On the Validity and Merits of ESE Technology

1. Introduction

Effective lightning protection is achieved via proper handling of the lightning current from the interception point down to the ground. Hence, an effective lightning protection system (LPS) must have (i) a reliable capture point – the "air terminal(s)", (ii) a low-impedance path to ground – the "downconductor(s)", and (iii) an area for dissipation into the soil – the "earthing system" [1].

The range over which an air terminal of the LPS captures the downward leader emanating from the thundercloud defines its "protection area" and hence determines the number of air terminals required. It also determines the most effective position for the air terminal on the structure. Quantification of the protection area requires an analysis of the lightning attachment process (LAP) and, specifically, the dependence of striking distance on several variables [2]. Analysis of the LAP is complicated further by the "stochastic" nature of lightning and the path it takes as it approaches a ground object. Fractal modelling of lightning is one approach to model and simulate these effects [3].

Despite being formulated as an approximation to the LAP more than half a century ago, the rolling sphere method (RSM) is still commonly proposed and included in various standards around the world. However, its simplicity and age mean it has several inherent flaws, including:

- Ignoring the well-known dependence of striking distance on structure height, e.g., see [4] and [5], which span the original and most recent work on this accepted principle;
- A sphere radius and, hence, striking distance that ultimately results in a "useless height" for structures taller than that radius, which is completely ignored in most standards;
- Lightning does not always strike the closest point, as space charge effects and local electric field enhancement have a large influence in the LAP. Space charge effects are complex and have been determined from laboratory studies, calculations / computer simulations and field experiments, e.g., [6-8];
- The number of strikes per annum to any structure depends strongly on its height, yet the RSM assigns an equal probability to a very low structure and the tallest skyscraper.

Because of these flaws, other technologies have arisen to improve the efficiency of protection and, importantly, provide users with a *cost-effective solution*. Conventional Franklin rod systems have been used for a long time, but the design is often extremely costly to implement and, on many occasions, aesthetically unpalatable.

In this paper, Early Streamer Emission (ESE) technology is presented. ESE technology had its origins in the early 1990's [9], which led to the publication of the first ESE standard in 1995. This standard was the first in the world to provide a test regime for these air terminals and, importantly, a method for translating the test results into a protection area and hence protection methodology.

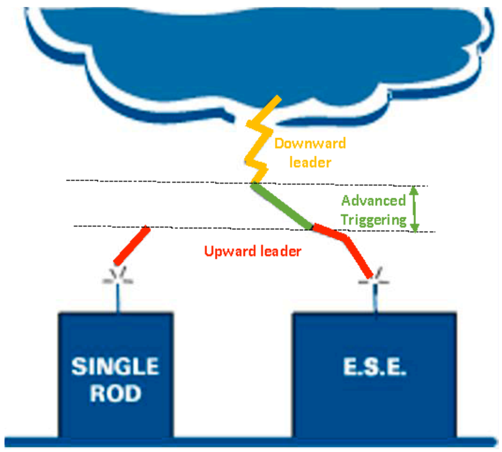
The remainder of the paper elaborates on the above concept, and covers ESE validation in the laboratory and field, the Standards that ensure compliance of the terminals, ESE acceptance around the world by users, and ESE experience around the world. →

2. ESE Concept

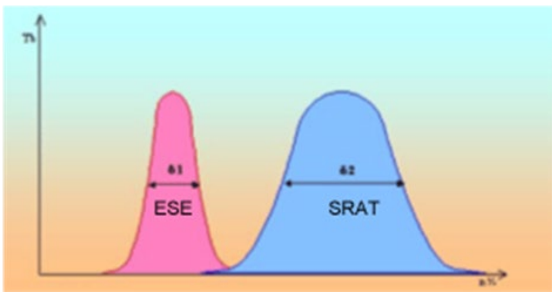
While a Franklin rod is the “conventional” method of providing the interception component of a LPS, the radius of protection of a such a rod is limited due to it passive nature and tendency to be influenced by space charge. There are many documented cases of Franklin rods having a much smaller capture range than expected. The latest scientific research is showing that the production of excessive space charge around the rod can delay leader initiation and therefore reduce its protection range. This work was commenced by Moore et al in their famous mountain experiment in New Mexico, USA [10].

Studies suggest that any upward leader that is launched from the tip of a rod before other such points will intercept the lightning downward leader over a larger area [9]. New research is showing that the “quenching” that occurs on adjacent points when the first streamer-leader is initiated is a significant factor, e.g., [11,12]. High-voltage laboratory tests and individual research carried out by various organisations and companies around the world, e.g., [13], demonstrate that early streamer emission results in a greater radius of protection and hence a more efficient LPS.

ESE air terminals use various physical principles to enable the earthed central rod to launch an upward streamer and, subsequently, a continuously propagating upward leader at the correct time in relation to the descent of the downward stepped leader. Hence, the downward leader is intercepted earlier and at a greater distance, which means it is captured over a larger range than a standard Franklin rod. This concept is illustrated in Figure 1.

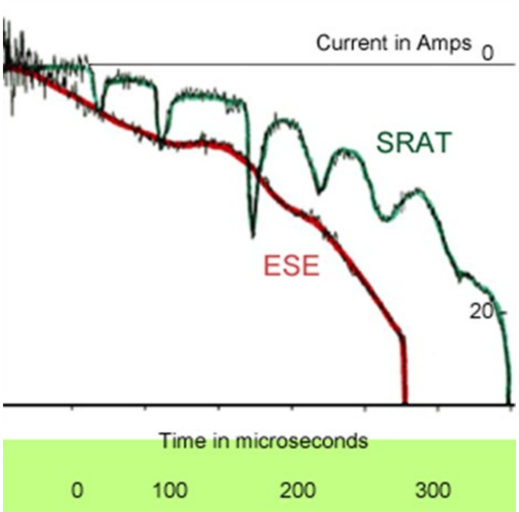


(a)



(b)

Figure 1: (a) ESE concept of time advance. (b) Statistically significant time advance of an ESE over a Franklin rod (SRAT) of the same height.



(c)

Figure 1 (continued): (c) Example of measured current flow for an upward leader from an ESE vs a conventional rod.

3. ESE Validation

Validation of any LPS necessarily involves three key aspects, namely computations / modelling, laboratory experiments and field trials. It is therefore somewhat surprising that in the 265 years of the use of the conventional rod for lightning protection, the main validation that has taken place was the empirical review carried out by the Federal Interagency Lightning Protection User Group in 2001 [14]. The report concludes that protecting structures is an effective measure for preventing fires but does not quantify the interception efficiency of the conventional protection systems surveyed.

On the other hand, ESE technologies have been validated in many ways over the last 30 years, including:

- Calculations and modelling as imposed by standards (see later section of this report);
- Laboratory experiments that quantify the performance of the air terminal when installed in practical scenarios, e.g., [13].
- In-situ, controlled tests using rocket-triggered lightning flashes, e.g., [15] (see Fig. 2a).
- In-situ, controlled tests using natural lightning flashes, e.g., [16] (see Fig. 2b).
- Empirical field studies of *actual installations*, e.g., [17, 18].
- Instrumented field studies of actual installations [19].

Over one million ESE terminals have been installed worldwide, in all types of geographic and climatic conditions. The majority of these air terminals are protecting structures and facilities in countries with the highest lightning activity, particularly around Asia. The accumulated experience of these installed units is equivalent to more than ten million years of operation and exposure to lightning.

The feedback from users and owners of buildings and facilities protected with ESE terminals has been extremely favourable [18,20]. The number of problems have been insignificant, both for their statistically small number and for the irrelevance of the damage. The latter have been, in any case, very similar to those occurring in conventional LPSs.

(a) (b)

Figure 2: (a) In-situ rocket-triggered lightning tests of ESE terminals. (b) Natural lightning tests of ESE terminals.

4. ESE Standards

The standardisation process plays and important role not only in ensuring compliance of products but also in the gradual improvement of LPSs over time. Conversely, experience and technological development can also feed back into the standardisation process.

4.1. Process and Uptake

The standardisation of ESE technology is now very mature having gone through a rigorous regulatory background. It originated in France, commencing from the 1987 edition of standard NF C 17-100. The standard NF C 17-102 "Early Streamer Emission (ESE) lightning protection systems" was published in 1995. A second edition of NF C 17-102 was published in 2011. An increasing number of countries have published ESE standards, namely:

- Angola: NA 33-2014
- Argentina: IMRA 2426
- France: NF C 17-102
- Lithuania: STR. 2.01.06:2003
- Macedonia: MKS N B 4810
- Portugal: NP 4426
- Romania: I 20
- Serbia: JUS N B 4810
- Spain: UNE 21 186
- Turkey: TS 13709

At the time of writing this paper, ESE standards development was also ongoing in several other countries. In the USA, Underwriters Laboratories (UL) delivers UL listing for ESE terminals as well as Master Labels to ESE-protected buildings.

Furthermore, translated versions of NF C 17-102 in English, Spanish and Portuguese have been used in many other countries around the world, such as Australia, to design and install ESE LPSs. This lasting standardisation experience has been very positive, offering guidance to engineers, installers and users on ESE technology as an alternative way of protecting buildings, facilities and their contents. The uptake of the standard proves the consistency over time of the rules established in the document.

4.2. Compliance and Validity

The matter of alignment and compliance of ESE standards with existing lightning protection national or international standards, such as IEC 62305, was raised in 2009. The matter was raised since, in Europe, several countries (all members of CENELEC (European Committee for Electrotechnical Standardisation), such as Spain, Romania, Portugal and France) have two standards available for LPS design.
CENELEC was asked to confirm the compliance and validity of ESE standards. The Technical Board 134 (BT134) confirmed in April 2009 the non-conflicting character of NF C 17-102. This standard (and all of its derivatives) can therefore coexist with EN/IEC 62305. In August 2011, the CENELEC Director General, Elena Santiago Cid, clarified the relationship between EN/IEC 62305 and the existing ESE standards in a letter to the President of ICLP:

> With regard to your specific questions, we can only but reiterate the elements of our response dated 10 December 2010 i.e.
>
> *According to the CEN-CENELEC Internal Regulations, there is no conflict between ESE standards and EN 62305 series since:*
>
> - *Their scopes are different.*
> - *ESE Lightning Protection Systems are not included in the EN 62305 series.*
>
> *BT have not ordered to withdraw ESE standards.*
>
> *ESE national standards are in force and this in line with the CEN-CENELEC Internal Regulations.*

4.3. Testing and Certification

The aforementioned ESE standards include various stringent tests to be performed on the air terminal to prove its performance in real-world situations. One of the most important test is the early streamer / time advantage test that must be performed in a high-voltage laboratory to determine the capture range of the air terminal per a formula in the standard.

It must be noted that *no other standard in the world provides a performance criterion for air terminals* that enable the positioning and number of terminals to be determined. For example, the worldwide standard IEC 62305 provides no direction regarding testing the expected performance of Franklin rods under lightning electric fields. The accompanying standard IEC 62561-2 only makes an assessment of dimensions and current-carrying capacity.

Tests according to ESE standards must be made under controlled climatic conditions. They must also be performed on a particular order in order to prove that it can endure the full range of tests. The product must pass all the tests successfully to be approved by the verifying/testing institute or laboratory.

The list of tests that an ESE air terminal must pass are the following:

(a) Marking tests;
(b) Mechanical tests;
(c) Environmental tests;
(d) Electrical test (lightning current withstand, 100 kA at 10/350 μs); and
(e) Time advance (ΔT) determination in accordance with a strict standard deviation criterion.

EMC tests are also required for some variants of ESE technology. The stringent test procedure is shown graphically in Figure 3.

Detailed test reports from ENAC / ILAC accredited laboratories are available on request.

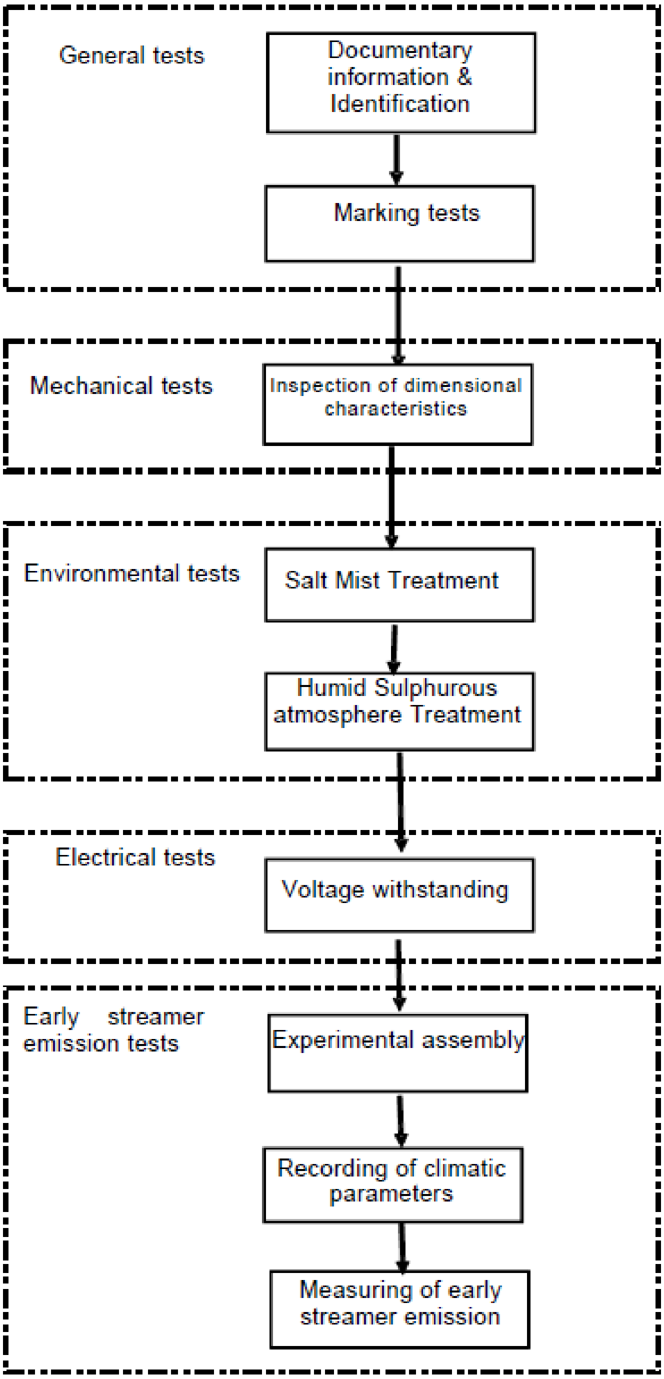


Figure 3: Test procedure per ESE standards.

5. ESE Usage, Performance and Experience Worldwide

5.1. Usage

Drawing on the findings and outcomes of continuous research and development in the field of lightning protection, new and improved ESE air terminals have been developed over time. ESE systems have been successful in protecting some of the most renowned sites and structures around the world, as shown in Figure 4.

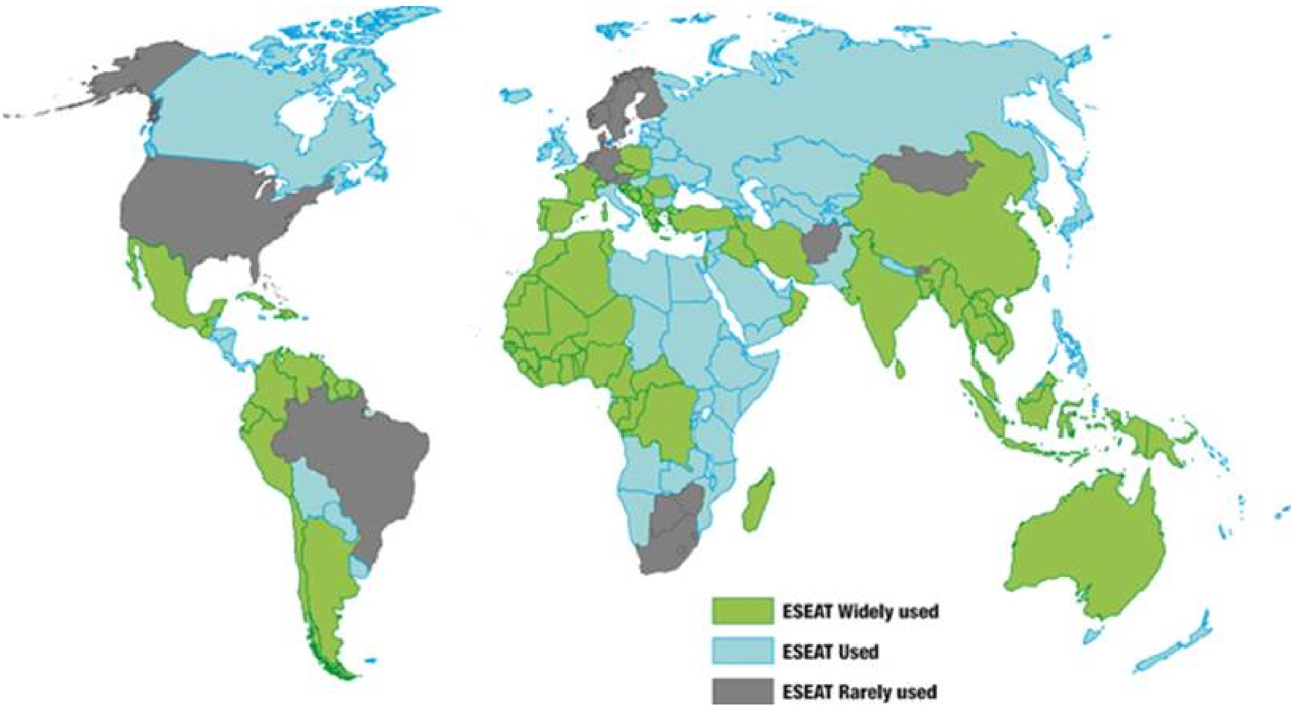


Figure 4: Map show usage of ESE air terminals around the world.

5.2. Performance (Field Validation)

Many informal surveys of ESE performance have been carried out on ESE systems over the years. However, a landmark formal study was carried out by an independent consultancy company called "Mega Jati Sdn Bhd" (https://megajaticonsult.com/) in 2016. This study was requested by the Malaysian Energy Commission "Suruhanjaya Tenaga" (https://www.st.gov.my/).

In this study, a lightning protection survey was conducted on two types of lightning protection systems that are common in Malaysia, namely ESE systems and conventional "meshed cage" systems. A total of 419 buildings were surveyed in the study, covering a wide range of applications, e.g., residential, condominiums, schools, factories, airports, etc. Around 88% of these buildings were equipped with a LPS. This proportion of protected buildings is higher than other countries, most likely due to the high lightning activity in Malaysia.

The full findings of the study can be found by navigating to the following link on the Suruhanjaya Tenaga web site:

https://www.st.gov.my/contents/files/download/160/Kajian_Penggunaan_Alat_Penangkap_Kilat.pdf

However, some of the key findings included:

- 306 buildings were protected by a conventional LPS (258 buildings equipped with meshed cage/single rods, 13 using metal roof, 29 using copper tape conductors, 6 “not sighted”). A total of 22 buildings (7.2%) incurred damage due to lightning (either to the physical structure or electrical / IT interruption / equipment loss).
- 64 buildings were protected by an ESE LPS. Only 3 buildings (4.7%) incurred lightning damage.

Hence, the study found that the rate of lightning incidents on ESE-protected structures is actually lower than structures protected using a conventional LPS.

5.3. Experience

ESE technology has been deployed successfully worldwide by LPI since the company’s inception in 2002. Some of the landmark references with LPI’s ESE installations across a wide range of market sectors worldwide, often in the most lightning prone areas of the world, are presented in Table 1.

Table 1: Examples of ESE installations.

Country / Territory	Sector
Australia	High-rise buildings (commercial and residential), Mining, Industrial facilities, Open area protection, Airports, Oil and Gas facilities.
Vietnam	Commercial high-rise buildings, large industrial facilities, Airports, Solar, Telecommunications, Broadcasting, Military, Oil and Gas / Refinery and Processing facilities, Open area, Golf Courses, Resorts / Hotels, Hospitals.
Indonesia	Commercial and Residential high-rise buildings, Airports. Industrial facilities, Telecommunications, Television and Broadcasting, Railways, Power Utilities, Bridges, Resorts and Hotels, Banks, Mining, Oil and Gas facilities, Schools.
Thailand	Aviation facilities, High-rise buildings (commercial and residential), Vessels, Defence, Sporting centres and Golf Courses, Resorts. Industrial facilities, Petrochemical facilities.
India	Cultural & Heritage buildings, Airports, high-rise buildings, solar farms, roof-top solar facilities, Temples, Industrial facilities, Railway applications, Telecommunication facilities, Mining, Hotels and Resorts, Military and Defence, Automotive factories.
China	Expo centres, Oil and Gas facilities, Airports, Bridges, high-rise buildings, Recreational facilities.

6. Summary and Conclusions

This paper has reviewed the main concepts behind ESE technology, its standardisation and its application around the world.

The following key points can be made in conclusion:

- Over one million ESE installations are currently protecting structures and facilities around the world. This translates into more than 10 million service years.
- ESE installations provide protection in a wide range of industry sectors and applications. LPI's ESE terminals have been successful in protecting facilities against the effects of lightning in the most lightning-prone areas of the world, such as in Asia.
- ESE terminals provide a good level of protection for structures and facilities provided they comply with NF C 17-102, which has a rigorous series of tests that must be passed before the air terminal is certified.
- The required lightning protection level (LPL) comes from the risk assessment methodology in NF C 17-102, which is essentially identical to the one described in IEC 62305-2.

References

[1] D'Alessandro, F., 2010, "A Systematic Lightning Protection Plan for Buildings, Sites and Facilities", Down to Earth Conference 2010, Perth, Australia, pp. 1-15.

[2] D'Alessandro, F., 2003, "Striking distance factors and practical lightning rod installations: a quantitative study", J. Electrostat., Vol. 59, pp. 25-41.

[3] Petrov, N.I., Petrova, G.N. & D'Alessandro, F., 2003, "Quantification of the probability of lightning strikes to structures using a fractal approach", IEEE Trans. Dielectr. Electr. Insulat., Vol. 10, pp. 641-654.

[4] Petrov N.I. & Waters R.T., 1995, "Determination of the striking distance of lightning to earthed structures", Proc. Roy. Soc. A, Vol. 450, pp. 589-601.

[5] Cooray, V., Nucci, C.A. & Rachidi, F., 2012, "On the Possible Variation of the Lightning Striking Distance as Defined in the IEC Lightning Protection Standard as a Function of Structure Height", 31st International Conference on Lightning Protection, Vienna, Austria, pp. 638-642.

[6] Xie, Y., He, H., He, J. & Wu, C., 2014, "The Effect of Corona Discharge on Leader Initiation in Long Air Gaps", IEEE Trans. Plasma Sci., Vol. 42, pp. 890-895.

[7] Rizk, F.A.M., 2010, "Modeling of Lightning Exposure of Sharp and Blunt Rods", IEEE Trans. Pow. Deliv., Vol. 25, pp. 3122-3132.

[8] Moore, C.B., Rison, W., Mathis, J. & Aulich, G., 2000, "Lightning rod improvement studies", J. Appl. Meteorol., Vol. 39, pp. 593–609.

[9] GIMELEC, 1991, "Rod and Early Emission Lightning Conductors", Paris, France (unpublished manuscript).

[10] Moore, C.B., Aulich, G. & Rison, W., 2003, "The case for using blunt-tipped lightning rods as strike receptors", J. Appl. Met., Vol. 42, pp. 984-993.

[11] Moore, C.B., Aulich, G.D. & Rison, W., 2000, "Measurement of lightning rod responses to nearby strikes", J. Geophys. Res., Vol. 27, pp. 1487-1490.

[12] Ait-Amar, S. & Berger, G., 2006, "Attractive Radius of Elevated Building", Proc. 28th Internat. Conf. Lightn. Protect. (ICLP), Kanazawa, Japan, Paper IV-14.

[13] Pecastaing, L., Reess, T., De Ferron, A., Souakri, S., Smycz, E., Skopec, A. & Stec, C., 2015, "Experimental Demonstration of the Effectiveness of an Early Streamer Emission Air Terminal Versus a Franklin Rod", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 22, No. 2, pp. 789-798.

[14] Federal Interagency Lightning Protection User Group, 2001, "The Basis of Conventional Lightning Protection Technology", USA (unpublished manuscript).

[15] Eybert-Bérard, A., Thirion, B., Boilloz, P., Saba, M. & Solorzano, N., 2004, "An experimental study of leaders initiated by single and advanced (ESE) lightning rods", Proc. 27th Internat. Conf. Lightn. Protect., Avignon, France, Paper 4.9.

[16] Sigogne, C., Pignolet, P., Reess, T., Silvestre de Ferron, A., Berger, G., Lafon, G., Serrie, G., 2013, "New Results at the Pic du Midi Lightning Station", Proc. Internat. Symp. Lightn. Protect. (XII SIPDA), Belo Horizonte.

[17] Ruiz, D., Polo, S. & Pomar, V., 2011, "Lightning protection: Basis and Practice", 1st International Lightning Protection Symposium, Valencia, Spain.

[18] Pomar, V., Polo, S., Faveaux, S. & Llovera, P., 2011, "Effectiveness of worldwide existing ESE lightning protection systems manufactured in Europe", 1st International Lightning Protection Symposium, Valencia, Spain.

[19] Fauveaux, S., Zoro, R. & Thirion, B., 2010, "In-Situ Performance Example of Lightning Protection System", Intern. Conf. Grounding & Earthing and 4th Internat. Conf. Lightn. Physics & Effects, Salvador, Brazil.

[20] Lefort, A., Gruet, P. & Diey, M., 20xx, "Feedback on the lightning protection of high-risk industrial facilities in France", Proc. 27th Internat. Conf. Lightn. Protect., Avignon, France, Paper 10.6.

Head Office | 49 Patriarch Drive, Huntingfield Tasmania, Australia 7055
Postal | PO Box 379 Kingston, Tasmania, Australia 7051
Web | www.lpi.com.au
Phone | + 61 3 6281 2475
Facsimile | + 61 3 6229 1900
Email | info@lpi.com.au