

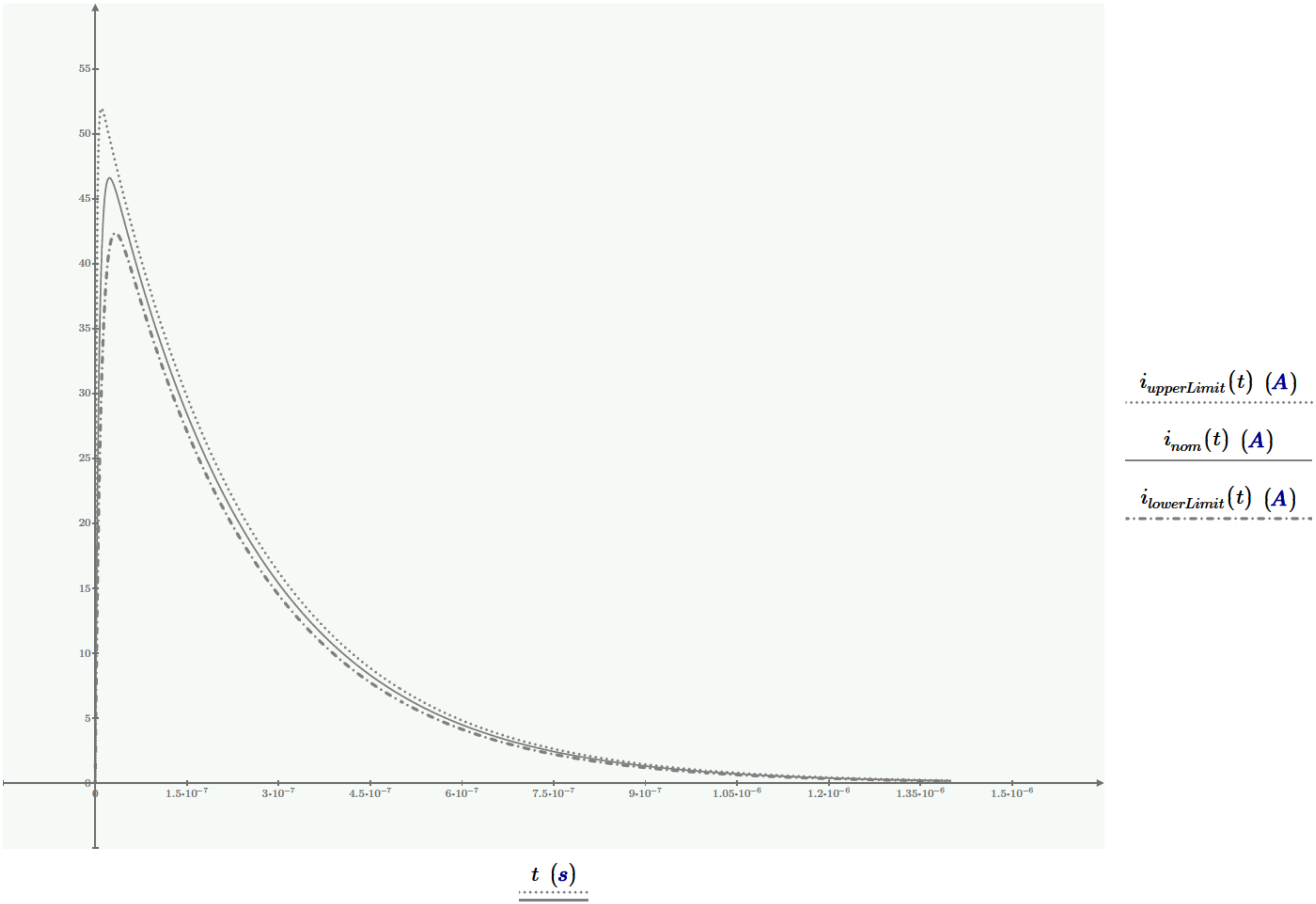



Zoomed in View of Rise Time



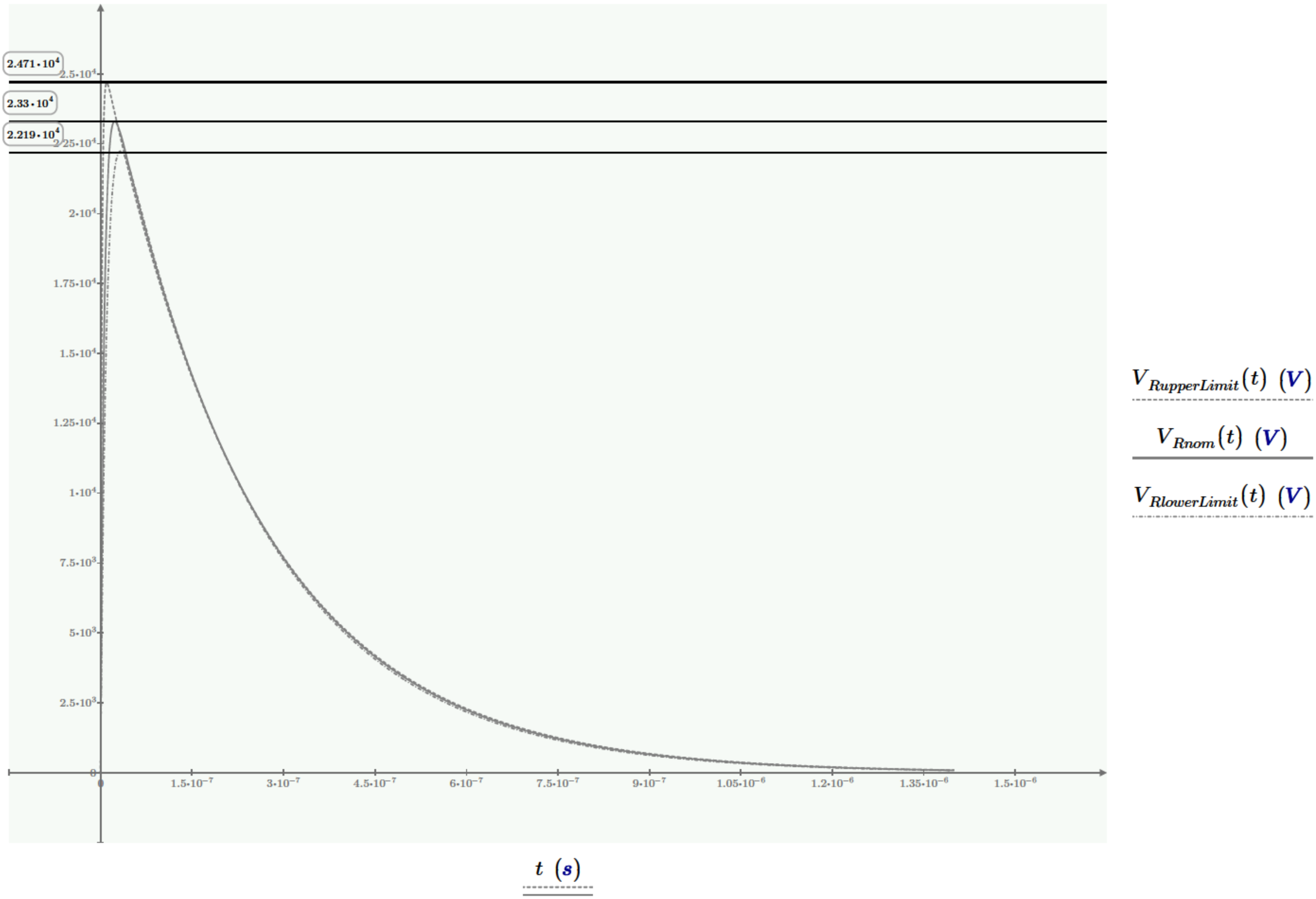
# Appendix B

## Current Waveform Graphs with Upper, Nominal, & Lower Values



Appendix B

Voltage Waveform Graphs with Upper, Lower, & Nominal Values



# Appendix C

# PESD 5000 Ohm Calibration Calculations

## Appendix B

Calculations for Personnel Bourne ESD (PESD) with nominal values of 25kV, 5000 Ohms, and 500 pF

(Only positive traces are shown negative traces are identical except inverted)

Time span and initial condition values:

$$t := (0, .0003 \cdot \mu s .. 13 \cdot \mu s)$$

$$i_{initial} := 0\ A$$

Nominal values for voltage, resistance, inductance, and capacitance:

$$R_{nom} := 5000\ \Omega \qquad C_{nom} := 500\ pF \qquad L_{nom} := 3\ \mu H \qquad V_{nom} := 25000\ V$$

Calculations for alpha and omega based on nominal values listed above:

$$\alpha_{nom} := \frac{R_{nom}}{2 \cdot L_{nom}} \qquad \omega_{nom} := \frac{1}{\sqrt{L_{nom} \cdot C_{nom}}}$$

$$\alpha_{nom} = \left(8.333 \cdot 10^{8}\right) \frac{1}{s} \qquad \omega_{nom} = \left(2.582 \cdot 10^{7}\right) \frac{1}{s}$$

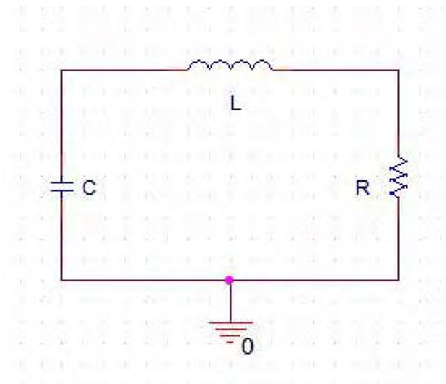



Figure 1 Series RLC Circuit

Calculations for S1 and S2 based on nominal values of alpha and omega

$$s_{1nom} := -\alpha_{nom} + \sqrt{{\alpha_{nom}}^{2} - {\omega_{nom}}^{2}} \qquad s_{2nom} := -\alpha_{nom} - \sqrt{{\alpha_{nom}}^{2} - {\omega_{nom}}^{2}}$$

$$s_{1nom} = -4.001 \cdot 10^{5}\ \frac{1}{s} \qquad s_{2nom} = -1.666 \cdot 10^{9}\ \frac{1}{s}$$

Calculations for A1 and A2 based on nominal values:

$$A_{2nom} := \frac{\left(\frac{-1}{L_{nom}} \cdot \left(R_{nom} \cdot i_{initial} + V_{nom}\right)\right) - \left(i_{initial} \cdot s_{2nom}\right)}{\left(s_{2nom} - s_{1nom}\right)}$$

$$A_{2nom} = 5.002\ A$$

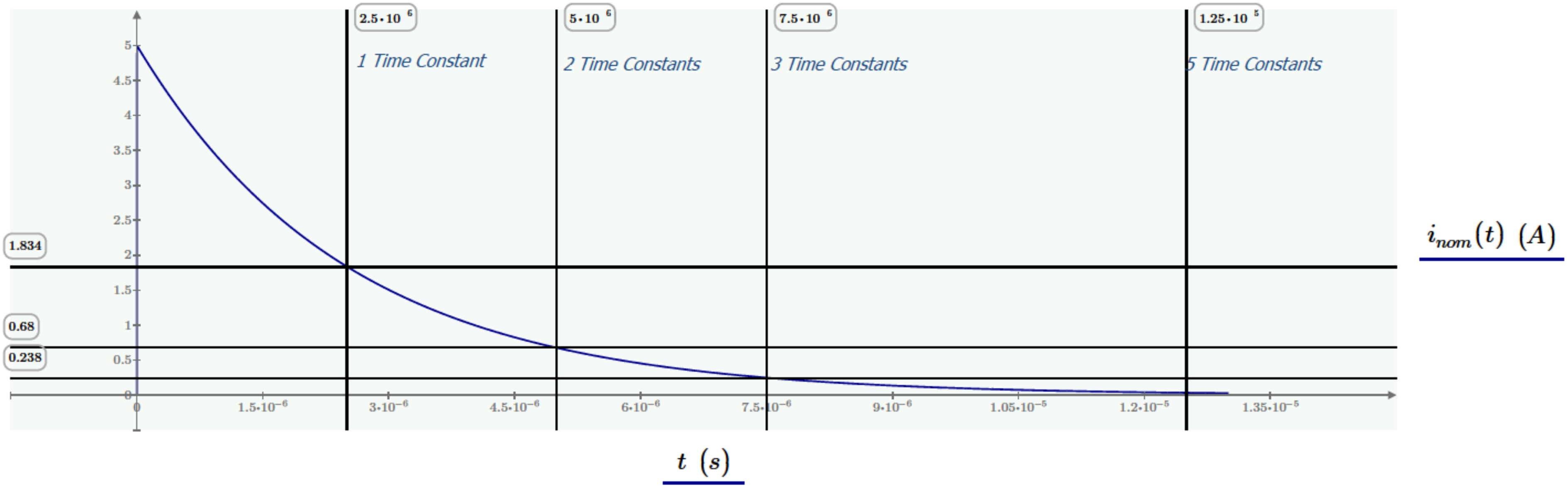
$$A_{1nom} := i_{initial} - A_{2nom}$$

$$A_{1nom} = -5.002\ A$$

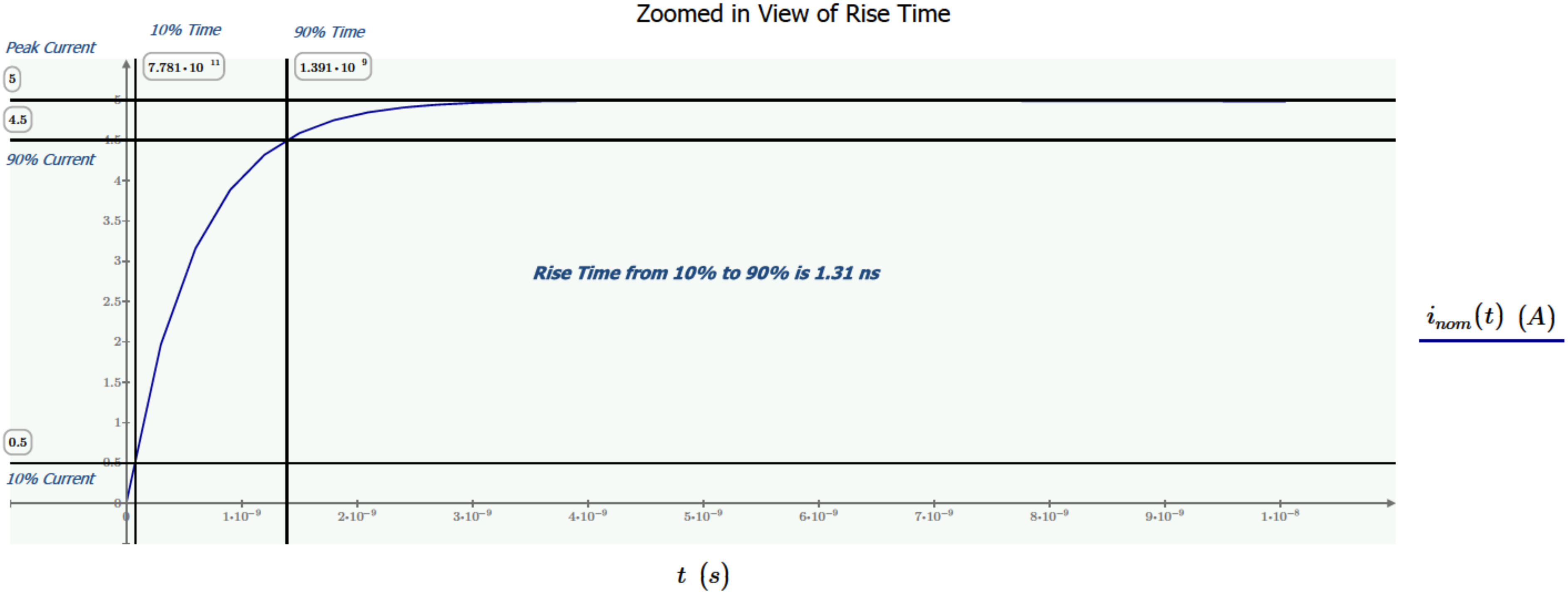
Double exponential equation for current & voltage waveforms based on nominal value calculations:

$$i_{nom}(t) := -\left(A_{1nom} \cdot e^{s_{1nom} \cdot t} + A_{2nom} \cdot e^{s_{2nom} \cdot t}\right) \qquad V_{Rnom}(t) := i_{nom}(t) \cdot R_{nom}$$

Double exponential graph of current waveform using nominal values




Zoomed in View of Rise Time



Upper Limit values for voltage (maximum), resistance (minimum), inductance (minimum), and capacitance (maximum):

$$R_{min} := R_{nom} - \left(R_{nom} \cdot 0.05\right) \qquad C_{max} := C_{nom} + \left(C_{nom} \cdot 0.05\right) \qquad L_{min} := 1\ \mu H \qquad V_{max} := 25500\ V$$

$$R_{min} = \left(4.75 \cdot 10^{3}\right)\ \Omega \qquad C_{max} = 525\ pF$$

Calculations for alpha and omega based on Upper Limit values listed above:

$$\alpha_{upperLimit} := \frac{R_{min}}{2 \cdot L_{min}} \qquad \omega_{upperLimit} := \frac{1}{\sqrt{L_{min} \cdot C_{max}}}$$

$$\alpha_{upperLimit} = \left(2.375 \cdot 10^{9}\right)\ \frac{1}{s} \qquad \omega_{upperLimit} = \left(4.364 \cdot 10^{7}\right)\ \frac{1}{s}$$

Calculations for S1 and S2 based on Upper Limit values of alpha and omega listed above:

$$s_{1upperLimit} := -\alpha_{upperLimit} + \sqrt{\alpha_{upperLimit}{}^{2} - \omega_{upperLimit}{}^{2}} \qquad s_{2upperLimit} := -\alpha_{upperLimit} - \sqrt{\alpha_{upperLimit}{}^{2} - \omega_{upperLimit}{}^{2}}$$

$$s_{1upperLimit} = -4.01 \cdot 10^{5}\ \frac{1}{s} \qquad s_{2upperLimit} = -4.75 \cdot 10^{9}\ \frac{1}{s}$$

Calculations for A1 and A2 based on Upper Limit values listed above:

$$A_{2upperLimit} := \frac{\left(\frac{-1}{L_{min}} \cdot \left(R_{min} \cdot i_{initial} + V_{max}\right)\right) - \left(i_{initial} \cdot s_{2upperLimit}\right)}{\left(s_{2upperLimit} - s_{1upperLimit}\right)}$$

$$A_{2upperLimit} = 5.369\ A$$

$$A_{1upperLimit} := i_{initial} - A_{2upperLimit}$$

$$A_{1upperLimit} = -5.369\ A$$

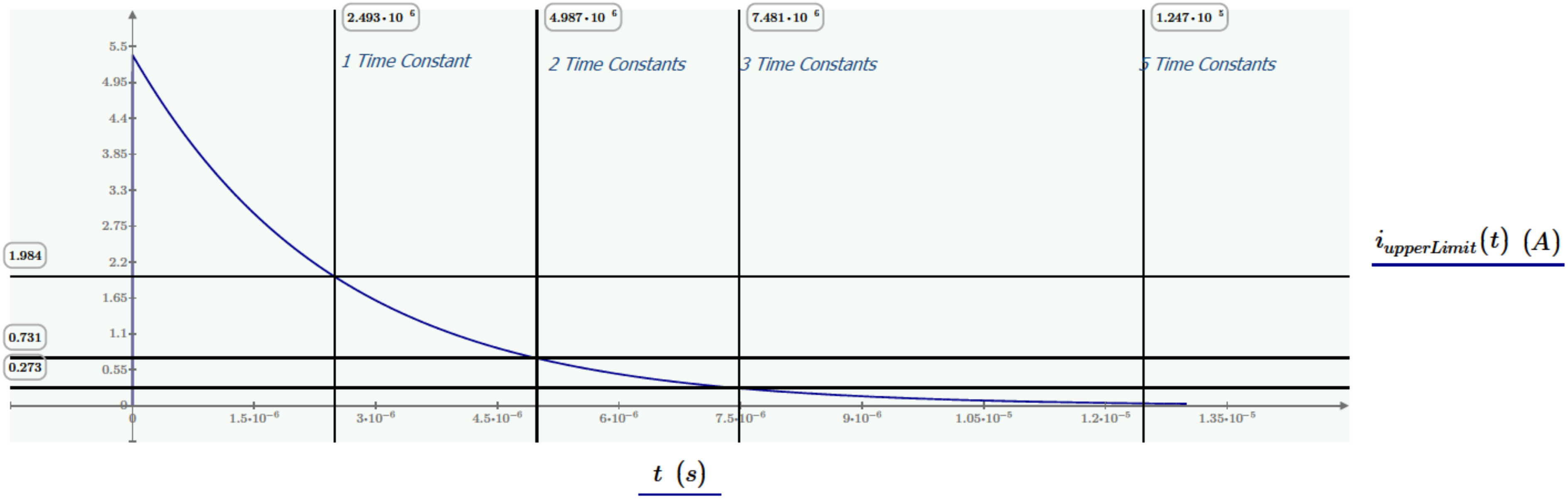
Double exponential equation for current & voltage waveforms based on Upper Limit value calculations:

$$i_{upperLimit}(t) := -\left(A_{1upperLimit} \cdot e^{s_{1upperLimit} \cdot t} + A_{2upperLimit} \cdot e^{s_{2upperLimit} \cdot t}\right)$$

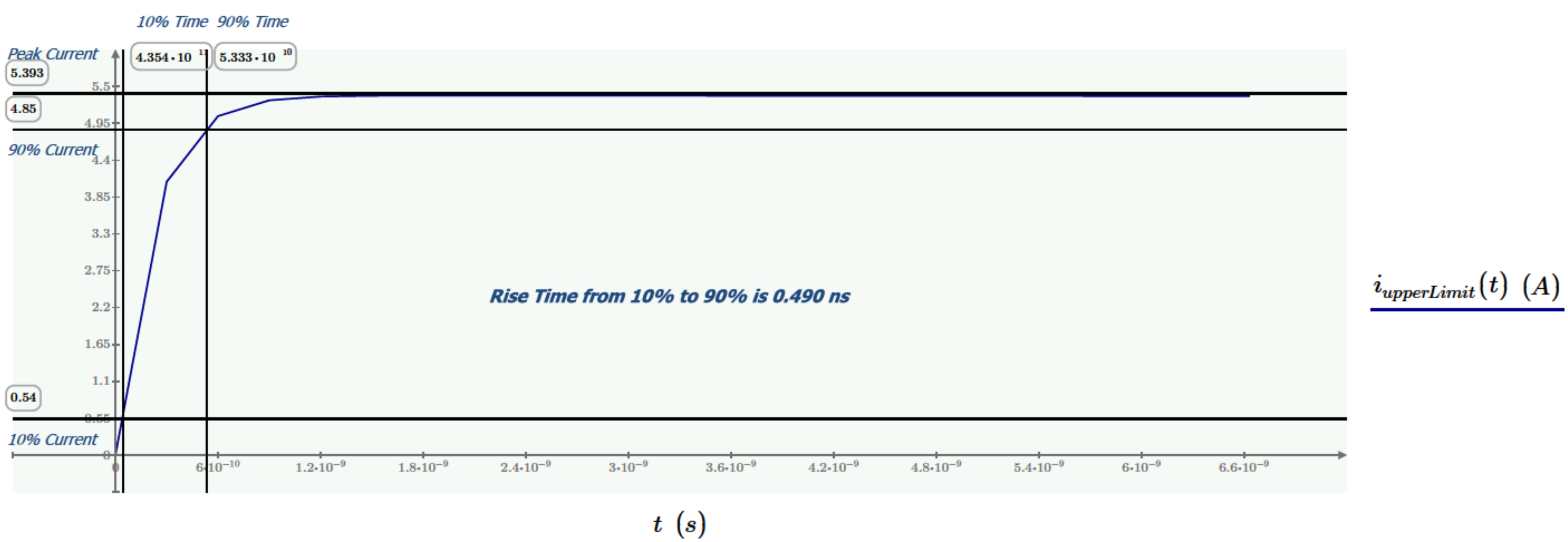
$$V_{RupperLimit}(t) := i_{upperLimit}(t) \cdot R_{min}$$

# Appendix B

## Double Exponential Waveform Graph Based on Upper Limit Values




## Zoomed in View of Rise Time



Lower Limit values for voltage (minimum), resistance (maximum), inductance (maximum), and capacitance (minimum):

$$R_{max} := R_{nom} + \left(R_{nom} \cdot 0.05\right) \qquad C_{min} := C_{nom} - \left(C_{nom} \cdot 0.05\right) \qquad L_{max} := 5\ \mu H \qquad V_{min} := 24500\ V$$

$$R_{max} = \left(5.25 \cdot 10^{3}\right)\ \Omega \qquad C_{min} = 475\ pF$$

Calculations for alpha ans omega based on Lower Limit values listed above:

$$\alpha_{lowerLimit} := \frac{R_{max}}{2 \cdot L_{max}} \qquad \omega_{lowerLimit} := \frac{1}{\sqrt{L_{max} \cdot C_{min}}}$$

$$\alpha_{lowerLimit} = \left(5.25 \cdot 10^{8}\right)\ \frac{1}{s} \qquad \omega_{lowerLimit} = \left(2.052 \cdot 10^{7}\right)\ \frac{1}{s}$$

Calculations for S1 and S2 based on the Lower Limit values of alpha and omega listed above:

$$s_{1lowerLimit} := -\alpha_{lowerLimit} + \sqrt{\alpha_{lowerLimit}^{\ 2} - \omega_{lowerLimit}^{\ 2}} \qquad s_{2lowerLimit} := -\alpha_{lowerLimit} - \sqrt{\alpha_{lowerLimit}^{\ 2} - \omega_{lowerLimit}^{\ 2}}$$

$$s_{1lowerLimit} = -4.012 \cdot 10^{5}\ \frac{1}{s} \qquad s_{2lowerLimit} = -1.05 \cdot 10^{9}\ \frac{1}{s}$$

Calculations for A1 and A2 based on Lower Limit values listed above:

$$A_{2lowerLimit} := \frac{\left(\frac{-1}{L_{max}} \cdot \left(R_{max} \cdot i_{initial} + V_{min}\right)\right) - \left(i_{initial} \cdot s_{2lowerLimit}\right)}{\left(s_{2lowerLimit} - s_{1lowerLimit}\right)}$$

$$A_{2lowerLimit} = 4.67\ A$$

$$A_{1lowerLimit} := i_{initial} - A_{2lowerLimit}$$

$$A_{1lowerLimit} = -4.67\ A$$

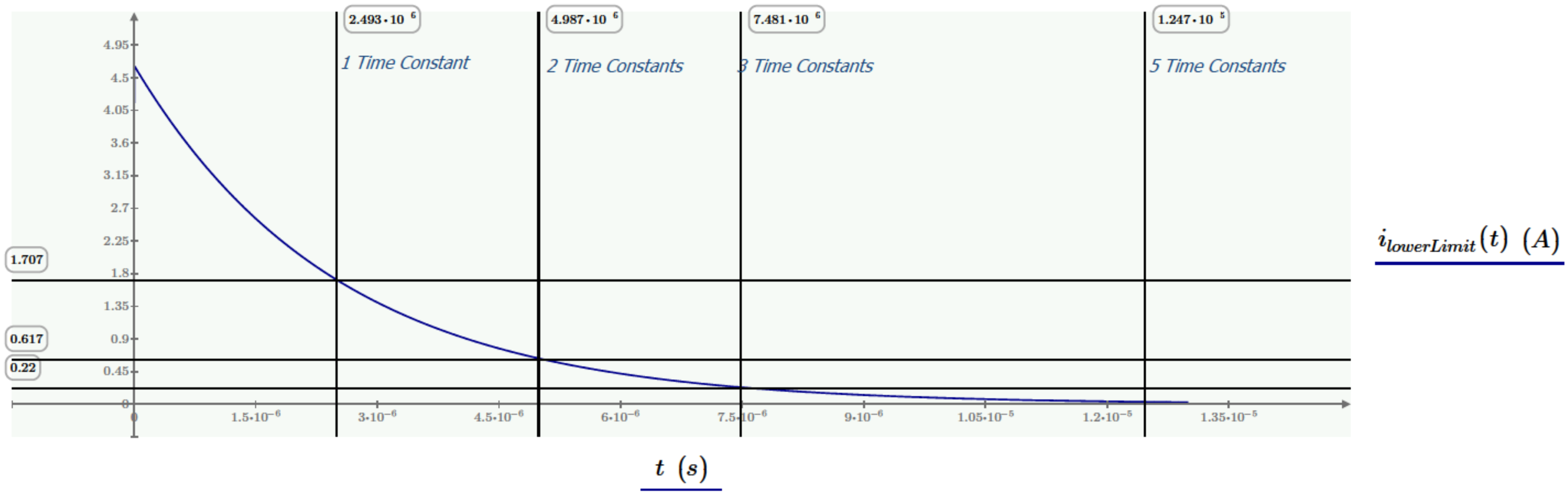
Double exponential equation for current & voltage waveforms based on Lower Limit value calculations:

$$i_{lowerLimit}(t) := -\left(A_{1lowerLimit} \cdot e^{s_{1lowerLimit} \cdot t} + A_{2lowerLimit} \cdot e^{s_{2lowerLimit} \cdot t}\right)$$

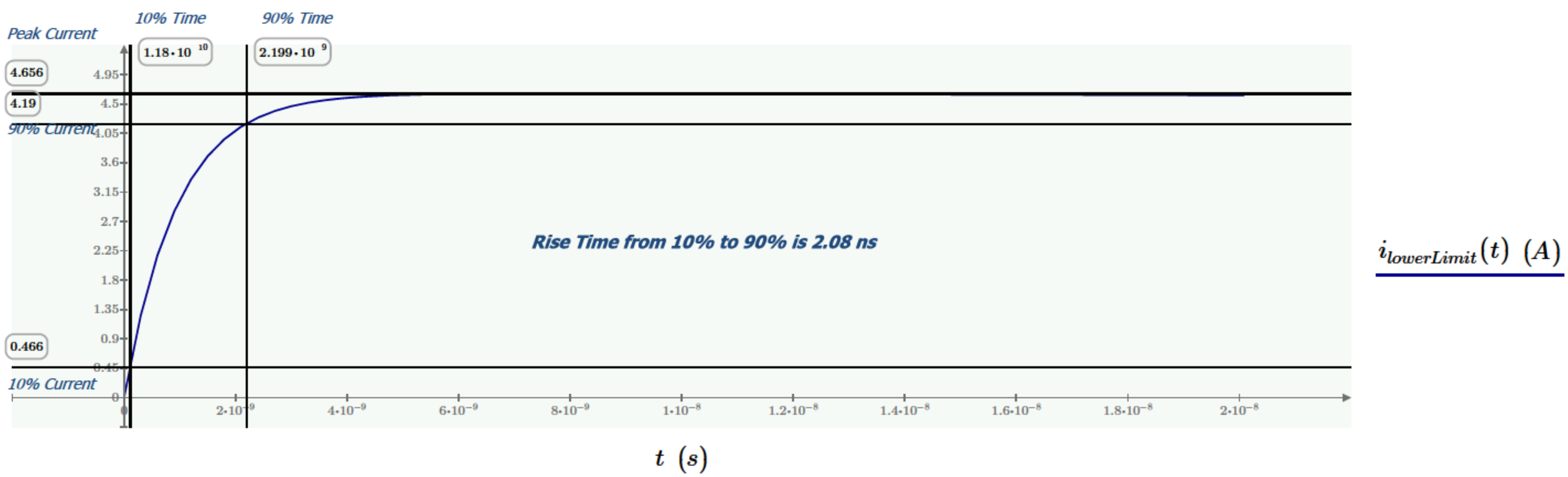
$$V_{RlowerLimit}(t) := i_{lowerLimit}(t) \cdot R_{max}$$

## Appendix B

### Double Exponential Current Waveform Graph Based on Lower Limit Values

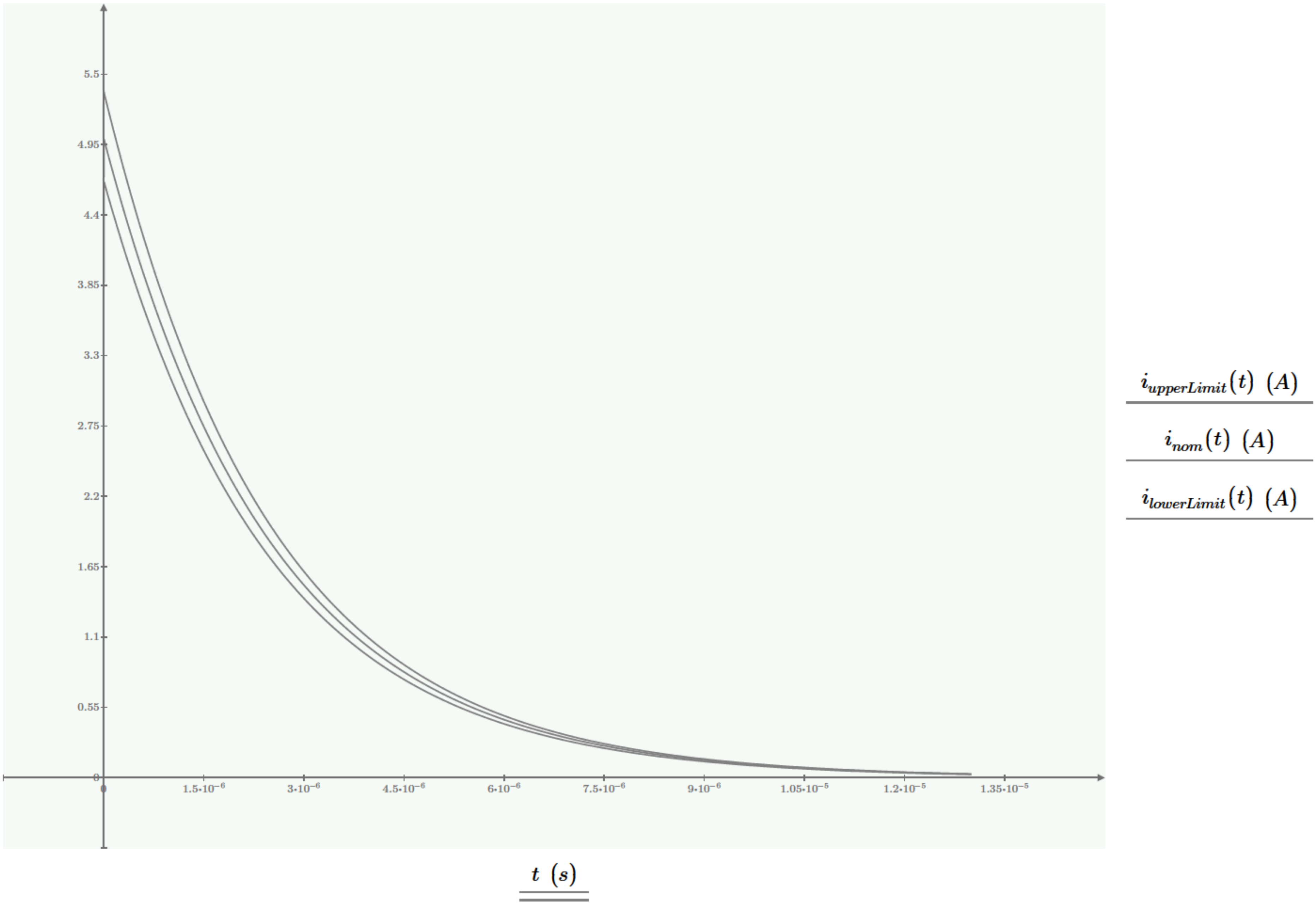



### Zoomed in View of Rise Time



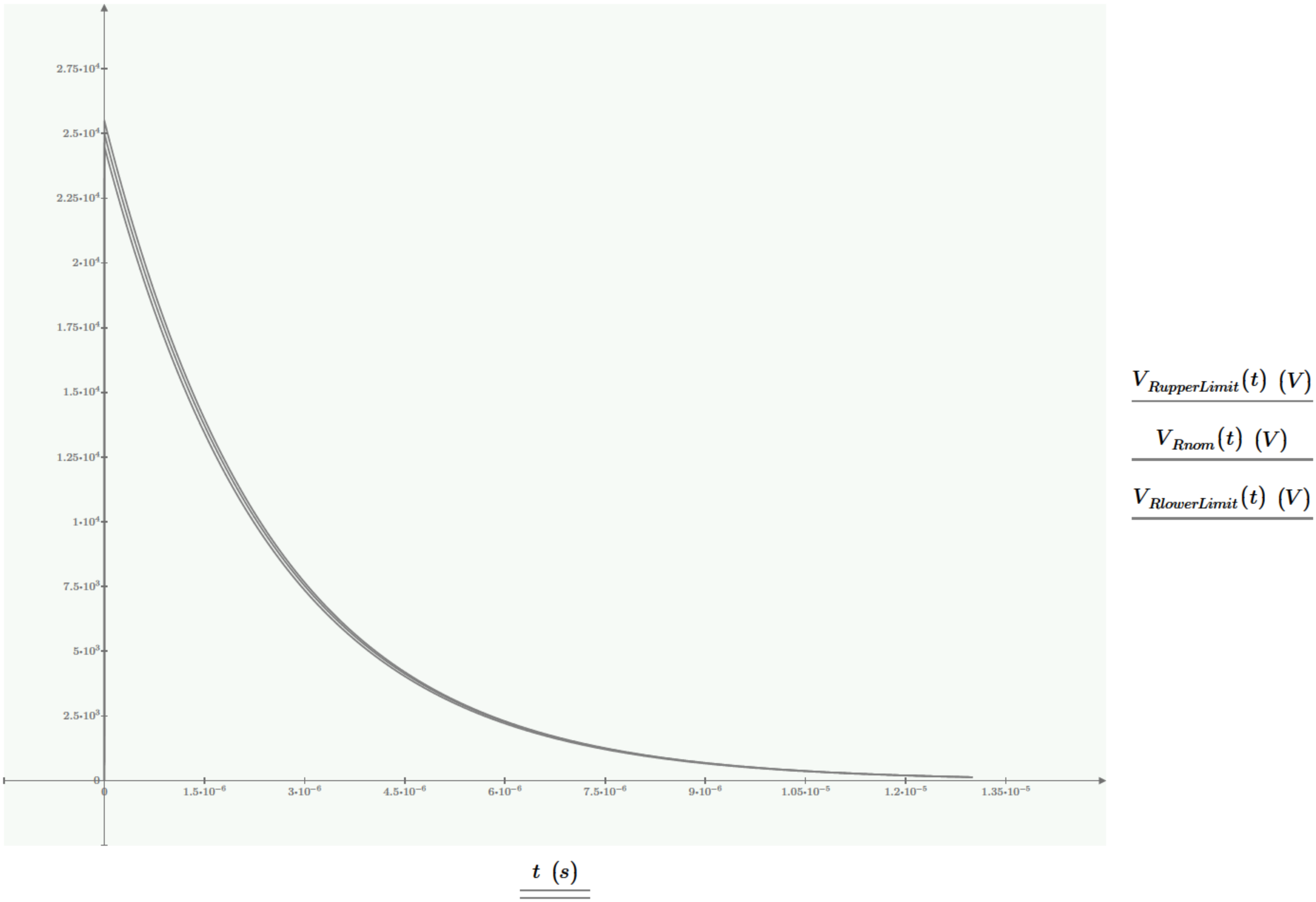
# Appendix B

## Current Waveform Graphs with Upper, Nominal, & Lower Values



Appendix B

Voltage Waveform Graphs with Upper, Lower, & Nominal Values



# Joint Ordnance Test Procedure-062

# Personnel and Helicopter ESD Faraday Cage Test Report

# Executive Summary

MIL STD 464C provides the top level requirements for ordnance safety when ordnance items or systems are exposed to personnel and helicopter borne ElectroStatic Discharge (ESD). However, the requirements are general and do not provide specific instruction to evaluate ordnance items to these general requirements. MIL STD 331C provides some additional requirements and guidance for the ESD tests, but this additional guidance is not clear and complete enough to eliminate different interpretations by the Services. Therefore, the current implementation of the existing requirements is not consistent across the Services and leads to unnecessary testing of items and/or shipping containers to meet the specific Service's interpretation.

The Joint Ordnance Test Procedure (JOTP) Faraday cage testing evaluated the existing ESD test approach used by each of the Services, and the general requirements in MIL STD 464C to determine a common Joint Service ESD analysis approach for defining Faraday cage protection for each Service to accept the results from the Joint Service test and produce consistent results and eliminate unnecessary testing.

As a result of the Faraday cage testing, the following changes have been integrated into the JOTP Personnel ESD (PESD) and Helicopter ESD (HESD) documents to provide additional specific guidance for performing the testing, documenting the testing, and classification of the results:

1. Add 0.016 inch minimum thickness for metal surrounding any ordnance device with no openings or electrical interfaces as a Faraday cage that does not require testing to validate.

2. Add 0.016 inch minimum thickness for metal shipping container surrounding any ordnance material with no openings or electrical interfaces as a Faraday cage that does not require testing to validate.

3. Add a requirement that the ordnance device and shipping container drawings must be provided in the ESD report and the ordnance device and shipping container drawings must specify the material and thickness to perform the Faraday cage analysis.

# JOTP ESD Faraday Cage Test Report
## Review and Concurrence

CRAVEN.JEFFERY.D.1230665016 Digitally signed by CRAVEN.JEFFERY.D.1230665016 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=CRAVEN.JEFFERY.D.1230665016 Date: 2014.11.13 09:06:06 -06'00'

Redstone Test Center:
Sr. Electronics Engineer: Jeff Craven

ROY.THOMAS.E.1268469555 Digitally signed by ROY.THOMAS.E.1268469555 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=CONTRACTOR, cn=ROY.THOMAS.E.1268469555 Date: 2014.11.13 09:22:24 -06'00'

Redstone Test Center:
Engineer III, AI Signal Research, Inc.: Thomas E. Roy

JESSON.STEPHANIE.S.1232198768 Digitally signed by JESSON.STEPHANIE.S.1232198768 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=JESSON.STEPHANIE.S.1232198768 Date: 2014.11.13 13:26:07 -07'00'

White Sands Test Center:
Electromagnetic Radiation Branch Chief: Stephanie Jesson

ROBERTS.WILLIAM.LEONARD.1297715808 Digitally signed by ROBERTS.WILLIAM.LEONARD.1297715808 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USA, cn=ROBERTS.WILLIAM.LEONARD.1297715808 Date: 2014.11.13 14:25:52 -07'00'

White Sands Test Center:
Facility Engineer: Dr. William Roberts

Naval Surface Warfare Center, Indian Head:
Navy ESD Technical Agent: Spencer Johnson

JOHNSON.SPENCER.T.1364442544 Digitally signed by JOHNSON.SPENCER.T.1364442544 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USN, cn=JOHNSON.SPENCER.T.1364442544 Date: 2014.11.17 09:52:10 -05'00'

Naval Ordnance Safety and Security Activity:
Navy E3 Ordnance Safety: Joe Sferrella

SFERRELLA.JOSEPH.V.1229422975 Digitally signed by SFERRELLA.JOSEPH.V.1229422975 DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USN, cn=SFERRELLA.JOSEPH.V.1229422975 Date: 2014.11.17 11:35:38 -05'00'

JOTP ESD Faraday Cage Test Report
Review and Concurrence

Air Force Safety Center
Electrical System Safety: Rodolfo A. Ramos

RAMOS.RODOLFO.A.1183853933

Digitally signed by RAMOS.RODOLFO.A.1183853933
DN: c=US, o=U.S. Government, ou=DoD, ou=PKI, ou=USAF, cn=RAMOS.RODOLFO.A.1183853933
Date: 2014.12.01 06:31:46 -07'00'

# Table of Contents

JOTP ESD Faraday Cage Test Report

**1.0 Purpose:**

The purpose of the JOTP ESD Faraday Cage testing is:

1. To determine a minimum thickness of any type of metal surrounding an ordnance item that will provide protection to all bare energetic material and Electrically Initiated Devices (EIDs) exposed to the PESD and HESD test requirements in the JOTP PESD and HESD documents.

2. To determine if different types of metal commonly used for ordnance items and shipping containers provide the same level of ESD protection when exposed to the PESD and HESD environments.

3. To determine what specific information must be provided for each type of ordnance item to document the Faraday cage protection to satisfy Service specific interpretations of the MIL STD 464C ESD requirements.

**2.0 Background:**

MIL STD 464C provides the top level requirements for ordnance safety when ordnance items or systems are exposed to personnel and helicopter borne ESD. However, the requirements are general and do not provide specific instruction to ensure the implementation of the general requirements by each of the Services produces consistent and repeatable results. Currently, each Service evaluates an ordnance item to its specific operational requirements, and there is no guidance in MIL STD 464C or MIL STD 331CC to define a Faraday cage for ESD protection of ordnance items. This results in unnecessary testing of items that is not consistent among the Services.

The purpose of the Faraday cage ESD testing was not to define an absolute minimum metal thickness for 25 kV ESD protection and separately for 300 kV ESD protection in the shipping configuration. The purpose was to determine a metal thickness, independent of the specific metal material, that would provide burn through protection from multiple 300 kV ESD discharges, and also prevent any internal current from being generated on a bridgewire device in the metal faraday cage container. It was also intended that the metal thickness that met the above requirements would also be used to qualify bare percussion initiated devices as insensitive to 25 kV and 300 kV ESD based on the same Faraday cage protection.

**3.0 Faraday Cage Test Requirements:**

This section will identify the issues identified during development of the JOTP ESD procedure regarding the ESD test or analysis processes used by each of the Services for metallic items and containers, and the differences in the interpretations of the MIL STD 464C and MIL STD 331C requirements related to testing these items. The differences will be investigated during the Faraday cage testing to provide a common ESD test procedure requirement for Faraday cage items, a common analysis requirement defining the minimum metal thickness required for all metallic percussion initiated ordnance items and shipping containers, and a common ESD test report certification for the metallic item or container.

For the purposes of this document, the following information is provided:

The metal thicknesses used in the Faraday cage testing were not based on shipping container metal thicknesses. Instead, the evaluation focused on the metal types and thicknesses for common ordnance items that are already considered Faraday cage items by each of the Services, but have no supporting test documentation or common analysis requirements to support the classification. Typical examples include grenades, cartridges, and percussion initiated cartridge actuated devices. This testing was to provide guidance in the JOTP to document the Faraday cage protection related to the HESD test requirement for shipping containers, and also to also provide guidance for evaluating ordnance items to the bare PESD and HESD exposure requirements in the JOTP.

Additionally, it was decided that a separate evaluation for a minimum metal thickness to provide Faraday cage protection of ordnance items to the PESD requirements was not required. Although the minimum thickness would be much thinner for meeting the PESD Faraday cage requirements, the metal thickness documented in the drawings for common cartridges and percussion initiated cartridge actuated devices was chosen as the baseline for the HESD Faraday cage test evaluation.  Therefore, a separate evaluation for PESD exposure was not performed.

Although there are a wide variety of metals available, the Faraday cage testing concentrated on the most common metal types used in the construction of ordnance items and containers. These metals are: C260 cartridge brass, T-6061 aluminum, and 304 stainless steel. Cartridge brass is used for most cartridge cases, 304 stainless steel is used for most cartridge actuated devices and metal ammo containers, and T-6061 aluminum is used for many shipping containers.

The Faraday cage testing also did not focus on defining an HESD “barrier bag” thickness to provide Faraday cage protection for electrically initiated devices that are not safe for bare exposure to the HESD requirements, or for metal foils that are used in some electrically initiated and percussion initiated items for ESD protection, unless the barrier bags and foils meet the faraday cage requirements defined in this document. Those items are usually constructed of multiple materials that include non-conductive materials, and are out of the scope of this testing. Examples of these foils are: foils used to cover openings in flash bang items with energetic material directly under the openings, and the foil shield on the nozzle opening for 2.75 inch Mk 66 rocket motors. Most of these foils are actually a combination of foil with some sort of flexible membrane underneath, and the foils are much thinner than the thicknesses used for the Faraday cage evaluation.

The goals of the Faraday cage testing were:

**3.1**: Determine the minimum thickness of metal required to provide “Faraday cage” protection to electrically initiated ordnance items in metal containers for VERTREP exposure.

Rationale: MIL STD 464C calls out 2 different HESD requirements to evaluate: (1) VERTREP and (2) bare item carry. The only additional guidance provided is the voltage level, capacitance, and maximum circuit resistance and inductance. There is no guidance for defining a Faraday cage, or guidance for when testing is not required, resulting in differences in how each Service documents Faraday cage protection or applies the requirement to test metal containers or metal non-electrically initiated devices.

JOTP Requirements: Electrically initiated devices contained in metal shipping containers are required to be evaluated for HESD exposure in MIL STD 464C. Metal containers provide protection from the HESD test requirements, but the protection has never been documented except through testing of each individual item in its specified shipping container, or through a general analysis stating the metal is thick enough to provide burn through protection, and therefore protect the item from the HESD exposure. The Faraday cage testing will focus on documenting the level of protection to electrically initiated devices by different types of metals and different thicknesses of metals and determining the requirements to include in the JOTP to eliminate the differences used by each of the Services for evaluating the containers used for these devices.

**3.2**: Determine metal thickness required for multiple discharges (more than the two discharges required in MIL STD 331CC for HESD exposure) to the same location for bare percussion initiated devices to prevent burn-through/melting/visible damage during HESD exposure.

Rationale: Although MIL STD 331CC specifies two discharges for HESD exposure, the metal thickness must also prevent damage to bare non-electrically initiated items and containers being evaluated for bare HESD exposure. To meet this requirement, the Faraday cage testing will evaluate the different metals and thicknesses of the metals for damage (including burn through) after multiple HESD exposures, so a common metal thickness requirement for both bare items and containers can be included in the JOTP.

JOTP Requirements: Percussion initiated devices completely surrounded by metal are required to be evaluated for HESD exposure in MIL STD 464C. Metal may provide protection from the HESD test environment, but the protection has never been documented except through testing of each individual item, or through a general analysis stating the metal is a Faraday cage, and therefore protects the item from the HESD exposure. The Faraday cage testing will focus on documenting the level of protection by different thicknesses of metals and determining the requirements to include in the JOTP to eliminate the differences used by each of the Services for evaluating all metal percussion initiated devices.

**3.3**: Evaluate different types of metals to determine if the same metal minimum thickness for each metal would prevent burn-through/melting/visible damage for HESD exposure.

Rationale: Although MIL STD 331CC specifies two discharges for HESD exposure, the metal thickness must also prevent damage to bare non-electrically initiated items and containers being evaluated for bare HESD exposure. If the item is a container, it must shield internal EEDs. To meet this requirement, the Faraday cage testing will evaluate the different metals commonly used for containers and for ordnance items and different thicknesses of the metals for damage (including burn through) after multiple HESD exposures, to determine if a common metal thickness independent of metal type can be included in the JOTP.

JOTP Requirements: Percussion initiated devices completely surrounded by metal are required to be evaluated for HESD exposure in MIL STD 464C. Metal provides protection from the HESD test requirements, but the protection has never been documented except through testing of each individual item, or through a general analysis stating the metal is a Faraday cage, and therefore protects the item from the HESD exposure. The Faraday cage testing will focus on documenting the level of protection by different types of metals commonly used for shipping containers and percussion initiated devices and determining the requirements to include in the JOTP to eliminate the differences used by each of the Services for evaluating all metal percussion initiated devices.

**4.0 Validation Test Results:**

The results below correlate to the appropriate subsection from Section 3 Faraday cage test requirements. The test equipment models and manufacturers are noted for all equipment used for measuring the data for documentation purposes. Multiple models of the current transformers were used to validate the output between all the various models currently used by the Services.

**4.1 Requirement 1:** Determine minimum thickness of metal to provide “Faraday cage” protection to electrically initiated ordnance items in metal containers for VERTREP exposure.

**4.2 Requirement 2:** Determine metal thickness required for multiple discharges (more than the two discharges required in MIL STD 331CC for HESD exposure) to the same location for bare percussion initiated devices to prevent burn-through/melting/visible damage during HESD exposure.

**4.3 Requirement 3:** Evaluate different types of metals to determine if the same metal minimum thickness for each metal would prevent burn-through/melting/visible damage for HESD exposure.

Requirement Discussion:
The initial plan was to document the types of materials used for common shipping containers and test those materials in several thicknesses to determine a minimum thickness to shield electrically initiated devices in the shipping container. Percussion materials would be evaluated separately, and then the evaluation of the minimum thickness for different metal types would be performed. However, the goals for Requirement 1 and Requirement 2 for the metal types for percussion devices were very similar, and only cartridge brass was commonly used for a percussion device and was not used for shipping containers. Additionally, the thicknesses of the metal components of the percussion devices reviewed were very similar to some of the standard shipping containers, particularly for small ordnance devices. For this reason, all the metal types and thicknesses were tested to satisfy the goals of Requirements 3.1, 3.2 and 3.3 identified in Section 3.

The attached drawings in Appendix A document the material thickness for a rifle primer as 0.025 inches, and the case thickness as 0.017 inches. Although all cartridges would have different thicknesses based on internal pressure specifications, the minimum material thickness was chosen as 0.016 inches for the testing for all material types chosen for testing, since 0.016 inches was the thinnest material commonly available in sheet form. The 0.40 inch thickness was chosen to be a minimum thickness for a storage container, such as a metal ammunition container.

Also, when testing the metals, it became readily apparent that the C260 brass was superior to the other metals, and since there was no measured current in the inert bridgewire for the 0.016 inch box, no testing was performed with the 0.040 inch brass box as it was not necessary.

The inert bridgewire was constructed of stainless steel wire of sufficient length to be approximately one ohm, and a Pearson Electronics 2877 current monitor was used to measure the current on the bridgewire. See Figure 1 for a picture of the bridgewire setup inside the box.

The boxes were all constructed of sheet material, using six sheets to make each box. The boxes were fabricated by using aluminum tape to join the edges together. Each box was tested with multiple discharges to 3 sides in relation to the bridgewire inside, and measurements were recorded for each discharge orientation. Each box was also inspected for damage and burn through after each discharge. See Figure 2 for the discharge locations.

After testing the 304 stainless steel and measuring the damped sinusoid, an additional test was performed using an ammunition container with the inert bridgewire and current monitor.

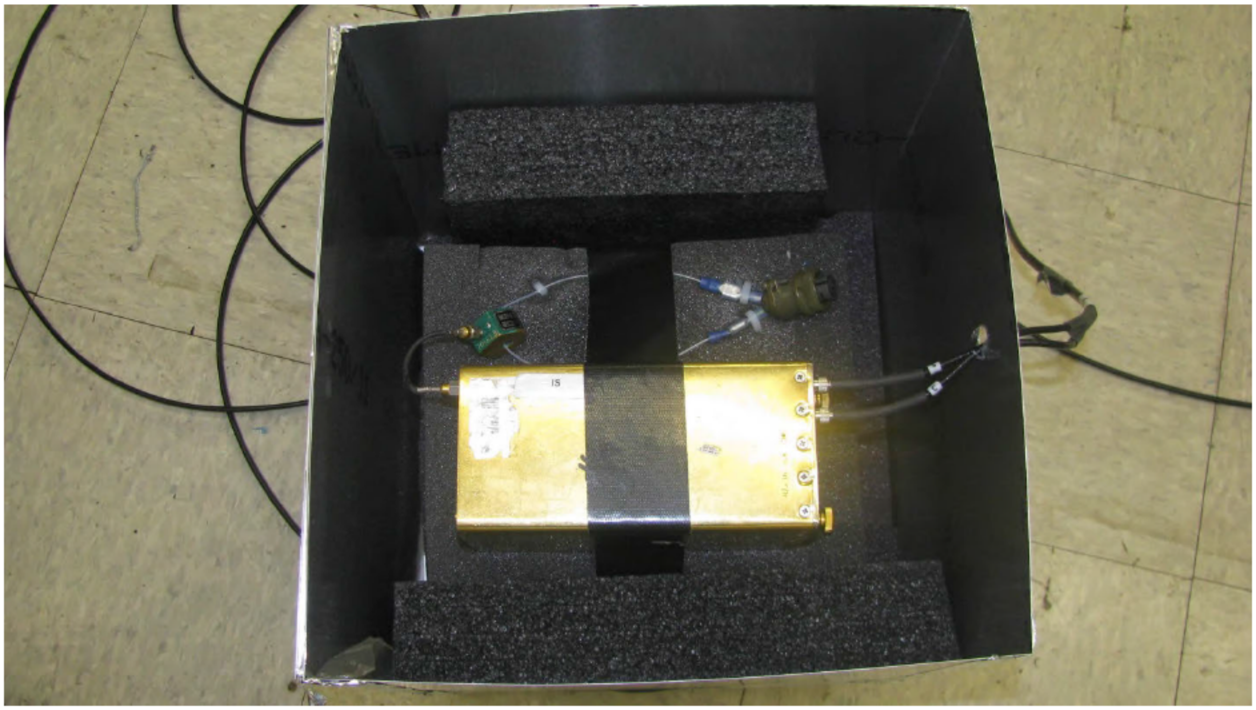


Figure 1: Inert bridgewire test setup

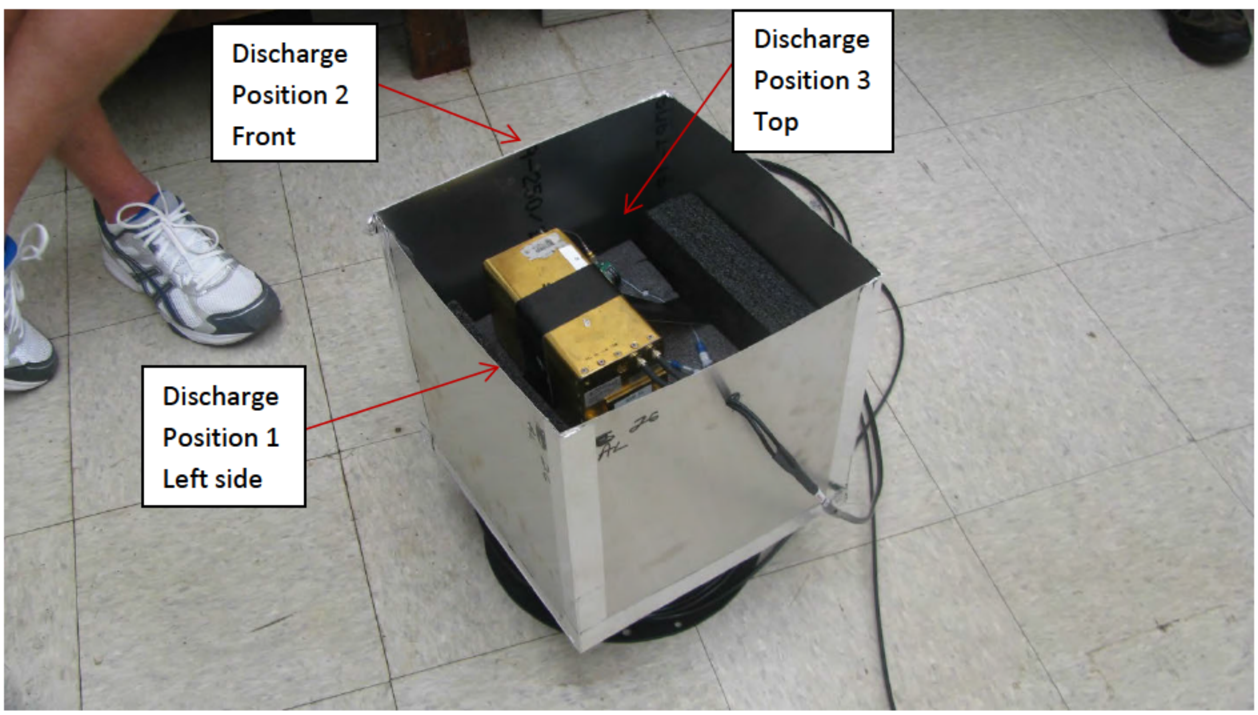



Figure 2: Inert bridgewire test setup discharge locations

Faraday Cage Test Plan Requirements:

A. Measure the output from VERTREP HESD test equipment discharged to an inert bridgewire in a 304 stainless steel box constructed of 0.016 inch metal using the Nanofast fiber optic instrumentation system and Pearson current transformer (possibly several models). Are the captured waveforms from the current transformers less than 10 milliamps? Are the captured waveforms repeatable using the same test setup?

B. Measure the output from VERTREP HESD test equipment discharged to an inert bridgewire in a C260 cartridge brass box constructed of 0.016 inch metal using the Nanofast instrumentation system and Pearson current transformer (possibly several models). Are the captured waveforms from the current transformers less than 10 milliamps? Are the captured waveforms repeatable using the same test setup?

C. Measure the output from VERTREP HESD test equipment discharged to an inert bridgewire in a T-6061aluminum box constructed of 0.016 inch metal using the Nanofast instrumentation system and Pearson current transformer (possibly several models). Are the captured waveforms from the current transformers less than 10 milliamps? Are the captured waveforms repeatable using the same test setup?

D. Measure the output from VERTREP HESD test equipment discharged to an inert bridgewire in a 304 stainless steel box constructed of 0.040 inch metal using the Nanofast instrumentation system and Pearson current transformer (possibly several models). Are the captured waveforms from the current transformers less than 10 milliamps? Are the captured waveforms repeatable using the same test setup?

E. Measure the output from VERTREP HESD test equipment discharged to an inert bridgewire in a T-6061aluminum box constructed of 0.040 inch metal using the Nanofast instrumentation system and Pearson current transformer (possibly several models). Are the captured waveforms from the current transformers less than 10 milliamps? Are the captured waveforms repeatable using the same test setup?

Validation Test Requirement 1 Procedure:
A. A box was constructed of 12 inch by 12 inch panels of 0.016 inch 304 stainless steel. The box was lined with foam for the bottom and sides, and an inert bridgewire with a 1 ohm resistance was placed on the foam in the box. A Pearson Electronics current transformer (several different models used) was cabled to the Nanofast Instrumentation system for measuring the output current. The VERTREP equipment was set up with the toroid (output from the capacitor bank) on top of a 4 foot tall PVC cage. The toroid was approximately 4 feet above the ground. The capacitor bank was charged to approximately 300 kV (6 capacitors in a series configuration). The ground probe was moved to the test point rapidly to generate the discharge from the capacitor bank. Approximate probe speed was 4 feet per second. See Figure 3 for a picture of the 0.016 inch 304 stainless steel test setup.

B. A box was constructed of 12 inch by 12 inch panels of 0.016 inch C260 cartridge brass. The box was lined with foam for the bottom and sides, and an inert bridgewire with a 1 ohm resistance was placed on the foam in the box. A Pearson Electronics current transformer (several different models used) was cabled to the Nanofast Instrumentation system for measuring the output current. The VERTREP equipment was set up with the toroid (output from the capacitor bank) on top of a 4 foot tall PVC cage. The toroid was approximately 4 feet above the ground. The capacitor bank was charged to approximately 300 kV (6 capacitors in a series configuration). The ground probe was moved to the test point rapidly to generate the discharge from the capacitor bank. Approximate probe speed was 4 feet per second. See Figure 4 for a picture of the 0.016 inch C260 cartridge brass test setup.

C. A box was constructed of 12 inch by 12 inch panels of 0.016 inch T-6061 aluminum. The box was lined with foam for the bottom and sides, and an inert bridgewire with a 1 ohm resistance was placed on the foam in the box. A Pearson Electronics current transformer (several different models used) was cabled to the Nanofast Instrumentation system for measuring the output current. The VERTREP equipment was set up with the toroid (output from the capacitor bank) on top of a 4 foot tall PVC cage. The toroid was approximately 4 feet above the ground. The capacitor bank was charged to approximately 300 kV (6 capacitors in a series configuration). The ground probe was moved to the test point rapidly to generate the discharge from the capacitor bank. Approximate probe speed was 4 feet per second. See Figure 5 for a picture of the 0.016 inch T-6061 aluminum test setup.

D. A box was constructed of 12 inch by 12 inch panels of 0.40 inch 304 stainless steel. The box was lined with foam for the bottom and sides, and an inert bridgewire with a 1 ohm resistance was placed on the foam in the box. A Pearson Electronics current transformer (several different models used) was cabled to the Nanofast Instrumentation system for measuring the output current. The VERTREP equipment was set up with the toroid (output from the capacitor bank) on top of a 4 foot tall PVC cage. The toroid was approximately 4 feet above the ground. The capacitor bank was charged to approximately 300 kV (6 capacitors in a series configuration). The ground probe was moved to the test point rapidly to generate the discharge from the capacitor bank. Approximate probe speed was 4 feet per second. See Figure 6 for a picture of the 0.040 inch 304 stainless steel test setup.

E. A box was constructed of 12 inch by 12 inch panels of 0.040 inch T-6061 aluminum. The box was lined with foam for the bottom and sides, and an inert bridgewire with a 1 ohm resistance was placed on the foam in the box. A Pearson Electronics current transformer (several different models used) was cabled to the Nanofast Instrumentation system for measuring the output current. The 300 kV ESD equipment was set up with the toroid (output from the capacitor bank) on top of a 4 foot tall PVC cage. The toroid was approximately 4 feet above the ground. The capacitor bank was charged to approximately 300 kV (6 capacitors in a series configuration). The ground probe was moved to the test point rapidly to generate the discharge from the capacitor bank. Approximate probe speed was 4 feet per second. See Figure 7 for a picture of the 0.040 inch T-6061 aluminum test setup.

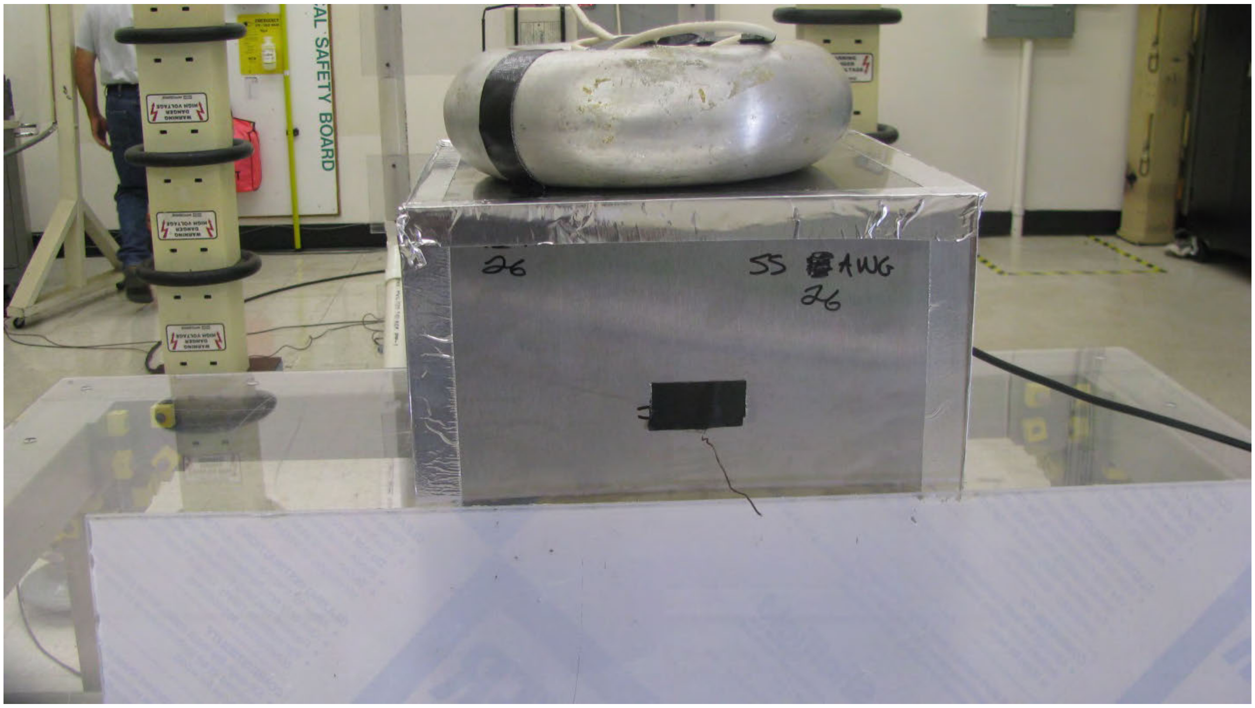



Figure 3: 0.016 inch 304 Stainless Steel test equipment setup

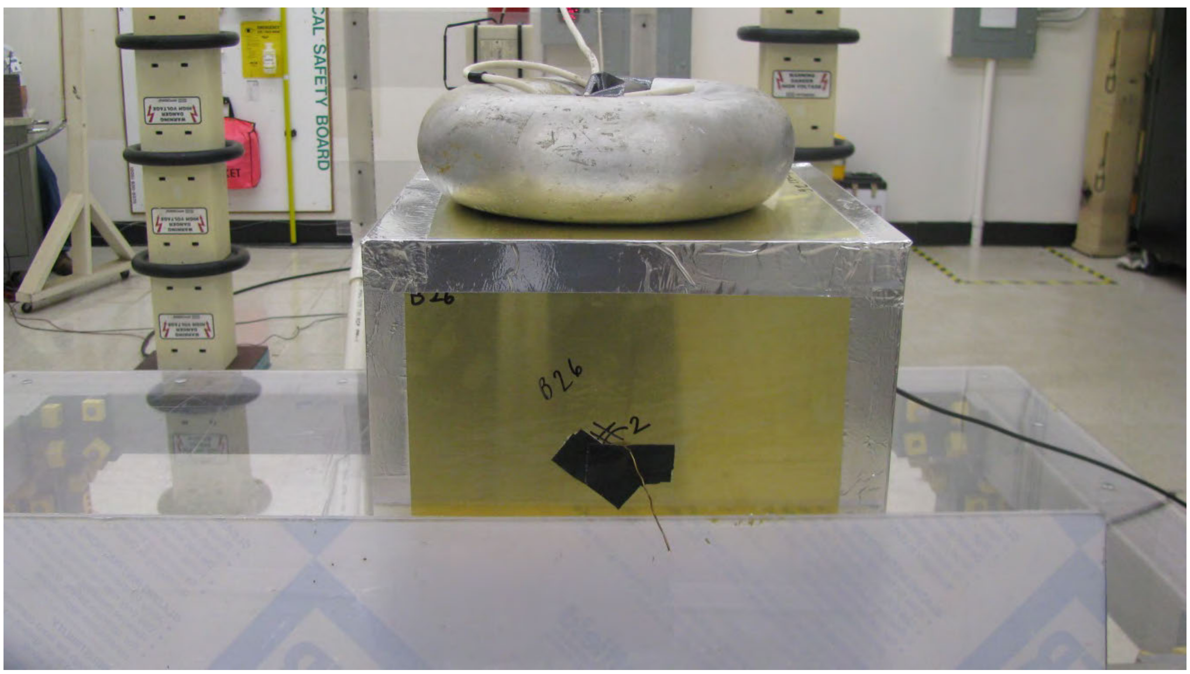



Figure 4: 0.016 inch C260 Cartridge Brass test equipment setup

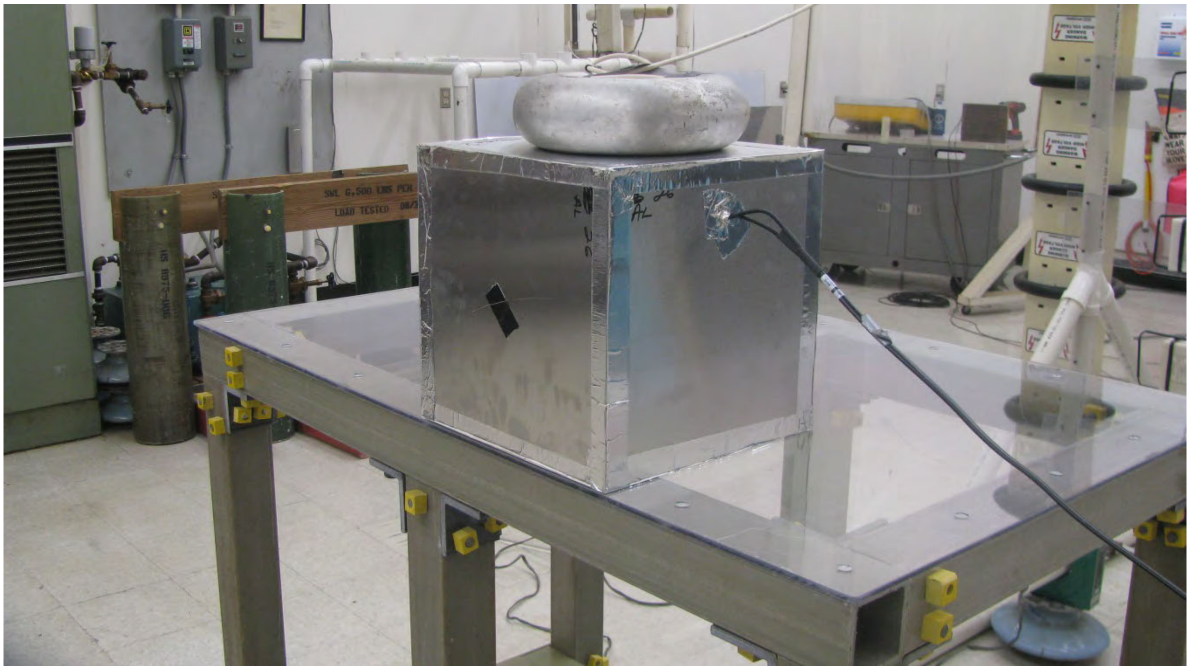


Figure 5: 0.016 inch T-6061 Aluminum test equipment setup

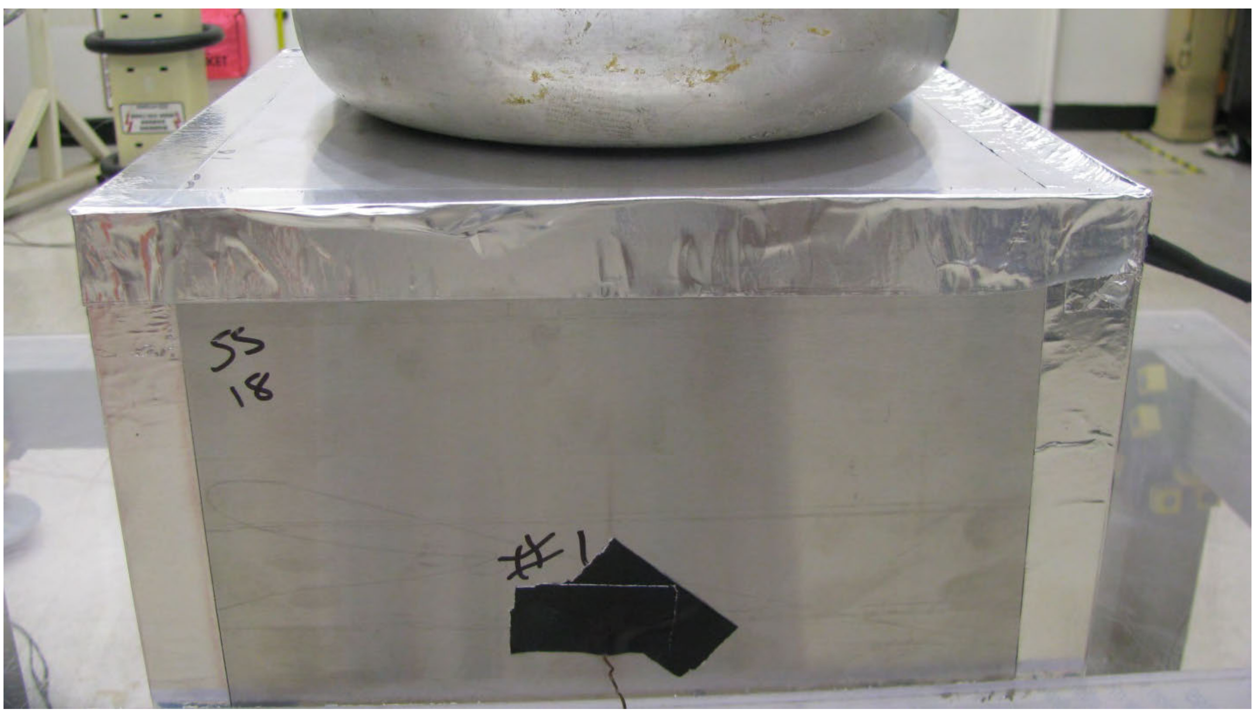



Figure 6: 0.040 inch 304 Stainless Steel test equipment setup

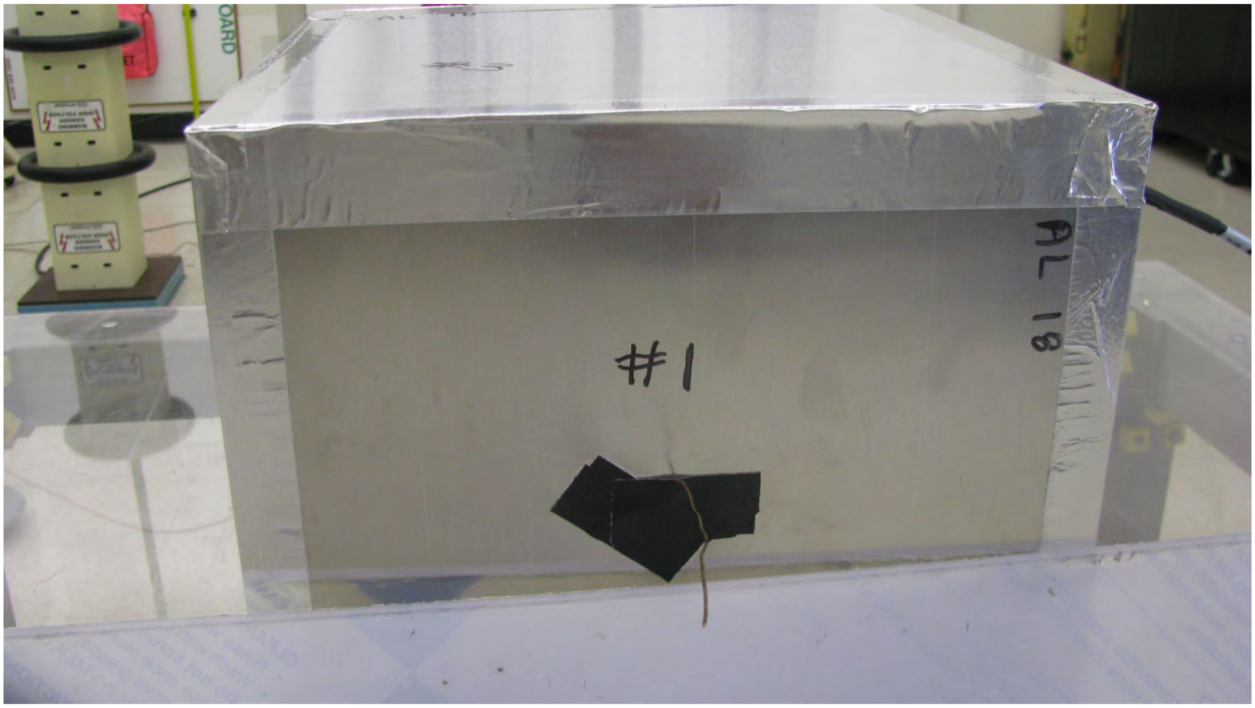



Figure 7: 0.040 inch T-6061 Aluminum test equipment setup

Faraday Cage Test Requirement 1 Results:

A. The data from the bridgewire in the 0.016 inch 304 stainless steel box indicates some differences in the energy measured depending on the discharge position. The 304 stainless steel also indicated a current waveform in the measured data that appeared to mimic the damped sinusoid of the discharge waveform. See Figure 8 for a typical measured bridgewire current for Discharge Position 1 on the side of the box. See Figure 9 for a typical measured bridgewire current for Discharge Position 2 on the front of the box. See Figure 10 for a typical measured bridgewire current for Discharge Position 3 on the top of the box. Salients were used to direct the discharge to each test point.

B. The data from the bridgewire in the 0.016 inch C260 cartridge brass box indicates no energy measured regardless of the discharge position. See Figure 11 for a typical measured bridgewire current for Discharge Position 1 on the side of the box. See Figure 12 for a typical measured bridgewire current for Discharge Position 2 on the front of the box. See Figure 13 for a typical measured bridgewire current for Discharge Position 3 on the top of the box. Salients were used to direct the discharge to each test point.

C. The data from the bridgewire in the 0.016 inch T-6061 aluminum box was consistent independent of the discharge position. The T-6061 aluminum data also shows a very narrow current peak in the measured data that appears to be induced from the discharge waveform. See Figure 14 for a typical measured bridgewire current for Discharge Position 1 on the side of the box. See Figure 15 for a typical measured bridgewire current for Discharge Position 2 on the front of the box. See Figure 16 for a typical measured bridgewire current for Discharge Position 3 on the top of the box. Salients were used to direct the discharge to each test point.

D. The data from the bridgewire in the 0.040 inch 304 stainless steel box indicates some differences in the peak energy measured depending on the discharge position. The 304 stainless also indicated a current waveform in the measured data that appeared to mimic the damped sinusoid of the discharge waveform. See Figure 17 for a typical measured bridgewire current for Discharge Position 1 on the side of the box. See Figure 18 for a typical measured bridgewire current for Discharge Position 2 on the front of the box. See Figure 19 for a typical measured bridgewire current for Discharge Position 3 on the top of the box. Salients were used to direct the discharge to each test point.

E. The data from the bridgewire in the 0.040 inch T-6061 aluminum box was consistent independent of the discharge position. The T-6061 aluminum data also shows a very narrow current peak in the measured data that appears to be induced from the discharge waveform. See Figure 20 for a typical measured bridgewire current for Discharge Position 1 on the side of the box. See Figure 21 for a typical measured bridgewire current for Discharge Position 2 on the front of the box. See Figure 22 for a typical measured bridgewire current for Discharge Position 3 on the top of the box. Salients were used to direct the discharge to each test point.

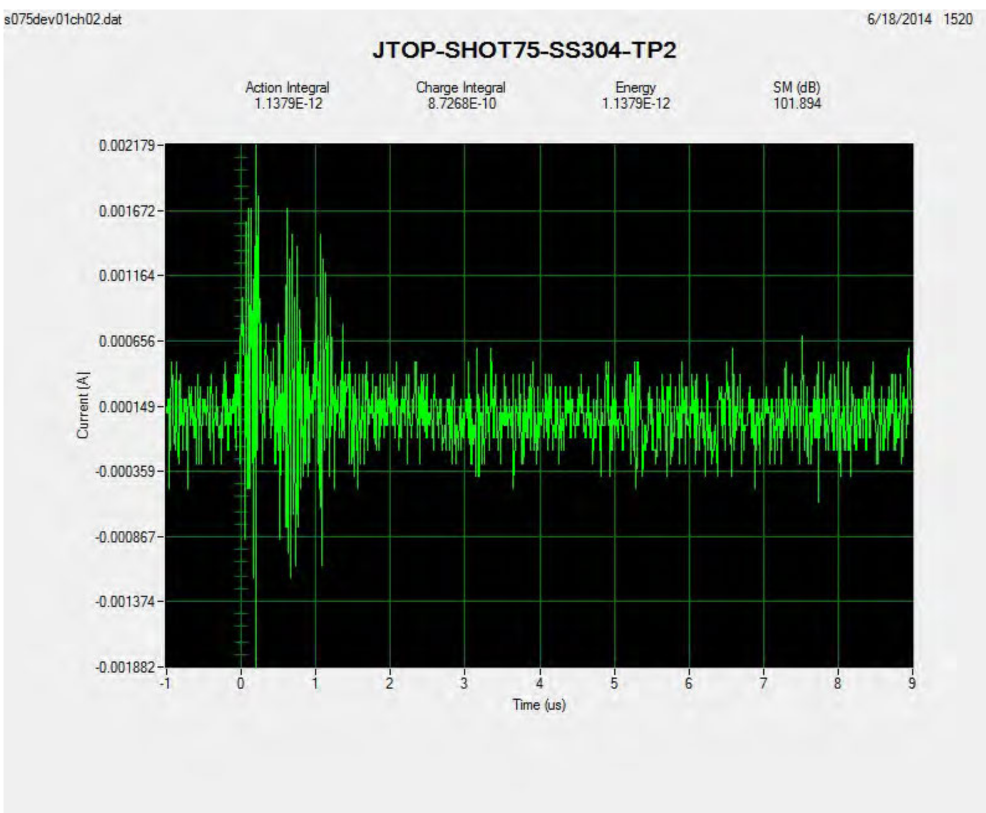



Figure 8: 304 Stainless Steel (0.016) Discharge Position 1 bridgewire current

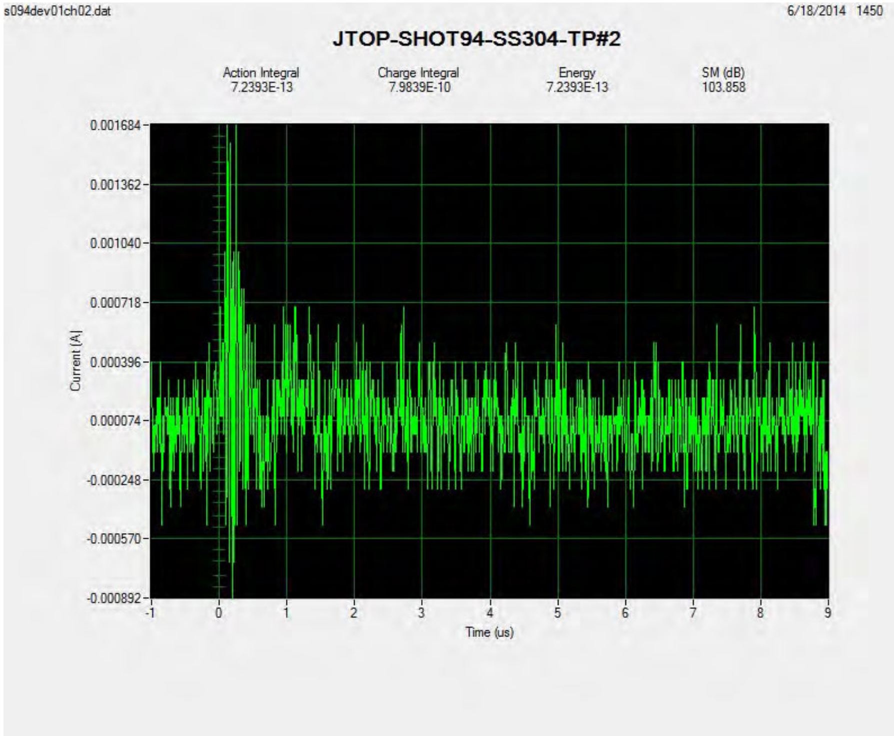



Figure 9: 304 Stainless Steel (0.016) Discharge Position 2 bridgewire current

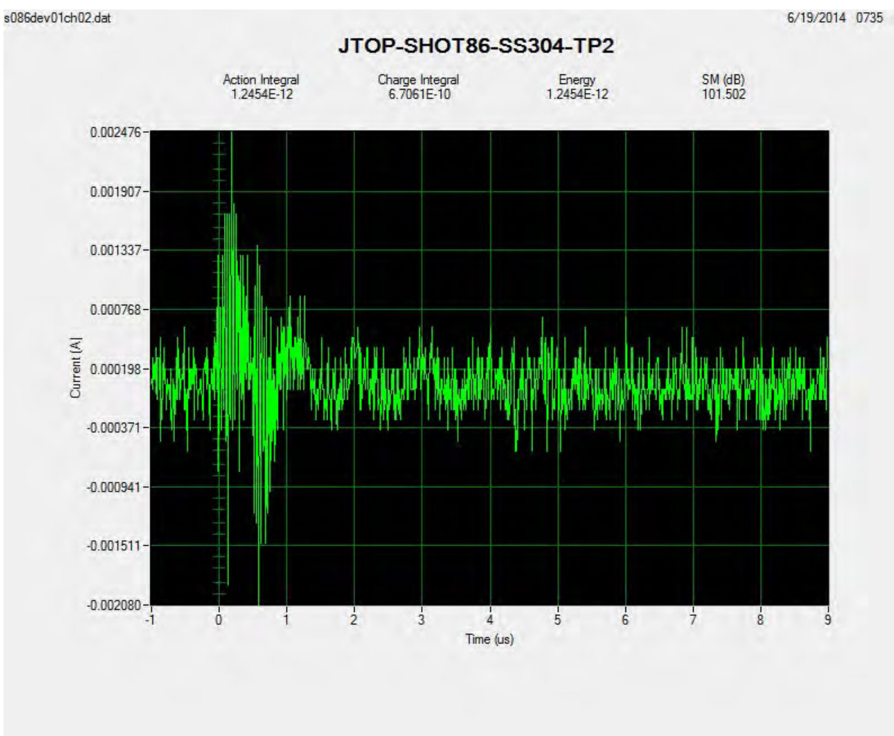



Figure 10: 304 Stainless Steel (0.016) Discharge Position 3 bridgewire current

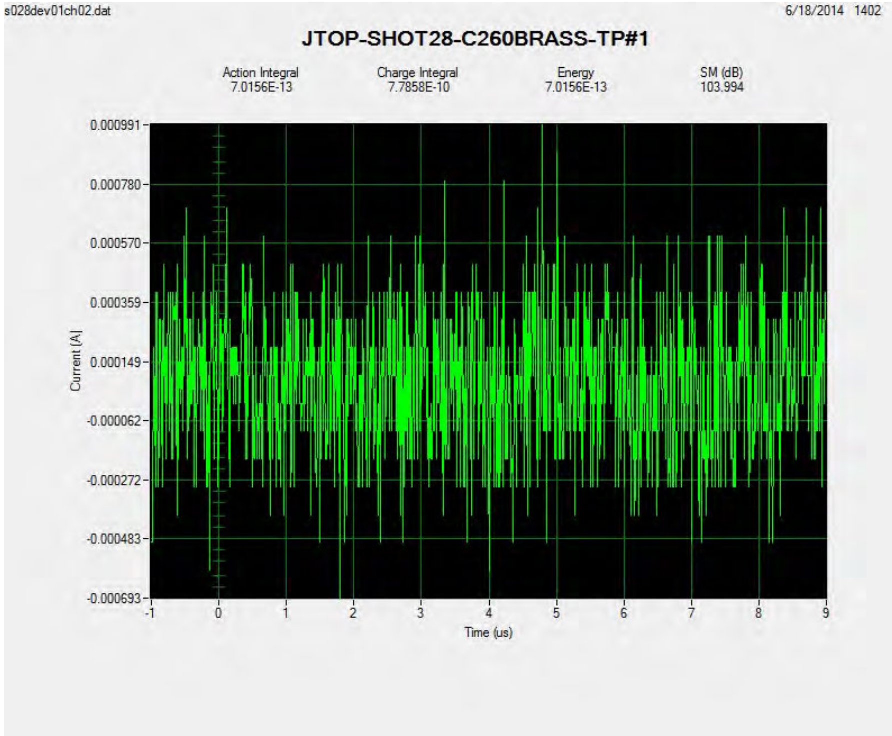



Figure 11: C260 (0.016) Discharge Position 1 bridgewire current

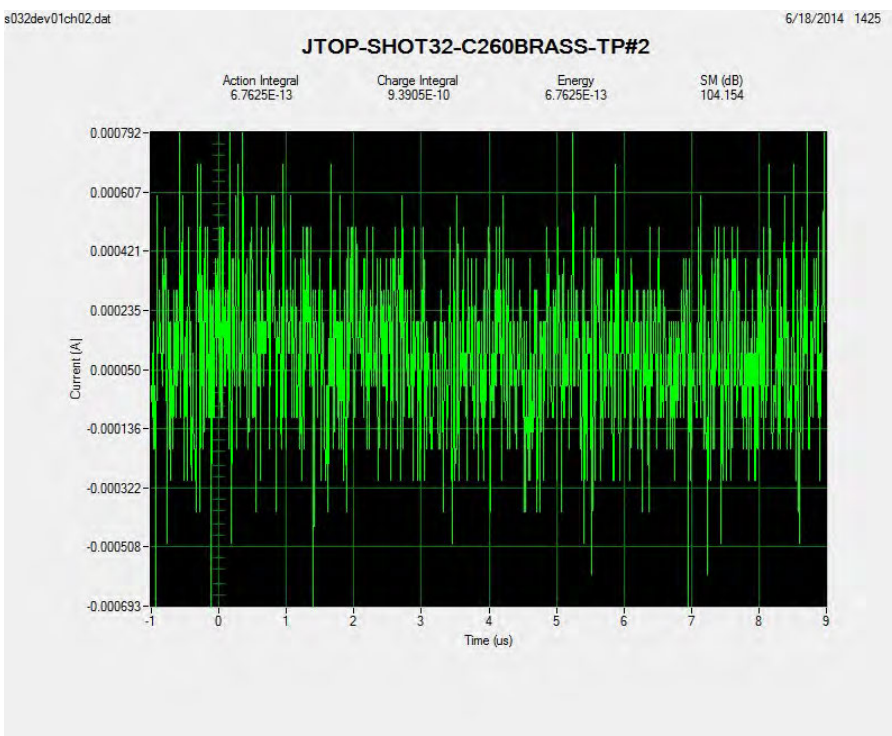



Figure 12: C260 (0.016) Discharge Position 2 bridgewire current

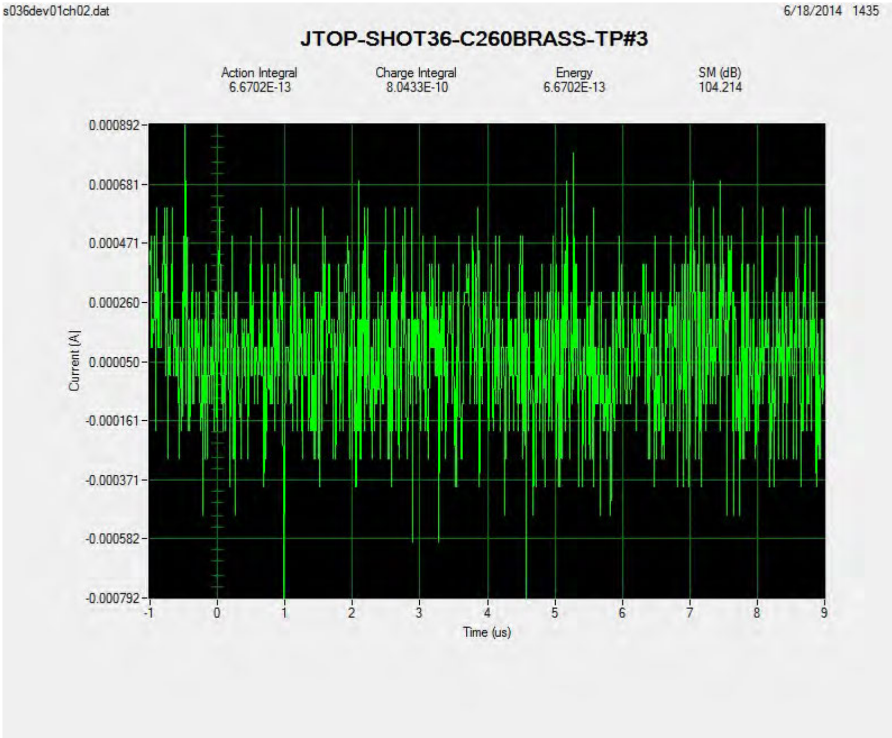



Figure 13: C260 (0.016) Discharge Position 3 bridgewire current

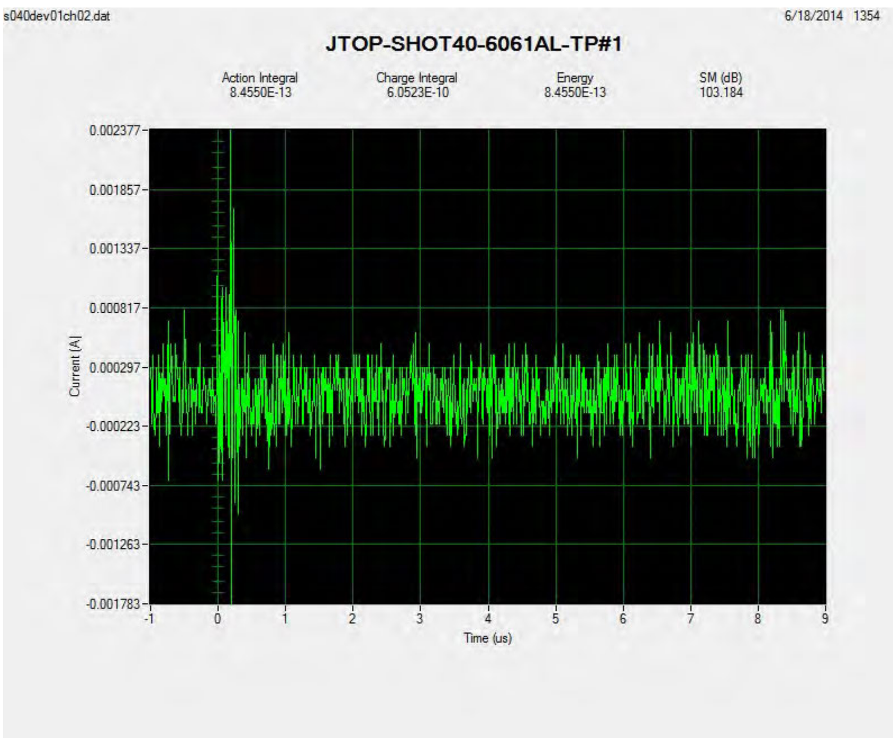



Figure 14: T-6061 (0.016) Discharge Position 1 bridgewire current

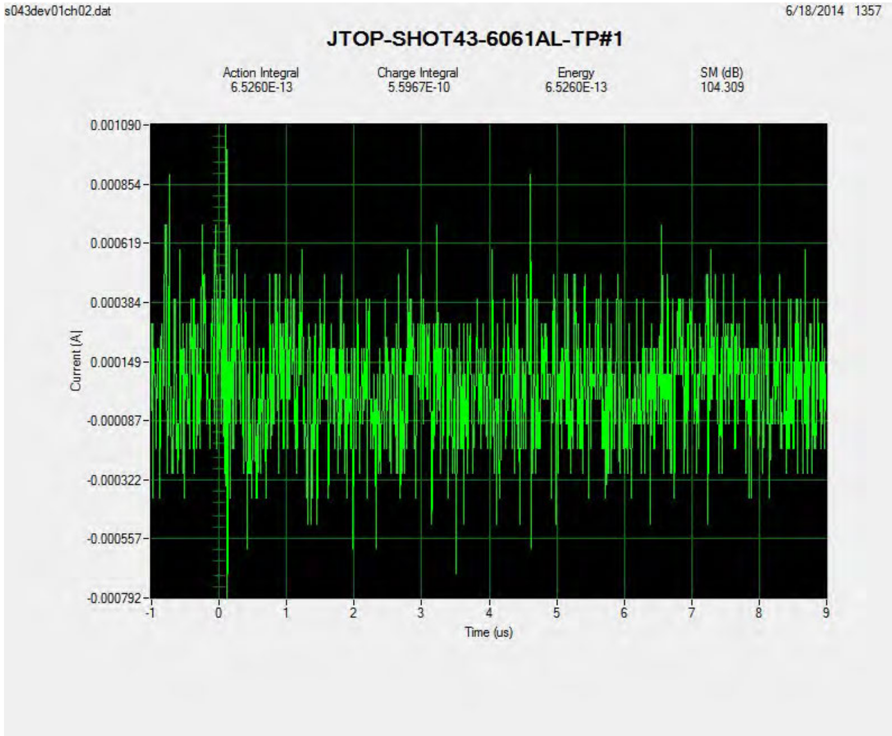



Figure 15: T-6061 (0.016) Discharge Position 2 bridgewire current

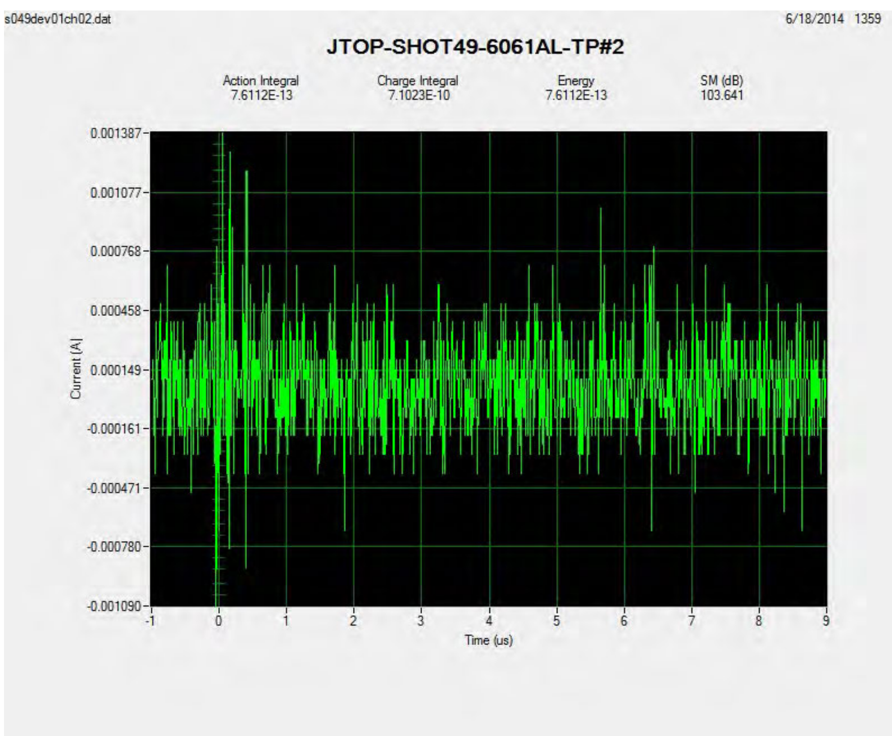



Figure 16: T-6061 (0.016) Discharge Position 3 bridgewire current

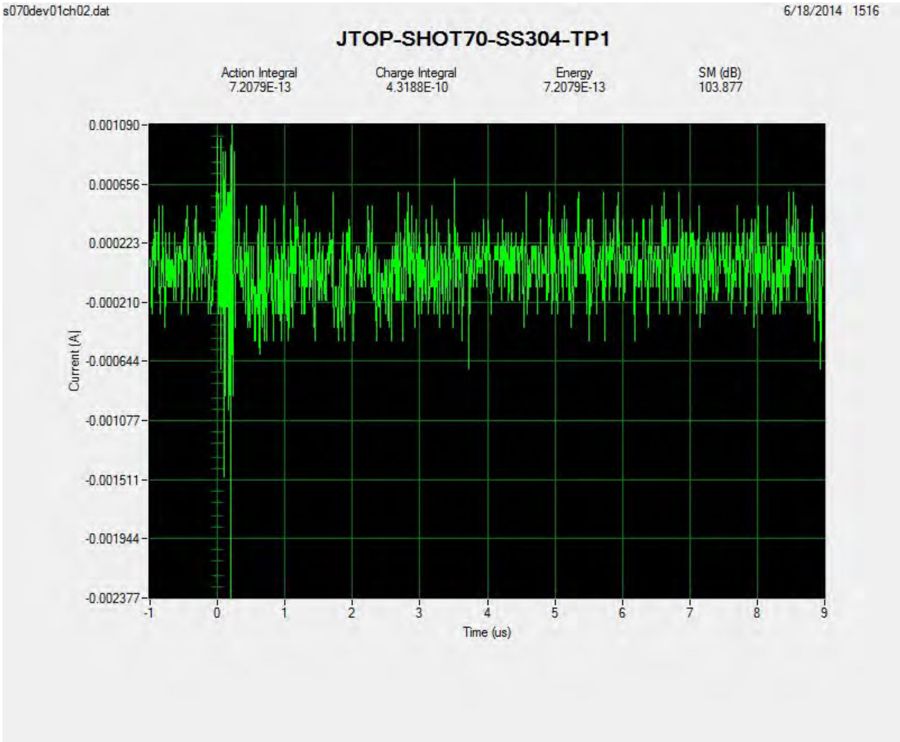



Figure 17: 304 Stainless Steel (0.040) Discharge Position 1 bridgewire current

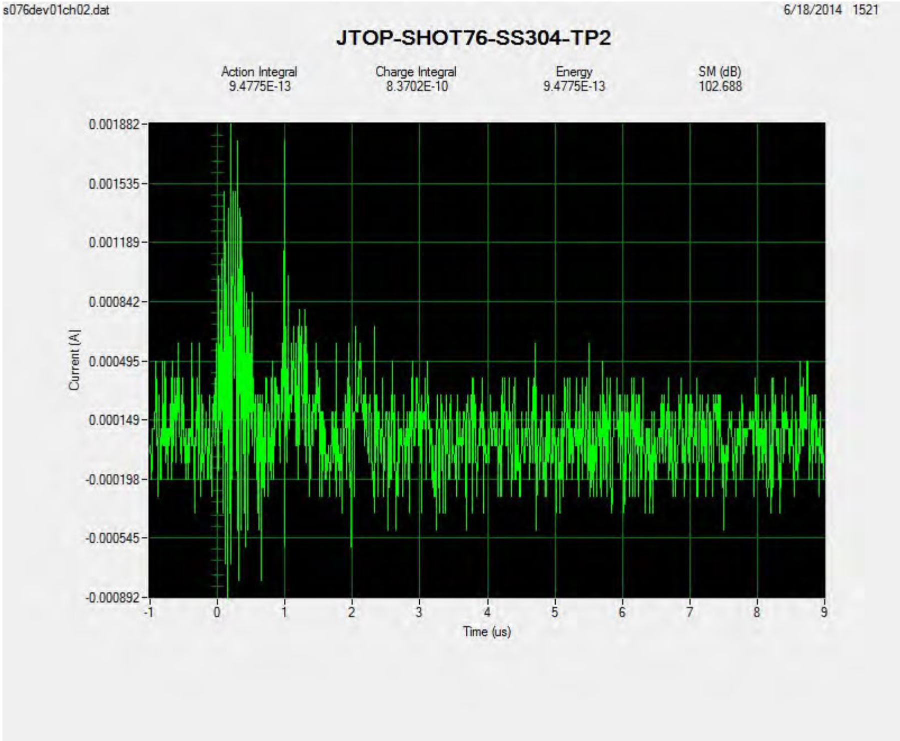



Figure 18: 304 Stainless Steel (0.040) Discharge Position 2 bridgewire current

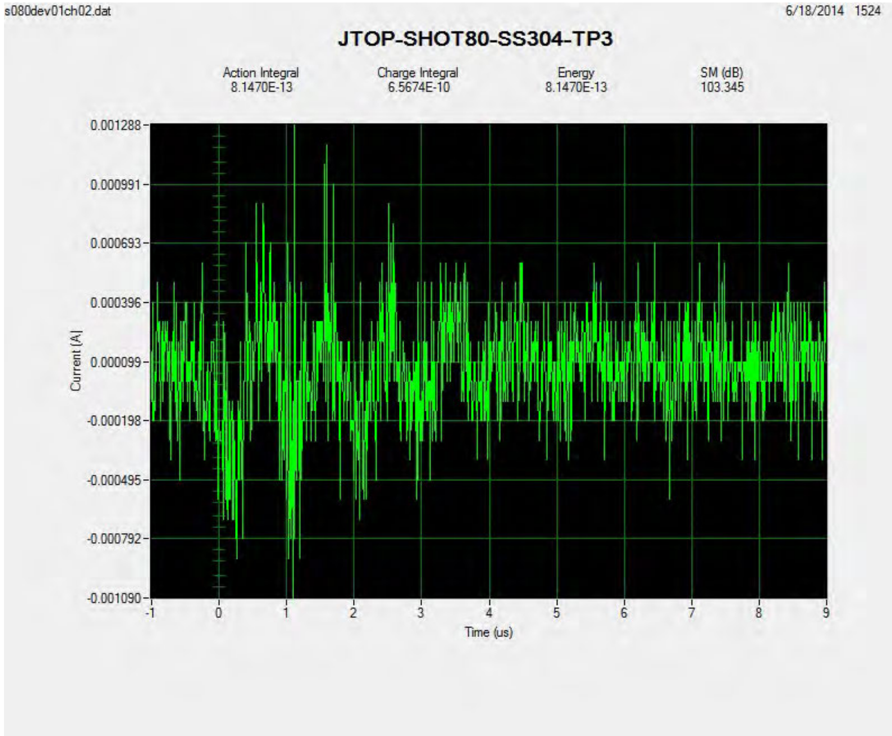



Figure 19: 304 Stainless Steel (0.040)  Discharge Position 3 bridgewire current

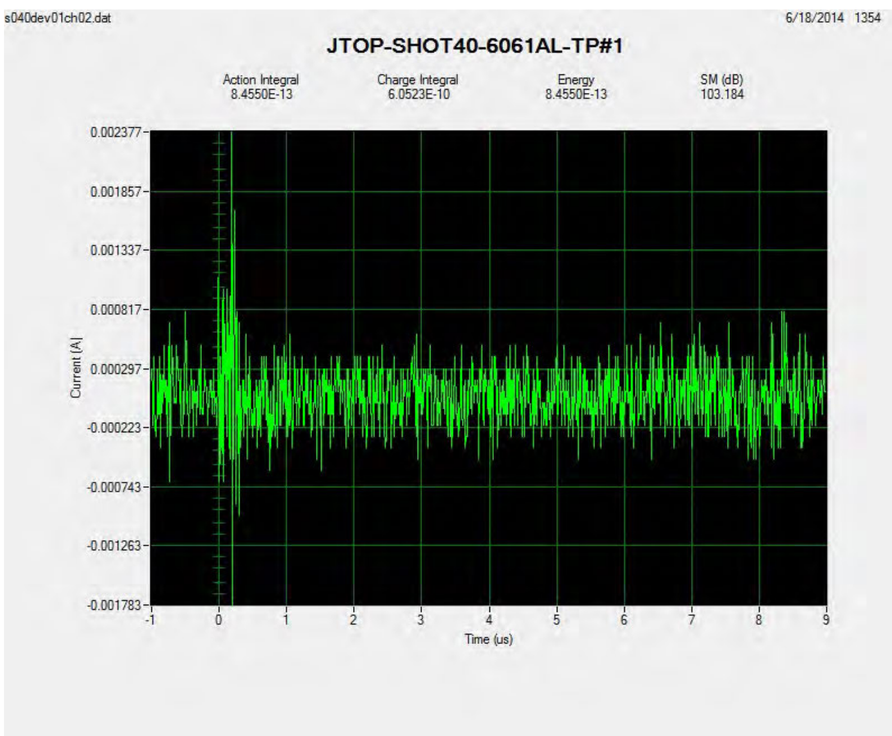



Figure 20: T-6061 (0.040) Discharge Position 1 bridgewire current

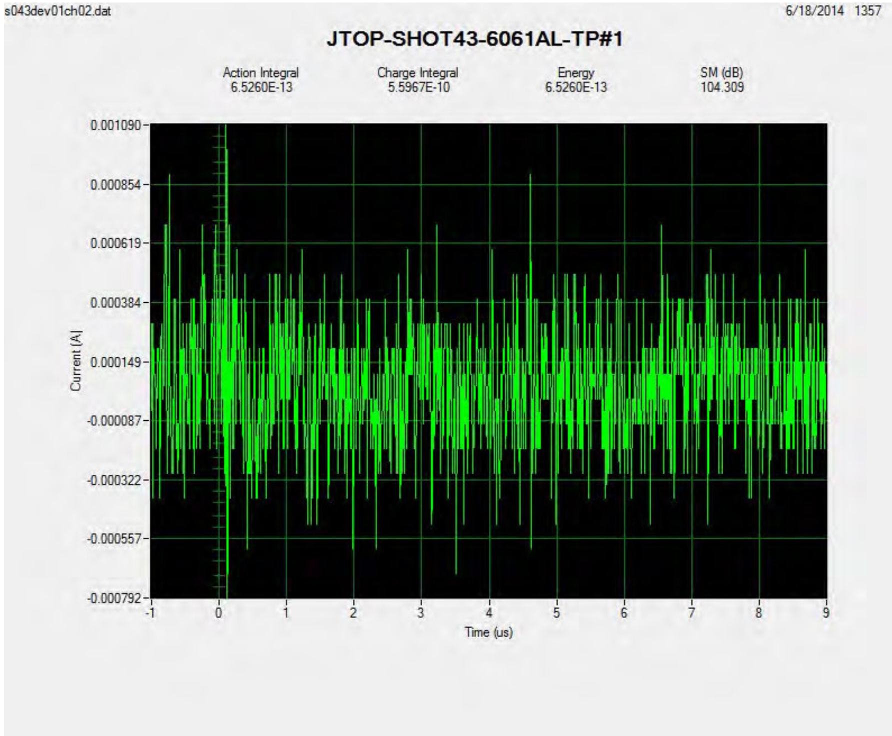



Figure 21: T-6061 (0.040) Discharge Position 2 bridgewire current

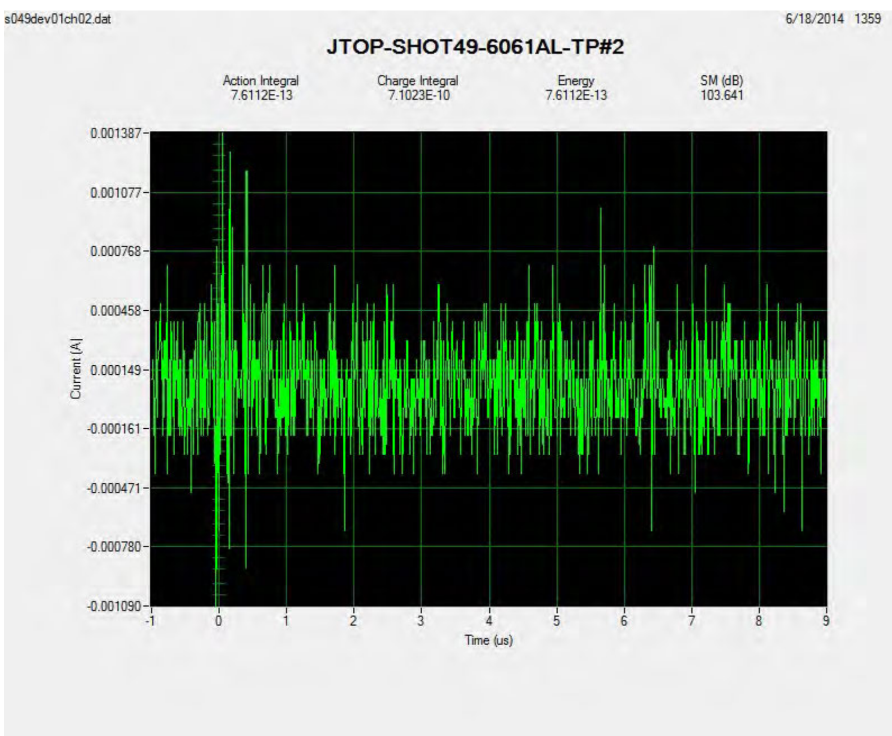



Figure 22: T-6061 (0.040) Discharge Position 3 bridgewire current

Faraday Cage Test Requirement 1 Results Discussion:
There were some common results and some distinct differences in the measured data inside the containers for each of the metals.

None of the metals experienced any melting/burn through or damage from repeated 300 kV ESD discharges to the same location in either of the thicknesses chosen for testing.
The measured energy from the inert electrically initiated device for each of the metal thicknesses evaluated was always in the picojoule range, which is well below a level that could initiate an electrically initiated ordnance device. It should be noted that the amplitude scale is not identical on each of the data plots since the scope was set for autoscaling.

The measured data from the inert electrically initiated device in the 304 Stainless Steel box clearly showed the damped sinusoid waveform from the ESD discharge. A typical 300 kV ESD calibration waveform is shown in Figure 23. The current peak average was approximately 2.5 milliamps after subtracting the noise level, with the duration less than 0.20 microseconds.

The measured data from the inert electrically initiated device in the C260 cartridge brass box was essentially the measurement system noise only in all test orientations.

The measured data from the inert electrically initiated device in the T-6061 aluminum box clearly showed a current peak slightly above the measurement noise level, but no clear indication of the damped sinusoid waveform from the ESD discharge.


Figure 23: Marx calibration discharge

To further evaluate the stainless steel effects, additional testing was performed using the inert instrumented bridgewire from the earlier testing inside a 30 MM M592 ammunition container that is constructed of 12 gauge 304 stainless steel. The test setup is shown in Figure 24, and the testing used the same 3 discharge positions as the previous testing (left side, front, and top). See Figure 25 for a typical measured bridgewire current for Discharge Position 1 on the side of the box. See Figure 26 for a typical measured bridgewire current for Discharge Position 2 on the front of the box. The waveform data from the M592 was similar to the test results measured in the 0.016 and 0.040 inch stainless boxes. Salients were used to direct the discharges to the test points.

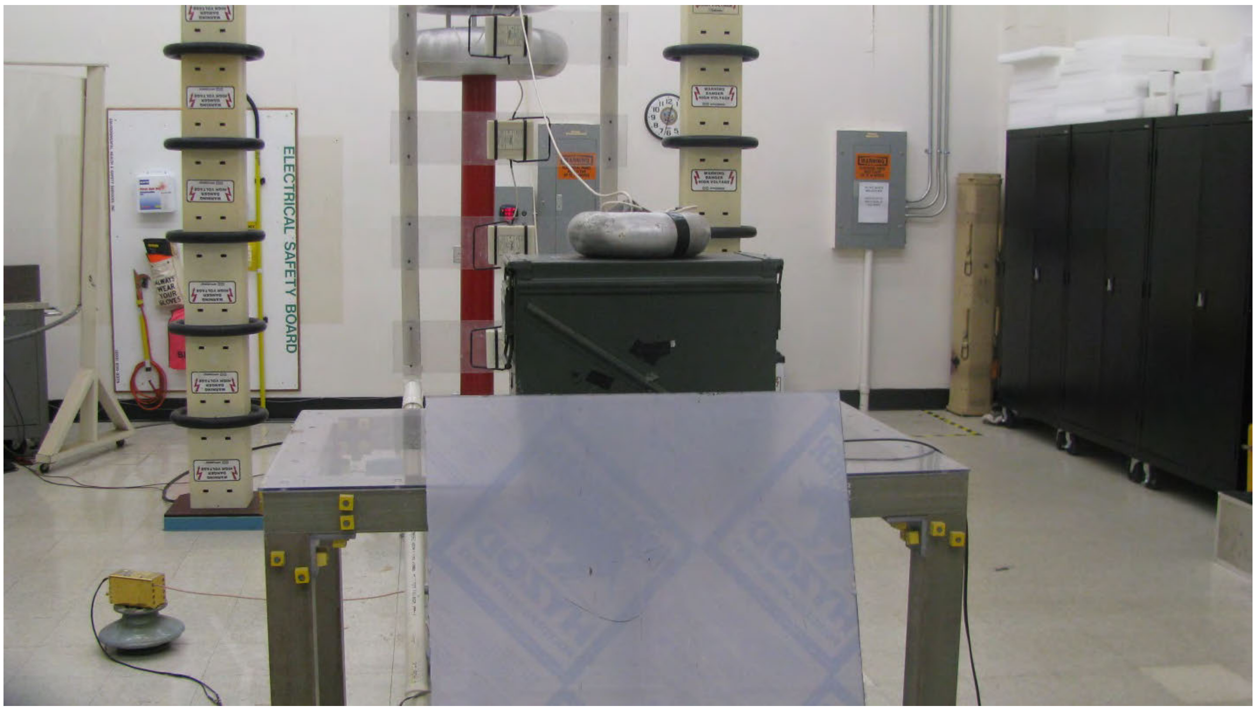



Figure 24: M592 ammunition container test setup

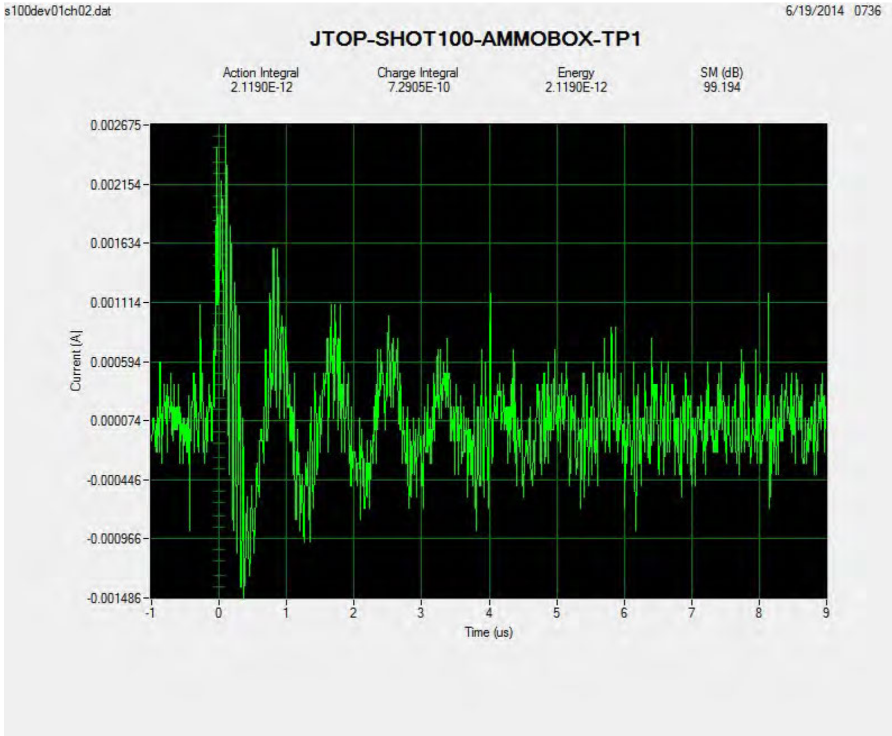



Figure 25: M592 Discharge Position 1 bridgewire current

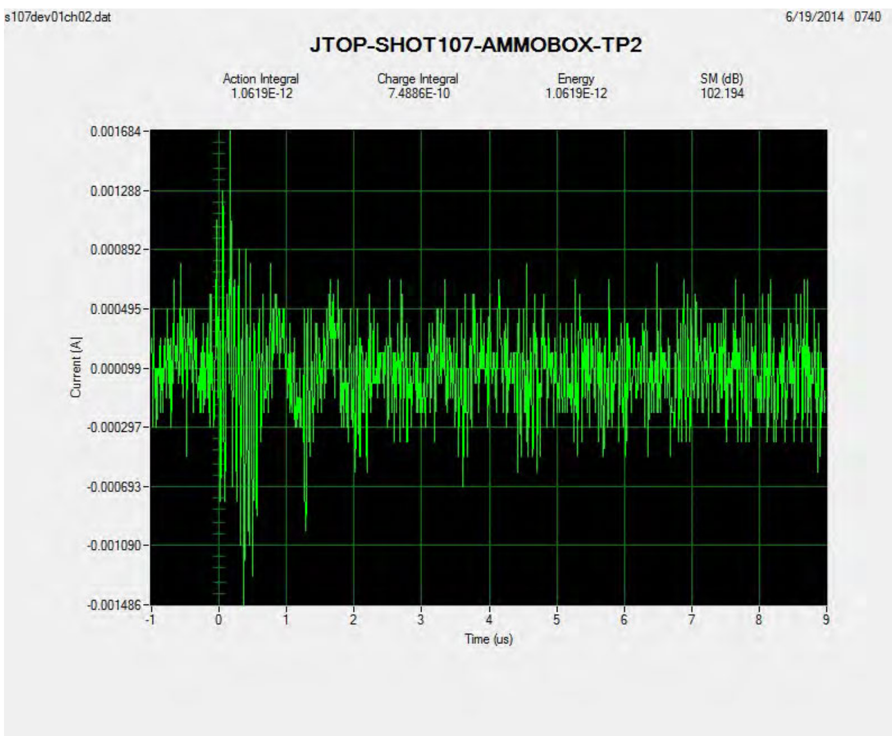



Figure 26: M592 Discharge Position 2 bridgewire current

**5.0 Conclusions:**

**Requirement 1:** Determine minimum thickness of metal to provide “Faraday cage” protection to electrically initiated ordnance items in metal containers for 300 kV ESD exposure.

The initial “baseline” for determining whether the container provided Faraday cage protection was chosen as 10 milliamps to meet the no-fire current requirement for an igniter circuit tester used to measure bridgewire resistance in live ordnance items. The measurements recorded using the inert bridgewire in all of the container materials used for the 300 kV ESD testing were significantly below this threshold, and were also not steady state currents, but were very short duration peaks in some of the materials.

Although the results for all the materials were below the 10 milliamp “safety” threshold discussed above, there were noticeable differences in the data from each material. The C260 cartridge brass container bridgewire measurements did not indicate any current peaks above the noise level in any discharge position. This indicates the high copper content of the C260 brass provides excellent shielding from any electrical energy. The T-6061aluminum container bridgewire measurements, in both the 0.016 and the 0.040 inch thicknesses, clearly showed a current spike from the ESD discharge, but the spike was a single positive to negative spike that was about twice the amplitude of the background noise level. This translates to peak currents of about 2 milliamps with a duration of approximately 0.2 microseconds. The energy levels were always in the low picojoule range. The SS304 stainless steel container bridgewire measurements, in both the 0.016 and the 0.040 inch thicknesses, clearly showed a current spike from the ESD discharge, but the spike was a repetitive damped sinusoid with multiple positive to negative transitions that was several times the amplitude of the background noise level. This translates to peak currents of about 2.5 milliamps with a duration of approximately 2 to 4 microseconds. The energy levels were again always in the low picojoule range.

All three materials provided adequate shielding to the 1 ohm bridgewire from the 300 kV ESD discharge to alleviate any safety concerns, with the enclosed data plots clearly showing 100 dB safety margins for all the materials and measurements.

**Requirement 2:** Determine metal thickness required for multiple discharges (more than the two discharges required in MIL STD 331CC for HESD exposure) to the same location for bare percussion initiated devices to prevent burn-through/melting/visible damage during HESD exposure.

**Requirement 3:** Evaluate different types of metals to determine if the same metal minimum thickness for each metal would prevent burn-through/melting/visible damage for HESD exposure.

None of the materials or thicknesses tested showed any signs of melting, burn through, or visible damage after being subjected to multiple discharges at the same test point. The 0.016 inch thick material meets the Faraday cage definition for melting, burn through, or visible damage for all the materials tested.

**6.0 Recommendations:**

1. Use a minimum 0.016 inch thick metal as the Faraday cage requirement in the JOTP for Faraday cage protection for shipping containers containing electrically initiated devices.

2. Use a minimum 0.016 inch thick metal as the Faraday cage requirement in the JOTP for Faraday cage protection for bare percussion initiated ordnance items.

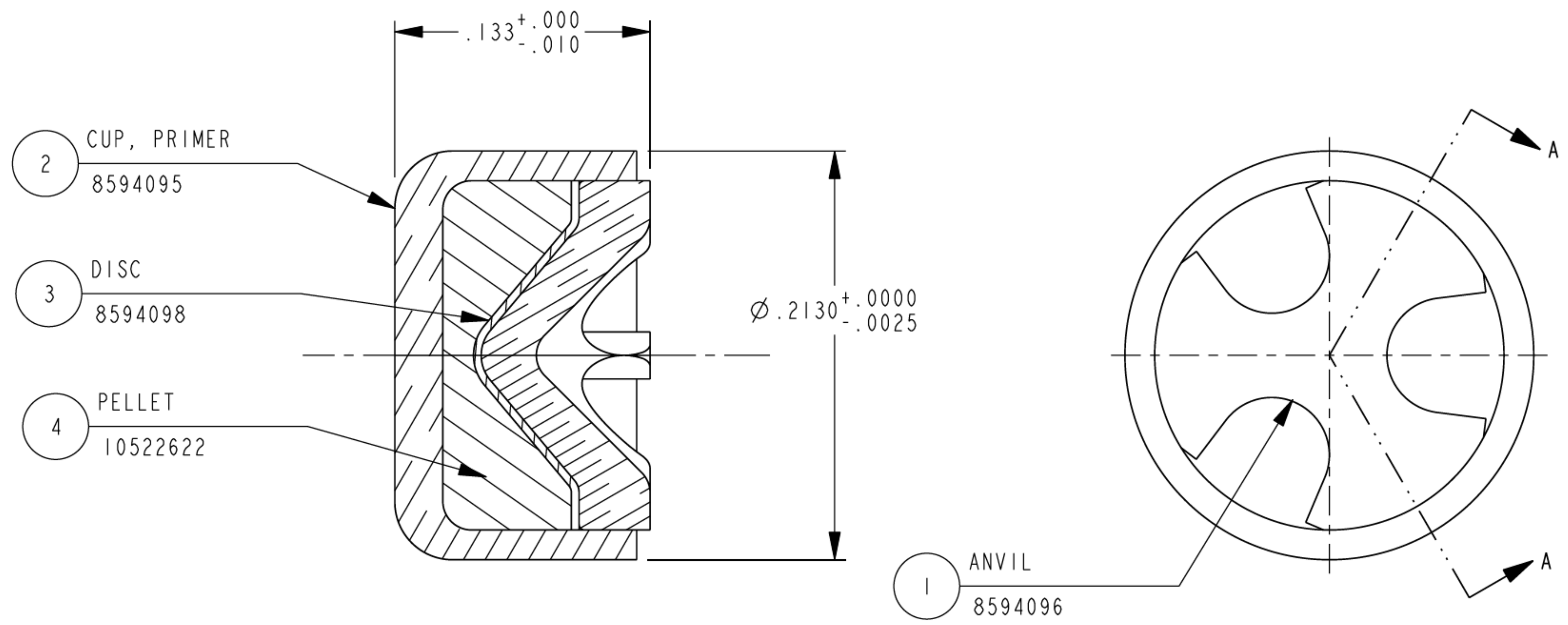
3. Add a requirement in the JOTP for providing device drawings identifying the materials and thicknesses for percussion items and shipping containers for ordnance items in the ESD report.

# Appendix A

# Cartridge Drawings

| REVISIONS | | | | |
|---|---|---|---|---|
| MODEL REV | DRAW REV | DESCRIPTION | DATE(YEAR-MO-DA) | APPROVED |
| - | U | REDRAWN WITH CHANGE NOR R07S3063 / 2008-08-14 | 2008-09-08 | RLV |

| PART NUMBER | CARTRIDGE | DRAWING NO. |
|---|---|---|
| 10522621-1 | CRTG, 7.62MM NATO, BALL, M59 | 7553702 |
| | CRTG, 7.62MM NATO, AP, M61 | 7553704 |
| | CRTG, 7.62MM NATO, BALL, M80 | 10521998 |
| | CRTG, 7.62MM NATO, TRACER, M62 | 10522000 |
| | CRTG, 7.62MM NATO, BALL, M80, OVHD F APPL | 10523088 |
| | CRTG, 7.62MM NATO, TRACER, M62, OVHD F APPL | 10535493 |
| | CRTG, 7.62MM: DIM TRACER, M276 | 10542714 |
| 10522621-2 | CRTG, 7.62MM NATO, BLANK, M82 | 8597283 |
| | CRTG, 7.62MM, BLANK M192 | 10523631 |
| 10522621-3 | CRTG, 7.62MM, NATO, GRENADE, RIFLE, M64 | 7553707 |
| 10522621-4 | CRTG, 7.62MM NATO, T, HP, M60 | 7553703 |
| 10522621-5 | CRTG, 7.62MM REFERENCE | 8596190 |
| 10522621-6 | CRTG, 7.62MM NATO, SPECIAL BALL, M118 | 8597555 |
| 10522621-7 | CRTG, 7.62MM NATO, BALL, FRANGIBLE, M160 | 10522476 |
| 10522621-8 | CRTG, 7.62MM NATO, BALL, DUPLEX, M198 | 10534595 |
| 10522621-9 | CRTG, 7.62 X 39MM, BALL | 11731648 |
| 10522621-10 | CRTG, 7.62 X 39MM, BLANK | 11738731 |
| 10522621-11 | CRTG, CAL .30, TRACER, M1 | 6006764 |
| | CRTG, CAL .30, BALL, M2 | 6137544 |
| | CRTG, CAL .30, BALL, M2, STEEL CASE | 7553431 |
| | CRTG, CAL .30, AP, M2 | 6138194 |
| | CRTG, CAL .30, API, M14 | 7638431 |
| | CRTG, CAL .30, TRACER, M25 | 7640667 |
| | CRTG, CAL .30, TRACER, M25, STEEL CASE | 7553949 |
| | CRTG, CAL .30 BALL, M2, OVHD F APPL | 10542449 |
| | CRTG, CAL .30, AP, M2, STEEL CASE | 8594162 |
| 10522621-12 | CRTG, CAL .30, REFERENCE | 8595416 |
| 10522621-13 | CRTG, CAL .30, BLANK, M1909 | 6006152 |
| 10522621-14 | CRTG, CAL .30, T. HP, M1 | 6016308 |
| 10522621-15 | CRTG, CAL .30, MATCH, M72 | 8595432 |
| 10522621-16 | CRTG, CAL .30, BALL, FRANGIBLE, M22 | 7640951 |
| 10522621-17 | CRTG, CAL .30, RIFLE, GRENADE, M3 | 6173949 |
| 10522621-18 | PRIMER, ARTILLERY, PERCUSSION, M82 | 8861197 |




SECTION A-A

DOD HAZARD CLASSIFICATION: 1.4
DOD STORAGE COMPATIBILITY: B
DEPARTMENT OF TRANSPORTATION (DOT) HAZARD CLASS: C
DOT CONTAINER MARKINGS: SMALL ARMS PRIMERS, "HANDLE CAREFULLY"

| ITEM OR FIND NO. | QTY. REQ. | CAGE CODE | PART NO. OR IDENTIFYING NO. | NOMENCLATURE OR DESCRIPTION | REMARKS |
|---|---|---|---|---|---|
| 4 | 1 | 19200 | 10522622 | PELLET | |
| 3 | 1 | 19200 | 8594098 | DISC | |
| 2 | 1 | 19200 | 8594095 | CUP, PRIMER | |
| 1 | 1 | 19200 | 8594096 | ANVIL | |

NOTES

1. SPEC MIL-A-2550, MIL-P-46610 AND ANSI 14.5M-1983.
2. UNEVENNESS OF ANVIL SEATING PERMITTED, PROVIDED OVERALL HEIGHT OF PRIMER, INCLUDING PROTRUSION OF AN ANVIL LEG, DOES NOT EXCEED .133.
3. A DROP OF SHELLAC (SPEC TT-S-300, TYPE I, GRADE B, BODY 4 OR BODY 1, 9±1% SOLIDS OR JAN-S-732, TYPE II) SHALL BE APPLIED. (A DROP OF LACQUER, SPEC MIL-L-10287, USING ETHYL AGETATE SPEC TT-E-751 AS A THINNER OR LACQUER, SPEC MIL-L-46075 MAY BE USED IN LIEU OF THE SHELLAC.)

DESTRUCTION NOTICE - DESTROY BY ANY METHOD THAT WILL PREVENT DISCLOSURE OF CONTENTS OR RECONSTRUCTION OF THE DOCUMENTS.

WARNING - THIS DOCUMENT CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC. 2751, ET SEQ.) OR THE EXPORT ADMINISTRATION ACT OF 1979 AS AMENDED, TITLE 50, U.S.C. APP. 2401 ET SEQ. VIOLATIONS OF THESE EXPORT LAWS ARE SUBJECT TO SEVERE CRIMINAL PENALTIES. DISSEMINATE IN ACCORDANCE WITH PROVISIONS OF DOD DIRECTIVE 5230.25.

DISTRIBUTION STATEMENT D. DISTRIBUTION AUTHORIZED TO THE DEPARTMENT OF DEFENSE (DOD) AND U.S. DOD CONTRACTORS ONLY; ADMINISTRATIVE OR OPERATIONAL USE, 3/15/2007. OTHER REQUESTS SHALL BE REFERRED TO THE OFFICE OF THE PROJECT MANAGER FOR MANEUVER AMMUNITION SYSTEMS, ATTN: SFAE-AMO-MAS-LC, PICATINNY, NJ 07806-5000.

THIS DRAWING WAS GENERATED FROM A SOLID MODEL AND IS CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.

CURRENT DESIGN ACTIVITY CAGE CODE 19200
US ARMY
ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
PICATINNY ARSENAL, NEW JERSEY 07806-5000

**PART NO.** 10522621

PMIC

MECHANICAL PROPERTIES

YP
TS
EL2
RA
BH
RH

SEE TABLE

| NEXT ASSY | USED ON |
|---|---|
| APPLICATION | |

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES

TOLERANCE ON ANGLES ± °
2 PLACE DECIMALS ±
3 PLACE DECIMALS ±

THIRD ANGLE PROJECTION

MATL ENGR
MODELED BY J. KREIDER

CONTRACT NUMBER
CONTRACTOR

| | |
|---|---|
| DRAWN BY J. KREIDER | DATE(YEAR-MO-DA) 1962-07-02 |
| CHECKER D. SHAW | ENGINEER |
| ENGINEER | QUALITY ENGINEER |
| DRAWING APPROVAL C. GANDY | 2008-08-14 |
| DESIGN APPROVAL D. GUZIEWICZ | 2008-08-14 |

DESIGN ACTIVITY
US ARMY
FRANKFORD ARSENAL
PHILADELPHIA, PA 19137

PRIMER NO. 34

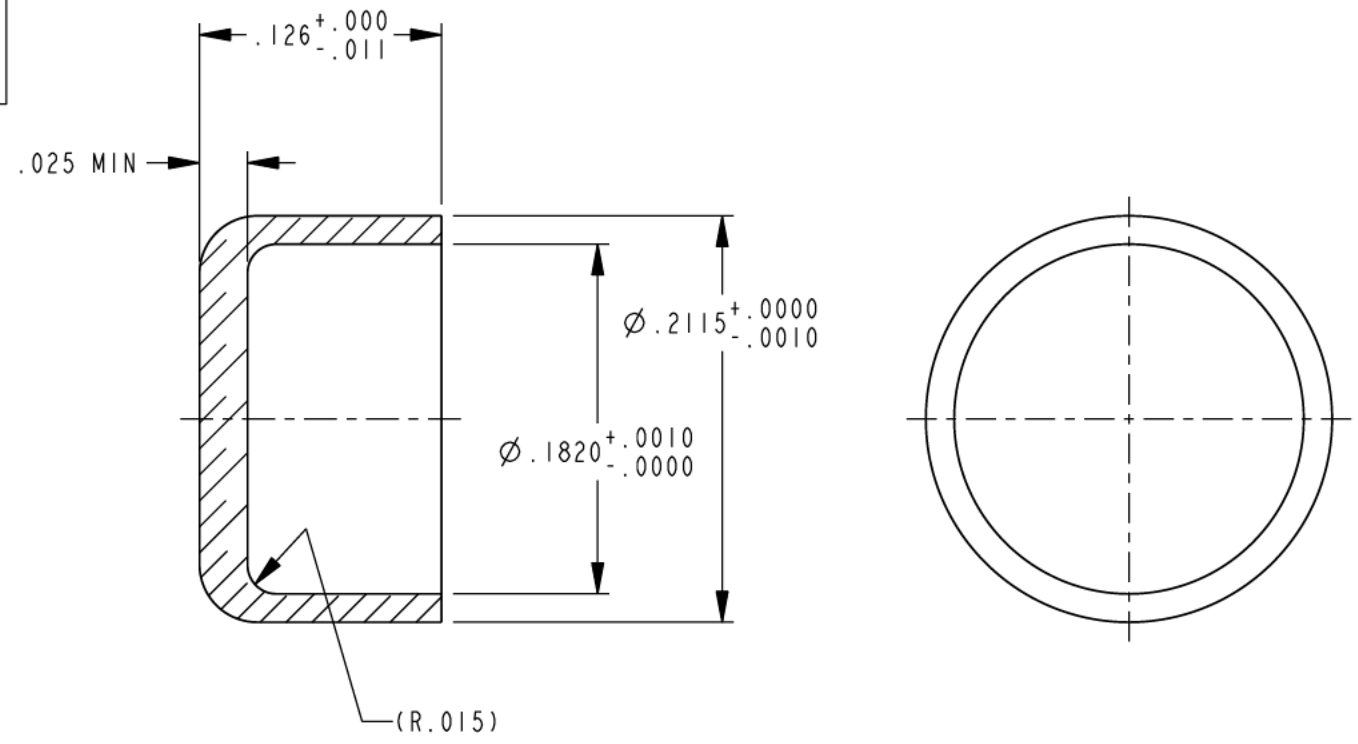
| SIZE | CAGE CODE | DWG NO. |
|---|---|---|
| C | 19200 | 10522621 |

SCALE 14.000 UNIT WT. 5.43-.52 GR(ADV) SHEET 1 OF 1

NOTICE - WHEN GOVERNMENT DRAWINGS, SPECIFICATIONS, OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE UNITED STATES GOVERNMENT THEREBY INCURS NO RESPONSIBILITY NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE, OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

## REVISIONS

| MODEL REV | DRAW REV | DESCRIPTION | DATE(YEAR-MO-DA) | APPROVED |
|---|---|---|---|---|
| - | M | REDRAWN WITH CHANGE NOR R07S3063 / 2008-08-14 | 2008-09-08 | RLV |




NOTES:

1. METAL STRIP .0270±.0005 THICKNESS (ADVISORY).
2. COPPER ALLOY NO. C26000 PER ASTM B19, ANNEALED.
3. UNIT WEIGHT ADVISORY ONLY.

DESTRUCTION NOTICE - DESTROY BY ANY METHOD THAT WILL PREVENT DISCLOSURE OF CONTENTS OR RECONSTRUCTION OF THE DOCUMENTS.

WARNING - THIS DOCUMENT CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC. 2751, ET SEQ.) OR THE EXPORT ADMINISTRATION ACT OF 1979 AS AMENDED, TITLE 50, U.S.C. APP. 2401 ET SEQ. VIOLATIONS OF THESE EXPORT LAWS ARE SUBJECT TO SEVERE CRIMINAL PENALTIES. DISSEMINATE IN ACCORDANCE WITH PROVISIONS OF DOD DIRECTIVE 5230.25.

DISTRIBUTION STATEMENT D. DISTRIBUTION AUTHORIZED TO THE DEPARTMENT OF DEFENSE (DOD) AND U.S. DOD CONTRACTORS ONLY; ADMINISTRATIVE OR OPERATIONAL USE, 3/15/2007. OTHER REQUESTS SHALL BE REFERRED TO THE OFFICE OF THE PROJECT MANAGER FOR MANEUVER AMMUNITION SYSTEMS, ATTN: SFAE-AMO-MAS-LC, PICATINNY, NJ 07806-5000.

CURRENT DESIGN ACTIVITY CAGE CODE 19200
US ARMY
ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
PICATINNY ARSENAL, NEW JERSEY 07806-5000

THIS DRAWING WAS GENERATED FROM A SOLID MODEL AND IS CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.

**PART NO. 8594095**

PMIC

MECHANICAL PROPERTIES

| | |
|---|---|
| YP | |
| TS | |
| EL2 | |
| RA | |
| BH | |
| RH | |

| NEXT ASSY | USED ON |
|---|---|
| | |
| | |
| | |
| | |
| 10535489 | NO. 43 PRIMER |
| 10522621 | NO. 34 PRIMER |
| 8594094 | NO. 36 PRIMER |
| 8595819 | NO. 36M PRIMER |

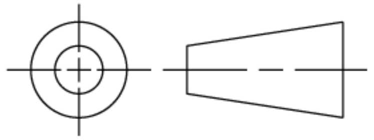
APPLICATION

DO NOT SCALE DRAWING

UNLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES

TOLERANCE ON ANGLES ± °
2 PLACE DECIMALS ±
3 PLACE DECIMALS ±
DECIMALS ± .005

THIRD ANGLE PROJECTION



MATL ENGR

MODELED BY J. KREIDER

CONTRACT NUMBER

CONTRACTOR

| | |
|---|---|
| DRAWN BY J. KREIDER | DATE (YEAR-MO-DA) 1957-05-17 |
| CHECKER D. SHAW | ENGINEER |
| ENGINEER | QUALITY ENGINEER |
| DRAWING APPROVAL C. GANDY | 2008-08-14 |
| DESIGN APPROVAL D. GUZIEWICZ | 2008-08-14 |

DESIGN ACTIVITY
US ARMY
ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
PICATINNY ARSENAL, NEW JERSEY 07806-5000

CUP, PRIMER

| SIZE | CAGE CODE | DWG NO. |
|---|---|---|
| B | 19200 | 8594095 |

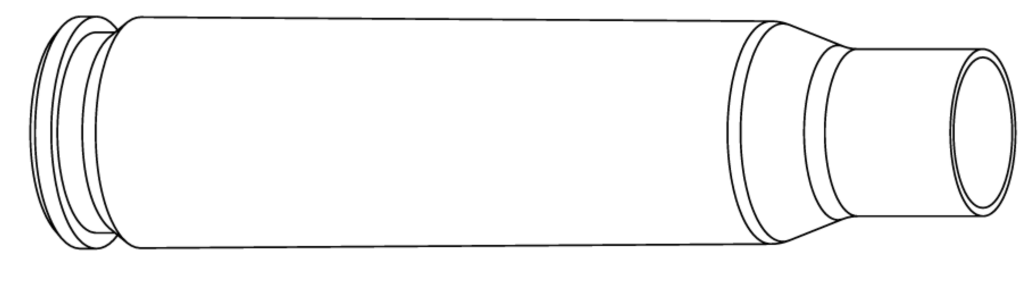
| SCALE | UNIT WT | SHEET |
|---|---|---|
| 10/1 | 3.5±.15 GR | 1 OF 1 |

**REVISIONS**

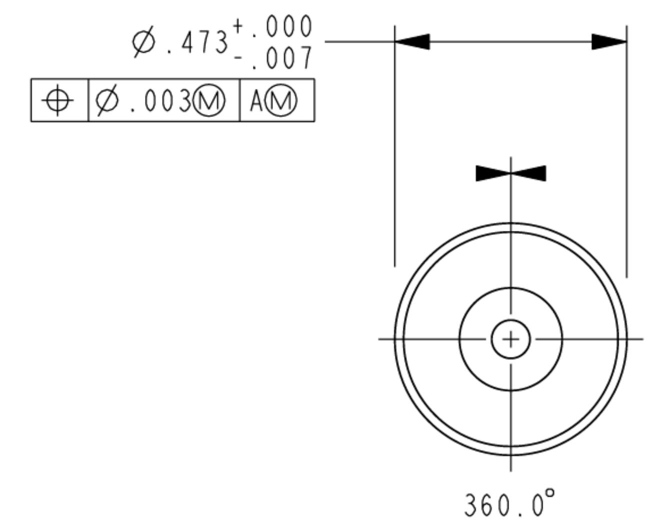
| MODEL REV | DRAWING REV | DESCRIPTION | DATE(YEAR-MO-DA) | APPROVED |
|---|---|---|---|---|
| - | AD | REDRAWN WITH CHANGE NOR R07S3063 / 2008-08-14 | 2008-09-08 | RLV |

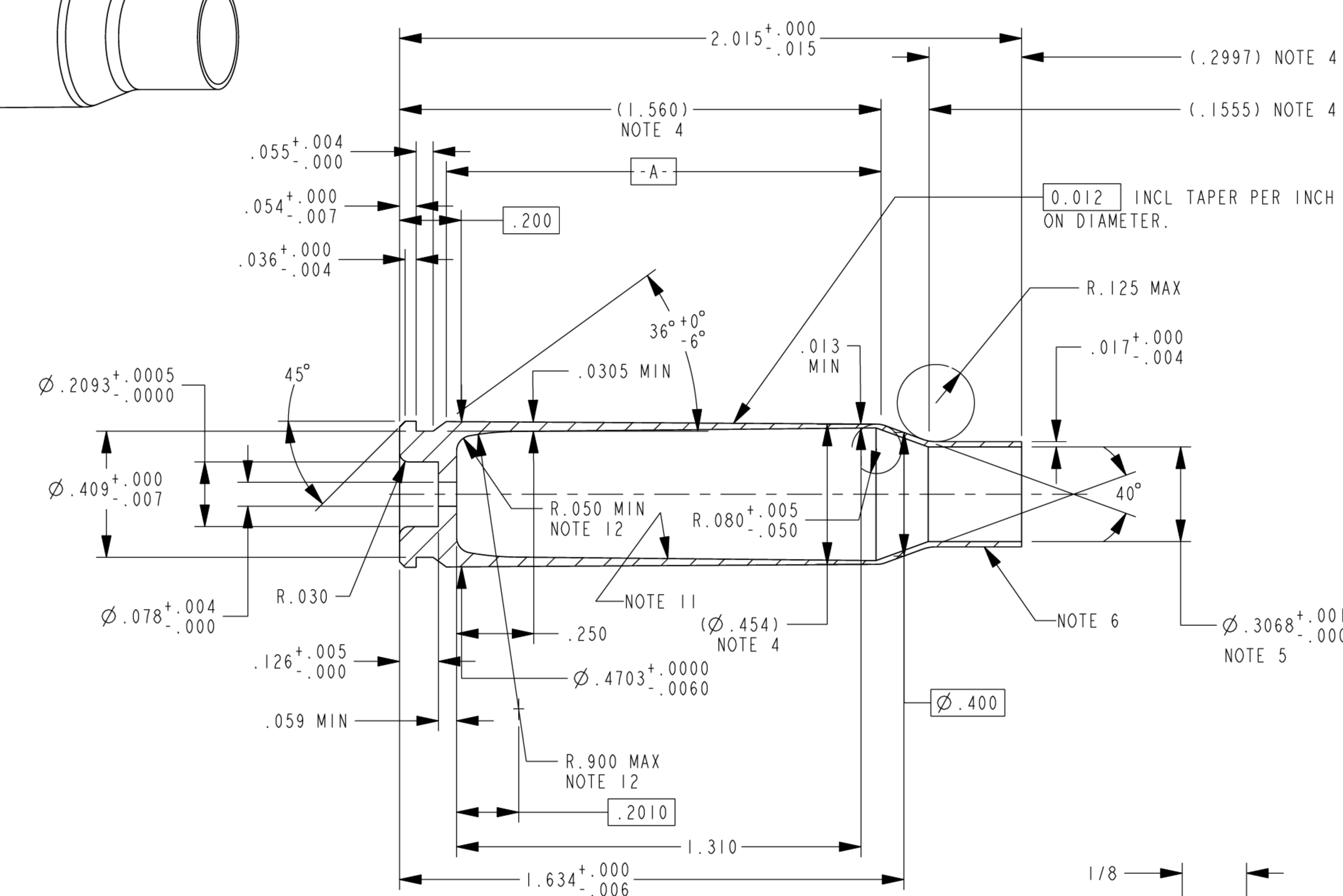
NOTES

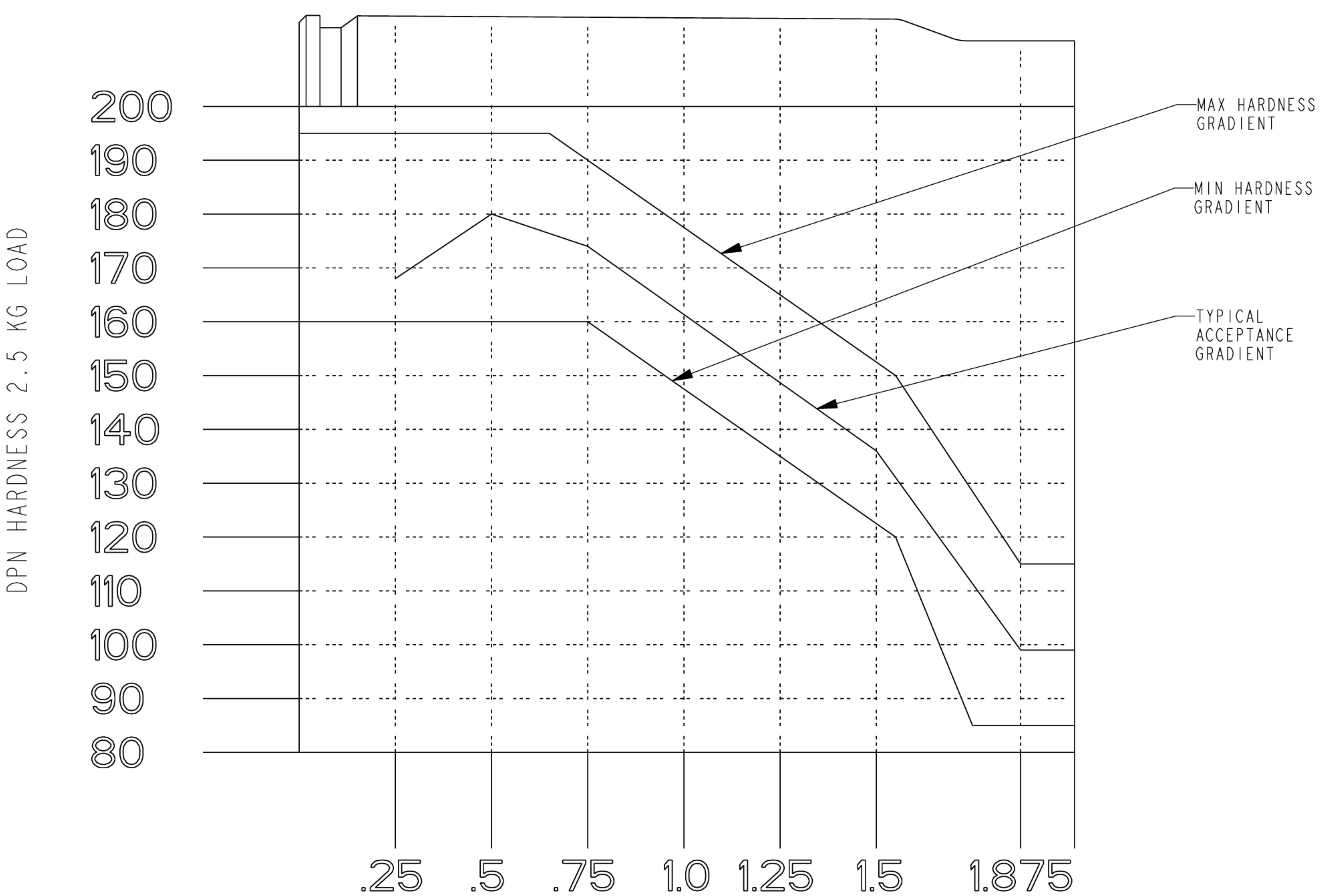
1. APPLICABLE STANDARDS/SPECIFICATIONS:
   A. ANSI Y14.5M-1982
   B. MIL-A-2550
2. THE AVERAGE HARDNESS READINGS OF 10 FINISHED CARTRIDGE CASES AT EACH POSITION INDICATED SHALL FALL WITHIN THE RANGE FOR THAT POSITION DEFINED BY THE MAXIMUIM AND MINIMUM HARDNESS GRADIENTS. THE GREATEST PROBABILITY OF SATISFACTORY FUNCTION OF CARTRIDGES ASSEMBLED WITH THESE CASES OCCURS WHEN THE GRAPH OF THESE AVERAGE READINGS IS GENERALLY PARALLEL TO THE LIMIT GRADIENTS AND IS FREE FROM SHARP ANGULAR DEPARTURES THEREFROM IN THE REGION "0.5 FROM THE HEAD TO 1.875" FROM THE HEAD.
3. MINIMUM HARDNESS AT POINT A TO BE 165 DPN. MINIMUM HARDNESS AT POINTS B, C AND D TO BE 180 DPN. HARDNESS SHALL BE DETERMINED ON SECTIONED CASE.
4. DIMENSIONS GIVEN AT INTERSECTION OF LINES.
5. DIMENSIONS AT PLUGGING OPERATION FOLLOWING TAPER (INFORMATIONAL).
6. AN INCLUDED TAPER NOT TO EXCEED .002 IS ALLOWABLE IN NECK DUE TO VARIABLE EXPANSION OF BRASS.
7. NATO IDENTIFICATION MARK.
8. STAMP INITIALS OF MANUFACTURER OR RECOGNIZED TRADE MARK.
9. STAMP LAST TWO FIGURES OF YEAR OF MANUFACTURE.
10. STAMPING MUST BE LEGIBLE AND NOT ENCROACH ON THE PRIMER CRIMP OR HEAD BEVEL.
11. INSIDE WALL TO BE A CONTINUOUS TAPER BETWEEN .0305 MIN AND .013 MIN.
12. R .050 MIN AND R .900 MAX ARE CONSTRUCTION DIMENSIONS WHICH INSURE THE MINIMUM PERMISSIBLE WALL THICKNESS.
13. MATERIAL: COPPER ALLOY 26000 PER ASTM B19, ANNEALED.
14. CUP (3 DRAW), DWG 10522459: ADVISORY UNLESS OTHERWISE SPECIFIED.
15. THIS CASE SHALL BE STANNIC STAINED (TINNED) FOR IDENTIFICATION PURPOSES WHEN USED FOR CARTRIDGE, 7.62MM, NATO TEST, HIGH PRESSURE, M60. ABSENCE OF STANNIC STAIN ON NECK AND SHOULDER CAUSED BY MOUTH AND NECK ANNEAL, PERMITTED.



ISO VIEW



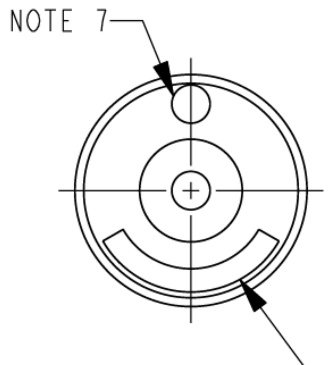
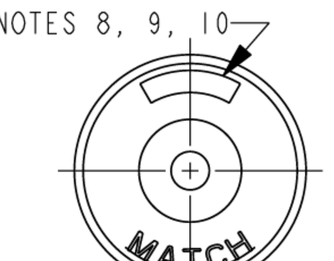



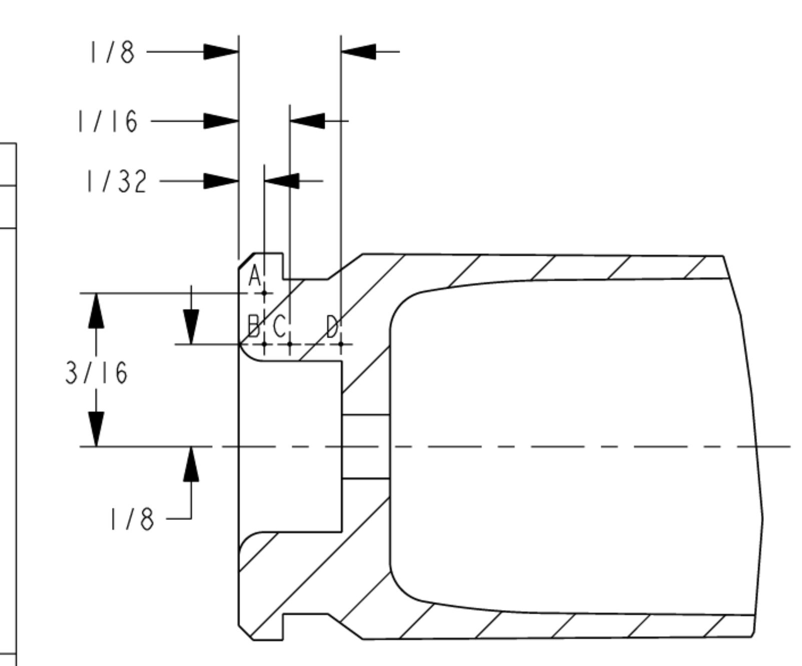




DISTANCE FROM HEAD (INCHES)
EXTERIOR SURFACE (NOTE 2)

HARDNESS GRADIENT

SCALE 4/1

| PART NO. | CARTRIDGE | HEAD STAMP DES | APPLICATION USED ON | NEXT ASSY | FINAL ASSY |
|---|---|---|---|---|---|
| 10521997-1 | CRTG, 7.62MM NATO (SEE USED ON COLUMN) | NOTE 7  NOTES 8, 9, 10 | M59 BALL<br>M60 HPT (NOTE 15)<br>M61 AP<br>M62 TRACER<br>M62 TRACER OHF<br>M63 DUMMY<br>M80 BALL<br>M80 REF<br>M80 BALL OHF<br>M160 FRANGIBLE<br>M172 DUMMY/INERT<br>M198 DUPLEX<br>XM276 DIM TRACER | 7553702<br>7553703<br>7553704<br>10522000<br>10535493<br>7553761<br>10521998<br>8596190<br>10523088<br>10522476<br>10522688<br>10534595<br>10542714 | 7553702<br>7553703<br>7553704<br>10522000<br>10535493<br>7553706<br>10521998<br>8596190<br>10523088<br>10522476<br>10522688<br>10534595<br>10542714 |
| 10521997-2 | CRTG, 7.62MM, NATO MATCH M852 | NOTES 8, 9, 10  | M852 MATCH | 8597567 | 9341551 |




2.5 KG LOAD
DPN HARDNESS
NOTE 3

HEAD AXIAL SECTION

DESTRUCTION NOTICE - DESTROY BY ANY METHOD THAT WILL PREVENT DISCLOSURE OF CONTENTS OR RECONSTRUCTION OF THE DOCUMENTS.

WARNING - THIS DOCUMENT CONTAINS TECHNICAL DATA WHOSE EXPORT IS RESTRICTED BY THE ARMS EXPORT CONTROL ACT (TITLE 22, U.S.C., SEC. 2751, ET SEQ.) OR THE EXPORT ADMINISTRATION ACT OF 1979 AS AMENDED, TITLE 50, U.S.C. APP. 2401 ET SEQ. VIOLATIONS OF THESE EXPORT LAWS ARE SUBJECT TO SEVERE CRIMINAL PENALTIES. DISSEMINATE IN ACCORDANCE WITH PROVISIONS OF DOD DIRECTIVE 5230.25.

CURRENT DESIGN ACTIVITY CAGE CODE 19200
US ARMY
ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
PICATINNY ARSENAL, NEW JERSEY 07806-5000

THIS DRAWING WAS GENERATED FROM A SOLID MODEL AND IS CAD MAINTAINED. CHANGES SHALL BE INCORPORATED BY THE DESIGN ACTIVITY.

PART NO. 10521997

DISTRIBUTION STATEMENT D. DISTRIBUTION AUTHORIZED TO THE DEPARTMENT OF DEFENSE (DOD) AND U.S. DOD CONTRACTORS ONLY; ADMINISTRATIVE OR OPERATIONAL USE, 3/15/2007. OTHER REQUESTS SHALL BE REFERRED TO THE OFFICE OF THE PROJECT MANAGER FOR MANEUVER AMMUNITION SYSTEMS, ATTN: SFAE-AMO-MAS-LC, PICATINNY, NJ 07806-5000.

| | |
|---|---|
| PMIC | |
| MECHANICAL PROPERTIES | |
| YP | |
| TS | |
| EL2 | |
| RA | |
| BH | |
| RH | |
| NEXT ASSY | USED ON |
| SEE TABLE | |
| APPLICATION | |

DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON ANGLES ± 0°30′
2 PLACE DECIMALS ±
3 PLACE DECIMALS ± .005
FRACTIONS ±1/64
THIRD ANGLE PROJECTION

| | |
|---|---|
| CONTRACT NUMBER | |
| CONTRACTOR | |
| DRAWN BY: L. RAMSEY | DATE(YEAR-MO-DA): 1962-01-29 |
| CHECKER: D. SHAW | ENGINEER |
| ENGINEER | QUALITY ENGINEER |
| DRAWING APPROVAL: C. GANDY | 2008-08-14 |
| DESIGN APPROVAL: D. GUZIEWICZ | 2008-08-14 |
| MATL ENGR | MODELED BY: G. STRAHL |

DESIGN ACTIVITY
US ARMY
FRANKFORD ARSENAL
PHILADELPHIA, PA 19137

CASE

| SIZE | CAGE CODE | DWG NO. |
|---|---|---|
| D | 19200 | 10521997 |
| SCALE 3/1 | UNIT WT. 190-20 GRAINS | SHEET 1 OF 1 |

# APPENDIX C1

## ACRONYMS

| | |
|---|---|
| AECTP | Allied Environmental Conditions and Test Procedures |
| AUR | All Up Round |
| DODIC | Department Of Defense Identification Code |
| E3 | Electromagnetic Environmental Effects |
| EED | Electro-explosive Device |
| EID | Electrically Initiated Device |
| ESD | Electrostatic Discharge |
| HE | Safe and operable for external carry HESD exposure |
| HESD | Helicopter-borne Electrostatic Discharge |
| HERO | Hazards of Electromagnetic Radiation to Ordnance |
| HS | Safe and operable for bare/man carry/hot tube loading HESD exposure |
| HV | Safe and operable for VERTREP HESD exposure |
| iLL | lower waveforms limits |
| iUL | upper waveforms limits |
| JOERAD | JSC Ordnance Electromagnetic Environmental Effects Risk Assessment Database |
| JOTP | Joint Ordnance Test Procedure |
| JSC | Joint Spectrum Center |
| MHz | Megahertz |
| MIL-STD | Military Standard |
| MK | Mark |
| NALC | Navy Ammunition Logistics Code |
| OIS | Ordnance Information System |
| PESD | Personnel-borne Electrostatic Discharge |
| pF | picoFarad |
| P-Static | Precipitation Static |
| S4 | Stockpile to Safe Separation Sequence |
| VERTREP | Vertical Replenishment |
| °C | Degrees Celsius |
| °F | Degrees Fahrenheit |
| Ω | Ohms |
| µH | microHenry |

# APPENDIX C2

## REFERENCES

AECTP-500, Category 508 Leaflet 2 Electrical/Electromagnetic Environmental Tests
MIL-DTL-23659F General Design Specification for Electric Initiators
MIL-STD-331 Department Of Defense Test Method Standard: Environmental and Performance Tests For Fuze and Fuze Components
MIL-STD-464 Department Of Defense Interface Standard: Requirements for Systems Electromagnetic Environmental Effects