



Induced Lightning Testing of Avionics – with Single Stroke, Multiple Stroke, and Multiple Burst

Environmental Condition and Test Procedures of Prevalent Standards for Airborne Equipment

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1 Introduction

A recent study of the Federal Aviation Administration reveals that the average civil aircraft is struck by lightning every 1000 flight hours. It is imperative that all aircraft be tested to withstand the effect of lightning. Lightning events differ mainly in current amplitude, in the transferred charge and in the impulse shape of the lightning current. Two lightning simulations can be defined:

- Simulation of the direct strike current and voltage
- Simulation of the induced currents and voltages within the aircraft resulting from the direct strike

The induced lightning current and voltage waveforms and impulse generator impedance values to create these waveforms have been measured on avionics systems within aircraft subjected to direct strike events. Test standards including MIL-464 and DO-160 specify both direct and induced strike pulse sequences and levels. Revision 3 of RTCA/DO-160 D (Dec. 2002) mandates that three sequences of pulses be used for induced lightning testing of avionics:

- Single Stroke (SS)
- Multiple Stroke (MS)
- Multiple Burst (MB)

SS events are used for damage assessment on avionics subsystem and equipment. The MS and MB events are applied to determine the electromagnetic compatibility of system, subsystem, and equipment. Multiple Stroke and Burst events are specified for the first time in Revision 3 of DO-160 D; although they have been anticipated for a number of years and even recommended by the FAA Advisory Circular AC 20-136 and manufacturer specific testing protocols. Test Engineers are now seeking commercial off the shelf test generator solutions for these MS and MB events. Understanding the nature of the MS and MB lightning events and their coupling modes is critical to selecting the appropriate test system for the lightning induced transient tests specified in DO-160 D Rev. 3 Section 22.

The test system must provide the capability to generate and inject all the specified induced lightning waveforms and impulse sequences in SS, MS, and MB modes while providing the specified waveform and level at the appropriate injection device output when loaded with the EUT and its cabling. In one commercially available solution produced by EMC PARTNER, all the high energy pulses, double exponential impulse waveforms (strokes), are generated by the multiple stroke generator. Lower energy waveforms, including one of the strokes and the damped sinusoidal pulses (bursts), are produced by the multiple burst generator. A brief explanation of the lightning source and coupling paths of each waveform along with a comparison of the specified limits and test levels of a leading commercially off the shelf DO-160 test system's output for each waveform follows.

2 Lightning Testing and DO-160

The disturbance levels inside the aircraft are induced from the external direct strike sequence of events and are a function of many structural details of the aircraft, penetration of apertures and seams, platform and cable resonances. Aircraft today are complex from a materials usage and electronics standpoint. Many structural materials are non-metallic and have unique electromagnetic properties which require careful consideration, while electronics performing critical functions are common and dispersed throughout the aircraft. The internal environment is usually expressed as the level of induced transient electrical current and voltage stresses appearing at the interface to the equipment. These internal stresses are typically associated with standardised lightning induced transient susceptibility requirements

for equipment as defined in the document RTCA/DO-160 "Environmental Conditions and Test Procedures for Airborne Equipment". The RTCA/DO-160 has a long history in avionics testing. The document covers standard procedures and environment test criteria for testing airborne avionics equipment for the entire spectrum of aircraft; from light general aviation aircraft and helicopter through the big aircraft and supersonic transport classes of aircraft. There is also a very high probability that this standard will be accepted for space system testing in addition to the IEC standards for commercial parts used in space stations. DO-160 is co-ordinated with EUROCAE and also recognised by the international organisation for standardisation (ISO). The document includes 25 sections and appendixes: Sections 15 to 23 and 25 cover EMC. The lightning induced transient susceptibility is defined in section 22 and the Electrostatic Discharge ESD in section 25. MIL-464, FAA Advisory Circular, and manufacturer specific lightning testing requirements typically share the waveform definitions of DO-160, but can have significant differences in the Multi Stroke and Multi Burst pulse sequences specified.

2.1 Idealised and standardised induced waveforms

The external lightning environment, simplified with the four component waveforms A to D (Fig.1), will interact with an aircraft to induce voltage and current transients in conductors such as wiring inside the aircraft. There are several mechanisms by which the external environment induces transients. These can be broadly divided into aperture coupling and resistive coupling. Most actual induced transients are complex waveforms which result from combinations of both coupling mechanisms. For design and verification purposes it has proven most practical to separate them and define the set of simpler waveforms described below.

2.1.1 Resistive coupling

- These mechanisms will produce voltages in loops existing between cables and the structure of an aircraft. These voltages may have the shape of the external environment waveform for highly conductive structures. Hence the most common transient voltage waveshape (waveform 4, 6.4/70µs) is that of the lightning stroke current waveshape of component A. This type of voltage waveform will also appear on conductors within shields due the product of shield current and shield transfer impedance.
- The current in low resistance cables connected to the airframe structure at each ends results from the redistribution of the external lightning event as it galvanically couples from relatively low inductance external airframe structure to the relatively high inductance of the cable with respect to the structure. Inside an airframe made of low impedance structure such as aluminium, the current in the cables will be long, but of insignificant amplitude. For cables inside a more resistive structure of carbon fibre for instance, the current can have an even longer double exponential waveform and with significant amplitude. The waveshape can vary widely and as a compromise two waveforms are defined: current waveform 5A (40/120µs) models resistive coupling in an aluminium airframe. and waveform 5B (50/500µs) models resistive coupling in a carbon fibre airframe. Current resulting on the conductive structure at a frequency characteristic of the length of the structure may induce voltage and current with the damped sinusoidal shape directly at a frequency characteristic of the length of the structure between 1 to 10MHz. Waveform 3 at 1 MHz and 10

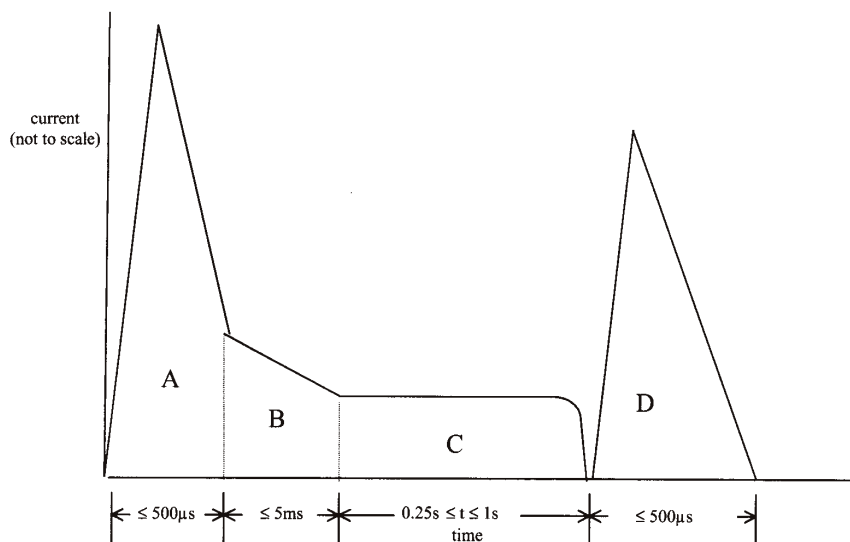


Fig. 1: Current components A through D for Direct Effects testing

MHz models this event.

2.1.1 Aperture coupling

- Magnetic fields penetrating through apertures will induce currents whose waveshape is that of the driving external environmental waveform A (waveform 1, 6.4/70 μ s).
- Voltage in loops existing between cables and the structure, whose waveshape is that of the derivative of the driving external environment component A generate (waveform 2, 0.1/6.4 μ s).
- Electric and or magnetic fields penetrating through apertures will drive or excite resonances on cables producing pulses which have the form of damped sinusoids waveform (waveform 3, 1 MHz and 10 MHz). The frequency will be dependent on the structure length and or cable length and termination components. Frequencies often range between 1 and 10 MHz.

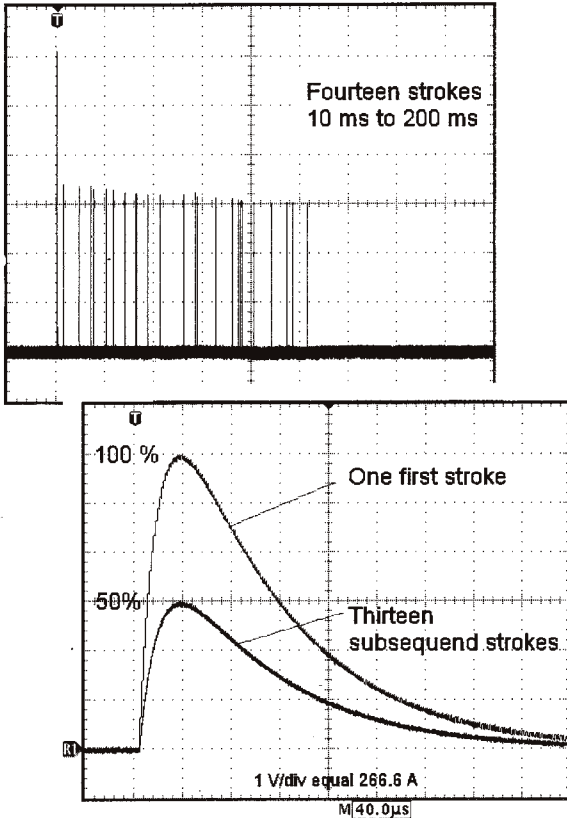


Fig. 2: Multiple Stroke generated with MIG0600MS

2.2 Multiple Stroke

Definition: The multiple stroke is defined as two or more lightning return strokes randomly spaced occurring during a single lightning flash.

Typical lightning events include several high current strokes following the first return stroke (component D Fig. 1). These occur at intervals of several milliseconds as different pockets in the cloud feed their charge into the lightning channel. Another source is the swept channel process. If a fast moving aircraft experiences a direct strike, then throughout the flash, the points of arc attachment are likely to be swept backward along the aircraft, since the lightning channel tends to remain stationary relative to the surrounding air.

The multiple stroke set includes a first transient which corresponds to the first return stroke followed by up to 13 or even up to 23 pulses which corresponds to subsequent return strokes. All of the transient waveform responses may occur in the multiple stroke mode.

- The multiple stroke generator must produce pulse sets which can be generated for all the waveforms defined in DO-160 D Rev. 3 with up to 24 pulses within 2 seconds (Fig. 2). Although DO-160 D Rev. 3 specifies 14 pulses over a period of up to 1.5 seconds manufacturers may base their own induced pulse sequence requirements on FAA Advisory Circular AC 20-136 or on MIL-464.
- Previous versions of EUROCAE ED 84 also specified the 24 pulses within 2 seconds. As long as direct strike standards specifying the 24 pulses within 2 seconds exist it is wise to have induced lightning test equipment which is capable of meeting that sequence. The military and manufacturers are free to specify the more severe testing and may be required to do so as part of their contractual requirements.

2.3 Multiple Burst

Definition: Randomly spaced groups of short duration, low amplitude current pulses, with each pulse characterised by rapidly changing currents. These pulses may result from lightning leader progression or branching. The pulses appear to be most intense at the time of initial leader attachment to the aircraft. Transient responses arising from the magnetic field of the external environment (component H) of the multiple burst waveform set will also occur in the induced multiple burst sequence. The predominant waveform responses are the damped sinusoidal Waveform 3 in a frequency range between 1 to 10 MHz.

- The multiple burst generator must be capable of producing pulse sets with Waveform 3 at 1 & 10 MHz in bursts containing 20 transients per burst with 24 bursts applied within 2 seconds with time intervals between pulses and bursts as defined in DO-160 with up to 24 x 20 individual pulses within two seconds (Fig. 3). This exceeds the 3 bursts within 300 ms specified in DO-160 D Rev. 3, and serves to enable the more severe testing called out by other Avionics standards as described above for Multiple Stroke.

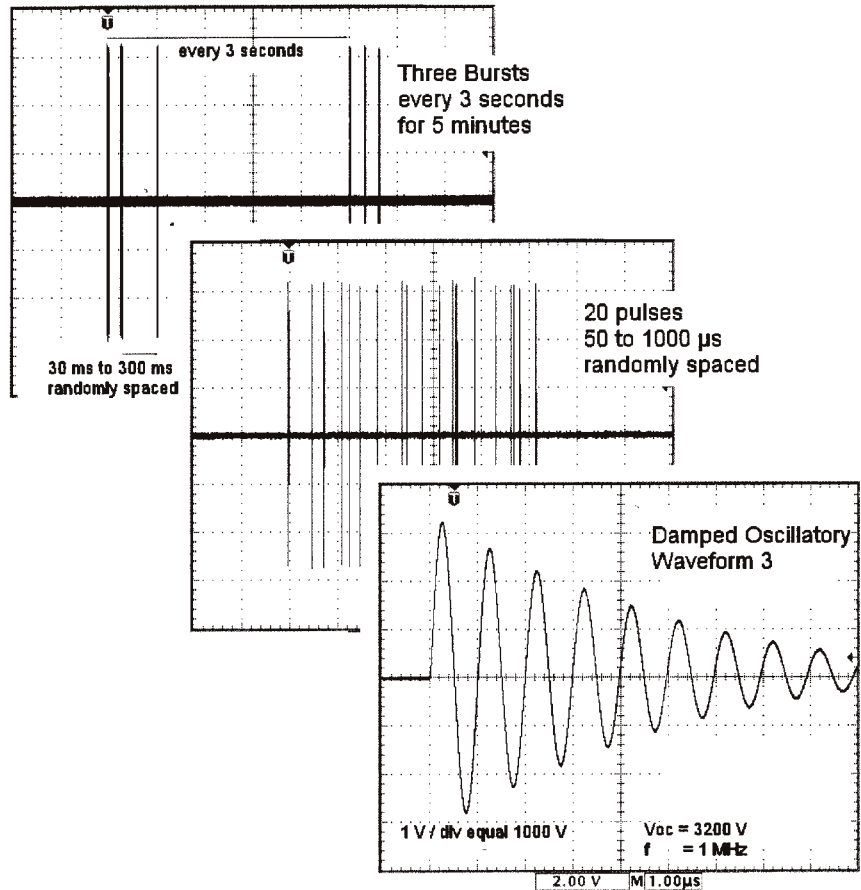


Fig. 3: Multiple Burst generated with MIG-OS-MB

3 Testing practice

Basically two tests can be differed: pin injection and cable bundle induction.

3.1 Pin injection tests

Pin injection tests are primarily for damage assessment and involve the injection of transients directly into EUT interface circuits. This method is used for assessing the dielectric withstand voltage or damage tolerance of equipment interface circuits. The waveform is defined as open circuit voltage V_{oc} and short circuit current I_{sc} at the injection point. The generator impedance is equal the V_{oc} / I_{sc} .

3.2 Cable bundle tests

Cable bundle tests determine whether functioning equipment will experience upset or component damage when the equipment and its interconnecting wiring are exposed to the applied transients. The test must be performed on fully configured and functioning equipment complete with interconnecting cable bundles and interface loads. The test requirement is satisfied by applying the specific waveform, verified in the calibration set-up. Voltage and current has to be monitored during the test to verify reaching either the test level or test limit. A consequence of cable bundle tests is that the actual levels reached are dependent on the load impedance presented by the EUT to the test generator.

4 Test Lab Equipment

In the past test labs typically performed only Single Stroke testing. Multiple Stroke and Multiple Burst were not yet required by standards and Single Stroke was that most labs could cobble together from various components commercially available. There was no single vendor which could provide a complete system for SS, and certainly not for Multiple Stroke or Multiple Burst. Instead, the labs were forced to engineer their own test systems from disparate pieces of equipment. Home made impulse generators for double exponential pulses, amplifiers without enough power to reach upper test levels of damped oscillatory waves, coupling and monitor probes from yet other vendors; you get the picture. None of these components were intended to be used together. The results were endless test equipment set-up times, almost unobtainable test repeatability, and extraordinarily long test sequence times.

Today's additional requirements for Multiple Stroke and Multiple Burst along with



Fig. 4: MIG-OS-MB



Fig. 5: MIG0600MS

the increased diameters of cables bundles in aircraft make yesterday's approach to test lab equipment obsolete. It takes a precision engineered system to produce all these waveforms at the highest test levels for SS, MS and MB. A system with dedicated pulse and oscillatory waveform generators designed to couple with application specific injection probes and calibration set-ups. Yesterday's techniques just do not meet today's requirements. See Tables 1 & 2 for Equipment and Testing overviews.

Figures 4 & 5 depict off the shelf solutions for SS, MS (Fig. 5) and MB (Fig. 4). Today's systems use patented solid state high voltage switching to generate the MS and MB test sequences which were practically impossible to obtain from commercially available test equipment until recently. They provide incredible pulse repeatability and system reliability with application specific injection and monitor probes. These are truly integrated systems. Look for a vendor with years of service in some of the most gruelling testing environments world-wide, software with reporting and control capability to automate the entire process, and ability to program multiple stroke and multiple burst set from world wide avionics standards.

4.1 Summary of MS and MB waveforms and Commercially Lab equipment

- For PIN injection all tests specified in the DO-160 document up to level 5 can be generated.
- For single and multiple pulse test all levels up to 4 can be reached in cable induced mode. For certain loads also level 5 tests can be carried out. see table below.
- For multiple burst transients test all levels up to 5 can be reached in cable induced mode

An example is given for severe electronic environment with all waveforms in table 2.

Generators	Generators for all 6 waveforms. Test system covers the full range: The Multiple Burst Generator for W3 @ 1MHz, 10MHz and W2 0.1/6.4µs Multiple Stroke Generator for W1 & W4 6.4/70µs, W5A 40/120µs & W5B 50/500µs.
Coupling Clamps	For cable bundle injection. The clamp needs to be designed for high voltage time products and high amplitudes. It is highly desirable to have a single clamp to each generator for both strokes and bursts.
Ground Injection Transformer	To inject the required currents up to 10000A and to protect the generator from possible ground currents.
LISN	Two different Line Simulation Networks specially designed to handle the high peak voltages.
Measurement Probes	Current probes with a bandwidth >20MHz and a very high saturation level to measure long pulses up to 10000A. High voltage probes >20MHz and >4kV
Test Table	With a solid ground plate and a size of usually greater than 2m x 5m (only necessary for W2 and W3)

Table 1: Required test equipment for lightning tests in accordance with DO-160 section 22

Waveform	1	2	3	4	5A	5B
	Current pulse 6.4/70µs	Voltage pulse 0.1/6.4µs	Voltage pulse 1MHz, 10MHz	Voltage pulse 6.4/70µs	Current pulse 40/120µs	Current pulse 50/500µs
	Waveshape of initial return stroke	Derivative of initial return stroke	Through resonances in cables	Waveshape of initial return stroke	Through resistive voltage drop in aluminium structure	Through resistive voltage drop in carbon fibre structure
Single stroke	1500A	750V	1500V	750V	2000A	2000A
Multiple Stroke	1x750A +13x325A	1x750V + 13x325V	1X1500V + 13x750V	1x375V + 13x190V	1x800A + 13x400A	1x800V + 13x750V
Multiple Burst	---	---	3x20x900V	---	---	---

Table 2: Waveforms, Sequences and Test Levels for equipment installed in severe electromagnetic environments

For further information please do not hesitate to contact EMC PARTNER's representative in your region. You will find a complete list of our representatives and a lot of other useful information on our website:

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