Meeting the DO-160 Lightning Protection Standard
Introduction

It has been said that airplanes are the safest form of travel. If that is true, it is because of the efforts of countless engineers and technicians who design aviation equipment to function properly in a wide variety of conditions. As an example, an aircraft is designed so that externally mounted equipment such as antennae, exterior lights, air data probes, external sensors, and anti-ice equipment can withstand the effects of a direct lightning strike.

The analysis of external equipment must also consider all connecting cables and associated terminal equipment. One fairly obvious issue is that the aircraft designer has to prevent the lightning strike from igniting the aircraft’s fuel, a 200 microjoule sensitive fuel mixture. There is substantial art and science in the design of an aircraft which insures that the hundreds of thousands of Amperes of electricity from a lightning bolt flow through the skin of the aircraft and back out to the atmosphere (and eventually to ground). Defense embedded electronics within an aircraft are subject to a similar set of challenges posed by lightning strikes. This white paper will address both the industry standard that sets guidelines for lightning protection and the design practices that are used to comply with the standard.

Meeting the Design and Compliance Challenges

Requirements flow down from the department of defense or the prime contractor with specifications aimed at lightning safety qualification. This can often lead to confusion. For example, how does a Single Board Computer (SBC) protect itself against a 210,000 Amps direct lightning hit? What is required to comply with the applicable standard and how is the compliance validated?

As an aerospace electronics and COTS embedded computing chassis and backplane vendor, Atrenne Computing Solutions frequently has customers bring us these questions. Many C4ISR electronics system integrators lack experience with standards like DO-160 Section 22 and 23, which provide the specific guidelines for testing the resilience of a unit of equipment against lightning effects. Familiarity with the DO-160 standard and understanding design options for compliance are part of the guidance we offer to our integrator customers, helping them overcome these issues.

Read About
Radio Technical Commission for Aeronautics (RTCA)
DO-160 Qualification Testing
Transient Pulse Protection
Lightning: Direct vs Indirect Effects

Direct Effects

An aircraft is divided into zones. Some of these zones are protected from high voltage transients. Other zones are required to survive a high voltage direct strike. One of the important challenges is that a platform designer must understand how cabling and other conductive elements can couple a high energy transient to equipment in various parts of the aircraft.

Most airframes are made of metal and composite materials. If lightning were to strike the nose of the aircraft, for example, the charge would travel outside the plane to the tail and continue to ground through the atmosphere. The construction of the airframe acts as a Faraday cage with as low an impedance path as possible. This type of design minimizes coupling voltages and currents on the internal cabling and wiring of the aircraft and protects mission critical components located internally.

Recently, aircraft construction has increasingly used composite materials which are very lightweight but have greater impedance than metal frames. As impedance increases, it is more likely that voltages and currents will couple directly onto internal cables and into the avionics and other electronic equipment on the aircraft. Fortunately, design strategies within the electronics can mitigate these effects.

The platform designer must take electrical coupling into consideration in the overall platform system design. One of the challenges is that equipment internal to the aircraft can be electrically coupled to the externally mounted equipment by means of cabling. For example, an ISR back-end processing system is usually connected to an externally mounted sensor with a direct cable. Optical cabling is often preferred for these types of applications as it can be specified to run a desired length and it avoids the issue of electromagnetic coupling entirely. Where that is not practical, properly shielded cables can isolate current to the external skin (chassis ground) of sensitive electronics thus mitigating the lightning direct effect.

EMF Interference

Unshielded cable is not generally considered a “best practice,” but it is sometimes used due to its lighter weight. Even in cases where the huge surge of charge from a lightning direct effect has been safely conducted through the aircraft, unshielded cable would be more susceptible to EMF (electromagnetic field) interference which can still wreak havoc on sensitive electronics. The transient current from an EMF is termed a Lightning Indirect Effect or Lightning Induced Transient. A shielded cable contains insulation between the center conductor and the outer shield. A properly shielded cable will see very little EMF, even with the residual charge of a direct lightning strike on the outside of the shield, and will allow electronics to continue to operate normally without interference.

An EMF pulse on an unshielded cable can be on the order of 100 Amps at a few hundred volts, which is significantly more severe than a typical electrostatic discharge (ESD) from a human body. An experienced designer can mitigate these effects to a specified level by using design elements to clamp the voltage or sink current. This is clearly a last line of defense after considering everything else possible at the platform (aircraft) architecture level.
Qualification Testing

EMF noise coupled to an unshielded cable enters a processing subsystem through one of the external IO interfaces, essentially via one of the interface pins. The test to determine whether a system can withstand an EMF transient introduces a charge to the system’s IO interface pins. This is called a pin injection test. Pin injection tests determine whether damage is caused if transient voltage and current are injected directly into the electronics via the external IO pins. During a pin injection test, the point of injection is usually directly onto the IO pin with return to case ground.

RTCA

The RTCA (Radio Technical Commission for Aeronautics) is a non-profit organization, founded in 1935, dedicated to providing guidance and recommendations related to aviation and aviation electronic systems. It serves as a public-private partnership of more than 300 organizations internationally, including airlines, defense contractors, government agencies, manufacturing companies, R&D labs and electronic component suppliers. The organization functions as a Federal Advisory Committee which means that it provides advice and recommendations (not mandates) to the Federal Aviation Administration (FAA) and is governed by certain rules such as the requirement for open meetings, public involvement and reporting.

RTCA recommendations are effectively the work product of members and stakeholders of the aviation community who work together in a consensus-based, collaborative, peer-reviewed environment. The organization’s recommendations are not official statements of law or policy but they are often used as the basis for government and private sector aviation decisions and can be incorporated into law by a government agency with relevant statutory jurisdiction.

The DO-160 Standard

One of the key functions of the RTCA is to recommend solutions that increase safety and efficiency of air travel. One of the most important standards is DO-160 (“Environmental Conditions and Test Procedures for Airborne Equipment”) which seeks to define a minimum standard set of test procedures for airborne equipment.

DO-160 (or its precursor, DO-138) has been used as a standard for environmental qualification testing since 1958. These test procedures allow safety stakeholders to validate performance characteristics of equipment under conditions which are similar to those encountered in actual flight. In defense electronics, DO-160 serves as a set of design criteria and a standard for qualification testing. It appears frequently in RFP/RFQ’s that specify components or solutions for airborne platforms.

The Testing Guidelines Addressed in RTCA/DO-160 Include:

- Temperature and Altitude
- Temperature Variation
- Humidity
- Vibration
- Explosive Atmosphere
- Waterproofness
- Fluids Susceptibility
- Sand and Dust
- Fungus Resistance
- Salt Fog
- Power Input
- Voltage Spike
- Audio Frequency Conducted Susceptibility — Power Inputs
- Induced Signal Susceptibility
- Radio Frequency Susceptibility
- Emission of Radio Frequency Energy
- Lightning Induced Transient Susceptibility
- Lightning Direct Effects
- Icing
- Electrostatic Discharge (ESD)
- Fire, Flammability
- Environmental Test Identification
Lightning Induced Transient Susceptibility

RTCA/DO-160, Section 22

As discussed above, the direct lightning strike on an aircraft causes indirect voltage transients due to magnetic or electric field coupling. These indirect effects are covered specifically in Section 22 of RTCA/DO-160. Section 22 provides test methodology and procedures to validate that a set of equipment is able to withstand lightning induced effects such as the EMF pulse that is an indirect effect of a lightning direct hit. Note that RTCA/DO-160, Section 23 is a separate section that deals with Lightning Direct Effects. Table 1 defines lightning direct and indirect effects.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Definition</th>
<th>Qualification Testing Guidelines</th>
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<tbody>
<tr>
<td>Lightning Direct Effects</td>
<td>Huge surge of charge from a direct lightning hit to equipment mounted externally on an aircraft</td>
<td>Section 23</td>
</tr>
<tr>
<td>Lightning Indirect Effects</td>
<td>The transient current and voltage spike introduced into electronics cables as a result of the magnetic field generated by a large surge of charge traveling through the frame of the aircraft. Sometimes called a lightning transient or lightning induced effect.</td>
<td>Section 22</td>
</tr>
</tbody>
</table>

Table 1 Testing Guidelines for Lightning Effects

DO-160 Section 22 allows equipment to be tested to an appropriate anticipated exposure level consistent with the expected use and installation location on the aircraft. There are five levels for internal aircraft equipment and interconnecting wiring:

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Focus of Mitigation</th>
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<tbody>
<tr>
<td>1</td>
<td>Well-protected environment</td>
<td>IO Panel</td>
</tr>
<tr>
<td>2</td>
<td>Partially protected environment</td>
<td>IO Panel</td>
</tr>
<tr>
<td>3</td>
<td>Moderately protected environment</td>
<td>IO Panel</td>
</tr>
<tr>
<td>4 and 5</td>
<td>Severe electromagnetic environments</td>
<td>Platform design, shielding</td>
</tr>
</tbody>
</table>

Table 2 Environmental Levels

The aircraft is divided into a variety of zones and each of these zones has an associated electromagnetic severity profile. Some zones are subject to severe EMF indirect effects due to electromagnetic coupling and must be designed and tested to Level 5. Conversely, equipment installed in a well-protected environment (Level 1) has the least stringent requirements. C4ISR equipment based on the VPX architecture that needs to operate in Levels 4 and 5 must have the proper shielding and support from the platform architecture. Mitigation strategies within the design of the IO board and IO front panel are typically effective only to Level 3 and below, due the electronic component size required to safely suppress the Level 4 and 5 transients.
DO-160 Electronics Testing Details

There are two basic types of tests in RTCA/DO-160 Section 22:

Pin injection tests – a simulated EMF pulse is applied directly to the pins of the external IO interface, usually between each pin and the case ground. The purpose of this test is to demonstrate that the equipment under test displays the desired tolerance to transient current without disturbing application execution.

Cable bundle tests – a transient pulse is applied by cable induction or ground injection. The pulse may be applied to the cables one at a time or to the entire set of cables simultaneously.

Below is a table from DO-160 Section 22 which describes voltage and current transient wave forms. DO-160 specifies several canonical wave forms which emulate Lightning Induced Transients.

<table>
<thead>
<tr>
<th>Level</th>
<th>Waveform Generator Setting Levels for Pin Injection*</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Voc/Isc*</td>
</tr>
<tr>
<td>3/3</td>
<td>100/4</td>
</tr>
<tr>
<td>2</td>
<td>250/10</td>
</tr>
<tr>
<td>3</td>
<td>600/24</td>
</tr>
<tr>
<td>4</td>
<td>1500/60</td>
</tr>
<tr>
<td>5</td>
<td>3200/128</td>
</tr>
</tbody>
</table>

Table 3 Waveform Generator Setting Levels for Pin Injection*

Voc – Peak open circuit Voltage (Volts)
Isc – Peak short circuit current (Amps)

The standard defines a series of prototypical waveforms which are used to apply current and voltage to the interface pin of the unit under test. Table 3 above shows the general setting levels for pin injection testing. It shows the range of peak voltages and currents required to be qualified to various Levels. For example in the middle column of the table above, when pin injection tests are performed at Level 3, the voltage (300V) spike follows Waveform 4 and the current (60A) spike follows Waveform 1. Waveform 1 and Waveform 4 are shown below, which in this case, happen to be in phase and identical. Both Waveforms (see below) show a fast rise to peak amplitude and then a slower degradation. Other wave forms include variations of Waveform 1, sinusoids and multi-stroke pulses.
Design Considerations

ESD Protected Components

Design for RTCA/DO-160, Section 22 qualification requires a review of each interface individually and a design strategy for each. The design of the chassis IO panel can incorporate lightning protection circuitry depending on the unique requirements of each interface component. For example, a component with ESD protection is designed to survive a spike characteristic of a human electrostatic discharge, typically an 8 µsec pulse of 15 kV. When a pulse of this magnitude is encountered, the part has some clamping current limit, for example, the equivalent of 50 mA steady-state. Once this is known, it can be built upon. Circuitry can be added to the front panel IO circuit board of the chassis to withstand a Level 3 transient pulse and reduce it to a pulse which is within the ESD protection capability of the part in question.

It may be tempting to look at the ESD resistance of a part and conclude that it can pass lightning pin injection tests. However, this is rarely true given the unique waveforms and high voltage and current profiles associated with DO-160 Section 22. It is better to think of ESD protection as a starting point and then add circuitry to enhance that capability.

I/O Interfaces

Lightning protection is most easily implemented on lower speed signals such as 1553, RS-422/232, GPIO, and analog signals (such as might be connected to a digital POT or a 12V Op-Amp), which can tolerate the shunt capacitance inherent in the connected transient-suppressing circuitry. It is more challenging to protect high speed signals such as Gb Ethernet, SATA or USB beyond level 1 or 2. In the case of high-speed serial interfaces, it may be best to co-locate the high speed IO to common 38999 connectors and use shielded cabling rated for the application requirement.

Protection Components

Lightning protection circuitry employs various approaches including Zener diodes, transient voltage suppressors, thyristors, and others. As an example, a thyristor is a semiconductor device that can be used to conduct current to ground when the voltage exceeds a certain threshold level, for example 40V. During normal operation, voltage may be at 3.3V, 5V or 12V. The thyristor remains open with a parasitic capacitance of perhaps 100 picofarads. A Level 3 grade lightning surge is in the range of 300V to 600V. Once the thyristor’s voltage threshold is exceeded, it will conduct the short surge to chassis ground or clamp the voltage to a value that is within the downstream circuitry operating range.

The front IO panel and its associated circuit card assembly become key elements in any lightning mitigation design. It isolates the lightning protection circuitry to a separate card allowing the protection to be customized for each application. VPX boards can then be standard commercial-off-the-shelf (COTS) while still meeting the regulatory flow downs required by a specific program. In cases where there is no IO card, the lightning circuitry can be located on the backplane, real-estate permitting. As a last resort, payload modules can be redesigned with application specific lightning mitigation circuitry, but real-estate on COTS modules is very precious and usually reserved for market-driven general purpose functionality.
Summary

Mitigation of the effects of lightning on sensitive electronics requires a top-down design approach. Shielded cables and properly designed electronic packaging can isolate sensitive electronics from a lightning direct hit and/or lightning indirect effects. Unshielded cabling is susceptible to large voltage and current spikes due to EMF interference. These effects can be managed at the IO front panel and IO circuit card using a number of circuit design strategies. This allows a COTS integrated design to be enhanced to pass RTCA/DO-160 Section 22 qualification.

Learn More

White Paper: The Cure for the System Test and Qualification Headache
Chassis Solutions Guide
Backplane Solutions Guide

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