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**Lightning protection, earthing and bonding:  
Practical procedures for radio base stations**

Recommendation ITU-T K.112





## Recommendation ITU-T K.112

### Lightning protection, earthing and bonding: Practical procedures for radio base stations

#### Summary

Recommendation ITU-T K.112 provides a set of practical procedures related to the lightning protection, earthing and bonding of radio base stations (RBSs). It considers two types of RBS: those that are stand-alone installations, comprising a tower and the associated equipment and those that are installed on the roof of a building. In both cases, this Recommendation provides the procedures for the design and installation of the lightning air-termination system, down-conductors, earthing network, bonding conductors and surge protective devices (SPDs). This includes the specification of the materials, anti-corrosion protection and special treatment for rocky areas. Particular attention is directed to the protection of the navigation light systems and of the electric power conductors that feed the RBS, especially in the case where the RBS is installed on the roof of a building. Annex A presents practical examples of earthing network design, whereas Annex B presents an overview of the techniques for measuring the earthing resistance and the earth resistivity.

#### History

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# Recommendation ITU-T K.112

## Lightning protection, earthing and bonding: Practical procedures for radio base stations

### 1 Scope

This Recommendation addresses the practical procedures concerning the lightning protection, earthing and bonding of radio base station (RBS) sites. The purpose of this Recommendation is to give detailed guidance on protection procedures, so that an engineer who is not a lightning protection expert can accomplish the design of the lightning protection, earthing and bonding of an RBS by following the guidelines contained in this Recommendation.

### 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [IEC 61643-11] IEC 61643-11 (2011), *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power distribution systems – Requirements and test methods.*
- [IEC 61643-12] IEC 60143-12 (2008), *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles.*
- [IEC 62305-2] IEC 62305-2 (2010), *Protection against lightning – Part 2: Risk management.*
- [IEC 62305-3] IEC 62305-3 (2010), *Protection against lightning – Part 3: Physical damage to structures and life hazard.*

### 3 Definitions

#### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

**3.1.1 equipotential bonding** [b-ITU-T K.27]: Electrical connection putting various exposed conductive parts and extraneous conductive parts at a substantially equal potential.

**3.1.2 earthing network** [b-ITU-T K.27]: The part of an earthing installation that is restricted to the earth electrodes and their interconnections.

#### 3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

**3.2.1 air-termination system:** Part of an external lightning protection system (LPS) using metallic elements such as rods, mesh conductors or catenary wires intended to intercept lightning flashes.

**3.2.2 down-conductor:** Part of an external lightning protection system (LPS) intended to conduct lightning currents between the air-termination system and earth termination system.

**3.2.3 lightning protection system (LPS):** Complete system used to reduce physical damage due to lightning flashes to a structure.

NOTE – An LPS consists of both external and internal lightning protection system.

**3.2.4 navigation light control box (NLCB):** The box that controls the light on the tower to warn pilots of airplanes about the presence of the tower.

## **4 Abbreviations and acronyms**

This Recommendation uses the following abbreviations and acronyms:

ACDB Alternating Current Distribution Board

ATS Automatic Transfer Switch

BR Battery Return

EMC Electromagnetic Compatibility

GPS Global Positioning System

LED Light Emitting Diode

LPL Lightning Protection Level

LPS Lightning Protection System

MET Main Earthing Terminal

MTS Manual Transfer Switch

NL Navigation Light

NLCB Navigation Light Control Box

PDB Power Distribution Box

PE Protective Earth

PMB Power Meter Box

RBS Radio Base Station

SPD Surge Protective Device

## **5 Conventions**

The keywords "is required to" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "is recommended" indicate a requirement which is recommended but which is not absolutely required. Thus this requirement need not be present to claim conformance.

The keywords "is prohibited from" indicate a requirement which must be strictly followed and from which no deviation is permitted if conformance to this Recommendation is to be claimed.

The keywords "can optionally" indicate an optional requirement which is permissible, without implying any sense of being recommended. This term is not intended to imply that the vendor's implementation must provide the option and the feature can be optionally enabled by the network operator/service provider. Rather, it means the vendor may optionally provide the feature and still claim conformance with this Recommendation.



## 6 Lightning protection and earthing of tower RBS

### 6.1 Earthing network of a tower site

The most important objective of the radio base station (RBS) earthing network is to minimize the differences in potential between the conductive parts within the RBS site (equipotential bonding), which is beneficial for the safety, lightning protection and electromagnetic compatibility (EMC) performance of the equipment. In order to achieve this, a ring loop shall surround the tower, the equipment room and the fence.

The earthing resistance of an RBS is not very important, but an RBS with a low earthing resistance minimizes the surge current that goes outwards from the RBS through the metallic services connections (such as power lines and telecommunication lines with metallic elements), when lightning strikes the tower. Therefore, whenever it is feasible, the RBS earthing resistance should be as low as  $10 \Omega$ . Alternatively, instead of achieving a low earthing resistance value, a minimum earthing network mean radius should be achieved.

#### 6.1.1 Mean radius of an RBS earthing network

The earthing network of an RBS should be formed by a ring loop surrounding the tower, equipment room and fence, at a minimum.

The mean radius  $r_e$  of this ring loop should be not less than  $l_1$ , as indicated in Figure 1 and this value depends on the lightning protection system (LPS) class and on the soil resistivity. Class III or IV LPS may be suitable for a regular tower site. Alternatively, the user can define the LPS class by carrying out a risk assessment according to [IEC 62305-2].

When the LPS class has been determined, the user can define the value of earthing network mean radius according to Figure 1. The minimum required ring loop area  $S_m$  can be calculated by the equation below:

$$S_m = \pi \cdot l_1^2 \quad (1)$$

If the ring loop area  $S_r$  of the RBS earthing network is smaller than the required minimum ring loop area  $S_m$ , additional earthing electrodes should be added. The mean value  $r_e$  corresponding to  $S_r$  can be calculated by the equation below:

$$r_e = \sqrt{\frac{S_r}{\pi}} \quad (2)$$

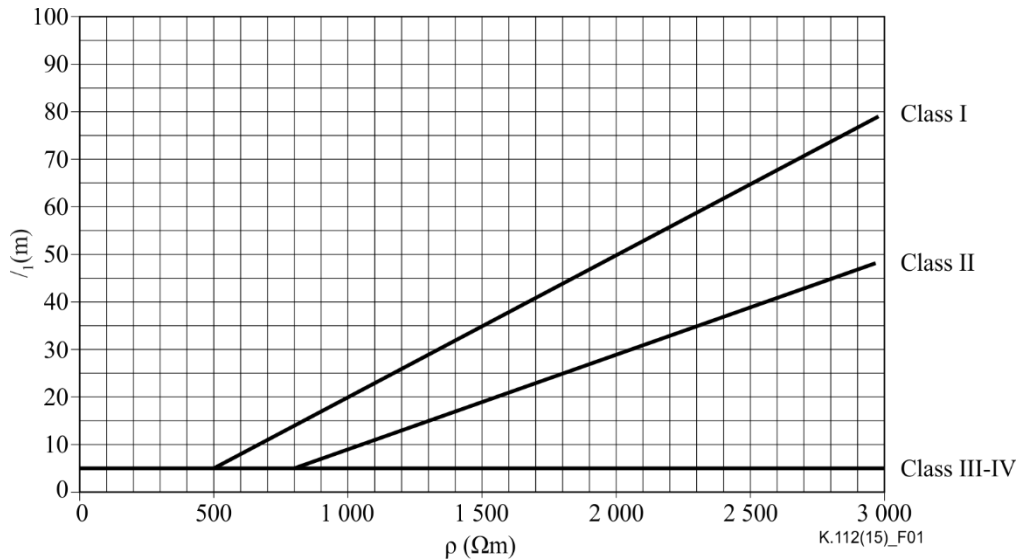
The required minimum length of additional earthing electrode  $l_r$  (horizontal) or  $l_v$  (vertical) is given by the following equation:

$$l_r = l_1 - r_e \quad (3)$$

$$l_v = (l_1 - r_e)/2 \quad (4)$$

The additional earthing electrode is recommended to be added at the four corners of the ring loop and the minimum number of electrodes is four. Figure 2 shows an example of an RBS earthing network.

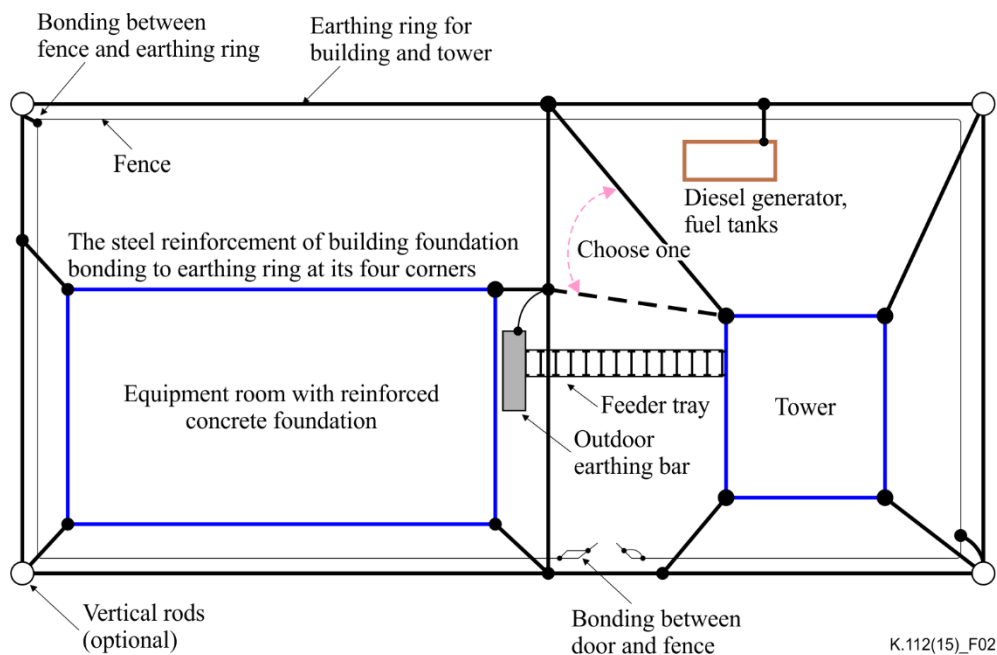
Annex A provides an example of how to design the earthing network when  $r_e$  is less than  $l_1$ , as indicated in Figure 1.



**Figure 1 – Minimum radius  $l_1$  of ring loop according to the class of LPS**

### 6.1.2 The structure of an RBS earthing network

A ring loop surrounding the RBS fence is recommended and the four legs of a metallic tower shall be connected to the ring loop by means of short buried conductors. The four corners of the equipment room shall also be connected to the ring by short conductors, when the equipment room is metallic or has steel-reinforced foundations, as shown in Figure 2. An additional horizontal conductor shall be installed across the ring, between the equipment room and the tower and the earthing terminal at the feeder entrance window shall be connected to this conductor (see Figure 2).



**Figure 2 – Earthing network of the RBS**

The ring loop shall be in contact with the earth for at least 80% of its total length. The earthing electrode should preferably be buried at a depth of at least 0.7 m and at a distance of about 1 m from the external walls of the equipment room. The top of the vertical rods shall be connected to the four corners of the ring loop (see Figure 2).

### 6.1.3 The earthing material

The earthing electrodes could be made of copper, tin plated copper, copper coated steel, hot-dipped galvanized steel, or stainless steel. Table 1, adapted from [IEC 62305-3], shows the main characteristics of the earthing electrodes.

**Table 1 – Material, configuration and minimum dimensions of earth electrodes**

Material	Configuration	Dimensions		
		Earth rod diameter mm	Earth conductor mm <sup>2</sup>	Earth plate mm
Copper Tin plated copper	Stranded		50	
	Solid round	15	50	
	Solid tape		50	
	Pipe	20		
	Solid plate			500 × 500
	Lattice plate <sup>c</sup>			600 × 600
Hot dipped galvanized steel	Solid round	14	78	
	Pipe	25		
	Solid tape		90	
	Solid plate			500 × 500
	Lattice plate <sup>c</sup>			600 × 600
	Profile	<sup>d</sup>		
Bare steel <sup>b</sup>	Stranded		70	
	Solid round		78	
	Solid tape		75	
Copper coated steel	Solid round	14 <sup>f</sup>	50	
	Solid tape		90	
Stainless steel	Solid round	15 <sup>f</sup>	78	
	Solid tape		100	

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

<sup>b</sup> Shall be embedded in concrete for a minimum depth of 50 mm.

<sup>c</sup> Lattice plate constructed with a minimum total length of the conductor of 4.8 m.

<sup>d</sup> Different profiles are permitted with a cross-section of 290 mm<sup>2</sup> and a minimum thickness of 3 mm, e.g., cross profile.

<sup>e</sup> In case of a Type B arrangement foundation earthing system, the earth electrode shall be correctly connected at least every 5 m with the reinforcement steel.

<sup>f</sup> In some countries, the diameter may be reduced to 12.7 mm.

### 6.1.4 Protection against corrosion

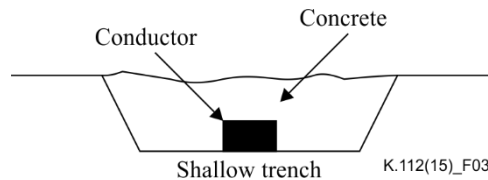
In order to avoid electrochemical corrosion, the metallic materials underground should not be connected to different metallic materials, including the underground part of the down-conductor.

Anti-corrosion treatment must be performed for all welding points or connecting points between earthing electrodes, except those buried in concrete. The anti-corrosion protection of the connecting

points or welding points can be achieved by wrapping these connections with waterproof tape or coating them with anti-corrosion paint, silica gel, or asphalt.

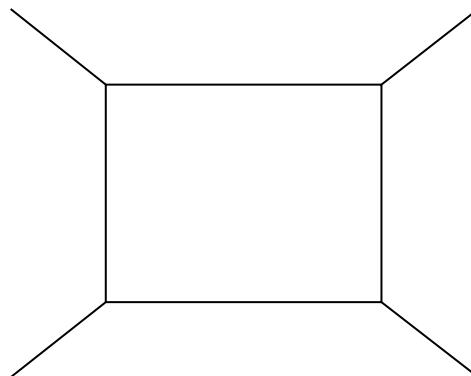
### 6.1.5 Site in rocky area

When the RBS is installed in a rocky area, the horizontal ring conductor can be installed on the rock surface. In this case, a concrete layer shall be used to protect the ring conductor against mechanical damage, as shown in Figure 3. The ring conductor shall be laid inside a shallow trench and covered with concrete in order to achieve mechanical protection.



**Figure 3 – Conductor protected by concrete against mechanical damage**

The use of a vertical rod is not recommended in rocky areas, because it is difficult to drive the rod into the rock. In this case, a ring conductor surrounding the site is very important in order to minimize the difference in potentials within the RBS. If the mean radius  $r_e$  does not fulfil the required value given in Figure 1, then additional radial earthing electrodes shall be installed, as shown in Figure 4. The minimum length of these additional radial electrodes is given by equation (3).



**Figure 4 – Earthing network in rocky area**

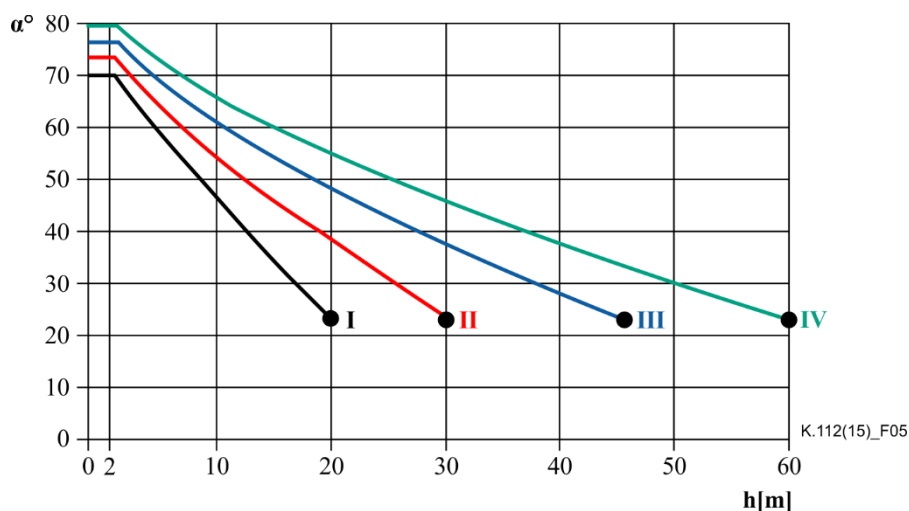
## 6.2 External lightning protection system

### 6.2.1 Protection zone of air-termination system

All structures in an RBS must be within the protective range of its air-termination system, including the equipment room, antennas, feeders, GPS system, power distribution boxes, etc.

The height of the air-termination system of an RBS shall be such that the RBS is within the cone formed by the protective angle.

The protective angle shall be determined based on the lightning protection level (LPL) and the height of the air-termination system. Figure 5, which is adapted from [IEC 62305-3], shows the relationship between the height of the air-termination system and the protective angle, for different values of the LPL.



**Figure 5 – Relationship between the lightning protection system type and  $\alpha$  and  $h$**

### 6.2.2 Down-conductor material

The material of the down-conductors can be copper, tin plated copper, aluminium, aluminium alloy, copper coated steel, hot-dipped galvanized steel, or stainless steel. Details of these materials are given in Table 2, adapted from [IEC 62305-3].

**Table 2 – Material, configuration and minimum cross-sectional area of air-termination conductors, air-termination rods and down-conductors**

Material	Configuration	Minimum cross-sectional area mm <sup>2</sup>	Comments <sup>10)</sup>
Copper	Solid tape	50 <sup>8)</sup>	2 mm min. thickness
	Solid round <sup>7)</sup>	50 <sup>8)</sup>	8 mm diameter
	Stranded	50 <sup>8)</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>3), 4)</sup>	200 <sup>8)</sup>	16 mm diameter
Tin plated copper <sup>1)</sup>	Solid tape	50 <sup>8)</sup>	2 mm min. thickness
	Solid round <sup>7)</sup>	50 <sup>8)</sup>	8 mm diameter
	Stranded	50 <sup>8)</sup>	1.7 mm min. diameter of each strand
Aluminium	Solid tape	70	3 mm min. thickness
	Solid round	50 <sup>8)</sup>	8 mm diameter
	Stranded	50 <sup>8)</sup>	1.7 mm min. diameter of each strand
Aluminium alloy	Solid tape	50 <sup>8)</sup>	2.5 mm min. thickness
	Solid round	50	8 mm diameter
	Stranded	50 <sup>8)</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>3)</sup>	200 <sup>8)</sup>	16 mm diameter
Hot dipped galvanized steel <sup>2)</sup>	Solid tape	50 <sup>8)</sup>	2.5 mm min. thickness
	Solid round <sup>9)</sup>	50	8 mm diameter

**Table 2 – Material, configuration and minimum cross-sectional area of air-termination conductors, air-termination rods and down-conductors**

Material	Configuration	Minimum cross-sectional area mm <sup>2</sup>	Comments <sup>10)</sup>
	Stranded	50 <sup>8)</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>3), 4), 9)</sup>	200 <sup>8)</sup>	16 mm diameter
Stainless steel <sup>5)</sup>	Solid tape <sup>6)</sup>	50 <sup>8)</sup>	2 mm min. thickness
	Solid round <sup>6)</sup>	50	8 mm diameter
	Stranded	70 <sup>8)</sup>	1.7 mm min. diameter of each strand
	Solid round <sup>3), 4)</sup>	200 <sup>8)</sup>	16 mm diameter

- 1) Hot dipped or electroplated minimum thickness coating of 1 µm.
- 2) The coating should be smooth, continuous and free from flux stains with a minimum thickness coating of 50 µm.
- 3) Applicable for air-termination rods only. For applications where mechanical stress such as wind loading is not critical, a 10 mm diameter, 1 m long maximum air-termination rod with an additional fixing may be used.
- 4) Applicable to earth lead-in rods only.
- 5) Chromium ≥ 16%, nickel ≥ 8%, carbon ≤ 0.07%.
- 6) For stainless steel embedded in concrete, and/or in direct contact with flammable material, the minimum sizes should be increased to 78 mm<sup>2</sup> (10 mm diameter) for solid round and 75 mm<sup>2</sup> (3 mm minimum thickness) for solid tape.
- 7) 50 mm<sup>2</sup> (8 mm diameter) may be reduced to 28 mm<sup>2</sup> (6 mm diameter) in certain applications where mechanical strength is not an essential requirement. Consideration should, in this case, be given to reducing the spacing of the fasteners.
- 8) If thermal and mechanical considerations are important, these dimensions can be increased to 60 mm<sup>2</sup> for solid tape and to 78 mm<sup>2</sup> for solid round.
- 9) The minimum cross-section to avoid melting is 16 mm<sup>2</sup> (copper), 25 mm<sup>2</sup> (aluminium), 50 mm<sup>2</sup> (steel) and 50 mm<sup>2</sup> (stainless steel) for a specific energy of 10 000 kJ/Ω. For further information, see Annex E of [IEC 62305-3].
- 10) Thickness, width and diameter are defined at ±10%.

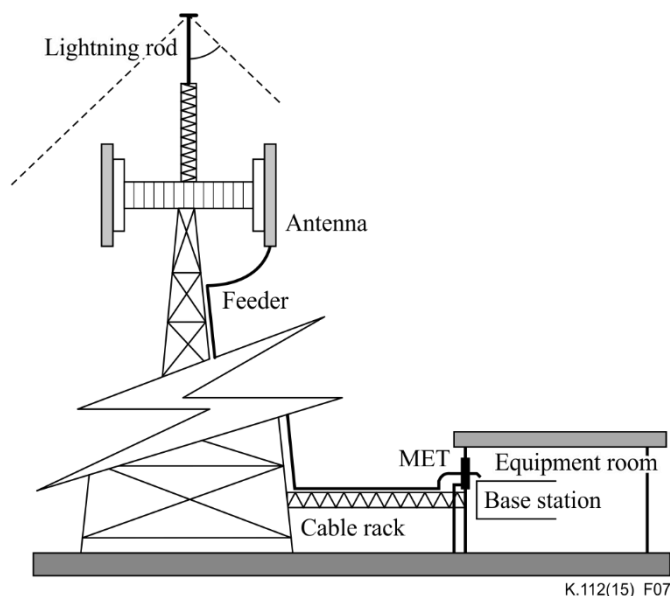
### 6.2.3 Installation of the air-termination system

Air-termination systems are installed on the top of a tower or pole by welding or using screws, as shown in Figure 6. A general overview of the protective angle provided by the air-termination system is shown in Figure 7.

It is recommended to use solid round steel bars with a diameter of 10 mm or higher as lightning rods on the top of the tower or mast. The minimum length of the lightning rod shall be 1 m.



**Figure 6 – Air-termination system installed on the top of a mast**



**Figure 7 – Air-termination system installed at a tower site**

#### **6.2.4 Lightning down-conductor**

As a lightning rod is directly connected to the metallic tower by welding or using screws, the metallic tower body can act as a natural lightning down-conductor. Therefore, a dedicated lightning down-conductor is not necessary for a metallic tower site.

The impedance of a metallic tower to the lightning current is very low, even if the tower is formed by many pieces of metal joined together in a lattice formation. Any contact resistance between adjacent parts of the tower structure is not relevant, as these connections are likely to be punctured and welded by the lightning current.

If the tower or mast is not made of metallic material, then a down-conductor is needed for the air-termination system. Down-conductors can be made of aluminium, galvanized steel, copper, or stainless steel conductors with a minimum cross-sectional area of 125 mm<sup>2</sup>. Aluminium conductors should not be buried in soil or concrete. The lightning rod shall be connected to the down-conductor or to the tower by welding or using screws. Aluminium, copper and galvanized steel conductors can be interconnected above the earth surface.

#### **6.2.5 Anti-corrosion measures**

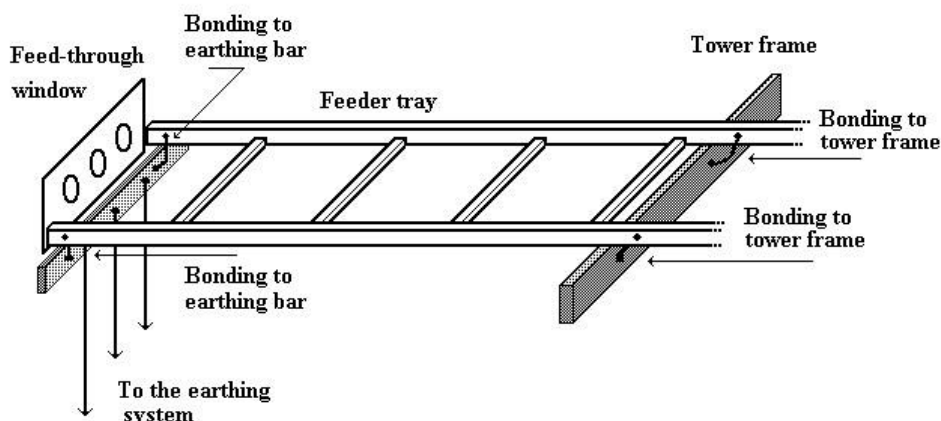
The anti-corrosion treatment must be performed for all welding points or connecting points between earthing electrodes, except those buried in concrete. If a down-conductor is partially inserted into the earth, anti-corrosion and anti-rust measures must be taken for the part 50 cm above the earth surface and the part 50 cm below the earth surface.

Waterproof adhesive tapes, heat-shrink tubing, anti-rust paint, silicon adhesive, or asphalt can be applied to the down-conductor. The down-conductors should be placed away from sewage tubes and drains when they are installed below the earth surface. The down-conductor section that is above the earth surface shall be protected against mechanical damage.

### 6.3 Earthing and bonding network outside equipment room

#### 6.3.1 Feeder tray

The feeder tray shall be continuous and bonded to the tower and to the earthing bar located near the feed-through window of the building, as shown in Figure 8.



**Figure 8 – Feeder tray bonded at both ends**

#### 6.3.2 The facilities and equipment on the tower

The facilities and equipment within a metallic shell installed on the tower shall be bonded to the tower directly. If the conductor terminal cannot be directly connected to the tower, it shall be bonded to a bonding bar first and the bonding bar shall be bonded to the tower.

#### 6.3.3 The cable along the tower

The feeder cable should be bonded at the top of the tower and at the earthing bar near the feed-through window. If the antenna is inherently connected to the tower by design, it is not necessary to use an earthing kit to bond the feeder cable to the tower (or feeder tray), as it is bonded through the antenna structure already.

Depending on the length of the horizontal section of the feeder tray (from the tower to the equipment building), it is recommended to bond the feeder cables to the tower (or to the feeder tray) at the point where they leave the tower (bending point). The minimum length of the horizontal section that requires this bonding is given in Table 3.

**Table 3 – Minimum length of the horizontal section of the feeder tray that requires bonding of feeder cables at the bending point**

LPL	I	II	III-IV
Feeder tray length	10 m	15 m	20 m

NOTE – Regardless of the bonding at the bending point, the feeder cables shall always be bonded to the bonding bar installed near the feed-through window.

The bonding configuration of other shielded cables that are installed along the tower follows the same rule.



When the cable installed along the tower is unshielded, it shall be bonded to the tower through surge protective devices (SPDs). The SPDs shall be installed in at least three places: at the top of the tower, at the bending point where the cable leaves the tower and at the feed-through window.

If the equipment on the top of the tower is connected to an unshielded cable and has an appropriate protection module inside, then it is not necessary to install additional SPDs outside the equipment (at the top of the tower).

### 6.3.4 The connection of the down-conductor and earthing network

The tower legs and any large metallic bodies buried or on the earth surface shall be connected to the earthing network through bonding conductors. These bonding conductors must be securely connected to the earthing electrodes by exothermic welding, electric welding, crimping, or by using fixtures.

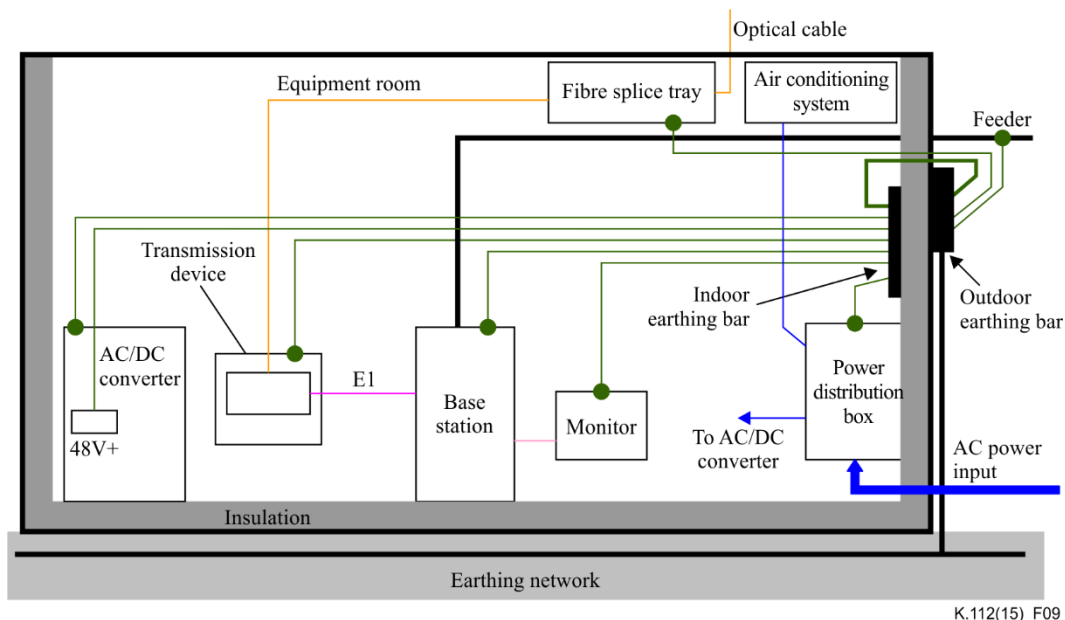
Bonding conductors below the earth surface and crossing the earth surface must be made of the same metal material as the earthing electrodes. Otherwise, electrochemical corrosion may occur. For example, if the earthing network is made of galvanized steel, the bonding conductors must also be made of galvanized steel. However, if the earthing network is made of copper-clad steel, the bonding conductors must be made of copper-clad steel or copper.

## 6.4 Bonding configuration inside the equipment room

In order to limit the overvoltages and the overcurrents in the equipment room, all conductors, frameworks and metallic parts in the equipment room must be bonded to the earthing network, directly or by means of SPDs.

### 6.4.1 Bonding configuration A

The bonding configuration A in the equipment room is illustrated in Figure 9.



**Figure 9 – Bonding configuration A in the equipment room**

The bonding configuration A has the following features:

- The AC power supply and the feeder cables enter the equipment room from the same side. The indoor earthing bar and the power distribution box (PDB) are installed close to the feeder panel. The PDB has SPDs connected between the power conductors and the earthing bar.

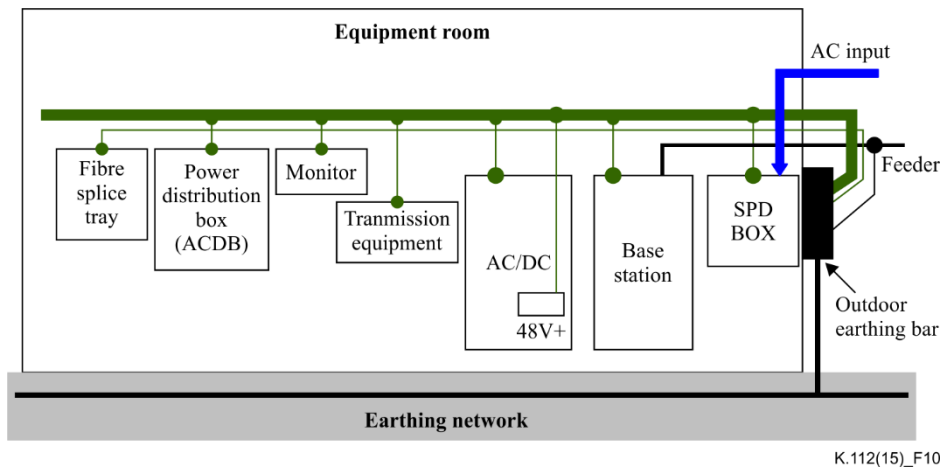
- The indoor earthing bar is provided for the bonding connection of the PDB and all the equipment inside the equipment room.
- The indoor earthing bar is connected to the outdoor earthing bar. The outdoor earthing bar functions as the main earthing terminal (MET) for the equipment room and it is connected to the RBS earthing network.
- The indoor earthing bar and all equipment in the equipment room shall be insulated from the floor, walls and ceiling of the building. Insulating measures should be taken between the metal shells of the equipment or the earthing bar and the floor, walls and ceiling. The thickness of the insulation layer shall not be less than 2 mm.

The bonding configuration A specifies the following requirements:

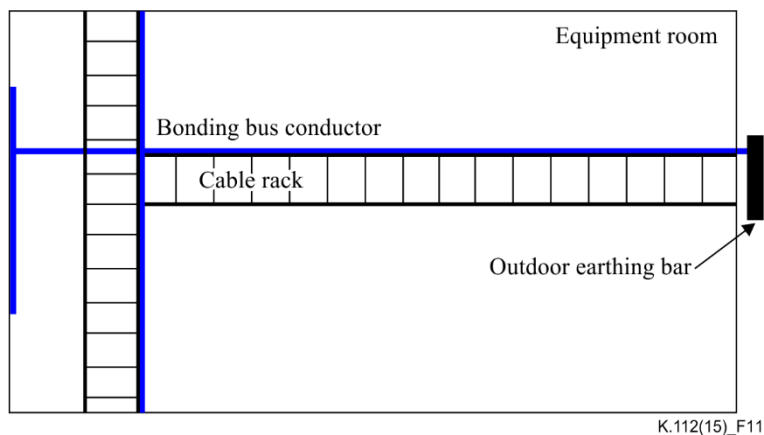
- The indoor and the outdoor earthing bars are installed close to the feed-through window, and the indoor earthing bar is connected to the outdoor earthing bar by using a conductor shorter than 1m. The indoor earthing bar should not be directly connected to the earthing network.
- The PDB should be installed close to the indoor earthing bar. The PDB should be connected to the indoor earthing bar by using a bonding conductor shorter than 1 m. An AC SPD should be integrated in the PDB in the case where the protection of the AC power port is required by the network operator.
- It is recommended to install the navigation light control box (NLCB) directly on the wall. If the NLCB needs to be installed in a public cabinet, insulation measures must be taken between the NLCB and the cabinet, in order to avoid the surge current on the lighting cable to flow through the other circuits of the public cabinet.
- The fibre splice tray should be connected to the MET directly. If an optical fibre has metal strength members, the metal strength members must be bonded to the fibre splice tray. The fibre splice tray should be insulated from other metallic parts in the equipment room.
- The rectifier, RBS equipment, transmission equipment, monitor unit, metallic battery rack and any other equipment in the equipment room shall be connected to the indoor earthing bar by using a protective bonding conductor. The length of the bonding conductor shall be as short as possible.
- The battery return (BR) terminal of the rectifier should be connected to the indoor earthing bar by using a bonding conductor. If the BR of the rectifier has been internally connected to the metallic shell of the rectifier, then it does not need to be connected to the indoor earthing bar again.
- The installation of the PDB, indoor earthing bar, rectifier, RBS equipment, transmission equipment, monitor unit, NLCB and the fibre splice tray shall satisfy the insulation requirements. The shells of the mentioned equipment must be insulated from the floors, walls and ceilings of the equipment room to avoid unexpected earthing connections of the equipment that violate the bonding configuration A.
- The cable rack in the equipment room shall be connected to the indoor earthing bar and it shall be electrically continuous.
- It is recommended to use copper bars with a minimum cross-sectional area of 300 mm<sup>2</sup> and a minimum thickness of 5 mm as indoor earthing bars.

#### **6.4.2 Bonding configuration B**

The bonding configuration B in the equipment room is illustrated in Figures 10 and 11.



**Figure 10 – Bonding configuration B in the equipment room**



**Figure 11 – Bonding ring conductor along cable tray and internal wall**

The bonding configuration B has the following features:

- The bonding configuration B uses a bonding ring instead of an indoor earthing bar.
- All equipment are connected to the bonding ring by using bonding conductors.
- Most of the equipment are installed below the indoor cable tray. Box type equipment, including the PDB, monitoring unit and fibre splice tray, can be mounted on the wall or installed inside the public cabinet.

The bonding configuration B specifies the following requirements:

- It is recommended to use 40 mm × 4 mm flat galvanized steel, or 25 mm × 3 mm copper straps, or copper conductors with a cross-sectional area not less than 70 mm<sup>2</sup> as an indoor bonding ring conductor.
- The bonding ring conductor and cable tray shall have good electrical connections and they do not need to be insulated.
- When the equipment in the equipment room are mounted on the wall, the bonding ring conductor can be deployed along the internal wall of the equipment room.
- If the PDB, transmission unit and monitoring unit are mounted on the wall, a bonding conductor should be deployed along the wall and connected to the ring conductor.
- The PDB should be installed close to the feed-through window. The PDB should be connected to the ring conductor bar by using a bonding conductor less than 1 m long.
- The bonding ring conductor should be prepared to receive the bonding conductors.

The fibre splice tray should be bonded to the MET. The metallic strength member and the metallic screen (if any) in the fibre splice tray must be earthed. Insulation measures must be taken between the fibre splice tray and other metallic parts inside the equipment room.

## 6.5 Protection of the navigation light system

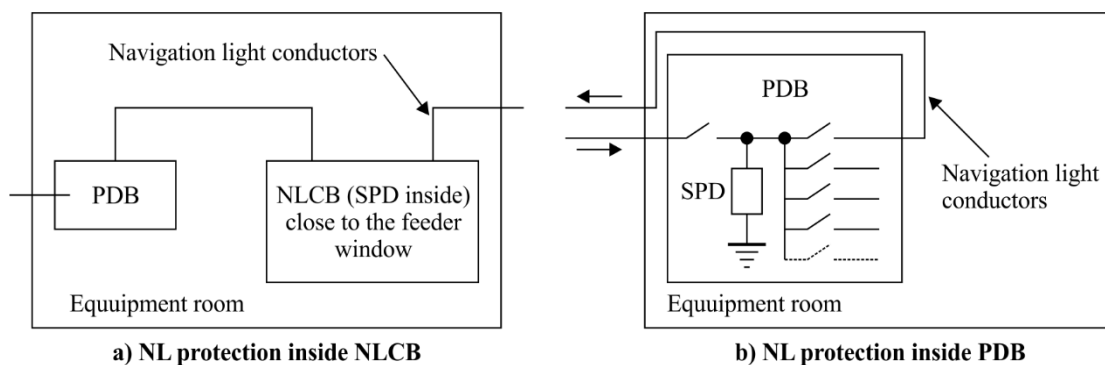
### 6.5.1 Navigation light equipment in the equipment room

The power and signal conductors and the control box that are connected to the navigation light (NL) system should be protected against lightning. Besides protecting the conductor and the control box, this protection also prevents damages to other equipment and facilities due to surge overvoltages and overcurrents carried by the conductors of the NL system.

The NLCB is used to control the on/off status of the NL system. If an equipment room has an independent NLCB, an SPD should be integrated into the NLCB to prevent the surge overvoltages and overcurrents from damaging the NLCB. If the power to the NL is supplied with AC voltage from the PDB, the SPD installed in the NLCB (at the building entrance point normally) shall be coordinated with the SPD installed in the PDB. Refer to [IEC 61643-12] for the relevant information.

If the NL is directly powered by PDB in the equipment room, an SPD should be integrated into the PDB. The bonding conductor of the PDB is recommended to be shorter than 1 m. The protection module of the navigation light monitoring unit can be installed in the NLCB or in the PDB.

Figure 12 shows protection of the navigation light system in the equipment room.



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**Figure 12 – Protection of the navigation light system in the equipment room**

### 6.5.2 Navigation lights on the tower top

If the NL has internal control circuits or it is based on LED technology, then an SPD is required on the top of the tower to protect the lamp. This SPD can be integrated into the lamp box.

If the NL does not have any internal control circuit and if it is not based on LED technology, then an SPD is not required to protect the lamp.

If an SPD needs to be added in case of a monitoring port, it can be integrated into the lamp box.

### 6.5.3 The cable connected to the NL

The power cable and the monitoring cable of the lights should be shielded. In the case of using unshielded power and monitoring cables, they shall be installed in a metallic duct. The two ends of the shielded cable or metallic duct shall be bonded to the metallic tower structure or earthed. For the bonding of the shielded cable, please refer to clause 6.3.3.

The use of an unshielded cable installed without a metallic duct requires the installation of adequate SPDs close to the lighting hardware and connected between the conductors and the tower structure.

Another set of SPDs is also required at the point where the lighting conductors enter the building and these SPDs shall be bonded to the earthing bar installed below the feed-through window.

#### 6.5.4 The current capability of SPD for NLCB and NL

If the conductors supplying power to the NL are unshielded and installed without a metallic duct, it is necessary to install SPDs close to the NL and at the point where the conductors enter the building, as described in clause 6.5.1. These SPDs shall comply with [IEC 61643-11] and have a current rating complying with Table 4.

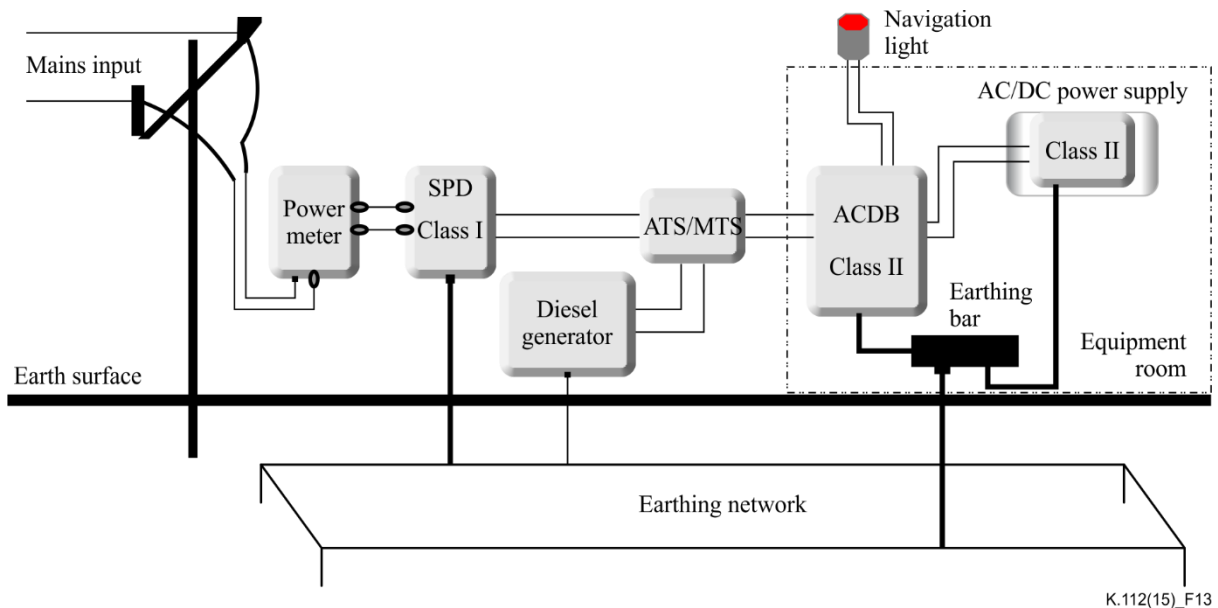
**Table 4 – 8/20  $\mu$ s single-pulse peak current of SPD for unshielded lighting cable**

LPL	I	II	III – IV
Current (kA)	40	30	20

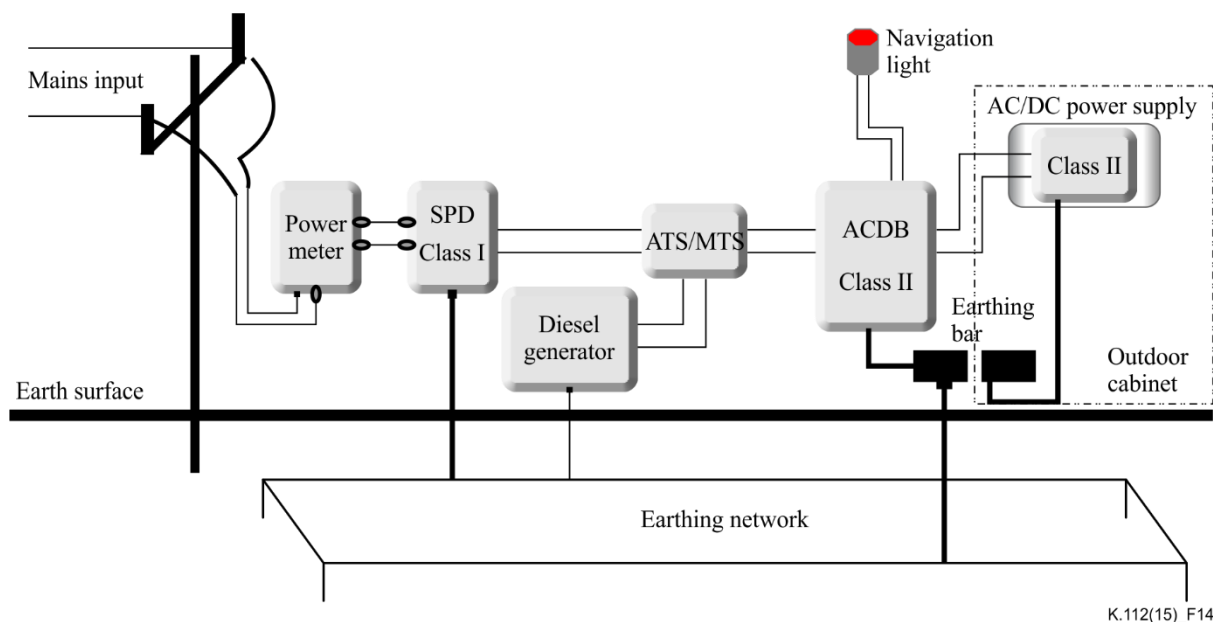
### 6.6 Protection of AC power supplies at the tower

#### 6.6.1 Installing a Class I SPD outside the ACDB

In this application scenario, mains power is supplied to the site, a diesel generator is available as an alternative power supply and the automatic transfer switch (ATS) / manual transfer switch (MTS) to connect the diesel generator is located before the alternating current distribution board (ACDB), as shown in Figures 13 and 14.



**Figure 13 – Lightning protection solution for an indoor site (ATS/MTS outside ACDB)**



**Figure 14 – Lightning protection solution for an outdoor site (ATS/MTS outside ACDB)**

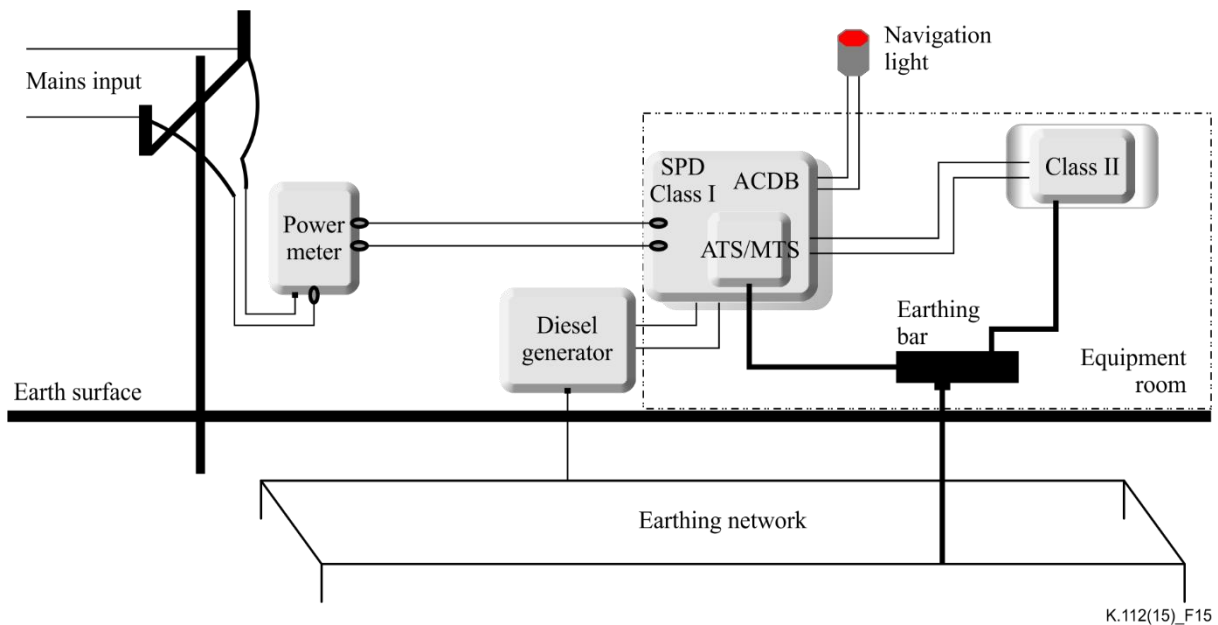
The Class I SPD can be installed on a pole or in the power meter box (PMB). This SPD shall be located between the power meter and the ATS/MTS, as shown in Figures 13 and 14. The SPD should be earthed to the earthing network by an earthing conductor shorter than 2 m and with a minimum cross-sectional area of 16 mm<sup>2</sup>.

It is recommended to bond the Class I SPD and Class II SPD together by using the protective earth (PE) conductor that is routed together with the power conductors.

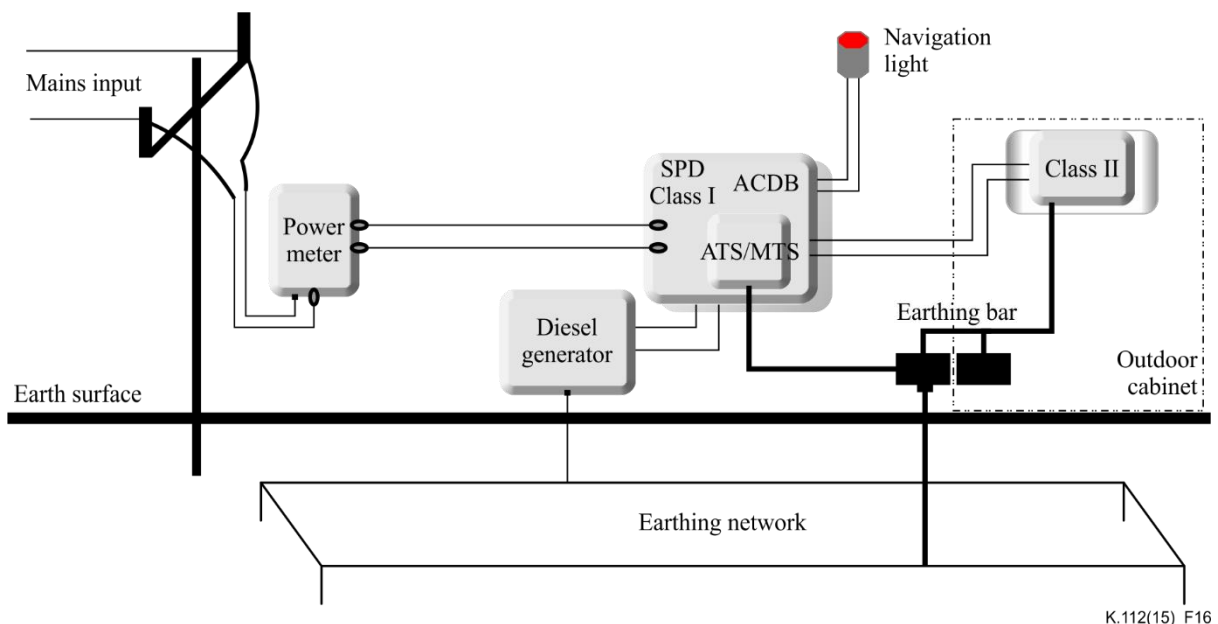
The Class II SPD should be installed in the ACDB, which should be connected to the indoor or outdoor earthing bar directly. When the Class II SPD is installed in the equipment room, the length of the bonding conductor connecting the Class II SPD and the indoor earthing bar should be less than 1 m. When the Class II SPD is installed outside the equipment room, the length of the bonding conductor connecting the Class II SPD and the outdoor earthing bar is recommended to be less than 1.5 m. The minimum cross-sectional area of the bonding conductor is 16 mm<sup>2</sup>.

### 6.6.2 Installing a Class I SPD inside the ACDB

In this application scenario, the mains power is supplied to the site, a diesel generator is available as an alternative power supply and the ATS/MTS to connect the diesel generator is installed inside the ACDB, as shown in Figures 15 and 16.



**Figure 15 – Lightning protection solution for an indoor site (ATS/MTS inside ACDB)**



**Figure 16 – Lightning protection solution for an outdoor site (ATS/MTS inside ACDB)**

The Class I SPD shall be installed inside the ACDB, which should be connected to the indoor or outdoor earthing bar directly. When the Class I SPD is installed in the equipment room, the length of the bonding conductor connecting the Class I SPD to the indoor earthing bar should be less than 1 m. When the Class I SPD is installed outside the equipment room, the length of the bonding conductor connecting the Class I SPD to the outdoor earthing bar is recommended to be less than 1.5 m. The minimum cross-sectional area of the bonding conductor is 16 mm<sup>2</sup>.

## 7 Lightning protection, earthing and bonding of a rooftop RBS

NOTE – The isolated LPS system for buildings is not considered in this Recommendation.

## 7.1 Earthing network

### 7.1.1 Sharing the earthing network of the building

If the earthing network of the building can be shared, the RBS at a roof site should share the same earthing network with the building.

### 7.1.2 Use of the concrete steelwork of the building as an earthing network

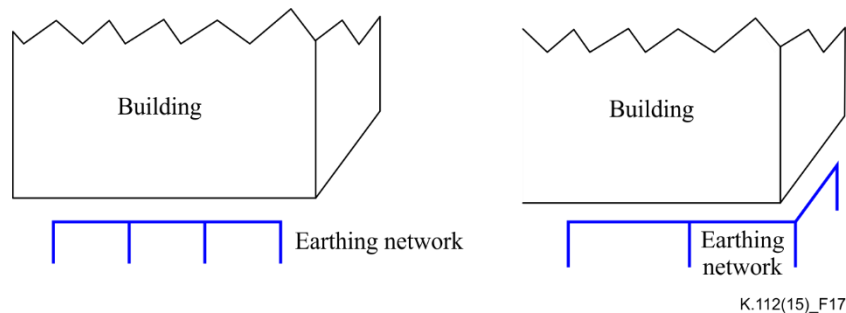
In the case where the building is made of concrete, the electrical continuity of its reinforcing steelwork is reliable and if it is permitted by the building owner and national laws, the natural earthing network formed by the building steelwork can be used as an earthing network for the rooftop RBS. Please refer to [IEC 62305-3] for details.

### 7.1.3 New earthing network for a rooftop RBS

If the building earthing network (including its natural earthing network) is not available, a new earthing network for the rooftop RBS shall be constructed.

A simplified earthing network can be constructed at one side or at one corner of the building, or close to the building, as shown in Figure 17.

For information on the material of an earthing network, please refer to Table 1.



**Figure 17 – Earthing network of a rooftop RBS**

## 7.2 Down-conductors of a rooftop RBS

### 7.2.1 Sharing the down-conductors of the building

If the down-conductors of the building can be shared, the rooftop RBS should share the down-conductors of the building.

### 7.2.2 Use of the reinforced building steelwork as a natural down-conductor

In the case where the building is made of concrete, the electrical continuity of its reinforcing steelwork is reliable and if it is permitted by the building owner and national laws, the down-conductors made by the steelwork of the building can be used as down-conductors for the rooftop RBS. Please refer to [IEC 62305-3] for details.

### 7.2.3 New down-conductors of the rooftop RBS

If the building down-conductors (including natural down-conductors) are not available, new down-conductors for the rooftop RBS shall be constructed.

Down-conductors of a rooftop RBS can be secured on the walls by using appropriate fixtures, as shown in Figure 18.

At least two down-conductors shall be installed. The down-conductors should be connected to the earthing network and to the rooftop bonding network by welding or using fixtures and screws. Anti-corrosion measures must be taken at the joint points between the down-conductors and the

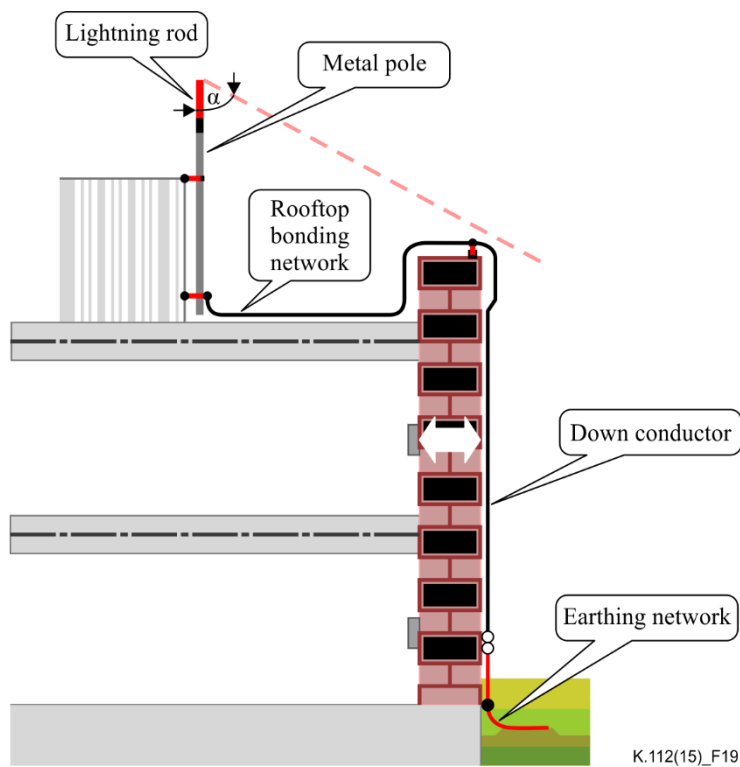


earthing network. Figure 19 shows an example of the installation of down-conductors for a rooftop RBS.

For information on the material of down-conductors, please refer to Table 2.



**Figure 18 – Down-conductor of a rooftop RBS secured on the wall**



**Figure 19 – Down-conductor connected to the earthing network and to the rooftop bonding network**

### 7.3 Air-termination system of buildings

#### 7.3.1 The need for an LPS

The need for an LPS for the building that has an RBS installed on its roof should be evaluated according to [IEC 62305-2].

If an LPS is needed, the RBS on the roof should be protected by an air-terminal system connected to the down-conductors as described in clause 7.2. The bonding network of the RBS on the roof is needed and should be connected to the air-terminal system of the roof.

If an LPS is not necessary for the building, the RBS on the roof still needs a bonding network and lightning protection facilities, such as a lightning rod and bonding conductors. These kinds of lightning protection facilities is not intended to provide lightning protection to the building.

The risk assessment should be carried out again according to [IEC 62305-2] if the RBS and its lightning protection facilities increase the height of the building. If the risk  $R_1$  is still lower than the tolerable risk, no additional measure need be taken. However, if the risk  $R_1$  is higher than the tolerable risk, then the LPS system should be expanded in order to protect the building.

### **7.3.2 Responsibility for construction of the building air-termination system**

The building owner is responsible for the construction of the building's air-termination system.

When the LPS is provided by the building owner, the lightning protection facilities that protect only the new RBS on the roof should be constructed by the network operator and should be connected to the original air-termination system of the building.

If the risk  $R_1$  was lower than the tolerable risk prior to the installation of an RBS on the roof, but changes and is higher than the tolerable risk after the RBS is installed on the roof, then the building owner and the network operator should discuss the responsibility for constructing the air-termination system of the building.

When an LPS is not necessary for the building (with or without the RBS on its roof), then the lightning protection facilities that protect the RBS on the roof should be constructed by the network operator.

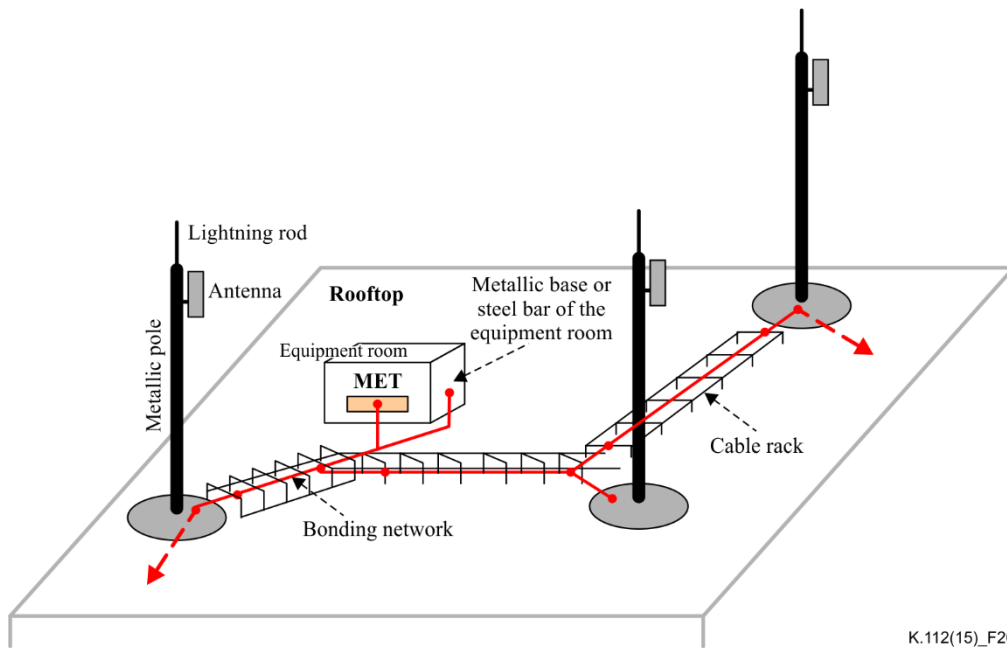
### **7.3.3 Lightning protection facilities that protect the RBS on the roof**

All parts of an RBS on the roof should be within the protective zone of the lightning protection facilities. These lightning protection facilities could be the air-termination system that protects the building or the lightning protection facilities that protect only the RBS (see clause 7.3.1).

The lightning rod should be installed on a metallic pole using a weld or screws, without any insulating measures. An insulated down-conductor along the metallic pole in order to connect the lightning rod is not required, as the metallic pole itself will act as a down-conductor.

The lightning protection facilities should be connected to the down-conductor at least at two points.

A lightning protection facility is illustrated in Figure 20.



NOTE – The dotted lines with arrows indicate the possible places for installing down conductors.

**Figure 20 – Lightning protection facilities that protect the RBS on the roof**

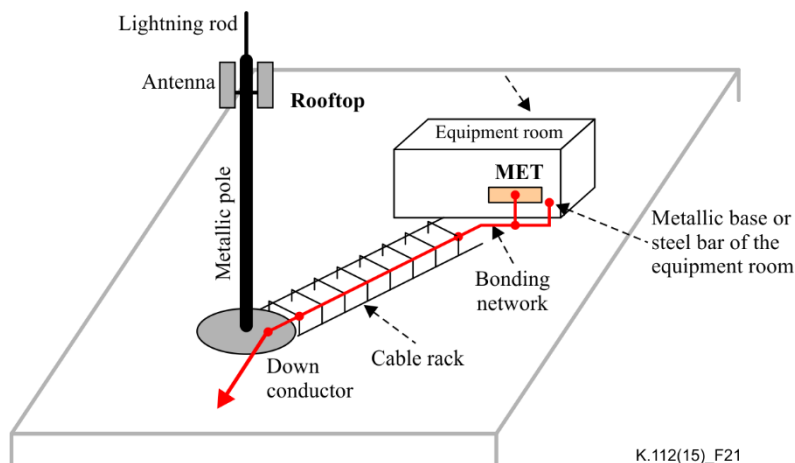
## 7.4 Rooftop bonding network

### 7.4.1 Rooftop bonding network available

If the rooftop bonding network is available before installing the RBS on the roof, it should be shared with the RBS.

### 7.4.2 Rooftop bonding network unavailable

In the case that a bonding network is not available before installing the RBS on the roof, then a rooftop bonding network should be constructed. Figure 21 gives an example of the configuration of a rooftop bonding network.



**Figure 21 – Example of a rooftop bonding network with the lightning rod and all antennas installed on the same pole**

The configuration of a rooftop bonding network shall observe the following procedures:

- The new bonding network is recommended to be installed along the cable tray, without any insulation measures. It shall be achieved with a good electrical connection between the bonding

network and cable tray. The bonding network can use the following materials: copper, tinned copper, aluminum, aluminum alloy, hot-dipped galvanized steel, stainless steel, or copper-clad steel.

- All equipment and facilities of the RBS on the roof that need to be earthed should be connected to the bonding network, including the bonding bar inside the equipment room, the metal base or steel structure of the equipment room, the cable racks and the base of the metal pole.
- The bonding network shall be connected to the air-termination system and to the other lightning protection facilities on the roof.
- The base of the metallic pole and the bonding network shall be connected together by a weld or screws.
- The cable rack shall be bonded to the bonding network at least at two ends and the electrical continuity of the cable tray shall be ensured.
- The MET of the equipment room or cabinet should be connected to the bonding network on the roof.
- The metal base of the equipment room, such as a container, mini-shelter, or outdoor cabinet, should be bonded to the bonding network.
- The cable tray and the bonding network should not be deployed along the edge of the roof.

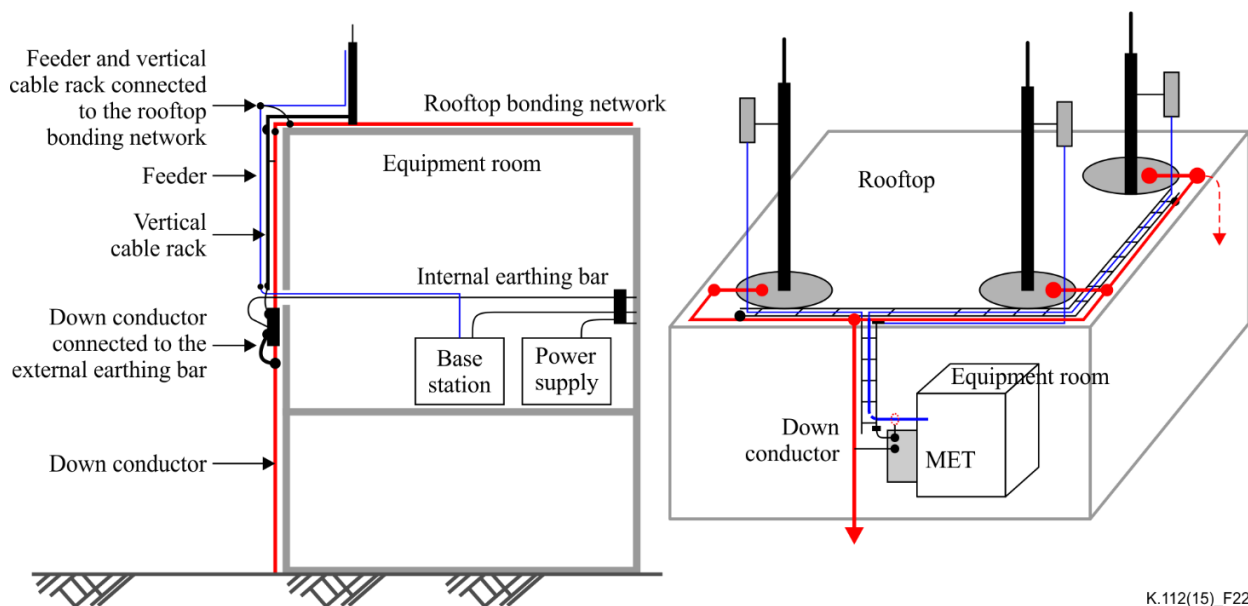
Welding, crimping, or fixtures are acceptable connection measures to connect the bonding conductors and the metallic structures to the bonding network.

## 7.5 Bonding configuration inside the equipment room

For information on the bonding configuration inside the equipment room, please refer to clause 6.4.

## 7.6 The equipment room in the building

Figure 22 illustrates an example of the earthing and bonding configuration when the equipment room is inside the building.



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**Figure 22 – Earthing and bonding configuration when the equipment room is inside building**

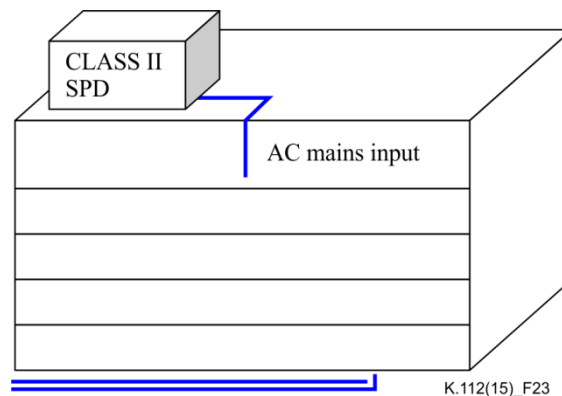
The earthing and bonding configuration when the equipment room is inside the building shall observe the following procedures:

- A down-conductor shall be installed close to the vertical cable tray, between the cable tray on the roof and the MET of equipment room.
- The vertical cable tray shall be bonded to the closest down-conductor at least at two ends.
- The MET of equipment room shall be bonded to the closest down-conductor.
- The internal bonding bar of the equipment room shall be bonded to the MET of the equipment room.
- Insulation measures shall not be adopted between the vertical cable trays and closest down-conductor.

The cable tray and the bonding network shall not be deployed along the edge of the roof.

### 7.7 Protection of AC power supplies of a rooftop RBS

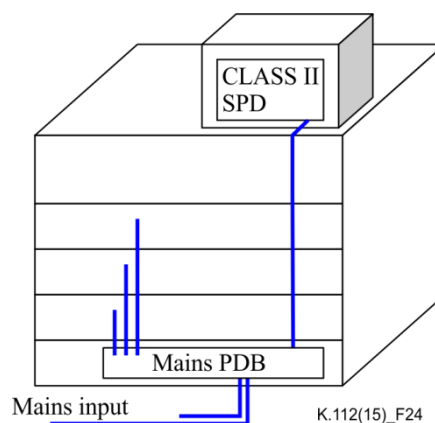
The AC power supply of the RBS on the roof is directly obtained from the power source of the building. Class II SPDs are recommended to be installed in the PDB of the RBS equipment room, as shown in Figure 23.



**Figure 23 – Class II SPD inside PDB of RBS equipment room**

It is more beneficial for other electrical facilities in the building that the RBS on the roof has a set of independent power conductors from the main PDB of the building, as shown in Figure 24. The independent power conductors can mitigate the coupling between the RBS on the roof and other electrical facilities in building. This procedure is recommended to be adopted as much as possible.

The Class I SPD should be installed in the main PDB. The building owner is responsible for the installation of the Class I SPD of the building.



**Figure 24 – Independent power conductors for the RBS**

## 8 Circuit diagram and current capability of Class I/II SPD

### 8.1 SPD configuration for three-phase AC power supply

The 3+1 type surge protection diagram is recommended for three-phase AC power supply systems, as shown in Figure 25.

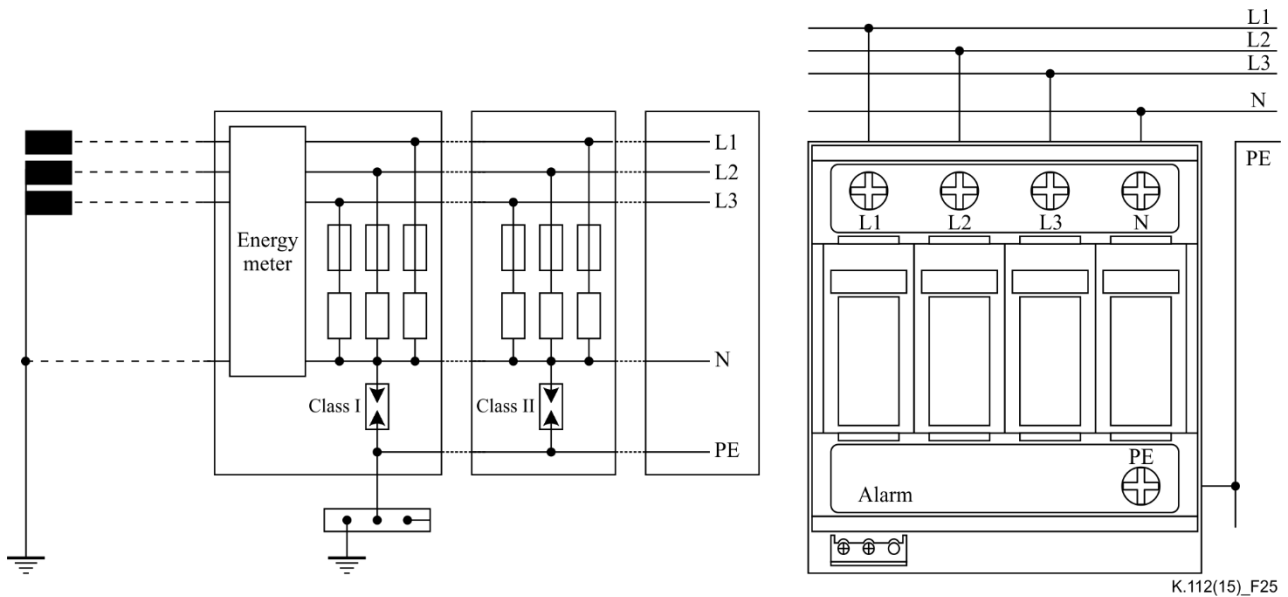


Figure 25 – Surge protection diagram for three-phase AC power supply systems

### 8.2 SPD configuration solution for two-phase AC power supply

The recommended surge protection diagram for a two-phase power supply system is shown in Figure 26.

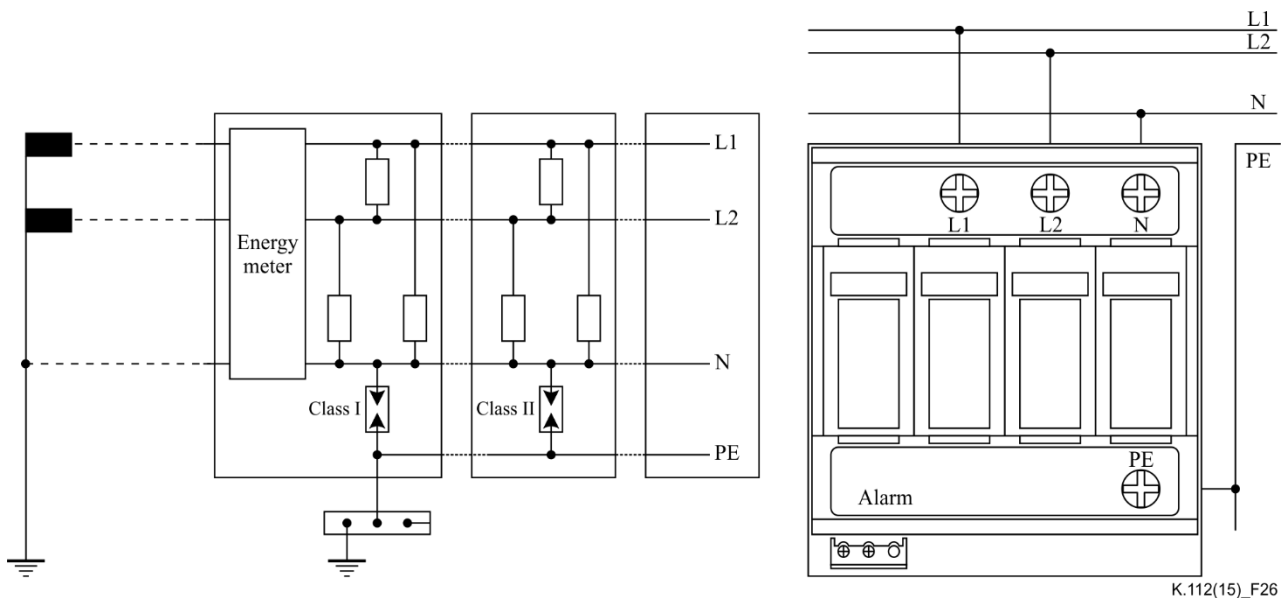


Figure 26 – Surge protection diagram for two-phase AC power supply systems

### 8.3 SPD configuration for single-phase AC power supply

The recommended surge protection diagram for a single-phase power supply system is shown in Figures 27 and 28.

The protection diagram in Figure 27 is a symmetric circuit, which is suitable in the case of the live conductor and neutral conductor with the risk of reverse connection.

The protection diagram in Figure 28 is an asymmetric circuit, which is suitable in the case of the live conductor and neutral conductor without the risk of reverse connection.

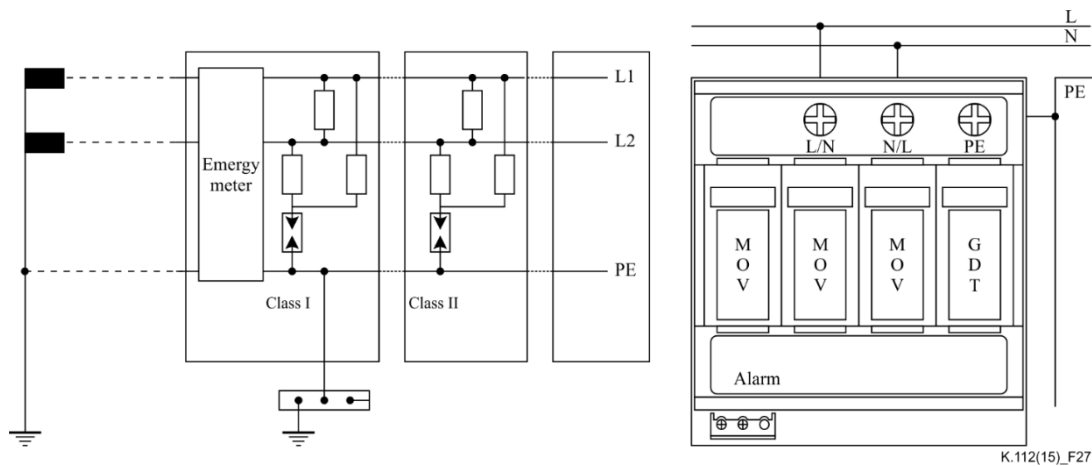


Figure 27 – Symmetric surge protection diagram for single-phase AC power supply systems

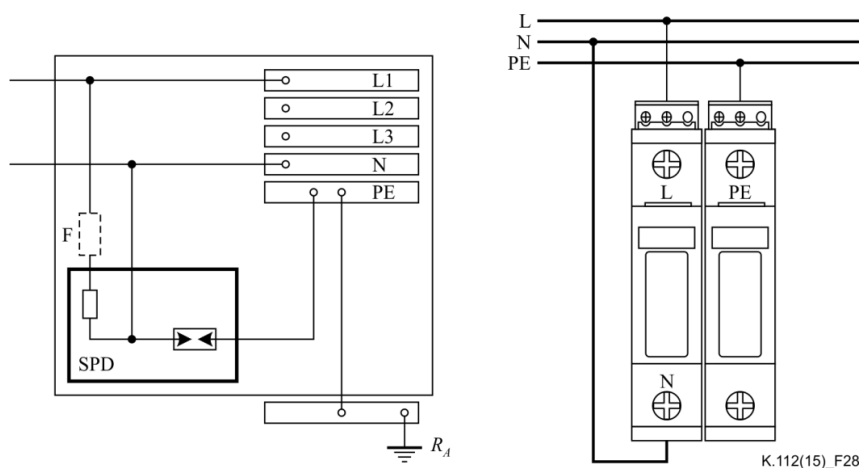


Figure 28 – Asymmetric surge protection diagram for single-phase AC power supply systems

#### 8.4 Specification of SPDs

The default specification of Class I SPDs is  $I_{imp} = 25 \text{ kA}$  (10/350  $\mu\text{s}$ ).

The default specification of Class II SPDs is  $I_{max} = 40 \text{ kA}$  (8/20  $\mu\text{s}$ ).

Table 5 – SPD specification (recommended)

SPD type	Specification	Protective circuit mode	Power supply mode
Class I (voltage switching type)	$I_{imp} = 25 \text{ kA}$ (10/350 $\mu\text{s}$ )	Figure 25	Three-phase
		Figure 26	Dual-live lines
		Figure 28	Single-phase
Class II (voltage limiting type)	$I_{max} = 40 \text{ kA}$ (8/20 $\mu\text{s}$ )	Figure 25	Three-phase
		Figure 26	Dual-live lines
		Figures 27/28	Single-phase

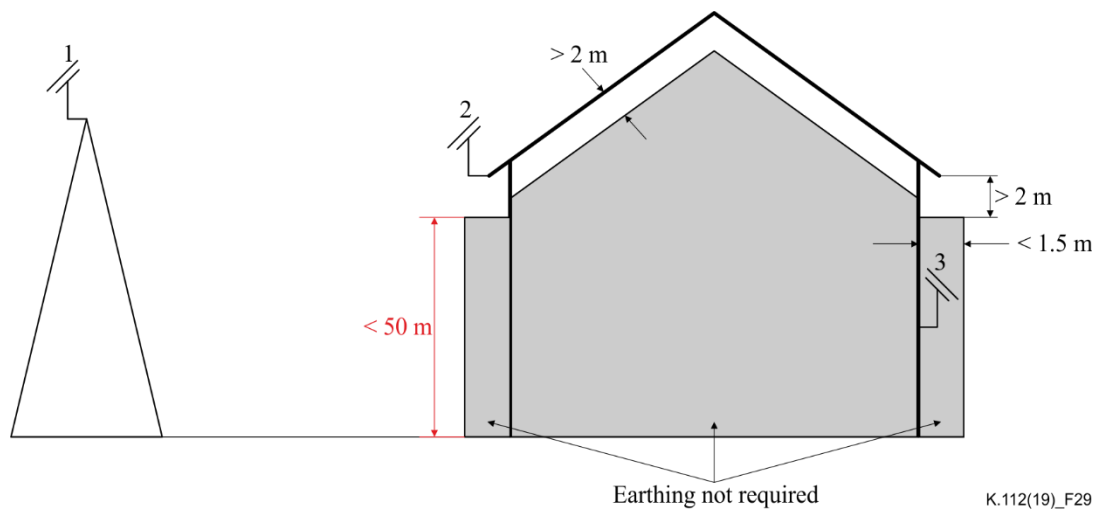
The values in Table 6 are provided as a reference for those countries where the 8/20 test waveshape is adopted for Class I SPD.

**Table 6 – SPD specification (considering 8/20 waveshape for Class I SPD)**

SPD Type	Specification	Protective circuit mode	Power supply mode
Class I (voltage limiting type)	$I_{\max} = 100 \text{ kA (8/20 } \mu\text{s)}$	3+1	Three-phase
			Dual-live lines
			Single-phase

## 9 Protection of antenna system

As stated in [b-ITU-T K.44], antenna ports on equipment need to be classified according to the location of the antenna and the intended use of the equipment. Where the equipment will only be connected to antennas installed in an inherently protected location, i.e., the shaded area in Figure 29, the antenna port could be classified as an internal port. The complete antenna and all antenna cables have to fit and to be installed into the protected area. If the port could be connected to antennas installed in exposed locations, e.g., antenna positions 1 and 2, the antenna port should be classified as an external port. If it is unclear where the antenna may be installed, it shall be conservative and classify the antenna port as an external port.



**Figure 29 – Classification of antenna ports (Figure A.2-4 of [b-ITU-T K.44])**

### 9.1 Arrangement 1

If the antenna is installed on the top of telecommunication tower, e.g., antenna positions 1 of Figure 29, it is considered to be impacted by or exposed to direct lightning strikes.

Refer to [IEC 62305-3] for detail information about the protection angles and volume protected by an air termination system.

#### 9.1.1 Air termination

Where the antenna is installed on the top of telecommunication tower, the outer antenna system shall be installed in a location where it will be protected from direct lightning strikes by either the air termination of tower or the antenna mast itself.



In this case, the bonding conductor connecting the antenna to the antenna mast and the antenna mast to the LPS shall be in accordance with Table 6 of [IEC 62305-3].

### **9.1.2 Earthing and bonding**

The antenna mast shall be bonded to the tower. The outer conductor of the coaxial cable shall be bonded to the antenna mast at one end and to the connected equipment at the other end. Refer to clause 6.3.3 for detail.

### **9.1.3 Resistibility**

As stated in [b-ITU-T K.44], in this case, the antenna port of equipment which is connected to the antenna should be classified as an external port. Accordingly, the test conditions refer to [b-ITU-T K.20], [b-ITU-T K.21] or [b-ITU-T K.45] respectively. The enhanced test level is the minimum requirement in this case.

## **9.2 Arrangement 2**

If the antenna is installed on the rooftop, e.g., antenna positions 2 of Figure 29, depending on the relative height of building and the installation of the antenna system, it may be considered to be inherently protected from direct lightning strikes or be impacted by or exposed to direct lightning strikes.

Refer to [IEC 62305-3] for detail information about the protection angles and volume protected by an air termination system.

### **9.2.1 Earthing and bonding**

Generally, the outer antenna system should be installed in a location where it will be protected from direct lightning strikes by either the air termination of the building or the antenna mast itself. The antenna mast should be bonded to the building's LPS. The outer conductor of the coaxial cable should be bonded to the antenna mast at one end and to the connected equipment at the other end.

Where the building is relatively low, i.e., lower than 8m in rural areas or beside the high buildings or structures in urban areas, or the length of exposed antenna cable is no longer than 5m at maximum, the outer antenna system could be isolated or insulated from the LPS. See clause 6.3 of [IEC 62305-3] for further information on the required clearance or separation distance. For antenna system installed on street pole or similar situation, this rule can also be followed.

### **9.2.2 Resistibility**

As stated in [b-ITU-T K.44], in this case, the antenna port of equipment which is connected to the antenna should be classified as an external port. Accordingly, the test conditions refer to [b-ITU-T K.20], [b-ITU-T K.21] or [b-ITU-T K.45] respectively. It is recommended to select enhanced test level when the outer antenna system is bonded to the LPS, and the basic test level for the outer antenna system being isolated or insulated from the LPS.

## **9.3 Arrangement 3**

If the antenna and all antenna cables are installed within the shaded area of Figure 29, it is considered to be inherently protected from direct lightning strikes and less-exposed to lightning surge.

### **9.3.1 Earthing and bonding**

When an LPS does not exist, earthing of the outer antenna system, i.e., both the antenna and the outdoor antenna cables, is not required.

When there is an LPS, the outer antenna system shall either be bonded to the LPS or be adequately isolated or insulated from the LPS. See clause 6.3 of [IEC 62305-3] for further information on the required clearance or separation distance.

### **9.3.2 Resistibility**

As stated in [b-ITU-T K.44], in this case, the antenna port of equipment which is connected to the antenna could be classified as an internal port. Accordingly, the test conditions refer to [b-ITU-T K.20], [b-ITU-T K.21] or [b-ITU-T K.45] respectively. It is recommended to select the enhanced test level when the outer antenna system is bonded to the LPS, and the basic test level for the outer antenna system being isolated or insulated from the LPS or an LPS does not exist.

## Annex A

### Example of earthing network design of a tower site

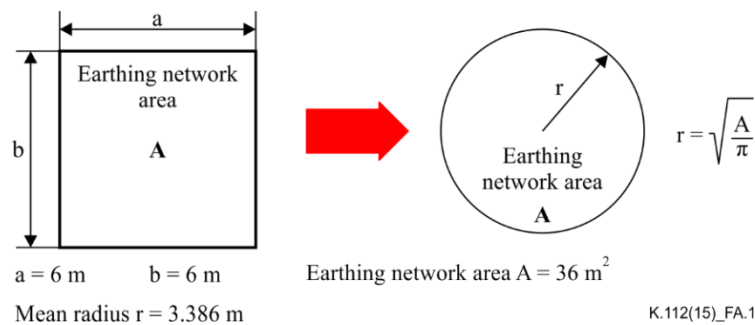
(This annex forms an integral part of this Recommendation.)

If the LPS III or LPS IV is adopted by an RBS tower site, the user could refer to the examples in clauses A.1 and A.2.

#### A.1 Example where additional earthing electrodes are necessary

In this example the size of the RBS earthing network is 6 m × 6 m, as shown in Figure A.1. The mean radius of the area enclosed by the earthing ring is calculated as follows:

$$r = \sqrt{A/\pi} = \sqrt{6*6/3.14} \approx 3.386 \text{ m}$$

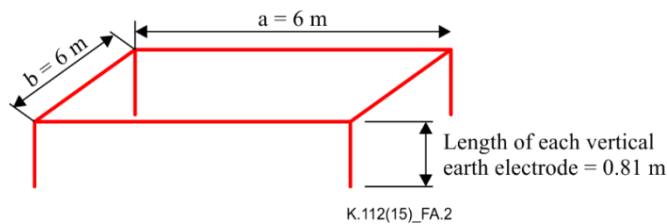


**Figure A.1 – Calculation of the earthing ring mean radius (Case 1)**

According to Figure 1, the mean radius should be at least 5 m, so in this example (Case 1) additional horizontal or vertical earth electrodes shall be installed. If vertical electrodes are chosen, the minimum length of each vertical electrode can be calculated as follows:

$$l_v = (5 - 3.386) / 2 = 0.807 \text{ m}$$

Then vertical electrodes not shorter than 0.81 m shall be installed at least at the four corners of the horizontal earthing ring, as shown in Figure A.2.

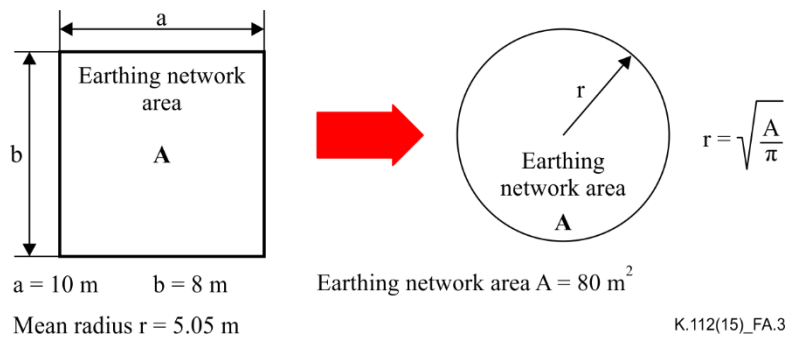


**Figure A.2 – Additional vertical electrodes installed at the four corners of the earthing ring**

#### A.2 Example where additional earthing electrodes are not necessary

In this example (Case 2), the size of the RBS earthing network is 8 m × 10 m, as shown in Figure A.3. The mean radius of the area enclosed by the ring earthing electrode is calculated as follows:

$$r = \sqrt{A/\pi} = \sqrt{10*8/3.14} \approx 5.05 \text{ m}$$



**Figure A.3 – Calculation of the earthing ring mean radius (Case 2)**

Since the mean radius is greater than 5 m, then the horizontal earthing ring is sufficient and no additional electrode is required (see Figure 1).

## Annex B

### Earthing resistance and soil resistivity test guide

(This annex forms an integral part of this Recommendation.)

#### B.1 General requirements for measurement

As a basic physical property of soil, the earth resistivity is the electrical resistance of two opposite surfaces of a unit soil cube and it is expressed in  $\Omega \cdot m$ .

Before measuring the earth resistivity, the geologic age and structure of the soil should be known and the local earth resistivity can be estimated by reference to Table B.1.

**Table B.1 – Resistivity  $\rho$  ( $\Omega \cdot m$ ) of different soils**

Soil type	Resistivity ( $\Omega \cdot m$ )		
	Minimum	Medium	Maximum
Surface soils, loam, etc.	1		50
Clay	2		100
Sand and gravel	50		1000
Surface limestone	100		10000
Limestones	5		4000
Shales	5		100
Sandstones	20		2000
Granites, basalts		10000	
Decomposed gneisses	50		500
Slates, etc.	10		100
Fresh water lakes		200	
Tap water	10		50
Sea water	0.2	1	2
Pastoral, low hills, rich soil		30	
Flat country, marshy, densely wooded		100	
Pastoral, medium hills and forestation		200	
Rocky soil, steep hills	10	500	1000
Sandy, dry, flat, typical of coastal country	300	500	10000
City, industrial areas		1000	10000
Fills, ashes, cinders, brine, waste	6	25	70
Clay, shale, gumbo, loam	3	40	200
Same – with varying proportion of sand and gravel	10	150	1000
Gravel, sandstones with little clay of loam, granite	500	1000	10000

While measuring the earthing resistance and earth resistivity, note the following:

- The test electrodes should be solid and metallic. No thread rods should be used.
- In rocky soil zones, it is recommended to drive the test electrodes into the ground at a certain angle to the vertical line and the test electrodes should be kept away from the top of rocks.
- To avoid disturbance of buried metallic objects on the measurement, the test electrodes may be arranged in perpendicular to the orientation of underground metallic objects (e.g., metallic tubes).

The measurement shall not be carried out after rain or when the soil is wet.

The test electrodes are inserted into the soil where the water content is high. In dry or sandy soil, some water should be used to keep wet the places where test electrodes are driven.

The measurement methods for earthing resistance include the two-point method, three-point method, single clamp method and double clamp method. These methods have their own characteristics and should be properly selected to ensure accurate and correct measurement results during actual measurement.

The three-point method and single clamp method should be adopted for the measurement of earthing resistance and the four-point method should be adopted for the measurement of earthing resistivity.

## B.2 Four-point method for the measurement of earthing resistivity

### B.2.1 Measurement method for earthing resistivity

- Four test electrodes are inserted into the ground with a spacing of "a" and at a depth of "h" ( $h \leq a / 20$ ), as shown in Figure B.1;
- The four test electrodes shall be aligned, of these, the two in the middle (p1 and p2) are the voltage electrodes and the other two outside (c1 and c2) are the current electrodes;
- Figure B.1 shows the connections of the test electrodes to the measuring instrument.

The resistance value  $R$  provided by the instrument shall be recorded. The earth resistivity is calculated by:

$$\rho = 2 \pi a R \quad (\text{B.1})$$

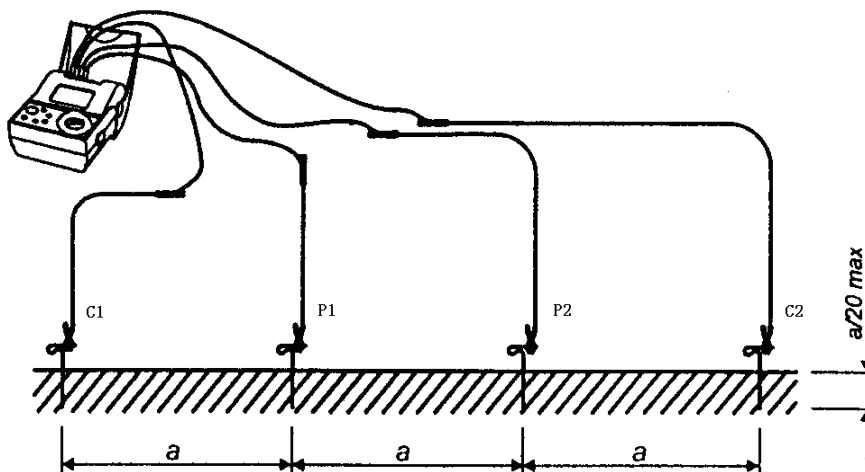


Figure B.1 – Four-point method for the measurement of earth resistivity

### B.3 Three-point method for the measurement of earthing resistance

The three-point method is a common method for the measurement of earthing resistance, as shown in Figure B.2.

- To make the measurement, set up one current electrode (C) and one voltage electrode (P). The earthing network (E), current electrode (C) and voltage electrode (P) should be aligned, as shown in Figure B.3.
- The current electrode should be arranged as far as possible from the earthing network to reduce their mutual coupling.
- In general, the distance  $d_{EP}$  between the voltage electrode (P) and the earthing network (E) shall be about 50% to 60% of the distance  $d_{EC}$  between the current electrode (C) and the earthing network (E).
- To make the measurement, move the voltage electrode (P) along the connecting line between the earthing network (E) and the current electrode (C) three times, with the distance of movement at each time being about 5% of  $d_{EC}$ . If the measured values after the three movements are similar, the results can be used. If the difference between the three measured values is relatively high, re-measurement after re-arrangement of the earthing electrodes is required.

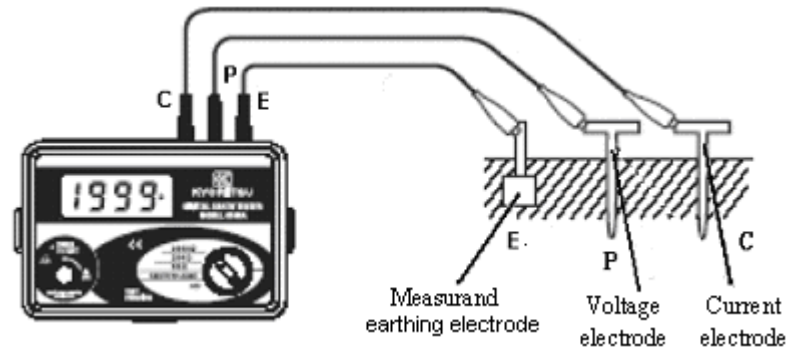


Figure B.2 – Layout of earthing electrodes for the measurement with the three-point method

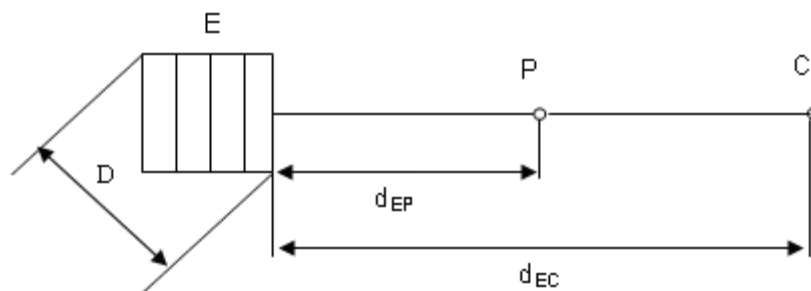
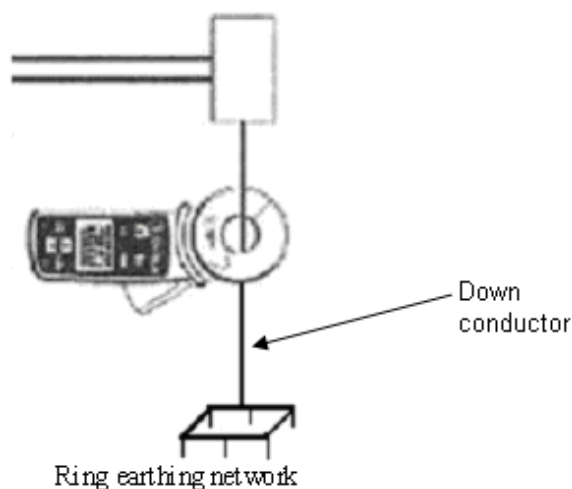


Figure B.3 – Equivalent diagram for the measurement with the three-point method

## B.4 Single clamp / double clamp method for the measurement of earthing resistance

### B.4.1 Single clamp method for measuring the earthing resistance

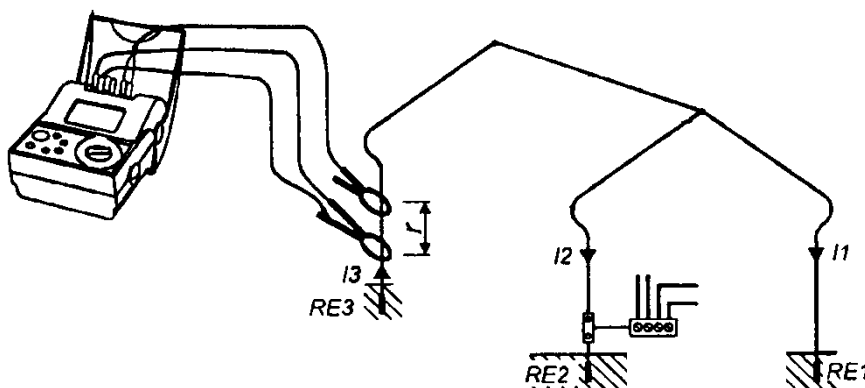


**Figure B.4 – Single clamp method for measuring the earthing resistance**

To measure the earthing resistance by using the single clamp method as shown in Figure B.4, perform the following steps:

- Open the clamp jaws and verify that the jaws can join closely, without dust, dirt, or any foreign objects on the joint surface.
- Rotate the switch of the clamp meter to the  $\Omega$  position and perform the clamp meter calibration.
- Place the down-conductor into the die of the clamp meter and start the clamp meter.
- Record the earthing resistance provided by the clamp meter.

### B.4.2 Double clamp method for measuring the earthing resistance



**Figure B.5 – Double clamp method for measuring the earthing resistance**

To test the earthing resistance by using the double clamp method, perform the following steps:

- Attach the clamp meter to the down-conductor, as shown in Figure B.5. The two clamps must be at least 30 cm apart.
- Rotate the switch of the clamp meter to the measuring position and record the reading.

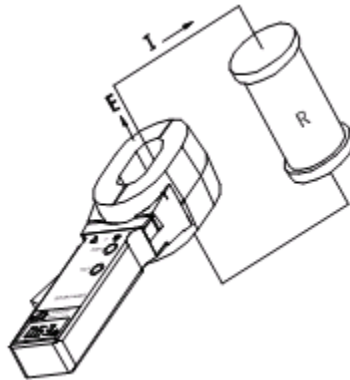


### B.4.3 The scenarios for using a clamp meter

The basic principle to have in mind for the measurement of earthing resistance by a clamp meter is that it measures the loop resistance.

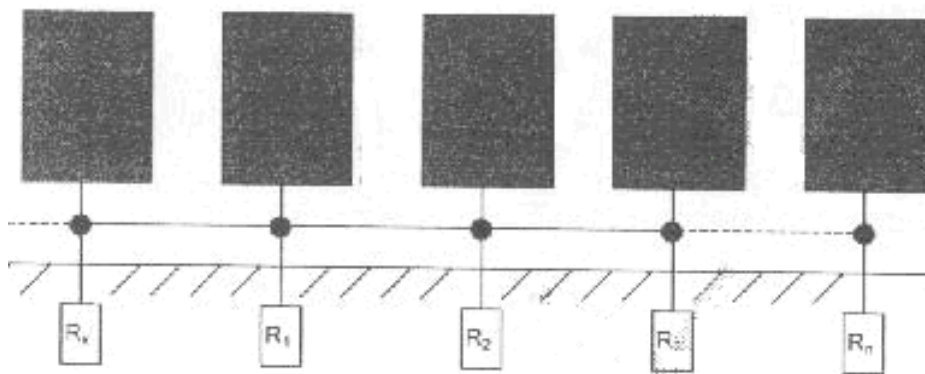
The jaw of the clamp meter is composed of a voltage coil and a current coil. The voltage coil supplies the excitation signal and induces an electromotive force  $E$  on the measured loop. As a consequence, the current  $I$  is produced on the measured loop. Measuring  $E$  and  $I$  with the clamp meter, the loop resistance  $R$  is obtained by the equation:

$$R = \frac{E}{I} \quad (\text{B.2})$$

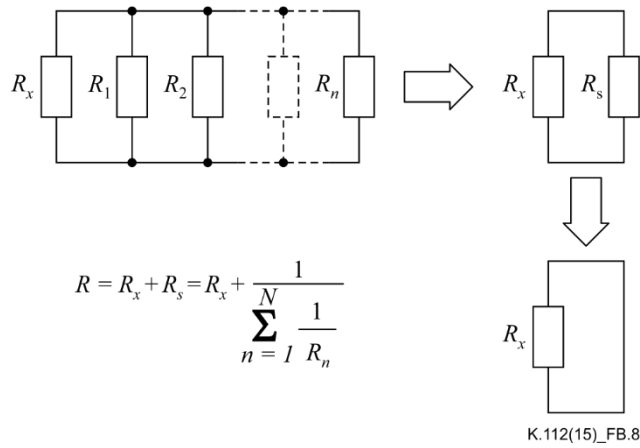


**Figure B.6 – Schematic diagram of the clamp meter measurement**

Consider a conductor that has several earthing networks connected in parallel, where the earthing resistance of the measured earthing network is  $R_x$  and that the other earthing resistances are  $R_1, R_2, R_3, \dots, R_n$ , as shown in Figure B.7. The combined resistance provided by the parallel association of  $R_1, R_2, R_3, \dots, R_n$  is  $R_S$ . By using the clamp meter at  $R_x$ , its reading will be  $R_x + R_S$ . Therefore, the clamp meter can be used only when  $R_S \ll R_x$ , as illustrated in Figure B.8.



**Figure B.7 – Multi-earthing networks connected in parallel**



**Figure B.8 – Schematic diagram of the use of a clamp meter measurement**

In the earthing system for a single wireless base station, the earthing network, down-conductors and metal conductors make a test loop. By using a clamp meter, the earthing resistance of the entire loop can be measured, but not the earthing resistance of the earthing network. Therefore, the clamp meter cannot be used for measuring the earthing resistance of a single earthing network, for example, the earthing network of a tower site.

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