Military and Aerospace EMC Testing:
Recent Advancements and Future Changes

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EMC Testing – Military

- <u>EMC is Required by Military Regulations</u> – Though enforcement is not universal…
- EMC testing requirements are based on the Environment(s) of Intended Use:
  - ❑ Ground
    - ❑ Vehicles, Personnel, Buildings
  - ❑ Aircraft
    - ❑ Air Force, Army, Navy
  - ❑ Shipboard
    - ❑ Army/Navy, Above/Below Decks, Submarines
- Susceptibility test levels and Emission limits are based on the installation ("Platform") where the system is used
- Standard for Military EMC in the US (and in most of the rest of the world) is MIL-STD-461G
- Note: Power Input covered by MIL-STD-704 (A-F) and MIL-HDBK-704-(1-8)

MIL-STD-461 History

- Written by the Tri-Service Working Group
- MIL-STD-461 (and 462) published in 1967
  - 461: Requirements
  - 462: Test Methods and Procedures
- MIL-STD-461A published in 1968
- MIL-STD-461B published in 1980
- MIL-STD-461C published in 1986
- MIL-STD-461D published in 1993
  - MIL-STD-462D also published in 1993
  - Multiple “Notices” for MIL-STD-462 released between 1967 and 1993
- MIL-STD-461E published in 1999, rolling in test methods from 462
- MIL-STD-461F published in 2007
- MIL-STD-461G published in 2015
  - Significant Change in Section 4 “General Requirements”
    - “After the initial calibration, passive devices such as measurement antennas, current probes, and LISNs, require no further formal calibration unless the device is repaired. The measurement system integrity check in the procedures is sufficient to determine acceptability of passive devices.”

MIL-STD-461G

- "REQUIREMENTS FOR THE CONTROL OF ELECTROMAGNETIC INTERFERENCE CHARACTERISTICS OF SUBSYSTEMS AND EQUIPMENT"
  - "This standard establishes interface and associated verification requirements for the control of the electromagnetic interference (EMI) emission and susceptibility characteristics of electronic, electrical, and electromechanical equipment and subsystems designed or procured for use by activities and agencies of the Department of Defense (DoD)."
- 19 Tests Methods with requirements and procedures
  - 3 Conducted Emissions
  - 10 Conducted Susceptibility
  - 3 Radiated Emissions
  - 3 Radiated Susceptibility
- Appendix A: Detailed and extensive "Application Guide"

EMC Testing – Aerospace (Civil Aircraft)

- **FAA Regulations specify the EMC requirements for any and all electrical/electronic equipment operated onboard a commercial aircraft.**
- **Minimum requirement for all equipment is RF Emissions and Magnetic Effect – Thou Shalt Not Interfere with Communications or Navigation!**
- **Systems that are required for safe aircraft operation, and/or passenger safety, have additional FAA regulations.**
- **Other equipment may have contractual requirements for Susceptibility.**
- **The standard for Civil Aircraft EMC in the US (and the world) is DO-160G, published by RTCA, Inc.**
- **Note: In Europe, this document is published by EUROCAE, and is known as ED-14G**

RTCA/DO-160 History

- DO-160 released in 1975
- DO-160A released in 1980
- DO-160B released in 1984
- DO-160C released in 1989 (3 changes)
- DO-160D released in 1997 (3 changes)
- DO-160E released in December 2004
- DO-160F released in December 2007
- DO-160G released in December 2010
  - User Guide DO-357 published December 2014
- DO-160H in work now – planned release date 2021(?)
  - Significant changes planned for many sections

DO-160G

- Published by RTCA, Inc., a Not-for-Profit corporation
  - Until May of 2018, a “Federal Advisory Committee” – now a “Standards Development Organization”
  - EC equivalent is the European Organization for Civil Aviation Electronics or “EUROCAE”
  - DO-160 is written by Special Committee 135, the longest standing continuous committee within RTCA – meeting since October, 1977 without interruption

DO-160G

- "Environmental Conditions and Test Procedures for Airborne Equipment"
  - "... defines a series of minimum standard environmental test conditions (categories) and applicable test procedures for airborne equipment. The purpose of these tests is to provide a laboratory means of determining the performance characteristics of airborne equipment in environmental conditions representative of those which may be encountered in airborne operation of the equipment."
- 3 sections of General Information
- 13 sections covering the Physical Environment
- 10 sections on Electrical / Electromagnetic Environment
- 3 appendices

MIL-STD-461G and DO-160G Comparison

MIL-STD-461 (Method)	DO-160 (Section)	Test
RE101 (Sort of)	15	Magnetic Effect / Magnetic Field Emissions
(MIL-STD-704), CE101	16	Power Input
CS106 (461F)	17	Voltage Spike
CS101	18	Audio Frequency Conducted Susceptibility - Power Inputs
CS109, CS115, CS116, RS101	19	Induced Signal Susceptibility
CS114, RS103	20	Radio Frequency Susceptibility (Radiated and Conducted)
CE102, RE102	21	Emission of Radio Frequency Energy
CS117	22	Lightning Induced Transient Susceptibility
CS118	25	Electrostatic Discharge

- MIL-STD-461G Antenna tests -- CE106, RE103, CS103, CS104, CS105: equivalent tests in FAA regulations (TSO MOPS)
- DO-160G Section 23 (Direct Strike Lightning): equivalent requirements in MIL-STD-464C
- MIL-STD-461G RS105 (NEMP): no equivalent test in DO-160G or FAA regulations (yet)

Power Input: Section 16, MIL-STD-704 & MIL-HDBK-704

- DO-160G Section 16 and MIL-STD-704:
  - Very similar requirements and test methods
  - Steady State over/under voltage & frequency
  - Voltage Surges, Sags, Distortions & Interruptions
  - Amplitude & Frequency Modulation on AC inputs
  - Current Harmonics
  - In-Rush Current
  - DC Content in AC Input
  - Power Factor
  - DC Ripple
  - Re-Generated Energy
  - Current Modulation

- MIL-STD-461G CE101
  - 0.03-10kHz, power leads only, measured with a current probe
  - 2 limits: 28V or less and >28V

Magnetic Effect / Magnetic Field Emissions: Section 15, RE101

- DO-160G Section 15: DC Magnetic Field Emissions
  - Tests how much the EUT will deflect a compass needle
  - EUT is moved closer to a magnetic compass until needle deflects 1 degree
  - 5 Categories, with distance ranging from 0 to 300cm
  - No significant changes planned for DO-160H

- MIL-STD-461G RE101: Audio Frequency Magnetic Field Emissions
  - Measurement made with a small loop antenna, 7cm from EUT surface
  - 30Hz to 100kHz
  - 2 Limits: Army & Navy
  - No significant changes for 461G

Voltage Spike: Section 17, CS106 (MIL-STD-461F)

- Section 17: Voltage Spike
  - 10 micro-second spike that is transformer coupled into power input
  - 50Ω source impedance
  - 2 equipment categories (test levels): 600V and 2x Line voltage
  - No significant changes planned for DO-160H

- CS106: Conducted Susceptibility, Transients, Power Leads
  - 5 micro-second spike
  - ≤ 2 ohm source impedance
  - 400V test level, pre-calibrated across 5 ohms
  - Eliminated in 461G

AF Conducted Susceptibility - Power Leads: Section 18, CS101

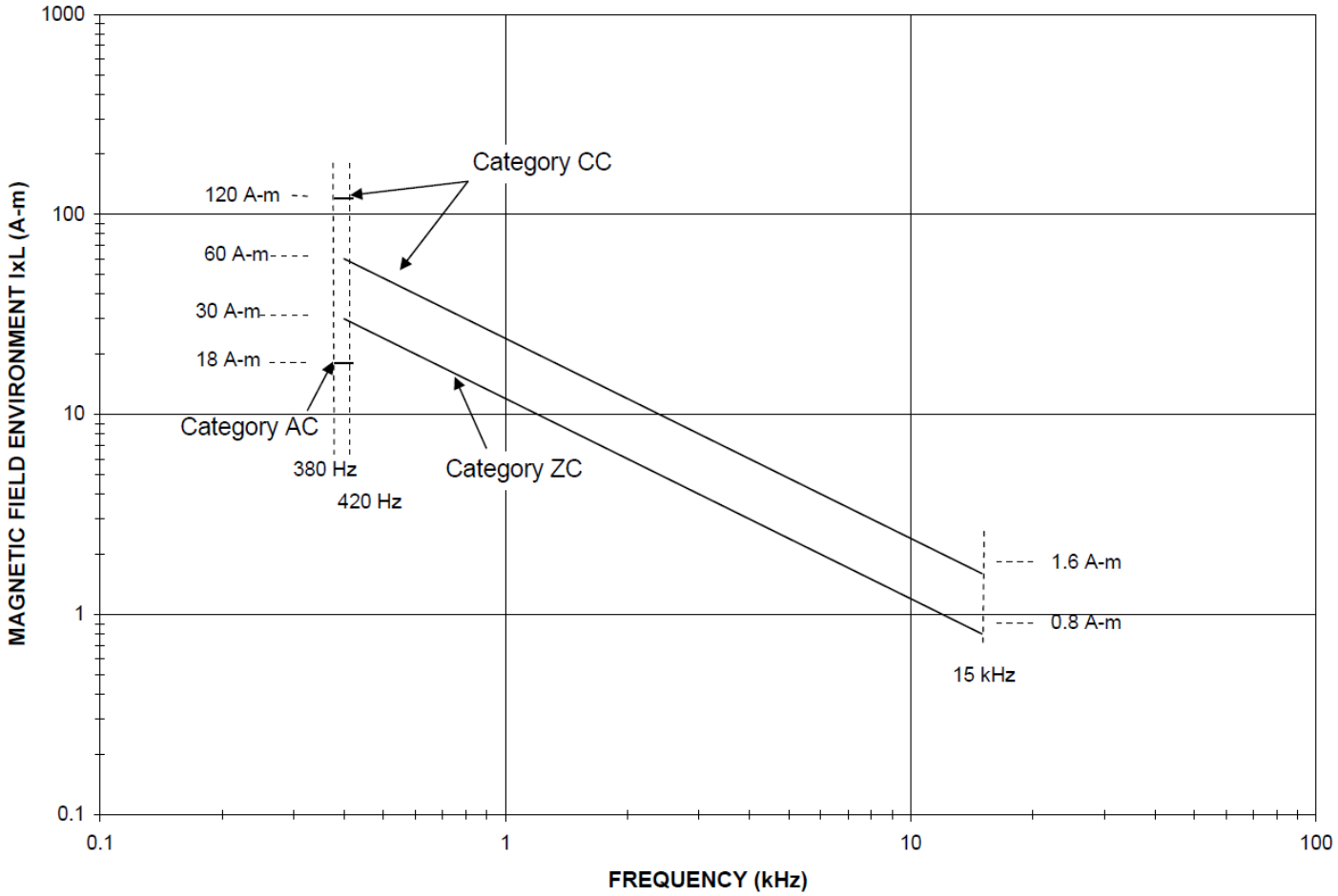
- Section 18: Audio Frequency Conducted Susceptibility
  - 0.01 to 150kHz frequency range; test levels up to 8% of input AC rms voltage
  - 8 Equipment Categories, depending on type of power
  - Current limit 36A max induced current
  - No significant changes planned for DO-160H

- CS101: Conducted Susceptibility, Power Leads
  - 0.03 to 150kHz frequency range; test levels up to 8% of input rms voltage
  - 2 test levels: 28V or less; >28V
  - Pre-calibrated power limit up to 80W
  - No significant changes for MIL-STD-461G

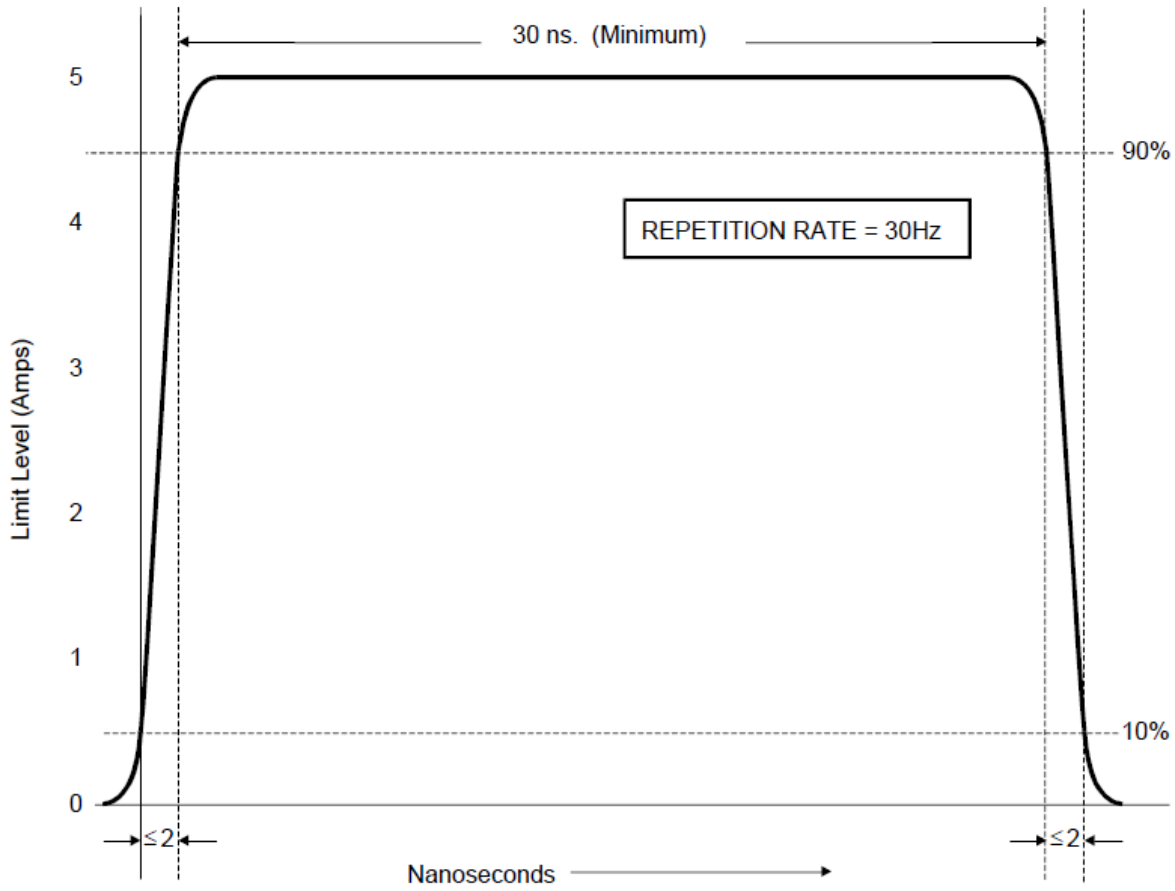
Induced Signal Susceptibility: Section 19, CS109/CS115/CS116/RS101

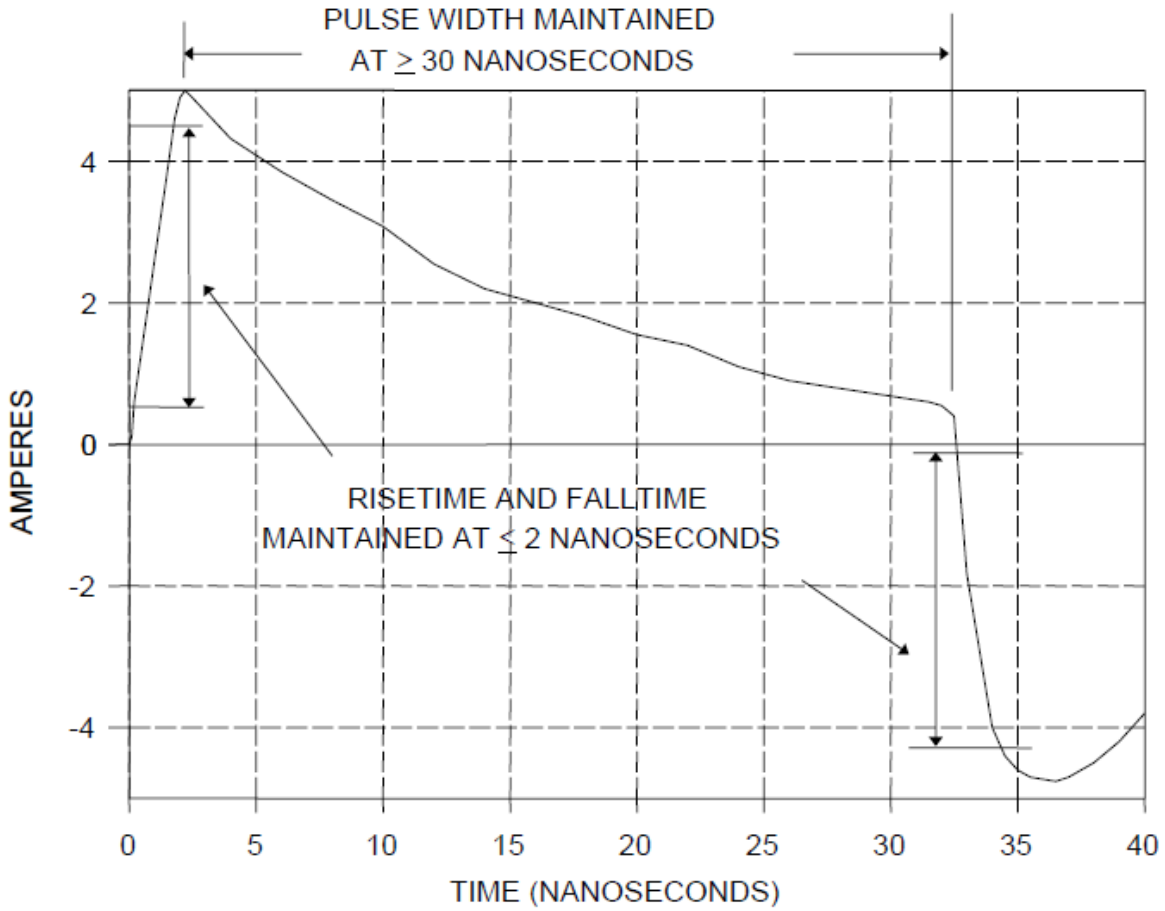
- DO-160G Section 19: Induced Signal Susceptibility
  - Power Frequency Magnetic and Electric Fields Induced into Equipment
  - Power and/or Audio Frequency Magnetic and Electric Fields Induced into Interconnecting Cables
  - Electrical Transient Generated Spikes
  - 4 Test Levels and 3 Power Frequency types = 12 Equipment Categories
  - Power leads are NOT tested
  - Planned changes for DO-160H: “Chattering Relay” test (hopefully) replaced by CS115
- MIL-STD-461G CS109: Conducted Susceptibility, Structure Current
  - 0.06 to 100kHz frequency range, 1 test level
- MIL-STD-461G CS115: Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
  - 30 nSec pulse, 30 Hz rep rate, 1 test level: 5A peak, pre-calibrated in 50 ohm fixture
- MIL-STD-461G CS116: Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads
  - 0.01, 0.1, 1, 10, 30, & 100MHz test frequencies
  - Test levels up to 10A peak, pre-calibrated in 50 ohm fixture or actual induced current during test
- MIL-STD-461G RS101: Radiated Susceptibility, Magnetic Field
  - Small radiating loop antenna, 5cm from EUT surface
  - 30Hz to 100kHz
  - 2 Limits: Army & Navy
- No significant changes for any of the 461G test methods

Magnetic Fields Induced into Cables Test Levels

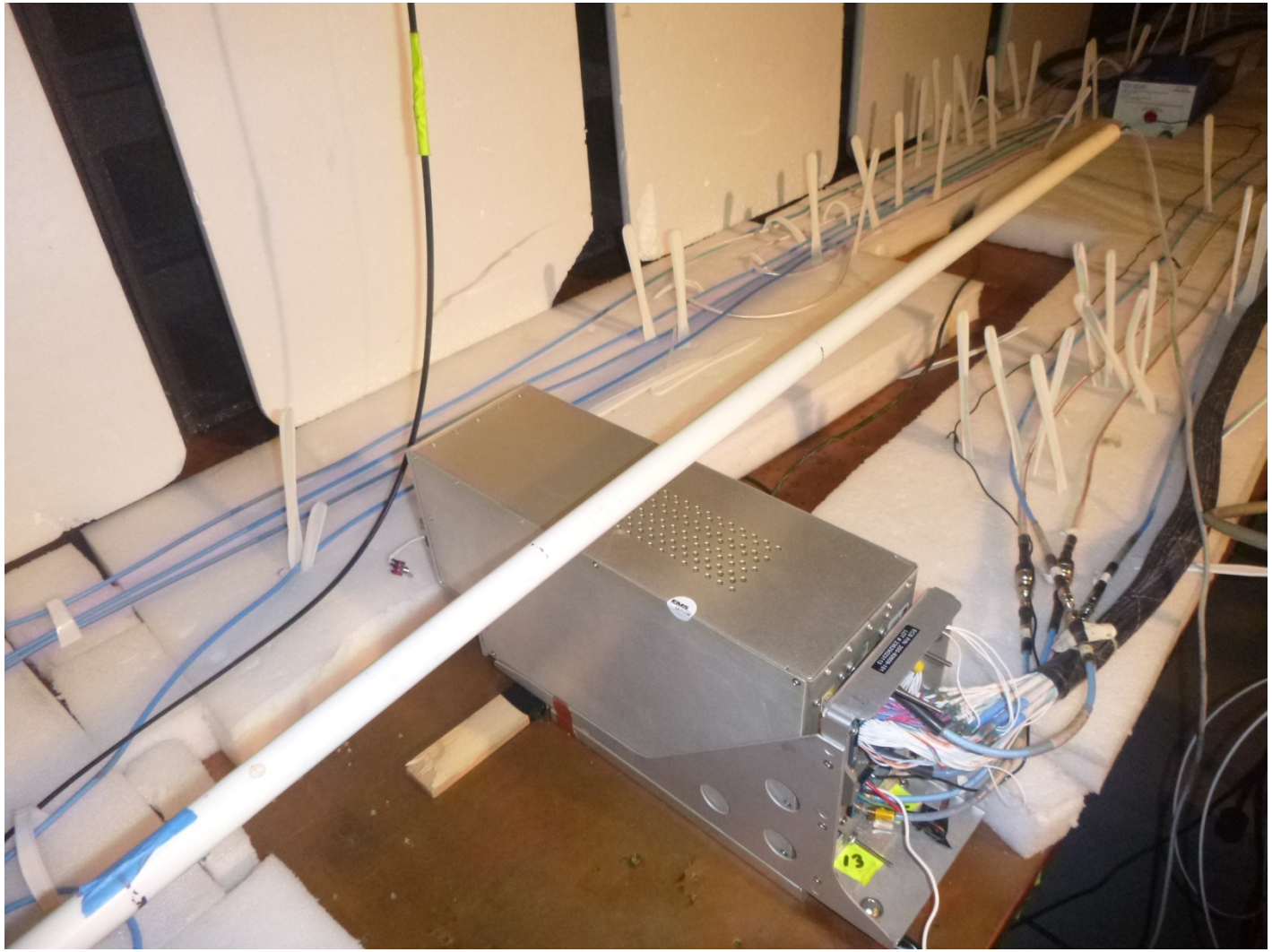


CS115 Test Waveform





Section 19 Magnetic Fields Induced into Equipment Test Setup



RF Conducted Susceptibility: Section 20.4, CS114

- DO-160G Section 20.4: RF Susceptibility (Conducted)
  - BCI at 0.01 to 400MHz, up to 300mA calibration/test level
  - 7 Equipment Categories, all requiring CW and 1kHz SW
  - Pre-calibration in a 50 ohm fixture, induced current monitored during test

- MIL-STD-461G CS114: Conducted Susceptibility, Bulk Cable Injection
  - 0.01 to 200MHz, 1kHz SW
  - 5 test levels depending upon the details of the installation/platform, up to
  - Special 4-10kHz test for Navy ships & submarines at 77dBuA
  - Pre-calibration in a 50 ohm fixture, induced current monitored during test
  - Significant change for MIL-STD-461G: Test System Verification with monitor probe in a 2nd 50 ohm fixture

CS114 Calibration and Verification Setups

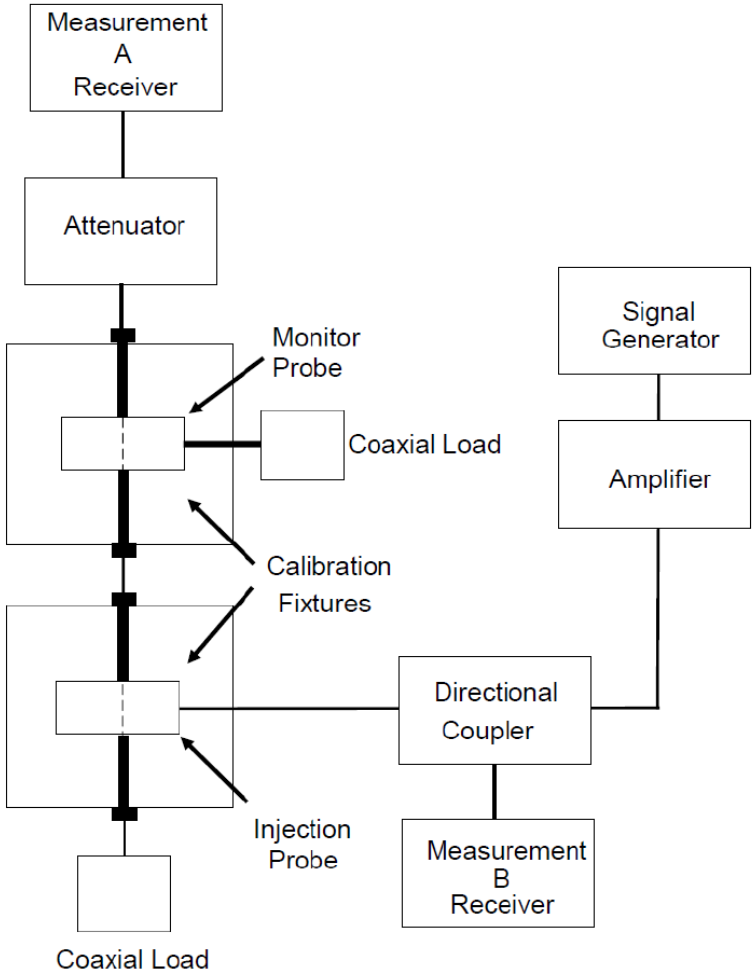


FIGURE CS114-3. Calibration setup.

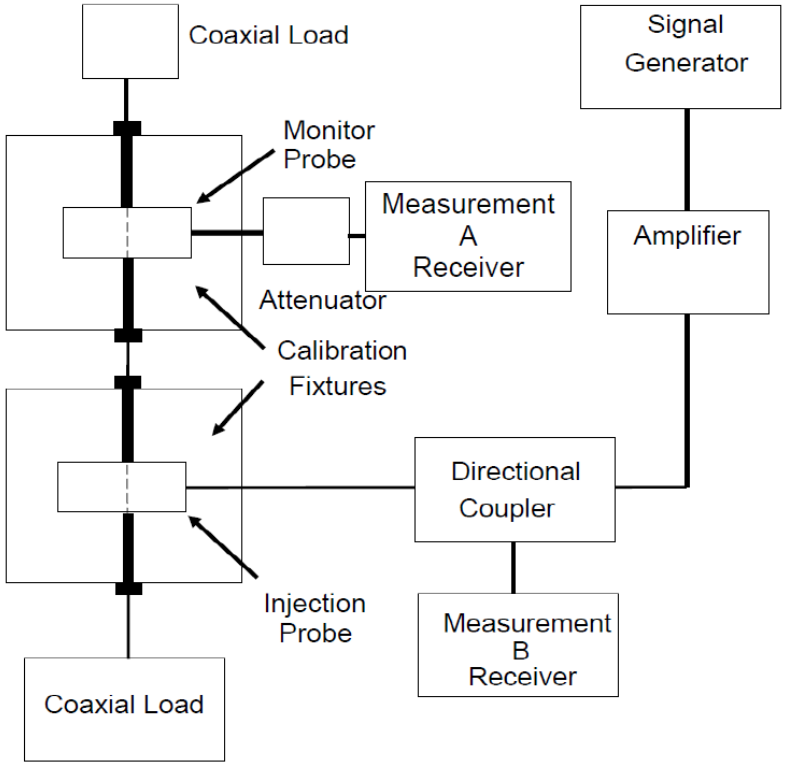


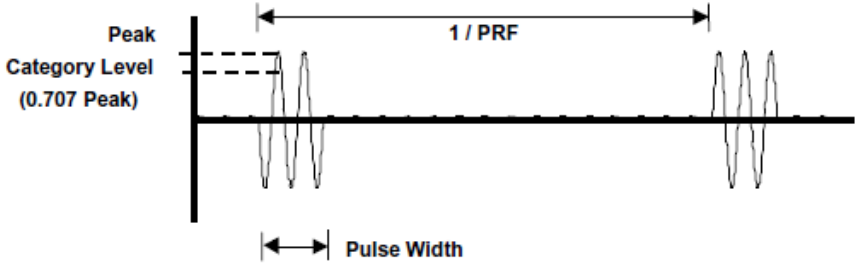
FIGURE CS114-4. Verification setup.

RF Conducted Susceptibility Test Setup

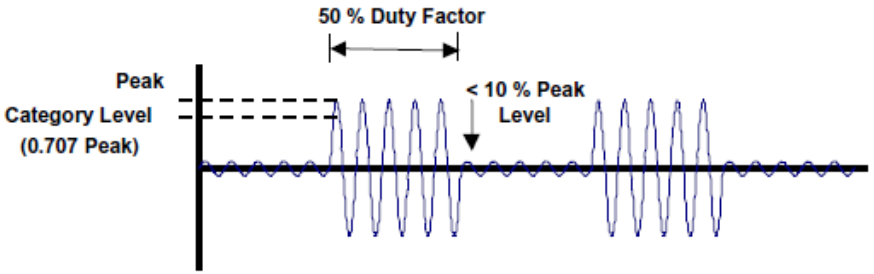
RF Radiated Susceptibility: DO-160G Section 20.5/20.6

- Section 20 RF Susceptibility (Radiated), Anechoic or Reverberation Chamber
  - 10 Equipment Categories, from "S" (1V/m) to "L" (up to 7200V/m); 0.1 to 18GHz
  - CW and 1kHz SW for all Categories; Pulse Modulation for "HIRF" Categories
  - Default minimum of 100 frequency steps/decade and 1 second dwell time
  - Anechoic Chamber (20.5)
    - Placement and performance of RF Absorber is specified
    - Field calibration using an E-field probe with an "empty" groundplane
    - Calibrated power level used during test with EUT in place on the groundplane
    - EUT and 1st ½ half wavelength of cabling must be within the 3dB beamwidth of the antenna
    - Vertical and Horizontal antenna polarizations and a 1 meter antenna distance required
    - "Directly expose apertures in the EUT to the transmitting antenna" ;-)
  - Reverberation Chamber (20.6)
    - Field Uniformity verification using E-field probes with empty and "loaded" chamber
    - Chamber calibration with EUT in place to determine power required for test
    - Maximum received power over one tuner rotation used to calculate field strength (see related presentation)
    - Chamber time constant is calculated and pulse widths increased as needed
    - Continuous tuner rotation with a default minimum 4 RPM <1GHz, 2 RPM >1GHz (see related presentation)

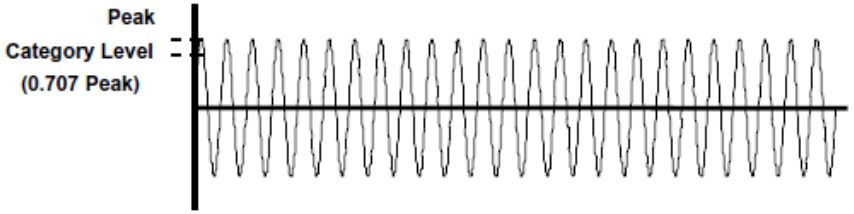
RF Susceptibility Modulations and Test Level



Pulse Modulated Waveform

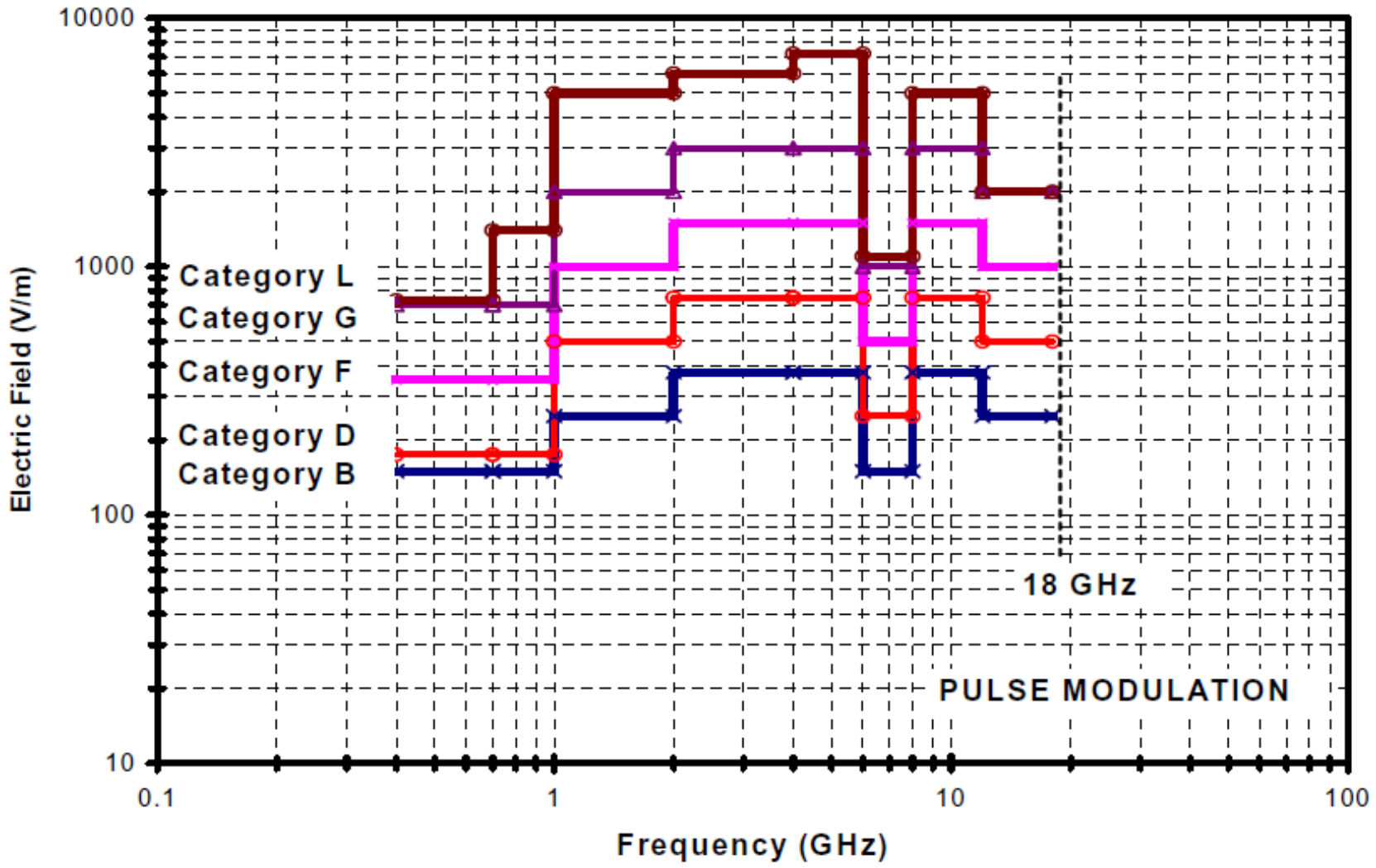


Square Wave (SW) Modulated Waveform



Unmodulated (CW) Waveform

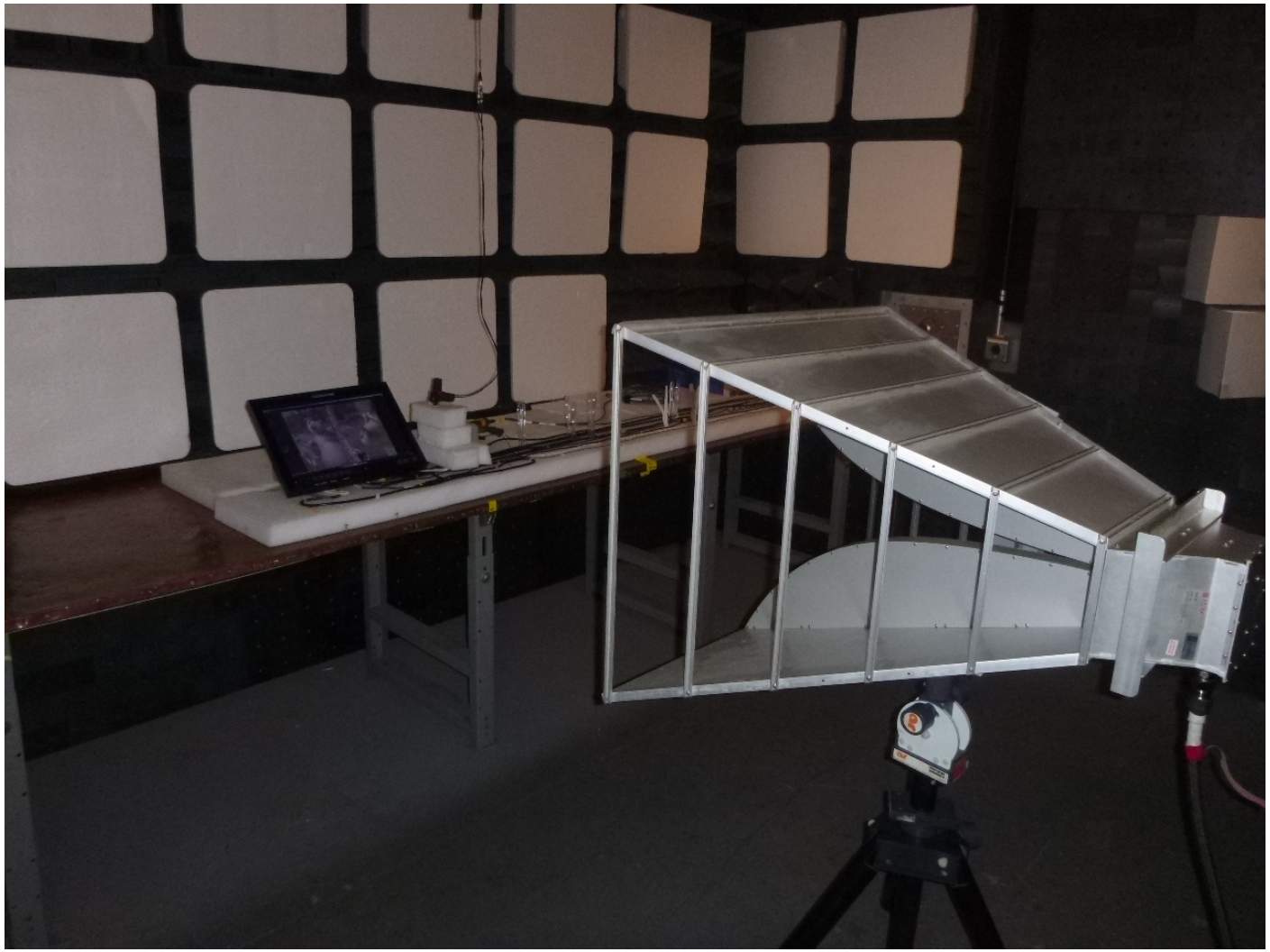
RS Categories – Pulse



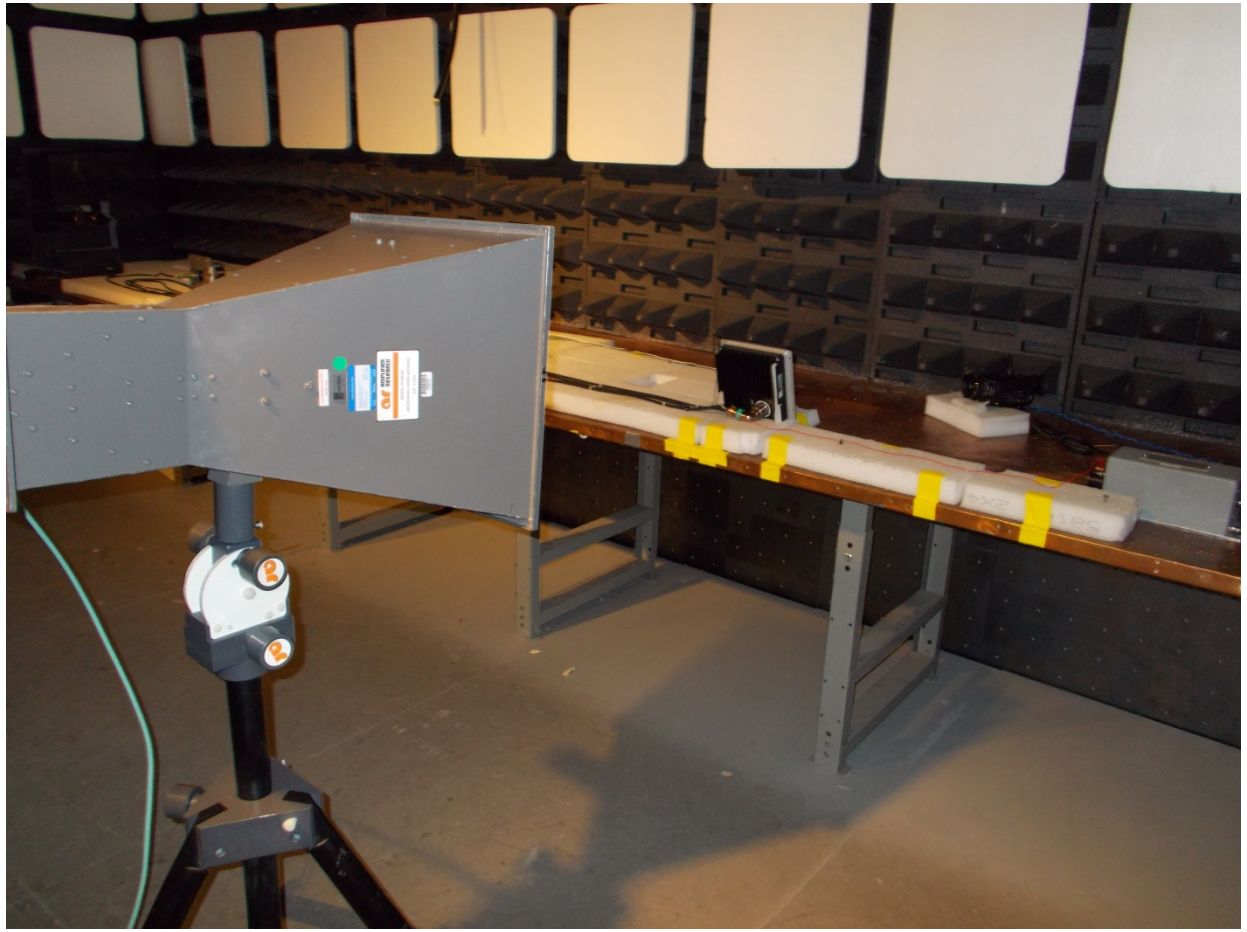
RF Radiated Susceptibility: MIL-STD-461G RS103

- RS103 Radiated Susceptibility, Electric Field
  - Test levels from 5V/m to 200V/m, 1kHz SW only
  - 30MHz to 18GHz applicable for all, 2-30MHz and/or 18-40GHz optional (must be specified)
  - Frequency step size varies with frequency range (5% to 0.25%); 3 second minimum dwell time
  - Anechoic Chamber Method
    - Placement and performance of RF Absorber is specified
    - "Real-time" E-field measurement during test using E-field sensors
    - Sensors placed on or near the EUT, directly opposite the transmitting antenna
    - <200MHz, antenna is centered on the "test setup boundary"
    - >200MHz, EUT and the first 35cm or 7cm of cabling must be within the 3dB beamwidth of the antenna
    - Vertical (>2MHz) and Horizontal (>30MHz) antenna polarizations and a 1 meter antenna distance required
    - "EUTs shall be oriented such that surfaces which … respond most readily to radiated signals face the … antennas " ;-)
    - Significant change for MIL-STD-461G: No option for anechoic chamber field measurement with receive antenna
  - Reverberation Chamber Method
    - >200MHz only, mode-tuned only
    - Lowest usable frequency for a given chamber is based on chamber size (volume)
    - Chamber calibration with EUT in place using E-field sensor or (>1GHz) receive antenna (2 different equations)
    - Number of Tuner steps (12 to 50) is specified by frequency range

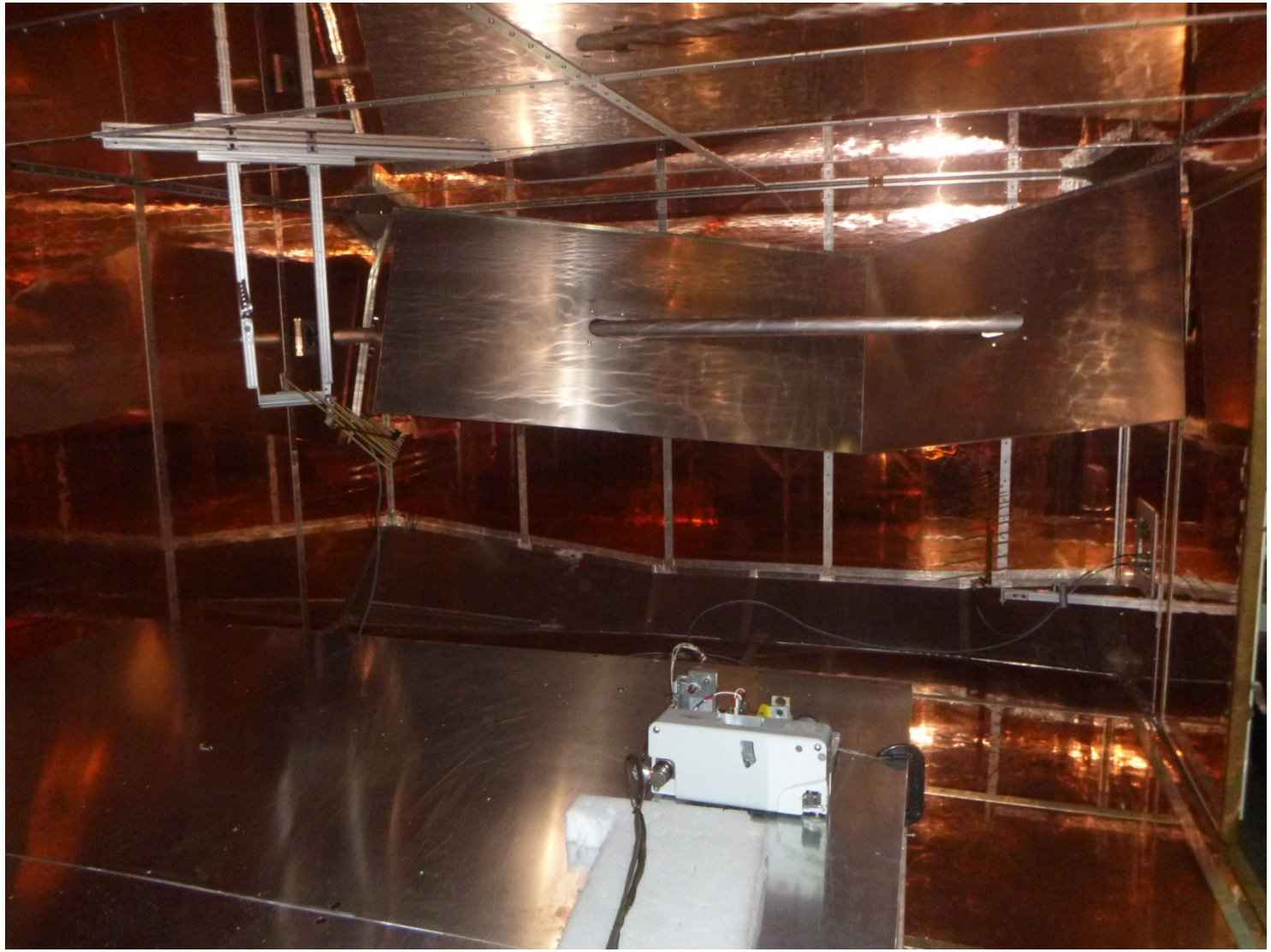
Radiated RF Susceptibility Setup – RS103



Section 20 Radiated Calibration & Test Setups



Section 20 Radiated (Reverb Chamber) Test Setup

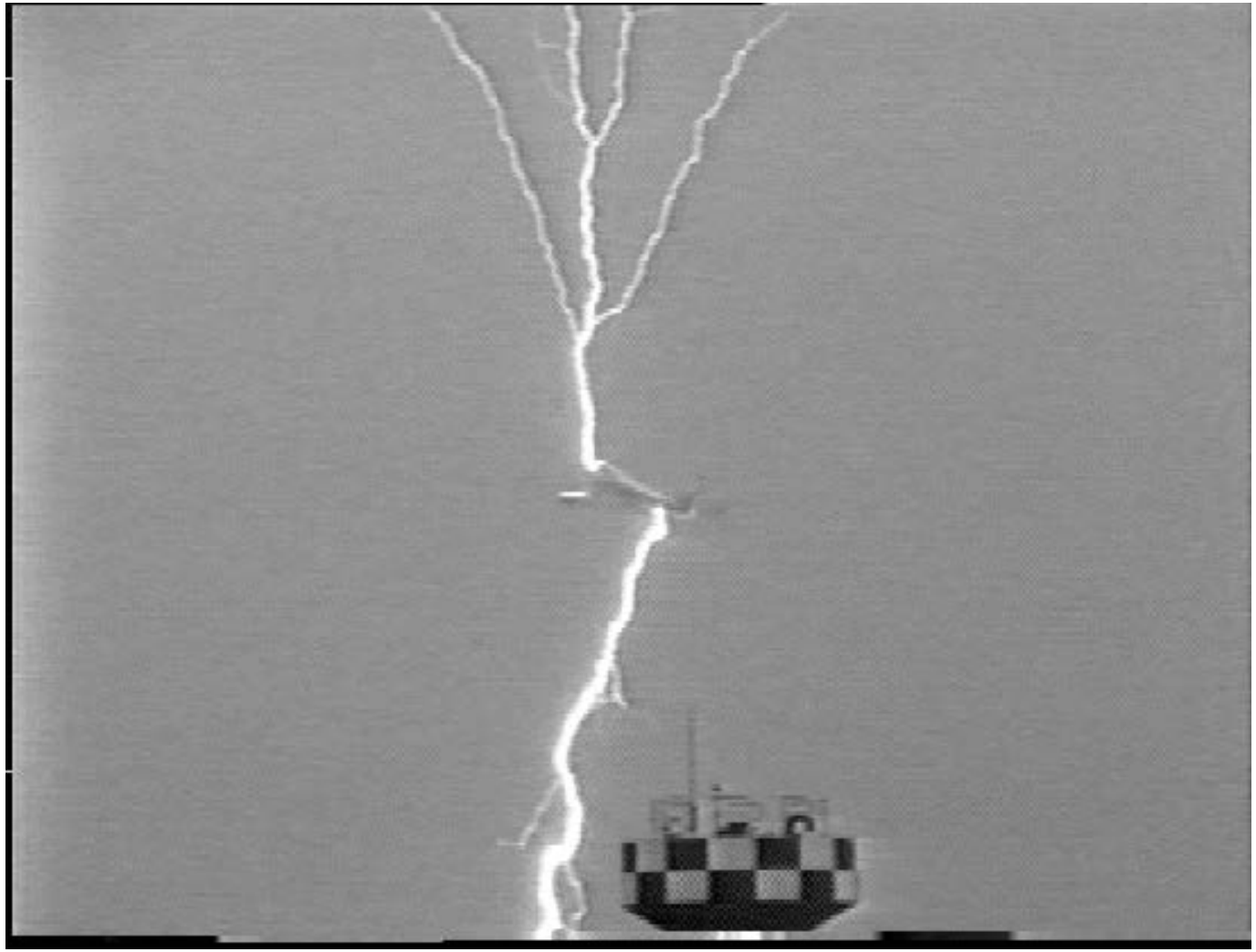


RF Emissions: Section 21, CE102/RE102

- DO-160G Section 21: Emissions of Radio Frequency Energy
  - 6 Equipment Categories, based on location of equipment on the aircraft and protection level required
  - Conducted emissions on interconnecting cables and power leads using a current probe, 0.15 to 152MHz
  - Radiated emissions 0.1 to 6GHz using either Anechoic or Reverberation Chamber (Mode-stirred)
  - No significant changes planned for DO-160H

- MIL-STD-461G CE102: Conducted Emissions, Radio Frequency Potential, Power Leads, and RE102: Radiated Emissions, Electric Field
  - CE is 0.01 to 10MHz, power leads only, using LISN RF port
  - 6 limits, depending upon input voltage
  - No significant change in CE102 for MIL-STD-461G
  - RE uses Anechoic Chamber only
  - 9 limits (10kHz to 18GHz or 2MHz to 18GHz) depending upon details of installation
  - Significant change in RE102 for MIL-STD-461G: Note stating - *"Testing is required up to 1 GHz or 10 times the highest intentionally generated frequency within the EUT, whichever is greater."* - HAS BEEN DELETED. Testing to 18GHz is now REQUIRED for ALL equipment and systems.

Lightning



Lightning Induced Transient Susceptibility: Section 22, CS117

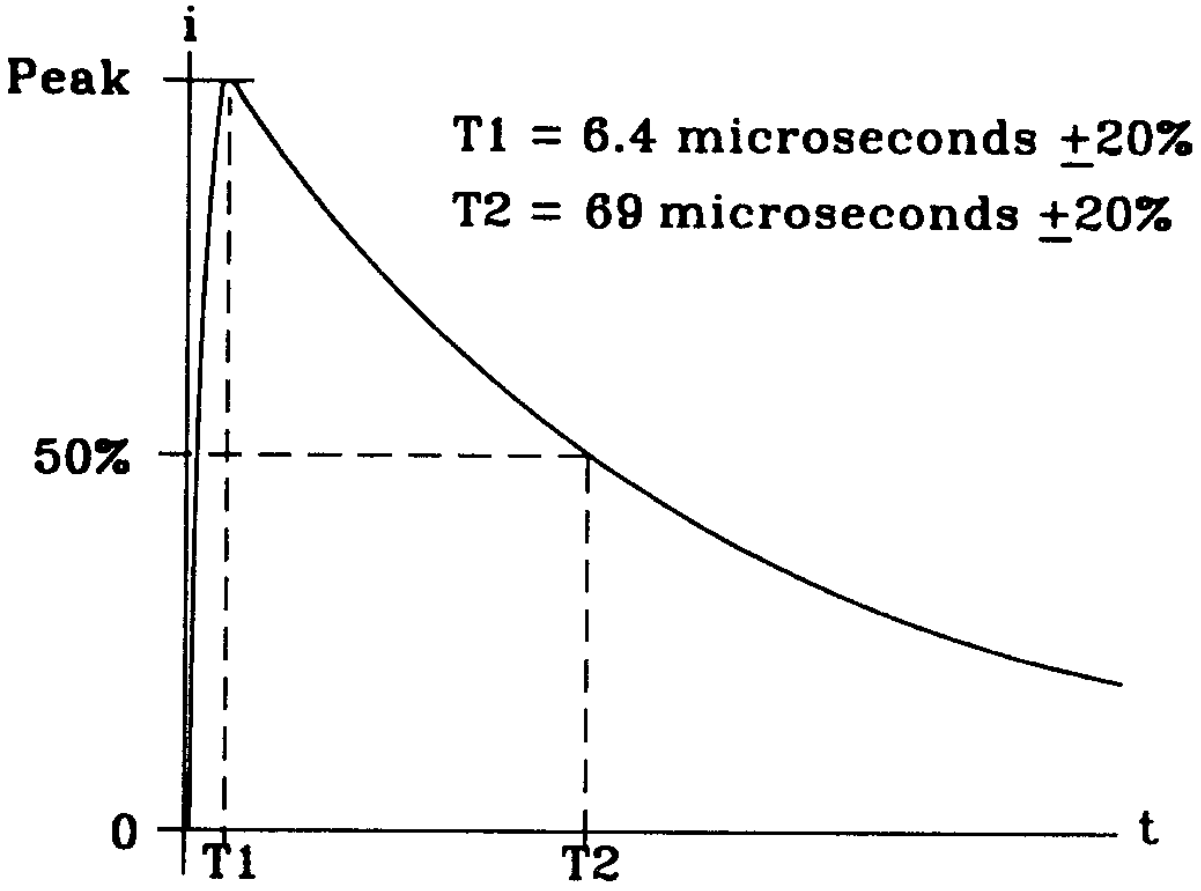
- DO-160G Section 22: Lightning Induced Transient Susceptibility
  - Multiple Burst, Multiple Stroke, Single Stroke to Cables
  - Pin Injection tests to the interface connector pins
  - Cable Induction or Ground Injection tests on the interconnecting cables and power leads
  - 6 Waveforms, 12 Waveform sets
  - 5 Test Levels up to 3200V peak / 5000A peak
  - Categories defined by type of injection (pin or cable), waveform set, and test level
  - Category designations consist of six characters that describe the pin and cable test Waveform Sets and test levels. For example, category "A3G4L3" indicates:
    - A - Pin Test Waveform Set A
      3 - Pin Test Level 3
      G - Cable Bundle Waveform Set G
      4 - Cable Bundle Single and Multiple Stroke Test Level 4
      L - Multiple-Burst Waveform Set L
      3 - Cable Bundle Multiple Burst Test Level 3

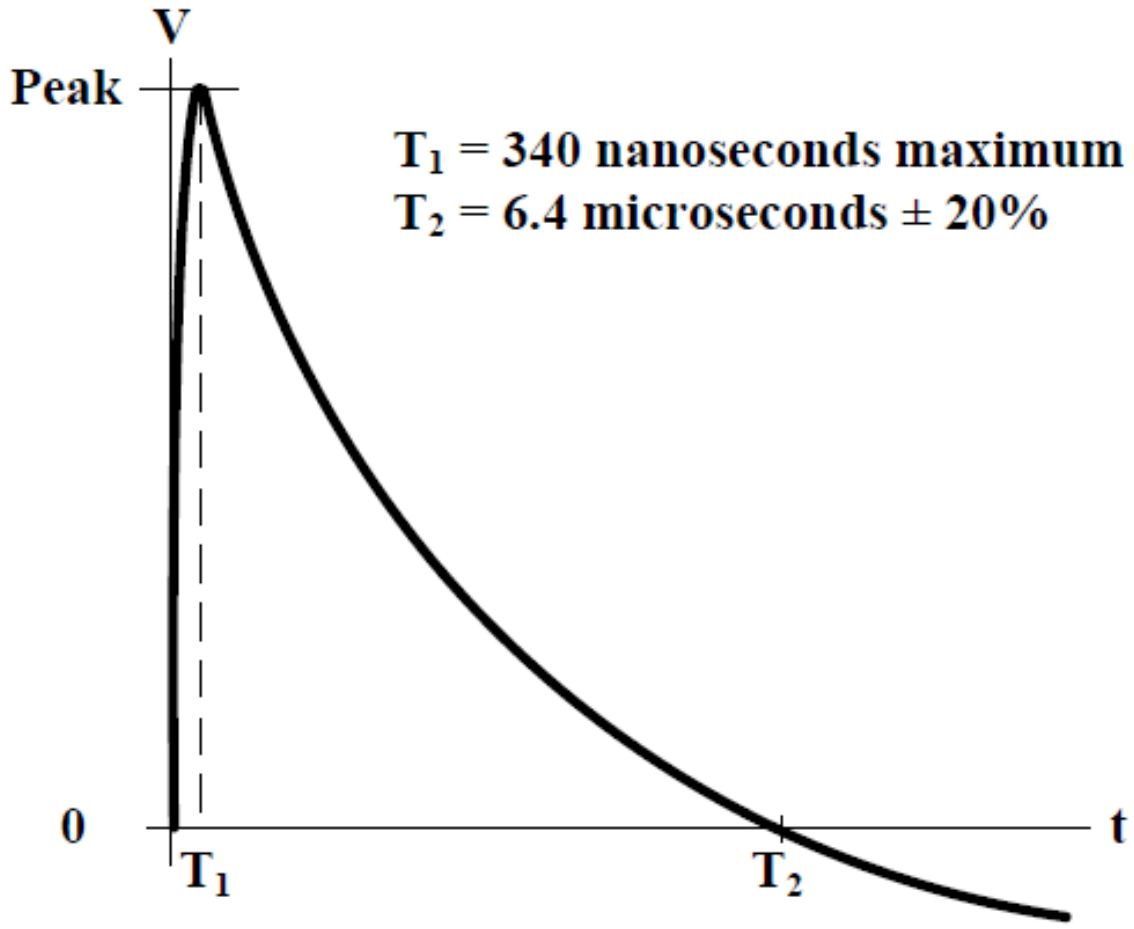
- SIGNIFICANT CHANGES planned for DO-160H
  - Cable Bundle test level will be pre-calibrated using a specified load
  - Voltage Monitor Loop will no longer be used during Cable Induction test

Lightning Induced Transient Susceptibility: Section 22, CS117

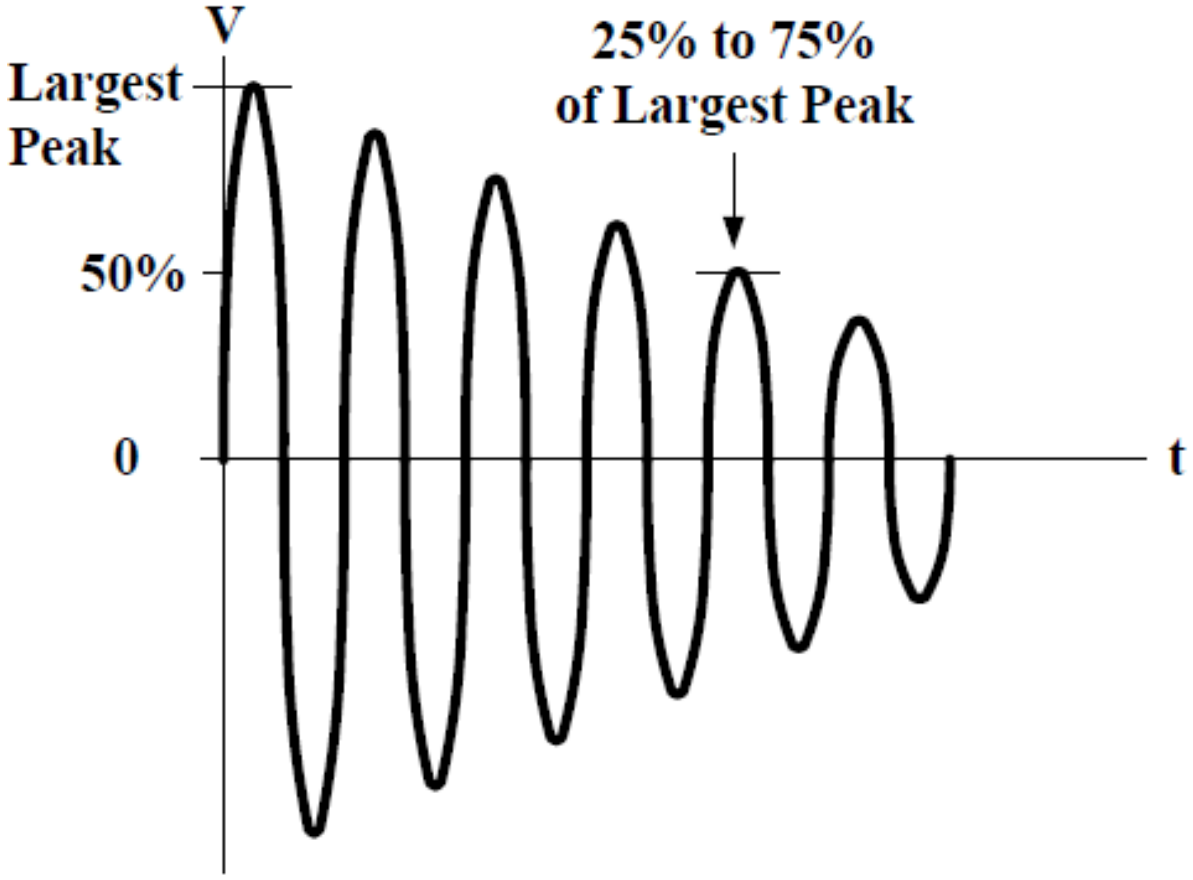
- MIL-STD-461G CS117: Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads.
  - NEW for MIL-STD-461G
  - Multiple Burst and Multiple Stroke waveforms applied to interconnecting cables and power leads
  - Pin Injection tests NOT performed
  - Cable Induction only, Ground Injection not supported
  - 6 Waveforms, 2 Test Levels (Internal or External Equipment)
  - Test Levels given for full cables and individual power leads
  - Multiple Stroke Waveform 1, 2, & 3 required for all installations
  - Multiple Stroke Waveform 4 & 5A required for installations in areas with composites
  - Multiple Burst Waveform 3 required for all installations
  - Multiple Burst Waveform 6 required for installations that "…utilize short, low impedance cable bundle installations." – such as engine harnesses

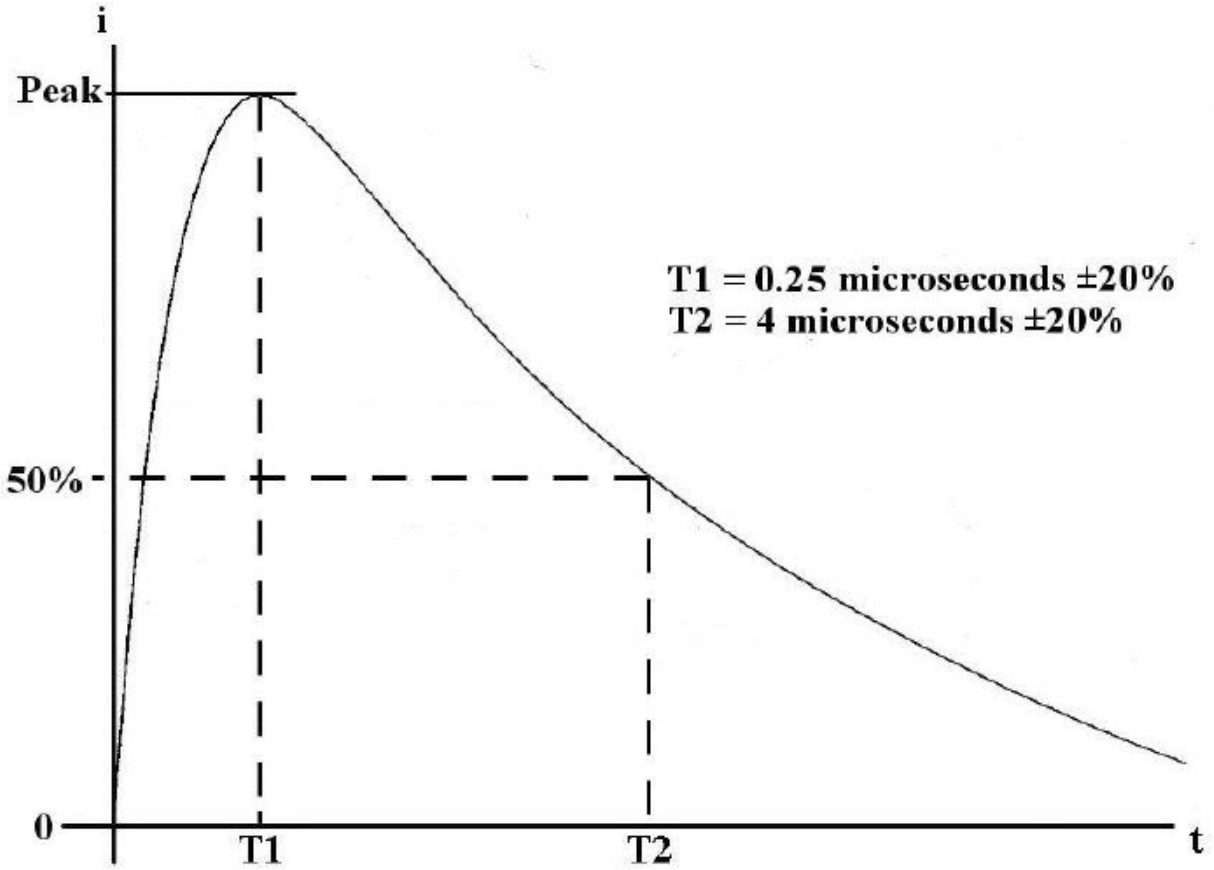
Waveform 1 / 2


i
Peak
T1 = 6.4 microseconds ±20%
T2 = 69 microseconds ±20%
50%
0
T1
T2
t


V
Peak
T1 = 340 nanoseconds maximum
T2 = 6.4 microseconds ± 20%
0
T1
T2
t

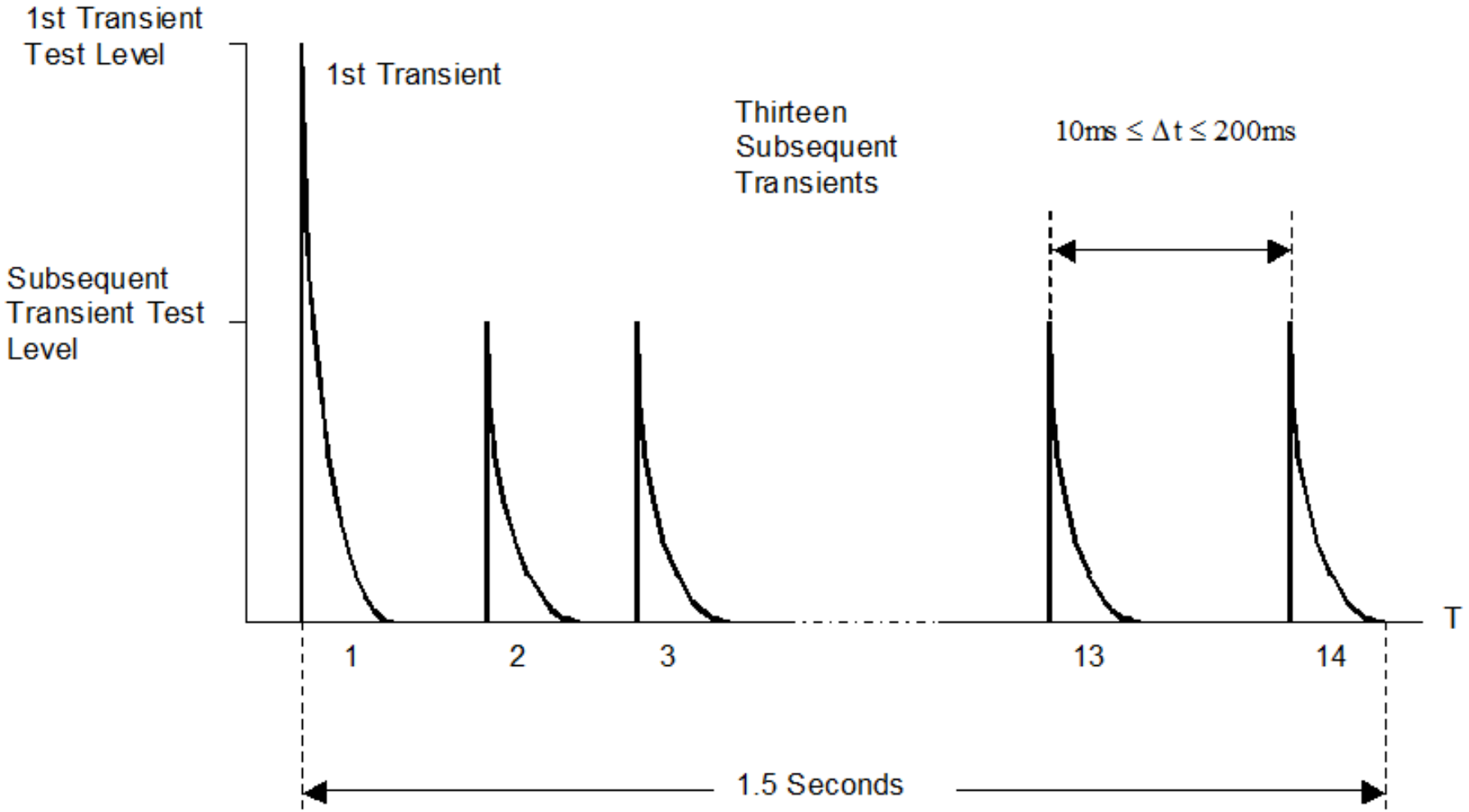
Waveform 3 and Waveform 6





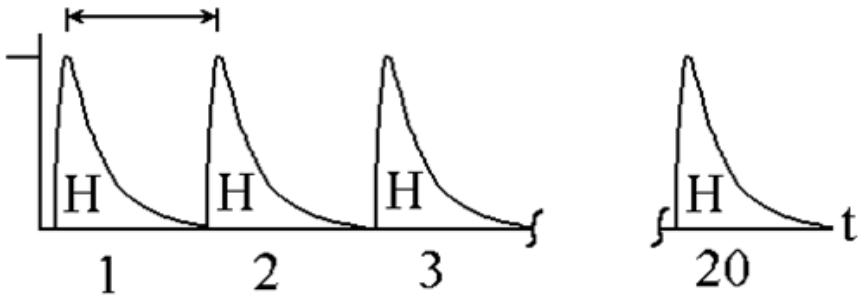
NOTE:
The waveshape may have either a damped sine or cosine waveshape.

Multiple Stroke Waveform Timing

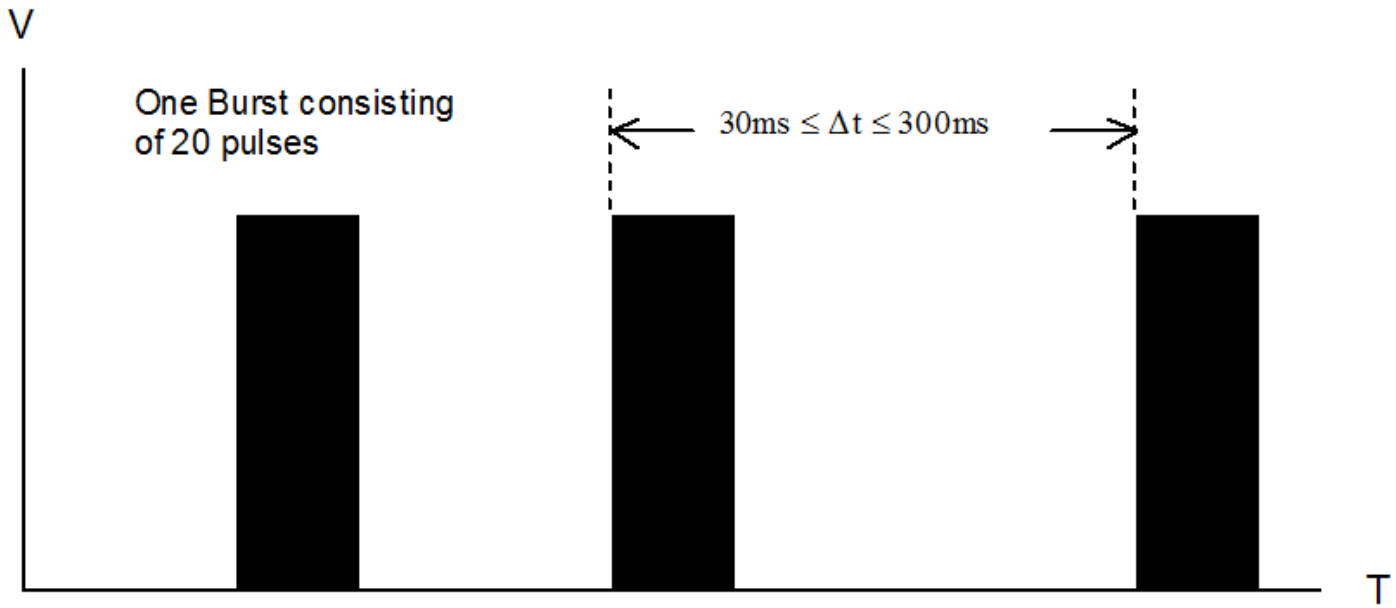


For combined Single-Stroke and Multiple-Stroke test, 1st stroke = SS level, Subsequent strokes = MS level

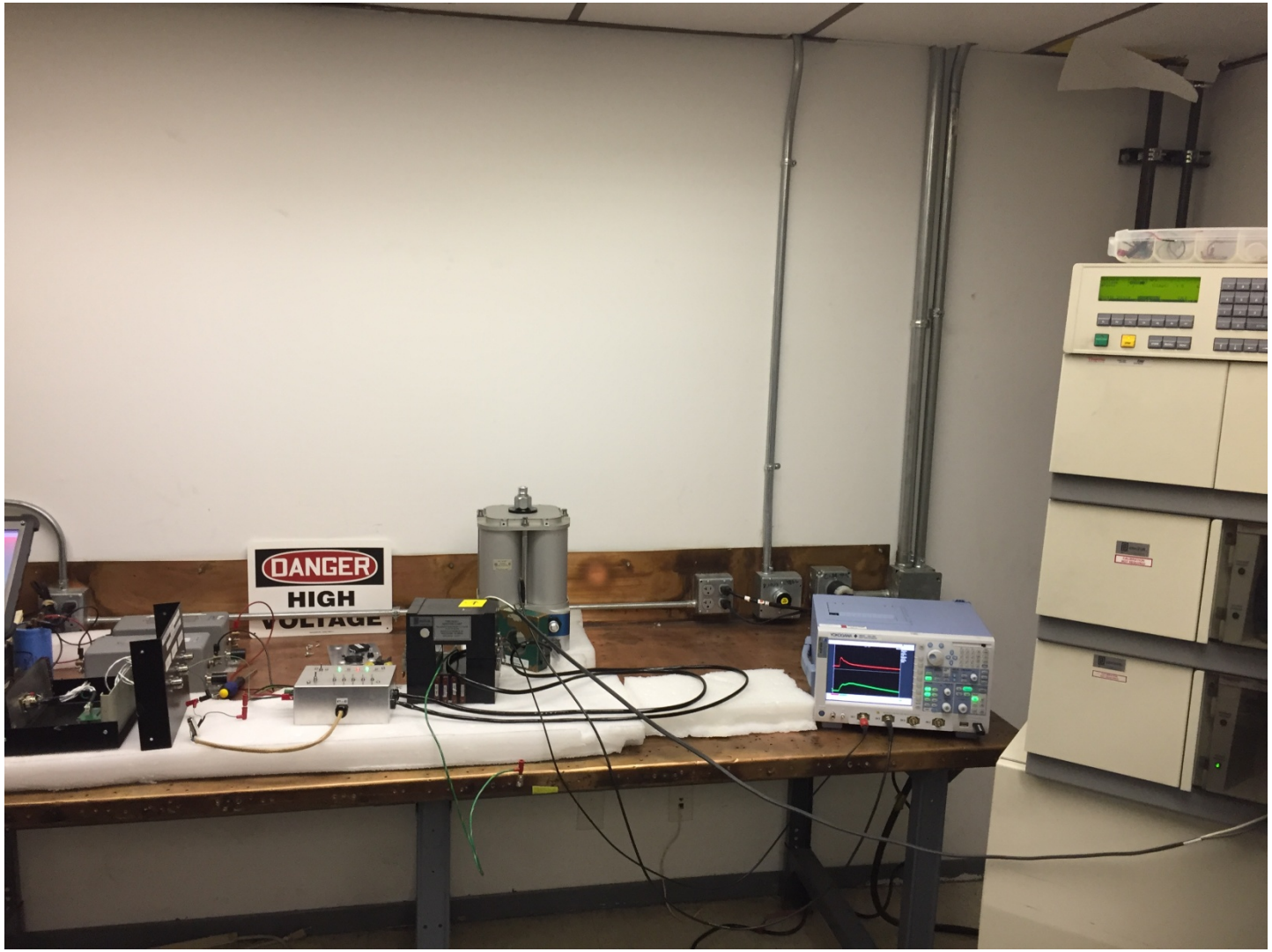
Multiple Burst Waveform Timing



One burst is composed of 20 pulses.

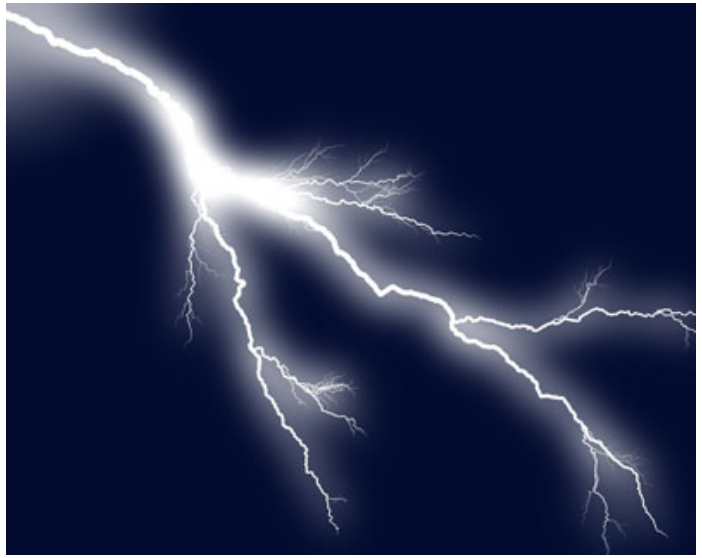


Cable Injection Lightning



Section 23 and MIL-STD-464C: Lightning Direct Effects

- Simulates direct lightning strikes to equipment mounted on the skin of the aircraft
- Test levels and waveforms are determined after analysis of aircraft design to determine what "Lightning Zone" the equipment will be located in
- Test levels up to <u>2400 kV / 200 kA</u>



Electrostatic Discharge: Section 25, CS118

- Section 25: ESD
  - Patterned after EN 61000-4-2 (150pF & 330 ohm)
  - Air discharge to equipment only
  - Single test level of +/-15 kV
  - Only 1 equipment category
  - Connector pins are NOT tested
  - “Calibrated” ESD Generator required, but no specific calibration procedure specified
  - No significant changes planned for DO-160H

- CS118
  - NEW for MIL-STD-461G
  - Patterned after EN 61000-4-2 (150pF & 330 ohm)
  - Contact Discharge at +/-8 kV for conductive surfaces
  - Air Discharge at +/-2 kV to +/-15 kV only required where Contact Discharge cannot be applied
  - Connector pins are NOT tested
  - ESD Generator must be calibrated using a precision (expensive) target and a 1 GHz (expensive) digital oscilloscope, before EVERY TEST

Summary

- DO-160H and DO-357A will be worked for all sections over the next 4 years
  - Significant revisions planned for Environmental sections
  - Power Input section will continue to grow, but will (hopefully) be easier to use
  - Section 19 Induced Spikes will (hopefully) be revised to a CS-115 test method
  - Section 20 Reverb will (likely) get a new Field Uniformity Verification procedure
  - Section 22 will get a new Cable Bundle calibration procedure

- MIL-STD-461G incorporates significant changes:
  - Section 4 – Periodic calibration of passive devices no longer required
  - CS106 eliminated
  - CS114 – system verification procedure expanded
  - CS117 added
  - CS118 added
  - RE102 – option to limit frequency range to 1GHz eliminated
  - RS103 – option to measure field level with antenna eliminated

Questions?

Thank you!