IALA

IALA GUIDELINE

G1012
THE PROTECTION OF LIGHTHOUSES AND OTHER AIDS TO NAVIGATION AGAINST DAMAGE FROM LIGHTNING

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DOCUMENT REVISION

Revisions to this document are to be noted in the table prior to the issue of a revised document.

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December 2005	Entire document reformatted to reflect IALA documentation hierarchy.	Council 37
May 2013	Additional sections added and document updated to reflect changes to the IEC standard.	Council 55
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1. INTRODUCTION

Lightning is an atmospheric discharge of electricity accompanied by thunder, which typically occurs during thunderstorms.

Lightning generates the following effects:

- Thermal blowouts.
- Electrodynamics
- Rise in the earth voltage (risk of electrocution).
- Over voltages of several thousand volts and destructive induced currents (damage to electrical and electronic equipment, resulting in interruption to operation).

A lightning protection system needs to be designed to ensure that the lightning discharge is diverted away from the equipment that is to be protected. To do this, a path with very low impedance to earth has to be provided such that the discharge occurs and the equipment remains in a protected zone similar to an umbrella and rain.

Protection against the effect of lightning is based essentially on:

- catching and discharging the current to earth;
- use of voltage protectors; and
- the passive protection of the installation.

Protection from lightning can be achieved with a reasonable amount of success. Successful protection can be expensive, and therefore, the decision to protect should be made considering the cost of the equipment to be protected and the critical need of the equipment/service.

2. SCOPE

Persons and equipment within buildings can be at risk from lightning currents and associated voltages that may be conducted into the building as a consequence of a lightning strike to the building or associated services. Some equipment (e.g., electronic equipment, including computers) is especially susceptible to damage from over voltages in the electricity supply caused by lightning, and such damage may occur even when the lightning strike is remote from the building (e.g., from a surge conducted into the building via the electricity supply).

Measures should be taken to protect persons and equipment within buildings from the effects of lightning.

These guidelines describe the practical approach to risk assessment, design, installation, inspection and testing of lightning protection systems for Marine Aids to Navigation structures, equipment and systems.

These guidelines are not intended as a rigorous treatise on lightning protection, and the reader should refer to their national or an international standard for a more complete description of the protection methods.

3. BRIEF HISTORY ON THE ORIGIN OF LIGHTNING RODS

Throughout the years, man has developed a series of devices for protection against lightning, generally called lightning rods or air terminals.

Benjamin Franklin invented the lightning rod in 1752, when he discovered that lightning strikes were an electrical phenomenon (see Figure 1).

Figure 1 Benjamin Franklin's experience

Lightning rods are a very simple protection system composed of an air termination (the rod), which is used to capture lightning. These are connected to one or more down conductors and an earth electrode.

The system has the capability to intercept, guide and disperse the lightning energy coming from storm clouds into the soil, thus preventing the appearance of dangerous voltages and currents to man, animals and equipment contained in the volume to be protected.

Its function is based on a physical phenomenon called "corona effect", which consists in the ionization of air surrounding the rod's tip. When the electric field in the vicinity reaches a specific magnitude, this creates a "preferred path" for the lightning strike to discharge on to and be further conducted down to the soil, where it is dissipated.

In 1914, with the objective of making the ionization more effective, Szillard, a Hungarian physicist, proposed the use of Radium-226 radiation source on Franklin lightning rods after he detected an increase in electrical current in a rod which contained radium salt that was submitted to an electric field.

In 1931, Gustav Capart, a physicist from Belgium, patented the first ionizing rod using radioactivity, but it was his son Alphonse that, in 1953, introduced several improvements in his father's equipment for commercial purposes.

The advantage of the use of the new device was the enhanced ionization of the atmosphere surrounding the rod, caused by the radioactive element. This fact would accelerate air ionization at the moment of the electric discharge, in order to increase the area of protection.

It became commercially available by the end of the fifties, and many units have been installed since. Until the sixties, the commercial rods had Radium-226, and from that time onwards, they were replaced by Americium-241, an element with lower cost and larger availability in the market (see Figure 2). These radioactive lightning protection rods are now no longer commercially available.

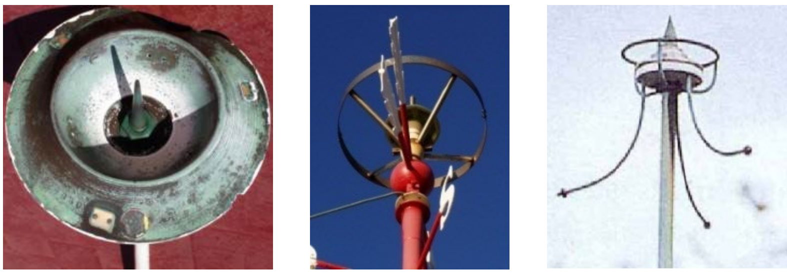


Figure 2 Some types of radioactive lightning rods

Currently, on the market, are some lightning rods with an ionizing device that is not radioactive, these are called ignition advance devices see Figure 3, Figure 4 and Figure 5.

There are three types:

- Piezoelectric – whose operation is based on air ionization by Venturi and Piezoelectric effects which generate high voltages as the wind passes by.
- Dielectric – whose design allows the generation of a high voltage between the two parts of the device, based on a dielectric effect.
- Pulse generator – which have an electronic device which sends high frequency pulses, some of which need an auxiliary power source.

Figure 3 Piezoelectric lightning rod

Figure 4 Dielectric lightning rod

Figure 5 Pulse generator lightning rod

4. NEEDS ANALYSIS

It must be emphasized at the outset that complete protection from the effects of lightning is not always practicable. It is an unfortunate fact that solid-state elements (transistors, integrated circuits, microchips etc.) essential to complex modern electronics systems are inherently much more susceptible to damage from excessive voltages than older types of equipment.

There are several factors that have to be considered when evaluating the need for lightning protection:

- Is there enough of a threat from lightning to justify protection?
- Is the cost of replacement of the equipment sufficient to justify the cost of protection?
- Is the service critical enough to justify the cost of protection?
- The environment of the equipment must be considered because a dry ground plane will require an extensive installation, whilst a wet one will provide a ground path with a minimum installation.

The protection level to be installed can be calculated by doing a risk analysis according to International Standard *IEC 62305-2* [16] (see the example in annex B), the results of which will lead to a suitable lightning protection level (LPL) to mitigate the risk, and will be proportional to the investment made. This standard takes into account the following parameters:

- Size, composition and geographic location of the structure
- Occupancy and contents of the structure
- Definition of the surrounding area
- Environment nature (Keraunic [1] level, see Figure 6)
- Consequential impact (result)

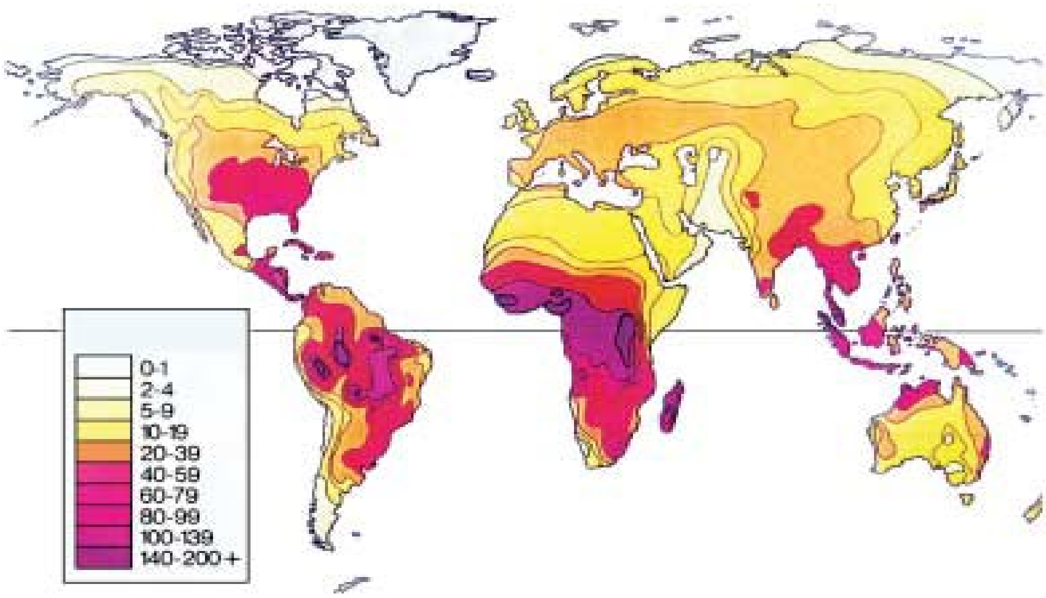


Figure 6 Keraunic levels worldwide

The decision to install protection is based mainly on the vulnerability of the equipment contained within the installation or the structure itself. If the structure is particularly resilient against lightning strike (such as a metallic day mark) or contains no equipment vulnerable to a strike, protection is not warranted.

For most sites proper grounding installations for lighthouses and equipment accommodation are essential to minimize danger to personnel and damage to buildings. Simple and relatively inexpensive measures for the treatment of incoming telecommunication line circuits and electrical power supply circuits should give worthwhile additional protection, even to the modern types of communications and telemetry equipment.

5. TYPES OF LIGHTNING DAMAGE

There are two main categories of lightning strike. In the first category (direct strike) the building or structure is struck by lightning, and very high currents flow to earth (ground potential) via the lightning protection system and in some cases, also via the fabric of the structure. The second type (indirect strike) is where other buildings, structures, trees or the ground some distance from the structure are struck, and the current flows to the remote site. The potential (voltage) can be just as high in an indirect strike.

1 Keraunic level - it is defined as the annual number of days where thunder can be heard.

5.1. DIRECT STRIKE

During a direct lightning strike on a building or structure, currents of up to 200,000 Amps flow to earth. The electrical potential of the earth in the immediate vicinity of the strike may rise to several hundred kilovolts above that of its surroundings. Side flashing will occur between lightning conductors and any conducting surface that is not electrically bonded by means of a low impedance path to the lightning protection earth system. Very high, damaging, currents will flow in these side flashes if the conducting surface has a separate earth path (e.g., incoming services, buried cables etc.).

5.2. INDIRECT STRIKE

Lightning does not have to strike a Marine Aid to Navigation (AtoN) for damage to be caused to it or its contents. As with the direct strike, the electrical potential of the earth in the area of the strike will rise rapidly to many kilovolts above normal and this transient voltage will be induced or conducted into any services (which have conducting parts) passing through or near the area of the strike. If these services are connected to an AtoN then the transient voltages will appear on that AtoN and may, if the services are not bonded to the aid's lightning protection earth system, cause side flashing within the aid, even if the strike is several kilometres away. This is probably the most common form of lightning damage.

6. DESIGN

6.1. THE BASICS OF LIGHTNING PROTECTION

The magnitude of a lightning discharge defies any attempt to block lightning current from damaging equipment. As a result, the basic philosophy of lightning protection is to divert the lightning current past personnel and vulnerable equipment along an efficient path to the ground where it can safely dissipate.

6.2. STRUCTURAL LIGHTNING PROTECTION DESIGN.

The first stage in designing and installing lightning protection is the location of suitable air terminations, down conductors and a ground termination network that will collect any lightning discharges and get them to earth with the minimum of disturbance. The design of the lightning termination network should be completed in accordance with appropriate national or international standards.

Currently there are generally three types of calculation methods that can be used to protect structures against lightning strikes, but only the two most suitable methods are discussed here. Both of these methods help to determine the best location for the air terminals.

6.2.1. PROTECTION ANGLE METHOD

This method uses an inverted cone to define the angle of protection and is most suitable for tall, lone structures. Air terminations should be fitted at the top of each cone (See Figure 7). The angle of protection varies with the height of the structure and the level of protection (See Table 1). Additionally, any structures that fall outside the cone of protection will in turn, need an air termination and a second cone of protection based on its height. All air terminations need to be suitably bonded together.

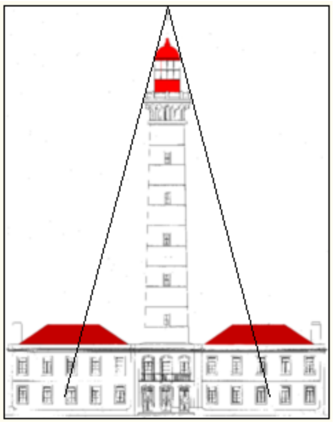


Figure 7 Protection Angle Method (Inverted Cone)

6.2.2. ROLLING SPHERE METHOD

This method is applied when the area to be protected has an attached building(s) or is a more complicated shape (See Figure 8). In this case, a sphere of a given size, based on the level of protection required, (see Table 1) is rolled over the structure, and at each touching point, an air termination is required. As above, these will need to be suitably bonded together.

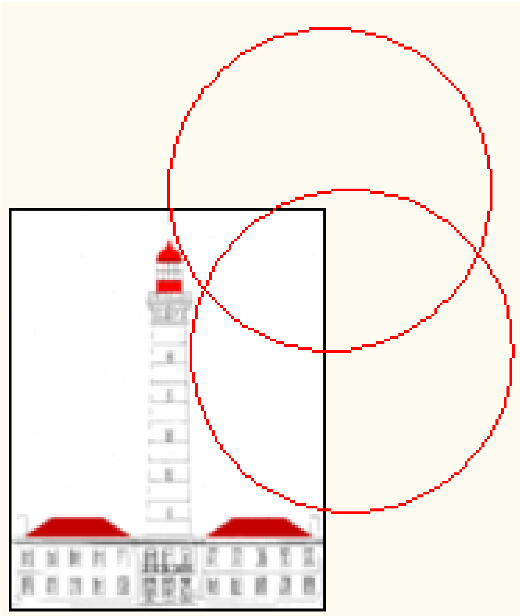


Figure 8 Rolling Sphere Method

6.2.3. ROLLING SPHERE METHOD WHEN USING EXCITED LIGHTNING RODS

Although this is not in the IEC standard, in some countries non-radioactive ionizing or pulse excited lightning rods are used. When these devices are to be employed for protection, then the rolling sphere method is enhanced in radius for the same level of protection (See Figure 9).

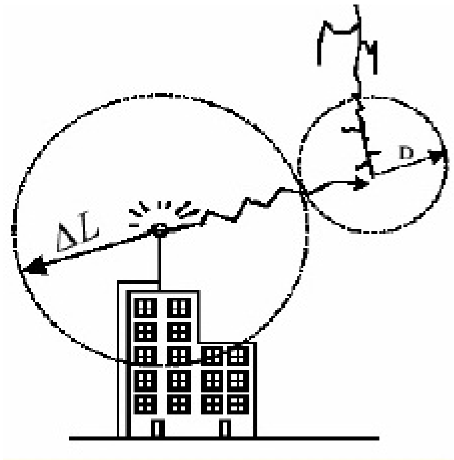


Figure 9 Enhanced Rolling Sphere Method

The level of enhancement is determined by the following formula and is defined by the French Standard *NF C 17-102 (1995)* [11] and the Portuguese Standard *NP4426 (2003)* [10].

$$Rp = \sqrt{h(2D - h) + \Delta L(2D + \Delta L)} \quad \text{for } h \geq 5\, metres$$

Equation 1 Protection Radius Calculation

where:

Rp is the protection radius

h is the lightning rod height in relation to the horizontal plane that goes through the vertex of the element to protect.

D is 20 m for protection level I, 30 m for protection level II, 45 m for protection level III and 60 m for protection level IV, according to the specific risk analysis.

ΔL = ΔT of the lightning rod (rod response) to be installed (refer to the manufacturer's tables).

Table 1 Extract from IEC62305-3

PROTECTION LEVEL	Height of the vertex of the cone of protection (meters) (a)						Rolling sphere radius (m)
	10	20	30	40	50	60	
	Protection angle (degrees) (b)						
I (Very height)	45	20	©	©	©	©	20
II (height)	55	35	25	©	©	©	30
III (Normal)	60	45	35	25	©	©	45
IV (weak)	65	55	45	35	30	25	60

a - For different heights of these can be used a linear interpolation of values given for angles of protection.

b - Angle between the vertical and the cone edge.

c - In this case, applies the method of rolling sphere.

Figure 10 aims to simulate the areas protected by a lightning rod or rods, assuming, a level of protection III (normal) with 45 m of radius of the rolling sphere.

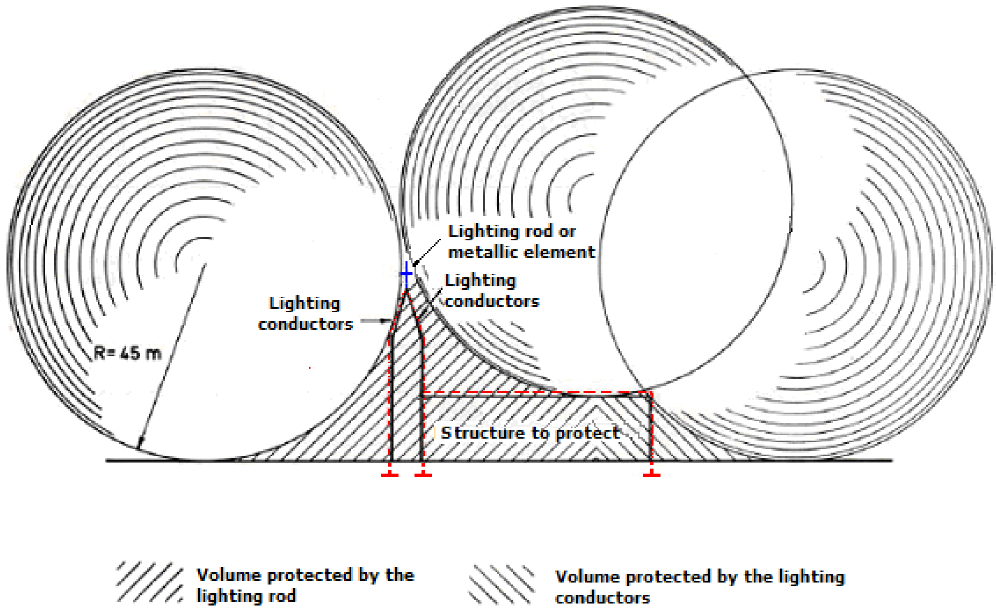


Figure 10 Verification of protection by the rolling sphere model

The choice of method used and the level of protection required will be determined by the outcome of risk analysis outlined earlier. However, as a general rule the rolling sphere technique, using a 10 kA (45 m radius) sphere, is recommended for determining the location of air terminations at all but the most rudimentary navigational facilities. For simple structures not exceeding 20 m in height, the 45-degree zone of protection technique is adequate.

6.3. INTERNAL LIGHTNING PROTECTION DESIGN

The second stage in the design of lightning protection systems and an equally important one is bonding, shielding and interface protection. The concept here is that even with an efficient termination network, lightning is such a violent phenomenon that large voltages and electromagnetic fields will still be created at the site and can cause damage.

The steps to be taken here, which may have been identified as mitigation actions during the risk analysis stage usually fall into the following areas:

- Ideally locate equipment within given areas, to simplify the creation of equipotential zones within a building where equipment, control cubicles and cable screening can all be suitably bonded.
- Fit suitable surge protective devices (SPD) to all cables as close as possible to the point of entry into the equipotential zones from outside.

If there is a significant vertical distance between equipotential zones, then the protection can be enhanced by the fitting of SPD for cables entering or exiting the chosen equipotential zones.

- If possible, locate all incoming or outgoing services together and fit SPD at point of entry/exit to the building.
- Cross bond all equipotential zones with a suitably sized earth conductor, to a main earth point.
- Cross bonding of the internal earthing point with the external lightning protection system should occur only at ground level for an isolated external lightning protection system.

6.4. APPLYING LIGHTNING PROTECTION METHODS TO EQUIPOTENTIALISE A STRUCTURE

To illustrate this, Figure 11 shows a lighthouse and building powered by an overhead supply. The installation is remotely monitored though a telephone line. The lightning termination system in Figure 11 has been properly designed and an earth impedance of 2 ohms created to dissipate the lightning current. Bonding of the tower and building and the down conductor has resulted in very low-down conductor resistance although the tower lighthouse may create a down conductor inductance of approximately 10 µH.

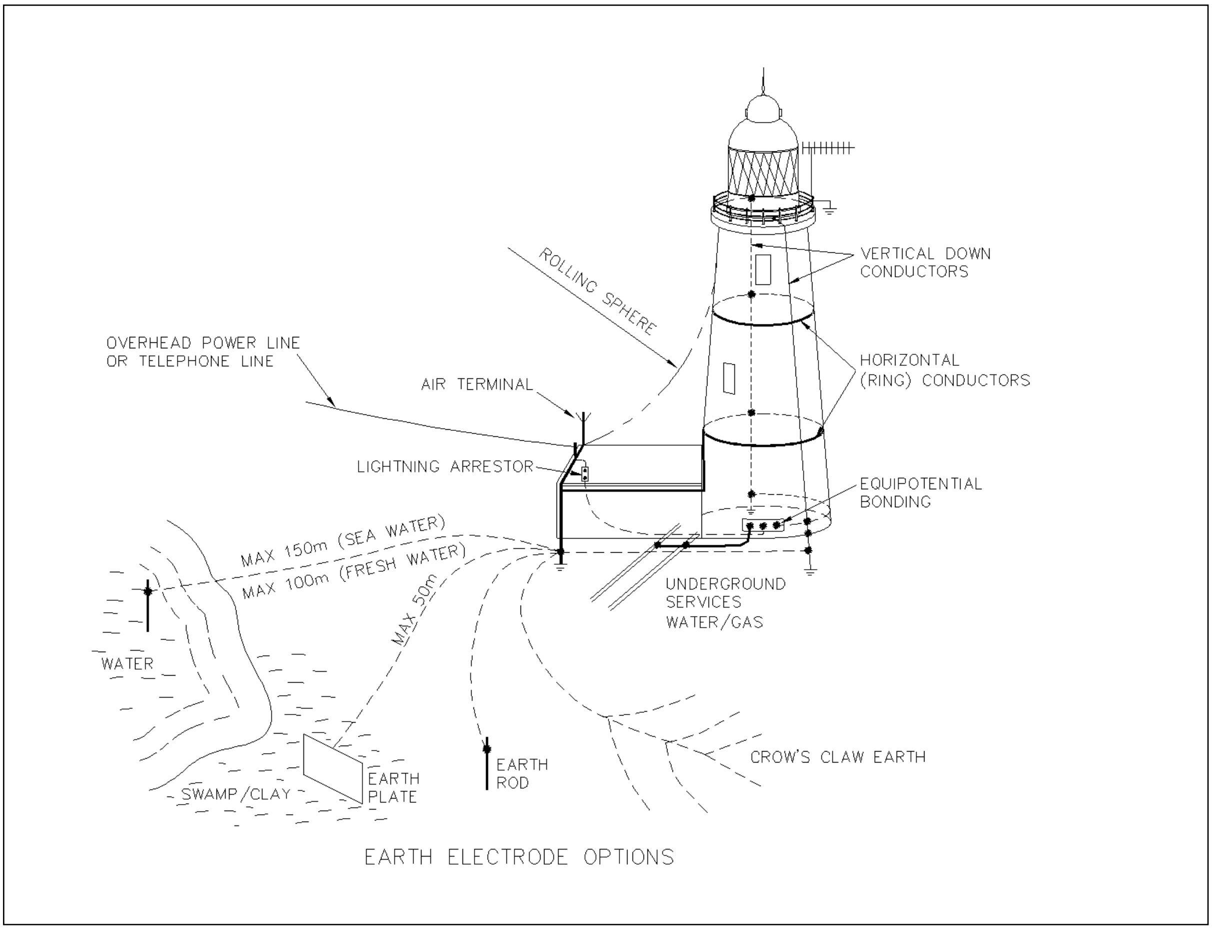


Figure 11 Sketch illustrating various bonding and earthing arrangements

Even though the lightning termination network has been properly designed and installed, significant voltages will still be generated at this site during even a moderate discharge. If this installation is hit by a moderate lightning strike with a 1µs rise time to 100 kA, 10 kV will be generated across the inductance of the tower during the rising front of the strike. As the power supply cable for the light also runs up the tower and is connected to earth at each end, this voltage is impressed across this cable and more importantly, across its terminations. Consequently, these terminations (e.g., the lamp changer or the power supply output stage) will be damaged by over voltage if not correctly protected.

During the same strike, 20 kV is also generated across the earthing impedance at the peak current of the strike. As the site is connected through the Public Switched Telephone Network (PSTN) to a remote site not disturbed by the lightning strike, this voltage will be impressed across the interface to the PSTN line and the line itself. This will result in current flow from the site to the undisturbed remote earth, with resulting damage to the interface.

The response to this problem is to use bonding to create equipotential zones at the site and to ensure that connections between these equipotential zones are suitably protected. In the example, bonding should be used at the top of the tower (at the light) and within the power supply building. The aim of this bonding is to ensure that during a strike no significant voltages are generated between equipment within each equipotential zone. Bonding should then be used to connect these equipotential zones efficiently and by the shortest path to the lightning protection system. If possible, only one connection should be made to the lightning protection down conductor from each equipotential zone in order to ensure that direct lightning current does not flow through the bonding network of the zone on its way to earth.

The lightning protection system needs to be designed to ensure that the absolute minimum of voltage is generated along the lightning discharge path. Otherwise, unnecessary voltage will be generated between the equipotential zones complicating the protection of interfaces connecting the zones. Protection of the interfaces and cables which interconnect the zones including cables from remote areas, for example PSTN lines, need to be designed to prevent damage given the voltages which are expected and the lightning protection termination system installed.

6.5. SUMMARY OF DESIGN APPROACH

The installation of full lightning protection in accordance with these guidelines may not be cost effective for all lighthouses and aids to navigation. However, there are some measures which are considered essential.

6.5.1. MANDATORY PROTECTION

The following measures should be undertaken:

- Building and structure protection in accordance with Structure Protection below
- Earthing in accordance with the section on earthing
- Bonding of incoming and outgoing electricity, telephone, water and gas services
- Installation of surge arrestors in all incoming and outgoing electrical and communications circuits

6.5.2. HIGHLY DESIRABLE PROTECTION

The following measures should be undertaken:

- Bonding of solar photo voltaic arrays, remote fog signals etc.
- Installation of bonding conductor(s) on cable trays and trucking
- Bonding of metal enclosures and backplanes in insulated enclosures
- Bonding of radio communications and radio beacon antenna feeder cable screens.

6.5.3. RECOMMENDED ADDITIONAL MEASURES

The following measures will further reduce the risk of damage:

- Positioning control and monitoring equipment to reduce vertical cable runs
- Installation of surge arrestors on long power, telemetry, control and sensor cables
- Relocation of incoming services to allow short, direct bonding
- Additional external down conductors will reduce the current in internal conductors
- Use of distributed intelligence monitoring to reduce the number of sensor cables
- Use of fibre optics on long sensor runs
- Install surge arrestors in radio communications antenna feeder cables
- Concentrate the sensitive AtoN in a restricted area and provide a zone of protection encompassing the restricted area by the provision of surge arrestors fitted to all cables entering and leaving the zone.

7. INSTALLATION

7.1. PROTECTION OF STRUCTURES

7.1.1. GENERAL

A minimum of two vertical down conductors of not less than 50 $mm^{2,}$ typically in copper, should be provided (other materials maybe be used, see Table 2). These should be evenly spaced horizontally around the perimeter of the outside of the building (at a maximum spacing of 10 m). This can be increased up to 20 m but is dependent on the class of the lightning protection system, determined from the risk assessment.

The down cables should be fixed to the structure by suitable clamps at a rate of 3 per metre whenever possible.

Each down conductor should run vertically, sharp bends are to be avoided wherever possible, and re-entrant loops exceeding 8d are not permitted (For the definition of “d” see Figure 12).

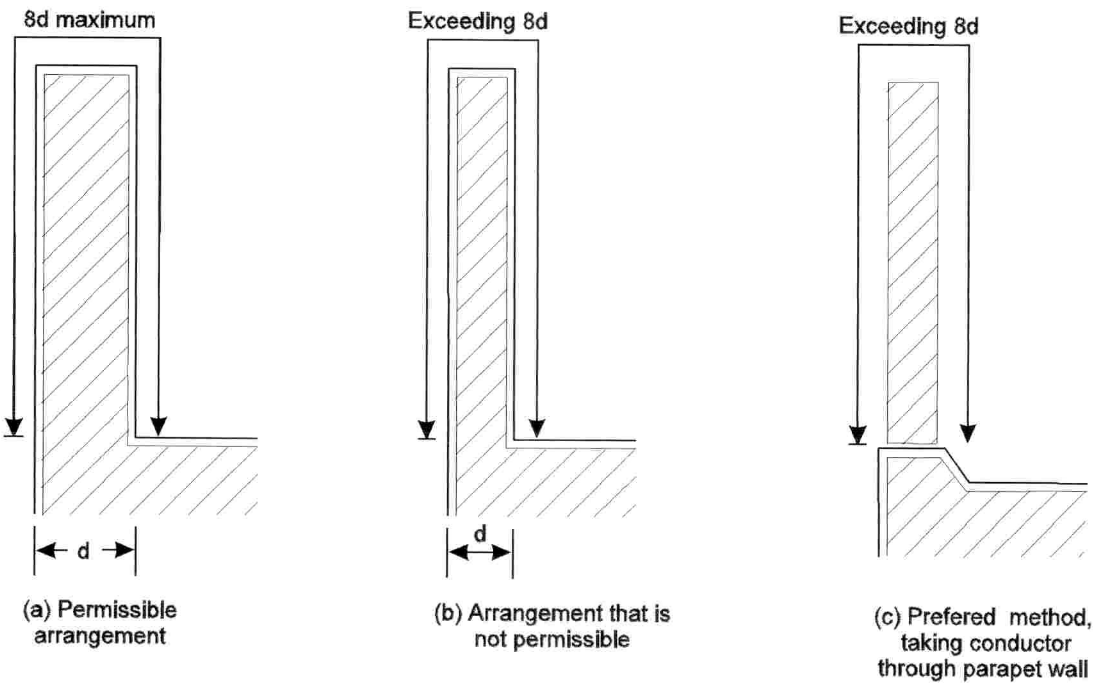


Figure 12 Arrangements loops

Each earth electrode should have a test joint at a suitable height for the situation, but usually between 0.3 m and 3 m above ground level. Mechanical protection to the down conductors maybe required close to ground level to ensure security of the system.

For statistical analysis purposes, it is optional to install a discharge meter in one of the down cables.

All down conductors should be connected together by a continuous horizontal (ring) conductor of not less than 50 mm2, typically in copper. Other materials may be used, see Table 2. This band should be located at the lowest possible point above the test joints. Where the structure exceeds 20m in height, additional ring conductors should be provided (see Figure 13), spaced evenly throughout the height of the structure at intervals not exceeding 20 m.

Table 2 Extract from IEC62305-3 of material sizes and types

Material	Configuration	Cross-sectional area mm²
Copper, Tin plated copper	Solid Tape	50
	Solid round[b]	50
	Stranded[b]	50
	Solid round[c]	176
Aluminium	Solid tape	70
	Solid round	50
	Stranded	50
Aluminium alloy	Solid tape	50
	Solid round	50
	Stranded	50
	Solid round[c]	176
Copper coated aluminium alloy	Solid round	50
Hot dipped galvanised steel	Solid tape	50
	Solid round	50
	Stranded	50
	Solid round[c]	176
Copper coated steel	Solid round	50
	Solid tape	50
Stainless Steel	Solid tape[d]	50
	Solid round[d]	50
	Stranded	70
	Solid round[c]	176

a Mechanical and electrical characteristics as well as corrosion resistance properties shall meet the requirements of the future IEC 62561 series.

b 50 mm² (8 mm diameter) may be reduced to 25 mm² in certain applications where mechanical strength is not an essential requirement. Consideration should in this case be given to reducing the spacing between the fasteners.

c Applicable for air-termination rods and earth lead-in rods. For air-termination rods where mechanical stress such as wind loading is not critical, a 9.5 mm diameter, 1 m long rod may be used.

d If thermal and mechanical considerations are important then these values should be increased to 75 mm².

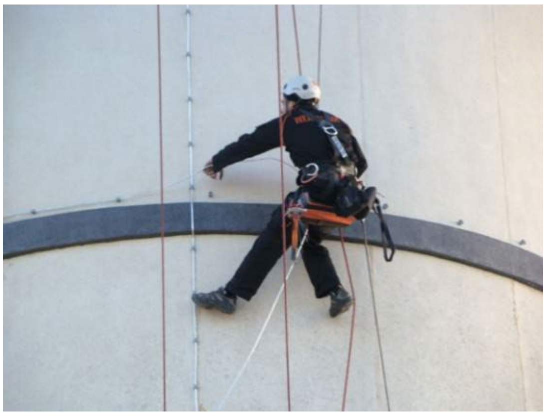


Figure 13 Installation of the horizontal ring

It is essential that each down conductor should have a separate earth electrode.

Existing down conductors should be inspected and tested. A test joint should be fitted if one does not already exist. The earth should be inspected and tested in accordance with section 8.2.

Where the AtoN is a lantern and it has a metal murette and roof, the roof structure can be used as the air termination, but each down conductor should have its top bonded to the murette base (see Figure 14).

Figure 14 An example of murette bonding

Where the lantern or lantern roof is nonconductive, an air termination network should be provided at the highest point on the structure and all down conductors bonded to this network. The air termination should be in the form of a mesh of strip conductors set out so that no part of the roof is more than 5 m from a conductor. Where vertical air termination finials are provided, these should be greater than 0.3 m in height, must be higher than any antenna, located at intersections of the horizontal mesh and spaced not more than 10 m apart. All metallic projections on or above the roof should be bonded to the air termination. Where handrails are provided on the roof, these may form the air termination provided that they are bonded at frequent intervals to a ring conductor that is bonded to the down conductors. Where metal structures exist at the gallery level, like ladders, antenna mountings, solar panel structure, balconies, handrails, etc., these must be cross bonded with the down conductors.

7.1.2. INDEPENDENT BUILDINGS AND STRUCTURES

Where a station comprises two or more separate buildings e.g., lighthouse, generator building, fog signal house etc. each building should be provided with its own lightning protection system which should be interconnected to the main building lightning protection system by means of a conductor of not less than 50 mm^2. Services (telephone, mains electricity etc.) to these buildings should be bonded to the outbuilding lightning protection system in the same manner as for the main building.

7.1.3. STEEL LATTICE TOWERS

Each leg of a steel lattice tower should be provided with a lightning protection earth. These separate piles of earth should be interconnected between the tower leg and the earth test joint; the interconnection should be further bonded to the main building lightning protection system (See Figure 15).

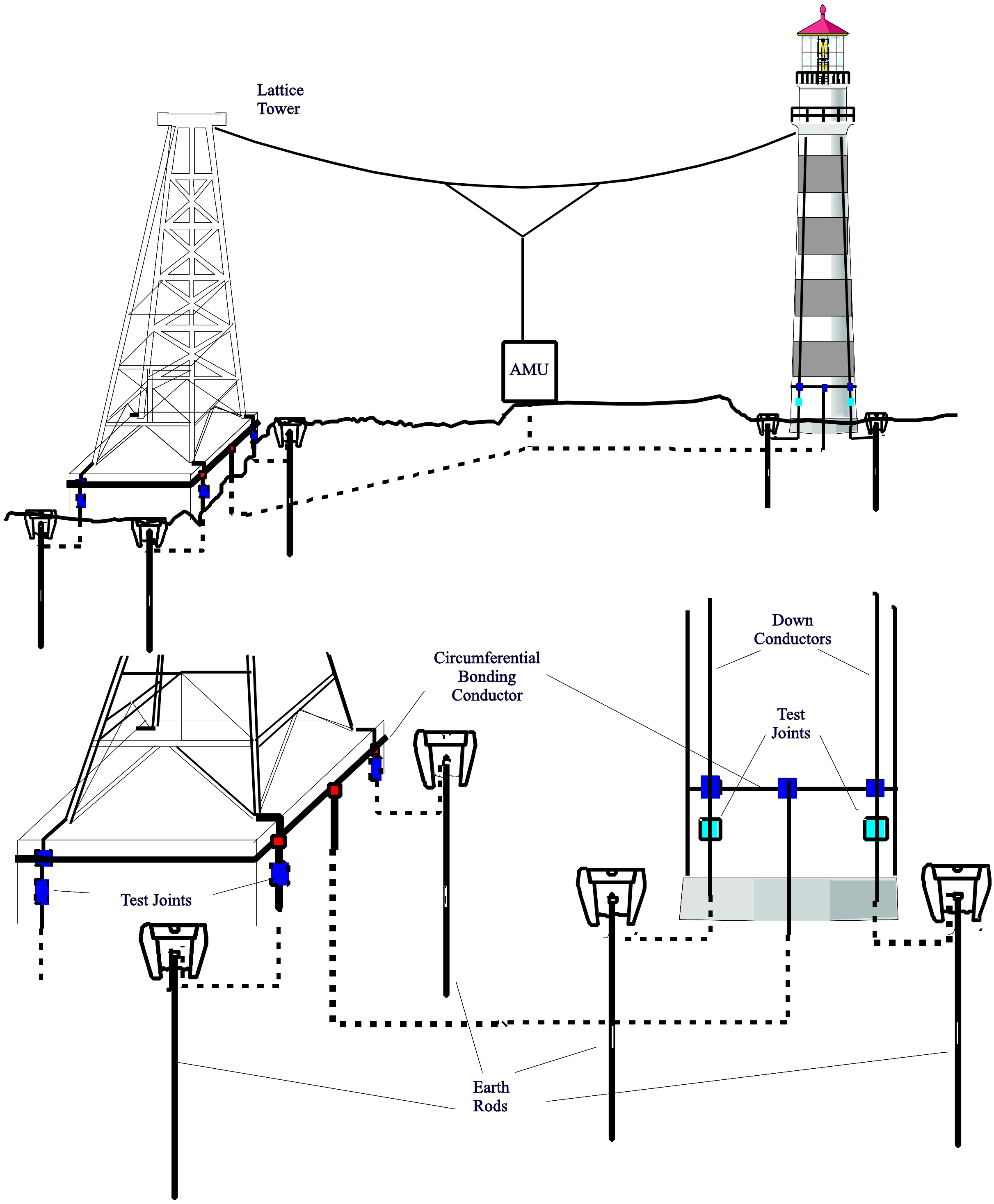


Figure 15 Lightning protection system

7.1.4. FLOATING AIDS

The majority of floating aids such as light vessels, light floats, LANBY and buoys are of metallic structure and form a Faraday cage, effectively shielding sensitive electronic equipment mounted within the hull or superstructure. However, induced voltages are possible and can be avoided by ensuring that metallic enclosures are earthed to the metallic structure of the vessel. A discharge path to earth consisting of surge arrestors should be provided for radio and navigational equipment antennas.

Plastic or GRP hulled vessels, including buoys should be fitted with an air termination with a low impedance path to earth to avoid structural damage to metallic superstructure. The metallic superstructure may act as the air termination. The earth terminal should consist of copper or other conducting material not less than 0.25 m^2 compatible with seawater and mounted such that it is permanently immersed below the water line.

7.2. BONDING

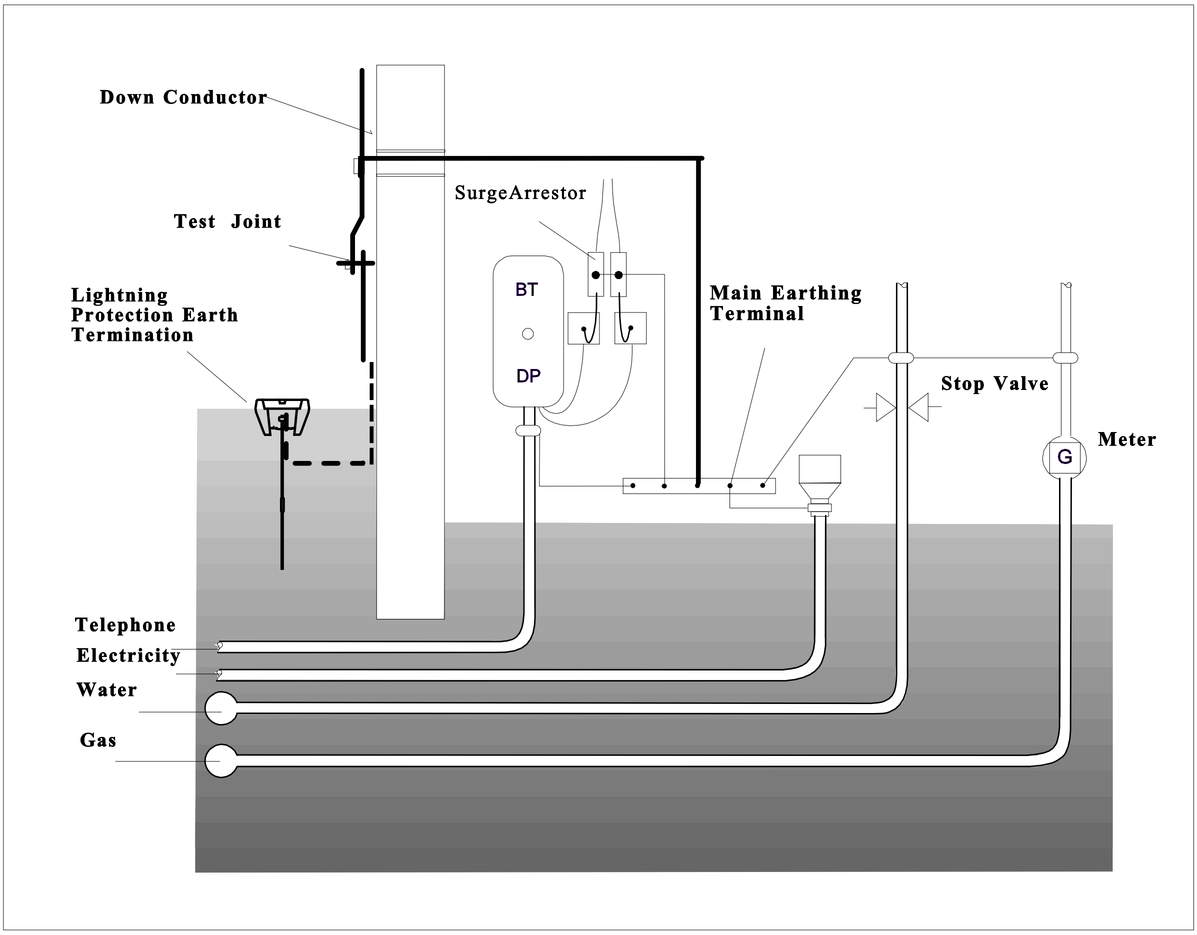


Figure 16 Example of bonds

7.2.1. SERVICES

All incoming and outgoing services should be bonded to the lightning protection system at the point of entry into the building. These bonds should be as short and direct as possible, see Figure 16. The size of the copper bonding conductor should be not less than 16mm2. Conductors used for compliance with current national wiring regulations are not suitable for lightning protection purposes.

The appropriate utility provider may need to be consulted before this work is carried out. In some cases, it may be necessary for the provider to relocate the point of entry into the building.

Conductors entering the building could be carrying lightning currents or voltage transients and are considered to be "dirty". Internal conductors after the earth bonding point, and surge protection where appropriate (see section 7.3), are considered "clean". It is essential that clean conductors are not routed near or parallel to dirty conductors. Figure 17 shows the arrangement for routing cables to and from surge protectors.

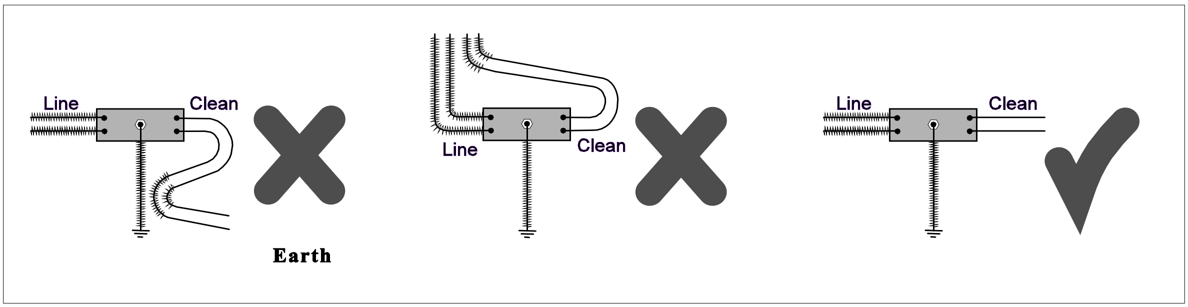


Figure 17 Arrangements for routing cables

7.2.2. ELECTRICITY SUPPLY

All electricity circuits including station and domestic supplies should be protected. The minimum requirement is for the armour of underground cables to be bonded by means of a short, direct connection to the lightning protection system (Figure 16). On particularly vulnerable stations, e.g., those stations where the low voltage transformer is off site and/or those with a high earth resistively may require additional protection in the form of surge suppression.

7.2.3. TELEPHONE CIRCUITS

All telephone circuits, including station and domestic circuits should be protected, because if only the telemetry circuit is protected, surges on the other circuits can induce high voltages into the protected circuits. The minimum requirement is for all telephone lines to be fitted with surge suppression at the point of entry/exit. Where the incoming telephone lines are in the form of an armoured underground cable, the local telephone company should be asked to allow bonding of the armour to the lightning protection system.

7.2.4. WATER SUPPLY

Incoming metal water pipes (or internal metal water pipes where the incoming supply is in plastic) should be bonded to the lightning protection system.

7.2.5. GAS SUPPLY

Incoming metal gas mains should be bonded to the lightning protection system on the consumer side of the meter.

7.3. STRUCTURAL METALWORK

7.3.1. GENERAL

All isolated metalwork, e.g., sector light pedestals, metal windows, rainwater pipes and metal soil pipes, should be bonded to the lightning protection system. Vertical metal pipes should be bonded at the top and bottom. Voltage drops in conductors are due to inductance rather than resistance, and it is therefore essential that the bonding conductors are kept as short and straight as possible.

7.3.2. WEIGHT TUBES

The weight tube probably forms the best lightning protection system for the installation (where it is still intact) and should be bonded to the lightning protection system at its lowest point. Even where the weight tube has been removed, totally or partially, the foundations may still provide a very useful addition to the main building earth system and should be utilized for this purpose, see Figure 18.

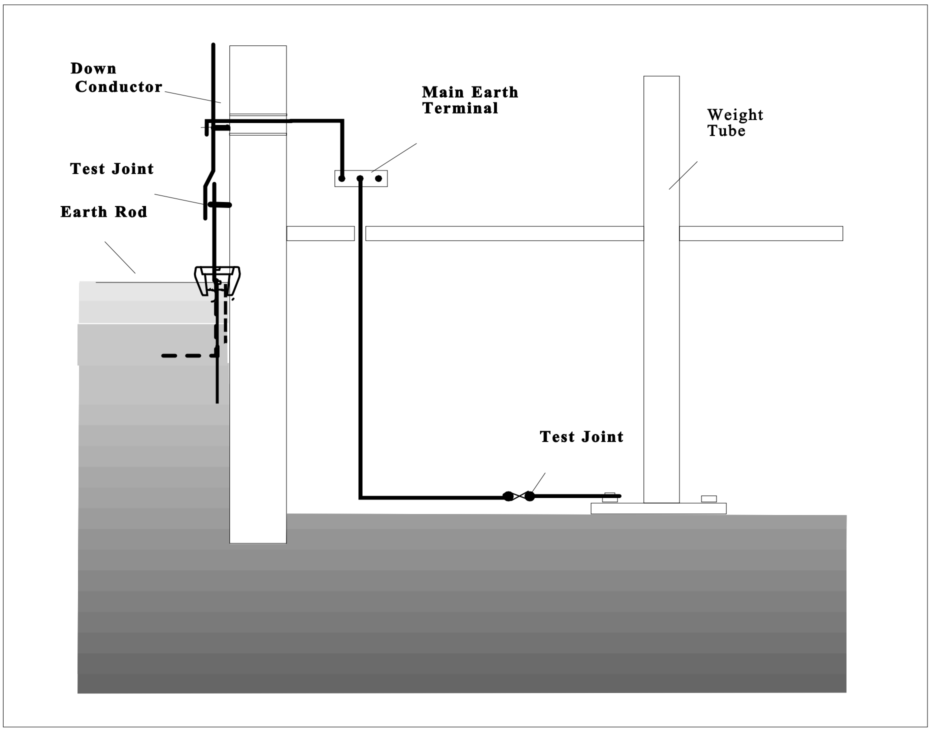


Figure 18 Earth connection

7.3.3. STAIRWAY HANDRAILS

All metal handrails should be bonded to the lightning protection system.

7.4. CABLE DISTRIBUTION SYSTEMS

7.4.1. CONDUIT

Galvanised steel conduit provides the best protection for cables against the effects of lightning. Therefore, this method is recommended for cables connecting vulnerable equipment. All joints should be screwed into the full depth of the coupler.

7.4.2. TRUNKING

Metal trunking provides the second-best form of protection provided that the removable covers are permanently bonded by means of a permanent, flexible connection at each end.

7.4.3. CABLE TRAYS

Metal cable trays form the third best (and most common) protection, provided that the following are adhered to:

- Cable trays and trunking should not be used as the sole means of bonding.

Because of the large number of joints and discontinuities in cable tray and trunking routes, there is a high risk of high resistance joints forming. It should be noted that stainless steel has a significantly higher resistivity per unit length than aluminium, mild steel or copper.

A continuous, insulated, copper conductor of at least 16 mm^2 should be provided on the full length of the cable tray and should be bonded to the tray at all joints and discontinuities. Any joints in the copper conductor should be soft soldered and bolted using spring washers, or riveted connections from cabinets and cable trays etc., should be tinned to reduce the risk of electrolytic action. This conductor should be bonded to the lightning protection earth system at its lowest point. The preferred method would be to provide two equal conductors with a total cross section of at least 30 mm^2, one on each outer edge of the tray. Each conductor should be bonded as above.

7.4.4. FIRE DETECTION CIRCUITS

Because of the length of most of these cable runs, mineral insulated cables should be used, bonded to the lightning protection system at both ends.

Alternatively, cables meeting the requirements of IEC 60332 for flame retardant cables may be used. These should be fitted with surge arrestors at their point of entry and exit from the equipotential zone.

7.4.5. EQUIPMENT CABINETS AND CUBICLES

Metal equipment cabinets and cubicles should be bonded to the earth conductor on the cable tray or trunking by means of a short, direct, flexible conductor of not less than 6 mm^2 (16 mm^2 preferred). The use of non-metallic equipment housings should be avoided wherever possible, but where these are used, the metal back-plane should be bonded as for a metal housing.

7.4.6. SENSOR, CONTROL AND DATA CABLES

All interconnecting sensor, control and data cables should use screened cable. The screen should be bonded to the lightning protection earth conductor at both ends. (A cable screen, bonded at one end only is ineffective at screening against lightning induced voltages). In the majority of cases, the effect of this on circulating currents is negligible.

Where single point earthing is essential due to induced noise onto signal conductors, additional surge arrestors may be used to provide the earth at the remote end. In addition, the use of double screen cables may be considered with the outer sheath earthed at both ends for lightning protection purposes and the inner sheath earthed at one end to minimize induced noise.

Where external sensor, control or data cables are installed, e.g., fuel storage tanks, the cables should be fitted with a surge arrestor, earthed to the lightning protection system at the point of entry to the building. Consideration should be given to implementing extended data cable runs for computers and distributed control systems using fibre optic cables, which are inherently immune to damage by lightning discharge voltages. Fibre optic cables may have a metallic sheath which should be stripped well back (2 m) from one end if electrical isolation is intended.

Where long sensor cable runs exist, these should use MICC cable with the copper sheath bonded at each end to the lightning protection system or bonded metal enclosure. Alternatively, standard sensor cables may be run in conduit or be fitted with surge arrestors at their point of entry and exit from each equipotential zone.

7.4.7. RADIO COMMUNICATION ANTENNAS AND FEEDER CABLES

The screens of all radio communication antenna feeder cables should be bonded to the lightning protection system at the antenna and again at the point of entry to the building. Where a surge arrestor is fitted, this should be at the point of entry to the building and should be bonded to the lightning protection system.

The radio equipment should also be bonded to the lightning protection system.

The mountings of single element antennas and the mounting pole of Yagi antennas should be bonded by a short direct route to the building lightning protection system.

7.5. RADIO BEACON ANTENNAS

7.5.1. EARTH MAT

The radio beacon earth mat often forms a much better earth conductor than the lightning protection earths. It is essential that this earth mat is bonded to the station lightning protection system, using 50 mm^2 copper tape or cable.

7.5.2. Antenna feeder Cable

The screen of the radio beacon antenna feeder cable should be bonded to the earth mat at the antenna matching unit and to the station lightning protection earth at the point of entry to the building.

7.5.3. Antenna support structures

All antenna support structures should be connected to its own earth electrode and bonded to the radio beacon earth mat. If the earth resistance of the earth mat is greater than 10 ohms then additional earth rods may be required, depending upon ground conditions (e.g., rock).

If the antenna support structure is a steel lattice tower, then the earthing arrangements for lattice towers will apply.

All ground anchors for guyed poles should be bonded to the earth mat.

All building anchors for "T " antennas etc. should be bonded to the building lightning protection system.

7.6. OTHER EQUIPMENT

7.6.1. Fog detectors

Fog detectors and their mountings should be bonded to the lightning protection system, and the interconnecting cables should be screened (bonded at both ends) or run in metal conduit, and surge protection should be provided.

7.6.2. Fog signals

The metalwork of a fog signal should be bonded to the lightning protection system. Where the fog signal is remote from the lighthouse, an earth conductor of not less than 16mm^2 should be provided between the fog emitter and the building. This conductor should follow the same route as the emitter drive cables and should be bonded to the lightning earth at the point of entry into the building. Consideration may need to be given to providing a lightning protection earth at the fog emitter where this is at a considerable distance from the main building; if this is provided then the cross-bonding conductor should not be less than 50 mm^2.

7.6.3. Emergency lights

Where an emergency light is installed on the roof of the lantern, for example, it may be necessary to provide an air terminal above the emergency light (minimum height difference of 300 mm), bonded to the building lightning protection system. In addition, surge protection should be provided at the point of entry into the building.

7.6.4. Solar photovoltaic arrays

Photo-voltaic (PV) arrays are vulnerable to lightning damage, particularly where they are located at a distance from the main building. A separate earth termination should be installed locally, connected to the array mounting frame. This should be bonded to the main lightning earth using a bonding conductor of not less than 50 mm^2, which should follow closely the route of the DC cables between the photovoltaic array and the main building. When assessing this requirement, the rolling sphere technique (see Table 1) should be used based on the required lightning protection level and taking into account the location of the photovoltaic array.

All cables should be run either on cable tray, in conduit/trunking or tightly against earthed metalwork/conductor tapes.

7.6.5. Generators

The frame of the generator(s) should be bonded to the lightning protection system by means of a flexible conductor of not less than 16 mm^2.

7.6.6. Fuel storage tanks

Service tanks should be bonded to the lightning protection system.

External storage tanks should be adequately earthed and cross bonded to the generator building lightning protection system.

7.6.7. FUEL LEVEL SENSORS

Level sensor connections etc., should be in screened cable, earthed at each end and ideally run in solid drawn metal conduit or MICC. The sensor wires should be fitted with a surge arrestor, bonded to the lightning protection system at the point of entry into the building. In extreme conditions consideration could be given to the use of self-powered fibre optic sensors where the storage tank is remote from the main building.

7.6.8. RADAR ANTENNAS

Radar antennas consist of a rotating scanner mounted on a housing containing the drive motor and gearbox. This antenna assembly is connected to the transmitter via an electrically continuous, rectangular copper waveguide. Both the waveguide and the drive housing should be bonded to the vessel superstructure or in the case of a lighthouse to the lightning protection system, the latter at its point of entry into the lighthouse.

7.6.9. AIS UNITS

Any cables passing into the equipotential zone from an AIS unit need to have surge arrestors fitted at the entry point into this zone. All VHF antennas and feeder cables should be treated as detailed in section 7.4.7 Radio Communication Antennas and Feeder Cables.

7.7. SURGE PROTECTION

7.7.1. GENERAL

All incoming and outgoing power, telephone, data communications, telemetry sensor and control cables, and radio antenna feeder cables should be fitted with surge protection at (or as near as practicable to) the point of entry into the building.

All surge protectors should be installed in accordance with the manufacturers' instructions.

Owing to the nature of lighthouse installations, it is likely that there will be a significant number of vertical cable runs. This considerably increases the risk of both resistive coupled and induced transient over voltages being introduced into many of the internal power, control, monitoring and telecommunications circuits. It is, therefore, essential that each installation be assessed and appropriate surge suppression installed. Reference documents listed at the end of these guidelines should be used, and if necessary, the advice of consultants and manufacturers should be sought in making this assessment.

7.7.2. ELECTRICITY SUPPLIES

- The type and rating of the protector should be appropriate for the supply voltage.
- The protector should have continuous indication of its protection status.
- The status indication should warn of protection failure between all combinations of conductors, including neutral to earth (otherwise a potentially dangerous neutral earth short could go undetected).
- The protector should be rated for a peak discharge current of not less than 10 kA, 8/20 microsecond waveform (8 μs rise time/20 μs 3 dB pulse width).
- The protector should limit transient over voltage to less than the equipment damage level. The peak transient let through voltage should not be exceeded for all combinations of conductors, e.g., P-N, N-E and P-E.
- The protector should not interfere with or restrict the system's normal operation; nor should it corrupt or shut down the power supply after operation.

- The protector should not have a high earth leakage current.

7.7.3. UNINTERRUPTIBLE POWER SUPPLIES (UPS)

Despite some manufacturers' claims to the contrary, most UPS do not have surge protection suitable for lightning protection. It is essential that both the input and output (or input of each load) of each UPS are adequately protected.

7.7.4. SOLAR PHOTOVOLTAIC ARRAYS

Photo-voltaic arrays, particularly those installed at a distance from the main building, should have surge protectors installed in the DC cables, at the point of entry into the building to protect the photo-voltaic voltage regulator.

Such devices for 12/24 V DC systems should have minimal insertion loss and very small leakage current.

7.7.5. TELEPHONE, DATA, CONTROL AND MONITORING CIRCUITS

Circuits between buildings should be protected at *both* ends in order to protect both pieces of equipment.

The protective device should have the appropriate rating for the application e.g., a PSTN telephone surge protector is *not* suitable for telemetry I/O and vice versa.

The protector should be capable of being installed in groups or individually with appropriate mounting and earth communing kits.

The protector should not interfere with the normal operation or affect the performance of the service being protected.

Where internal circuits are of significant length or the equipment being interconnected is of prime importance or especially vulnerable, then surge protection should be provided at both ends of each interconnecting circuit.

Protective devices for PSTN and Private wire use should be rated at 10kA (8/20μs).

7.7.6. CO-AXIAL AND SCREENED CIRCUITS

Certain types of coaxial and screened circuits, e.g., Local Area Networks and some types of sensors, should only be earthed at one point. The use of an appropriate transient overvoltage protector will provide the additional bonding required by these guidelines whilst maintaining isolation of the screening.

7.8. EARTHING

7.8.1. GENERAL

Earthing of a system involves the provision of a connection to the general mass of earth. This connection should have a resistance not greater than 10 ohms. In typical AtoN installations, it is often difficult to achieve this ideal. In such conditions, the general philosophy of protection must be to provide an equipotential site so that damage due to voltage differences within the site are minimized.

Earth electrodes can be installed in a variety of combinations of forms, including deep driven spikes, plates, horizontal strips or conductors and sea terminations (see Figure 19). The type(s) of electrode used depend on local conditions.

Figure 19 Different types of earth electrodes

The resistance to earth of a given electrode depends upon the electrical resistivity of the soil in which it is installed.

The soil resistivity can be calculated by the Wenner Method (see ANNEX C and ANNEX D).

The length of earth electrode required, depending on the section used, can be determined using the following formula or through the use of free software provided by manufacturers:

7.8.1.1. Rectangular Section Horizontal Strips.

Equation 2 Length of earth electrode - Rectangular Section Horizontal Strips

$$R = \frac{\rho}{275L} Log_{10} \frac{200L^2}{wD}$$

7.8.1.2. Circular Section Horizontal Strips

Equation 3 Length of earth electrode - Circular Section Horizontal Strips

$$R = \frac{\rho}{275L} Log_{10} \frac{100L^2}{\phi D}$$

7.8.1.3. Rectangular Sectional Vertical Strips

Equation 4 Length of earth electrode - Rectangular Sectional Vertical Strips

$$R = \frac{\rho}{275L} Log_{10} \frac{800L^2}{wD}$$

7.8.1.4. Circular Sectional Vertical Strips

Equation 5 Length of earth electrode - Circular Sectional Vertical Strips

$$R = \frac{\rho}{275L} Log_{10} \frac{400L^2}{ND}$$

where:

R is the apparent earth electrode resistance in ohms

ρ is the soil resistivity in ohm centimetres

D is the depth of electrode in metres

ϕ is the diameter of electrode in centimetres

L is the length of electrode in metres

w is the width of electrode in centimetres

N is the number of electrodes

7.8.2. ON SOIL

Each down conductor should have an associated earth network. This may comprise of a single earth electrode or a number of electrodes connected together to form a single network.

The best connection method is aluminothermic (exothermic) welding that will never loosen, corrode or increase in resistance (See Figure 20).

The total earth resistance of the complete earth network should ideally not exceed 10 ohms.

Figure 20 Aluminothermic Welding

7.8.3. ON ROCK

Where a structure is built on rock, it may not be possible to achieve the 10 ohm maximum value for earth resistance.

Where this is the case, no maximum value is stated, and the following procedure should be adopted.

Each earth electrode should be formed by inserting a 2.4 m earth rod into a 75 mm diameter hole, core drilled to a minimum depth of 2.4 m and the hole back filled with cement mixed with a conductive carbonaceous aggregate, for example, Marconite. Bentonite may be used as a substitute for the cement mix, but care will be needed to ensure that the Bentonite is not washed out of the hole or that it becomes dry.

It is important to note that in cases where a low resistance earth cannot be achieved, the local ground potential rise during a lightning event can be very extreme indeed. If suitable bonding arrangements have been put in place at the site, this alone may not cause significant damage to the installation, but extreme damage may occur to interfaces and wired connections between the site and remote earths (such as PSTN, electric power and remote monitoring connections). As a consequence, careful attention needs to be put towards protecting such interfaces at sites where low resistance earths cannot be achieved.

7.8.4. ON THIN SOIL

Where the station is built on rock with a thin covering of soil, the earth may be formed by burying strip electrodes in trenches. The trench should be at least 1-metre-deep, and the system should be installed below the frost line and below the area, which may be subject to seasonal changes.

7.8.5. SEA EARTH ELECTRODES

On structures built on rock, a sea earth electrode can be used as an alternative or in addition to the earth rod system. The earth electrode comprises a mesh of 20 mm x 3 mm copper tape of at least 1 m x 1 m, attached to the rock below the low tide water line. Secure fixing is difficult as the electrode is in the wave area and consequently subject to severe conditions.

8. PERIODIC INSPECTION AND MAINTENANCE

8.1. INSPECTION

All lightning protection systems should be visually inspected by a competent person during installation, after completion and after alteration or extension, in order to verify that they are in accordance with the recommendations in these guidelines and with IEC 62305 or the appropriate national or international standard. Visual inspections of the installation and of the lightning surge arrestors should be repeated at fixed intervals not exceeding 12 months.

In addition, the mechanical condition of all conductors, bonds, joints, terminations and earth electrodes (including reference electrodes) should be checked, and the observations noted. If for any reason, such as site works, it is temporarily not possible to inspect certain parts of the installation, this should also be noted.

During periodic inspection of the lightning protection system, the bonding of any recently added services should be checked to ensure that they are in accordance with these guidelines.

8.2. TESTING

Only disconnect one earth electrode at a time for testing. If only one earth electrode exists, then the installation *must* be disconnected from all sources of main power (including generators) before the earth electrode is disconnected for testing. It is not sufficient to remove the mains earth bond for this test as other connections between the lightning protection system and mains earth will probably exist.

8.2.1. GENERAL

On completion of the installation or any modification to it, the following measurements and/or checks should be made and the results recorded in a lightning protection system logbook:

1 The resistance to earth of the earth termination network and of each earth electrode.

2 The results of a visual check on all conductors, bonds and joints or their measured electrical continuity.

Tests should be repeated at fixed intervals, preferably not exceeding 12 months.

8.2.2. TESTING EARTH ELECTRODE RESISTANCE

The resistance of each earth electrode should be measured with that electrode disconnected from the rest of the lightning protection system and the results recorded. The preferred method of measurement is illustrated in Figure 21. A known current is passed between the earth electrode (E) under test and the test electrode (TE1), and the voltage between E and a second test electrode (TE2) is measured. From these values, the earth electrode resistance can be calculated. Measuring instruments are available that combine the above functions and indicate earth electrode resistance directly. Alternatively, the Wenner method can be used (See ANNEX C and ANNEX D).

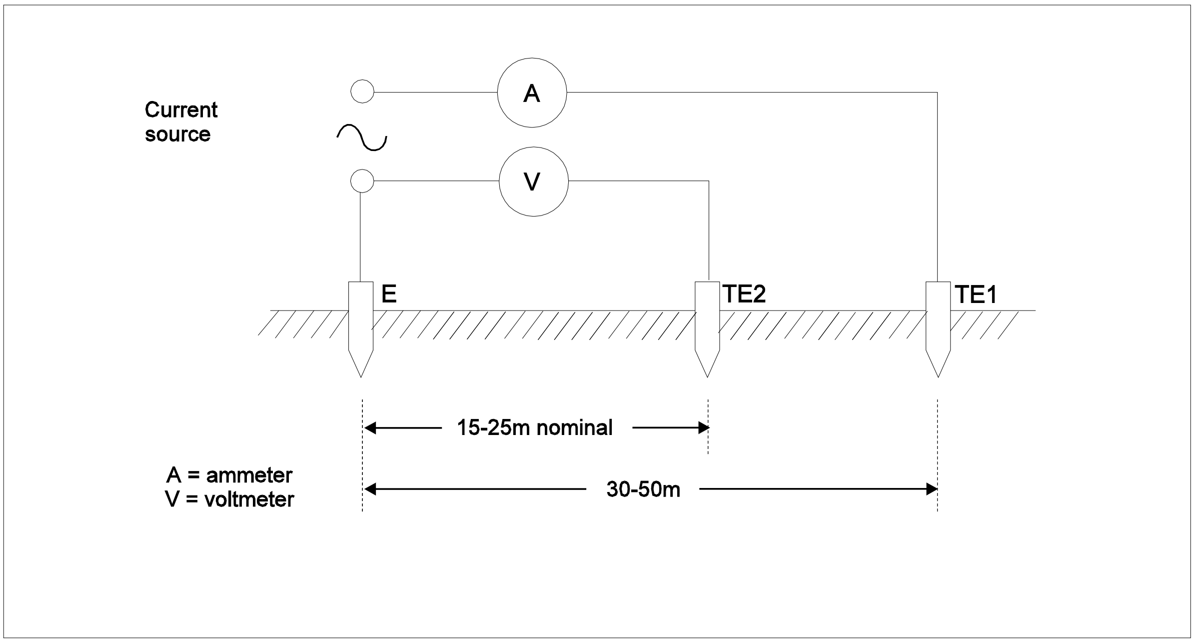


Figure 21 Preferred method of measurement of the earth electrode resistance

The current test electrode (TE1) should be inserted into the ground some 30 to 50 m from the lightning earth electrode under test. Initially, the voltage electrode (TE2) should be inserted about midway between E and TE1. The earth electrode resistance should be measured and recorded. Two further readings should be taken and recorded with TE2 placed 7 m closer to and then 7m further from E. If the three readings match within 5%, then the position of TE1, the initial position of TE2 and the initial value obtained should be recorded for comparison with future tests. If the three results do not agree, then the distance between E and TE1 should be increased and the three tests repeated. This process should be repeated until the three readings agree with the required accuracy.

If the resistance to earth of the lightning protection system exceeds 10 ohms except on rock (see section 8.2.3), or if the resistance of an individual electrode exceeds 10 ohms multiplied by the total number of electrodes, the value should be reduced. If the resistance is less than 10 ohms but significantly higher than the previous reading, the cause should be investigated and any necessary remedial action taken.

8.2.3. TESTING EARTH ELECTRODES ON ROCK

Where possible, two permanent test electrodes should be provided, located in accordance with Figure 21. Earth electrode resistance measurements should be made and recorded using these test electrodes.

Where this is not possible (e.g., on a rock station) then each earth electrode should be disconnected in turn and the resistance between the isolated electrode and the rest of the system measured and recorded (see Note 1).

- Note 1: It is emphasized that before disconnecting a lightning protection earth, it should be tested to ensure that it is not "live" using a sensitive voltage testing device.
- Note 2: It may be advantageous to choose a period slightly less than 12 months in order to vary the season in which the tests are made.
- Note 3: The presence of buried conductors, e.g., underground mains and telephone cables, gas and water pipes, radio beacon earth mats etc., can considerably influence the results of earth electrode resistance measurements. Every effort should be made to locate these services and, wherever possible, select a measurement site away from these services.

8.3. MAINTENANCE OF SURGE ARRESTORS

As a result of the many ways that protection devices can fail without causing long term interruptions, many manufacturers build metal oxide varistor (MOV) protectors with failure indicators on the front, which indicate which MOV has failed and which are still operational. Maintenance will be restricted to periodic visual inspection and checking of the earth connections to ensure that they have not deteriorated and that all other connections are secure.

"In circuit" resistance measurements could be carried out on other surge protectors to establish the integrity of surge arrestors, but frequent checking is not advisable as faults in many instances are self-revealing. There is a real chance that routine disconnection and reconnection can lead to errors with crossed wires because of the large number of surge arrestors that may be present in an installation.

8.4. RECORDS

The following records should be kept on site or by the person responsible for the upkeep of the installation:

- Scale drawings showing the nature, dimensions, materials and positions of all component parts of the lightning protection system
- The nature of the soil and any special earthing arrangements
- The type and position of the earth electrodes, including reference electrodes
- The test conditions and the results obtained (see testing)
- Any alterations, additions, or repairs to the system
- The name of the person responsible for the installation or its upkeep
- A label should be attached at the origin of the electrical installation, worded as follows:

"This installation is provided with a lightning protection system. The bonding to other services and the main equal potential bonding should be maintained accordingly."

8.5. MAINTENANCE

The periodic inspections and tests recommended above will show what maintenance, if any, is needed. Particular attention should be given to the following:

- Earthing
- Evidence of corrosion or conditions likely to lead to corrosion
- Alterations and additions to the structure which may affect the lightning protection system (e.g., changes in the use of the building, the erection of radio antennas etc.)

9. DEFINITIONS

The definitions of terms used in this Guideline can be found in the *International Dictionary of Marine Aids to Navigation* (IALA Dictionary) at http://www.iala-aism.org/wiki/dictionary and were checked as correct at the time of going to print. Where conflict arises, the IALA Dictionary should be considered as the authoritative source of definitions used in IALA documents.

10. ABBREVIATIONS

A	ampere(s)
AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
AtoN	Aid(s) to Navigation
dB	deciBel
DC	Direct current
E	Earth Electrode
GRP	Glass Reinforced Plastic (fibreglass
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities - AISM
IEC	International Electrotechnical Commissio
IT	Information Technology
ITN	Nuclear and Technologic Institute (Portugal)
kA	kiloampere(s)
kV	kilovolt
LANBY	Large Automatic Navigation Buoy
LPL	Lightning Protection Level
m	metre(s)
m^2	square metre(s)
MICC	Mineral-insulated copper-clad (cable)
mm	millimetre(s)
MOV	Metal Oxide Varistor
NBR	Norma Brasiliera
NP	Norma Portuguesa
PSTN	Public Switched Telephone Network

PV	Photovoltaic
SPD	Surge Protective Device(s)
TE	Test Electrode
UPS	Uninterruptible Power Supplies
USCG	United States Coast Guard
V	volt(s)
VHF	Very High Frequency (30 MHz to 300 MHz)
µH	nanohenry
µs	nanosecond(s)
Ω	ohm(s)

11. REFERENCES

Two publications of the British Standards Institution are particularly important in this context and reference will be made to them throughout the remainder of these guidelines. They are:

[1] British Standard 6651: 1992, 'The protection of structures against lightning'

[2] British Standard Code of Practice BS7430: 1991, 'Earthing'

Other documents considered:

[3] General Lighthouse Authorities; Development Department Report, 'Guidelines for the Protection of Lighthouses and Aids to Navigation against Damage from Lightning', No. 20/RPD/1995, Trinity House Lighthouse Service, 1995

[4] 'Lightning Protection', Australian Maritime Safety Authority (AMSA): AS-1768-1991

[5] 'Lightning Protection', Norwegian Coastal Administration, 1997

[6] 'Lightning Protection for Radio Transmitter Stations', Nautel Ltd., 1985

[7] 'Lightning Protection Systems', USCG, 1995

Other relevant documents:

[8] IEC 61024 'Protection of Structures against Lightning'

[9] IEC 61312 'Protection against Lightning Electromagnetic Impulses – IT Systems'

[10] NP 4426, December 2003, Portuguese standard 'Protection of structures against lightning with Lightning rod with no radioactive ignition advancing'

[11] NFC 17-102, 1995 French standard 'Protection of structures against lightning with Lightning rod with no radioactive ignition advancing'

[12] UNE 21186, 1986 Spanish standard 'Protection of structures against lightning with Lightning rod with no radioactive ignition advancing'

[13] NBR 7117, December 1981, Brazilian standard, measurement of soil resistivity with four points method (Wenner method)'

[14] IEC 61643-1, March 2005, dst

[15] IEC 62305-1 ed 2.0, December 2010, Protection against lightning – Part 1: General principles

[16] IEC 62305-2 ed 2, December 2010, Protection against lightning – Part 2: Risk management

[17] IEC 62305-3 ed 2.0, December 2010, Protection against lightning – Part 3: Physical damage to structures and life hazard

[18] IEC 62305-4 ed 2.0, December 2010, Protection against lightning – Part 4: Electrical and electronic system within structures

[19] Necessity of the surge protector in the modern electronic world, IALA Bulletin 2010/4

ANNEX A EXAMPLE

A.1. BACKGROUND

Radium-226 has a half-life period of 1.600 years, and the Americium-241 has a half-life period of 432.6 years.

A half-life is the amount of time it takes for the radioactivity to drop by half. This means that for every half-life that passes, the activity is reduced to half the previous one until it reaches a negligible value, which doesn't allow us to distinguish its radiation from background radiation. In most cases, it is considered that after 10 half-lives that level is reached.

A.2. RISKS AND IMPACT

Exposure risks associated with the americium radioactive lightning rods are relatively moderate. However, the risk of radioactive contamination to the environment could be high.

The human organs that are most susceptible to being affected by the radioactivity are the bones, kidneys and lungs.

In the case of radium lightning rods, the exposure and contamination risks are higher at distances of less than one meter.

Given that the lightning rods are located on top of the structures, the risk of exposure to the radiation is normally small, since the dose of radiation received by an individual varies inversely with the square of the distance to the source. However, where work is done close to the source of the radiation and for longer periods of time, the level of exposure can be significant and should be avoided.

The radioactive biological effects mainly depend on the following:

- Radiation type
- The radionuclide half-life
- The amount of dose
- The organs where it is accumulated.

In the human body, these effects are manifested on a somatic and on genetic level.

On a somatic level, an individual exposed to the radiation may show physical symptoms, whereas the effects of the radiation on a genetic level, which are impossible to avoid, manifest themselves only in the offspring of the exposed person.

A.3. ACTIONS

The radioactive lightning rods that were used up to the nineteen eighties no longer meet the current standards and are a potential hazard that needs to be removed.

With the awareness of the danger of radioactivity, and the possibility of no efficacy of these devices due to the ageing or deterioration of the material, it has been recommended since 1991 that these types of lightning rods are not to use and should be removed.

Most countries should have an organisation that has the responsibility to store and treat radioactive waste and provide the necessary instructions for safe handling.

After being removed, they are considered radioactive waste and should be treated as such.

The Portuguese Nuclear and Technologic Institute (ITN) advise followings these rules when handling radioactive lightning rods:

- Do not damage the rod.
- Use gloves.
- Avoid contact with the tip of the lightning rod or the porcelain parts where the radioactive sources are.
- Cut the pole slightly below the arms or the metal ring.
- Wrap up the tip of the lightning rod with lead foil.
- Pack in a wooden box.
- Contact the approved organisation to pick it up.

ANNEX B RISK ANALYSIS (EXAMPLE)

Date: 12-11-07

Risk analyse (lightning strike protection) — **Vila R.S.António Lighthouse**

INPUT DATA

Local Keraunic index	9
Coefficient C1	0.75
Coefficient C2	1
Coefficient C3	2
Coefficient C4	3
Coefficient C5	5
Height of tower	46

Result of calculations

Ng density of impacts per Km2, year	0.78453981
Nd expected frequency of impacts on the structure	0.03872504
Nc acceptable frequency of impacts on the structure	0.00018333
E efficiency of protection to install ≥	0.99526577

If Na - Nc is negative it is not necessary protection 0.0385417

Struture characterization

C1 ; Coefficient

Structure located in an area where there are other structures or trees of the same height or higher	0.5
Structure surrounded by lower structures	0.75
Isolated Structure	1
Isolated structure situated on a hill or promontory	2

C2 ; Strutural coefficient

Roff	Metalic	Common	Flammable
Metal	0.5	1	2
Common	1	1	2.5
Flammable	2	2.5	3

C3 ; Sture content

without value or not flamable	0.5
Commom value or normaly flammable	2
High value or particularly flammable	5
Exceptional value, irreplaceable or highly flammable, explosive	10

C4 ; Occupancy of the structure

Unoccupied	0.5
Normally occupied	3
Difficult to evacuate or risk of panic	7

C5 ; Consequences of impact

No need for continuity of service and some effect on the neighbourhood	1
Need for continuity of service and some effect on the neighbourhood	5
effect on the neighbourhood	10

Efficiency of protection to install ≥ 1

Table B.10

E Efficiency calculated	Level of protection corresponding	I(kA) Rated crest maximum	D(m) Distance from start
E > 0,999	Nível I++	(a)	(a)
0,99 < E ≤ 0,999	Nível I+	(b)	(b)
0,98 < E ≤ 0,999	Nível I	3	20
0,95 < E ≤ 0,98	Nível II	5	30
0,90 < E ≤ 0,95	Nível III	10	45
0,90 < E ≤ 0,80	Nível IV	16	60
E < 0	It is not necessary protection		

Selecting the level of protection
if Nd ≤ Nc protection is not neccessary
If Nd > Nc you must install protection system of efficiency (E) and corresponding level of protection in selected table B.10

Additional measures: (a) Struture protected by PDI with decrease protection radius
(b) Struture protected by PDI

Outcome of risk analysis:

The spreadsheet shown above and the one in ANNEX C are available as a single Excel Workbook from IALA (contact@iala-aism.org).

ANNEX C WENNER METHOD TO EARTH ELECTRODE RESISTANCE

In practice, the soil is not usually homogeneous, and its resistivity varies differently with depth.

Measurement of soil resistivity and consequential length of earth electrode can be determined in the following manner.

Four equally spaced electrodes are driven into the soil to a depth not exceeding 5% of the spacing between any two electrodes. A current source is connected to the outer two electrodes (C1 & C2), and the resulting circulating current in the ground will lead to a potential difference being produced. This voltage is measured between the middle two electrodes (P1 & P2), see Figure 22. From the values of the voltage and current, a value for "Rt" can be calculated (most resistivity measuring equipment gives a direct reading of Rt).

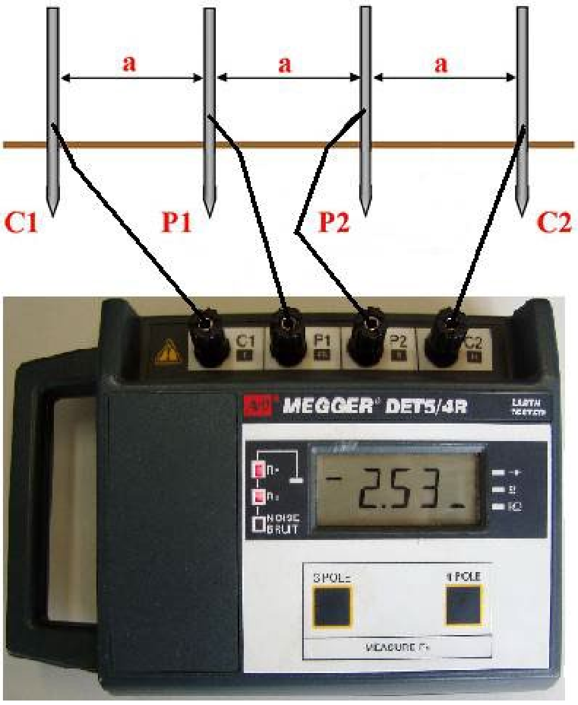


Figure 22 Wenner method connection scheme

The soil resistivity can be calculated with the simplified formula[2]:

Equation 6 Soil resistivity

$$\rho = 2\pi . a . Rt$$

where:

ρ is soil resistivity in ohm meters (Ωm)

a is the distance between electrodes

Rt is the resistance (in ohms) measured between the electrodes

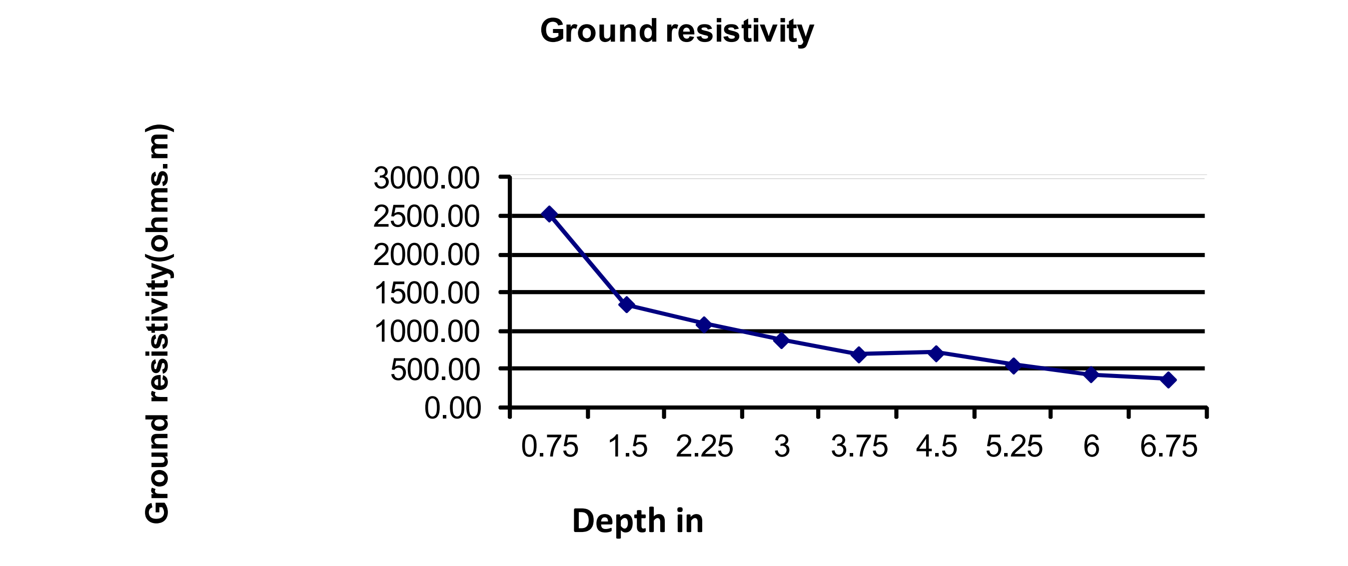
This measurement gives the soil resistivity at a depth equal to 75% of the distance between the electrodes.

2 For the complete formula see NBR 7117, Brazilian standard.

If the distance between the electrodes is varied, the measurement repeated, and the results recorded, soil resistance at various depths will be obtained.

ANNEX D CALCULATION SHEET TO DETERMINE THE RESISTIVITY OF THE SOIL (EXAMPLE)

Local	Vila real de Santo António Lighthouse		Date:	12/11/2007
Analysis of ground resistivity using the Wenner method				
	Test electrodes depth	0.3	Metres	
Depth estimated	Distance between electrodes (metres)	Measured value (Ω)	Ground resistivity (Ω.m)	
			Simplified formula	Complete formula
0.75	1	335	2230.54	2538.80
1.5	2	104	1306.91	1356.61
2.25	3	57	1074.43	1092.94
3	4	35	879.65	888.23
3.75	5	22.2	697.44	701.80
4.5	6	18.9		715.62
5.25	7	12.6	712.51	555.95
6	8	8.8	554.18	443.42
6.75	9	6.6	442.34	373.95



Profiles of resistivity

Ascendent: Clay surface area and wet bottom and rocky

Descending: Surface area very dry and sandy area below

Plan: Rocky ground dry

Obs:
This is an area of dune where the surface is dry and loose sand