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SERIES K: PROTECTION AGAINST INTERFERENCE

Protection of radio base stations against lightning discharges

Recommendation ITU-T K.56

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Summary

Recommendation ITU-T K.56 presents the techniques applied to a telecommunication radio base station in order to protect it against lightning discharges. The need of protection is obtained from the methodology contained in IEC 62305-2, which is used to determine the relevant lightning protection level (LPL) for the installation. The protection techniques for the external area cover the lightning protection system (LPS), bonding procedures, earthing and the installation of surge protective devices (SPDs) at the power meter station. The protection techniques for the equipment building cover the feeder and lighting cables, the electric power conductors, the telecommunication cabling and the earthing/bonding procedures applied to cable trays and equipment frames. This Recommendation also provides guidelines in order to achieve adequate protection of the telecommunication equipment based on the coordination between equipment resistibility, SPD protection level and installation characteristics.

History

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Recommendation ITU-T K.56

Protection of radio base stations against lightning discharges

1 Scope and purpose

This Recommendation addresses radio base stations (RBSs) made of a shelter or small building to house the equipment and a nearby tower to hold the antennas. The purpose of this Recommendation is to provide a set of procedures to protect the RBS against lightning discharges. [b-ITU-T K.71] gives information on the protection of antenna installations in or on a customer building.

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.

[ITU-T K.12] Recommendation ITU-T K.12 (2010), *Characteristics of gas discharge tubes for the protection of telecommunications installations*.

[ITU-T K.27] Recommendation ITU-T K.27 (2015), *Bonding configurations and earthing inside a telecommunication building*.

[ITU-T K.35] Recommendation ITU-T K.35 (2020), *Bonding configurations and earthing at remote electronic sites*.

[ITU-T K.44] Recommendation ITU-T K.44 (2019), *Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents – Basic Recommendation*.

[ITU-T K.46] Recommendation ITU-T K.46 (2012), *Protection of telecommunication lines using metallic symmetric conductors against lightning-induced surges*.

[ITU-T K.47] Recommendation ITU-T K.47 (2012), *Protection of telecommunication lines using metallic conductors against direct lightning discharges*.

[ITU-T K.66] Recommendation ITU-T K.66 (2019), *Protection of customer premises from overvoltages*.

[ITU-T K.72] Recommendation ITU-T K.72 (2011), *Protection of telecommunication lines using metallic conductors against lightning – Risk management*.

[IEC 61643-11] IEC 61643-11:2011, *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems – Requirements and test methods*.

[IEC 61643-12] IEC 61643-12:2020, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles*.

[IEC 61643-22] IEC 61643-22:2015, *Low-voltage surge protective devices – Part 22: Surge protective devices connected to telecommunications and signalling networks – Selection and application principles*.

[IEC 62305-1] IEC 62305-1: 2010, *Protection against lightning – Part 1: General 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 nominal discharge current for class II test (In) [IEC 61643-11]: Crest value of the current through the SPD having a current waveshape of 8/20.

3.1.2 maximum discharge current (Imax) [IEC 61643-11]: Crest value of a current through the SPD having an 8/20 waveshape and magnitude according to the manufacturers specification. Imax is equal to or greater than In.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 cable tray: Rigid structural system used to securely fasten or support cables.

3.2.2 feeder cable: Wave-guide or coaxial cable that conducts signals to an antenna.

3.2.3 lightning protection system (LPS) rod: Metallic rod that makes part of the LPS and is intended to intercept a lightning strike. It is also designated as "lightning air termination" or "lightning finial".

3.2.4 radio base station: Installation intended to provide access to the telecommunication system by means of radio waves.

3.2.5 shielding factor: Factor that represents the attenuation of the voltage or current in a conductor due to the presence of a nearby shielding conductor.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

GDT Gas Discharge Tube

LPL Lightning Protection Level

LPS Lightning Protection System

MEB Main Earthing Bar

PE Protective Earth

RBS Radio Base Station

SPD Surge Protective Device

5 Conventions

None.

6 Need of protection

The risk assessment of the RBS shall be performed according to [IEC 62305-2] in order to determine a lightning protection level (LPL) for the design of the protection procedures. Table 1 shows some lightning flash parameters associated with each LPL.

Table 1 – Lightning flash parameters from [IEC 62305-1]

Parameter	Unit	LPL			
		I	II	III	IV
Maximum peak current	kA	200	150	100	100
Maximum current rate of rise	kA/μs	200	150	100	100
Radius of electro-geometric sphere	m	20	30	45	60
Probability of flash	%	99	98	95	90

NOTE – The risk assessment may indicate an LPL for the design of the LPS that is different from the LPL considered for the design of the other protection procedures.

7 External area

Figure 1 shows the main earthing and bonding procedures applied to the external area. These procedures, as well as others not shown in the figure, are detailed in the subsequent clauses.

7.1 Lightning protection system (LPS)

In order to protect the antennas and auxiliary equipment from a direct strike, it may be necessary to install an LPS in the tower. If the nearby tower does not protect the shelter, it may be necessary to install an LPS in the shelter too. The assessment of the need for an LPS and the determination of its positioning shall be performed with the rolling sphere method described in [IEC 62305-3]. The following clauses give some procedures for the installation of the LPS.

7.1.1 Metallic tower

The LPS rod(s) shall be connected directly to the structure of the metallic tower. Therefore, the structure of the metallic tower will conduct the stroke current to ground and there is no need to install lightning down conductors.

NOTE – If the total cross-section of the tower structure is less than 125 mm^2, then the tower shall be treated as a non-metallic tower, as described in clause 7.1.2.

7.1.2 Non-metallic tower

If the structure that supports the antennas is not metallic (e.g., wood pole) or if it is metallic but its cross-section is less than 125 mm^2, it is necessary to install two down-conductors to earth the LPS rod(s). The down conductors shall not be insulated from the tower and they shall have a minimum cross-section of 50 mm^2 each. The down conductors shall be installed on opposite sides of the tower.

7.1.3 Building

In the majority of the cases, the nearby tower will protect the building against direct strikes. However, the need for an LPS in the building shall be investigated with the rolling sphere method described in [IEC 62305-3]. If the building requires an LPS, it shall be earthed in the earthing system of the RBS, which is described in clause 7.3.

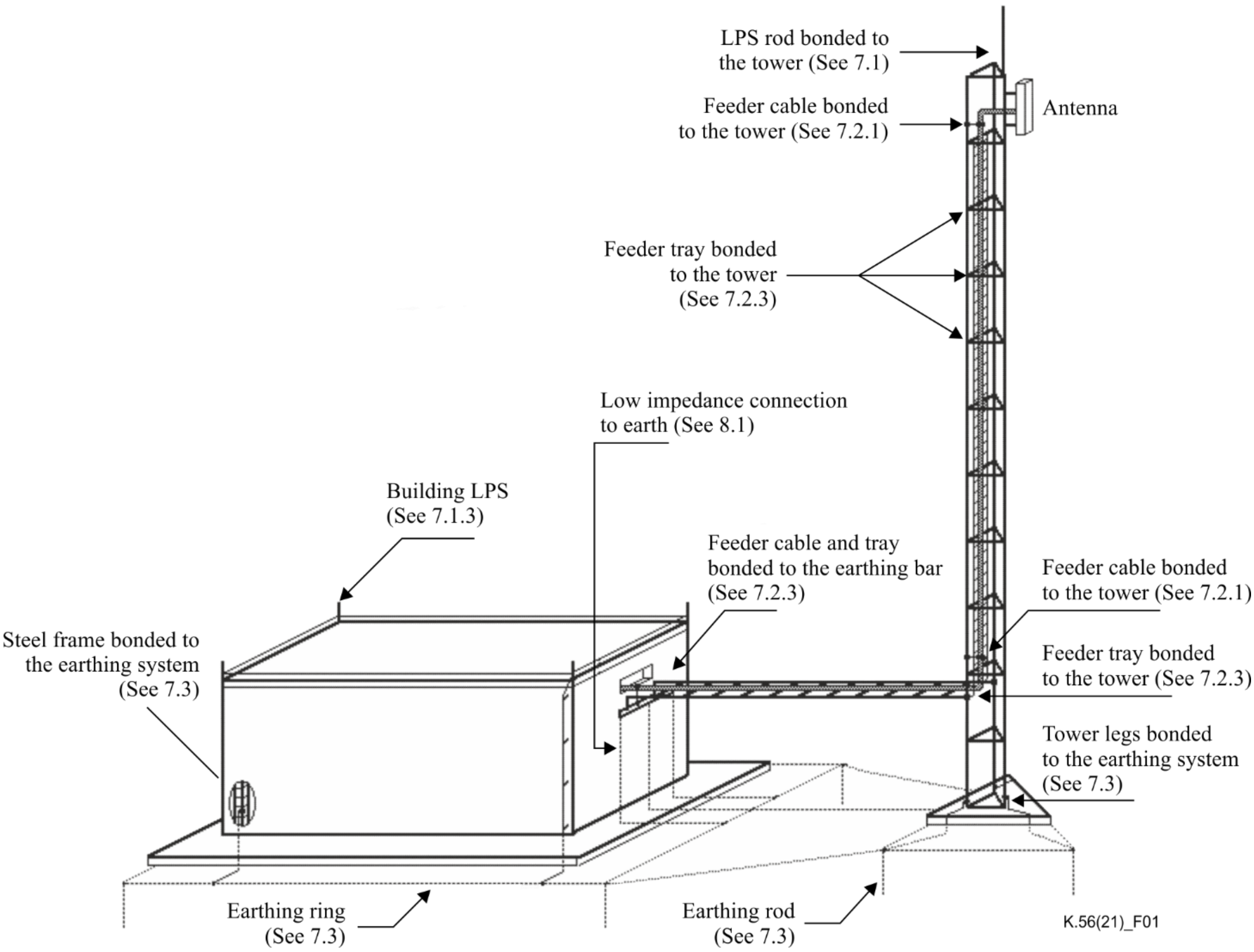

Figure 1 – General view of earthing and bonding procedures in the external area

7.2 Bonding in the tower

7.2.1 Feeder cables

The wave-guide and the external conductor of coaxial cables, henceforth referred as feeder cables, shall be bonded to the metallic tower (or to the feeder tray) near the antenna, as shown in Figure 1. A weatherproof connector shall make the connection to the feeder cable in order to avoid corrosion, and the connection to the tower (or feeder tray) structure shall also be protected to avoid ingression of moisture. Usually, the cable manufacturers provide appropriated earthing kits for these connections. The earthing kits shall have a connector to be attached on the bare outer surface of the feeder (the feeder plastic outer jacket shall be removed), another connector to be attached to the tower structure (paint shall be removed) and a conductor bonding the two connectors. The earthing kit shall also contain protective coatings to be applied on the connections. Figure 2 shows schematically the installation of an earthing kit before the application of the protective coating.

NOTE 1 – For non-metallic towers or metallic towers with a cross-section smaller than 125 mm^2, the bonding shall be made to the lightning down conductor.

NOTE 2 – Some types of antenna are inherently connected to the tower by design. In this case, it is not necessary to use an earthing kit to bond the feeder to the tower (or feeder tray), as it is already bonded through the antenna structure.

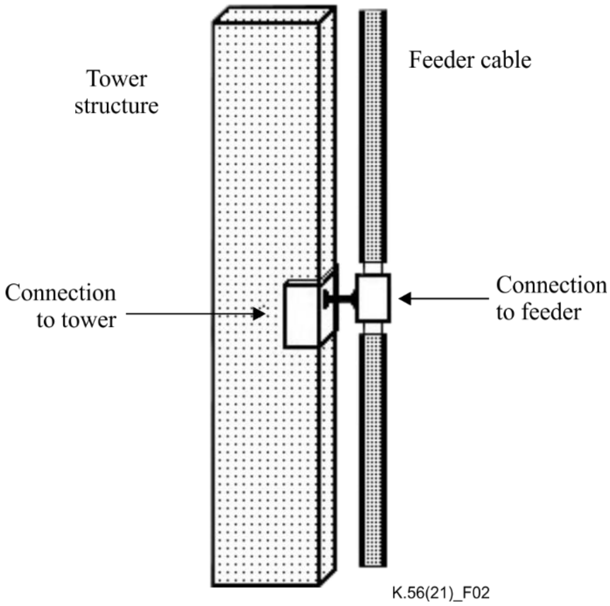

Figure 2 – Example of installation of earthing kit on feeder cable (protective coating not shown)

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 2.

Table 2 – Minimum length of the horizontal section of the feeder tray that requires bonding of feeders 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, as described in clause 7.2.3.

7.2.2 Cable supplying power to the tower lights

The cable used for supplying power to the lights of the tower shall be protected from the lightning current by one of the options described in this clause. When the power to the lights is supplied by an equipment (e.g., AC/DC converter), an SPD set may be required close to this equipment, in addition to the protection measures described in the following.

7.2.2.1 Metallic duct

An unshielded cable should be installed inside a metallic duct and this duct shall be electrically continuous for its entire length. The duct shall be bonded to the tower at least at its upper end. The length of cable that may run outside the metallic duct shall be as short as possible. Preferably, the cable should run inside the metallic duct up to the lighting hardware. The metallic duct can be made of galvanized steel and shall have a cross-section area not less than 16 mm^2. The openings in the duct shall be adequately sealed in order to prevent the ingression of moisture. The metallic duct shall also be bonded to the earthing bar installed near the feed-through window.

7.2.2.2 Shielded cable

A shielded cable can be installed directly along the tower, i.e., without a metallic duct. The shield of the cable shall be electrically continuous for its entire length and shall be bonded to the tower at its upper end. The shield shall be terminated as close as possible to the lighting hardware and shall be bonded to the earthing bar installed near the feed-through window.

7.2.2.3 Unshielded cable

The use of 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 enters the building and these SPDs shall be bonded to the earthing bar installed below the feed-through window. Requirements for these SPDs are given in clause 8.1.2.

7.2.3 Feeder tray

The feeder cables are supported by a metallic structure, here designated as a feeder tray. The feeder tray shall be kept continuous in its trajectory along the tower and it shall be bonded to the tower by its supporting hardware (i.e., screws, clamps or welding). In the upper side of the tower, the feeders shall leave the feeder tray as close as possible to the antennas.

The feeder tray shall be continuous when it leaves the tower towards the building, preferably using a curved section as shown in Figure 3. In the trajectory between the building and the tower, 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. The objective of this bonding is to provide a path to the lightning current in parallel to the feeders, which reduces significantly the current carried by the feeders. The bonding shall be made at least in the two sides of the tray, as shown in Figure 4. On the tower side, the bonding between the feeder and the tower frame is normally achieved by mounting clamps or bolts. On the building side, it is necessary to install bonding conductors between the feeder tray and the earthing bar.

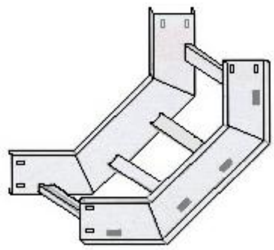

Figure 3 – Curved section used to maintain the continuity of the feeder tray

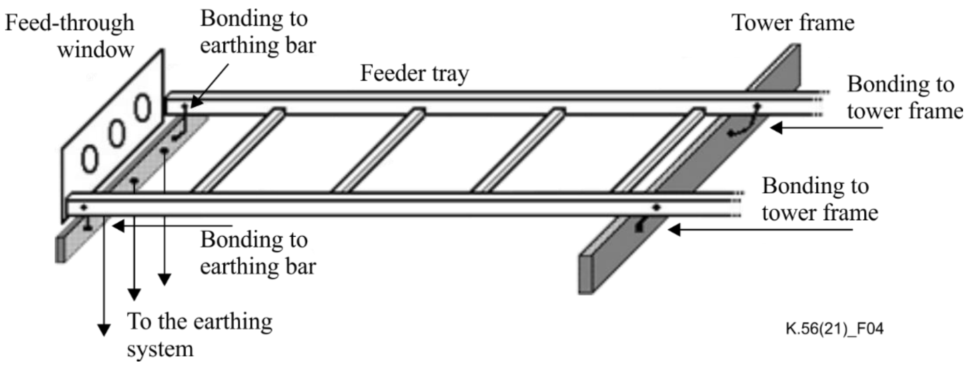

Figure 4 – Feeder tray bonded at both ends

7.3 Earthing

7.3.1 Earthing configuration

The earthing system of the RBS is intended to provide a safe path for the lightning current to earth and to reduce the potential gradient at the earth surface around the RBS. The earthing resistance (or impedance) of the earthing system is not of prime importance for the protection of the RBS. However, this resistance (or impedance) has an important influence on the surges transferred from the RBS to its neighbourhood through the metallic services connected to it (e.g., power lines). In order to reduce these surges, the earthing resistance (or impedance) shall be as low as possible.

NOTE – A low value of earthing resistance may not be feasible in areas with high resistivity soil. In these situations, it is recommended to apply measures in order to reduce the current exiting the RBS on the service conductors. One possibility for power conductors is to use a dedicated medium voltage/low voltage transformer to feed power to the RBS. Alternatively, shielding techniques should be applied to the service cables, as described in [ITU-T K.47].

Figure 5 shows the configuration of an earthing system that fulfils the requirements for the protection of the RBS. The main characteristics of this earthing system are:

– A bare conductor forms a ring electrode around the building and another ring around the tower. Multiple earthing conductors are used to interconnect the two rings (three, in the figure).
– The distance of the buried conductor from the associated structure shall be approximately 1.0 m, and the depth of the conductor shall be at least 0.5 m.
– Vertical rods should be installed along the ring electrode, as shown in Figures 1 and 5. These rods should be made of steel covered with copper or made of galvanized steel, and they shall be attached to the earth electrode by appropriate connectors.
– The legs of a metallic tower (or the down conductors of a non-metallic tower) shall be bonded through short connections to the tower's earthing ring. The steel reinforcement of the tower's basement, if any, shall also be connected to the earthing ring (see Figures 1 and 5).
– The steel reinforcement of the building's structure shall be bonded to the earthing ring at least at its four corners. If the building is metallic, its feet shall be bonded to the earthing ring.
– The earthing ring of the building shall be connected to the main earthing bar (MEB) located inside the building, preferably on the wall that faces the tower. The earthing conductor shall be as short as possible and have 50 mm^2 as the minimum cross-section area.
– All conductors in contact with the earth should be made of copper or steel covered with copper and have 50 mm^2 as the minimum cross-section area. Galvanized steel conductors could also be used, with 90 mm^2 as the minimum cross-section area.

If the earthing system of a given installation does not fulfil the minimum length of earthing electrodes determined by [IEC 62305-3], additional earthing electrodes shall be installed. These additional electrodes should preferably be in the form of horizontal conductors extending from the tower earthing ring.

Any large metallic object in the vicinity of the earthing system shall be bonded to it. This applies to fuels tanks, stacks, pipes, air conditioning, reinforcing steel, etc., located within 3 m of the earthing electrodes. The bonding should be made by a copper conductor and connected to the nearest earth electrode. Alternatively, a steel conductor covered with copper or galvanized steel conductors could also be used. The length of the bonding conductor shall be as short as possible.

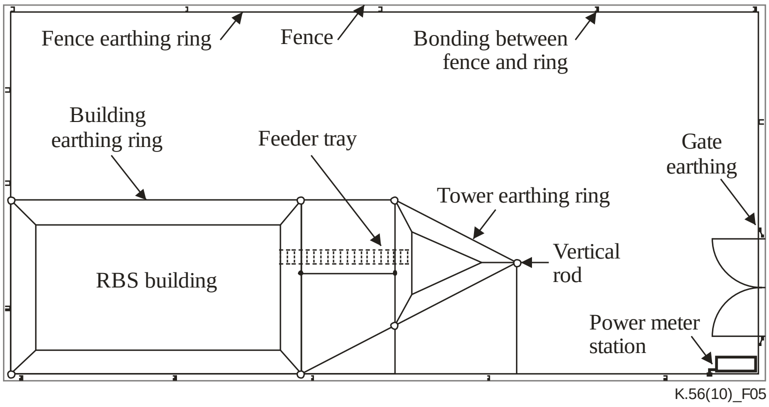

Figure 5 – Earthing system of the RBS

7.3.2 Surface covering

A risk analysis carried out according to [IEC 62305-2] shows that the risk of injury to people is much less than the tolerable risk due to the fact that only seldom persons are present in the RBS. In any case, it is recommended that the area around the RBS be covered with a crushed-stone layer. This procedure increases significantly the resistivity of the upper layer of the soil and, therefore, reduces the harm from the voltage gradient in the soil. The crushed-stone layer also helps in keeping the humidity of the soil, thus maintaining the soil conductivity stability during the dry season. The thickness of the crushed-stone layer shall be at least 0.08 m. The covered area shall be as large as possible and shall extend at least 1 m beyond the earthing electrodes.

7.3.3 Fences

A fence usually surrounds the terrain where the RBS is located. If the fence is metallic, some precautions have to be taken in order to minimize the hazard due to the voltages transferred by the fence. Figure 5 shows the recommended procedures, which are as follows:

– A ring earthing electrode shall be installed along the fence, and the fence shall be bonded to this electrode at regular intervals.

– If the gate is metallic, it shall also be bonded to the ring electrode by a flexible conductor.

– The fence ring electrode shall be bonded to the earthing system of the RBS at regular intervals. In the example of Figure 5, a section of electrode is shared by the building and the fence rings.

– All electrodes in contact with the earth should be made of copper or steel covered with copper and they shall have 50 mm^2 as the minimum cross section area. Alternatively, galvanized steel conductors having 90 mm^2 as the minimum cross section area could be used.

– The crushed-stone layer described in clause 7.3.2 shall be extended up to the fence. However, if a risk analysis carried out according to [IEC 62305-2] shows that the risk of injury to people standing outside the fence and touching the fence is higher than the tolerable risk, complimentary protective measures shall be taken. These measures may include extending the crushed-stone layer at least 1 m beyond the fence.

7.4 Power meter station

The electric utility usually delivers power to the RBS up to a power meter station located at the boundary of the terrain. This station is usually equipped with a power meter and a set of circuit breakers. In addition to the earthing procedures that may be required by the power utility (e.g., installation of an earthing rod close to the station), the earthing bar of the power meter station shall be bonded to the RBS earthing system. The bonding conductor shall extend from the power meter station up to the closest point of the RBS earthing system and, when applicable, it shall be in contact with the soil. This conductor shall be treated as part of the RBS earthing system and shall have a minimum cross section equal to 50 mm^2. In many situations, this bonding is made to the fence's earthing ring.

Surge protective devices (SPDs) shall be installed at the RBS side of the power meter station (i.e., downstream of the circuit breakers). These SPDs shall comply with [IEC 61643-11] and withstand the current:

$$I_{SPD} = \frac{I_{LPL}}{2\,n\,m} \qquad (1)$$

where:

I_{SPD} is the 10/350 μs single-pulse peak current of the SPD

I_{LPL} is the maximum lightning peak current given in Table 1

n is the number of metallic services entering the RBS

m is the number of conductors of the power line.

NOTE – Field experience shows that it is possible to use a device rated for an 8/20 μs waveshape, provided it has an adequate current rating.

The continuous operating voltage (service voltage) of the SPD shall be sufficiently high so that it will not operate under normal operation or fault conditions of the power line. [IEC 61643-11] provides guidelines for the selection of the SPD continuous operating voltage.

8 Equipment building

All conductors that enter the equipment building shall be treated in order to limit the voltages and currents that they can carry to the interior of the building. Furthermore, equipment frames and metallic ducts and trays shall be adequately earthed and bonded in order to control the surges induced in the internal cabling. This clause describes the procedures to be applied.

8.1 Feeder and lighting cables

8.1.1 Bonding at the feed-through window

Wave-guides and the outer conductor of coaxial cables shall be directly bonded to the bonding bar located near the feed-through window. This bonding shall be made by means of short connections and using a weatherproof connector to make contact with the feeder cable. The cable manufacturers usually provide appropriate earthing kits for these connections. Figure 6 shows schematically this installation.

The earthing bar located near the feed-through window shall be connected to the earthing system through a low-impedance connection. A possibility to achieve a low-impedance connection is to install parallel conductors between the earthing bar and the earthing electrode (see Figures 1 and 6).

If the conductors supplying power to the tower lights (lighting cable) are installed inside a metallic duct (see clause 7.2.2.1) or if they are shielded (see clause 7.2.2.2), the metallic duct or the shield shall be bonded to the earthing bar located near the feed-through window. In both cases, the bonding shall be made by means of a conductor as short as possible.

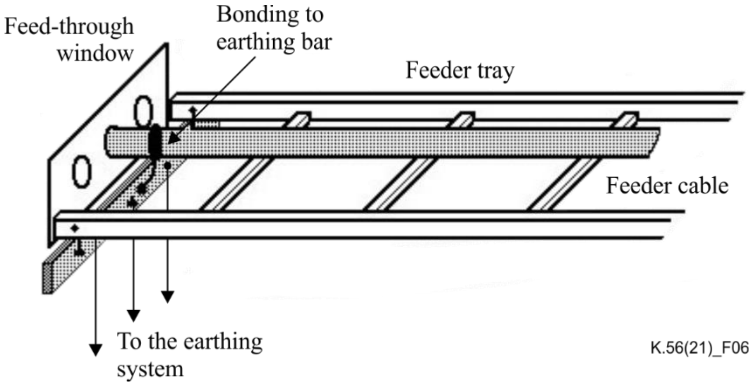

Figure 6 – Example of earthing the feeder cable at the feed-through window

8.1.2 Use of SPDs

The need of SPDs on the feeder coaxial cables depends on the intensity of the highest stroke current corresponding to the selected LPL, the resistibility level of the radio interface connected to the coaxial cable and the transfer impedance of the system. The transfer impedance of the system is the impedance that relates the voltage appearing at the end of the coaxial cable to the stroke current. It is made by three components:

– The shielding factor of the tower (α_T), which determines the fraction of the stroke current that flows through the feeder tray and the conductors attached to it.

– The shielding factor of the feeder tray (α_F), which determines the fraction of the current in the feeder tray that flows through a specific feeder cable.

– The transfer impedance (Z_T) of the feeder coaxial cable, determined by its construction.

The exact values of α_T can be calculated from the tower and feeder geometry. Typical values are:

– Tubular tower (mast): $\alpha_T = 0.30$

– Three-legged tower: $\alpha_T = 0.20$

– Four-legged tower: $\alpha_T = 0.15$

The exact values of α_F can be calculated from the feeder tray dimensions, number of feeders and their radius. The following equation provides an approximate value, where *n* is the number of cables in the feeder tray:

$$\alpha_F = \frac{1}{n+3.5} \qquad (2)$$

NOTE 1 – This simplified equation assumes that the feeder tray is continuous along the tower and bonded to the tower structure, as described in clause 7.2.3.

In the frequency bandwidth of stroke current, the transfer impedance of a tubular coaxial cable is very close to its DC resistance. Therefore, the value of Z_T can be calculated by multiplying the DC resistance of the external conductor of the coaxial cable by its length. Table 3 gives some typical values of DC resistance of coaxial cables for the RBS. For single-braided coaxial cables, the transfer impedance is also a function of the frequency, as part of the magnetic flux generated by a current flowing in the external conductor coupled with the differential circuit. However, single-braided coaxial cables are normally not used in RBSs due to other disadvantages they present, such as undesired interference between circuits.

Table 3 – Typical values of DC resistance of the external conductor of coaxial feeder cables (Z_T)

External diameter (mm)	7.8	10.2	13.7	27.5	39.0	50.3	59.9
DC resistance (Ω/km)	6.6	5.3	3.4	1.04	0.62	0.47	0.31

The peak voltage expected at the end of the feeder cable is given by:

$$V_T = I_{LPL}\, \alpha_T\, \alpha_F\, Z_T\, l \qquad (3)$$

where:

I_{LPL} is the peak lightning current associated with the LPL (see Table 1)

l is the length of the feeder cable.

If V_T is higher than the resistibility level of the equipment, then an SPD is necessary close to the junction between the feeder and the equipment. Otherwise, an SPD is not necessary. The SPD selected for this application shall not interfere with the radio-frequency signal in the feeder.

If the conductors supplying power to the tower lights are unshielded and installed without a metallic tube, it is necessary to install SPDs close to the lighting hardware and at the point where the conductors enter the building, as described in clause 7.2.2.3. These SPDs shall comply with [IEC 61643-11] and have nominal discharge current rating complying with Table 4. In Table 4 the recommended maximum discharge current [I_{max}], if declared, of the SPDs is also provided.

Table 4 – 8/20 μs nominal discharge current/recommended maximum discharge current of SPD for unshielded lighting cable

LPL	I	II	III – IV
Current (kA)	20/40	15/30	10/20

NOTE 2 – If the power to the tower lights is supplied with AC voltage from the electric board, the SPD installed at the building entrance (on the conductor supplying power to the tower lights) shall be coordinated with the SPD installed in the electric board. Refer to [IEC 61643-12] for the relevant information.

NOTE 3 – If the power to the tower lights is supplied with DC voltage from an AC/DC converter, an SPD set may be necessary at the AC/DC converter. Refer to clause 9 in order to assess the need for this SPD set.

8.2 Power conductors

The power conductors can endanger the RBS equipment in case of a lightning flash striking the tower as well as in case of a flash striking at or near the power line. The protection procedures for any of these cases consist of limiting the surges between the power conductors and the RBS earthing. The installation of surge protective devices and the adequate bonding of cable trays and ducts provide adequate protection.

8.2.1 Electric board

Power conductors shall enter the RBS close to the electric board. The electric board shall contain circuit breakers, surge protective devices (SPDs) and one earthing bar. The earthing bar shall be connected to the building ring electrode by a short earthing conductor having a 50 mm^2 minimum cross-section area. The SPD and the board frame shall be connected to the earthing bar. For TN-C systems, the neutral wire shall also be connected to the earthing bar. Figure 7 shows an example of an electric board. The following aspects shall be considered:

– If the power cable is shielded, its shield shall be bonded to the electric board's earthing bar.

– Preferably, the power conductors shall leave the electric board inside metallic ducts or trays that shall be bonded to the board frame. The use of plastic duct to carry the power conductors may require the installation of another set of SPDs close to the AC powered equipment (e.g., the power supply). The need of this set of SPDs is assessed in clause 9.

– The selection of the primary circuit breakers shall take into account that they shall not trip due to surge currents originated by the operation of the SPD.

– The conductors for supplying power to the tower lights shall derive from an exclusive secondary circuit breaker and, preferably, run inside a dedicated duct or tray. See clause 7.2.2 for detailed information on these conductors.

– The earthing bar of the electric board shall be connected to the main earthing bar (MEB) through a bonding conductor with a cross-section area not less than 16 mm^2, and the length of this conductor shall be as short as possible.

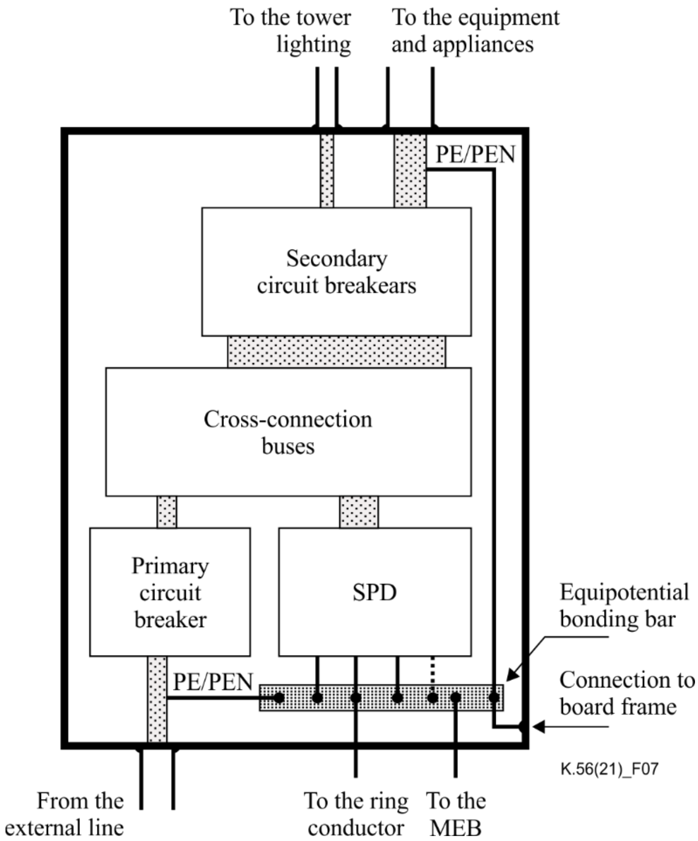

Figure 7 – Diagram of the electric board

8.2.2 Installation of SPD in the electric board

The installation of SPDs in the electric board depends on the type of electric power system used. Figure 8 shows the diagram for SPD installation for a TN-C system, where the neutral conductor is directly bonded to the earthing bar and the phase conductors are protected by SPDs. Figure 9 shows two diagrams for an TN-S, TT or IT system, where the phases and neutral conductors are connected to the SPD. The length of leads connecting the power conductors to the SPD and the SPD to the electric board's earthing bar shall be as short as possible. The effect of the SPD lead length is evaluated in clause 9.1.

NOTE – Annex A of [ITU-T K.66] gives information on SPD installation for different power systems.

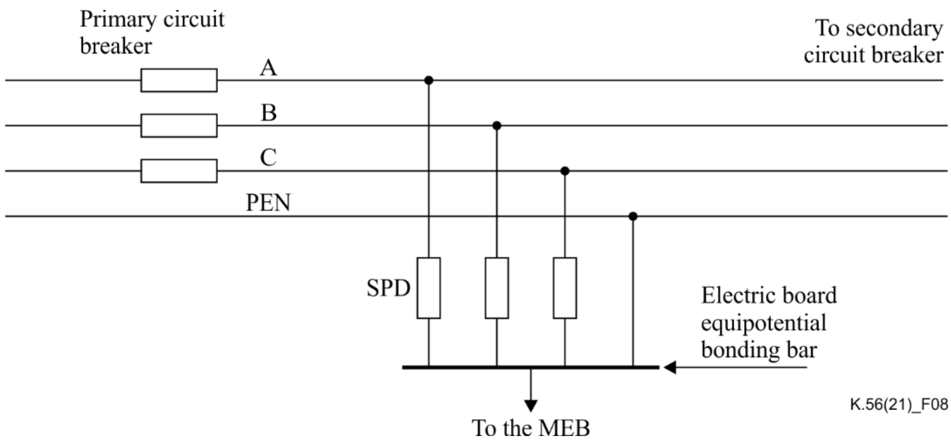

Figure 8 – Scheme for SPD installation on TN-C power systems

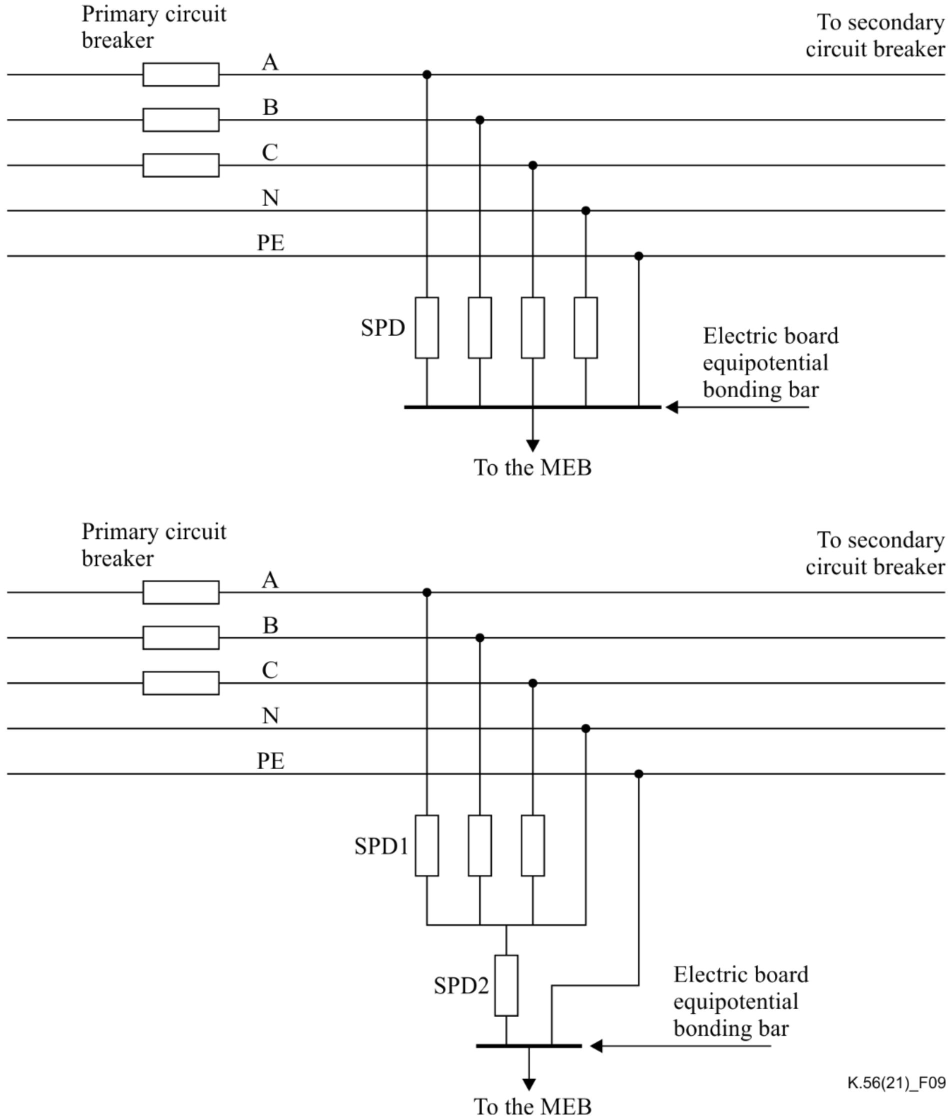

Figure 9 – Schemes for SPD installation on TN-S, TT or IT power systems

8.2.3 Selection of SPDs

If the installation does not have a power meter station equipped with SPDs as required in clause 7.4, then the SPD of the electric board shall comply with the requirements of clause 7.4. Otherwise, the SPD of the electric board shall comply with [IEC 61643-11] and have the nominal discharge current rating given in Table 5. In Table 5 the recommended maximum discharge current [I_{max}], if declared, of the SPD is provided.

Table 5 – 8/20 μs nominal discharge current/recommended maximum discharge current of the electric board SPD

LPL	I	II	III – IV
Current (kA)	30/60	20/40	15/30

NOTE – The current rating of SPD2 in Figure 9 shall be determined considering that it carries the total current that flows through the service conductors.

The continuous operating voltage (service voltage) of the SPD shall be sufficiently high so that it will not operate under the normal operation or fault conditions of the power line. [IEC 61643-11] provides guidelines for the selection of the SPD continuous operating voltage. The SPD installed in the electric board shall coordinate with the SPD installed in the power meter station (see clause 7.4). Refer to [IEC 61643-12] for the relevant information to achieve this coordination.

8.3 Telecommunication conductors

The telecommunication conductors can endanger the RBS equipment in case of a lightning flash striking the tower as well as in case of a flash striking at or near the telecommunication line. The protection procedures for any of these cases consist of limiting the surges between the telecommunication conductors and the RBS earthing. The installation of surge protective devices and adequate earthing of the conductors provides this protection.

NOTE – The procedures for the protection of telecommunication lines against direct and indirect lightning discharges can be found in [ITU-T K.47] and [ITU-T K.46], respectively, taking into account [ITU-T K.72].

8.3.1 Distribution frame

The telecommunication cables shall enter the RBS close to the distribution frame. The distribution frame shall have an earthing bar connected to the building ring electrode by a short earthing conductor having a 50 mm^2 minimum cross-section area. The earthing bar shall also be connected to the main earthing bar (MEB) by a conductor as short as possible having a 16 mm^2 minimum cross section area. Inside the cabinet, the following components shall be connected to the distribution frame's earthing bar:

– metallic sheath of the telecommunication cable;

– metallic strength element of the telecommunication cable (if any);

– surge protective devices connected to the metallic symmetric pairs;

– metallic structure of the distribution frame.

The internal cable that leaves the distribution frame and goes to the equipment shall preferably be supported by a metallic duct or tray, and this duct or tray shall be bonded to the earthing bar of the distribution frame (e.g., through the metallic structure of the distribution frame) and to the equipment frame. Figure 10 shows a diagram of the telecommunication distribution frame and its earthing connections.

NOTE – If the internal cable is shielded, the shield shall be continuous and bonded at both ends, i.e., to the distribution frame and to the equipment frame.

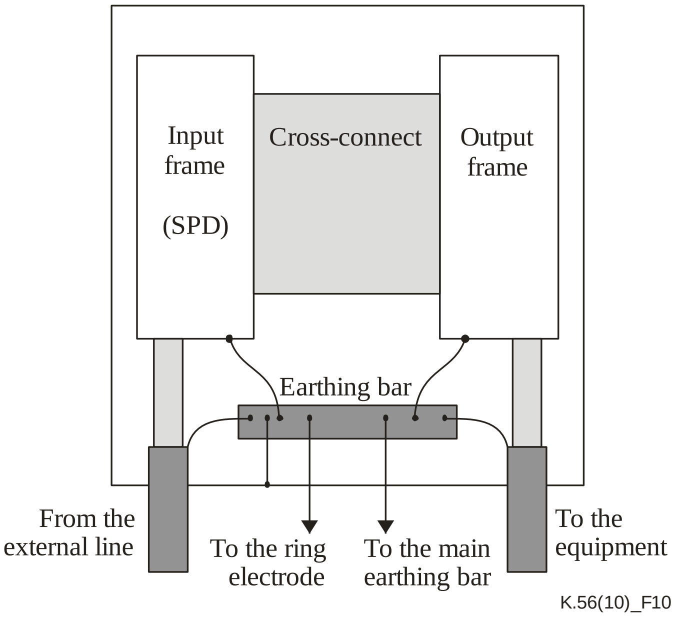

Figure 10 – Diagram of the telecommunication distribution frame

8.3.2 Installation of SPDs in the distribution frame

A three-terminal SPD should be used for symmetric pair lines, as shown in Figure 11. The SPD should be equipped with a fail-safe device which short-circuits it in case of overheating. The minimum DC turn-on voltage of the SPD shall be selected by the operator based on the maximum working voltage that can be applied to the line-to-earth circuit.

NOTE 1 – The minimum DC turn-on voltage should not be too low in order to avoid frequent and unnecessary operation of the SPD due to distant lightning activity or power-frequency induction, which may reduce the throughput of the communication channel and the service life of the SPD.

The impulse current rating of the SPD is assessed by the following approximate equation:

$$I_{SPD} = \frac{I_{LPL}}{2\,n\left(m + m_s\right)} \tag{4}$$

where:

- I_{SPD} is the 10/350 μs single-pulse peak current of the SPD
- I_{LPL} is the maximum lightning peak current given by Table 1
- n is the number of metallic services entering the RBS
- m is the number of conductors in the telecommunication cable
- m_S is the number of conductors equivalent to the shield.

NOTE 2 – Field experience shows that it is possible to use a device rated for an 8/20 μs waveshape, provided it has an adequate current rating.

The value of m_S can be obtained by making the resistance of the shield equal to the resistance of m_S conductors. If the cable is unshielded, then $m_S = 0$. A representative value of m_S for standard aluminium shield is $m_S = 30$. For example, for LPL III (I_{LPL} = 100 kA), two services (e.g., power and telecommunication) and twenty conductors in the telecommunication cable (10 pairs), equation 4 gives I_{SPD} = 500 A.

The capability of the telecommunication conductors to withstand the impulse current shall be investigated using [ITU-T K.47], and some protection procedures may be necessary in order to protect the external telecommunication cable.

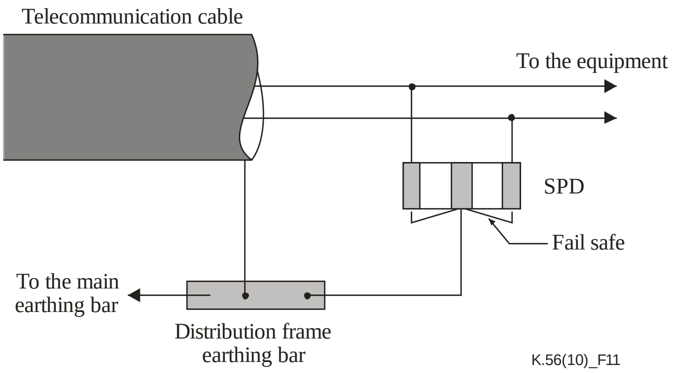

Figure 11 – Installation of SPD in the distribution frame

8.4 Earthing and bonding of metallic elements

The earthing and bonding of the metallic elements inside the equipment building (cable trays, equipment frames, equipotential bonding conductors, etc.) aim to minimize the voltages between accessible metallic parts (for personnel safety) and to reduce the transfer impedance of the installation, i.e., part of the lightning current may flow through the metallic elements, but the voltages transferred to the equipment ports are controlled within acceptable levels. In order to achieve this, it is necessary to connect the metallic elements as follows:

– An equipotential bonding conductor should be installed inside or outside the cable trays and bonded to the equipment frames and to the cable trays. This conductor should also be connected to the main earthing bar (MEB), as shown in Figure 12. Alternatively, this equipotential bonding conductor could be installed around the room (forming a ring) and connected to the equipment frames and trays by short conductors (see Figure 13). This ring equipotential bonding conductor may be installed near the ceiling (as described in [ITU-T K.35]) or near the floor (as described in [ITU-T K.27]).

– The metallic shield of shielded cables shall be connected to equipment metallic frames at both ends.

– The external conductor of feeder cables shall be connected to equipment frames.

– The metallic ducts or trays that carry the cabling shall be connected to the equipment metallic frame (or structure) at both ends, as shown in Figure 14.

– The metallic ducts and trays shall be electrically continuous for their entire length. The continuity at joints shall be achieved at least in two symmetrically spaced points (e.g., by the use of two bonding clamps on the sides of the tray), as shown in Figure 15.

Annex C shows an example of the earthing and bonding inside an RBS. More information on the implementation of earthing and bonding configurations can be found in [ITU-T K.27] and [ITU-T K.35], including the treatment of the protective earth (PE) conductor.

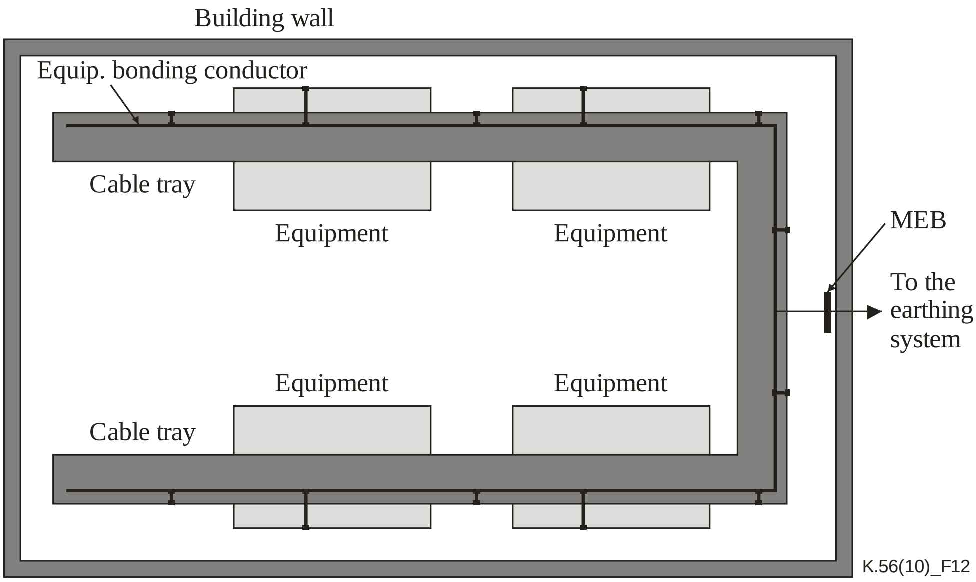

Figure 12 – Equipotential bonding conductor in the cable trays

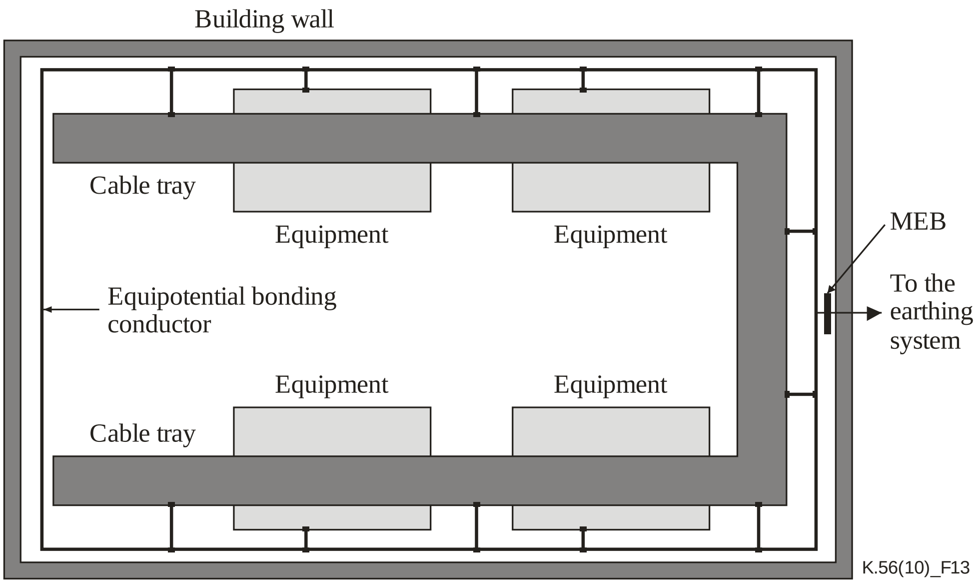

Figure 13 – Equipotential bonding conductor around the equipment room

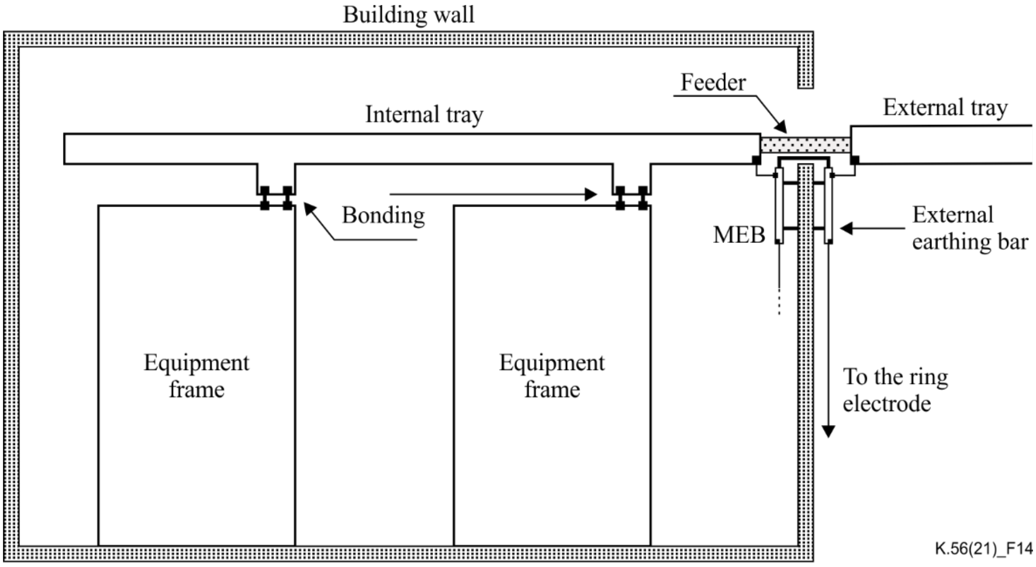

Figure 14 – Lateral view of the RBS showing the bonding between internal tray and equipment frame

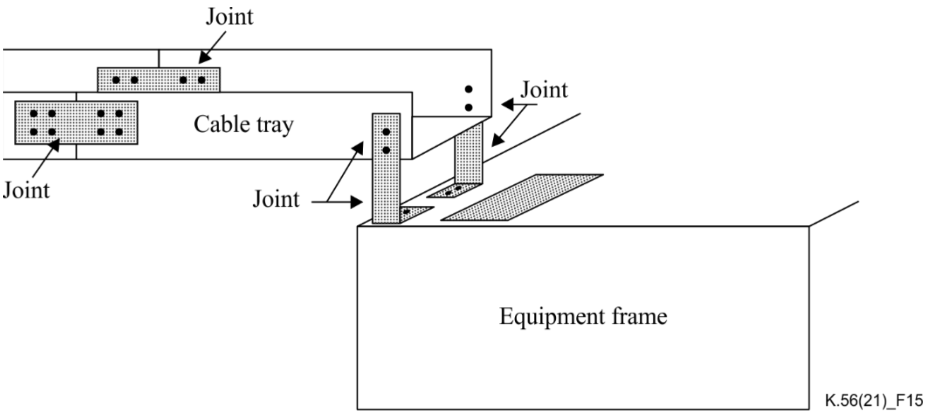

Figure 15 – Detail of the electrical continuity in trays and equipment frame

9 Protection of RBS equipment

The RBS equipment usually presents high common-mode impedance at its input port. In some cases, low impedance may be found if there are secondary SPDs installed in a common-mode configuration within the equipment and these SPDs operate. Alternatively, an analysis according to this clause may require the installation of an SPD close to the equipment port (secondary SPD). In both cases, coordination between the secondary SPD and any primary SPD installed upstream (e.g., at the electric power board or telecommunication distribution frame) needs to be achieved. [ITU-T K.44] and [IEC 61643-22] give procedures to coordinate primary and secondary SPDs in telecommunication lines and [IEC 61643-12] gives procedures for power lines. This clause refers to the common-mode overvoltage (henceforth referred to simply as overvoltage) applied to an equipment port that is not equipped with secondary SPDs.

The protection of RBS equipment is achieved whenever the overvoltage at its port is equal to or lower than its withstand voltage (resistibility level). One or a combination of the following procedures can protect RBS equipment:

– select a primary SPD with adequate protection level;
– improve the installation in order to reduce the overvoltage developed across the SPD connecting leads;
– improve the installation in order to reduce the overvoltage induced in the internal cabling;

– install a set of secondary SPDs close to the equipment.

This clause guides the design of the electric installation inside the RBS equipment building in order to achieve adequate protection of the equipment against lightning discharges. It considers that the overvoltage applied to the equipment port may have three components:

– the effective protection level of the SPD (U_P);

– the peak value of the inductive voltage drop across the SPD connecting leads (U_D);

– the peak value of the voltage induced in the cabling section between the SPD and equipment (U_I).

The equipment resistibility is quantified by its withstand voltage U_W, which is the voltage that the equipment can withstand without suffering damage or leading to spark-over of its insulation. It is considered that there is a safety margin between the value of U_W declared by the equipment manufacturer and the voltage that will produce damage or spark-over, so it is not necessary to introduce any additional safety margin. Therefore, the equipment is protected whenever the overvoltage applied to the equipment port is equal to or lower than the withstand voltage declared by the manufacturer. Depending on the SPD type, one of the following criteria applies:

– For clamping type SPD (e.g., varistor):

$$U_W \geq U_P + U_D + U_I \tag{5}$$

– For switching type SPD (e.g., GDT):

$$U_W \geq U_P + U_I \text{ and } U_W \geq U_D + U_I \tag{6}$$

In the derivation of equations 5 and 6, it is conservatively considered that, for clamping type SPDs, the voltages U_I, U_P and U_D are simultaneous, while for switching type SPDs, the voltage U_I may be simultaneous with U_P or U_D. In both cases, it is considered that the voltages U_I, U_P and U_D have the same polarity. Overvoltage due to the reflection of U_I , U_P and U_D at high impedance equipment ports is neglected because it is considered that, for typical RBS, the duration of this overvoltage is too short to cause breakdown of insulation or to impair SPD coordination.

The value of the SPD protection level (U_P) is usually provided by its manufacturer in the product data sheet. For clamping type SPDs (e.g., varistor), the protection level is the voltage across the device when tested with 8/20 current impulse with a crest value of I_{imp} (for class I SPDs) or I_n (for Class II SPDs). For sparking type SPDs (e.g., GDT), the protection level is the impulse sparking voltage. The following clauses are aimed to quantify the other parameters involved in the coordination criteria described in equations 5 and 6.

NOTE – The impulse sparking voltage of GDTs is determined to be under 1 kV/μs (see [ITU-T K.12]).

9.1 Inductive voltage drop across the SPD connecting leads

The installation of SPDs in the electric board and in the telecommunication distribution frame shall minimize the length of the leads connecting the conductor to the SPD and the SPD to the frame/board earthing bar. If the internal cabling leaves the electric board or the telecommunication distribution frame in a non-metallic duct, the length of the connecting lead between the frame/board earthing bar and the MEB shall also be considered. Equation 7 allows the evaluation of the inductive voltage drop (U_D):

$$U_D = \frac{R}{(R+Z)} \frac{d\, I_{LPL}}{d\,t} \frac{L_D\, l_L}{n\,m} \tag{7}$$

where:

dI_{LPL}/dt is the maximum current rate of rise determined by the LPL (see Table 1)

L_D is the inductance per unit length of a connecting lead ($L_D \approx 1$ μH/m)

l_L is the length of the connecting lead

m is the number of line conductors protected with SPDs or directly connected to the earthing bar at the board/frame (e.g., $m = 4$ in Figure 8); if a section of the connecting leads has a single conductor, then $m = 1$ for this section (e.g., leads of SPD2 in Figure 9)

n is the number of services connected to the RBS

R is the resistance of the RBS earthing system

Z is the surge impedance of the outside service line ($Z = 400\ \Omega$ and $100\ \Omega$ for aerial and buried lines, respectively).

9.2 Voltage induced in the internal cabling

If the internal conductors run inside shielded cables and the shield is bonded to the equipment frame at both ends, the induced voltage can be disregarded ($U_I = 0$). The same applies to unshielded cables installed inside metallic ducts or closed trays. For unshielded cables installed in metallic open trays, the magnetic field from the lightning current gives rise to an induced voltage U_I, which may be relevant. This voltage can be calculated by:

$$U_I = 0.2\ \frac{dI_{LPL}}{dt}\ h\ \eta\ p\ \beta\ \ln\left(\frac{d + l_T}{d}\right) \tag{8}$$

where:

dI_{LPL}/dt is the maximum current rate of rise determined by the LPL (see Table 1)

h is the height of the cable

η is the shielding factor of the walls (see Annex B)

p is a factor to take into account the metallic connection between the tower and the building ($p = 1.5$ for a typical RBS)

d is the shortest distance between the tower axis and the cable (see Figure 16)

l_T is the length of the cable in a radial direction from the tower (see Figure 16)

β is the shielding factor of the cable tray (see Annex A).

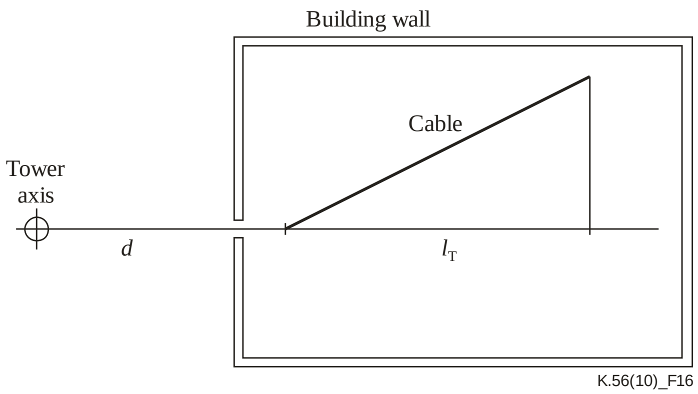

Figure 16 – Plan view representation of the distance *d* and length l_T

Annex A

Shielding factor (β) of cable trays

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

The shielding factor β of a metallic tray is the attenuation in the voltage induced in an internal cable due to its placement in a metallic tray which is continuous and bonded to an earthing bar/equipment frame at both sides. The shielding factor of a metallic duct or a channel tray with cover is close to zero ($\beta \approx 0$). On the other hand, the shielding factor of a tray that is not continuous from a equipment frame to another is unity ($\beta = 1$). The same applies to unshielded cables carried in non-metallic trays or ducts. Tables A.1 to A.4 give some shielding factor values for different sizes of open metallic trays, described by Figures A.1 and A.2.

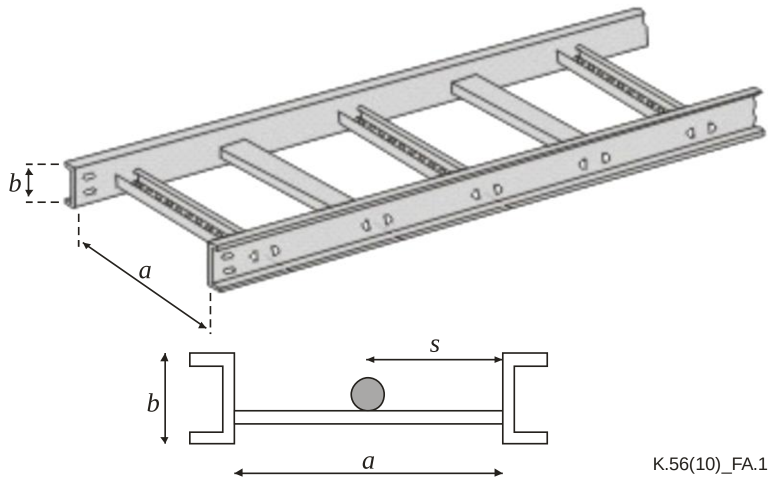

Figure A.1 – Ladder cable tray

Table A.1 – Shielding factor for ladder cable trays (*b* = 50 mm)

Position of the cable (s) in mm	Width of ladder cable tray (a) in mm			
	100	**200**	**300**	**400**
50	0.08	0.13	0.15	0.16
100	–	0.15	0.19	0.22
150	–	0.13	0.21	0.24
200	–	–	0.19	0.25

Table A.2 – Shielding factor for ladder cable trays (*b* = 100 mm)

Position of the cable (s) in mm	Width of ladder cable tray (a) in mm			
	100	**200**	**300**	**400**
50	0.04	0.08	0.09	0.11
100	–	0.10	0.13	0.16
150	–	0.08	0.14	0.18
200	–	–	0.13	0.18

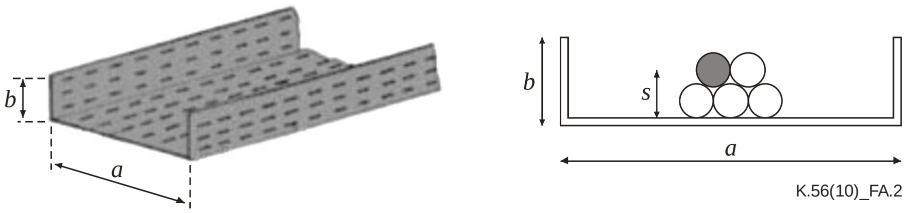

Figure A.2 – Channel cable tray

Table A.3 – Shielding factor for channel cable trays (*b* = 50 mm)

Position of the cable (*s*) in mm	Width of channel cable tray (*a*) in mm			
	100	**200**	**300**	**400**
2.5	0.008	0.006	0.005	0.005
5	0.016	0.012	0.010	0.009
10	0.030	0.024	0.021	0.018
20	0.057	0.047	0.040	0.035
30	0.079	0.069	0.059	0.052
40	0.099	0.088	0.077	0.068
50	0.115	0.107	0.094	0.084

Table A.4 – Shielding factor for channel cable trays (*b* = 100 mm)

Position of the cable (*s*) in mm	Width of channel cable tray (*a*) in mm			
	100	**200**	**300**	**400**
2.5	0.005	0.005	0.004	0.004
5	0.010	0.009	0.008	0.008
10	0.020	0.018	0.016	0.015
20	0.038	0.036	0.032	0.029
30	0.053	0.052	0.047	0.043
40	0.066	0.066	0.062	0.057
50	0.080	0.080	0.075	0.070

Annex B

Shielding factor (η) of building walls

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

Depending on the conductive characteristics of the building walls, they can provide a shielding effect against electromagnetic fields from lightning, which attenuates the voltages and currents induced inside the building. This attenuation is represented by the shielding factor η. Some shielding factor values for different shields are summarized in the following:

– Metallic container: $\eta = 0.01$. The metallic container shall have its metallic sheaths connected together at several points along the joints, forming a closed metallic cage (floor, ceiling and walls).

– Metallic grid: $\eta = w/8.5$. The grid width w is in metres and it shall form a cage around the building ($8.5 < w < 0.085$).

– Steel reinforcement of a concrete structure: $\eta = 0.5$. The steel reinforcement of a concrete framework shall be electrically continuous.

– Non-screening: $\eta = 1$. This applies to walls made of non-conductive materials, such as wood, bricks and concrete without continuous steel reinforcement.

NOTE – [IEC 62305-2] designates this shielding factor as factor K_{s1}.

Annex C

Example of earthing and bonding configuration inside an RBS

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

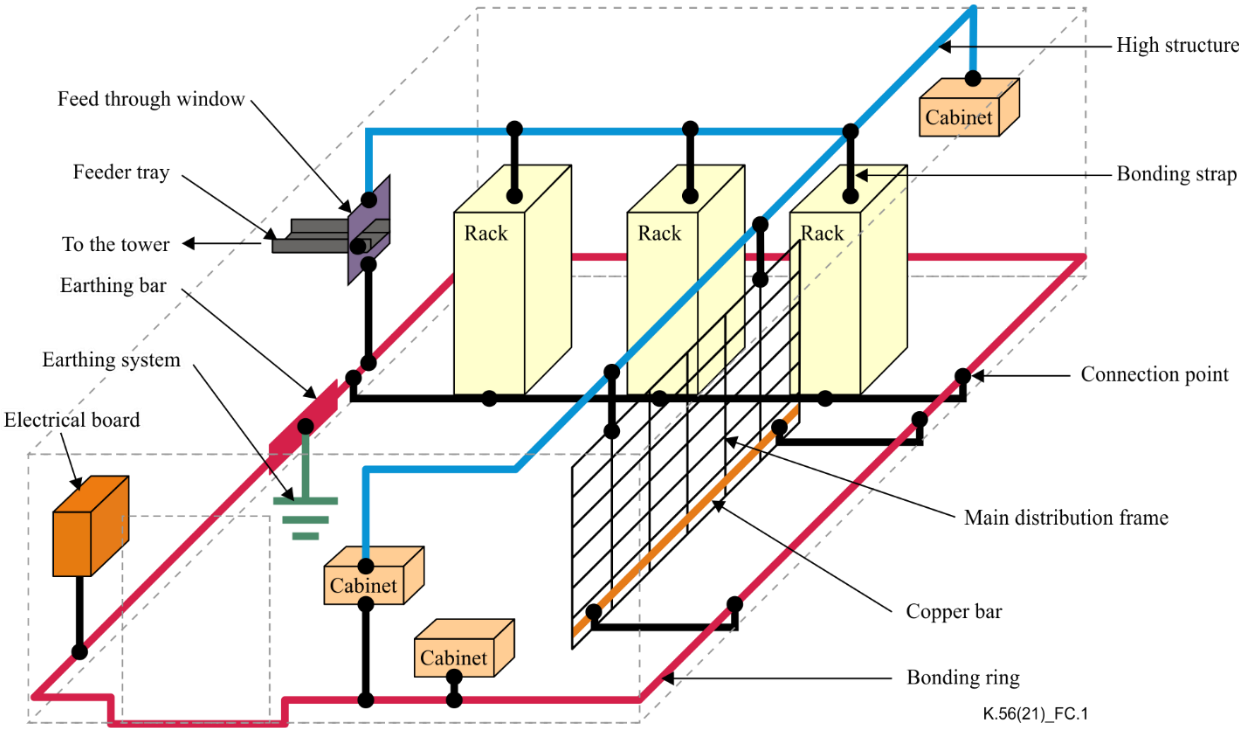

Figure C.1

Appendix I

Results of tests with rocket-triggered lightning on a radio base station

(This appendix does not form an integral part of this Recommendation.)

I.1 Introduction

A test site with rocket-triggered lightning in Cachoeira Paulista (Brazil) was active from 2000-2007. This test site had the participation of several institutions with different research interests, including the protection of telecommunication installations against lightning. The tests on the telecommunication installations were carried out under a cooperation among Fundação CPqD (Brazil), France Telecom R&D (France), Telstra Corp. (Australia), Federal University of Minas Gerais (Brazil) and University of Campinas (Brazil). Some tests were aimed at the investigation of the behaviour of a radio base station (RBS) under direct lightning strikes. In order to do that, an RBS was constructed at the test site, following the guidelines of this Recommendation. A rocket platform was installed on the top of the tower, in order to trigger the lightning discharges. The tower and the equipment building were instrumented with current and voltage probes, and oscilloscopes, so that the overcurrents and overvoltages could be measured at strategic locations. This appendix presents a summary of the results and compares them with the theoretical predictions from this Recommendation.

I.2 Description of the test site

The site is described in detail in [b-Barbosa 2], and this clause describes only its main features. The RBS is a 5 m × 6 m masonry building with a 30 m metallic tower nearby, as shown in Figure I.1. The RBS earthing and bonding system is made according to this Recommendation. At the top of the tower, there is a rocket platform with the capacity to fire up to four rockets during the same thunderstorm, which is also shown in Figure I.1. The platform is insulated from the tower, in such way that the current is forced to pass through a current probe that is connected to a well-shielded oscilloscope nearby. This oscilloscope is remotely controlled by a fibre-optic link and powered by battery and solar panel. Another fibre-optic link controls the firing of the rockets. Inside the RBS, there are oscilloscopes connected to current and voltage probes. The power line that feeds the RBS is made of three conductors (two phases and one neutral) and the external line has a buried section up to the power meter station and then an aerial section up to a power generator.

Figure I.1 – General view of the RBS and detail of the rocket platform on the tower top

I.3 Recordings of the lightning current

The experiments presented here are related to five flashes successfully triggered from the RBS, with an average of three strokes per flash. Figure I.2 shows a photograph of one of those flashes and the currents recorded at the tower top for two different strokes (with different rising times). Although rocket-triggered lightning differs from natural lightning in the initial stages of the return-stroke formation, it is generally recognized that its characteristics are very similar to subsequent strokes from natural lightning. The median peak value of the recorded lightning currents was 12 kA and the median time to half value was 30 μs. The median and maximum *di*/*dt* recorded were 40 kA/μs and 270 kA/μs, respectively.

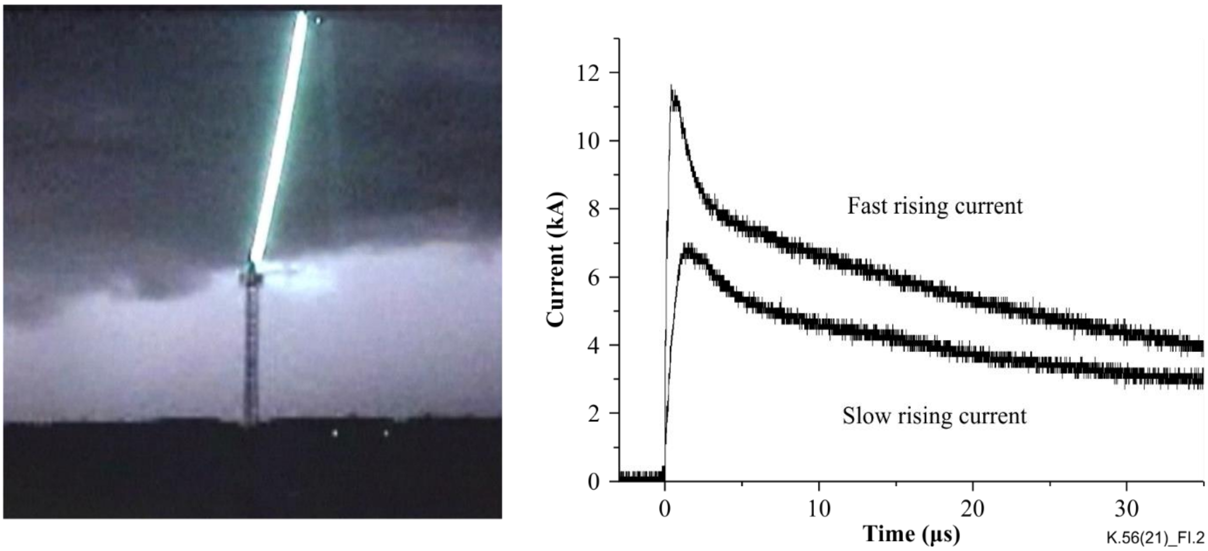

Figure I.2 – Photograph of rocket-triggered lightning and two current waveforms recorded at the tower top

I.4 Shielding factor of tower and feeder tray

As described in clause 8.1.2, the shielding factor of the tower (α_T) gives the fraction of the stroke current that flows through the feeder tray (and the conductors attached to it), while the shielding factor of the feeder tray (α_F) gives the fraction of the current in the feeder tray that flows through a specific feeder. Therefore, the product $\alpha_T \times \alpha_F$ gives the fraction of the stroke current that flows through a specific feeder. Clause 8.1.2 presents an approximate procedure to calculate the values for α_T and α_F for typical towers and feeder trays. At the test site, it was possible to measure simultaneously the stroke current at the tower top and the current in a feeder cable just before it entered the equipment building. Some results are shown in Figure I.3 for the stroke currents of Figure I.2.

The fast-rising stroke current of Figure I.2 leads to a peak in the feeder current, due to the stroke current reflection at the tower base, which is almost absent in the case of a slow-rising current. As the highest peak voltage transferred to the interior of the feeder is due to the first stroke, it comes out that the slow-rising current is more representative for the assessment of this voltage. The ratio between the peak values of the feeder current to the stroke current is 175 A/7000 A = 0.025. The tower used at the test site has three legs ($\alpha_T = 0.20$) and the feeder tray has three feeders ($\alpha_F = 0.15$), then the product $\alpha_T \times \alpha_F = 0.03$. Therefore, the shielding factor value given by the approximate procedure from clause 8.1.2 agrees reasonably well with the value measured in the test site. It is interesting that the calculated value is slightly above the measured one, which provides a design on the safe side. [b-Barbosa 2] gives detailed information on these measurements.

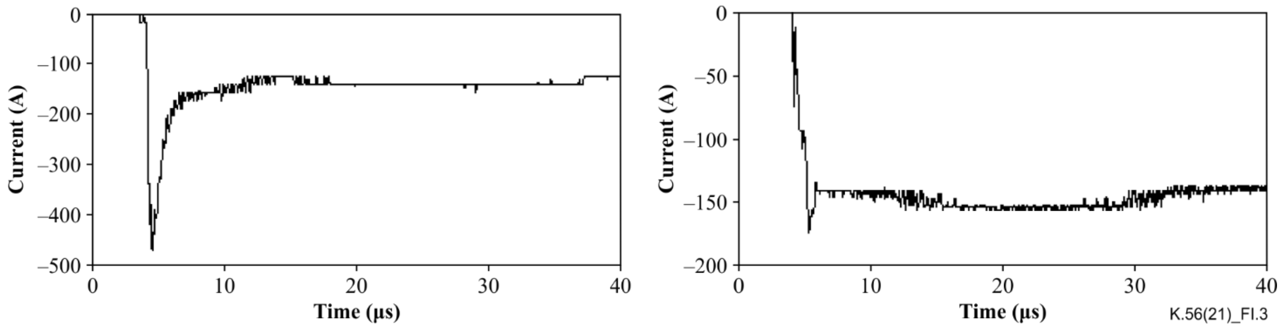

Figure I.3 – Feeder currents for fast-rising (left) and slow-rising (right) stroke currents

I.5 Bonding the feeder to the tower at ground level

The need to bond the feeders to the tower (or to the feeder tray) at ground level has been investigated at the test site by measuring the current in the feeder cable with and without this bonding. For each feeder current measurement, the stroke current at the tower top was simultaneously measured. Figure I.4 shows the feeder current for the bonded (earthed) and un-bonded (unearthed) conditions. As each current refers to a different stroke, their amplitudes are normalized by the peaks of the respective stroke current, which have similar waveforms.

These measurements show that bonding the feeder to the tower at ground level increases the current in the feeder by about 1/3 or, alternatively, un-bonding the feeder reduces the current by 1/4. This current change is designated as δi. Therefore, considering only the feeder current, this bonding should not be done.

However, the voltage between the feeder and the tower frame at the bending point could, under certain conditions, break down the insulation of the feeder cable. This voltage may be assessed if it is considered that the feeder/tower voltage is null for the bonded condition and that the un-bonded condition can be obtained from the bonded condition by injecting $-\delta i$ in the feeder. The feeder/tower voltage is then given by the current δi flowing through the inductance between the feeder and the feeder tray in the horizontal section between the tower and the feed-through window. This inductance is estimated as being equal to or lower than 0.5 µH/m. The feeder current is estimated as 3% of the stroke current (it is considered to have three feeders and a three-legged tower). For LPL I, the stroke current rate of rise is 200 kA/µs, so that the voltage between the feeder and tower is about 1 kV/m. From the feeder cable data-sheets, the minimum withstand voltage of the feeder outer sheath is 8 kV_{rms}, which gives a 11 kV peak. Therefore, 11 m of tray is necessary to lead to a peak impulse voltage between the feeder and tower equal to the cable withstand voltage. This value is aligned with the minimum length of the horizontal section of the feeder tray to require bonding of feeders as given in Table 2. [b-Barbosa 2] provides detailed information on these measurements.

NOTE – There is a reasonable safety margin between the power-frequency withstand voltage of the cable insulation and its breakdown voltage under impulse, so the values in Table 2 are conservative.

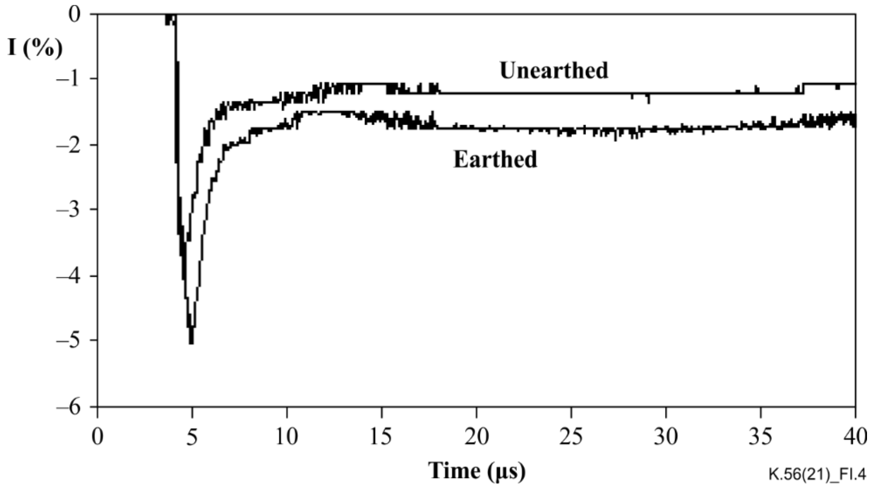

Figure I.4 – Feeder current as a function of the bonding procedure at ground level

I.6 Current flowing through service conductors

This Recommendation uses the approximate procedure from [IEC 62305-1] in order to assess the fraction of the total lightning current that flows through the service conductors, i.e., it is assumed that half of the current flows through the earthing system and the other half is distributed evenly by the metallic services connected to the installation. This distribution was verified at the test site by measuring the current that flows through the service conductors during a strike and measuring simultaneously the total stroke current. At the test site, there was only the power service and no SPD at the power meter station. The currents in the power conductors are shown in Figure I.5, corresponding to the fast-rising stroke current shown in Figure I.2. The peak current flowing through the power conductors is 1.9 kA for the phases and neutral. Therefore, the total current is 3.8 kA, which represents 32% of the stroke current. This value is somewhat lower than the 50% that would be expected by the approximate calculation, which indicates that the calculation provided a conservative value. The measured current may have been influenced by the relatively short length of the power line and by the good earthing system of the RBS.

Figure I.5 also shows that the neutral current is about twice the phase current, which may have been influenced by the direct bonding of the neutral conductor to the RBS earthing bar (TN-C system), while the phases were bonded through the SPD. If the neutral was equipped with an SPD, due to symmetry, it is expected that the current would divide evenly among the conductors. [b-Barbosa 1] provides detailed information on these measurements.

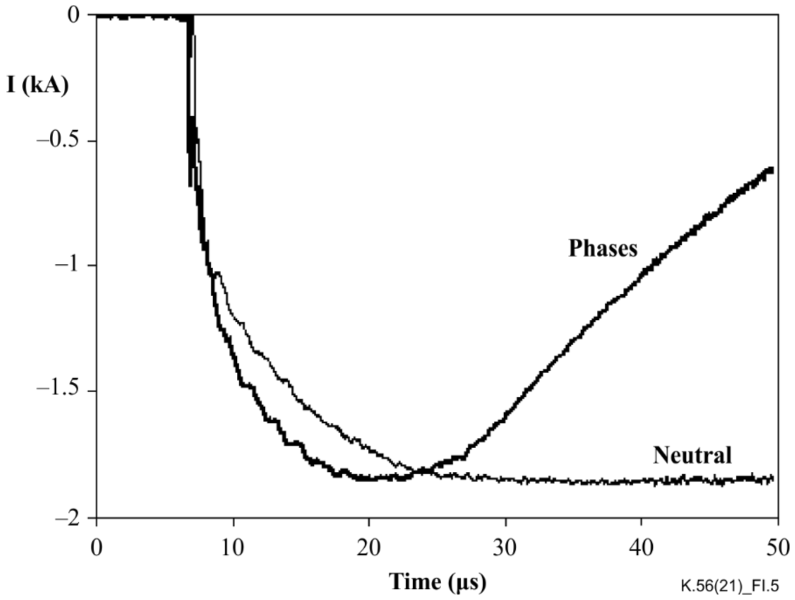

Figure I.5 – Currents in the power conductors for the fast-rising stroke current

I.7 Inductive voltage drop in the SPD connecting leads

The surge current flowing through the SPD connecting leads generates an inductive voltage drop in these leads, which is proportional to the inductance of the leads and the time derivative of the current flowing through the SPD. Comparing the currents in Figure I.5 to the fast-rising stroke current in Figure I.2, it is clear that currents in the power conductors have a time-derivative much lower than the stroke current. [b-Barbosa 1] gives a rationale for assessment of the time derivative of the SPD current, which is given by:

$$\left({di_P}/{dt} \right)_{\mathrm{MAX}} = \frac{R}{(R+Z)} \left({di_S}/{dt} \right)_{\mathrm{AVE}} \qquad \text{(I.1)}$$

where:

- $(di_P/dt)_{\mathrm{MAX}}$ is the maximum *di*/*dt* on the SPD connecting leads
- $(di_S/dt)_{\mathrm{AVE}}$ is the average *di*/*dt* of the lightning stroke current
- R is the earth resistance of the installation
- Z is the surge impedance of the line.

At the test site, the power line leaves the RBS underground, so that its surge impedance is $Z \approx 100\ \Omega$. The earthing resistance is $R = 20\ \Omega$ and the average rate-of-rise of the stroke current is 39 kA/µs, for the fast-rising current of Figure I.2. Inserting these numbers in equation I.1 gives the maximum rate-of-rise of the current in the power line equal to 6.5 kA/µs. This value agrees very well with the sum of the maximum *di/dt* measured on the power line conductors, which is given by: 1.7 + 1.7 + 2.8 = 6.2 kA/µs. This equation is used in clause 9.1 in order to assess the inductive voltage drop in the SDP connecting leads.

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