Whitepaper

Experiences with level 5 requirements for indirect lightning tests to RTCA DO-160

Test Equipment Requirements

DO-160 section 22 Indirect Lightning

Contents

1 Introduction

Aircraft design and assembly is a global phenomenon. Sub systems are designed, manufactured and tested in multiple locations, only being shipped to the aircraft assembly plant on demand. This global process requires comparable tests producing identical results no matter where in the world they are performed. Standardization of test methods and equipment go a long way to achieving these objectives. The RTCA D-160 is ideally suited to fulfil this standardization role.

Two sections of DO-160 deal with lightning effects and there is a close relationship between them.

Section 22 (Lightning induced transient susceptibility)

Section 23 (Lightning direct effects).

Section 22 specifies requirements for equipment level tests using indirect lightning effects, section 23 deals with direct lightning strikes.

Tests on individual LRUs (Line Replaceable Units) are treated as stand-alone black boxes. They can be sold to multiple aircraft manufacturers who require a baseline performance. This is provided by testing to the "generic" DO-160 section 22 requirements.

Direct lightning effects covered by section 23 of DO-160 are performed on whole aircraft usually in only a few locations (aircraft manufacturers) and therefore has very specific space requirements. The external or direct lightning event is characterized by high current discharges reaching 200kA and described as a „four component" test, there being four distinct phases to the lightning event.

The generation of such discharges requires large and very expensive test equipment and a lot of space. This type of testing is certainly more representative of the real event, but poses additional problems in evaluating the effects and assessing any latent damage that may have occurred to equipment, cabling or interfaces. This task could take many years and become significantly more expensive than the test itself.

2 Equipment location, waveform sets and test levels

When lightning strikes a metallic aircraft in flight, the Faraday cage effect protects systems mounted inside by conducting impulse current along the airframe outer skin to exit via wing tip or tail structures. Modern aircraft use significant amounts of composite material in the basic structure. This, combined with the increasing reliance on electronics for everything from seat controls to fly-by-wire systems, leads to problems not experienced in the past. Significantly, higher disturbances can be induced into electronic systems and the many miles of power supply and data communication cabling throughout an airframe.

Equipment location and critical nature determines applicable test levels and event types. External lightning zones specified in section 23 of DO160 refer to equipment mounted externally to the airframe and are not directly applicable to section 22 requirements. As a general rule DO160 suggests four installation protection zones.

Zone a) Well protected environment for example within the passenger cabin. Because equipment located in this environment is furthest from the aircraft skin and most likely receives protection through the systems it communicates with, the lowest test levels apply. For DO160, this is level 1

Zone b) Partially protected environments such as equipment electronic bays are distributed around the airframe with cables linking equipment in other zones or to another electronic bay. Cables linking electronic bays, regardless of whether they run through a well-protected environment, should be considered as belonging to the equipment bay category. DO 160 recommends testing to level 2 for such equipment and cables.

Zone c) Moderately protected environments are considered to be those areas potentially subject to direct electro-magnetic interference effects. Cockpit areas fall into this category and DO160 recommends equipment mounted here be subjected to tests at level 3.

Zone d) Equipment subject to severe electro-magnetic effects are most likely in airframes with significant amounts of composite material without wire meshing. In general equipment in this category could be landing gear or propulsion system controls. They are recommended to be tested to level 4 or 5.

Ultimately, an aircraft manufacturer is responsible for defining the internal zones and appropriate test levels. Proprietary documents describe equipment location, routing of cables, etc. and relate these to appropriate test levels. An example for a composite aircraft defines the following zones

Zone a) inside fuselage

Zone b) Flight deck areas specifically where cabling is within 1m of a window, tail cone, wheel wells, wing/body fairing and radomes

Zone c) Wings, empennages, struts and engines

Zone d) Landing gear

In each case, an appropriate waveform set and test level are given.

Typical of modern aircraft construction is the incorporation of multiple materials with differing electrical properties. The varying degrees of shielding, current carrying capability, etc. influence location category, waveform set and test levels to be applied.

3 Test requirements and costs for WF2 and WF3 generator.

From the previous discussion and zone examples, it can be deduced that the majority of equipment require testing to level 3. This has a direct influence on the test equipment requirements and cost.

A basic premise for designing any impulse generator, is that the calibration procedure, and for cable bundle tests, specifically the EUT load must be clearly defined and understood. When discussing a generator impedance, this is characterized by measuring waveforms into an open circuit and then a short circuit condition. Only these two states can be defined with any degree of certainty. Waveforms can therefore only be truly specified under these controlled conditions. Once an EUT is connected, the impedance is unknown, and the wave-shape may alter.

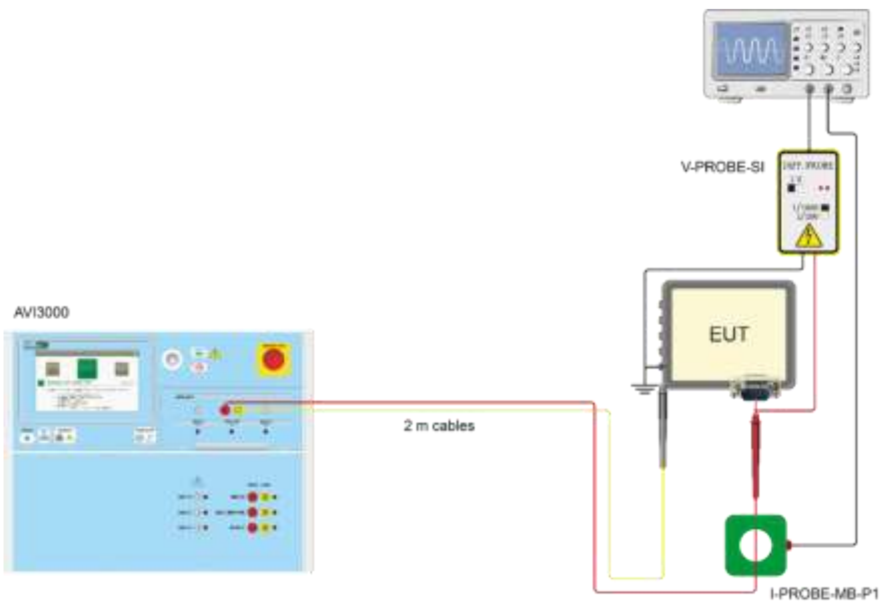

Figure 1: PIN Injection generator.

The transient generators specified in DO160 and characterized by PIN injection requirements are only for PIN injection tests and have limited use for cable bundle testing.

Most wave-forms are only slightly influenced by the connection leads and therefore the generator source impedance can be directly expressed as Voc / Isc.

Using this information and following the clearly defined calibration set-up in DO160, it is relatively straightforward to design a generator for PIN injection tests.

Table 22-2 of DO160, specifies Voc = Voltage amplitude in open circuit and Isc = Current amplitude in short circuit „at the injection point". This should be interpreted to include connection cables and test tips required to deliver the impulse to an EUT.

Table 22-2 Test Levels for Pin Injection

Level	Waveforms		
	3	4	5A
	Voc/Isc	Voc/Isc	Voc/Isc
1	100/4	50/10	50/50
2	250/10	125/25	125/125
3	600/24	300/60	300/300
4	1500/60	750/150	750/750
5	3200/128	1600/320	1600/1600

V_{oc} = open circuit voltage

I_{sc} = short circuit current

$$Z_{generator\ impedance} = V_{oc} / I_{sc}$$

Figure 2: PIN Injection requirements define generator impedance.

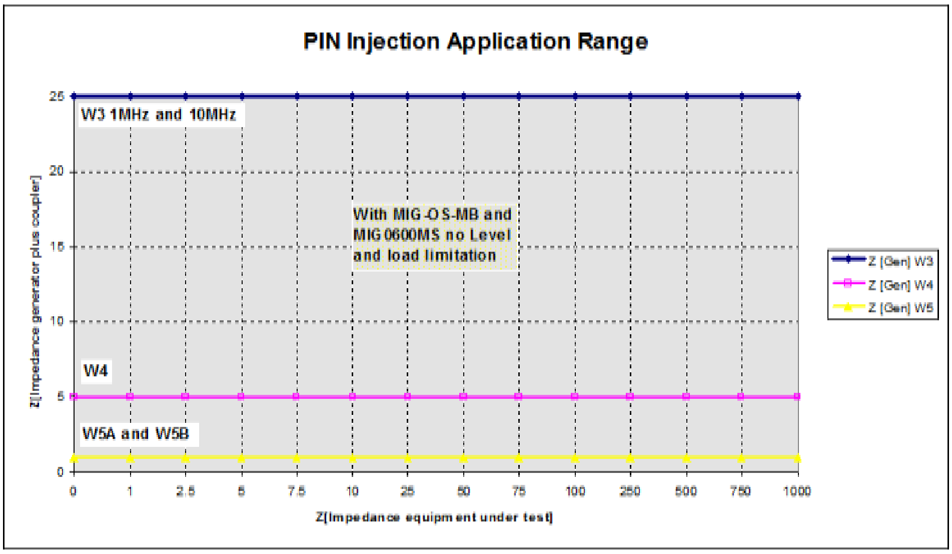

Figure 3: WF3, WF4, WF5A & WF5B calibrated PIN injection generators can be used for any EUT load condition.

Design of a generator for cable induction test is much more complex and requires an understanding not only of the test requirements, but an interpretation of those requirements for use in practical testing.

DO160 test for multiple burst, wave-form 3 1MHz and 10MHz, can easily reach all levels up to 5 because the energy requirement is relatively low, presenting no great technical challenge to test equipment designers. On the other hand, Level 5 single stroke and multiple stroke requirements are more difficult to attain.

DO160 requirements for cable bundle do not rely on a fixed impedance generator. Cable bundle tests take into account the potential influence of EUT cabling on the impulse waveshape focusing primarily on the amplitude by defining parameters of „I Test“ and „V Test“ or „I Limit“ and „V Limit“ values.

A „Test“ level is the ideal that should be reached if possible. The „Limit“ level is the maximum allowable value measured in a cable bundle to prevent over stressing the EUT. If limit vales are reached, the test is to be stopped and the applied waveform reassessed.

Table 22-3 Test Levels for Cable Bundles Single Stroke

	Waveforms				
	1	2	3	4	5A
Level	V_L/I_T	V_T/I_L	V_T/I_L	V_T/I_L	V_L/I_T
1	50/100	50/100	100/20	50/100	50/150
2	125/250	125/250	250/50	125/250	125/400
3	300/600	300/600	600/120	300/600	300/1000
4	750/1500	750/1500	1500/300	750/1500	750/2000
5	1600/3200	1600/3200	3200/640	1600/3200	1600/5000

V_L = voltage limit V_T = voltage test level

I_L = current limit I_T = current test level

$V_x/I_x = Z_{EUT}$ only then can V/I_L or V/I_T be reached

Figure 4: Cable bundle requirements do NOT define a generator impedance.

The „Test“ and „Limit“ values are sometimes misinterpreted as defining the generator impedance. As seen previously, generator impedance is given ONLY by the PIN injection requirements.

Because the cable bundle impedance is so significant, it naturally follows that type and routing of the cable, or the impulse injected can have a big influence as to whether the „Test“ or „Limit“ value is reached first.

The following charts help to illustrate this point for waveform 3.

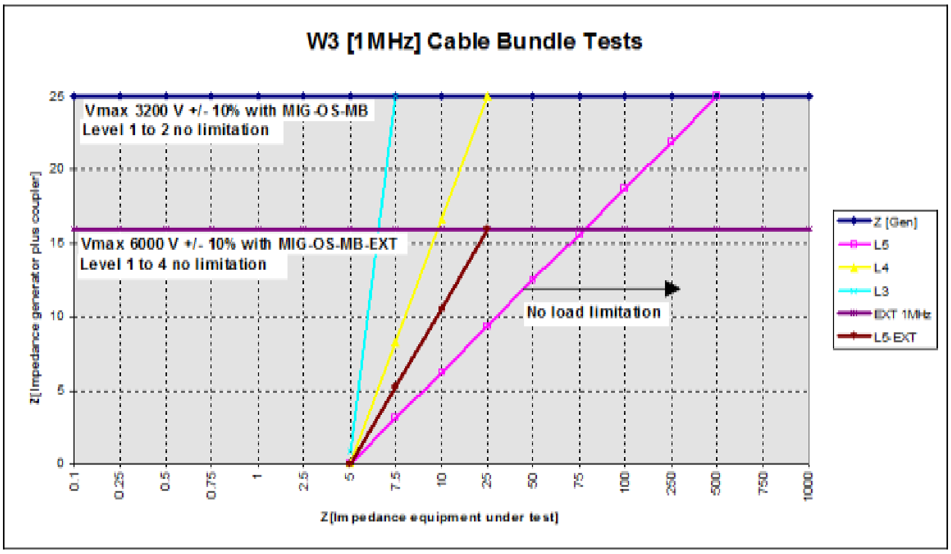

Figure 5: Cable bundle influence on waveform 3 test levels.

From table 22-3 of DO-160, we could deduce an EUT characteristic impedance of 5 Ohms for Waveform 3 (3200V/640A). This is only true under very specific circumstances as the following example illustrates.

Characteristic impedance for a cable is given by:

XL = 2 x π x f x L

For a multi-wire cable of 3.3m length, the inductance approximates to L = 1uH

At 1MHz, this equates to an impedance XL = 6.3ohm

This is very close to the 5ohm used by the standard.

At 10MHz and using the same cable the situation changes as follows:

XL = 62.8ohm

The new situation is reflected in the following chart.

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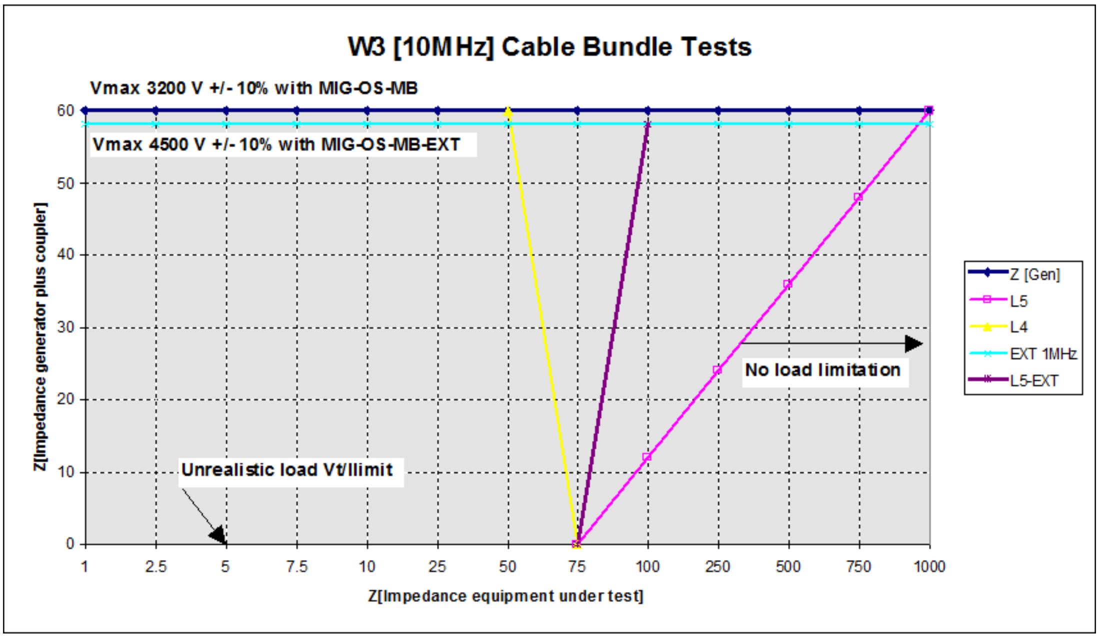


Figure 6: Cable bundle requirements do NOT define a generator impedance.

Because of these application limitations, multiple stroke level 5 waveforms can only be reached under certain conditions.
WF1 & WF5 specify voltage as „Limit“ and current as „Test“, this is equivalent to an EUT presenting a maximum impedance to the test system.
For WF2, WF3 & WF4 current is specified as „Limit“ and voltage as „Test“, this is equivalent to an EUT presenting minimum impedance to the test system.

4 Generator output voltage for waveform 3

Waveform 3 (1MHz and 10MHz) and its application according to DO-160 has some special parameters which make design and use of a suitable generator somewhat complex. For example, this type of damped sine-wave can only be reliably generated using an electronic switch. This waveform is defined as a hybrid, both voltage and current have the same form, with relatively high values for voltage and current (3,200V / 128A PIN injection). Following the earlier discussion, this defines the generator output impedance to be Zout = 25 ohms. Now we come to the next problem. Because of the relatively high frequencies involved (1MHz and 10MHz), it is necessary to use co-axial cable to transfer energy from generator to coupling device. This method reduces waveform distortion and interference with the environment. For the 10MHz signal in particular, use of 50 Ohm co-axial cable raises the effective generator impedance and the cable capacitance loads the generator, so that a much higher output voltage is needed to be able to drive the required current levels. Unfortunately, the simple solution of using a lower impedance co-axial cable does not help because lowering the cable impedance increases the capacitance and diverts energy away from the coupling device.

Further adding to the test equipment designer’s woes, is the fact that the EUT cable impedance will never be zero ohm. Cable bundles usually present an inductive impedance to the generator and coupler. Theoretically, it should be possible to lower the generator impedance but for practical reasons, this is not possible.

Due to all these factors and under normal applications, voltage can be reached in the test circuit but not always current. The following examples illustrate this point.

4.1 Cable Bundle and Voltage Relationship

Single wire with inductance approximately 1uH excited by WF3 at 1MHz

Voltage = 2xπxf x L = 6.28 x1 106 0.9 10-6 640A = 3.6 kV

Cable bundle with reduced inductance approximately 0.5uH

Excited by WF3 at 1MHz

V = 2xπxf x L = 6.28 x1 106 0.5 10-6 640A =2 kV.

Cable bundle with reduced inductance approximately 0.5uH

Excited by WF3 at 10 MHz

V = 2xπf x L = 6.28 x10 106 0.5 10-6 640A =20 kV !!!

The test voltage from DO-160 of 3200 V will be reached before the current limit,

5 Test equipment Requirement and costs for WF1, WF4 & WF5 generators

Waveforms WF1, WF4 and WF5 are much longer in duration and contain significant amounts of energy. To illustrate the point, a single stroke impulse generator for level 5, requires twice the output voltage and current than for level 4, with a corresponding increase in energy and price. Additionally, test levels for single stroke are twice the level required for multiple stroke. Therefore a multiple stroke generator can only be designed for maximum multiple stroke levels. The gap from multiple stroke to single stroke, can be bridged by using a separate generator design optimized for single stroke levels.

A generator specifically designed for single stroke level 5 testing. Such as that shown in figure 7 can fulfill all load conditions under the yellow line.

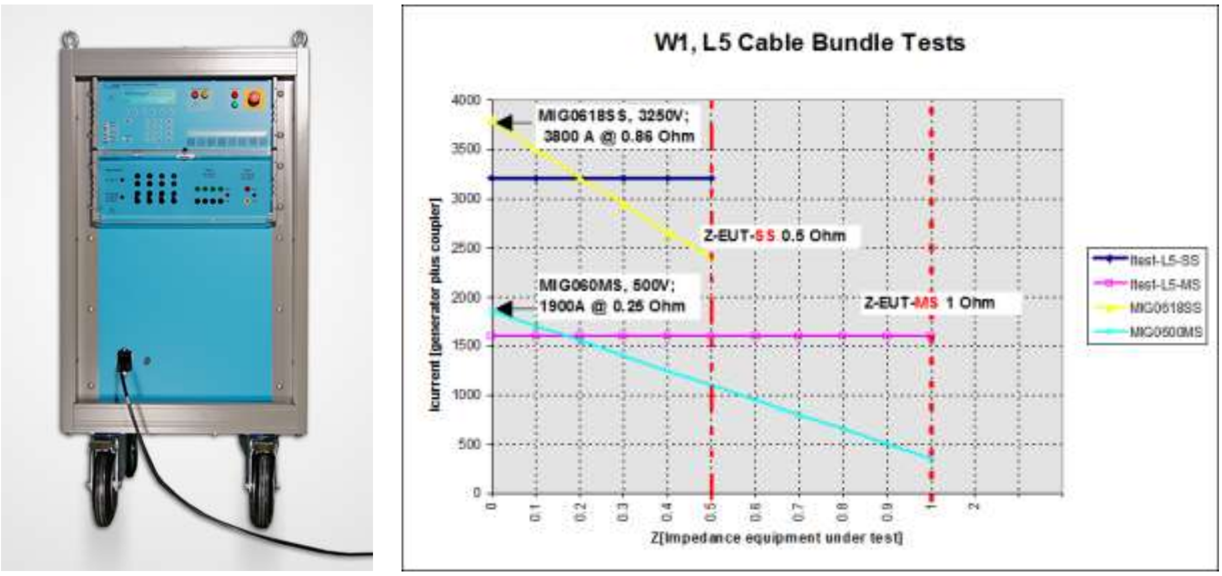


Figure 7: Cable bundle load effects on impulse generators.

The diagram in figure 7 illustrates the different generator requirements to achieve level 5 for both single stroke (SS) and multiple stroke (MS) tests.

6 Multiple Stroke & Multiple Burst Tests

A feature of indirect lightning testing is the application of multiple stroke and multiple burst sequences. Pulses are generated with high repetition rates and „random“ distribution. What is random and how can it influence equipment behaviour?

To start with, the degree of randomness is defined. Based on DO-160, there are significant variations in the requirement for multiple stroke and multiple burst. The following is a table comparing different requirements.

Standard	Parameter	MS Pattern	MB Pattern (Bx)	MB Pattern (Ax)
DO 160G	No of transients Distribution Impulse spacing Event duration Test time	14 strokes random 10 - 200ms 1.5s	20 of (WF3) random 50 - 1000µs	3 bursts of (B1) random 30ms - 300ms 3s 5min
Variation 1	No of transients Distribution Impulse spacing Event duration	24 strokes random Not Defined 2s	20 of (WF2 & 3) random Not Defined 1ms	24 random Not Defined 2s
Variation 2	No of transients Distribution Impulse spacing Event duration	24 random 10 - 200ms 2s		500 random 10µs - 10ms 2s
Variation 3	No of transients Distribution Impulse spacing Event duration Test time	14 strokes random 10 - 200ms 1.5s	20 of (WF3) random 50µs - 1000µs	3 bursts of (B1) random 30ms - 300ms 3s 5min.
Variation 4	No of transients Distribution Impulse spacing Event duration Test time		20 of (WF3) random 20µs - 50µs	24 random 10ms - 200ms 0.5 - 2s

Figure 8: Table comparing multiple stroke and multiple burst requirements.

Should a EUT fail during multiple stroke or multiple burst testing, an impulse distribution responsible for a failure cannot be exactly duplicated to help locate and identify a problem. Because of the uncertainty associated with random distributions, patterns with fixed impulse spacing and repeatability are used. The following is an example of a repeatable user programmed pattern on a remote computer.

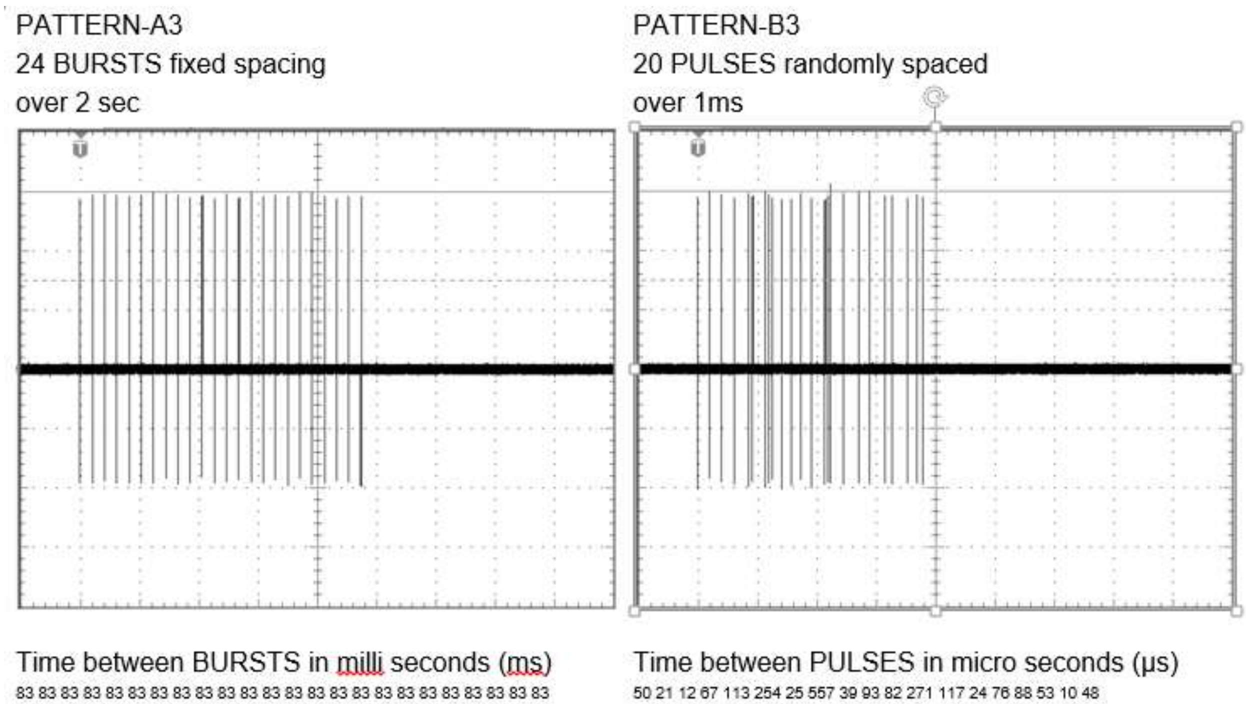


Figure 9: User programmable repeatable pulse sequence (Multiple Burst).

Particularly for failure analysis, an ability to program and change patterns according to system requirements is a distinct advantage.

7 Conclusion

Doubling a generator output voltage or current to achieve DO-160 level 5 means a significant hardware leap and consequently costs also increase. Earlier discussions indicate the majority of testing requirements are for level 3 and below. Although level 5 testing is not required for all equipment locations, there are strong arguments for employing test equipment capable of higher levels, particularly when testing cable bundles where the impedance is unknown and variable.

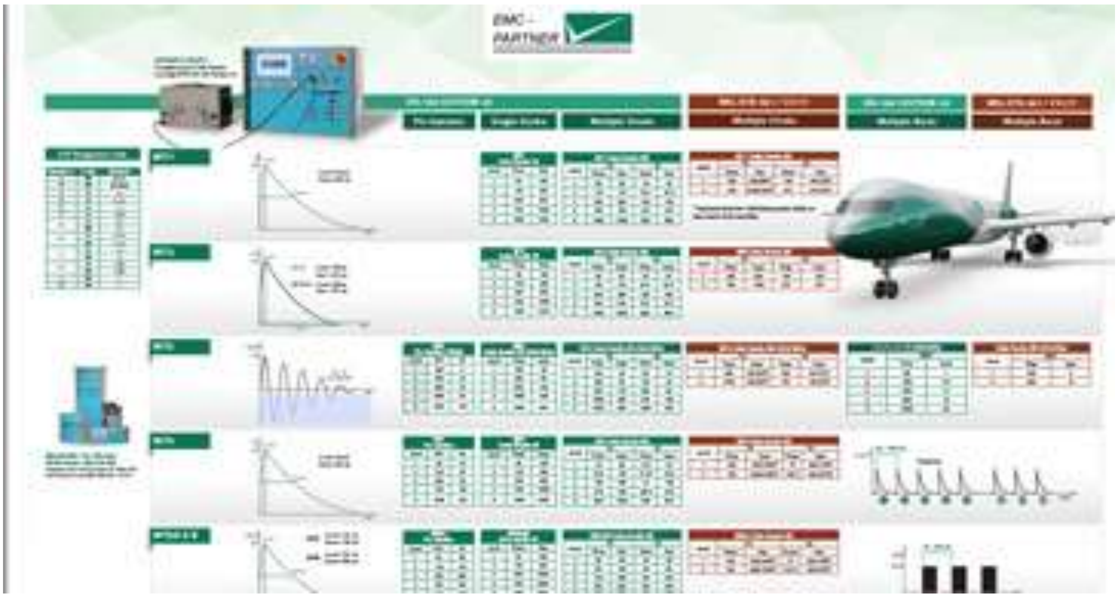
For the occasional level 5 test, a complete stand-alone system is difficult to justify from a purely financial perspective. It is clearly more advantageous to be able to expand an existing level 3 / 4 system. Apart from maintaining costs at a reasonable level, there is also the advantage that the same user interface eliminates costly re-training and loss of testing revenue.

Systems built on a modular basis, can even use the same hardware for other applications or to expand a system to include customer specific requirements. For example, additional waveforms or waveform 3 frequencies.

8 References

[1] RTCA / DO-160G Environmental Conditions and Test Procedures for Airborne Equipment Section 22 Lightning Induced Transient Susceptibility. 2010

[2] EUROCAE / ED-14 Environmental Conditions and Test Procedures for Airborne Equipment Section 22 Lightning Induced Transient Susceptibility. 2010



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