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Explanation and Experiences with RTCA/DO160 Level 5 avionics testing

Environmental Conditions and Test Procedures for Airborne Equipment: Section 22 Lightning Induced Transient Susceptibility.

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Contents

1 Introduction

Aircraft design and assembly is a global phenomena. Today, sub systems can be designed, manufactured or tested in any country, only being shipped to the aircraft assembly plant on demand. This global process requires that comparable tests shall produce identical results no matter where in the world they are performed. Standardisation of test methods and equipment go a long way to achieving these objectives. DO160 is ideally suited to fulfil the standardisation role.

Two sections of DO160 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 on airframes.

Section 22 is more applicable to the global nature of aircraft system and equipment production. It is limited to tests on LRUs (Line Replaceable Units).

Direct lightning effects covered by section 23 of DO160 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 characterised 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 are induced into the systems and many miles of cabling that carry both power supplies and data communication throughout an airframe.

Equipment location determines the applicable test level. 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 guide 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 level. Boeing and Airbus documents describe wiring location and relate this to appropriate test levels. An example for 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.

Fig. 1

- Carbon fibre composite
- High tech plastic with titanium
- Glare: Aluminium composite
- specially fabricated materials
- Thermo-dynamic plastic

Typical of modern aircraft construction is the A380. The different material types provide varying degrees of shielding and consequently influence the location category, waveform set and test levels to be applied to equipment within the different zones.

3 Test requirements and associated costs for W2 and W3 generator.

From the previous discussion and zone examples, it can be deduced that the vast majority of equipment within an aircraft only needs 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 characterised by measuring wave-forms into an open circuit and then a short circuit condition. These are the only two states that can be defined with any degree of certainty. Because of this, wave-forms can only be specified under these controlled conditions. Once an EUT is connected, the impedance is unknown, therefore the wave-shape will not be the same as in a calibration loop.

Fig. 2: PIN injection test setup

4 PIN injection generator

The transient generators specified in DO160 and characterised 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

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

Fig. 3

Fig. 4 shows that the W3, W4, W5A & W5B calibrated PIN injection generators can be used for any load.

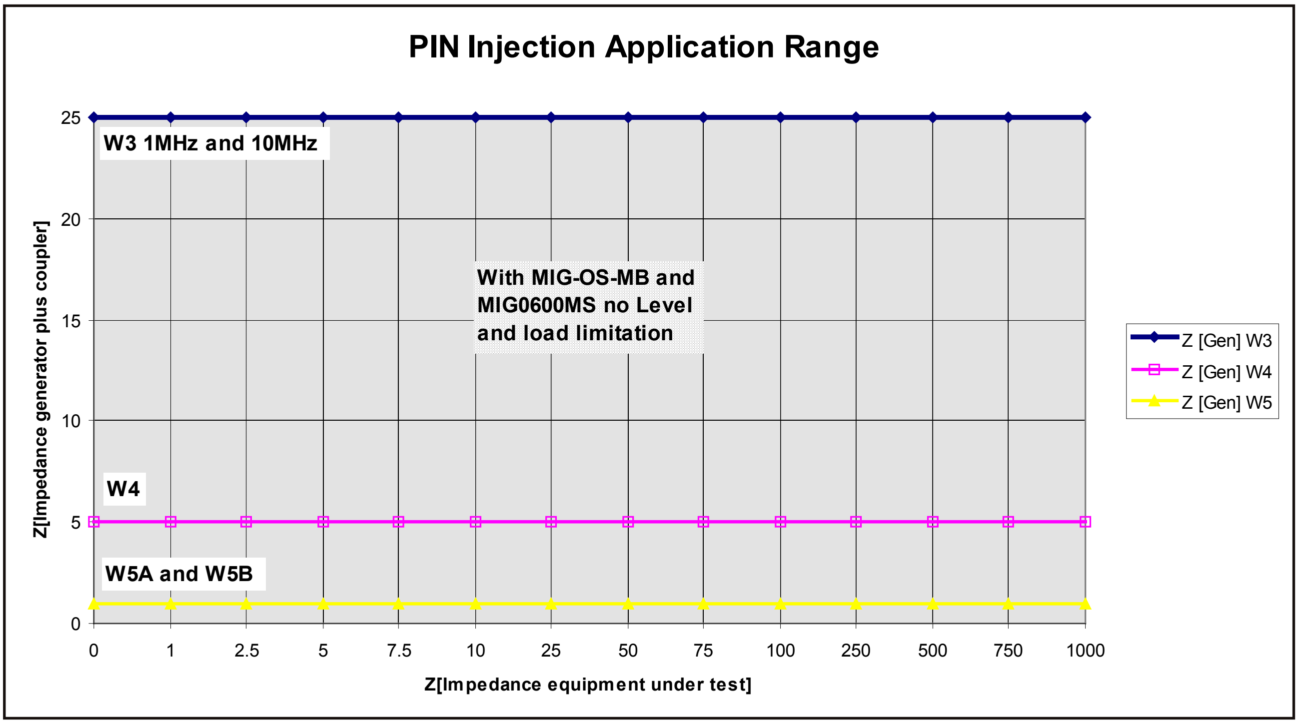


Fig. 4

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 and test voltages are significantly lower, presenting no great technical challenge to test equipment designers. On the other hand, Level 5 single stroke and multiple stroke requirements are far more difficult to attain.

DO160 introduces a concept that requires some further explanation here. All cable bundle tests take into account the potential influence of EUT cabling on the impulse focusing only on the amplitude by defining parameters of „I Test“ and „V Test“ or „I Limit“ and „V Limit“ values.

A „Test“ value is the ideal that should be reached if possible. The „Limit“ value is the maximum allowable value measured in a cable bundle to prevent over stressing the EUT. When this occurs, the test is deemed to have been completed.

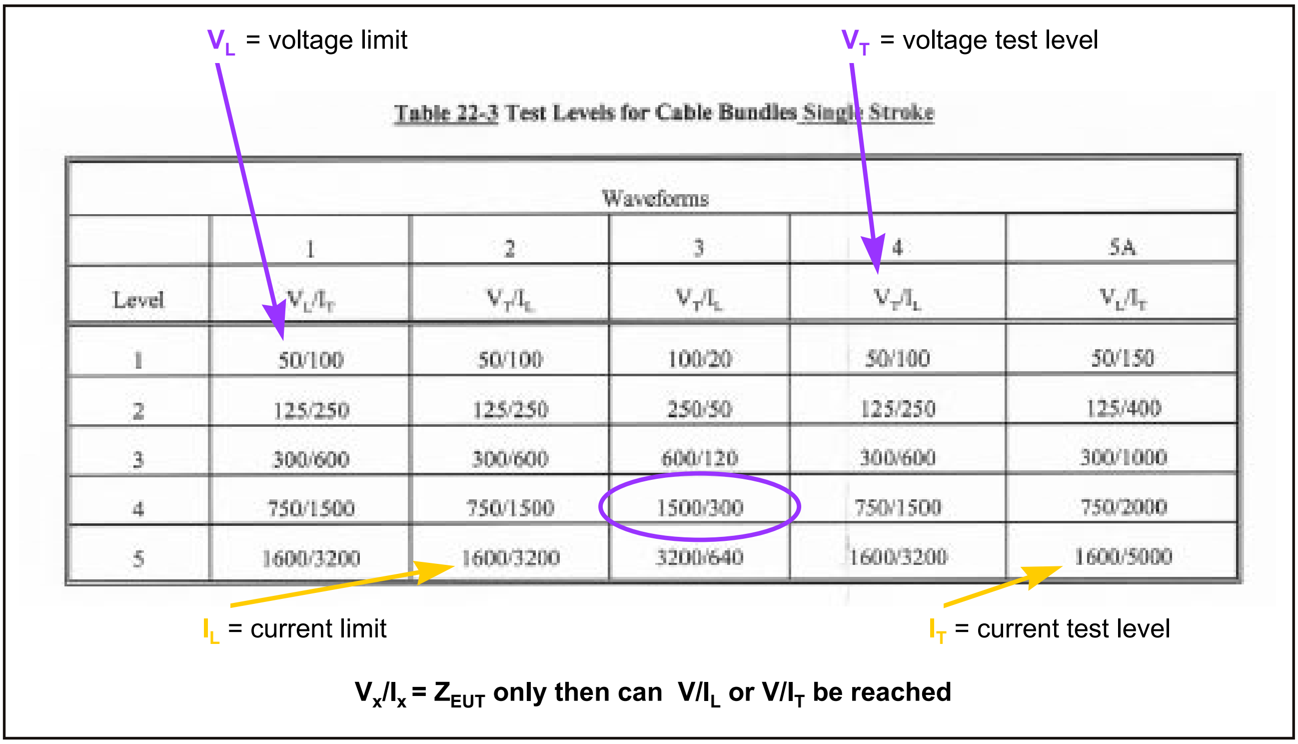


Table 22-3 Test Levels for Cable Bundles Single Stroke

	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

Fig. 5

Often, the „Test“ and „Limit“ values are misinterpreted as defining the generator impedance. As we have already established, 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 also have a big influence as to whether the „Test“ or „Limit“ value is reached first.

The following charts help to illustrate this point for wave-form 3.

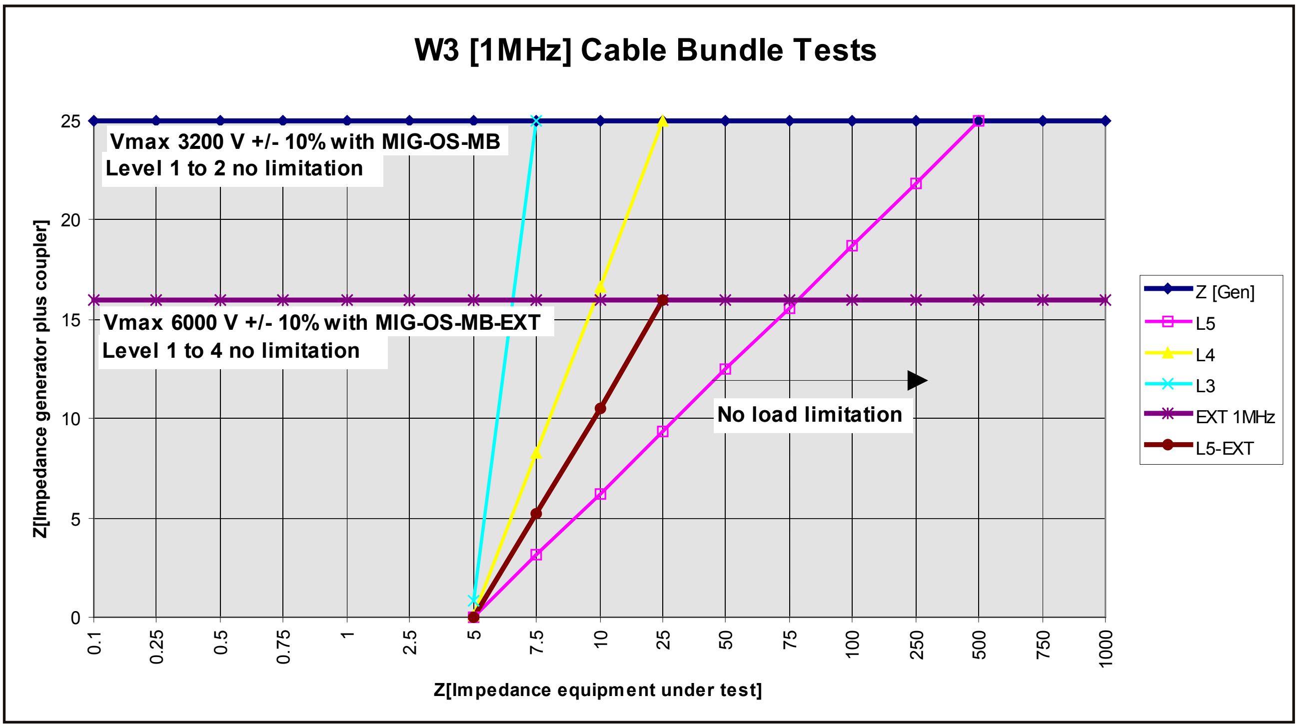


Fig. 6

From the table 22-3 of DO160 (Fig. 5), we can deduce an EUT impedance of 5ohms for Wave-form 3. In fact this tells only half the story 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 **X_L = 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:
X_L = 62.8ohm
The new situation is reflected in the following chart.

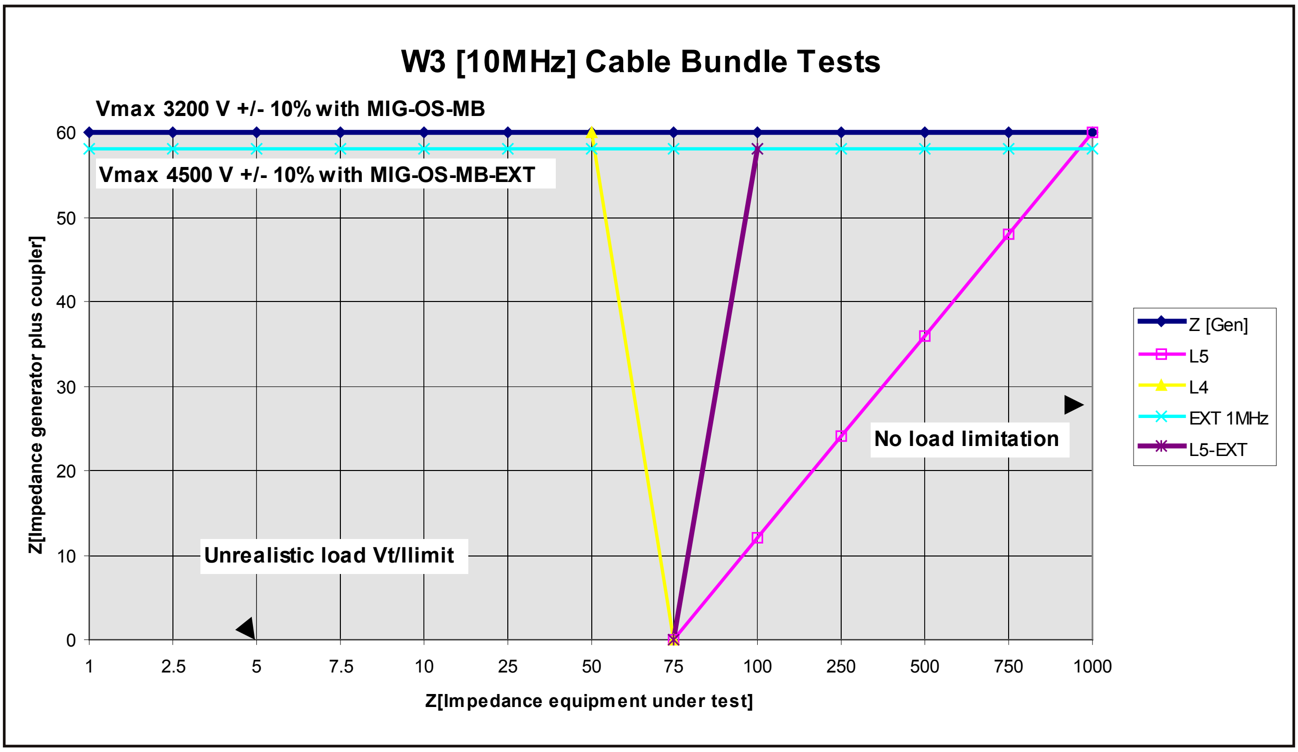


Fig. 7

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.
After examining all these facts and taking into account the potentially endless variety of EUT's, it is relatively easy to see that a complete DO 160 test system to meet section 22 requires more than one impulse generator.

5 Generator output voltage approximation for waveform W3

Waveform 3 (1MHz and 10MHz) and it's application according to DO160 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.

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

Voltage = 2πf x L I = 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 = 2πf x L I = 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 = 2πf x L I = 6.28 x10 106 0.5 10-6 640A =20 kV !!!

The test voltage from DO160 of 3200 V will be reached before the current limit

6 Test equipment and associated costs for W1, W4 & W5 generators

The wave-forms W1, W4 and W5 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. Therefor a multiple stroke generator can only be designed for maximum multiple stroke levels. The gap from multiple stroke to single stroke, can only be bridges by using a separate design optimised for single stroke levels.
A generator specifically designed for single stroke level 5 testing. Such as that shown in figure 8 can fulfill all load conditions under the yellow line of figure 9.

To further complicate matters, cable bundle tests must take into account the fact that the cable impedance will influence the level a generator can achieve.

The diagram in figure 9 illustrates the different generator requirements to achieve level 5 for both single stroke (SS) and multiple stroke (MS) tests.

Fig. 8: MIG0618SS for W1, W4or W5 generation

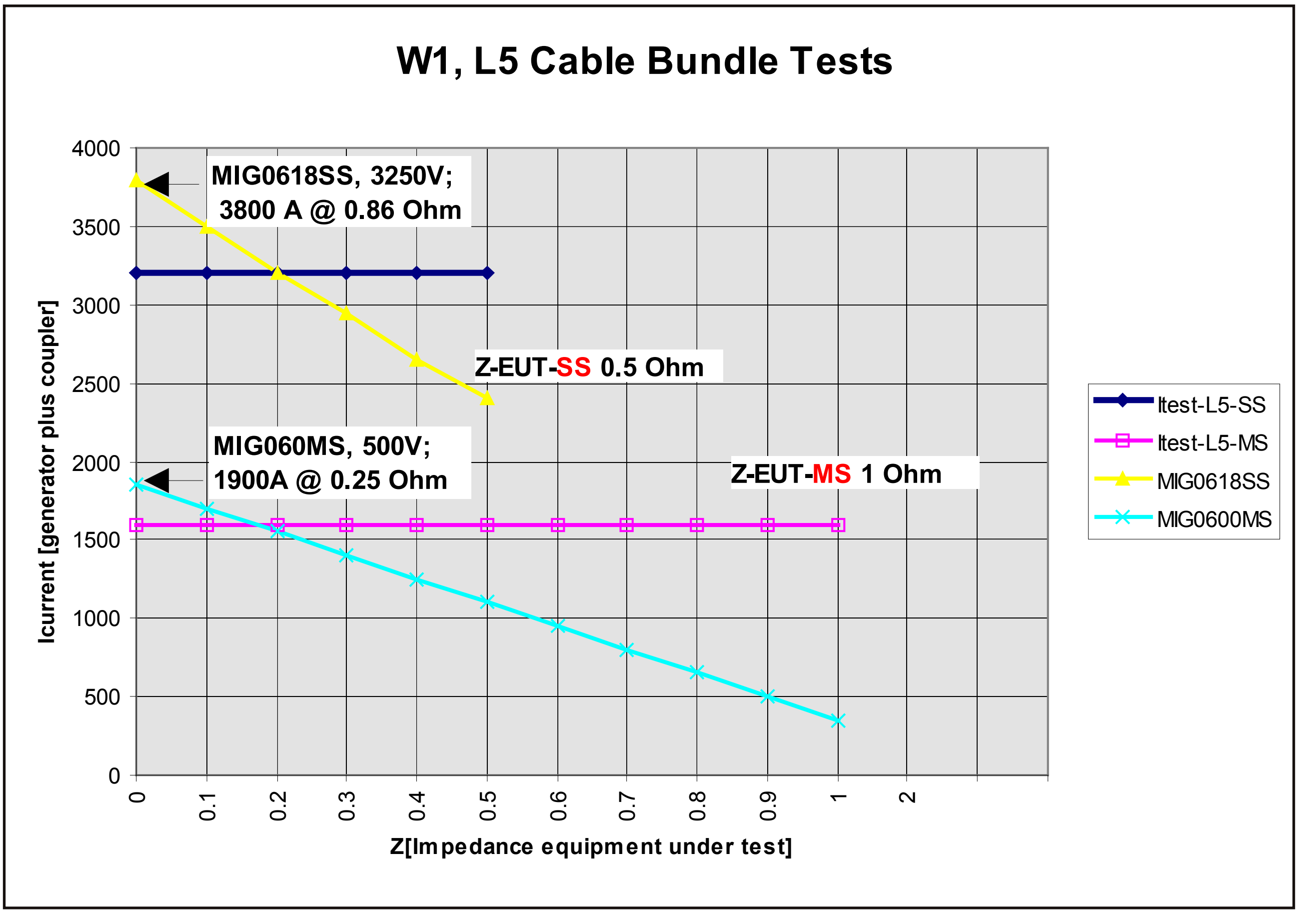


Fig. 9

7 Experience with DO 160 multiple stroke and multiple burst tests

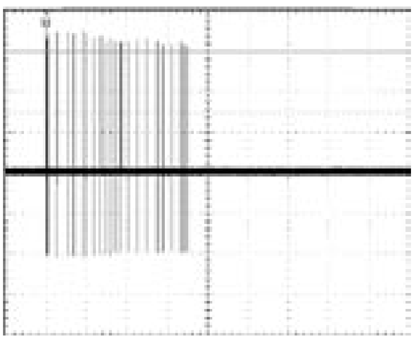
A feature of DO160 multiple stroke and multiple burst sequences is the „random“ impulse distribution requested by the standard. But what is random and how does it affect the test process?

To start with, the degree of randomness is clearly defined. Multiple stroke impulse excursions are required to be within 10 to 200ms from the preceding impulse. Aircraft manufacturers have their own ideas of randomness. The following is a table comparing requirements from different standards.

Standard	Parameter	MS Pattern	MB Pattern (Bx)	MB Pattern (Ax)
DO 160D	No of transients	14 strokes	20 of (WF3)	3 bursts of (B1)
	Distribution	random	random	random
	Impulse spacing	10 - 200ms	50 - 1000µs	30ms - 300ms
	Event duration	1.5s		3s
	Test time			5min
NH90	No of transients	24 strokes	20 of (WF2 & 3)	24
	Distribution	random	random	random
	Impulse spacing	N/D	N/D	N/D
	Event duration	2s	1ms	2s
Airbus A380	No of transients	24		500
	Distribution	random		random
	Impulse spacing	10 - 200ms		10µs - 10ms
	Event duration	2s		2s
SAE-ARP5412	No of transients	14 strokes	20 of (WF3)	3 bursts of (B1)
	Distribution	random	random	random
	Impulse spacing	10 - 200ms	50µs - 1000µs	30ms - 300ms
	Event duration	1.5s		3s
	Test time			5min.
Boeing D6	No of transients		20 of (WF3)	24
	Distribution		random	random
	Impulse spacing		20µs - 50µs	10ms - 200ms
	Event duration			
	Test time			0.5 - 2s

Even this pseudo-randomness, is not necessarily ideal from a testing perspective. Problems occur once an EUT fails the test. Because of it's very nature, 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 often used. The following is an example of a repeatable pattern programmed using EMC PARTNER software on a remote computer.

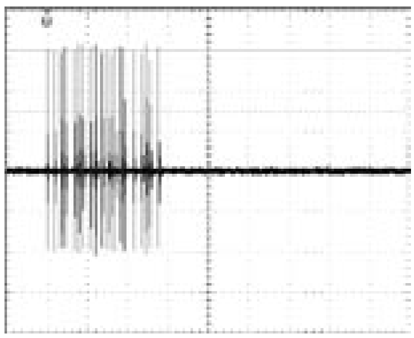
PATTERN-A3 (NH 90 helicopter)
24 bursts randomly spaced
over 2 sec



Time between bursts in milli seconds

80 10 41 73 130 26 222 14 19 147 88 96 111 190 33 19 42 57 39 150 100 91 24

PATTERN-B3 (NH 90 helicopter)
20 pulses randomly spaced
over 1ms



Time between pulses in micro seconds

50 21 12 67 113 254 25 557 39 93 82 271 117 24 76 88 53 10 48

Fig. 10

Particularly for failure analysis, an ability to program and change patterns according to system requirements is a distinct advantage. This ability is particularly useful for test laboratories or equipment designers.

8 Conclusion

Doubling a generator output voltage or current to achieve level 5 means a significant technological leap and consequently hardware costs also increase. Earlier discussions indicate that the vast 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.

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 frequencies.

DO160 only specifies waveform 3 to be used in multiple burst applications, but there are additional standards, such as EUROCAE, which discuss waveform requirements to simulate currents arising from magnetic field coupling. The waveform 6H requirement from EUROCAE can easily be incorporated into a modular system. Where a dominant platform resonance exists at frequencies other than the DO160 1 and 10MHz, additional frequency modules can easily be integrated.

Fig. 11: MIG-OS-MB with Extension

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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