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SERIES K: PROTECTION AGAINST INTERFERENCE

**Lightning protection of distributed base
stations**

Recommendation ITU-T K.97



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Lightning protection of distributed base stations

Summary

Recommendation ITU-T K.97 deals with lightning protection of a distributed base station (DBS) on the tower site. A DBS is a new type of radio base station which consists of a remote radio unit (RRU) located on the tower, and a base band unit (BBU) inside the shelter at the bottom of the tower. Lightning protection of DBS is not fully covered by Recommendation ITU-T K.56.

The main objective of this Recommendation is the lightning protection of RRU and rectifier interfaces with direct current (DC) power cable, and bonding of the DBS.

Protection of these interfaces is achieved by installing a protection module. Possible protection schemes for such installations are also described.

This Recommendation indicates when these protection modules should be used, and provides indication of their withstand current. The surge protective device (SPD) needed on the feeder cable is also indicated.

Bonding configurations of the protection module and of the optical fibre cable are also illustrated.

Appendix I shows an example of an isolated protection solution.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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* To access the Recommendation, type the URL <http://handle.itu.int/> in the address field of your web browser, followed by the Recommendation's unique ID. For example, <http://handle.itu.int/11.1002/1000/11830-en>.

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Recommendation ITU-T K.97

Lightning protection of distributed base stations

1 Scope

This Recommendation addresses distributed base stations (DBSs) composed of a shelter or an outdoor cabinet to house equipment, and a nearby tower for antennas and equipment. The tower will prevent lightning from hitting the shelter or outdoor cabinet. The purpose of this Recommendation is to give criteria for the definition of procedures that will protect DBSs 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.

- [ITU-T K.27] Recommendation ITU-T K.27 (1996), *Bonding configurations and earthing inside a telecommunication building.*
- [ITU-T K.39] Recommendation ITU-T K.39 (1996), *Risk assessment of damages to telecommunication sites due to lightning discharges.*
- [ITU-T K.40] Recommendation ITU-T K.40 (1996), *Protection against LEMP in telecommunications centres.*
- [ITU-T K.56] Recommendation ITU-T K.56 (2010), *Protection of radio base stations against lightning discharges.*
- [ITU-T K.85] Recommendation ITU-T K.85 (2011), *Requirements for the mitigation of lightning effects on home networks installed in customer premises.*
- [IEC 62305-2] IEC 62305-2 ed2.0 (2010), *Protection against lightning – Part 2: Risk management.*

3 Definitions

3.1 Terms defined elsewhere

The definitions contained in the referenced documents apply to this Recommendation.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 base band unit (BBU): The base band module of a radio base station (RBS) which can be installed separated from the remote radio unit (RRU).

NOTE – Optical fibre is commonly used to connect the base band unit (BBU) to the remote radio unit (RRU).

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

3.2.3 distributed base station (DBS): One kind of radio base station (RBS), where the remote radio unit (RRU) and the base band unit (BBU) can be installed separated.

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

3.2.5 remote radio unit (RRU): The radio frequency module of a radio base station (RBS) which can be installed separated from the base band unit (BBU).

NOTE 1 – Optical fibre is commonly used to connect the base band unit (BBU) to the remote radio unit (RRU).

NOTE 2 – The radio frequency module is also called remote radio head (RRH).

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC	Alternating Current
BBU	Base Band Unit
DBS	Distributed Base Station
GDT	Gas Discharge Tube
MEB	Main Earthing Bar
MET	Main Earth Terminal
MOV	Metal-Oxide Varistor
LPL	Lightning Protection Level
LPZ	Lightning Protective Zone
ODF	Optical fibre Distribution Frame
RBS	Radio Base Station
RRH	Remote Radio Head
RRU	Remote Radio Unit
RTN	Return
SPC	Surge Protective Component
SPD	Surge Protective Device

5 Reference configuration

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

In Figure 1, RRU is installed very close to the antenna and is, in general, connected to the antenna by a coaxial feeder cable and to BBU by an optical fibre cable.

RRU is powered from the rectifier by a shielded or unshielded direct current (DC) power cable.

Both optical fibre and DC power cables run along the tower and enter the shelter.

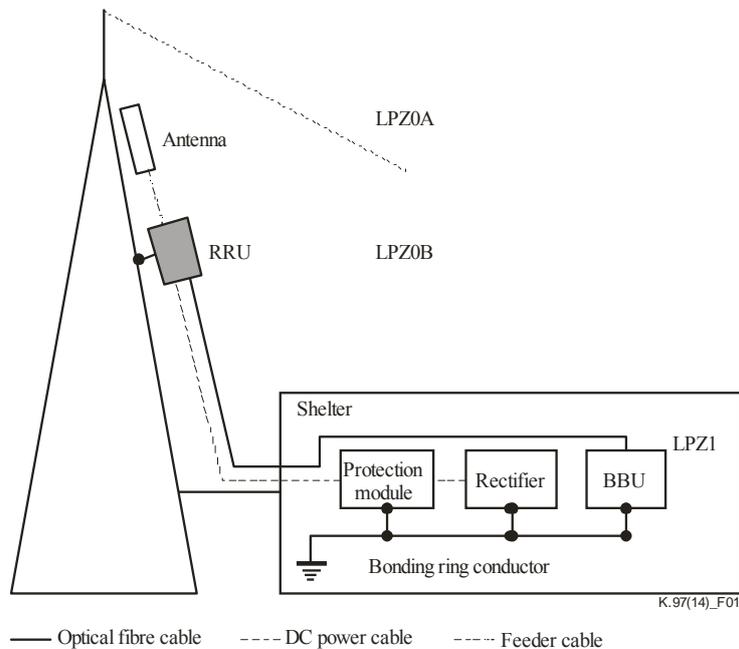


Figure 1 – Reference configuration for a DBS

6 Protections of DBS

The main difference between distributed base station (DBS) and traditional radio base station (RBS) is that RRU (RRH) is separately installed from BBU.

RRU can be installed very close to the antenna and powered by the inverter located inside the shelter or outdoor cabinet. Therefore, the emphasis of DBS lightning protection are the RRU and inverter interfaces with DC power cable.

The DC power cable to RRU should not be exposed to direct lightning strikes and, therefore, should be located in lightning protection zone LPZ0B.

[ITU-T K.56] is the basic Recommendation that a DBS should comply with. Requirements for DBS protection not included in [ITU-T K.56] are described in the following clauses.

6.1 Protection need

The protection need shall be evaluated by the risk assessment of loss of services (R_2) according to [IEC 62305-2]. When the risk is greater than the tolerable risk R_T , defined by the network operator, protection measures are necessary. The comparison between the risk and the tolerable risk allows determining the lightning protection level (LPL) that the protection measure at each equipment interface has to withstand to reduce the risk below the tolerable risk.

For the particular application, this Recommendation presents a simplified approach for the evaluation of the protection need based on [IEC 62305-2]. In this approach, the protection needs can be evaluated by considering the frequency of damage (F), as described in [ITU-T K.39] and [ITU-T K.85], instead of the risk of loss of services.

In general, the frequency of damage is the sum of the frequencies of damage due to:

- direct flashes to (F_D) and near (F_N) the tower,
- direct flashes to (F_{SD}) and near (F_{SN}) the services entering the DBS.

Considering that the protective measures contained in [ITU-T K.56] are applied in the services entering the DBS, the frequency components F_{SD} and F_{SN} can be neglected. Furthermore, considering the RRU protection module, the damages due to flashes near the tower (F_N) are negligible in comparison with damages caused by direct flashes to the tower (F_D). Then:

$$F = F_D = N_D \times P_{SPD} \quad (1)$$

where:

N_D number of direct flashes to the tower per year

P_{SPD} protection factor of the protection module

When the frequency of damage is greater than the tolerable value ($F > F_T$), then protection measures are necessary. The tolerable frequency of damage value should be defined by the network operator. For example, $F_T = 0.05$ means that, in average, 1 damage in 20 years (1/20) is acceptable.

The number of direct flashes to the tower can be calculated by:

$$N_D = 9 \times \pi \times c \times h_t^2 \times N_g \quad (2)$$

where

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

h_t tower height (km)

N_g ground flash density (flashes \times km⁻² \times year⁻¹)

The ratio between the tolerable (F_T) and expected number of direct flashes to the tower (N_D) gives the probability associated with the lightning peak current to be considered (P_{SPD}):

$$P_{SPD} = F_T / N_D \quad (3)$$

The value of P_{SPD} shall be used in Table 1 in order to determine the LPL to be considered in the protection design. In doing so, the P_{SPD} value calculated by Equation 3 shall be converted to the next lower value in Table 1, e.g., a value $P_{SPD} = 0.03$ shall be converted to $P_{SPD} = 0.02$.

Table 1 – Lightning protection level (LPL) as function of P_{SPD}

LPL	I [kA]	P_{SPD}
III-IV	100	0.05
II	150	0.02
I	200	0.01
SPDs having better characteristics (see [IEC 62305-2] Table B.3 for more information).		0.005-0.001

6.2 RRU protection

6.2.1 RRU protection module

The protection module of RRU port with DC power cable can be a box outside RRU, or can be a protection circuit inside RRU, as shown in Figures 2 and 3.

The SPD protection level should be selected in order to achieve that the effective protection level should be less than the resistibility of the RRU and the rectifier (see clause 8 of [ITU-T K.56]).

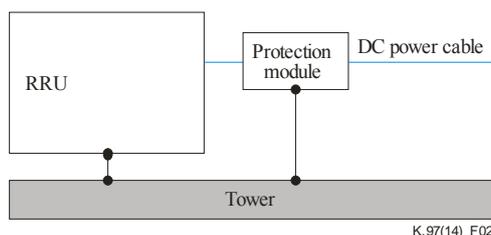


Figure 2 – Protection module on DC power cable outside RRU

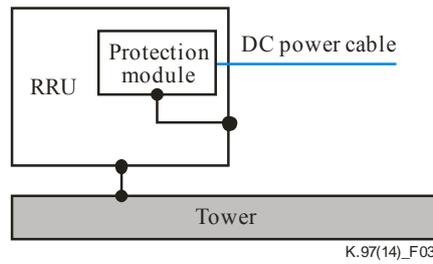


Figure 3 – Protection circuit integrated inside RRU

Possible protection schemes of the protection module are illustrated in Figure 4. Figures 4-a, 4-b and 4-c are suitable for d.c.-I configuration; Figure 4-d is suitable for d.c.-C configuration. These configurations are described in [ITU-T K.27].

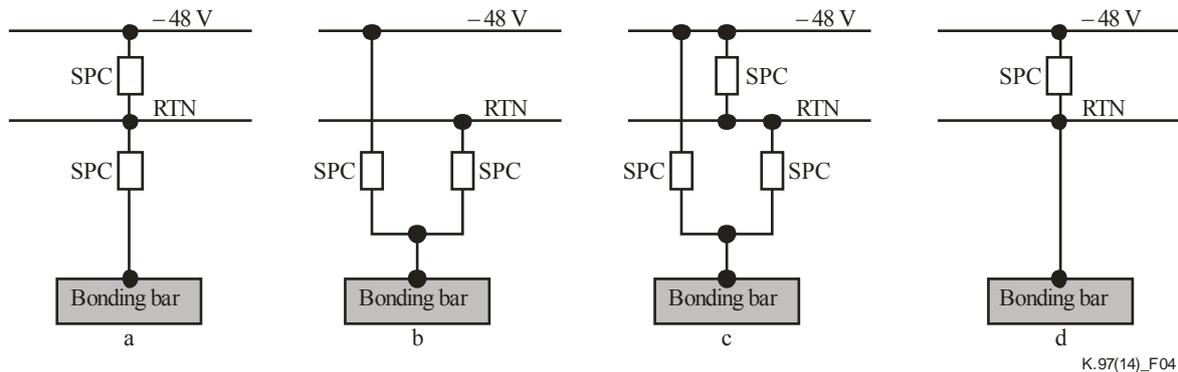


Figure 4 – Possible protection schemes of RRU protection module

6.2.2 Need of protection module at RRU port with dc power cable

When unshielded DC power cable is used where RRU is installed on the tower, the DC protection module upstream RRU (or protection circuit inside RRU) is necessary, as shown in Figure 2 or Figure 3.

When shielded DC power cable (or unshielded DC power cable inside a metallic duct along the total length) is used, the shield (or the metallic duct) shall be connected to the tower (or to the metallic shell of RRU) and to the equipotential bonding bar of the BBU shelter or cabinet (see [ITU-T K.56]).

The peak value of the current that enters the DC power cable (I_{DC}) can be calculated by:

$$I_{DC} = I_{LPL} \alpha_T \alpha_F \quad (4)$$

where:

I_{LPL} is the peak lightning current associated with the LPL

α_T is the shielding factor of the tower

α_F is the shielding factor of the cable tray

The values of α_T can be calculated from the tower and cable tray geometry. The approximate values are:

- Tubular tower (0.5 m radius): $\alpha_T = 0.10$
- Tubular tower (0.15 m radius): $\alpha_T = 0.30$
- Three-legged tower: $\alpha_T = 0.20$
- Four-legged tower: $\alpha_T = 0.15$

NOTE – The maximum height of a tubular tower with 0.15 m radius which supports RRUs is around 20 m.

The values of α_F can be calculated accurately from the cable tray dimensions and cables number and configuration. The following equation provides an approximate value, where n is the number of cables in the feeder tray:

$$\alpha_F = \frac{1}{n + 3.5} \quad (5)$$

When shielded DC power cable (or the unshielded cable inside a metallic duct along the total length) is used, the need of protection module upstream the RRU can be calculated by the formula:

$$V_T = I_{LPL} \alpha_T \alpha_F Z_T l \quad (6)$$

where:

Z_T is the transfer impedance of the shielded DC power cable (or metallic duct), which is equal to the shield (or metallic duct) DC resistance per unit length (Ω/m)

l is the length of the shielded DC power cable (or metallic duct) (m)

If V_T is lower than the surge over-voltage withstand capability of DC primary circuit of RRU (and also the surge over-voltage withstand capability between inner conductors and screen of shielded DC power cable), the protection can be achieved without protection module upstream RRU. Otherwise, a protection module should be installed upstream the RRU.

An isolated protection solution indicates the case when no protective components are used inside RRU and V_T is less than the common mode surge withstand voltage capability between DC primary circuit and internal reference earthing plane of RRU, and between DC primary circuit and DC secondary circuit. An example of isolated protection solution is shown in Appendix I.

6.2.3 Withstand current of the RRU DC power protection module

When the protection module (or the protection circuit inside RRU) is used in an unshielded cable without a metallic duct, it has to withstand the lightning current peak value calculated by Equation 7, where m is the number of conductors inside the cable (e.g., –48 V and RTN). In this equation, it is assumed that the current divides evenly among the conductors of the cable.

$$I_C = \frac{I_{DC}}{m} \quad (7)$$

For example, considering $I_{LPL} = 200$ kA, tubular tower of 0.15 m radius ($\alpha_T = 0.3$), only 3 DC power cables ($n = 3$) along the tower no other cables (such as feeder cable), and 2 conductors per cable ($m = 2$) leads to $I_C = 4.6$ kA ≈ 5 kA.

The actual current wave shape that will flow through each surge protective component (SPC) of the protection module depends on several parameters:

- The configuration and geometry of the installation (number of cables along the tower, height of tower, etc.);
- The type of the DC power cable (wire size, shielded or unshielded);
- The configuration of the protection module;
- The type of SPCs and their impedance characteristics (MOVs, GDTs, etc.).

The above parameters could vary significantly from site to site, which results in significant differences on the expected currents conducted through the SPC modules. For example, the current wave shape through clamping type protective devices will be significantly reduced in many cases due to characteristic of the clamping device.

However, as long as clamping type SPCs are considered (e.g., metal oxide varistor – MOV), the energy delivered to each SPC can be conservatively assessed from a relatively small number of parameters. Appendix II provides information on how to assess the energy rating of clamping type SPCs used in RRU and rectifier protection modules.

The rating of sparking type SPCs is under study.

6.3 Protection of rectifier

A protection module downstream of the rectifier which powers RRU is recommended when RRU is installed on the tower, whatever shielded or unshielded DC power cable is used to power RRU.

For the energy rating of protection modules, please refer to Appendix II.

The protection scheme is described in Figure 5.

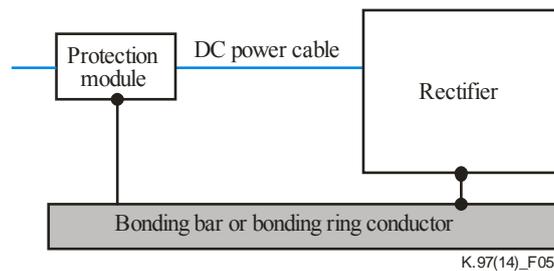


Figure 5 – Protection modules of rectifier which power the outside RRU

When the RRU is installed inside the shelter, the protection module is usually not necessary for the rectifier dc power port. In this case, the protection procedures are contained in [ITU-T K.56].

6.4 The need of feeder SPD

When the RRU is installed on the top of the tower, the feeder cable between antenna and RRU is very short. If the calculation according to [ITU-T K.56] is carried out, the value of the voltage V_T will be very small, so that usually a feeder SPD is not necessary.

When the RRU is installed inside the shelter, then the feeder cable is run along the tower and the need of feeder SPD can be calculated by [ITU-T K.56].

7 Bonding of DBS

7.1 Bonding RRU and protection module

RRU can be installed on the tower, or inside the shelter, as shown in Figure 6.

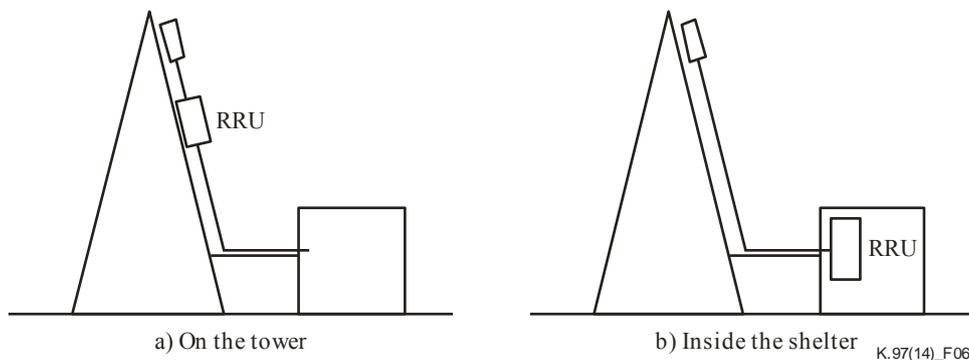


Figure 6 – Different RRU locations

When the RRU is installed on the tower, the RRU should be directly bonded to the tower metallic structure or to a bonding bar on the tower. The bonding bar should be directly bonded to the tower using a bonding conductor as short as possible. In this case, the procedures from [ITU-T K.56] apply.

When the RRU is installed inside the shelter, the RRU should be directly bonded to the bonding network inside the shelter with a connection as short as possible.

The protection module at the RRU side should be bonded to the tower metallic structure as described for RRU.

7.2 DC power cable

7.2.1 Shielded DC power cable

The shielded DC power 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 bonding connection could be implemented by connecting the shield layer to the metallic shell of RRU, as shown in Figure 7.

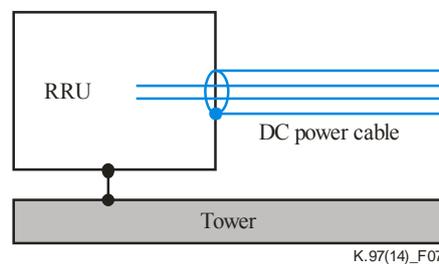


Figure 7 – Bonding the shield of DC power cable to RRU

When the protection module is installed outside the RRU, a bonding connection should be implemented by connecting the shield layer to the metallic shell of the protection module, as shown in Figure 8.

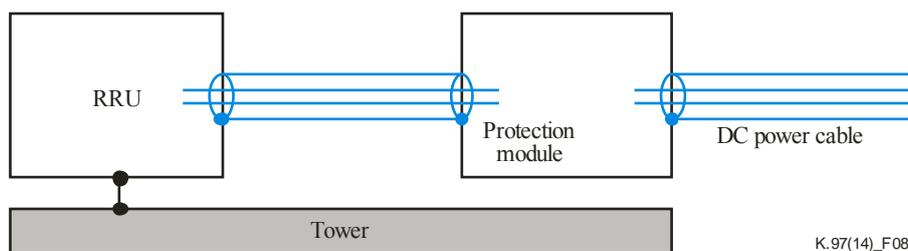


Figure 8 – Bonding the shield of DC power cable to protection module

The shield layer should also be bonded to the earthing bar installed near the feed-through window directly or by the protection module.

7.2.2 Metallic duct

An unshielded DC power cable could be installed inside a metallic duct. This duct shall be electrically continuous for its entire length and shall be bonded to the tower at least at its upper end, as shown in Figure 9. The length of cable that may run outside the metallic duct shall be as short as possible. The metallic duct can be made of galvanized steel and shall have a cross-section area not less than 16 mm². The openings in the duct shall be adequately sealed in order to prevent the ingress of moisture. The metallic duct shall also be bonded to the earthing bar installed near the feed-through window.

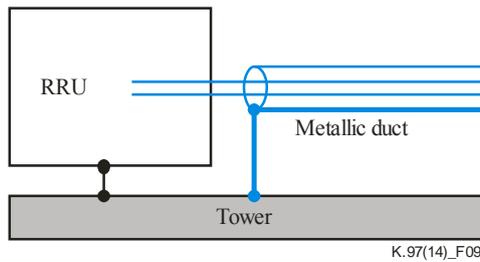


Figure 9 – Bonding the metallic duct at RRU side

When the protection module is installed outside the RRU, bonding configuration is shown in Figure 10.

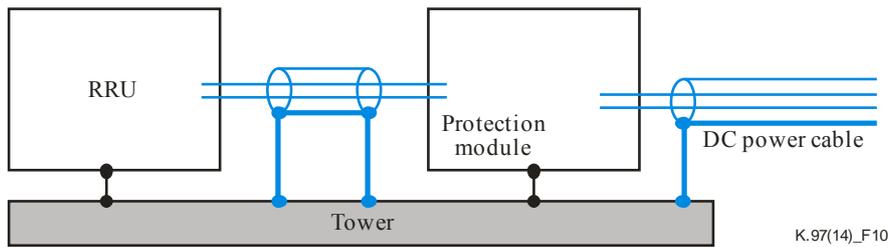


Figure 10 – Bonding the metallic duct at RRU side when protection module is outside RRU

7.2.3 Unshielded cable

The use of unshielded DC power cable installed without a metallic duct requires the installation of protection modules close to the RRU and connected between the conductors and the tower structure, as shown in Figure 2. Another set of SPDs is also required at the point where the DC power cable enters the shelter or outdoor equipment. These SPDs shall be bonded to the earthing bar installed below the feed-through window, as shown in Figure 13. For the energy rating of protection modules, please refer to Appendix II.

7.3 Bonding configuration of protection module at rectifier side

When the rectifier in the shelter is powering RRU on the tower, a protection module at rectifier side is needed. Five bonding configurations are possible.

7.3.1 Bonding configuration 1

This configuration is suitable for shielded DC power cable or unshielded DC power cable inside a metallic duct and rectifier installed inside the shelter.

The shield should be bonded to the earthing bar close to the feed-through window, as shown in Figure 11. The protection module at rectifier side should be installed inside the shelter and it should be bonded to the bonding network inside the shelter, as shown in Figure 11.

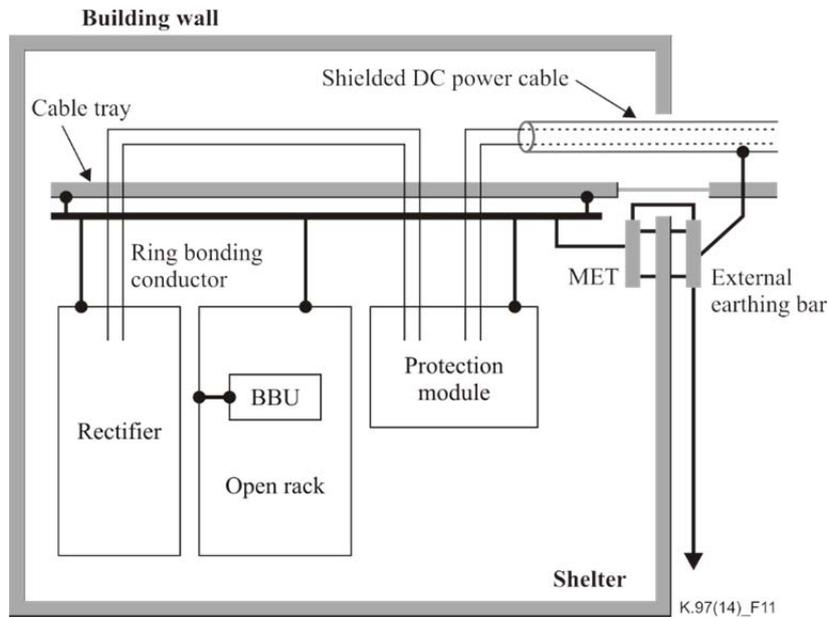


Figure 11 – Bonding configuration 1

All conductors (e.g., DC power cables, utility alternating current (AC) power cables, metallic telecommunication cables, etc.) are recommended to enter the shelter at the same point, such as feeder entrance panel. The cable shield should be bonded to the external earthing bar.

7.3.2 Bonding configuration 2

This configuration is suitable for shielded DC power cable or unshielded DC power cable inside a metallic duct and rectifier installed inside the shelter.

The shield should be bonded to the bonding bar inside the protection module, as shown in Figure 12. The protection module at the rectifier side should be installed inside the shelter and it should be bonded to the bonding network inside the shelter, shown as Figure 12.

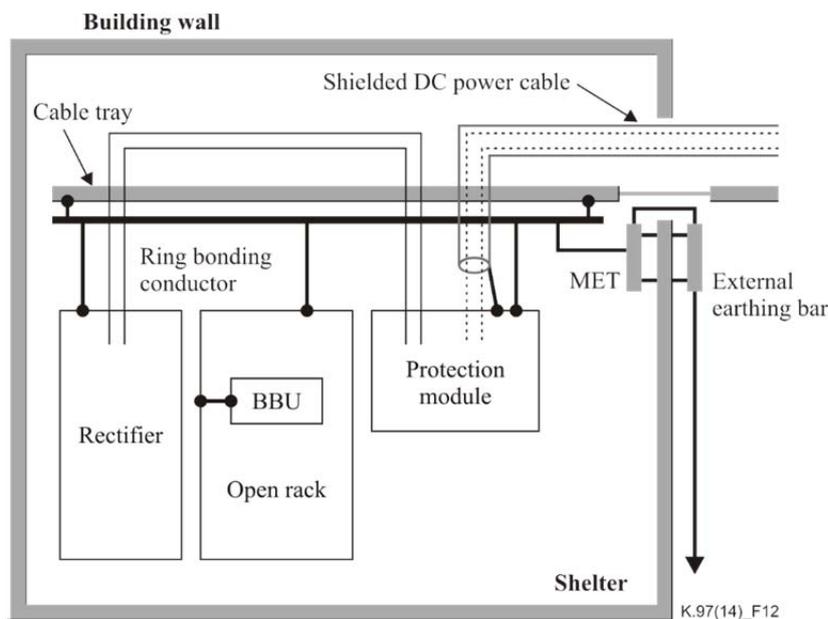


Figure 12 – Bonding configuration 2

All conductors (e.g., DC power cables, utility AC power cables, metallic telecommunication cables, etc.) are recommended to enter the shelter at the same point, such as the feeder entrance panel. The cable shield should be bonded to the external earthing bar.

7.3.3 Bonding configuration 3

This configuration is suitable for unshielded DC power cable and rectifier installed inside the shelter.

It is recommended to install the protection module on the shelter wall, which should be bonded to the external bonding bar close to the feed-through window, as shown in Figure 13.

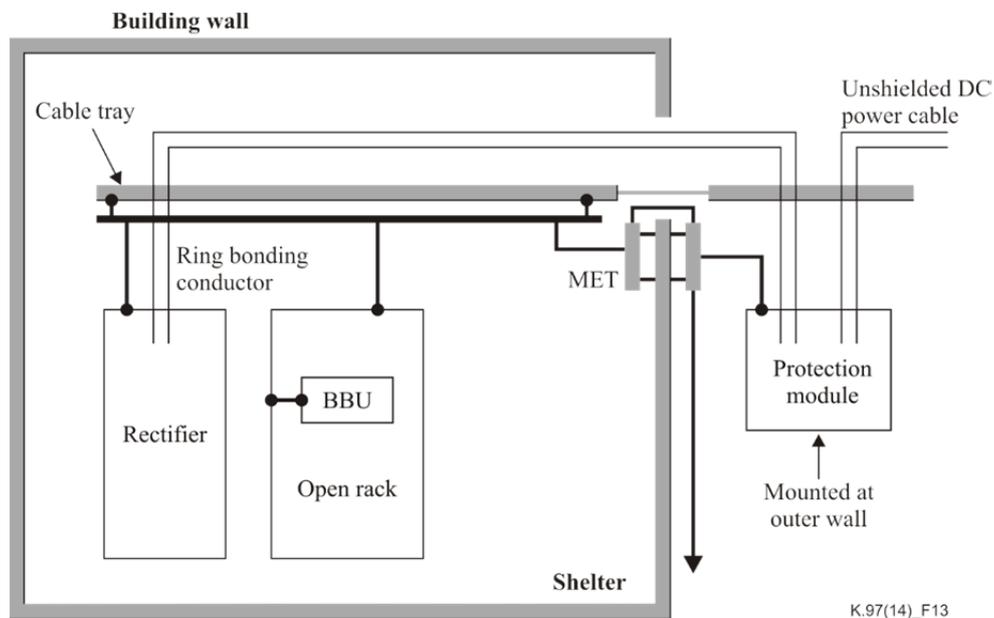


Figure 13 – Bonding configuration 3

All conductors (e.g., DC power cables, utility AC power cables, metallic telecommunication cables, etc.) are recommended to enter the shelter at the same point, such as the feeder entrance panel. The cable shield should be bonded to the external earthing bar.

NOTE – If the protection module has the risk of being stolen, the protection module could be installed inside the shelter close to the feed-through window.

7.3.4 Bonding configuration 4

This configuration is suitable for rectifier installed inside outdoor cabinet.

When the shielded DC power cable is used, the shield should be bonded to the bonding bar inside the outdoor cabinet. The protection module could be installed inside the outdoor cabinet and bonded to the metallic shell of the outdoor cabinet or to the bonding bar inside the outdoor cabinet, as shown in Figure 14-a.

When the metallic duct is used, the duct should be bonded to the earthing bar of the site. The protection module could be installed inside the outdoor cabinet and bonded to the metallic shell of the outdoor cabinet or to the bonding bar inside the outdoor cabinet, as shown in Figure 14-b.

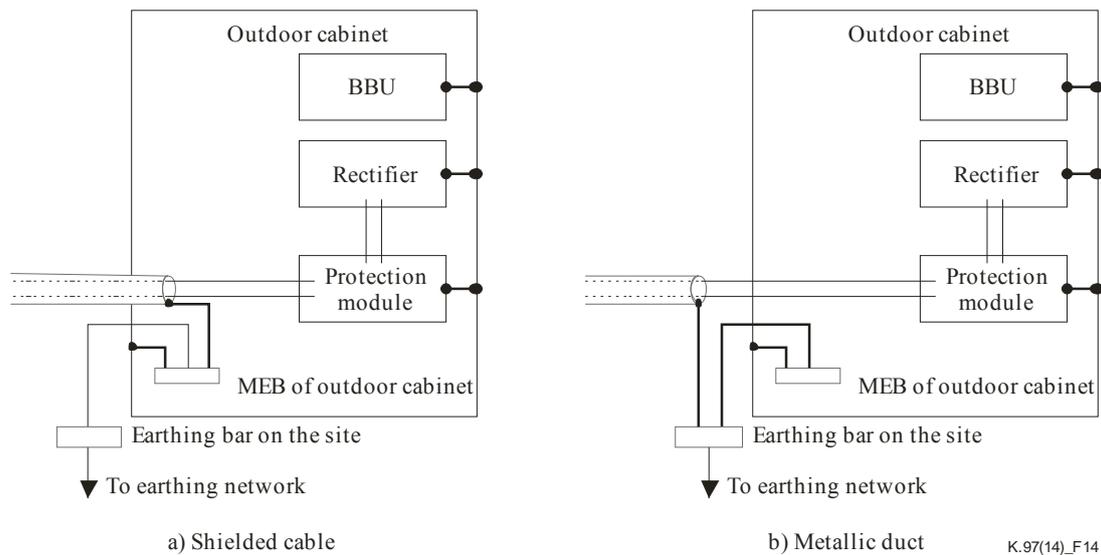


Figure 14 – Bonding configuration 4

7.3.5 Bonding configuration 5

This configuration is suitable for rectifier installed inside the outdoor cabinet and unshielded DC power cable.

It is recommended to install the protection module outside the cabinet. The protection module should be bonded to the earthing bar of the site, as shown in Figure 15.

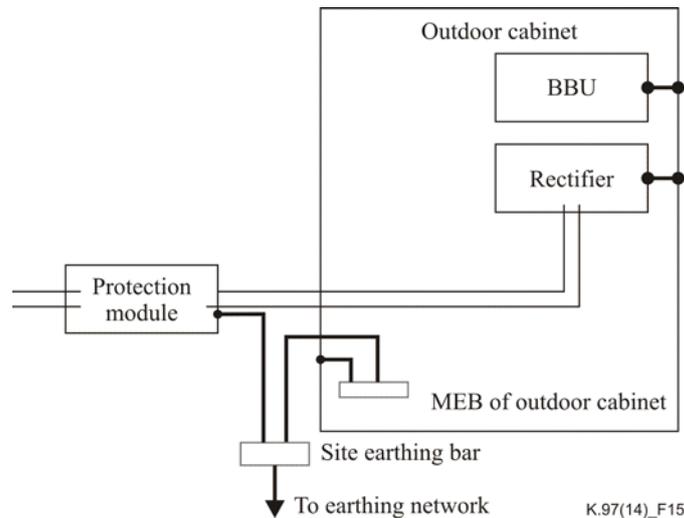


Figure 15 – Bonding configuration 5

NOTE – If the protection module has the risk of being stolen, it could be installed inside the cabinet, close to the entry point of the cables.

7.4 BBU bonding

The BBU can be installed in a cabinet and the BBU bonding can be implemented by two ways. In method one, the BBU metallic shell is directly bonded to the cabinet metallic shell; in method two, the BBU metallic shell is bonded to the bonding bar in the cabinet by a bonding conductor.

When the BBU is a stand-alone equipment inside the shelter, it can be directly bonded to the bonding bar in the shelter.

7.5 Bonding of optical fibre cable

A metal-free optical fibre cable is recommended to be used between RRU and BBU.

If an optical fibre cable with metallic element or metallic sheath is used, the metallic element or sheath should be bonded to the earth at least at the two cable ends.

7.5.1 Metal-free optical fibre cable

There is no bonding or protection requirement when the metal free optical fibre cable is used between RRU and BBU.

7.5.2 Optical fibre cable with metal element or sheath

The metallic element or sheath should be bonded to the tower with a bonding as short as possible before entering the RRU, when the RRU is mounted on the tower.

The metallic element or sheath should be bonded to the ring conductor when entering the shelter. The metallic element or sheath should not be connected to the BBU at the shelter side. The optical fibre distribution frame (ODF) is the rack where other equipment (such as transmission equipment) are located. The bonding bar inside ODF, which is used for fibre cable metal element or sheath earthing, should be insulated from the metallic shell of ODF, as shown in Figure 16.

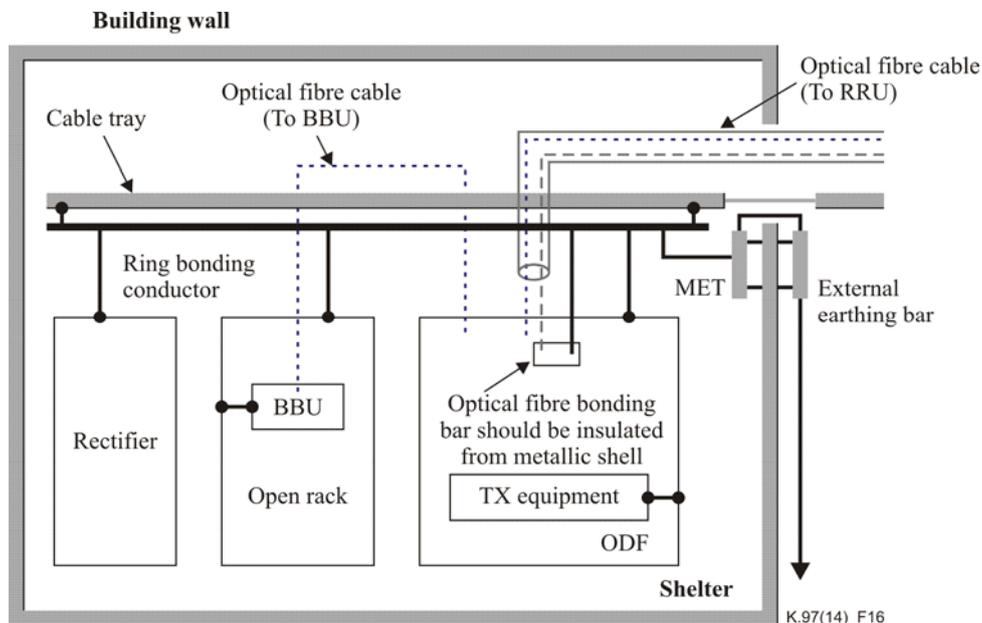


Figure 16 – Bonding of optical fibre cable at shelter side

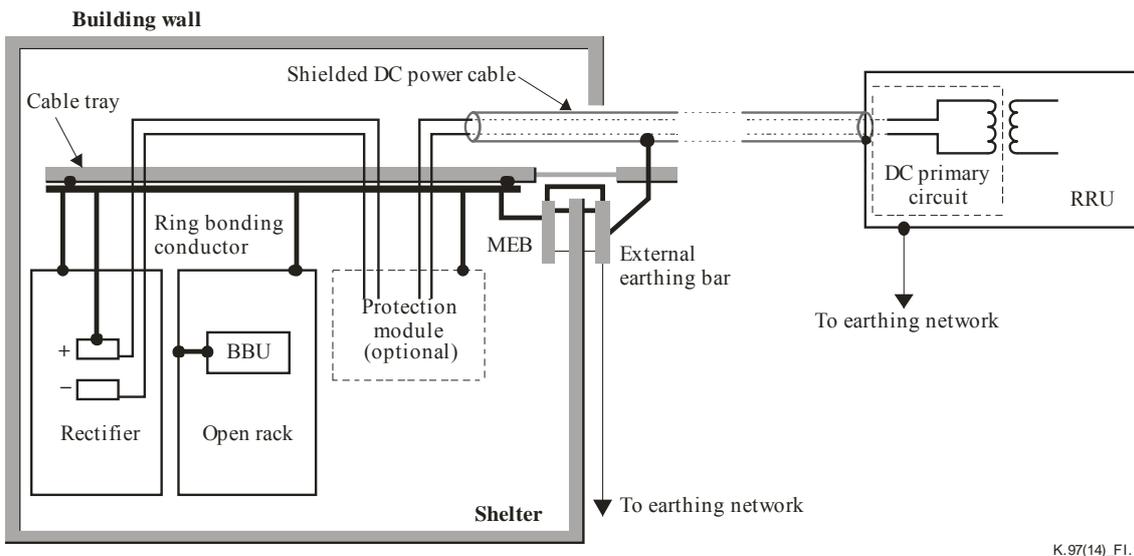
When BBU and other equipment are located in an outdoor cabinet (see clause 7.3.5), the metallic element or sheath should be directly bonded to the bonding bar inside the outdoor cabinet.

Appendix I

Isolated protection solution: Example

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

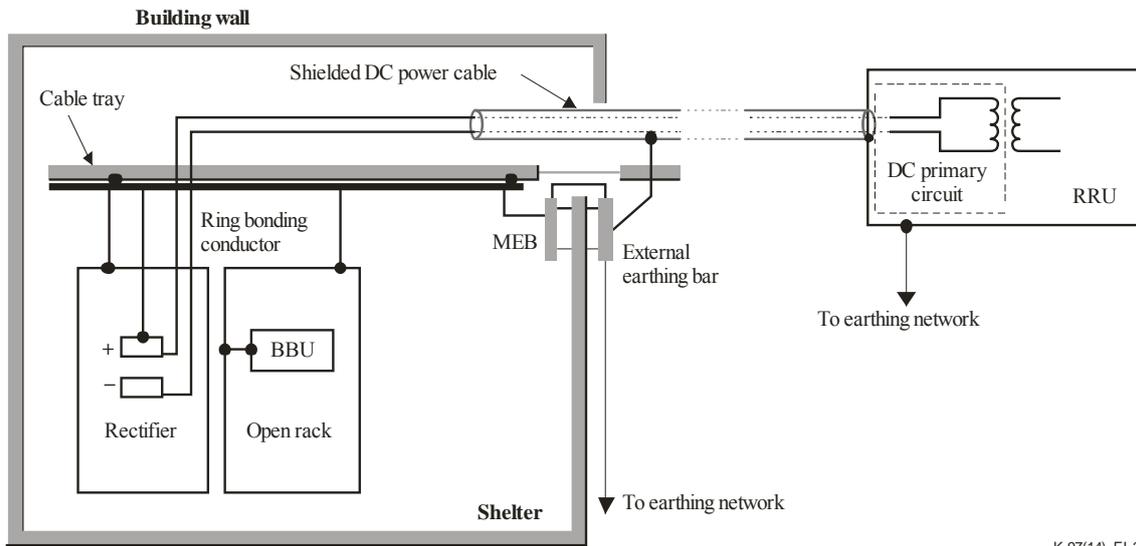
An isolated protection solution indicates the case in which no protective components are used inside RRU and V_T is less than the common-mode surge over-voltage withstand capability of the DC primary circuit of the RRU, as described in clause 6.2.2. See Figure I.1. The common-mode surge withstand voltage refers to the voltage between DC primary circuit and the reference earth of RRU, and between DC primary circuit and DC secondary circuit, which is connected to the functional circuit.



K.97(14)_F1.1

Figure I.1 – Isolated protection solution of DBS

When the isolated protection solution is used, the surge current will not cross the inner conductors of the shielded DC power cable; all the surge current on the shielded DC power cable will go through the screen. In this case, not only the protection module at the RRU side can be suppressed, but also the protection module at rectifier side is optional. The protection solution can be simplified as shown in Figure I.2.



K.97(14)_F1.2

Figure I.2 – Isolated protection solution of DBS (rectifier side without protection module)

All conductors (e.g., DC power cables, utility AC power cables, metallic telecommunication cables, etc.) are recommended to enter the shelter at the same point, such as the feeder entering window. The cable shield should be bonded to the external earthing bar.

Appendix II

Assessment of the energy delivered to clamping type SPC used in RRU protection module

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

Theoretical and experimental investigations have shown that the wave shape of the current flowing through clamping type SPC is significantly influenced by the SPC characteristics. If losses on the conductors are neglected, the energy (W) delivered to a couple of SPCs connected at both ends of an unshielded DC power conductor is:

$$W = \frac{1}{2} I_C^2 L \quad (\text{II.1})$$

where I_C is the conductor peak current evaluated as per Equation 7, and L is the inductance of the loop formed by the DC conductor and the cable tray. If it is considered that the two SPCs are identical, each one would absorb half of the energy trapped in the inductance:

$$W_{SPC} = \frac{1}{4} I_C^2 L \quad (\text{II.2})$$

The inductance L (in μH) is given by:

$$L = 0.2 h_T \ln\left(\frac{b}{a}\right) \quad (\text{II.3})$$

where h_T is the tower height (m), a is the conductor radius (mm), and b is the distance between the conductor axis, and the cable tray (mm). One interesting feature of Equation II.3 is that the logarithmic function makes the inductance little sensitive to variations of a and b . Considering the representative values $a = 1.3$ mm and $b = 16$ mm gives $L = 0.50$ $\mu\text{H}/\text{m}$.

The use of shielded cables reduces significantly the energy delivered to the SPC. The ratio between the energy delivered to an SPC installed in a shielded cable to the energy that would be delivered to the same SPC if the shield was absent is defined as the energy shielding factor (η). Based on several simulations, the energy shielding factor can be conservatively assumed as $\eta = 0.25$. This value is valid for the following conditions:

- SPC $U_{1\text{mA}}$ voltage equal to or greater than 82 V;
- Shield resistance equal to or lower than 15 Ω/km ;
- One clamping SPC is connected at each conductor end.

Below there is a specific calculation example:

Considering lightning protection level I (LPL I, see Table 1) and a 60 m three-legged tower ($\alpha_T = 0.2$) with only three unshielded DC power cables ($n = 3$) that run along the tower to feed three RRUs installed on the top of the tower:

$$I_C = \frac{I_{DC}}{2} = \frac{200 \times 0.2 \times 0.154}{2} \text{ kA} = 3.08 \text{ kA}$$

Each DC conductor has a size of 4 mm² (radius is 1.3 mm) and is installed at a distance of 70 mm from the cable tray, then the inductance of the DC conductor is

$$L = 0.2 \times 60 \times \ln\left(\frac{70}{1.3}\right) \mu\text{H} = 47.83 \mu\text{H}$$

Then, the energy delivered to clamping type SPC for unshielded cable will be:

$$W_{SPC} = \frac{1}{4} \times 3.08^2 \times 47.83 \text{ Joules} = 113 \text{ Joules}$$

If three shielded DC power cables are selected ($\eta = 0.25$), the energy delivered to clamping type SPC will be:

$$W_{SPC} = \frac{1}{4} \times 0.25 \times 3.08^2 \times 47.83 \text{ Joules} = 28 \text{ Joules}$$

For comparison, a standard 20 mm MOV of 82 V_{1mA} can absorb 27 J and withstand 6.5 kA, 8/20 μ s.

NOTE – This calculation approach gives a conservative design for the particular installation type.

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