MCT Brattberg

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White Paper

Lightning Protection and Cable Penetrations manufactured by MCT Brattberg AB

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About the author

The author Mr. Jan Olof Brink is an electronic engineer raised and schooled in Stockholm, Sweden. He started his occupational carrier as a radio maintenance engineer at Ericsson. He and his family moved to Karlskrona Sweden in 1986 and joined Karlskronavarvet AB (today named Saab Kockums AB) as an EMC engineer. He has been with the shipyard as responsible for all EMC issues ever since, in all new buildings, maintenance and refurbishment projects that the shipyard been engaged in.

For the last 25 years he has been titled as EMC-Specialist and since the beginning of 1990th he has taken the subject Lightning Protection as a special interest. He has designed Lightning Protection System for several ships and vessels as; large and small military ships built of different materials, small civilian sailing yachts and large wooden sailing ships.

Mr. Brink is retired from the shipyard since 2016 and is now working as an independent consultant in EMC and Lightning Protection.

Table Of Content

Preface

Mr. Jan Olof Brink has been commissioned by MCT Brattberg AB, the Swedish company manufacturing Multi Cable Transits, to write a White Paper about Lightning Protection System, for both primary and secondary effects.
This paper contains a neutral evaluation based on well-established and recognized scientific knowledge. Conclusions are made without any influence or interference from MCT Brattberg AB.

1. Background

In a modern structure, no matter the size shape or area of use, it is important to handle all environmental effects, both for personnel and equipment. Therefore, a method called Controlled Electromagnetic Topology, CET, is introduced in the entire EMC community to handle all purposes for grounding. This method was developed and established in the 1980th by the EMP community. (EMP = ElectroMagnetic Pulse from nuclear weapons). The main contribution to the development came from USA and, to mention only one person, Carl Baum at AFWL in Albuquerque N.M. Some contribution also came from Dr. Torbjörn Karlsson at Emicon AB in Sweden. In the Electromagnetic Environment Handbook, EMMA [1], published by Swedish Defence Materiel Administration the CET method is described and used as the base for all kind of grounding and shielding to provide EMC. DNV (Det Norske Veritas) is also handling CET as a guideline for achieving EMC in maritime systems.

2. CET - an Overview

ElectroMagnetic Topology

A conducting body's topological properties largely determine which electromagnetic coupling mechanisms dominate. A body can be stretched and bent without its topological properties being changed. Some electromagnetic properties are described better by topology than by the mechanical structure. One important example is the property of a shielded volume. The electromagnetic coupling through the shield between the inside and the outside is not very much dependent on the shape of the volume but making a hole in the shield will cause a leakage that has an immediate influence on the coupling. The topology changes from two volumes into one at the same time as there becomes a hole in the shield. In physics there are no such drastic changes, if the hole is much smaller than a wavelength the leakage is limited. Therefore, an intelligent translation between the topological model and the real world is always necessary. A hole in the topological model corresponds to a hole that can be observed with the electromagnetic wavelength of interest. When a hole in the shield is much smaller than a wavelength it is not observed by the electromagnetic wave and in the topological model there is no hole.

An important concept in CET is the generalized shield which is another intelligent translation from topology to the real world. A generalized shield may have small apertures according to what is discussed above. It may even consist of an open area close to a ground plane. It can be shown that the electromagnetic coupling between an object in open space and an object very close to the ground plane is controlled by the distance between the object and the ground plane. The coupling decreases when the object is approaching the ground plane.

A volume that contains a controlled electromagnetic environment is called a zone. There are zones with high-level EM fields around transmitters and noisy equipment, or Lightning down conductors, and there are low-level EM fields around receivers, sensors etc. All zones have a boundary that is attenuating the EM field at least as much as the difference between the controlled electromagnetic environments in the zones on each side of the boundary. Penetrations through a zone boundary must not destroy the attenuation. Electric energy can pass through a filter in the boundary, if it has a frequency spectrum that is allowed to the same level in the zones on both sides of the boundary. This is usually true for main power wall that provides the attenuation without passing through the boundary; it is just another topological zone, inside two other zones, with its own electromagnetic environment.

Electromagnetic compatibility is controlled by a division into zones each of which is allocated a defined electromagnetic environment and formulated with the help of the highest permitted voltage/current levels or field strengths. The specifications are usually frequency-dependent and shall apply within a specified frequency range. Any level is permitted in principle outside this frequency range.

EM topology is primarily a qualitative tool providing an overview and understanding of the system properties. It is guiding to a correct way of designing and specifying all components that are required for EMC.

In this overview the EM environment is represented by both EM fields and current/voltage or a combination of current/voltage and fields to show that CET may be used as a method both for Lightning Protection and for establishing EMC.

Grounding in CET

In an EM topological context grounding is defined as "connection to the local shield". Let us consider an example to illustrate the meaning of a local shield. In a shielded room the surrounding metal walls, i.e. the local shield, are obviously providing the best possible ground. Connecting to a wire that penetrates the wall and connects to earth outside the shielded room is not connecting to the local shield and must not be considered as a grounding alternative.

The generalized shield concept makes it possible to broaden the definition so that it becomes universal; grounding is always connecting to the reference in the generalized shield. There is always a well conducting reference in a generalized shield which provides the best possible grounding to the local shield in the zone. This viewpoint is immensely significant in creating a common grounding philosophy for all different disciplines.

Grounding can be seen as a very low frequency shielding measure. Zone boundaries between different grounding systems are created only through isolation.

Grounding is a connection between an object and the reference in the zone where the object finds itself. The reference is unambiguous if the ground refers to currents and voltages whose wavelength is much longer than that of the zone and the dimensions of the connection.

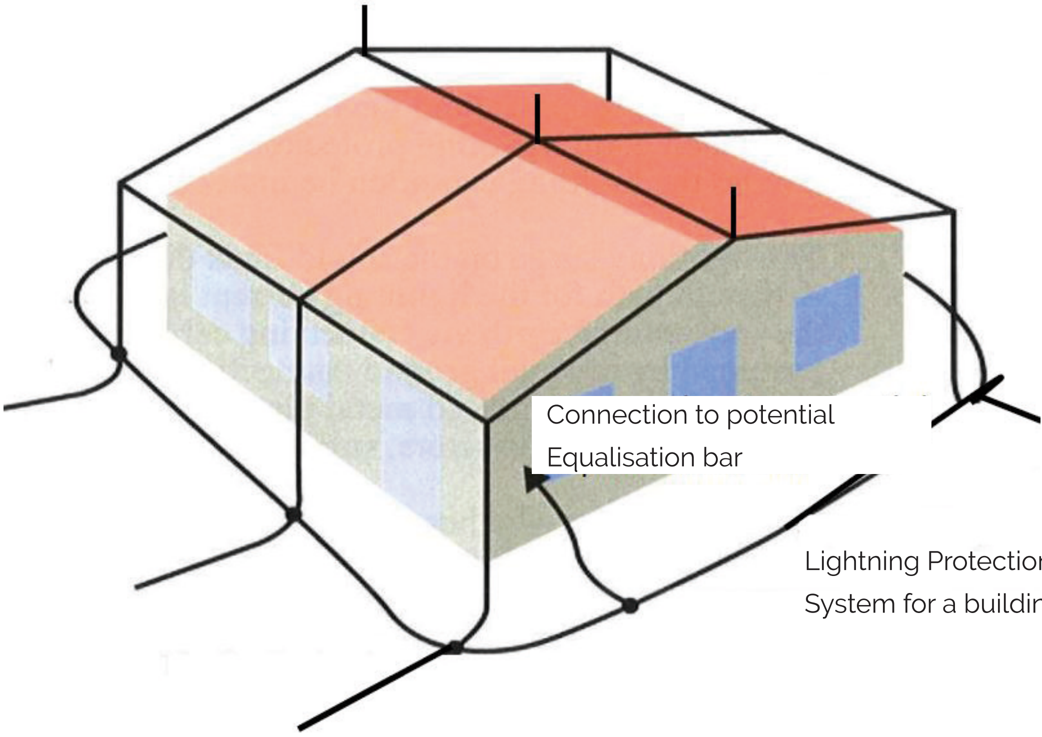
The most important purpose of grounding is to bind the metal structures to each other and connect an earth rail or equivalent so that it functions as a potential equaliser and a low frequency entry plate. In this way the currents are diverted before they reach sensitive equipment. The diversion is limited to such low frequencies for which the diverter circuit can be considered sufficiently short in proportion to the wavelength.

Grounding can provide a protective effect for the low frequency part of the coupling transients and Lightning Interference that can cause personal injury, mechanical damage and overvoltages.

An advantage with CET grounding method is that it makes it easy to specify relevant groundings and to avoid unnecessary grounding that may cause electromagnetic interference.

3 Lightning Protection

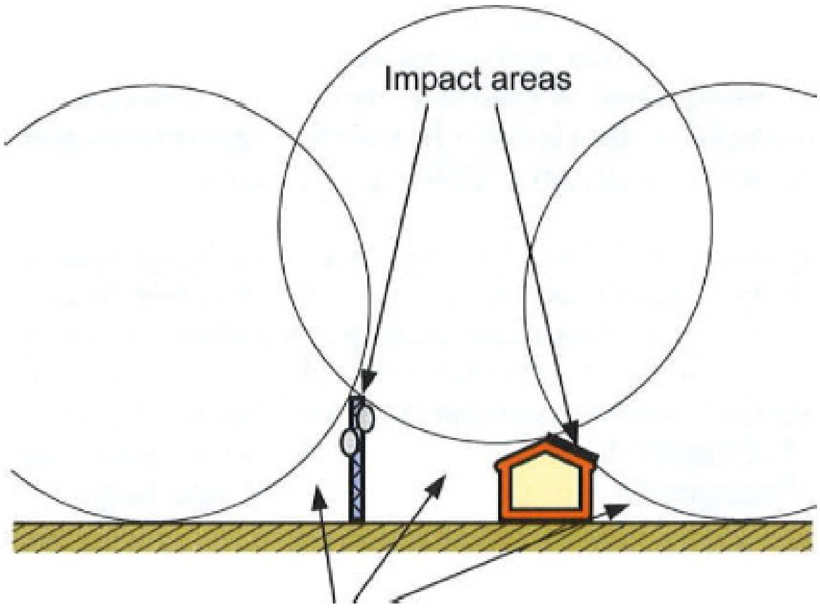
Lightning Protection of a building is based on; ground electrode, down conductors and dedicated interception points for lightning to strike (air terminals). The picture below shows that the air terminals will let the lightning current in to the down conductors, and the down conductors will end up in a circumferential ground electrode. It is essential that the Lightning Protection System is symmetrical built up, in purpose to divert lightning currents to more than one down conductor.



Lightning Protection System for a building.

The Protective Sphere

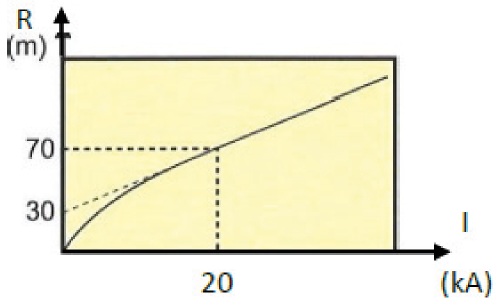
To acknowledge what parts of the structure is in danger of being hit by Lightning, the rolling sphere principle may be used, or commonly the widely discussed “thunder ball”, as that is one of the principals described in MIL-STD 464 [2] and NFPA 780 [3]. The rolling sphere method uses a theoretical sphere that is rolling over the structure and any point touched by the sphere is a potential interception point for Lightning. One of the major parameters for the calculation of the radius of this sphere is the current in the Lightning strike. If the current is small, the radius of the sphere is small, if the current is large, the radius will be large. The picture below shows that places where the ball hits the structure, there is a potential striking point. We are rolling the sphere over solid surface (ground or sea) and where the ball finds obstacles, this will be a striking point. Locations between these striking points are well protected against strikes.



The "thunder ball"

The protective sphere's radius R (m) is determined by the Lightning peak current I (kA)

Ex: I = 20 kA gives R = 70



Many scientists studied this striking distance and came up with different equations to determine the distance. We are using the Darveniza formula as this is used in Sweden since 1990th.

$$S = 2I + 30\left(1 - e^{\frac{-I}{6.8}}\right)$$

Lightning Protection for Vessels or other Structures

In principle it looks the same for a vessel or a tower as for a building, which is shown in the pictures above. The down conductors are symmetrically built up, surrounding the structure, thoroughly connected to the ground plates in the bottom of the vessel, or the Ring Line that encloses the structure and thus a sparse Faraday's cage is created. This will help in reducing the effects created by the heavy magnetic field caused by the Lightning Current running down to the ground reference (e.g. mother earth or sea water).

4 Lightning Protection Zones

Different protective zones may be established in accordance with CET. Zone No 1 is presented above giving a circumferential and sparse faraday's cage. This zone with its interception points, down conductors and ground reference may be called the primary protection.
Its ability to take care of lightning currents, big or small, is determined by the conductivity and cross section of the interception points, down conductors and ground reference, but also upon the choice of metallic material.
Of course, copper has the very best conductivity, but aluminum or stainless steel may be considered after assessment.
The primarily protection zone shall not be contaminated with cables and cable penetrations in other places than dedicated inlet plates, which are connected to the ground reference.

Zone No 2 shall be seen as a generalized zone in the EMC design of the structure. Zone 2 is thus a part of CET and shall not be designed to withstand heavy and major lightning currents, but only secondary effects caused by the major lightning currents in zone No 1.

5 Statistical Reality of Lightning Strikes

Studies on lightning currents demonstrate that most lightning strikes involve current levels significantly lower than 200 kA. Statistical data, such as from the CIGRE Technical Brochure 549 [4], indicate:
The average lightning current is approximately 30 kA.
Only about 5% of lightning strikes exceed 100 kA, and extremely few reach 200 kA.
Designing protection for such improbable extreme events results in over-dimensioning and inefficient use of resources.

6 Lightning Protection Zones and Risk Analysis under IEC 62305

IEC 62305-1 [5] promotes a risk-based approach where Lightning Protection Zones (LPZ) and risk assessments are used to tailor protection levels. If the structure has a low probability of direct lightning strikes (e.g. indoor installations or protected areas), the protection capacity should be adjusted to the actual risk.
A requirement of 200 kA is only relevant for direct lightning conductor systems in areas with extremely high lightning density, not for cable entries in low- or medium-risk environments.

7 Practical Design Limitations and Cost-Efficiency

Designing cable entries to withstand 200 kA requires over-engineered materials and costs, which are rarely justified for low- or medium-risk applications.
The primary purpose of the entry is to protect against indirect lightning currents and transients. A realistic requirement, based on statistical data, typically falls within 10–50 kA.

8 Combined Protection Mechanisms Reduce Requirements

Effective grounding systems and lightning conductors reduce the impact of lightning currents on individual components such as cable entries.

If additional protective measures, such as surge protection devices, are implemented the required capacity for the entry will be significantly lower.

9 Past Experience and Case Studies

References to real-world installations and tests can demonstrate that a design capacity of 10–50 kA is sufficient in most cases.

Companies and standards often design protection for the 90 - 95th percentile rather than for extreme outliers.

10 Conclusion

From a probability standpoint, the likelihood of a direct strike on the entry is extremely low if the structure already has protection against direct lightning strikes. The design should focus on realistic risks rather than hypothetical extreme cases.

References

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02. Mil-Std 464D

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03. NFPA 780

Standard for the installation of Lightning Protection Systems 01-01-2011

04. CIGRE TB549

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05. IEC 62305-1,

Protection against lightning, Part 1 General principles, Second edition, 2010

List of abbreviations

CET	Controlled Electromagnetic Topology
EM	ElectroMagnetic
EMC	ElectroMagnetic Compatibility
EME	ElectroMagnetic Environment
EMI	ElectroMagnetic Interference
EMP	ElectroMagnetic Pulse
HF	"High Frequency" usually meaning the frequency range 1 – 30 MHz
I	Current
kA	Kilo Ampere
LEMP	Lightning ElectroMagnetic Pulse. Voltage/current from a lightning strike
m	Meter
NEMP	Nuclear ElectroMagnetic Pulse. Generated by nuclear weapon

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