Whitepaper

Indirect Lightning Testing and the Influence of Couplers

The Influence of couplers used for DO-160 Testing

“System requirements”

Contents

1 Introduction

Indirect lightning tests described in RTCA DO-160 section 22 and EUROCAE ED14 define wave shapes and amplitudes for current and voltage impulses when applied using PIN injection and Cable Bundle methods.

Cable Bundle testing relies on a test system comprising impulse generator and coupling device. Because of the range of frequencies and impulse types, inductive couplers made from different materials are necessary to ensure energy transfer while maintaining wave shape integrity at the point of injection (coupler secondary).

Source impedance of a test system in general is defined as z = v(t) / i(t)

This is, however, only true when both the voltage (v) and current (i) waveforms are in phase. This is true for indirect lightning generators configured for PIN injection and Ground Injection.

Once a coupler becomes part of the test set-up, such as for Cable Bundle tests, the open loop voltage waveform is influenced by the coupler saturation characteristics.

In this situation, the conditions required for z(source) are no longer met (waveforms are altered). The system impedance is now referred to as a „virtual" impedance which can only be resolved mathematically and has no relation to the actual generator source impedance.

2 Capacitive versus inductive coupling

Capacitive coupling is one of the most commonly used methods for impulse superimposition in commercial standards. The advantages are:

- Easy operation
- Capacitor parameters are fixed and can be taken into account in the overall circuit design.
- reduced problems with the width of wave shapes in a high ohmic load.

The disadvantages are:

- The necessity to use a high value coupling capacitor (physically large) for coupling into low ohmic loads.
- Galvanic coupling with impulse circuit elements. For example, commercial standards specify 18 µF for coupling a combination wave shape (1.2/50 µs and 8/20 µs), to AC mains line to line. During testing with power, high AC current flows in the impulse generator circuit. For example:

C = 18 µF, f = 50 Hz, Xc=1/2πfc = 176.8 Ω , U = 230 V. AC current flow is 1.3 A

Relating this to an aircraft power system with 115V @ 400Hz, current would be increased by factor 4.

Additionally an 18 µF capacitor cannot couple WF5A or WF5B current pulses and maintain waveform integrity.

- Galvanic coupling with cable bundles comprising many individual wires is not practical.

For comparison, inductive coupling can be influenced by many parameters:

- Influence of the transformer on the generator impedance
- Saturation of the material
- Set-up and length of the EUT cables.
- etc.

3 Material and waveform integrity

Depending on the impulse energy content, couplers can be constructed of ferrite or silicon steel laminated materials. Ferrite saturates quickly when long duration pulses are applied causing significant waveform distortion. Ferrite is therefore only applicable to waveforms with low energy content (WF3, WF6). Although WF2 alone is also low energy content, it is a derivative of the more energetic WF1.

Long duration higher energy pulses are best coupled using laminated steel transformer material.

Coupling capability is determined by two parameters:

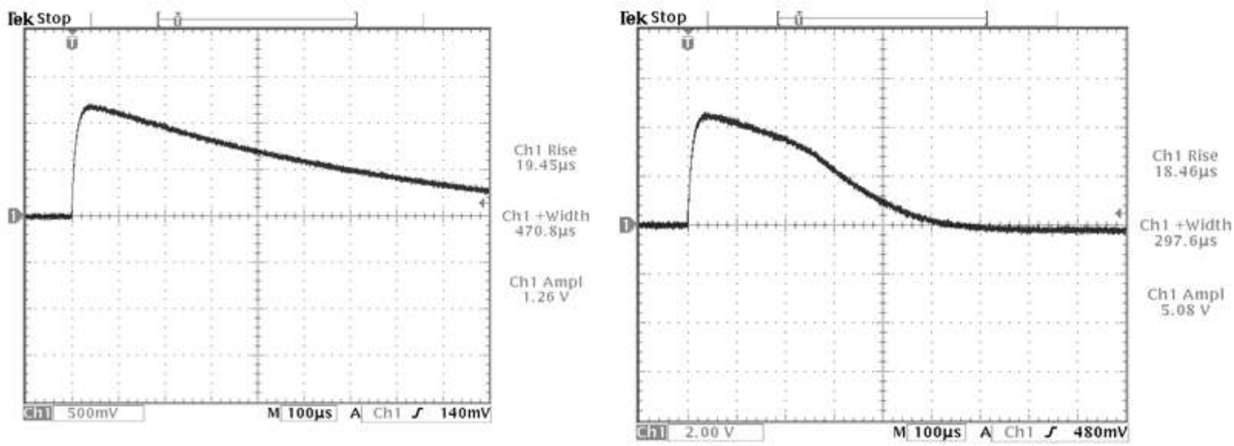
a) Impulse bandwidth

Given by the fastest frequencies is a waveform. In pulse waveforms, the highest frequency components are present in the risetime. WF1/4 = 6.4us = 156kHz, WF2 < 100ns = 10MHz, WF3 10MHz = 40MHz

I is necessary to use both steel and ferrite material due to saturation and frequency response.

b) saturation of the material

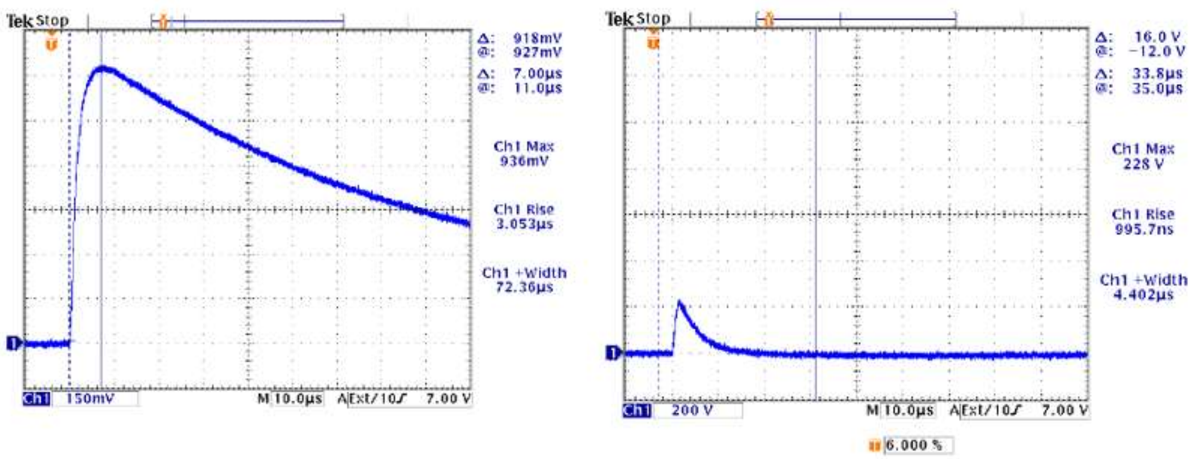
Saturation is represented by the voltage-time integral.



WF5B Iron core not saturated WF5B Iron core in saturation

Figure 1: Waveform 5B in Iron core coupler.

Couplers can be optimized for either voltage or current impulse transfer. This allows a relatively compact coupler dimension, but limits performance as the corresponding voltage or current waveform will not be transferred with the required amplitude or wave shape integrity.



WF1 Iron core (300A current) WF1 Iron core (voltage @ 300A)

Figure 2: Waveform 1 in Iron core coupler.

4 Influence of the coupler turns ration

Transformer theory states Rpri = n2 x Rsec
where
Rpri = Primary impedance,
Rsec = Secondary impedance
n = turns ration Npri / Nsec

We can deduce that Rsec = Rpri / n2

Level	Waveforms				
	2/1	2/1	3/3	**4/1**	4/5A
	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

Figure 3: DO-160 section 22 test level and limit values for single stroke testing.

Turns ratio Coupler	Generator impedance	Turns Ratio n^2	Virtual impedance
1T : 1T	1Ω	1	1Ω
2T : 1T	1Ω	4	0.25Ω
4T : 1T	1Ω	16	0.0625Ω

Figure 4: Influence of turns ration on system impedance (WF4/WF5A).

A 1:1 turns ratio enables testing to 1600A, sufficient to reach level 3. Increasing the turns ration to 2:1 increases the impulse current to 6,400A as required for level 5, but decreases the virtual impedance making the system more susceptible to changes in load impedance. This is not a problem for cable bundles with a known low impedance, for example cables fitted with over braids terminated at both ends. The available secondary limit voltage will however be decreased by a corresponding ratio, making it impossible to achieve the limit voltage. For low impedance cables this is the expected response.

Applying this type of generator / coupler combination to a hybrid cable bundle which includes a mixture of shielded and unshielded cables, could result in a situation where neither the test voltage nor limit current can be reached without significantly increasing generator output.

The following example compares current in a 3m cable loop against voltage across a 100R load resistor when the short-circuit loop is closed (nominal WF1) and open (nominal WF2 present)

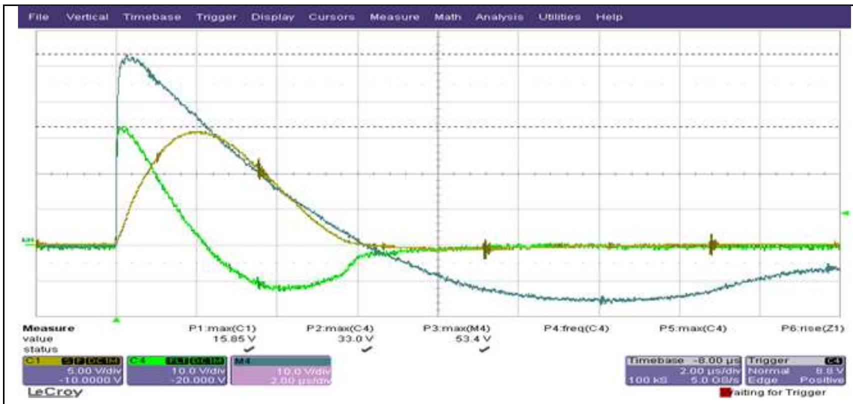
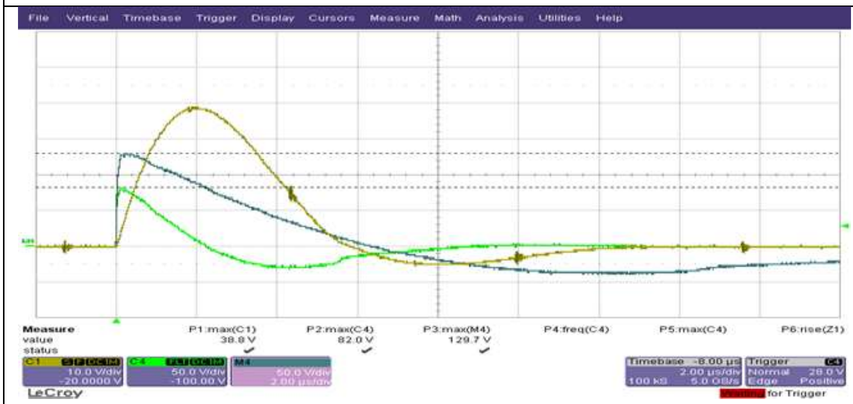
	WF2 Cable Injection Level 1: 50V Current in Short Circuit (3 m cable): 15.85A Voltage with 100 R load: 53.4 V (Open-winding) 33 V (Short-winding) (VT = 50 V, IL = 100 A)
	WF2 Cable Injection Level 2: 125V Current in Short Circuit (3 m cable): 38.8A Voltage with 100 R load: 129.7 V (Open-winding) 82 V (Short-winding) (VT = 125 V, IL = 250 A)
	WF2 Cable Injection Level 3: 300V Current in Short Circuit (3 m cable): 96.4A Voltage with 100 R load: 323 V (Open-winding) 210 V (Short-winding) (VT = 300 V, IL = 600 A)

Figure 5: Voltage across 100Ω (WF2) and current in short circuit (WF1).

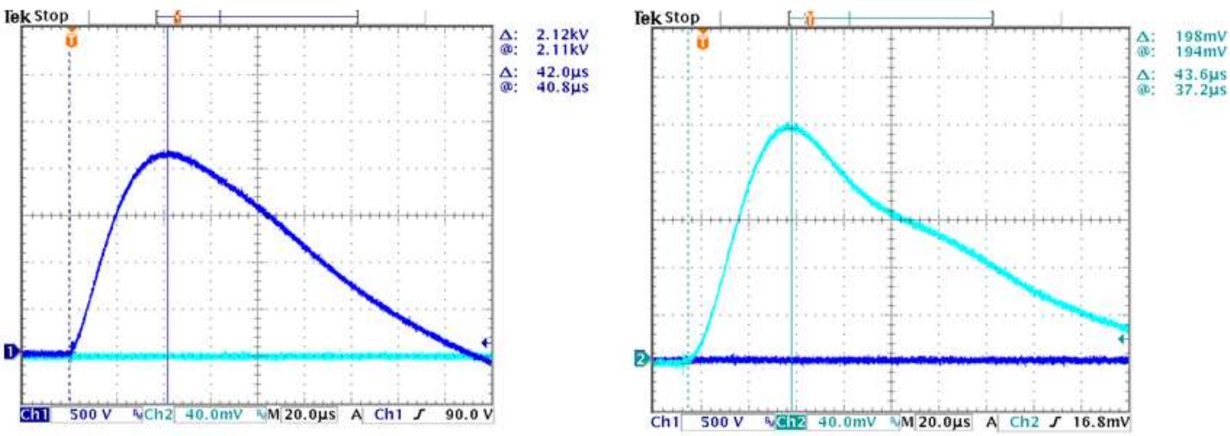
When a 3m short circuit cable is placed inside the coupler with WF2 applied, the voltage waveform is distorted and the voltage amplitude drops by approximately 30-35 %, however the current flowing through the short-circuit loop is well below the current limit level (~15-20 % of VL). This situation requires that the impulse generator output must be increased.

5 Specialist couplers

It is possible to design a test system (generator / coupler combination) that will deliver both voltage and current impulses, into a cable bundle, with a fixed impedance. These are known as hybrid circuits and are in fact utilized by some OEMs in indirect lightning requirements. The advantage of hybrid test systems is that they are independent of cable (load) impedance being defined into the extreme conditions of open and short circuit.

The following is an example of hybrid system with WF5A voltage and current waveforms.

Figure 6: Multiple stroke system with hybrid coupler (WF5A).



WF5A 2000V WF5A 2000A

Figure 7: Hybrid coupler waveform open and short circuit for WF5A.

6 Conclusions

Couplers are a vital element in any indirect lightning test system. Varying the turns ratio on a coupler can be used to either increase secondary CURRENT into the EUT or, by Increasing secondary turns (for cable bundle tests this can be the number of cable loops in the coupler) increasing the VOLTAGE into the EUT.

Hybrid systems eliminate calibration and cable bundle issues but are costly, large and very heavy making it difficult to comply with the requirements of DO-160 either in terms of cable length or test setup.

7 References

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

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