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SERIES K: PROTECTION AGAINST INTERFERENCE

Protection of radio base stations against lightning discharges

ITU-T Recommendation K.56

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Protection of radio base stations against lightning discharges

Summary

This Recommendation provides a quantitative procedure in order to protect radio base stations (RBS) for wireless access network against lightning discharges. The level of protection is based on the tolerable frequency of damage that is assigned to the RBS by the operator, considering the consequences of service interruption and loss of equipment. The RBS covered by this Recommendation is made up of a shelter or small building to house the equipment and a nearby tower to hold the antennas. The protection procedures include earthing, bonding, shielding and installation of surge protective devices (SPD).

Source

ITU-T Recommendation K.56 was prepared by ITU-T Study Group 16 (2001-2004) and approved under the ITU-T Recommendation A.8 procedure on 29 July 2003.

FOREWORD

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CONTENTS

Introduction

The widespread use of radio base stations (RBS) for mobile telephony and for wireless local loop brought concerns about their exposure to lightning discharges, which may cause damage to the RBS equipment and cabling. This Recommendation provides protection procedures for RBS equipment and cabling against lightning discharges, based on frequency analysis of the installation.

ITU-T Recommendation K.56

Protection of radio base stations against lightning discharges

1 Scope and purpose

This Recommendation addresses the RBS made up of a shelter or small building to house the equipment and a nearby tower to hold the antennas, in such way that the tower will prevent lightning from hitting the shelter or small building. The purpose of this Recommendation is to give criteria for the definition of procedures in order to protect the RBS against lightning discharges.

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.

[1] ITU-T Recommendation K.39 (1996), *Risk assessment of damages to telecommunication sites due to lightning discharges*.

[2] ITU-T Recommendation K.40 (1996), *Protection against LEMP in telecommunications centres*.

[3] ITU-T Recommendation K.27 (1996), *Bonding configurations and earthing inside a telecommunication building*.

[4] ITU-T Recommendation K.35 (1996), *Bonding configurations and earthing at remote electronic sites*.

[5] IEC 61024-1-1:1993, *Protection of structures against lightning – Part 1: General principles – Section 1: Guide A: Selection of protection levels for lightning protection systems*.

[6] IEC 61024-1-2:1998, *Protection of structures against lightning – Part 1-2: General principles – Guide B – Design, installation, maintenance and inspection of lightning protection systems*.

[7] IEC 61643-1:2002, *Surge protective devices connected to low voltage power distribution systems – Part 1: Performance requirements and testing methods*.

[8] IEC 61643-12:2002, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles*.

[9] IEC 61662:1995, *Assessment of the risk of damage due to lightning*.

[10] ETSI EG 200 053 (2002), *Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio site engineering for radio equipment and systems*.

3 Definitions

The definitions contained in the references apply to this Recommendation. Additional definitions needed for the protection of radio base stations (RBS) are in this clause.

3.1 radio base station (RBS): Installation intended to provide access to the telecommunication system by means of radio waves.

3.2 frequency of strikes (F): Number of times per year that lightning strikes a RBS.

3.3 tolerable frequency of damage (F_t): Maximum number of times per year that lightning strikes are allowed to damage a RBS.

3.4 ground flash density (N_g): Probable annual number of lightning flashes per square kilometre.

3.5 critical lightning current (I_c): Minimum peak value of lightning current that the RBS has to withstand in order not to exceed its tolerable frequency of damage (F_t). This parameter is associated to the return stroke of a lightning flash.

3.6 critical lightning current rate of rise ($\mathrm{d}i_c/\mathrm{d}t$): Minimum value of lightning current rate of rise that the RBS has to withstand in order not to exceed its tolerable frequency of damage (F_t). This parameter is associated to a subsequent stroke of a lightning flash.

3.7 tower factor (α): Factor that represents the fraction of the lightning current that flows through the bundle formed by the telecommunication conductors along the RBS tower.

3.8 shielding factor (η): Factor that represents the attenuation in the induced voltage in the telecommunication loops inside the RBS due to the shielding action of the CBN conductors.

3.9 induced voltage (V_i): Peak value of the induced voltage in the telecommunication loops inside the RBS due to the flow of the critical lightning current through the tower.

3.10 transfer factor (β): Factor that represents the fraction of the induced voltage in the telecommunication loops inside the RBS that is transferred to the inside unshielded cables.

3.11 geometric mean radius (r'): The geometric mean radius of a conductor(s) is the radius of an imaginary tubular conductor of infinitesimal wall thickness without internal magnetic flux that has the same external flux linkage as the total (internal + external) flux linkage of the original conductor(s).

4 Abbreviations

LPZ Lightning Protective Zone

RBS Radio Base Station

5 Reference configuration

Figure 1 shows the reference configuration considered in this Recommendation. In this figure can be seen the three lightning protective zones (LPZ) as described in ITU-T Rec. K.40:

– LPZ0: made by the tower, antennas, outside cables and the earthing system;

– LPZ1: made by the housing of the RBS, inside cables, cable trays, batteries, etc.;

– LPZ2: made by the equipment cabinet and its contents.

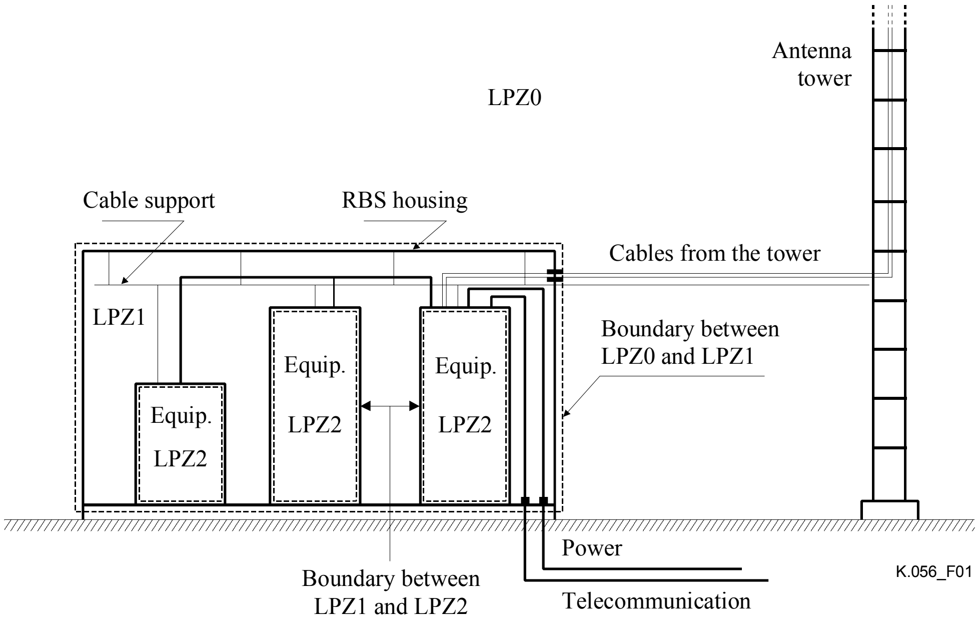

Figure 1/K.56 – Reference configuration for a RBS

6 Need of protection

In order to estimate the need of protection of a RBS against lightning, the user shall determine the tolerable frequency of damage (F_t) and to calculate the frequency of lightning strikes to the antenna tower of the RBS (F_a) and the housing (F_d). If $F_a + F_d$ is smaller than F_t, then the direct lightning discharge is not a phenomena of prime importance for the RBS and it can be treated as an ordinary remote electronic site, which is under the scope of ITU-T Rec. K.35. However, if $F_a + F_d$ is greater than F_t, then the RBS will need protection against direct lightning discharges. The implementation of such protection accordingly with this Recommendation, will also provide protection against the lightning discharges near the RBS, either if they hit the earth or if they hit the incoming services.

The second step is to compare F_a with F_d. If F_d is not negligible when compared with F_a, then the installation does not fall into the scope of this Recommendation. In this case, the user shall refer to IEC 61662 in order to protect the electrical and electronic systems within the RBS housing.

If F_d is negligible when compared with F_a, then the user shall follow the steps of this Recommendation to identify the lightning current parameters from which the RBS have to be protected. The protection procedures are divided into four steps:

– Protection against the voltages developed inside coaxial cables that come from the tower.
– Protection against the voltages and currents induced inside the RBS housing due to the flow of lightning current through the tower and the associated conductors (coaxial cable, metallic supports, etc.).
– Protection against the voltages and currents induced in the income power conductors due to the earth potential rise of the RBS.
– Protection against the voltages and currents induced in the income telecommunication conductors (if any) due to the earth potential rise of the RBS.

The flow diagram shown in Figure 2 describes the steps contained in this Recommendation. For each step, it makes reference to the relevant clause of this Recommendation. The work flow is defined by the bold arrows, while the references are indicated by normal lines.

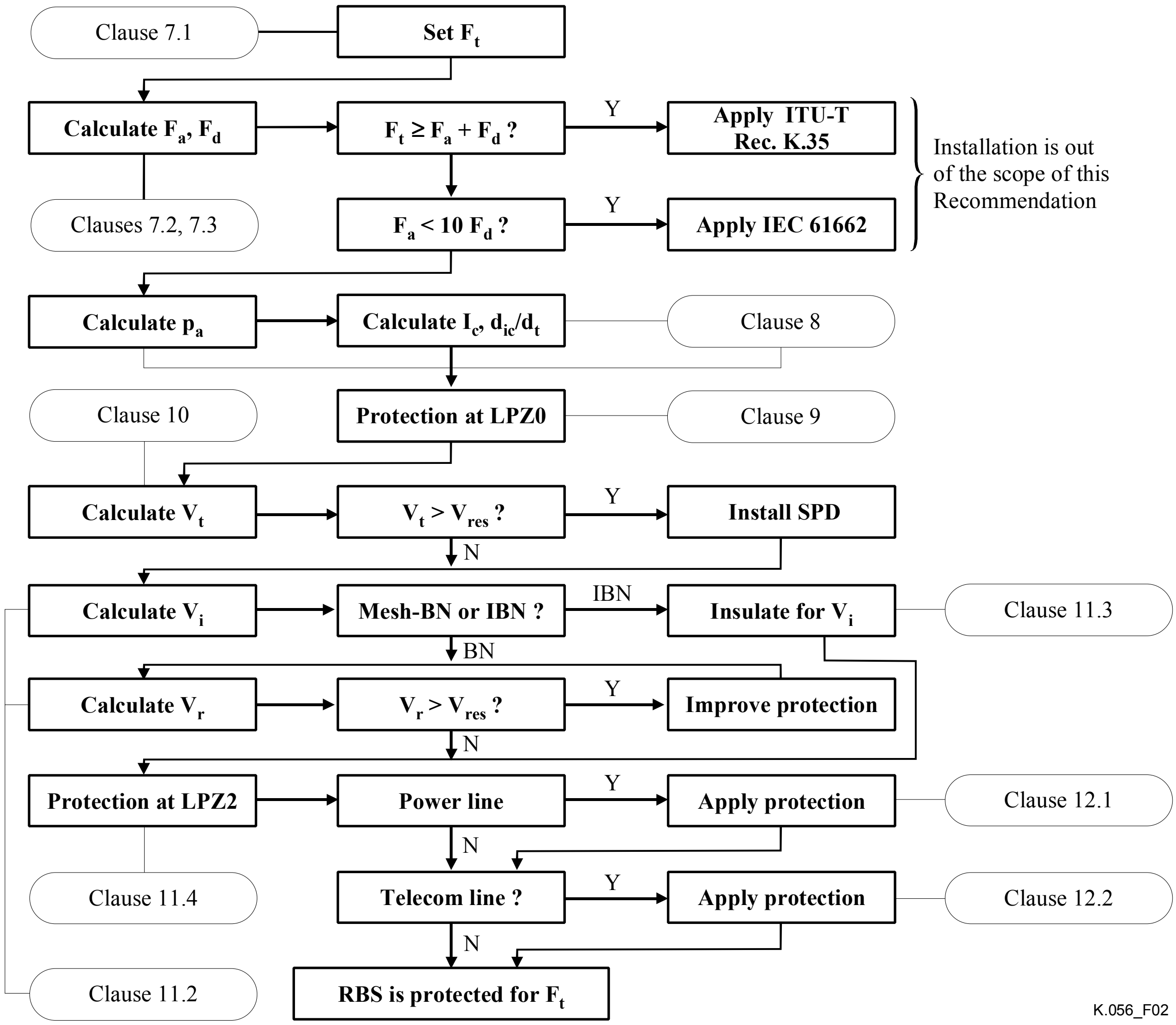

Figure 2/K.56 – Flow diagram for protecting a RBS against lightning

7 Probabilistic analysis

7.1 Tolerable frequency of damage (F_t)

The purpose of the protective measures described in this Recommendation is to reduce the economic losses due to damages to a level tolerable by the telecommunication operator. The protection procedures regarding the safety of people are determined by the relevant safety authority and is out of the scope of this Recommendation.

Considering the probabilistic nature of lightning, the operator has to tolerate a level of economic losses due to lightning in order to achieve a protection design based on a technical and economic compromise.

The tolerable frequency of damage (F_t) is given by:

$$F_t = L_t / L_d$$

where:

L_t = tolerable economic loss per year due to lightning strikes in a given RBS;

L_d = probable economic loss due to a damage caused by lightning in a given RBS.

The value of L_d can be computed by the operator considering the following sources of economic loss, among others:

- the loss of revenue due to service interruption;
- the fines that may be imposed by a company that contracted the interrupted service or by the Telecommunication Authority;
- the degradation of the company's image with the public;
- the cost of replacing the damaged equipment.

Therefore, the economic losses caused by one damage event depend on the characteristics of the RBS, such as traffic, contract fines, type of equipment, accessibility to maintenance staff, etc.

The value of L_t is defined by the operator, based on its business plan, and should take into account the cost of implementing the protection procedures. Typical values of F_t for RBS will be in the range from 0.10 to 0.01.

7.2 Frequency of strikes to the tower (F_a)

The frequency of strikes to the tower is given by:

$$F_a = 9\, c\, \pi\, H_t^2\, N_g \ \ [\text{damages} \times \text{year}^{-1}] \qquad (1)$$

where:

N_g = ground flash density (flashes × km^{-2} × year^{-1})

H_t = tower height (km)

c = exposition factor (c = 1 for flat ground and c = 2 for mountain top)

7.3 Frequency of strikes to the RBS housing (F_d)

If the RBS housing is inside a circular area around the tower defined by the radius 3 ($H_t - H_h$), where H_h is the housing height, then:

$$F_d = 0$$

Otherwise, the frequency of strikes is given by:

$$F_d = \left(a\, b + 6\, H_h\, a + 6\, H_h\, b + 9\, \pi\, H_h^2\right) N_g \left[\text{strikes} \times \text{year}^{-1}\right] \qquad (2)$$

where:

a = housing length (km)

b = housing width (km)

H_h = housing height (km)

7.4 Analysis of the frequency of strikes

Based on the values of F_t, F_a and F_d obtained previously, the following analysis shall be done:

- If $F_t \geq F_a + F_d$

then the direct lightning discharge is not a phenomena of prime importance for the RBS and it can be treated as an ordinary remote electronic site, which is under the scope of ITU-T Rec. K.35.

- If $F_t < F_a + F_d$ and $F_a < 10\, F_d$

then the installation does not fall into the scope of this Recommendation. In this case the user shall refer to IEC 62305-4 in order to protect the electrical and electronic systems within the RBS housing.

- If $F_t < F_a + F_d$ and $F_a \geq 10\, F_d$

then the user shall follow the steps of this Recommendation to identify the lightning current parameters for which the RBS have to be protected.

8 Determination of the lightning current parameters

The number of direct strikes to the tower is determined by the ground flash density of the region and tower height. Considering that the reduction in the tower height is not possible due to transmission constraints, the tolerable frequency of damage can be obtained by raising the RBS resistibility up to a given current level. Therefore, the direct strikes with currents below this critical level will cause no damage to the RBS. This critical lightning peak current is designated as I_c and given by:

$$I_c = (a - \ln(100\, p_a))/b \qquad [\text{kA}] \tag{3}$$

where:

p_a	$= F_t / F_a$					
a	$= 4.605$	and	$b = 0.0117$	for	$p_a > 0.79$
a	$= 5.063$	and	$b = 0.0346$	for	$p_a \le 0.79$

The critical lightning current rate of rise ($\mathrm{d}i_c/\mathrm{d}t$) is given by the following equation:

$$\frac{\mathrm{d}i_c}{\mathrm{d}t} = \frac{I_c}{t_{eff}} [\text{kA}/\mu\text{s}]$$

where:

t_{eff} = 1 µs is the effective front time described in Appendix I

The following clauses describe the protection procedures intended to protect the RBS up to the critical current considered.

NOTE – The lightning current peak value corresponds to the first stroke, while the di/dt corresponds to a subsequent stroke. The relation between these two parameters is in line with IEC 61662. For example, a lightning discharge with 100 kA peak current corresponds to a di/dt equal to 100 kA/µs. In this Recommendation, some protection procedures are determined by the current, while others are determined by the current rate of rise (di/dt).

9 Protection procedures in LPZ0

9.1 Procedures applied to the tower

The need of lightning rods in order to protect the antennas from a direct strike shall be assessed by the methods described in IEC 61024-1-1 [5]. For a metallic tower, there is no need to install down conductors in order to conduct the lightning current to earth, as the tower structure itself will do this job. For a non-metallic tower, the installation of down conductors is necessary. The down conductor specification and installation shall comply with IEC 61024-1-2 [6].

The wave guide and the external conductor of coaxial cables shall be bonded to the metallic tower through the antenna hardware. For non-metallic towers, the bonding shall be made to the lightning down conductor(s).

9.2 Earthing system

The earthing system for the RBS shall be in line with ITU-T Rec. K.35 [4] with some additional requirements. The description of the earthing system is given in this clause and its diagram is shown in Figure 3.

– The RBS shall have a buried exterior bare conductor forming a ring around the housing and the tower. One ring electrode shall encircle the housing and another ring shall encircle the tower.
– The distance from the buried conductor and the associated structure shall be approximately 0.65 m, where practical. The depth of the conductor shall be approximately 0.75 m.
– The two rings shall be interconnected by at least 3 spaced conductors (see Figure 3).
– The legs of a metallic tower or the down conductors of a non-metallic tower shall be bonded through short connections to its earth ring and to the metallic structure of its basement.
– If the housing has a foundation steel and/or steel reinforcement at the floor, they shall be bonded to the earth ring at least at the 4 corners. If the housing is metallic, its feet shall be bonded to the earth ring (see Figure 3).
– One earth conductor shall connect the earth ring of the housing with the Main Earthing Terminal (MET) located inside the housing, at the bottom of the wall that faces the tower. This conductor shall be as short as possible and have 50 mm^2 as minimum cross section area.
– All conductors in contact with the earth shall be preferable made of copper and have 50 mm^2 as minimum cross section area.
– National safety rules and/or the control of earth voltage gradient and/or the limitation of current injected into metallic services connected to the RBS may require additional earth electrodes. These additional electrodes shall preferably be vertical rods along the rings and/or horizontal radial conductors from the tower.

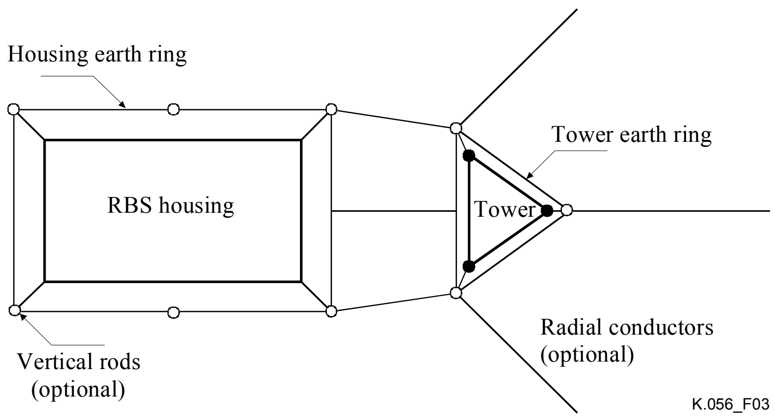

Figure 3/K.56 – Earth configuration for the RBS

10 Protection procedures for the cables that come from the tower

All cables that enter the RBS from the tower shall enter through the same window and shall be bonded to a bonding bar installed at this point. The wave guides and the outer conductor of coaxial cables shall be directly bonded to the bonding bar by means of short connections. The unshielded cables (for example, power cables for lighting the tower) shall be bonded through SPD. The bonding bar shall be bonded to the earthing system by means of vertical conductors (a minimum of three spaced conductors is recommended). If the RBS housing is made of metal, additional bonding shall be made between the bonding bar and the housing wall. The earth conductors and metallic cable supports inside the RBS housing shall be bonded to the bonding bar.

The need for installation of SPD between the inner and outer conductors of coaxial cables that come from the tower can be determined by the following steps:

– Determine the fraction of the lightning current that flows through the bundle of cables along the tower. This parameter is represented by the tower factor "α" that is determined by the procedures described in Annex A.
– Distribute the resultant current by the "n" conductors that make part of the bundle. For this calculation, it is considered that the current share of a given coaxial cable is proportional to its geometric mean radius (GMR). All conductors in the bundle, such as wave guides, coaxial cables, power cables, down conductors and bars of cable racks (if continuous along the tower) should be taken into consideration.
– Calculate the peak transverse voltage (V_t) in the coaxial cables by multiplying the peak current by the cable length and its transfer impedance per unit length. For tubular cables and the frequency range of lightning currents, the transfer impedance can be conservatively considered as equal to the DC resistance.
– Compare the transverse voltage obtained with the resistibility of the equipment interface connected to the cable. If the transverse voltage is greater than the resistibility, then SPD is necessary. Equation 4 summarizes the calculation of V_t.

$$V_t = I_c \, \alpha \, L \, z_t \, r_x / r_{all} \quad \text{[kV]} \tag{4}$$

where:

I_c: critical current [kA];

z_t: transfer impedance per unit length [Ω/m];

α: tower factor from Annex A [dimensionless];

L: length of the coaxial cable [m];

r_c: GMR of the coaxial cable [mm];

r_{all}: sum of GMR of all conductors in the bundle [mm].

NOTE – The criteria used for the assessment of a coaxial cable's current share is an approximation that will lead to conservative results when the cable is placed in the central region of the bundle.

11 Protection against the lightning effects inside the housing

In order to attenuate the inductive effects of the lightning current inside the RBS housing, the protection procedures can be based on Mesh-BN or Mesh-IBN configurations. The characteristics of these configurations are described in ITU-T Rec. K.27. In both configurations, the electromagnetic field inside the housing can be attenuated by the shield effect of metallic elements present at or near the housing walls. For the purposes of this Recommendation, these metallic elements constitute the boundary between LPZ0 and LPZ1.

11.1 Shielding factor (η)

The induced voltage inside the RBS housing is attenuated by the shielding action of metallic conductors coupled with the RBS cabling. This attenuation can be represented by the shielding factor "η". Some shielding factors for different shields are summarized in the following.

– Non-screening: η = 1 (from ITU-T Rec. K.39)

This applies to walls made of non-conductive materials, as wood, bricks and concrete without steel reinforcement.

– Metallic container: $\eta = 0.01$ (from ITU-T Rec. K.39)

The metallic container shall have its metallic sheaths connected together in several points along the joints, forming a closed metallic cage (floor, ceiling and walls).

– Metallic grid: $\eta = w / 8.5$ (from IEC 61662)

where w is the grid width in metres. The metallic grid shall form a cage around the housing.

– Earth conductors around the housing: see Annex B for η

The installation of earth conductors around the housing forming closed loops coupled with the internal cabling, provides a shield effect to the RBS. Annex B gives some values of shielding factors for different arrangements of earth conductors.

11.2 Mesh-BN configuration

The general characteristics of a Mesh-BN configuration are described in the ITU-T Rec. K.27 [3]. Due to practical considerations, the Mesh-BN is usually the preferable configuration for a RBS housing. Its application inside a RBS housing (LPZ1) requires the following procedures:

– All conductors such as equipment frames, racks, trays and cabinets shall be bonded together as well as at multiple points to the CBN.

– The CBN is composed of metallic conductors of the housing wall (structural steel or metallic wall), metallic conduits, PE conductors, air conditioning metallic hardware, etc. The CBN shall be bonded to the earth network at multiple points.

Figure 4 shows schematically the cabling of a RBS with Mesh-BN configuration. The voltage V_i induced in the largest loop inside the RBS housing is given by the following approximated equation:

$$V_i = 0.2 \frac{\mathrm{d}i_c}{\mathrm{d}t} h\, k\, \eta \ln \frac{f+e}{f} \qquad \text{[kV]} \tag{5}$$

where:

h, f, e: physical dimensions (in meters) as shown in Figure 4;

$\mathrm{d}i_c/\mathrm{d}t$: critical current rate of rise [kA/µs];

η: shielding factor (see 11.1);

k: factor to take into account the metallic connection between the tower and the RBS housing; for typical RBS this factor can be conservatively considered as $k = 1.5$.

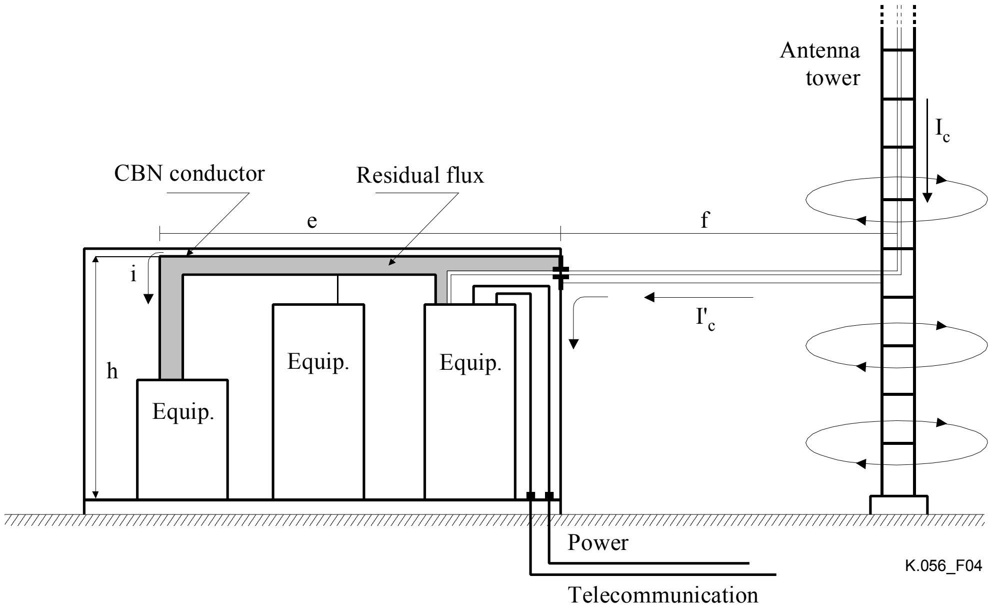

Figure 4/K.56 – RBS with Mesh-BN configuration

The induced voltage V_i will give rise to induced currents inside the RBS. The flow of these currents tend to cancel the magnetic flux at the closed loops inside the Mesh-BN. However, a residual flux will remain in open circuited loops made by signal and power cables, leading to a residual induced voltage, which is given by Equation 6:

$$V_r = \beta V_i \tag{6}$$

where:

V_r: residual induced voltage [kV];

V_i: induced voltage [kV] given by Equation 5 [kV];

β: transfer factor given in Annex C.

The residual voltage is applied between the unshielded signal or power conductors and the equipment frame. This voltage shall be compared with the equipment resistibility. If it is greater than the resistibility level, then the transfer factor (β) shall be reduced by means of shielding conductors (see Annex C) or SPD shall be installed at the equipment port (LPZ1/LPZ2 interface).

For shielded cables, the residual voltage is given by the product of the shield transfer impedance by the fraction of the induced current that flows through it. Considering the short length of cables inside a RBS, the induced voltages in a shielded conductor is usually negligible.

Therefore, combining Equation 5 with Equation 6 and replacing the residual voltage by the equipment resistibility (V_{res}) leads to the Equation 7 that states the condition for equipment protection inside a RBS housing using Mesh-BN configuration:

$$V_{res} \geq 0.2\, \beta\, \frac{\mathrm{d}i_c}{\mathrm{d}t}\, h\, k\, \eta \ln \frac{f+e}{f} \tag{7}$$

In order to comply with the Equation 7, one or more of the following procedures can be tried:

– Re-arrange the equipment inside the RBS in order to reduce the loop exposition by reducing the length "e" or the height "h" (see Figure 4).

– Improve the shielding factor of the RBS (see 11.1) in order to reduce η.

– Improve the coupling between the earth conductors and the cables (see Annex C) in order to reduce the transfer factor β.

– Increase the equipment resistibility (V_{res}) by adding SPDs at its ports.

11.3 Mesh-IBN configuration

The general characteristics of a Mesh-IBN configuration are described in ITU-T Rec K.27 [3]. Its application inside a RBS housing (LPZ1) requires the following procedures:

– All conductors shall enter the RBS housing through a single point connection window (SPCW). The SPCW shall be as small as possible. Preferably, all conductors (including cables from the tower, a.c. power and outside plant telecommunication cables) shall enter the RBS at the same window and be bonded to the same bonding bar.

– The equipment and cabling inside the RBS shall be insulated from the floor and the walls. This insulation shall be able to withstand the induced voltage V_i as given by Equation 5.

The Figure 5 shows schematically the cabling of a RBS with Mesh-IBN configuration.

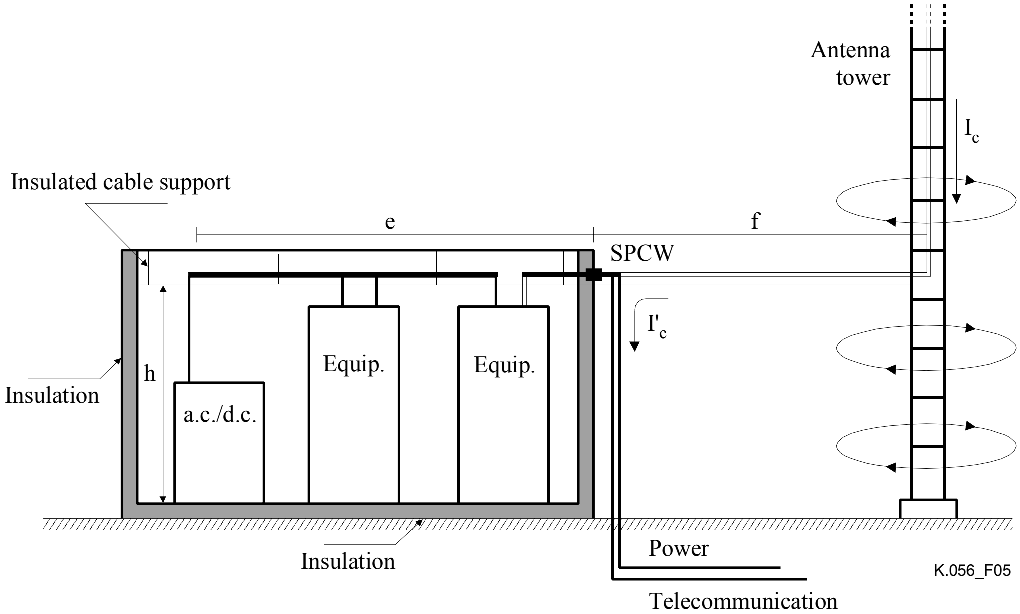

Figure 5/K.56 – RBS with Mesh-IBN configuration

11.4 Protection procedures at the boundary between LPZ1 and LPZ2

The boundary between LPZ1 and LPZ2 is the equipment cabinets and racks (see Figure 1). The following procedures are recommended:

– Shielded cables shall have their shield bonded to the equipment cabinets at both sides.

– Earth conductors (PE) shall be bonded to the equipment metallic racks.

– Metallic support of the cables (trays) shall be bonded to the equipment metallic racks at least in two spaced points.

– If necessary for Mesh-BN configuration, SPD shall be installed between the unshielded conductors and the equipment frame (see 11.2).

12 Protection against the lightning effects at the services entrances

Typical RBS have metallic connections with power and, sometimes, telecommunication services. The protection procedures applied to the services at the interface between LPZ0 and LPZ1 are given in this clause.

12.1 Power service

In order to protect the power interface against lightning strikes in the RBS tower, it is necessary to install SPDs at the point where the power conductors enter the RBS housing. These SPDs will also protect the RBS against lightning-induced surges conducted by the power conductors to the RBS. The SPDs shall comply with IEC 61643-1 and IEC 61643-12.

In order to reduce the residual voltage at the power entrance, the power conductor shall enter the RBS housing near the Main Earth Terminal (MET). The connections between the power conductors, the SPDs and the MET shall be made as short as possible and with conductors of reasonable cross section. Preferably, one individual conductor should be used for each connection to the MET (see Figure 6). If the power cable is shielded, its shield shall be bonded to the MET. In order to assure that the resistibility of the equipment's power input will not be exceeded by the residual voltage, the installation parameters shall be adjusted in order to comply with Equation 8 (see Figure 6):

$$V_{res} \geq 0.2 \frac{\mathrm{d}i_c}{\mathrm{d}t} L_p \left[\frac{R_g}{R_g + Z_p} \right] \ln \left[\frac{b + r_p}{r_p} \right] - V_{spd} \qquad (8)$$

where:

- V_{res}: resistibility of the power input port of the equipment [kV];
- L_p: length of the connection between the power conductors and the MET [m];
- r_p: geometric mean radius of the connection between the power conductors and the MET (directly or through SPDs) [m];
- b: distance between the SPDs and the equipment to be protected [m];
- V_{spd}: residual voltage of the SPD [kV];
- R_g: earth resistance of the RBS [Ω];
- Z_p: surge impedance of the power line [Ω].

The surge impedance of the power line is given by Equation 9:

$$Z_p = 60 \ln \left\{ \left[a + 648 \left(\rho / f_L \right)^{1/2} \right] / r_L \right\} \qquad [\Omega] \qquad (9)$$

where:

- ρ: earth resistivity [Ω.m];
- f_L: representative frequency of the a subsequent lightning strike [Hz];
- r_L: geometric mean radius of the power line [m];
- a: distance from power line to nearby earth [m].

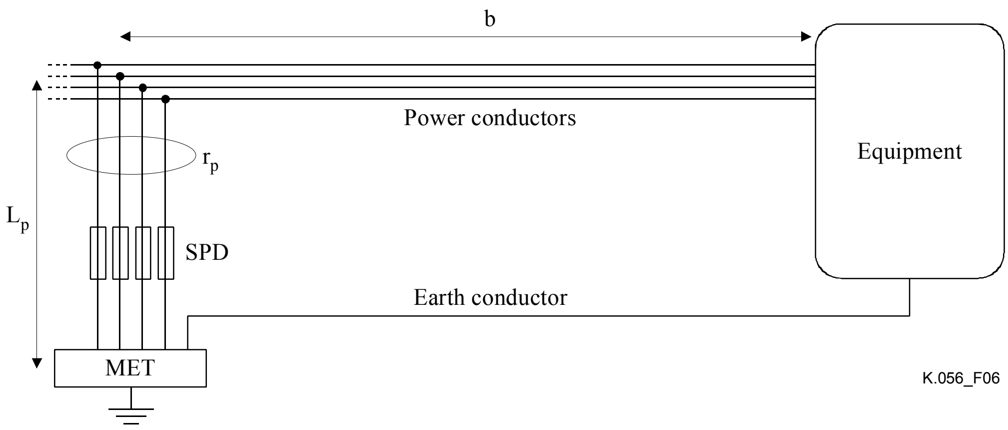

Figure 6/K.56 – Assessment of the maximum length between power conductors and MET

The SPD shall withstand an impulse peak current that complies with Equation 10:

$$I_{imp} \geq \frac{I_c}{2\,\mathrm{n} \times \mathrm{m}} \;[\mathrm{kA}] \tag{10}$$

where:

I_c: peak critical current (see clause 8) [kA];

n: number of metallic services connected to the RBS;

m: number of conductors in the power line.

12.2 Telecommunication service

For the protection of the telecommunication interfaces (connected to metallic lines) against lightning strikes in the RBS tower it is necessary to install SPDs at the point where the telecommunication conductors enter the RBS housing. These SPDs will also protect the RBS against lightning-induced surges conducted by the metallic telecommunication line to the RBS. The SPDs shall comply with ITU-T Rec. K.12.

In order to reduce the residual voltage at the telecommunication entrance, the telecommunication cable shall enter the RBS housing near the Main Earth Terminal (MET). The connections between the telecommunication conductors, the SPDs and the MET shall be made as short as possible, and with conductors of reasonable cross section. Preferably, more than one conductor should be used for the connection to the MET. If the telecommunication cable is shielded, its shield shall be bonded to the MET. In order to assure that the resistibility of the equipment's telecommunication input will not be exceeded by the residual voltage, the installation parameters shall be adjusted in order to comply with Equation 8, where the power data should be replaced by the corresponding telecommunication data.

The procedures for the protection of telecommunication lines against direct and indirect lightning discharges can be found in ITU-T Recs K.47 and K.46, respectively.

Annex A

Factor for current distribution along a tower (α)

During transient conditions created by a lightning strike, the current distribution among the conductors of the tower is determined by the magnetic flux linkage between the conductors. The tower factor "α" is defined as the fraction of the total lightning current that flows through the bundle formed by the telecommunication and associated conductors. Typical situations are considered in this annex. The assessment of the geometric mean radius for the conductors can be done with the procedure described in Annex D.

A.1 Tubular tower

If the telecom cables are placed inside the tower, the total lightning current flows through the tower, so that $\alpha = 0$. If the telecom cables are placed outside the tower, the distribution of current is determined by the following equation:

$$\alpha = \ln\left(s / r_t\right) \,/\, \ln\left(s^2 / r_t\, r_c\right)$$

where:

s: space between the axis of the tower and the axis of the bundle of conductors;

r_t: geometric mean radius of the tower;

r_c: geometric mean radius of the bundle of conductors.

Figure A.1 illustrates the dimensions considered.

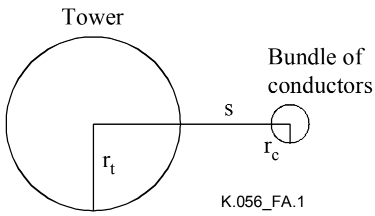

Figure A.1/K.56 – Distances for tubular tower

A.2 Three legs tower

For a three legs tower, the following typical situations can be found (see Figure A.2):

a) Cable at an arbitrary distance "s" from one leg (see Figure A.2)

$\alpha = \{1 + 3 \ln (s / r_c) / \ln [s\,(3d^2 + s^2 - 3\, d\, s) / (3\, r_t\, d^2)\,]\,\}^{-1}$

b) Cable in the centre of the tower ($s = d$)

$\alpha = [1 + 3 \ln (d / r_c) / \ln (d /3\, r_t\,)\,]^{-1}$

c) Cable in one lateral ($s = 3d/2$)

$\alpha = [1 + 3 \ln (3d / 2\, r_c) / \ln (3d / 8\, r_t)\,]^{-1}$

d) Cable near one leg ($s << d$)

$\alpha = [1 + 3 \ln (s / r_c) / \ln (s / r_t)\,]^{-1}$

The distance "d" is the distance from the leg to the axis of the tower.

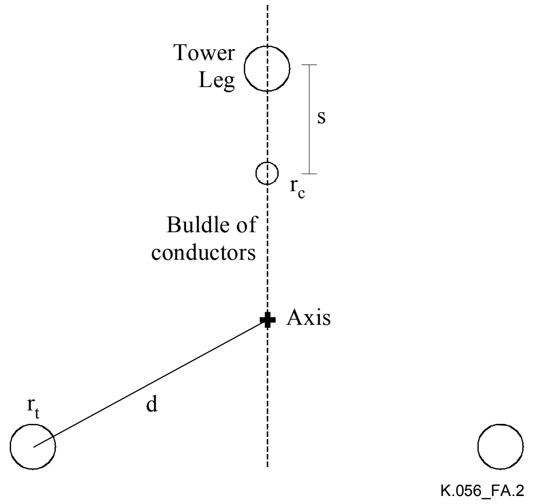

Figure A.2/K.56 – Distances for three legs tower

A.3 Four legs tower

For a four legs tower, the following typical situations can be found (see Figure A.3):

a) Cable at an arbitrary distance "s" from one leg (see Figure A.3)

$\alpha = \{1 + 4 \ln (s / r_c) / \ln [s (2d - s) / (2 r_t d)]\}^{-1}$

b) Cable in the centre of the tower ($s = d$)

$\alpha = [1 + 4 \ln (d / r_c) / \ln (d / 2 r_t)]^{-1}$

c) Cable near one leg ($s << d$)

$\alpha = [1 + 4 \ln (s / r_c) / \ln (s / r_t)]^{-1}$

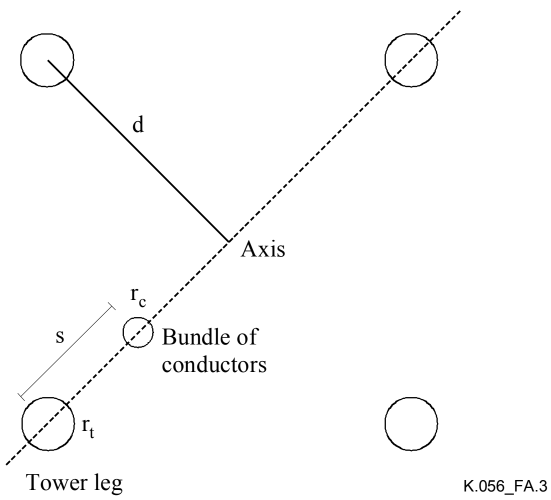

Figure A.3/K.56 – Distances for four legs tower

Annex B

Shielding factor (η) for CBN loops

The shielding factors (η) provided by the conductors of the CBN that form closed loops, coupled with the telecommunication conductors, are given in Table B.1: for typical conductor arrangements, see Figure B.1. The shielded loop is formed by the telecommunication cables, equipment racks and part of the CBN circuit (for example, the earthing system).

Table B.1/K.56 – Shielding factors for different CBN configurations

Configuration	Illustration	Shielding factor (η)		
		x = 0.15 m	x = 0.4 m	x = 0.8 m
Single loop	Figure B.1a	0.37	0.48	0.59
Cage	Figure B.1b	0.45	0.45	0.45
Cage with 1 sup. conductor	Figure B.1c	0.21	0.27	0.33
Cage with 3 sup. conductors	Figure B.1d	0.16	0.19	0.23
NOTE – These values have been obtained from a scale model representing a typical RBS.				

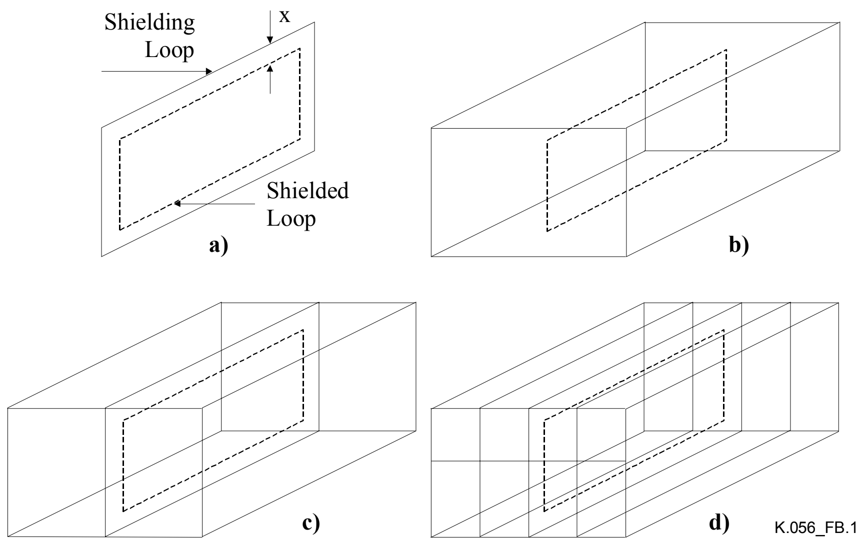

Figure B.1/K.56 – Typical shielding configuration for RBS

Annex C

Transfer factor (β) for cable trays and earth conductors

C.1 Single earth conductor

The transfer function provided by a single earth conductor is given by the following approximated equation:

$$\beta = \ln\left[s / r_e \right] / \ln\left[2\,h / r_e \right]$$

where:

s: spacing between the earth conductor and the telecom conductor (m);

r_e: radius of the earth conductor (m);

h: height of the earth conductor (m);

NOTE – Equation valid for $h >> s$.

Figure C.1 shows the conductors diagram and Table C.1 gives values of β for typical values of the parameters.

Table C.1/K.56 – Transfer function for single earth conductor (h = 2 m)

Spacing (s) in mm	Radius of earth conductor (r_e) in mm			
	1	2	3	4
10	0.28	0.21	0.17	0.13
25	0.39	0.33	0.29	0.27
50	0.47	0.42	0.39	0.37
100	0.56	0.51	0.49	0.47
200	0.64	0.61	0.58	0.57
500	0.75	0.73	0.71	0.70

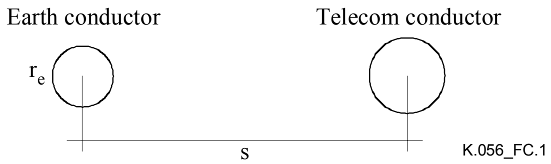

Figure C.1/K.56 – Circuit diagram for a single earth conductor

C.2 Double earth conductors

The transfer function provided by double earth conductors is given by the following approximated equation:

$$\beta = 0.5\ \ln\left[s(d-s) / d\,r_e \right] / \ln\left[\ 2\,h / (d\,r_e)^{1/2} \ \right]$$

where:

s: spacing between the earth conductor and the telecom conductor (m);

r_e: radius of the earth conductor (m);

h: height of the earth conductor (m);

d: distance between earth conductors (m).

NOTE – Equation valid for $h >> s$.

Figure C.2 shows the conductors diagram and Table C.2 gives values of β for typical values of the parameters.

Table C.2/K.56 – Transfer function for double earth conductors (h = 2 m and d = 0.4 m)

Spacing (s) in mm	**Radius of earth conductor (r_e) in mm**			
	1	**2**	**3**	**4**
10	0.21	0.16	0.12	0.10
25	0.30	0.25	0.22	0.19
50	0.36	0.31	0.28	0.26
100	0.41	0.37	0.34	0.32
200	0.43	0.40	0.37	0.35

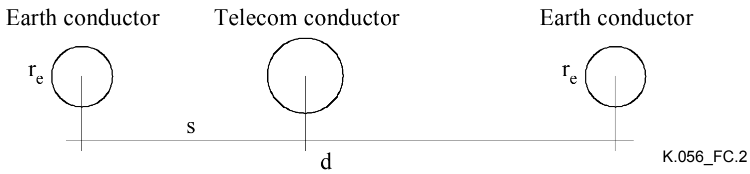

Figure C.2/K.56 – Circuit diagram for double earth conductors

C.3 Earth plate tray

The transfer function provided by a conductive plate tray is given by the following approximated equation:

$$\beta = (2\, s / a) \operatorname{arctg} (a / s) / \ln (2\, h\, \pi / a)$$

where:

s: spacing between the tray and the telecom conductor (m);

a: width of the earth tray (m);

h: height of the earth tray (m).

NOTE – Equation valid for $a >> s$, $h >> a$ and the distance from the telecom conductor to the border of the tray greater than s.

The Figure C.3 shows the conductors diagram and Table C.3 gives values of β for typical values of the parameters.

Table C.3/K.56 – Transfer function for earth plate tray (h = 2 m)

Spacing (s) in mm	Width of earth plate tray (a) in m			
	0.1	**0.2**	**0.3**	**0.4**
5	0.031	0.019	0.014	0.011
10	0.061	0.037	0.027	0.022
25	0.14	0.087	0.066	0.055
50	0.23	0.16	0.13	0.10
100	0.32	0.27	0.22	0.19

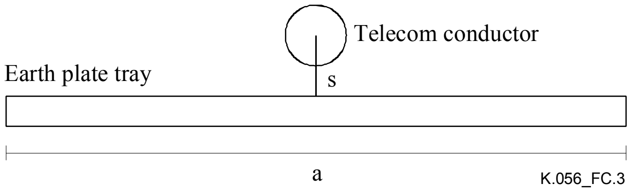

Figure C.3/K.56 – Circuit diagram for earth plate tray

Annex D

Geometric mean radius

Table D.1 gives the geometric mean radius for typical conductors arrangements.

Table D.1/K.56 – Geometric mean radius of conductors

Conductor (s)	Illustration	Geometric mean radius
Solid circular conductor	Figure D.1a	r
Solid rectangular conductor	Figure D.1b	0.318 (a + b)
Seven strand conductor	Figure D.1c	r
Two parallel conductors	Figure D.1d	$(d^2 r_1' r_2')^{1/4}$
Three parallel conductors	Figure D.1e	$(d_{12}^2 d_{13}^2 d_{23}^2 r_1' r_2' r_3')^{1/9}$
n parallel conductors	–	$(d_{12}^2 d_{13}^2 \ldots d_{1n}^2 d_{23}^2 \ldots d_{(n-1)n}^2 r_1' r_2' r_3' \ldots r_n')^{1/(n \cdot n)}$
NOTE – Considering the inductive effects of lightning current (high di/dt), the conductors internal magnetic flux has been neglected (perfect skin effect). For group of conductors, symmetric current density at the conductors periphery has been considered (proximity effect has been neglected).		

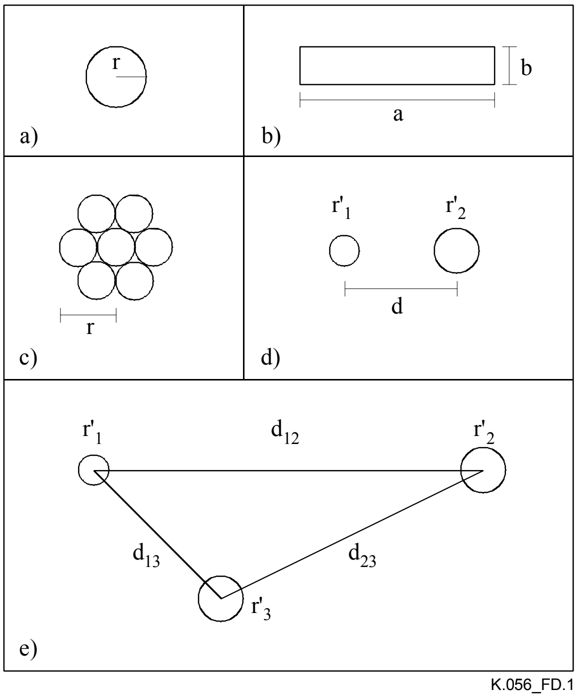

Figure D.1/K.56 – Geometric mean radius of typical conductors

Appendix I

Rationale for effective front time

The induced voltage close to a lightning discharge is proportional to the current rate of rise. The effective front time (t_{eff}) is an arbitrary value of time which divides the peak current and gives the maximum current rate of rise. Table I.1 gives the values of maximum rate of rise and peak current for the measurements conducted by Berger in Monte San Salvatore[1]. This data is relative to the first return stroke of downward negative discharges, which are the most probable discharges in RBS towers.

Table I.1/K.56 – Distribution of current rate of rise and peak value from Berger (*)

Parameter	Unit	Percentage exceeding the value in the table		
		95%	**50%**	**5%**
Maximum current rate of rise (di/dt)	kA/µs	9.1	24.3	65.0
First peak (I_1)	kA	12.9	27.7	59.5
Second peak (I_2)	kA	14.1	31.1	68.5
I_1 / (di/dt)	µs	1.42	1.14	0.92
I_2 / (di/dt)	µs	1.55	1.28	1.05

1 ANDERSON (R.B.), ERIKSSON (A.J.), Lightning parameters for engineering application, CIGRE Electra 69, 1980.

The ratio $I_l/(di/dt)$ is the effective front time (t_{eff}). It can be seen from Table I.1 that stating the value for t_{eff} = 1 µs allows a reasonable assessment of the current rate of rise from the peak value.

Appendix II

Example of application

Figure II.1 shows an example of a configuration of a RBS. The basic data is:

Antenna tower:

– 40 m high, 4 m from RBS housing (f = 4 m);
– three metallic legs, 2.6 m apart;
– each leg cylindrical with 0.4 m diameter.

Bundle of conductors at the centre of the tower (see Figure II.2):

– 3 coaxial cables from the mobile antennas (r = 12 mm, transfer impedance z_t = 1 Ω/km);
– 1 coaxial cable from the micro wave antenna (r = 8mm, transfer impedance z_t = 2 Ω/km);
– 2 bars for the cable support = 80 mm width, 5 mm thick.

RBS housing:	5 × 3 × 3 m, concrete (steel continuity unknown).
Cabling height:	2.4 m inside the RBS (h = 2.4 m).
Cabling length:	4 m inside the RBS (e = 4 m).
Power cable:	aerial LV line (6 m high).
Telecom cable:	none (upstream connection through microwave link).
Soil:	mountain top with average resistivity equal to 500 Ω.m.
Lightning density:	5 flashes to ground per km^2 per year (N_g = 5).

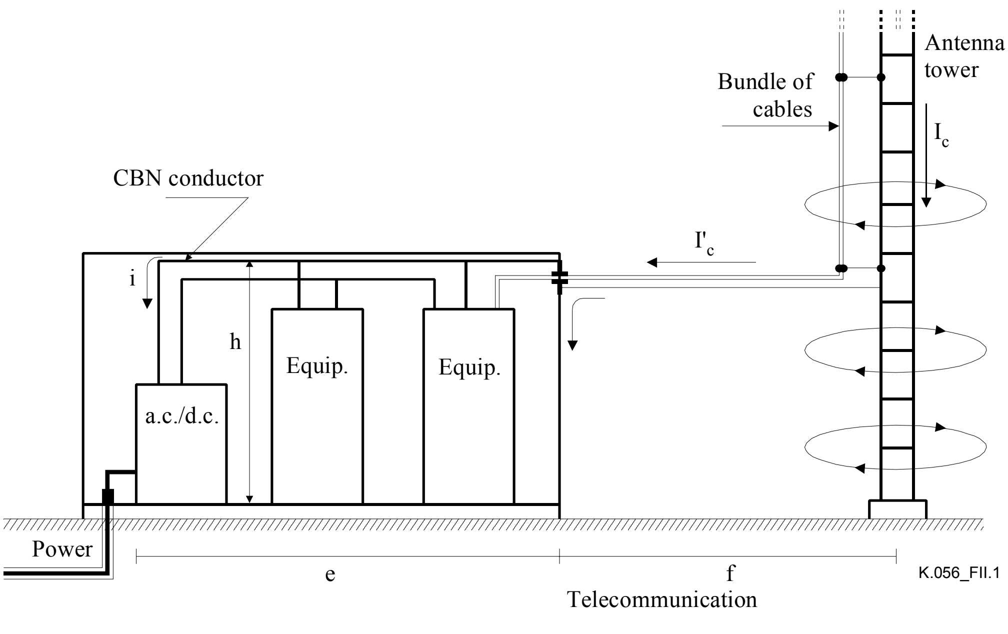

Figure II.1/K.56 – Example of RBS

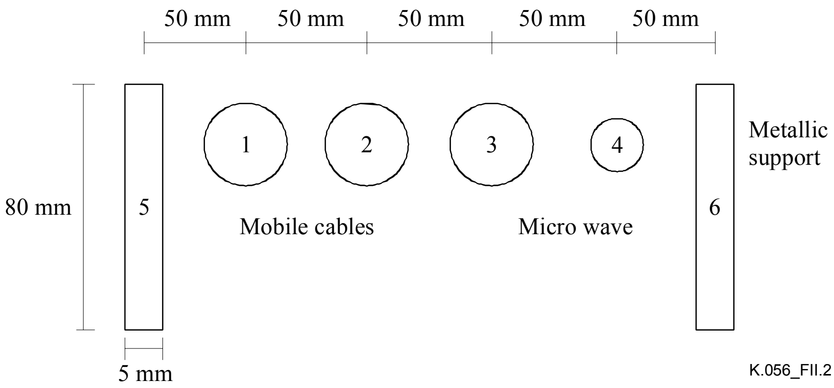

Figure II.2/K.56 – Bundle off conductors along the tower (cross section view)

To follow the steps, please refer to the flow diagram in Figure 2.

Step 1: Determination of the tolerable frequency of damage.

Considering a typical value suggested in 7.1:

$$F_t = 0.05$$

Step 2: Calculation of F_a and F_d.

Using Equation 1:

$$F_a = (9)\,(2)\,(\pi\,)\,(0.04)^2\,(5) = 0.45 \text{ strikes / year}$$

$$F_a = 0.45$$

Considering the procedure of 7.3, the area around the tower is defined by the radius:

$$R = (3)\,(40 - 3) = 111 \text{ m}$$

As the RBS housing is close to the tower (4 m < 111 m) the probability of a direct strike to the housing is negligible. Therefore:

$$F_d = 0$$

Step 3: Analysis of the probabilities.

$$F_t \geq F_a + F_d \quad ? \quad \text{No}$$

$$F_a < 10\,F_d \quad ? \quad \text{No}$$

NOTE – Answering "No" for the two questions above means that the installation falls within the scope of this Recommendation.

Step 4: Calculating the lightning parameters.

Based on Equations of clause 8:

$$p_a = R_t \,/\, R_a = 0.05 \,/\, 0.45 = 0.11$$

$$I_c = 77 \text{ kA}$$

$$\mathrm{d}i_c/\mathrm{d}t = 77 \text{ kA / µs}$$

Step 5: Earthing and bonding.

Clause 9 states some rules for the earthing and bonding outside the RBS housing.

Step 6: Need of SPD at the coaxial cables from the tower.

Based on clause 10 and Annex A:

$$d = (2.6) \,/\, (3)^{\,1/2} = 1.50 \text{ m (distance from the bundle and one leg)}$$

Geometric mean radius (GMR):

$$\text{Tower leg: } r_t = (0.4) / (2) = 0.2 \text{ m}$$

Bundle of conductors:

Considering the 6 conductors of Figure II.2, their GMR are:

Coaxial cables for mobile antenna: $r_1 = r_2 = r_3 = 12$ mm

Coaxial cable for micro wave link: $r_4 = 8$ mm

Bars of support: $r_5 = r_6 = 27$ mm

Distances between conductors:

$d_{12} = d_{23} = d_{34} = d_{15} = d_{46} = 50$ mm

$d_{25} = d_{24} = d_{13} = d_{36} = 100$ mm

$d_{14} = d_{35} = d_{26} = 150$ mm

$d_{45} = d_{16} = 200$ mm

$d_{56} = 250$ mm

Using the equation for "n" conductors in Table D.1:

$$r_c = [50^{10} \times 100^8 \times 150^6 \times 200^4 \times 250^2 \times 12^3 \times 27^2 \times 8]^{1/36}$$

$$r_c = 73 \text{ mm}$$

NOTE – The bundle has an equivalent flux linkage equivalent to a cylindrical conductor with 73 mm radius.

Considering that the bundle is at the centre of the tower:

$$\alpha = [1 + 3 \ln (1500 / 73) / \ln (1500 / 600)]^{-1} = 0.092$$

This means that 9.2% of the lightning current flows through the bundle.

Going back to clause 10:

Transverse voltage for coaxial cable of mobile antenna:

$$V_t = (77)\,(0.092)\,(40)\,(0.001)\,(12) / (36 + 8 + 54) = 0.035 \text{ kV}$$

Transverse voltage for coaxial cable of micro wave antenna:

$$V_t = (77)\,(0.092)\,(40)\,(0.002)\,(8) / (36 + 8 + 54) = 0.046 \text{ kV}$$

These values will probably be below the resistibility of the radio equipment considered and no SPD will be necessary.

Step 7: Induced voltage inside the housing (V_i).

The induced voltage can be calculated with Equation 5:

$$V_i = (0.2)\,(77)\,(2.4)\,(1.5)\,(1) \ln [(4 + 4) / 4] = 38.4 \text{ kV}$$

Step 8: Bonding configuration.

Considering the relatively high voltage induced inside the RBS and the difficulties for the establishment and maintenance of a Mesh-IBN system, it's made an option for the Mesh-BN configuration.

Step 9: Residual voltage at equipment interfaces.

Considering that the only shielding is provided by a single earth wire (4 mm diameter) placed at 100 mm from the telecommunication cables, Annex C gives $\beta = 0.51$. Going back to 11.2 gives:

$$V_r = (0.51)\,(38.4) = 19.6 \text{ kV}$$

This value is probably above the resistibility level of the equipment. Let us suppose that the resistibility level is 1 kV and that installation of SPD is not convenient (for example, because there are many unshielded conductors). Therefore, it is necessary to improve the shielding of the housing. One option is:

– To install 3 earth conductors around the housing, the central one placed about 40 cm from the main internal conductors (η = 0.27).

– Place an earth plate tray with 30 cm width below the conductors, in such a way that all conductors will be at least 25 mm from the tray (distance from conductor centre to the surface of the tray), and at least 25 mm from the tray's border. The tray shall be bonded to the equipment racks/cabinets at both extremities. This gives β = 0.066.

Therefore:

$$V_r = (38.4)\ (0.27)\ (0.066) = 0.68 \text{ kV}$$

This value is safely below the equipment resistibility considered.

Step 10: Bonding at equipment racks/cabinets.

The bonding procedures stated in 11.4 are intended to provide adequate shielding from the metallic elements inside the housing.

Step 11: Protection of power entrance.

Clause 12.1 gives a procedure to control the residual voltage across the connection of SPD at power entrance at the housing.

Let us suppose that we have the following values (see Figure 6):

Resistibility of rectifier input port: V_{res} = 2.0 kV

Geometric mean radius of SPD connection: r_p = 28 mm

(equivalent to 4 condutors, 6 mm^2 cross-section, regularly spaced at 50 mm one from the next)

Distance between SPD and rectifier: b = 4 m

(SPD at one side of the housing and rectifier at the other)

Residual voltage of SPD: V_{spd} = 1.0 kV (clamping type SPD)

Earth resistance of RBS: R_g = 5 Ω

Surge impedance of power line: Z_p = 458 Ω

(for ρ = 500 Ω.m, f_L = 1 MHz, r_L = 10 mm, heigh = 6 m)

In order to keep the residual voltage below the resistibility level of the equipment, the maximum length of cable for SPD connection is (see 12.1):

$$L_p = (2.0 - 1.0)\ (458 + 5)\ /\ \{\ (0.2)\ (77)\ (5) \ln [(4 + 0.028)\ /\ 0.028\ ]\} = 1.2 \text{ m}$$

This is the maximum distance from the connection of the SPD with the power wires to the main earth terminal (MET), as shown in Figure 6.

Considering that the only metallic service connected to the RBS is the power line and that it has 4 conductors (3 phases and 1 neutral), Equation 10 gives a peak value of current for the SPD as:

$$I_{imp} \geq 77\ /\ [\ (2)\ (1)\ (4)\ ]$$

$$I_{imp} \geq 9.6 \text{ kA}$$

Step 12: Protection of telecommunication entrance.

There is no telecommunication metallic line coming into the RBS housing.

Step 13: End of project.

The RBS is protected for the tolerable frequency of damage (F_t).

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