Whitepaper

Indirect Lightning Testing using Waveform 3

Indirect Lightning Testing using Waveform 3

“Issues relating to the use of waveform 3”

Contents

1 Summary

RTCA/DO-160 and EUROCAE ED-14 section 22 describe testing of indirect lightning into cable bundles using waveforms derived from high energy fields caused by waveform D lightning transients in the vicinity of an aircraft. Waveform 3 frequencies depend upon the length of the system and the length of the cables. Longer cables can sustain only lower frequency oscillations (inversely proportional to length). Standard requirements are for waveform 3 1MHz and 10MHz to give the same current response into low impedance cable bundles. However, for technical reasons it is (nearly) impossible to build a waveform 3 (WF3) generator for 1MHz and 10MHz having the same source impedance and delivering the cable bundle limit current required. This paper will discuss reasons why the 10MHz generator source impedance is higher than for 1MHz, what the consequences are for WF3 limit current and how this influences the design of a suitable waveform 3 impulse generator.

WF3 is defined for PIN injection (Single Stroke) and Cable injection (Single / Multiple Stroke and Multiple Burst) events.

WF3 Pin Injection		
Level	Voc	Isc
1	100	4
2	250	10
3	600	24
4	1500	60
5	3200	128

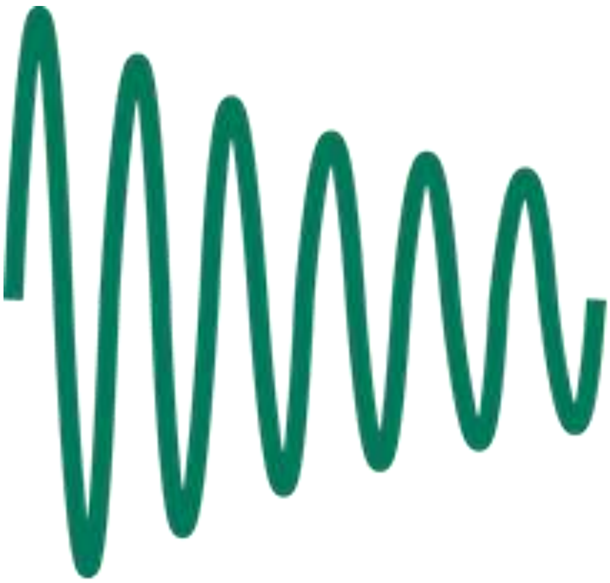

Figure 1: WF3 PIN injection test levels.

2 Introduction

For pin injection testing, waveform 3 shall only be applied at 1.0 MHz (±20%). It is not allowed to test both polarities of Waveform 3 using one polarity setting, even though the waveform is bi-polar. The waveform must be applied with a positive first half-cycle and then reversed for a negative first half-cycle.

With this restriction, RTCA/DO-160 table 22-2 specifies only the levels for WF3 1MHz open circuit (Voc) and short circuit (Isc). This in turn fixes the generator impedance at 25 Ω. The current required from the generator (128A) is realistic at 1MHz. So far, all good. No problem exists for the WF3 1MHz generation and application in PIN injection.

There are other standards where PIN injection can also be applied at 10MHz, so how does this affect the situation?

To transmit the 10MHz impulse to a EUT co-axial connection cable is required. Coaxial cables typically have either a characteristic impedance 50Ω or 75Ω. This in itself produces a new set of difficulties. At 1MHz a practicable cable length of 1m has only a small influence on the impedance of the test equipment, whereas at 10MHz the impedance increase can be calculated and verified by simulation.

Load impedance change with frequency varies with factor 10 from 1MHz to 10MHz.

$Z_L = 2\pi f L$

Taking a typical load value L = 1µH,

Then; ZL @ 1MHz = 6.28Ω and ZL @ 10MHz = 62.8Ω

We can confirm this difference at 10MHz by impulse circuit simulation

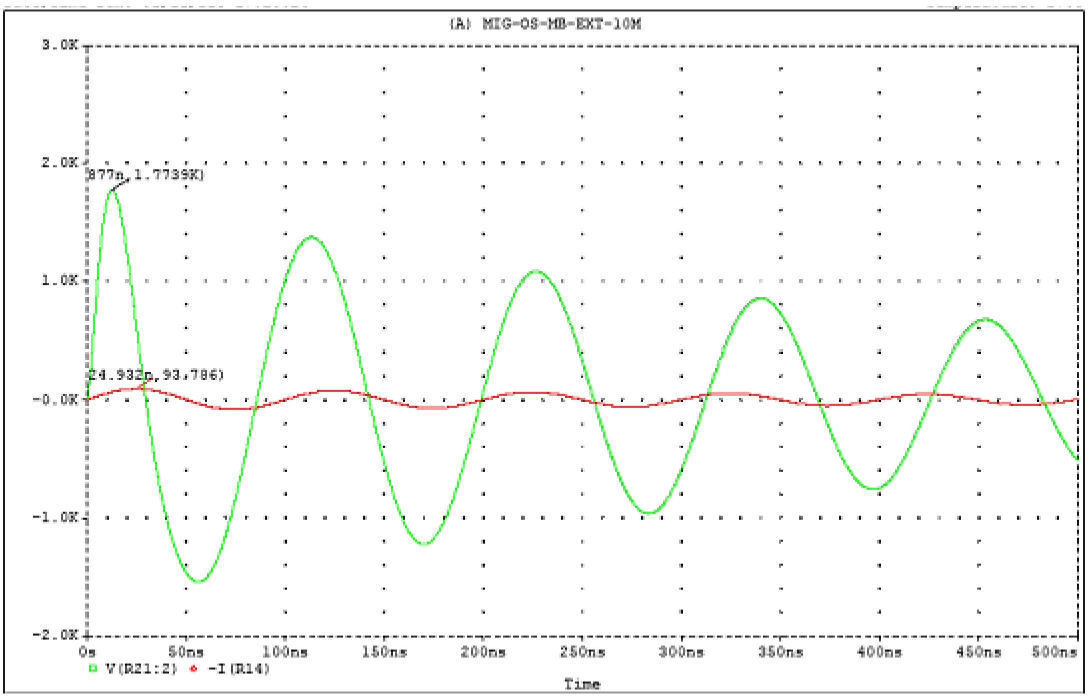

Figure 2: WF3 10MHz direct on impulse circuit   Z= Voc/Isc = 17739/93.786 = 18.9Ω

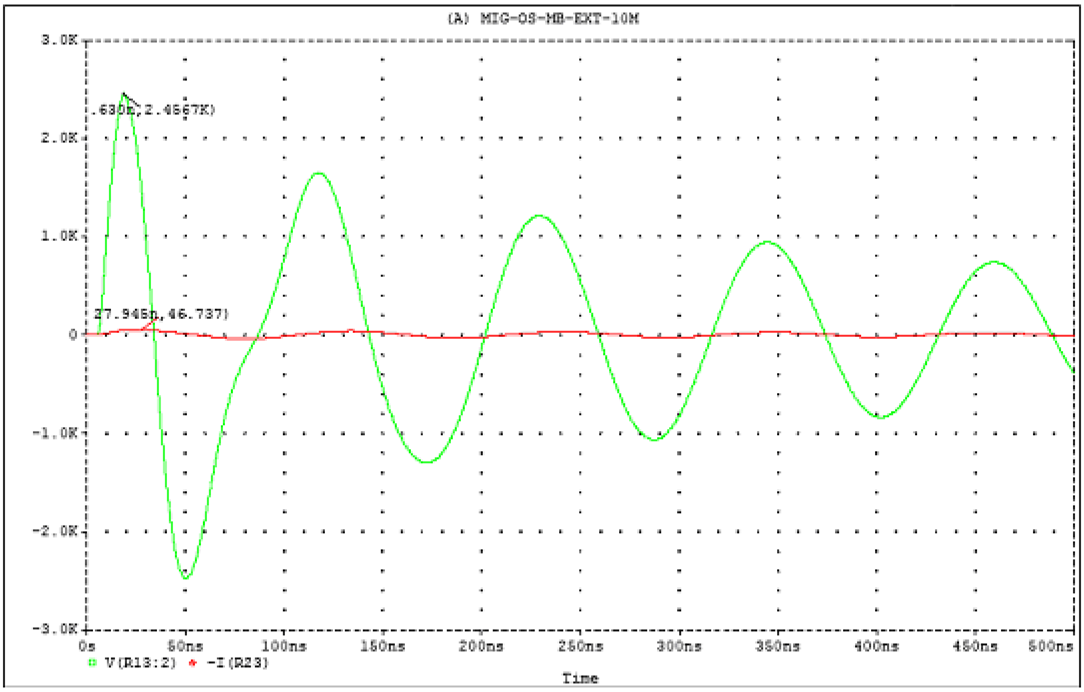

Figure 3: WF3 10MHz with 1m coaxial cable Z= Voc/Isc = 2456/46.737 = 52.5Ω

A 10MHz impulse through 50Ω coaxial cable introduces reflections that distort the waveform to an extent where the oscillatory form is just about preserved, but the impedance of 25 Ohm is not realistic.

This reinforces the RTCA/DO-160 requirement for 1MHz PIN injection testing only.

3 How does this situation translate to Cable Bundle testing?

Cable bundle tests require waveform 3 only as cable injection using a generator and coupler. However, both 1MHz and 10MHz should be applied. From the PIN injection example, it is clear that applying 10MHz signal with coaxial cable causes distortion and limits current, add into this a coupler to inject the impulse and the situation becomes more complex.

Waveform 3 is specified as a Single Stroke, Multiple Stroke and Multiple Burst event as indicated in the relevant tables of DO-160.

WF3 Cable Bundle SS		
Level	VTest	ILimit
1	100	20
2	250	50
3	600	120
4	1500	300
5	3200	640

WF3 Cable Bundle MS				
Level	FS		SS	
	VTest	ILimit	VTest	ILimit
1	100	20	50	10
2	250	50	125	25
3	600	120	300	60
4	1500	300	750	150
5	3200	640	1600	320

Cable Bundle MB		
Level	WF3	
	VTest	ILimit
1	60	1
2	150	2.5
3	360	6
4	900	15
5	1920	32

Figure 4: WF3 Cable bundle test levels

Cable bundle requirements do not define a system impedance, 3200/640 would be = 5Ω, rather a Test level to be reached and a Limit level not to be exceeded. Even with this definition and the explanation for PIN injection, the Limit current of 640A would never be reached for the 10MHz impulse under normal circumstances.
We already saw that:

- Z load increases between 1 MHz and 10MHz by a factor of 10
- The coaxial cable of 1 m increases the test equipment impedance > 2x

Applying WF3 @ 1MHz oscillation frequency to single wires or a cable bundle we can calculate the test system voltage required to reach the Test voltage and Limit current.

Example 1 WF3 1MHz Level 5 single wire
V = 2?f x L I = 6.28 x1 106 0.9 10-6 640A =3.6 kV

Example2 WF3 1MHz Level 5 cable bundle
V = 2?f x L I = 6.28 x1 106 0.5 10-6 640A =2 kV

For 1MHz, it is possible to reach both the Test voltage (3,200V) and the Current Limit (640A) with a generator that does not unduly stress the device being tested.

The situation changes when applying WF3 @ 10MHz oscillation frequency under the same conditions.
V generator = I x short circuit impedance with 1m coax = 640 A x 52Ω (from simulation) = 33.3kV!!!!

Developing the scenario with a cable bundle
V = (2?f L)x I = (6.28 x10 106 0.5 10-6) 640A = 20 kV !!!
It is possible to build such generators, but to achieve Limit current would be a massive over test of the Device being tested.

4 The Influence of Couplers

So far, we have only considered waveform 3 generators. What happens when we add a coupler for the cable bundle tests?

This section will evaluate the charging voltage requirement to obtain waveform 3 10MHz voltage (test) and current (limit) as defined in DO-160 section 22.

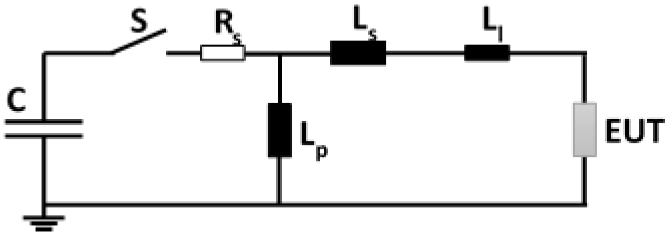

Figure 5: Schematic diagram of the impulse circuit required to generate and couple waveform 3 into cable bundles.

Assuming a capacitance value of 1 nF necessary to maintain the frequency within 10MHz ±20%. The following table summarizes the tradeoff to maintain the frequency at open circuit and short circuit within the required tolerance.

Capacitance C	Frequency (OC)	Inductance Lp	Frequency (SC)	Inductance Ls
1 nF	8 MHz	396 nH	12 MHz	317 nH
	9 MHz	313 nH	11 MHz	629 nH
	9.5 MHz	**281 nH**	**10.5 MHz**	**1267 nH**

Figure 6: Coupler characteristics to maintain 10MHz oscillation.

A small (317 nH) series inductance is essentially impossible to realize in practice. Even 629 nH is difficult, although not impossible, to realize in practice. Leaving only 1.2 uH as the most practical inductance.

The impedances of the three series inductance are:

Inductance Ls	Impedance at 10 MHz
317 nH	19.9
629 nH	39.5
1267 nH	79.6

From this table we can see that at 10 MHz, the required series inductances result in quite high impedances which make it very difficult to reach high short-circuit current amplitudes.

This is reinforces by a simulation of the coupler circuit as below:

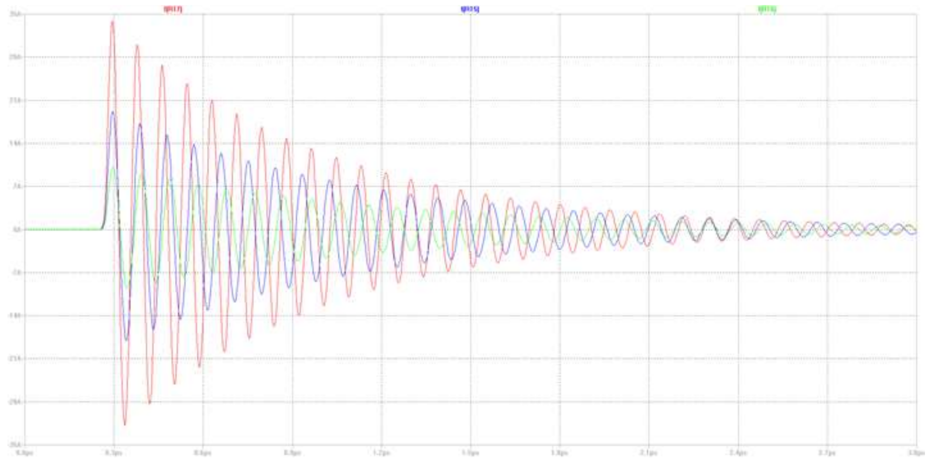

Figure 7: short-circuit currents in three cases (Rs = 500 milliohm, in all cases and Vc = 1kV)

Red: Ls = 317 nH
Blue: Ls = 629 nH
Green: Ls = 1267 nH

The currents with a charging voltage of 1 kV are 33.9 A, 19.1 A, and 10.1 A respectively.

Short-ciruit		Required charging voltage to reach:				
Case	Ls	Level 1 - 20 A	Level 2 - 50 A	Level 3 - 120 A	Level 4 - 300 A	Level 5 - 640 A
1	317 nH	0.59 kV	1.47 kV	3.54 kV	8.85 kV	18.8 kV
2	629 nH	1.05 kV	2.62 kV	6.28 kV	15.71 kV	33.51 kV
3	1267 nH	1.98 kV	4.95 kV	11.88 kV	29.70 kV	63.37 kV

Figure 8: charging voltages required into a short circuit

However the standard requires that under any condition either the test voltage or limit current need to be obtained. The worst case would be an impedance to attain the test level and the limit current at the same time, for WF3 this is the case for a EUT impedance of exactly 5 ohm.

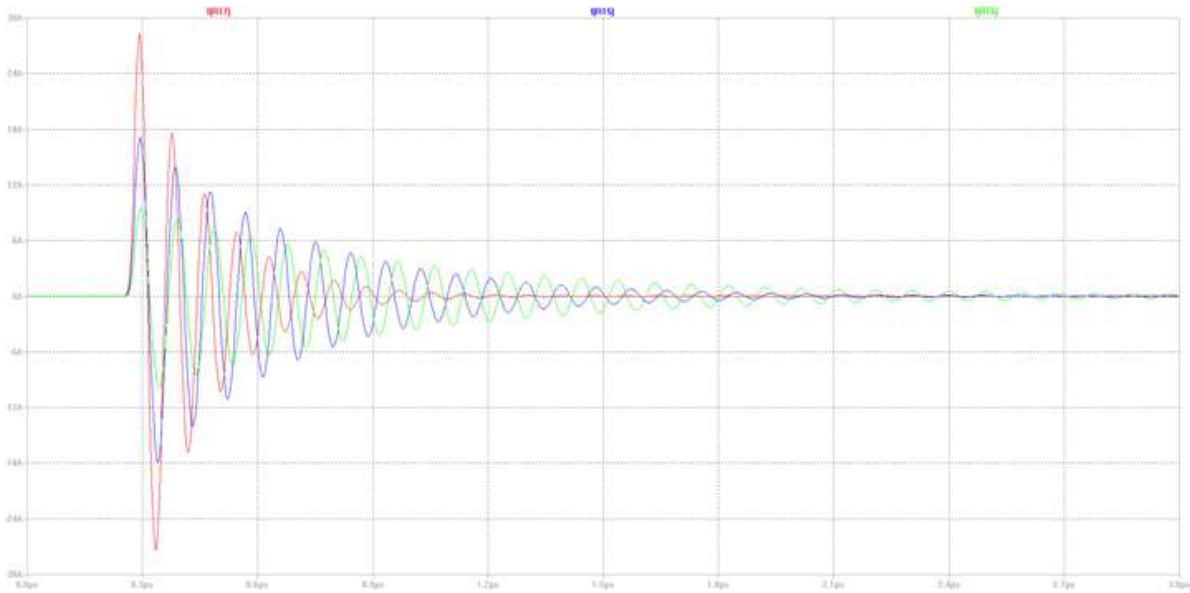

Figure 9: Currents obtained for a 5 ohm EUT

The currents with a charging voltage of 1 kV are 28.2 A, 17.1 A, and 9.5A respectively

EUT = 5 ohm		Required charging voltage to reach:				
Case	Ls	Level 1 - 20 A	Level 2 - 50 A	Level 3 - 120 A	Level 4 - 300 A	Level 5 - 640 A
1	317 nH	0.71 kV	1.77 kV	4.26 kV	10.64 kV	22.70 kV
2	629 nH	1.17 kV	2.92 kV	7.02 kV	17.54 kV	37.43 kV
3	1267 nH	2.11 kV	5.26 kV	12.63 kV	31.58 kV	67.37 kV

Figure 10: charging voltages required with a 5ohm load

Using a coupler with turns ratio of 2:1, 3:1, etc. would increase the currents by the applied turns ratio and help to obtain the required currents at lower voltages, however the leakage inductance and thus the series resistance would also increase dramatically (by the square of the number of primary turns!) which would completely annihilate the positive effect and probably result in even higher charging voltages.

Based on this analysis, we can see that a practical generator designed to deliver WF3 voltage pulses into cable bundles to a maximum 3,200V cannot deliver the limit current for 10MHz noted in DO-160 tables 22-3 and 22-4. The statement contained in section 22.5.2.1.1 (b)

"It is not necessary for the test generator to produce the associated voltage or current limit level and waveshape"

Should be rigorously applied in this case.

EMC PARTNER AG provide test systems capable of delivering waveform 3 impulses following the arguments set out in the previous discussion. An example of such a test system is the AVI-LV3 combined generator which includes WF3 for PIN injection and cable bundle together with an appropriate coupler.

Figure 11 AVI-LV3 generator

5 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

6 Further Reading

[1] Casanova, R. and Lutz, M., Induced Lightning Testing of Avionics - With Single Stroke, Multiple Stroke and Multiple Burst, EMC Partner AG, Laufen Switzerland.

[2] Lutz, M. and Wright, N., Explanation and experiences with RTCA/DO160 Level 5 avionics testing, EMC Partner AG, Laufen, Switzerland