Indirect Lightning Testing to DO 160 Section 22
And MIL STD 461G Section CS117

Presented By Louis A Feudi
Ametek CTS
For IEEE EMC Society
All Graphics taken from DO-160 and MIL STD 461G
Why Indirect Lightning Testing

- Previous planes were manufactured using all metal construction which created a Faraday Cage to prevent coupling of lightning on the internal wiring in the plane.
- All coupling was done via apertures in the plane hull, such as Radomes, windows, and other openings in the planes.
- With the use of Carbon Fiber Composite Materials in the construction of the plane, the plane became a giant resistor.
Why Indirect Lightning Testing

- Although many of the components on the plane are critical to the flight operation of the plane, many airframe manufacturers are concerned about the operation of non-mission critical components on the plane.

- Operations such as entertainment systems, WIFI, galley functions are especially critical when on long flights of 6 hours or more.
RTCA

- RTCA is the Radio Technical Commission for Aeronautics
- Publishes DO-160
- Has industry and regulators attending
SAE

- SAE serves the Aerospace, Automobile, Commercial Vehicle and Motorsport industries as a source of standardization of oil grades, transportation standards writing, and consulting services.
- AE2 is the committee for Section 22 “Indirect Lightning Test requirements” technical requirements.
- Attended by Industry Leaders such as test labs, FAA, Airframe Manufacturers and other standards Authorities.
EUROCAE

• EUROCAE is the European Organization for Civil Aviation Equipment
  • Publishes ED84: Aircraft Lightning Environment and Related Test Waveforms
  • Sits in on AE2
  • Practically the same requirements as DO 160
MIL STD 461

• MIL STD 461 is a Department of Defense Interface Standard
• Requirements for the control of Electromagnetic Interference Characteristics of Subsystems and Equipment
Waveform Requirements

- There are 7 waveforms called out by DO-160
- Waveform 1 – 6.4 us x 69 us (Current)
- Waveform 2 - 100 ns x 6.4 us (Voltage)
- Waveform 3 – 1 and 10 MHz (Ring Wave)
- Waveform 4 - 6.4 us x 69 us (Voltage)
- Waveform 5A - 40 us X 120 us (Current)
- Waveform 5B - 50 us X 500 us (Current)
- Waveform 6 - 250 ns X 4 us (Current)
Waveform Requirements

- Waveform 1 – 6.4 us x 69 us
- Current Waveform

- \( T1 = 6.4 \text{ microseconds} \pm 20\% \)
- \( T2 = 69 \text{ microseconds} \pm 20\% \)
Waveform Requirements

- Waveform 2-
- Voltage Waveform

- $T_1 = 100$ nanoseconds maximum $T_2 = 6.4$ microseconds $\pm 20\%$
Waveform Requirements

- Waveform 3  1 and 10 MHz
- Current Waveform

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

- Waveform 4
- Voltage Waveform

- $T_1 = 6.4$ microseconds $\pm 20\%$  
  $T_2 = 69$ microseconds $\pm 20\%$
Waveform Requirements

- Waveform 5A
- Current Waveform (Voltage for a select test)

- $T_1 = 40 \text{ microseconds} \pm 20\%$  
  $T_2 = 120 \text{ microseconds} \pm 20\%$
Waveform Requirements

- Waveform 5B
- Current Waveform

- \( T1 = 50 \text{ microseconds} \pm 20\% \)  \( T2 = 500 \text{ microseconds} \pm 20\% \)
- Waveform 6
- Current Waveform

  \[ T1 = 250 \text{ nanoseconds} \pm 20\% \quad T2 = 4 \text{ microseconds} \pm 20\% \]
• Power levels range from Level 1 for well protected equipment to Level 5 for element exposed equipment or Mission Critical Equipment
TestTypes

- Pin Injection – Direct discharge into the circuit under test
  - Achieved using:
    - inductive coupling onto the cable connected to the circuit
    - Direct connection of the generator to the pins
    - Ground injection using the cable ground shield to couple on the wires
TestTypes

- Cable Bundle – Inductive coupling of the waveform onto the plane’s cable bundles
- Three kinds of cable bundle waveform applications:
  - Single Stroke (Double Exponential)
  - Multi Stroke
  - Multi Burst
<table>
<thead>
<tr>
<th>Waveform Set</th>
<th>Test Type</th>
<th>Test Waveform</th>
</tr>
</thead>
<tbody>
<tr>
<td>C (unshielded, aperture coupling)</td>
<td>Single Stroke</td>
<td>2,3</td>
</tr>
<tr>
<td>D (unshielded, aperture and resistance coupling)</td>
<td>Single Stroke</td>
<td>2,3,4</td>
</tr>
<tr>
<td>E (shielded aperture coupling)</td>
<td>Single Stroke</td>
<td>1,3</td>
</tr>
<tr>
<td>F (shielded, aperture and resistance coupling)</td>
<td>Single Stroke</td>
<td>3,5A</td>
</tr>
<tr>
<td>G (unshielded, aperture coupling)</td>
<td>Single Stroke</td>
<td>2,3</td>
</tr>
<tr>
<td></td>
<td>Multiple Stroke</td>
<td>2, 3</td>
</tr>
<tr>
<td>H (unshielded, aperture and resistance coupling)</td>
<td>Single Stroke</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td></td>
<td>Multiple Stroke</td>
<td>2, 3, 4</td>
</tr>
<tr>
<td>J (shielded, aperture coupling)</td>
<td>Single Stroke</td>
<td>1, 3</td>
</tr>
<tr>
<td></td>
<td>Multiple Stroke</td>
<td>1, 3</td>
</tr>
<tr>
<td>K (shielded, aperture and resistance coupling)</td>
<td>Single Stroke</td>
<td>3,5A</td>
</tr>
<tr>
<td></td>
<td>Multiple Stroke</td>
<td>3, 5A</td>
</tr>
<tr>
<td>L</td>
<td>Multiple Burst</td>
<td>3</td>
</tr>
<tr>
<td>M</td>
<td>Multiple Burst</td>
<td>6</td>
</tr>
</tbody>
</table>
Multi Stroke

Simulates forked lightning strike

14 pulses total
Subsequent strokes are ½ the peak amplitude of the first stroke
Applied using cable bundle test method
Multi Burst

50 µs ≤ Δt ≤ 1000 µs

One burst is 20 transients spaced 50-1000 microseconds

30 ms ≤ Δt ≤ 300 ms

One burst application is 3 sets of bursts spaced 30-300 milliseconds
Cable Bundle Verification Setup

- Oscilloscope
- Voltage Monitor Probe
- Injection Transformer
- Current Monitor Probe
- Open Loop
- Shorted Loop
- Calibration Loop
- Transient Generator
- Monitor Loop
Bulk Cable Injection Test Setup

Oscilloscope

Voltage Monitor Probe

EUT

Current Monitor Probe

Injection Transformer

Voltage Monitor Probe

Monitor Loop

LISN 5-15 cm 5-50 cm

Transient Generator

5-15 cm 5-50 cm

Power Input

Interconnecting Cables

Actual or Simulated Loads and Signals
Ground Injection Test Setup

- Cable Bundle #2
- Current Monitoring Transformer (2)
- Oscilloscope
  - $I_2$
  - $I_1$
- Power Return Local Ground
- Injection Point
- EUT
- Probe
- Support Equipment
- Possible Injection Point
- Ground Plane

Components:
- LISN (28,000 μF Minimum)
- Transient Generator
- Oscilloscope

Setups:
- DC Power Input Setup for DC Power Input
- If Power Return is Local Ground
- AC Power Input Setup for AC Power Input
- If Power Return is NOT Local Ground
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Applicable to:

- all aircraft safety-critical equipment interconnecting cables, including complete power cables, and individual high side power leads
- non-safety critical equipment with interconnecting cables/electrical interfaces that are part of or connected to equipment performing safety critical functions.
- May be applicable to aircraft equipment performing non-safety critical functions when specified by the procuring activity
- This requirement applies to surface ship equipment which is located above deck or has interconnecting cables which are routed above deck.
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- No Pin Injection Testing
- Cable Bundle Testing only
- Multi-Stroke considered representative of Single Stroke Test
<table>
<thead>
<tr>
<th>Test Number</th>
<th>Test Description/Applicability</th>
<th>Internal Equipment Limits ¹</th>
<th>External Equipment limits ¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Multiple Stroke – Waveforms 1 and 2. Applicable to all aircraft.</td>
<td>Initial Stroke ( V_L = 300 \text{ volts (WF #2)} ) ( I_T = 600 \text{ amps (WF #1)} ) ( I_L = 60 \text{ amps} ) ( ² ) Subsequent Strokes ( V_L = 150 \text{ volts (WF #2)} ) ( I_T = 150 \text{ amps (WF #1)} ) ( I_L = 30 \text{ amps} ) ( ² )</td>
<td>Initial Stroke ( V_L = 750 \text{ volts (WF #2)} ) ( I_T = 1500 \text{ amps (WF #1)} ) ( I_L = 150 \text{ amps} ) ( ² ) Subsequent Strokes ( V_L = 375 \text{ volts (WF #2)} ) ( I_T = 375 \text{ amps (WF #1)} ) ( I_L = 75 \text{ amps} ) ( ² )</td>
</tr>
<tr>
<td>2</td>
<td>Multiple Stroke – Waveform 3, (apply at both 1 and 10 MHz) Applicable to all aircraft.</td>
<td>Initial Stroke ( V_T = 600 \text{ volts (WF #3)} ) ( I_L = 120 \text{ amps (WF #3)} ) ( I_T = 12 \text{ amps} ) ( ² ) Subsequent Strokes ( V_T = 300 \text{ volts (WF #3)} ) ( I_L = 60 \text{ amps (WF #3)} ) ( I_T = 12 \text{ amps} ) ( ² )</td>
<td>Initial Stroke ( V_T = 1500 \text{ volts (WF #3)} ) ( I_L = 300 \text{ amps (WF #3)} ) ( I_T = 60 \text{ amps} ) ( ² ) Subsequent Strokes ( V_T = 750 \text{ volts (WF #3)} ) ( I_L = 150 \text{ amps (WF #3)} ) ( I_T = 30 \text{ amps} ) ( ² )</td>
</tr>
<tr>
<td>3</td>
<td>Multiple Stroke – Waveform 4 and 5. Applicable to aircraft with composite skin/structure. Not applicable to an all-metal skin/structure aircraft.</td>
<td>Initial Stroke ( V_L = 300 \text{ volts (WF #4)} ) ( I_T = 1000 \text{ amps (WF #5)} ) ( I_L = 300 \text{ amps} ) ( ² ) Subsequent Strokes ( V_L = 75 \text{ volts (WF #2)} ) ( I_T = 200 \text{ amps (WF #1)} ) ( I_L = 150 \text{ amps} ) ( ² )</td>
<td>Initial Stroke ( V_L = 750 \text{ volts (WF #4)} ) ( I_T = 2000 \text{ amps (WF #5)} ) ( I_L = 750 \text{ amps} ) ( ² ) Subsequent Strokes ( V_L = 187.5 \text{ volts (WF #2)} ) ( I_T = 400 \text{ amps (WF #1)} ) ( I_L = 375 \text{ amps} ) ( ² )</td>
</tr>
<tr>
<td>4</td>
<td>Multiple Burst – Waveform 3, (apply at both 1 and 10 MHz). Applicable to all aircraft.</td>
<td>( V_T = 360 \text{ volts (WF #3)} ) ( I_L = 6 \text{ amps (WF #3)} ) ( F = 1 \text{ MHz, 10 MHz} )</td>
<td>( V_T = 900 \text{ volts (WF #3)} ) ( I_L = 15 \text{ amps (WF #3)} ) ( F = 1 \text{ MHz, 10 MHz} )</td>
</tr>
<tr>
<td>5</td>
<td>Multiple Burst – Waveform 6. Applicable to low impedance bundles only.</td>
<td>( V_T = 600 \text{ volts (WF #6)} ) ( I_L = 30 \text{ amps (WF #6)} )</td>
<td>( V_T = 1500 \text{ volts (WF #6)} ) ( I_L = 75 \text{amps (WF #6)} )</td>
</tr>
</tbody>
</table>

**NOTES:**

1/ Amplitude Tolerance is +20%, -0% for the all waveforms, except the tolerance is relaxed to +50%, -0% for the Subsequent Strokes. \( V_T \) represents the test voltage level in Volts and \( I_T \) represents the test current level in Amperes. \( V_L \) (Volts) and \( I_L \) (Amperes) represent limits intended to prevent over-stressing the EUT beyond the requirements.

2/ Levels intended for individual power leads or low count wire bundles. When multiple leads are tested together, this current shall be increased to the full bundle level or to the number of leads.
The EUT shall not exhibit any malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystem specification, when subjected to the levels and lightning transients specified in Table CS117-1 and supplemented by the waveform and timing definitions shown on Figures CS117-1 through CS117-8.

In the event that there is platform lightning transient data available, this data may be used to tailor the requirements with different selected levels or waveforms, pending approval by the procuring activity.
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- Single stroke same as DO-160

- For the Multiple Stroke test, at the generator setting established in 5.15.3.4c(2), apply a minimum of ten multiple stroke applications while monitoring the operation of the EUT. The maximum time between application of each Multiple Stroke transient shall be no greater than 5 minutes.

- (4) For the Multiple Burst test, at the generator setting established in 5.15.3.4c(2), apply a multiple burst application every 3 seconds (3 seconds between the start of each set of three bursts) continuously for at least 5 minutes.

- Reverse the transient generator polarity and repeat
Repeat on each cable bundle interfacing with each electrical connector on the EUT.

For power cables, perform on complete power cables (high sides and returns) and on the power cables with the power returns and chassis grounds (green wires) excluded from the cable bundle.

For connectors which include both interconnecting leads and power, perform

- on the entire bundle
- on the power leads (including returns and grounds) grouped separately
- and on the power leads grouped with the returns and grounds removed
MIL STD 461 Cable Bundle Test for bundles with Power leads and return removed

- Oscilloscope
- EUT
- Actual or Simulated Loads and Signals
- Current Monitor Probe
- Injection Transformer
- Voltage Monitor Probe
- Transient Generator
- LISN
- Injection Transformer
- 28,000 µF Minimum
- High Return
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Modified Waveform 2

Peak

T1 = 340 nanoseconds maximum
T2 = 6.4 microseconds ± 20%

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- No Waveform 5B!
- Waveforms 1, 3, 4, 5A and 6 the same
Q & A

Questions